ACTA UNIVERSITATIS GOTHOBURGENSIS
GOTHENBURG STUDIES IN CONSERVATION 52

Painting Treatments of Weather-Exposed Ferrous Heritage

Exploration of Oil Varnish Paints and Painting Skills

Arja Källbom

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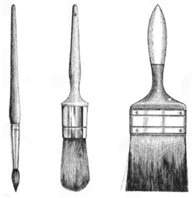

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Cover: Paper marbling by the author; symbolising black iron, red-lead primer paint, and aluminium-pigmented armour paint.

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ABSTRACT

This thesis is about industrial heritage – the protection of ferrous heritage by using anticorrosive fat oil varnish paints. The purpose of this thesis in *Kulturvård* and craft research is to provide guidelines, tools, concepts, and models that may be used in anticorrosive oil varnish painting maintenance of ferrous heritage. This is needed in in order to improve maintenance interventions and working descriptions.

The methodology is a holistic, multiple methods approach; involving methods that collect quantitative and qualitative data to enlighten the phenomena from different views and exemplify different types of quality assessments of substrates, paints, craft skills, and final results. The research is characterised by an insider perspective of the craft and paint materials. Different types of methods are used for material characterisation. Archive and field studies are conducted, and empirical work on oils, varnishes, and anticorrosive paints are used.

The maintenance could be improved by systematic *anamnesis, diagnosis, therapy, control* and *monitoring.* Tools for assessing the status of existing paint layers, a matrix for the specification of working procedures, and critical quality control of checkpoints and tools are provided. An example is a working procedure that encounters quality assessments that traditional architectural painters carry out while conducting painting treatments, taking into account the continuous correspondence between the materials and the painter. The paint types in focus are fat oil varnish paints, especially the so-called armour paints, used from the 1920s until the 1960s. The armour paints have long durability, and the concept of the paint system is explained in the research in terms of concept, origin, formulation, use, and characteristics. Armour paints produced with the guidance of historical recipes are aged naturally in Southern Sweden and in accelerated, standardised laboratory tests compared to historical paint samples. The armour paints consist of inhibitive primer and topcoats with lamellar, UV-radiation reflecting hematite and leafing metallic aluminium pigments. The paint binders consist of a bodied fat linseed oil varnish, stand oil, and tung oil mixture that empowers a rapid through-polymerisation for relatively thick layers, long-lasting adherence and elasticity, water-resistance, and durability. Such a paint composition enables an efficient protection of the ferrous substrate, over time.

Moreover, sensory profiling of drying oils and varnishes has been conducted by the using of methods common in sensory studies in the field of food and beverage, with support of engaged professional traditional architectural painters. A vocabulary for sensory quality assessments and communication is initiated. Improved communication methods could be used in practice and education, and to highlight the importance of craft skills and evidence-based experiences for the final results. There is a good level of consistency between present and historical descriptions of sensory characteristics of oils and varnishes, and technical descriptions. The latter are still difficult to connect to practical use and characteristics.

KEYWORDS: *Armour paints, linseed oil, linseed varnish, tung oil, oil varnishes, stand oil, aluminium pigments, micaceous iron oxide, leafing, anticorrosive, maintenance, management, heritage painting, painting craft, painting skills, practice, parlance, vocabulary, working procedures, sensory quality assessments, paint ageing, quality control, weather-exposure, atmospheric exposure, durability, sustainability.*

The Train Hall at the Swedish Railway Museum in Gävle.

PREFACE

He put a piece of black rubber sheet in my hand and said; “T*his is what I use as my role model, and what my efforts strive for*.”

I was standing in the gigantic, breath-taking, machine hall in Gävle, where the Swedish Railway Museum keeps its collection of historical trains and wagons. Master Painter Thom Olofsson explained how he and his team are working with the very ambitious preservation and reconstructions of historical vehicles. Many vehicles are wrecks that are brought to their original, operational conditions by very gentle, and authentic-like ambitions.

In the machine hall (seen on the facing page) – the research laboratory in which empirical work is combined with the compilation of information and clues from written historic sources, forensic in-situ material investigations, and the use of advanced craft skills and high problem-solving ability – Thom built concepts of different surface treatments and paint formulations that would manage the technical requirements while being conceptually beautiful. The rubber was used in the reconstructions of the convex linen fabric roofings (stretched over a wooden structure) for a wagon from the early twentieth century, painted with many layers of oil varnish paints in order to resist the tough exposure of atmosphere and mechanical forces. The final roofing should face exposure in a similar manner as the rubber: elastic and water-repellent for a long time, without cracking or material loss, with the purple colour of *Capuut Mortum*. In the formulation, he used many (to me) unexpected and exotic ingredients – several that I had never seen used together in an oil varnish paint context before, such as non-drying vegetable oils.

My curiosity woke and grew; how interesting it is to tailor-make the constructions, the materials for our purposes, in a way where the *material knowledge* and the knowledge of *how to make and to use* them are the leading stars. This is how this research project was initiated; *“Paint as material – for shaping, exposure, and restoration.”*

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SAMMANFATTNING

Den här avhandlingen inom Kulturvård och hantverksvetenskap handlar om rostskyddande målningsbehandlingar med linoljebaserade färger av industriella kulturarv tillverkade i järn och olegerat stål. Syftet är att möjliggöra förbättrade underhållsinsatser och arbetsbeskrivningar, med färgmaterial och hantverksmetoder som är historiskt relevanta och berikar våra kulturarv. Ansatsen är att kombinera olika forskningsmetoder och att undersöka olika delar av helheten, vilket genererar både kvantitativa och kvalitativa data, med ett inifrån-perspektiv på målerihantverket. Forskningen lyfter en del väsentliga aspekter på olika typer av kvalitetsbedömningar, av målningsunderlag, färg, hantverk och färdigt resultat.

Forskningen lyfter en del väsentliga aspekter på olika typer av kvalitetsbedömningar, av målningsunderlag, färg, hantverk och färdigt resultat. En modell har tagit fram, som föreslår metoder för kvalitetskontroll i förvaltnings- och utförandeled, och som visar en systematik för att göra och dokumentera målningsbehandlingar. En arbetsbeskrivning exemplifierar hantverksmässiga perspektiv på rostskyddsmålning. Pansarfärg är en färgtyp som används för målningsbehandling främst mellan 1920 till 1960-tal, och som har visat sig ha mycket lång livslängd. Avhandlingen besvarar delvis frågorna i vilket sammanhang färgtypen kom till, varför konceptet fungerade så bra, vilka beståndsdelar färgsystemet innehåller samt hur pansarfärger återskapade med ledning av historiska recept åldras. Likaså beskrivs utvecklingen av linoljebaserade bindemedel i rostskyddsfärger. Som ett sätt att sätta fokus på de sinnliga kvalitetsbedömningar som kulturmålare gör, har metoder som används inom livsmedels- och dryckesindustrin används. Det lägger grund för ett språkbruk som främjar uppmärksamhet i handling och som användas för att karakterisera färgmaterial eller torkande ytor.

NYCKELORD: *Pansarfärg, linoljefernissa, linolja, tungolja, standolja, aluminiumpigment, järnglans, järnglimmer, rostskyddsfärg, väderprovning, förvaltning, underhåll, hantverksskicklighet, arbetsbeskrivningar, språkbruk, uppmärksamhet i handling, kvalitetsbedömning, sinnliga bedömningar, hållbarhet*.

THE CONTENT

LIST OF PAPERS

The present thesis is based on the following six papers, which will be referred to in the text with their Roman numerals. The contribution of each co-author is described in each paper.

Paper	Authors, title, publication site
I	Källbom, A., and Almevik, G. (2020). Maintenance of Painted Steel Sheet Roofs on Historic Buildings in Sweden. *International Journal of Architectural Heritage, 14*(9). pp. 1–16.
II	Källbom, A (2021): The Concept of Anticorrosive Aluminium-Pigmented Armour Paint, for Sustainable Maintenance of Ferrous Heritage. *International Journal of Architectural Heritage*, *14*(10). pp. 1–19.
III	Källbom, A., Izzo, F., & Nevin, A. (2021). Multi-analytical Assessment of Armour Paints: The Ageing Characteristics of Historic Drying Oil Varnish Paints for Protection of Steel and Iron Surfaces in Sweden. *Heritage, 4*(3). pp. 1141–1164.
IV	Izzo, F. C., Källbom, A., & Nevin, A. (2021). Multi-analytical Assessment of Bodied Drying Oil Varnishes and their use as binders in Armour Paints. *Heritage, 4*. Manuscript submitted for publication.
V	Källbom, A. (2020). Using profiling methods to develop the sensory vocabulary of architectural painters who use linseed oils. Book chapter in *Anthology Craft + Science. Gothenburg: Kriterium, Acta Univeristatis Gothoburgensis. In press.*
VI	Källbom, A, Nilsen, A., & Örstrom, Å. (2018). Olfactory description for refined linseed oils for paints: Characterization for reconstructing material and craft skills in paintmaking. *Journal of Sensory Studies, 34*(2), pp.1–10.

DEFINITIONS USED IN THIS THESIS

Affordance: What conditions the situation, object or environment offers to the individual observer. For a painter, this means possible actions, such as adjusting the substrate, paint, or tools depending on the actual conditions and experiences, in order to achieve a result with the desired quality.

Aluminium armour paint: Leafing aluminium pigmented paint with linseed oil varnishes and other drying oils as binders, resulting in an aluminium metallic finish. MIO (Micaceous Iron Oxide) could be included in the formulation, or not.

Ample time: The sufficient (enough) time for achieving the appropriate drying (hardening, curing) stage of paint layers before they are overpainted with a new layer.

Armour paint: A paint with lamellar MIO and leafing aluminium pigments with linseed oil varnishes and other drying oils as binders, resulting in finish different grey colours. If the aluminium pigment content exceeds about 10 wt %, the painted finish is metallic.

Attribute: A perceptible characteristic, quality, feature, or phenomenon derived from materials.

Authentic: Genuine characteristic or contribution to a building, structure, or artifact, similar to the time when it was made historically or maintained; considered as *authentic-like*.

Blown linseed oils/varnishes: See *Heated oils*.

Bodied oil/varnish: Increased viscosity and body (corpus) of a drying oil via heat treatment and/or air-blowing, *and* the addition of driers (for varnish).

Boiled oil/varnish: Heat-induced pre-polymerisation due to heat treatment (about 220–290 °C). In the twentieth- and twenty-first century literature and standards it is common to use the term "boiled linseed oil" for *heated* linseed oils, in contrast to earlier sources. The term *boiled oil* is used as a synonym for varnish (varnish includes the addition of driers).

Characteristics: A feature or quality belonging typically to material or procedures, serving to distinguish or to compare them from others, like chemical, physical, or mechanical properties or sensations that are distinguishable by human perception (vision, haptic, audio, or olfactory) systems. A group of features is referred to as character.

Concept: The bearing idea.

Correspondence: The interactive and attentive process of inquiry and response used by the craft practitioner in order to control the material characteristics for the desired purpose (Ingold´s, *The Art of Correspondence*, 2013).

Corrosion: The deterioration, and material loss, of an exposed metal/material by interaction with its surrounding environment (into a more chemically stable form).

Craft skills: The experienced, developed expertise needed in order to successfully perform a craft-related task with specific quality goals. Involves problem-solving in connection to expected or unexpected affordances, and the ability to put knowledge into action.

Drier: A compound added to the oil that increases its drying power. Synonym for to *Siccative* and positive catalyst.

Drying power: The drying speed (rate) – i.e., the time for transforming liquid oil or oil varnish into a solid, through-dry solid film.

Ferrous heritage: Tangible and intangible aspects of making in alloys based on the metal iron. In this thesis, this is attributed to ferrous structures, objects, or components manufactured until the 1960s, when anticorrosive paints with drying oils (mainly linseed oils) were used for protection.

Guidelines: Information or statements by which to clarify and advise courses of actions based on routines and practice, in order to make the results more predictable and with a controlled quality.

Haptic: Phenomenon derived from sensory systems of touch and proprioception.

Heated oil/varnish: Air-blown and heated (130–150°C) linseed oil with the addition of liquid driers. Modern "boiled linseed oil", commonly produced from cold-pressed and purified linseed oil. Synonym for *Preparation varnishes* in this thesis.

Hiding power: The ability of an applied paint or a paint material to cover up (obscure) a background of contrasting colour, so that it cannot be seen (due to opacity), depending on the application method and paint film thickness.

Intersubjectivity: Norms, praxis, knowledge, qualities/values, or characteristics that could be interchanged, compared, and reviewed by a group of people, for instance, professional craft practitioners.

Intervention: Action taken in order to improve the status of physical heritage. Commonly, the actual surface preparations and painting treatments.

Lacquer: A protective clear coat of any kind. A clear coat of oil varnish is still a varnish.

Linseed oil paint: Paint whose binder consists of drying oils, and where > 50% of the binder is linseed oils in different forms, and the rest other drying oils (not alkyds). Synonym for *linseed oil varnish paint*.

Location paints: Paint layers applied on primer and previous layers of the same paint. Could be intermediate layers or topcoats.

Material intelligence: A conscious awareness about the nature, handling, production, and behaviour of materials that we meet in everyday life or in our professions. Material intelligence involves an active perception that trains attention and leads to expanding knowledge about material characteristics. This develops knowledge and craft skills.
Maxim: Formulated (operational) rules of thumb, understood from the knowledge that they express.
MIO armour paint: Paint pigmented with micaceous iron oxide (hematite) with linseed oil varnishes and other drying oils as binders. Also referred to as *Scale Armour Paint*.
Maintenance: A sum of the processes of preservation and the care of the status and function of an object, structure, building (etc.); service of a heritage performed repeatedly so that there will not be premature deterioration. Simultaneously, it should retain its cultural significance. Maintenance can include repair.
Maintenance repainting: A process of preserving the status of an existing paint system, by repeated cleaning, spot-painting, and/or overpainting.
Management: Strategic administration, cyclic practices or processes of preserving, protecting, and using built heritage with respect for the past, present and future. It involves technical, economic, and environmental aspects.
Modern linseed oil: See *Heated linseed oil/varnish*.
Odour: A phenomenon perceived by the olfactory perception system, derived from chemical emissions of substances. Synonymous with smell.
Olfaction: Sense of *smell*.
Paint: An applicable intimate mixture or dispersion of pigments and fillers in a liquid medium, with a body, that adheres well to the substrate, and solidifies and fulfils its purpose. A mixture of pigment and varnish is a paint, while a solution of stains in an oil or varnish with no pigments is not a paint.
Painters: Unless otherwise specified, traditional architectural painters are referred to. These types of painters are experienced in using pre-industrial and early industrial paints such as oil varnishes, distempers, lime paint, water glass paints, and so on.
Paint system: Paint products that together form a protective action to a degenerating exposure, when used.
Parlance: Language, words, or style of speaking used by a particular group of people (such as painting professionals). Synonym for vocabulary.
Practise: Repeating actions over time, resulting in (craft) skills.
Practitioner: The craft person.
Praxis: An accepted practice or process by which a theory or skill is embodied or realised.
Preparation varnish: A (type 2) varnish that is produced by no, or moderate heating (120–150°C), air-blowing, and the addition of liquid siccative. Synonym for heated or modern oils/varnishes.
Primer (paint): The first paint layer, closest to the substrate.
Quality attribute: A feature associated with quality assessment or characteristic.
Refinement: Actions are undertaken in order to change the characteristics of material towards the desired direction and use (to refined materials). The steps of the process are part of the refinement as refinement treatments.
Remake: To manufacture a historical product with the guidance of historical recipes and descriptions. This definition is preferred instead of reconstruction or reproduction (since these require continuous experience in paint making, very accurate recipes, instructions, described characteristics, and quality specifications).

Resinated: A varnish that has a resin addition.

Retention temperature: Processing at a certain temperature (or temperature interval).

Retention time: The time for holding/processing a product (an oil/varnish) at a certain temperature or pressure.

Rule: A principle, a known fact (or rule of thumb), as a result of cause and effect.

Scale armour paint: MIO pigmented paint with linseed oils and other drying oils as binders, resulting in a coarse, black greyish finish that sparkles in the sunlight. Synonym for *MIO armour paint*.

Sensibility time: The time between the cleaning of a ferrous substrate and the first application of the protective layer. Time refers to the sensibility of an active surface to react with the environment and to initiate reactions that may be detrimental to the quality of the painting treatment.

Sensorial assessment: An active perception in order to assess affordances and to consider this in further actions.

Siccative: See *Drier*. Siccativated is used in order to describe a varnish that has had an addition of solid or liquid catalysing compounds of any kind.

Substrate: The base to which paint is applied. Could be the metallic surface or old/new existing paint layers.

Through-drying: A curing process that proceeds through the entire solid varnish or paint film, not only drying at the surface.

Topcoat: The final paint layer that is put on (made for resisting weather exposure).

Tradition, traditional, traded: Knowledge and practice that are taught, traded, from different generations of painters to others, or within a craft society.

Turbidity: A loss of transparency in a liquid due to the presence of suspended particles or gases.

Varnish: Synonymous with the terms *(lin)oljefernissa* (Swedish), *Leinölfirnis* (German) for heat-treated linseed oil (i.e., boiled linseed oil *with* driers). Varnishes may contain tung oil or other oils or are produced by stand oil processes. Oil varnishes consist of fat drying oils without resins or solvents (called *fat varnish*) and are used as binders in paints. Varnish paints have binders of oil varnishes, for weather-resistant outdoor use.

Vocabulary: The manner of speaking, and descriptive words used in order to express perception. Synonym for *Parlance*.

Working procedure: A description, yet an approximation, of the chain of conscious actions, adapted to situation affordances (like an ongoing inquiry) in order to accomplish a craft-related task with specific goals and quality; from the start to an end of a treatment or intervention. Synonymous with craft procedure.

LIST OF ABBREVIATIONS

DFT	Dry Film Thickness
ISO	International Organization for Standardization
IVA	Kungliga Ingenjörs-vetenskapsakademin
Pb-Mn	Lead-Manganese
SJ	Kungliga Järnvägsstyrelsen or Statens Järnvägar
TAP	Traditional architectural painter
Vattenfall	Kungliga Vattenfallsstyrelsen
VOC	Volatile Organic Compounds
WFT	Wet Film Thickness
Vol%	Volume percentage
Wt%	Weight percentage
XRD	X-Ray Diffraction

CHAPTER 1

THE PROBLEMS

An example of a ferrous heritage; A decorative structure of wrought iron and cast grey iron.

"They are not ours. They belong partly to those who built them and partly to all the generations of mankind who are to follow us. The dead still have their right in them." (Ruskin, 1889, p. 197).

THE PROBLEMS

In this chapter, the background to the needs in the field of maintenance of ferrous heritage and the research questions in the present thesis are described. General tangible (the material) aspects of the ferrous materials and paints are exemplified, as well as the intimate interaction with the intangible (the immaterial) knowledge, as expressions of human creativity. Improved maintenance processes and procedures are put in the light of what could be considered as sustainable.

1.1 General

This research is about maintenance painting treatments of weather-exposed historical ferrous structures, objects or vehicles of mild steel, cast or forged irons, some made with production methods that are not in use any longer. Examples of structures and objects are steel and iron sheet roofing, bridges, pylons, platforms- all important carriers of industrial heritage. They remind us about Swedish industrial heritage, but also on the efforts that played, and which still play, an important role in the building of our society. For instance, they remind us of the efforts which has gone into engineer the infrastructure of our country.

Ferrous structures and objects are in a temporary state of equilibrium with the surroundings. The ferrous substrates do not form a passivating surface compound upon atmospheric exposure. The main rule is that cast iron, cast steel, wrought or rolled mild steel or other unalloyed steel suffer from atmospheric corrosion. The corrosion consumes metallic material and converts it to a mineral by redox reactions, thus reducing the cross-section of the metal which could lead to dangerous and costly failures. The ferrous substrates are therefore painted in order to protect them from corrosion damage. The painted layers are continuously deteriorated by atmospheric impacts, such as UV-radiation, moisture, temperature variations, and contaminants. The act of protecting a ferrous substrate by painting is an action in order to temporarily masters the laws of thermodynamics. Painted ferrous substrates are to be considered as a state and must therefore be repeated continuously when the sacrificial layers need to be renewed. A central inquiry in this study is how to manage, take care of, and protect the ferrous heritage with authentic-like anticorrosive paint treatments. This research investigates some tangible and intangible aspects of anticorrosive oil varnishes and paints, which are common paint materials until the mid-twentieth century.

The maintenance of the historical ferrous structures and objects is problematic by many means, as will be described. It deteriorates not only the physical carriers of heritage but also the economic resources of public financing. Maintenance is often demanding and costly, and for public and private stakeholders there is a need for guidelines on how this could be conducted in sustainable ways. Without financing, the structures will be abandoned or exchanged, leading to loss of the physical evidence of ferrous heritage.

1.2 The Ferrous Heritage

Kuijpers, an experimental archaeo-metallurgist, poses *"a challenging hypothesis: knowledge is partly based in the material and therefore might belong to the material—as a kind of heritage of materials"* (Kujpers 2019, p. 614). As a metallurgist, with an industrial background, I do not find this challenging at all; I rather consider this as a fact, applying to small-scaled and also modern, industrial production. The heritage of materials holds not only the tangible but also the intangible heritage.

The history of metal production is an astonishing example of how the continuous *Art of Correspondence* (see chapter 7.3) of humans, and the interplay with the produced materials, led to the development (that still proceeds) of alloys with extreme variations in characteristics and use. The production starts with the extraction of ores to the metallurgical high-temperature melt refinements, plasticising shaping operations, heat-treatments, and other post-refining methods, into tailor-made products for different needs.

This tangible and intangible knowledge is especially impressive when one considers that there are points during the history of metal production in which the chemistry had not yet been formulated and elements such as oxygen had not yet been discovered. Indeed, metal production has been on-going since the Iron Age. The metallurgists, the casters, the black-smiths and the heat-treaters, and many other groups of people, are truly combining their theory and practise into the development of advanced skills. Still, the development of modern metallurgy and metallography, based on the technical field of thermodynamics, is only about a hundred years old. The development of metallurgical and corrosion research both in Sweden and internationally advanced during the early twentieth century, with research programmes in laboratory and field (see chapter 6.3). Humans have made metallic materials, but those materials have really also formed us: our society and landscapes, our transportation systems, and our buildings and architecture. The first iron production in Sweden started at *Bergslagen* communities in 500 BCE, with copper mining in Falun and blast furnaces in the eleventh and twelfth centuries (Magnusson, 2002, pp. 10–11). The long history of metallurgical production and its impact on our society has been described by, for instance by Magnusson 2002: Cossons, 2007: Forsyth, 2008.

Cultural heritage should be considered as a non-renewable resource, and efforts must be put into balancing needs and protection (Fielden & Jokilehto, 1998, p. 12). The value of the authentic ferrous heritage is that they are physical, documentary evidence and sources of information about the human creative processes of different branches of knowledge and innovation, consistent with the values of cultural heritage as described by Jokilehto (2006, pp. 1–3). These include the values of the truthfulness or authenticity of different types of ferrous materials and production technologies, but also the painting materials and production technologies that are associated with the functional integrity of the heritage's survival from the past to today. Moreover, the repair is always to be prioritised before the replacement of ferrous components or parts, as pointed out for instance by, for instance, ICOMOS (2003, p. 4).

1.3 Sustainability

> *"Steel is being used more and more every day for buildings and other permanent structures and therefore on the prevention of this decay depends on the permanency of these works and the safety of future generations. Were it not for iron and steel, the erection of large works of engineering would be impossible and their very size and consequent high cost, representing as it does a large sum of human energy – which is after all the only true foundation for wealth – make it a duty to preserve them from decay."* (Sang, 1910, p. 1).

The quotation above reminds us of something very important, that seems to have changed in our society: the importance of the prevention of decay and damage, to remember and to make the most of our ancestors' efforts and knowledge, and for the responsible use of the earth´s resources.

What is gained first of all, by management and maintenance, is the carrying on of the ferrous structure or object to the benefit of present and future generations. This is, in itself, an act of sustainability; they are not replaced by newly produced materials of natural resources that negatively influence the environment by energy consumption and emissions. The establishment investments and ecological footprints made for the old ferrous products were made a long time ago, and from a life-cycle view they have already paid off some of their debts to climate and environmental changes. Responsible management and planned maintenance are basic conditions for the preservation of the ferrous heritage since this will prevent corrosion and structural failure that may include aspects of safety. Without the protection from paint systems, corrosion may lead to serious failures of the structures caused, for instance, by pitting corrosion, crevice corrosion, and bimetal corrosion.

By carrying on the use of authentic or replacement materials, clues about how they were produced and knowledge and practice associated with their production can be discovered. This gives perspective on our present knowledge too. Many metallurgical production processes are not in use any longer, such as the Lancashire method or other forging methods for the production of sheets. Even methods such as hot rolling that were used for the production of thin steel-sheets into the 1960s, are not used in Sweden any longer (Källbom, 2018, pp. 38–41). Profiles, sections and forgings received different characteristics when they were produced by decarburisation in the hearth, puddled or by ingot steel methods (the latter such as Bessemer, Martin, Thomas, Kaldo processes) that were introduced in 1858 (Magnusson, 2002, p. 24). Similarly, cast iron components produced by pig iron differs from today's scrap-based production regarding alloying elements. The original materials must be treated as irreplaceable documents of the tangible and intangible ferrous heritage, practised by skilled craft persons and engineers. This is the same materials such as cast iron or steel castings, hot-rolled profiles or corrugated sheets of mild steel.

Historic structures and objects are placed into their social context, as attributable to our common heritage. The works may add substantial aesthetical assets to architecture such as cast and decorative iron bridges or fences, arched roofing for trains or other vehicles, steel profile constructions such as masts or light-houses, a riveted steel-sheet facade and so on. The paints do not have a shape of their own; they follow the shape of the substrate. Still, the paint plays an important role in the perception of the ferrous structure or object due to the colour, texture, gloss, and the impression of volume or weight. The materiality of the substrate and the paint layers cohere to a unit that affects our perception of it, and to our relation to the ferrous structures or objects. Both the materials used for painting, and the substitution of metallic materials do play an important role in the perception and technical performance of the structure or object. The anticorrosive linseed oil varnish paints have many benefits on ferrous substrates that have already been mentioned, but they may also add a subtle beauty (if the objects are close enough to be viewed). The painting skills associated with these paints are important in order to carry on the outdoor-located heritage building of parts, structures, and objects, or to be used in eco-building. A more conscious strategy for the management of ferrous structures and objects involves the care of tangible and intangible aspects on the knowledge of metallic materials but also the paint materials and paints. An increased request could vitalise the profession in terms of stimulating entrepreneurship by, for instance, increasing the number of traditional architectural painters, paint-makers, casters, platers, metallisers, and so on that are needed for the sustainable maintenance and care of authentic-like paint treatments and production of substitutions. These are examples of social and economic aspects of sustainability in the management and maintenance of ferrous heritage. Skilled craft practitioners that carry out high-quality interventions for built heritage increase opportunities for local engagement and sustainability because interdisciplinary specialised processes need materials, expert competences, and social contacts (Vandesande & Van Balen, 2019, pp. 3–5).

In my perspective, paint as a product can never be sustainable, because resources in any form are consumed.[1] The most sustainable paint is the paint that is not used. Paints can only be more or less sustainable in relation to other solutions and factors, and are needed for several reasons – in this context, in order to protect the ferrous heritage as described. The origin of the paint ingredients and the maintenance intervals influence the environmental impact and loss of other sustainability values. A more durable paint system needs less maintenance (in longer intervals) and is, in this sense, more sustainable than a less durable paint. The applied paint system, the *sustainable shield*, could be considered in terms of durability, functionality, and beauty. Beauty does not only include the perceived architectural aesthetics of the painted surfaces but also the professional painters′ intersubjectivity of surface finishes. The intangible heritage of craft – the traditions, and profession associated with the use of the paint systems – are carried out in the sustainable shield.

1.4 Examples of Unsatisfactory Management and Maintenance

From 2016 to 2018, I worked on a research project in cooperation with stakeholders in Sweden, who were managing painted ferrous steel-sheet roofings (on heritage buildings). The

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[1] Paint types made of entirely renewable scrap materials do exist, but these are suitable for interior uses.

purpose was to give guidance on workings procedures regarding materials and methods. My work resulted in a research report (Källbom, 2018). Expanded implementation of what we already know, would be a huge and successful step forward. During the research project, both good and bad examples of maintenance and working procedures were found, providing me with the different perspectives and research questions discussed in my thesis. Here, I will try to describe my perception of the field (partly described in Källbom, 2018, pp. 3, 7–10, 274–275).

The common knowledge of how to protect ferrous heritage is low, also at a professional level at trustees. There are skilled professionals, but they are quite few in number. It is difficult to find good cases, where the painting treatments and anticorrosive actions were sufficiently quality controlled or documented. This leads to difficulties in managing individual buildings and objects in the longer term since this restricts a systematic experiencing and follow-up of solutions that work in a longer period, or do not.

The use of irrelevant and incomplete working procedures, made by laymen consultants who copy-paste other invalid working procedures or procedures from another field, is common. Some consultants inspect steel-sheet roofing from the ground, without ever getting a look at existing paint layers or the condition of the roofing before they make the planning of working procedures. Most (not all) superintendents or administrators of authorities rarely have even a basic understanding of the function of anticorrosive paints, paint treatments, or the conditions for corrosion to occur. Yet they have a responsibility for approving or rejecting what measures should or should not be undertaken for our common, listed ferrous heritage.[2] Heritage and technical controllers are accepted without having the appropriate – or sometimes any – competence, if technical controllers are even requested at all. I found steel-sheet roofing of listed buildings that were controlled by building conservators in the intervention process which had been approved for brush application of linseed oil paints, but where a modern polymeric paint had obviously been rolled on, thickly and with defects. These defects and out-of-context finishes disturbed not only the experience of the beauty of the built heritage but also my professional view of expected finishes. Some of these modern paints are potential threats to the substrates, and there are many examples of irreversible damage being caused due to the use of paints that could not be removed without injuring the substrate, or which age in a way that promotes under-film corrosion. A lot of frustrated traditional architectural painters have to accept invalid working procedures or had to accept that the offer was given to someone with less knowledge, resulting in poorer results (and costly corrections). On the other hand, painters are facing working procedures with detailed descriptions on outdoor applications that do not take into account the adjustments that the painters need to make during the work depending on working affordances. The skills and competence of the practitioners are reduced by so many means.

Therefore; I experience that there is an urgent need for improved management strategies, quality tools, and general working procedures for anticorrosive paint treatments of non-metallised ferrous substrates, in order to make it easier for stakeholders to make informed and well-grounded decisions. There is a need for procedures that exemplify critical quality assessments that skilled painters and practitioners carry out in the interplay with the materials. Such procedures would improve the quality of the painting treatments.

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[2] Maintenance of listed buildings (*byggnadsminnen*) may not require permission, but this varies in different regions. There are also a number of stakeholders that manage valuable historic buildings, which are not necessarily listed.

There are many common prejudices in the field of anticorrosive paints or outdoor oil paints generally. For instance, that anyone can paint, and that any paint will do. For the use of historic paint types and oil varnish paints, nothing could be more wrong. The prejudices about the nature and use of linseed oil paints are many; such as VOCs must be used, that the paint "never" dries, that the performance is low, and so on. This field requires deep material knowledge about paints and substrates, and the necessary skills to adjust and to handle the conditions in order to achieve the desired result in a historic context. In some cases, totally new and unproved paint materials were used for the painting treatments of precious black iron plates, with few features in common with the authentic materials. Or at least, the paint-maker claimed that there was, without being able to present any data or references. Only a few of the linseed oil varnish paint making companies in Sweden have working procedures or anticorrosive paint systems for metallic substrates. It is desirable to use authentic anticorrosive paints and working procedures, but this is problematic since the materials, craft traditions, procedures, and praxis have been changed compared to those utilised for the originals. Many laymen and professionals consider that the label "authentic linseed oil paints" is a quality label and are not aware of different paint formulations or how these paints have changed through time and for different purposes. There is a romanticised picture of the paint materials, that does not take into account how they function or how they could be used. This has been described in Karlsdotter Lyckman's thesis from 2005, but the results have unfortunately been poorly implemented (Karlsdotter Lyckman, 2005). A common conception in the field, is that any steel product may do, regardless of context, for the substitution of historic materials.

Therefore; the mentioned prejudices and lack of knowledge are considered as indicators that we have lost important material intelligence, certainly about authentic or authentic-like paints but also concerning the different values of the substrates.

Another difficulty is to navigate among the different kinds of existing commercial ready-made paints and to assess whether the paint formulation is relevant for heritage purposes. For historical objects, the authenticity is important, but it is almost impossible to assess what binders and pigment or other paint constituents have been used, despite data sheets. This is a great difficulty and most often a well-kept secret by the paint-makers. What I found in the archives– for instance, the corrosion tests conducted by Vattenfall and IVA (earliest started 1922–1923), where it was a strategy and an absolute condition to control and have knowledge about paint formulas– was in absolute contrast to the present situation as I perceived it. Today, it seems as if no one is in charge of the national or local strategies for protecting our ferrous heritage, and the "experts" are the paint manufacturers that ordinate how their products should be used. There are linseed oil paints with relatively short durability, though they claim to be traditional or authentic-like (though there are good examples too). I have seen, for instance, almost 200-year-old hot rolled steel-sheets with very old, extremely adhering and dense paint, and oil varnish layers that are very hard to remove from the substrate. On the other hand, the durability for a particular paint system may differ considerably (despite similar atmospheric exposure), indicating that the manners of conducting the paint treatments have significant impact on the results. There are cases and reports of the metallic armour paint which is still occasionally possible to see on original surfaces, applied approximately 80–90 years ago. This made me curious; what is this paint?

Therefore; I wonder what were the secrets of armour paints– the "Rolls-Royce" of oil varnish exterior paints? And could it be produced and used again for the protection of non-metallised ferrous heritage?

With the introduction of modern paint materials, the craft skills associated with the precursors gradually became impoverished. We have skilled traditional architectural painters, but we do not have so many of them. They are not always interested in these risky outdoor works, where for instance unstable weather conditions and incomplete workings procedures could pose future guarantee demands. I found skilled painters that worked as consultants, but the problem was that they were used to working with wooden substrates (where the procedures are different from metals due to the absorbent wooden substrate). I came into contact with several skilled painters who were in deep trouble because they had not been aware of the importance of having enough paint or controlling the paint layer thicknesses. The result of paint layer thicknesses that were too thin in total (and other premature failures) led to reclamations of large contracts, where the corrections could involve a large risk of bankruptcy for the company. The specification of layer thicknesses was not stated in working procedures, not discussed, and not controlled during the contract but mentioned merely as a recommendation from paint manufacturers. The common opinion, or "truth", that linseed oil paints should be painted onto a surface extremely thinly ("*...you should paint so thin that if you start with one litre, you should have two litres when you are finished*" is a common Swedish proverb); it does not work for anticorrosive purposes unless the object is painted with impractically many layers in order to reach sufficient total paint layer thicknesses, or to be repainted often with more weather-resistant oil varnish paints. In many cases, the painters are forced to undertake the interventions during inappropriate environmental conditions such as late autumn, when the weather is cold and humid, affecting the results negatively.

Therefore; again, it appeared as there is a gap and unconsciousness about the complex interaction between paint materials for challenging applications, the use and resulting quality, also among professionals.

Despite this, I also ran into brilliant examples of master painters´ skills, sound working procedures, and beneficial management strategies from different perspectives. When I tried to interview the masters about their sensory quality assessments (*sinnliga bedömningar*), I realised how difficult this was. It was probably the first time that they were discussing this with a colleague, and it was very difficult to find the words to depict the perception of the materials. Sensory perception as quality attributes could be found in historic literature, but most often very sweepingly. Some paint-makers told me that earlier generations of painters and paint-makers used their sense of smell in order to assess the quality of linseed oil barrels and their appropriate usage. I dare to say that this capacity is forgotten today. This made me very curious.

Therefore; How could professionals actively use our senses in order to describe quality assess oils and varnishes, and the interplay with the working procedures? If we start to pay attention to these aspects, could we improve our knowledge about the craft aspects of the materials? Could we take advantage of scientific methods used in other fields for this?

To give a ferrous substrate a paint treatment does not seem to be so complicated, on a first view, see **Figure 1**. Still, this is quite complicated. The paint layers on the substrate repress the electrochemical redox reactions by forming a physical barrier between the substrate

Figure 1: Ongoing painting treatment of a steel-sheet roofing, on a nineteenth-century church.

and the surrounding environment, protecting the substrate from corrosion by preventing the formation of corrosion cells (for a while).

In outdoor conditions, the variables on paint treatments in the short and longer terms are numerous and the synergetic interactions between the variables are difficult to evaluate. The quality of the treatments is affected by so many factors that we cannot artificially simulate the influence of all variables in a realistic or comprehensible way. The conditions for different surface preparations, paint making, paint application, paint layer thicknesses, weather conditions, and environmental impact, are examples of variables that have a great impact on the results and which are difficult to control. Trials by systematic one-by-one variation of variables are inappropriate and factorial design experiments would be quite complicated and extensive. There is a rigour-relevance gap between research (with limited focus) and evidence-based knowledge and applied science (wider facetted), that could be traced in this field. During the corrosion research that was conducted across almost four decades by IVA, researchers experienced some difficulties, such as correlating the protective power of paint systems to differences in varying paint layer thicknesses, differences in climate across the country, and difficulties in assessing and describing the paint layer deterioration consistently (Nylén, 1954, pp. 1047-1056: Trägårdh, 1954, pp. 1043-1047: 1961, pp. 10, 21–29). The time gap in full-scale exposure is a challenging variable since the outcome of used materials and working procedures requires 10–15 years of atmospheric exposure in Sweden. This required long-term project leadership and a quantifiable evaluation is not a trivial task. The paint formulations may have been changed during the period. The alternative is accelerated ageing tests that may, despite differences in exposure, still give valuable information.

The exterior paint types have changed during and after the Second World War (Karlsdotter Lyckman, 2005: Johansson, 2002: 2004: Standeven, 2011). The linseed oil paints have changed in different ways, such as the refining treatments and durability. These changes had begun already in the nineteenth century and still continue today. But did these changes result in reduced anticorrosive paint qualities? I found it very contradictory that the reports of the outstanding durability of armour paints that were reported by, for instance, IVA (1935, 1961) and Reuterswärd (2011a, 2011b, 2014), coincident with the time when the fire-boiled linseed oil varnishes generally were in general already replaced by preparation varnishes. Did the reduced performance of preparation varnishes motivate the additions of highly refined stand oils and tung oils, to anticorrosive paints?[3]

Therefore; by employing a scientific approach, I want to shed some more light on the historic, authentic linseed oil varnish paints and especially the armour paint concept. How do they respond to atmospheric exposure and how do they age?

Of course, I cannot find solutions and answers to all of these types of problems and questions. Any data-collecting or generating methods could only offer a piece to a larger picture. A narrowly selected research question or variable, suitable for controlled laboratory trials, I consider to be of limited use. It is unrealistic to expect that this, or any research, is the solution to the problem of lacking sound working procedures. It is impossible to provide a complete guideline about how to do the best practice in different situations because every situation is unique. There are always several ways to execute a working procedure, which differs depending on the present conditions and the craft practitioners' experiences. The conclusion is that reality is so complex that it could only be studied from different angles. Therefore, this work has a multi-methodological approach, limited to some selected crucial variables for the sustainable maintenance and management of ferrous heritage: the paint and paint materials, the painters‘ skills, and the working procedures. This could give more information and insights, such as the influence of authentic or authentic-like paint materials and craft practice on weathering resistance, evaluations and systematisation of working procedures. General working procedures concerning anticorrosive painting treatments for steel-sheet roofings have been formulated in earlier work (Källbom, 2018). In order to extend the usefulness of these results, it is desirable that the level of details in working procedures shifts from being general to more specific, concerning, for instance, the quality assessments that the craft practitioners undertake in the working process. This will bring further light onto the historic, authentic-like oil varnish paints and certainly the armour paint concept.

1.5 Disposition

The present thesis is a compilation thesis, with six different scientific papers that are referred to and put into context in the chapters. The structure of the thesis is described in **Figure 2**. Some chapters are quite deep in explaining and exemplifying context and implementation, and therefore the thesis shares some characteristics with a monography. Chapter 2 describes an orientation to earlier research in order to put the present thesis into a context, and situates how the work or quotation of others affected the framing of this research. The specific research questions and the possible impact of the results are described in chapter 3. How this research fits into the field of Kulturvård is described in chapter 4, as well as the research methodology, the research methods, and the valuing of different types of sources. Chapters 5–7 puts the content of the papers into context: the description of the demands on the weather-exposed paints and the need for quality assessments methods at different stages of maintenance (chapter 5); the varnish making and paint making, use of anticorrosive paints, the artisan and technical industry (chapter 6); the painting profession and the need for articulation of sensory quality assessments (chapter 7). Chapter 8 gives an example of the implementation of material and craft correspondence in a hypotised working procedure for painting treatment of ferrous

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[3] As stated by, for instance, Karlsdotter Lyckman, 2005, p. 136.

substrates. In this chapter, craft praxis and different sources are articulated and integrated in order to illustrate crucial variables to consider during (the making of) anticorrosive working procedures. The results are discussed and concluded in chapter 9, followed by suggestions for further research in chapter 10. The published papers are found in Supplement 1, as well as additional research data in Supplement 2-5.

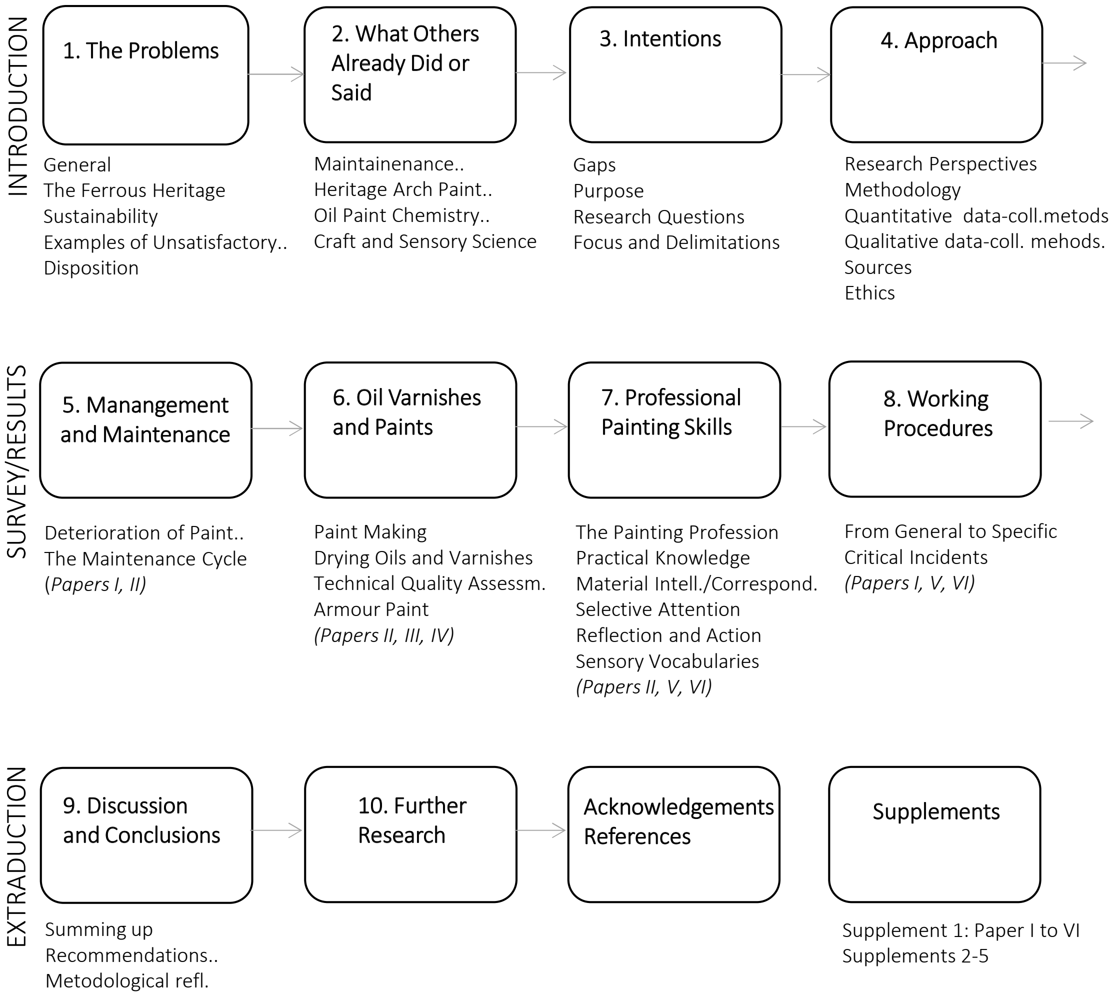


Figure 2: The structure of the thesis.

CHAPTER 2

WHAT OTHERS ALREADY DID OR SAID

An example of precious ferrous heritage; Wrought black iron sheet roofing (on right side).

WHAT OTHERS ALREADY DID OR SAID

The relation to the research field and evidence-based knowledge in terms of management, material and craft research is presented in the following chapter.

2.1 Maintenance and Protective Treatments of Ferrous Heritage

A number of extensive maintenance handbooks describe praxis, cases, practical solutions, and so on. They rarely frame a specific research question or refer to other sources, yet they provide very valuable information.

Metals in America's Historic Buildings: Uses and Preservation Treatments by Look & Waite (1980), and *The Maintenance and Repair of Architectural Cast Iron* by Waite (1991) and *Materials & Skills for Historic Building Conservation* by Forsyth *(2008), Scottish Iron Works* by Swailes (2006), *Conservation of Architectural Ironwork* by Mitchell (2016), and *Metals. Practical Building Conservation* by Martin & Wood (2012), are all examples of work that provide thorough information on the history of metal production methods, ferrous material characteristics, types of corrosion and damage, repairs, and surface preparation methods. The original linseed oil varnish paints are described in general, as are their overall characteristics and pigments for decorative use, and decorative finishing methods. Repainting systems of, for instance, epoxies, polyurethanes, and acrylics are recommended and the benefits and drawbacks of the modern paint types are described, but not for the original paint types. The oil varnish paints are described as slow drying, but with better protection capacity, and the limited accessibility on the market is stated as a limiting factor for repainting. The historic paint systems are recommended as long as users "*do your homework and understand to what you are buying and how it might be used*" (Mitchell, 2016, p. 161). Martin & Wood (2012) emphasise the original, authentic paint types but also describe the difficulties of using oil varnish paint types such as formulations with lead-white and red-lead pigments in terms of health hazards, environmental aspects, and limited accessibility. The publication *Handbok i rostskyddsmålning [Handbook in Anticorrosive Painting]* by Hult & Persson (2015), there is an overview of corrosion mechanisms and associated damage in water, earth, and air, as well as the preventive actions that can be taken to avoid such damage. Moreover, different surface preparation methods are described according to international standards, as well as preparation grades, standards, paint formulation (modern paints), corrosivity classes, and safety aspects. The handbook is very useful for a general introduction to anticorrosive treatments but it does not treat linseed or other oil varnish paints at all, and references are not given to anything but standards. A similar publication is *Byggnadsplåt. Målning, [Painting. Building Sheets]* by Fredriksson (2007). General technical aspects of different corrosion mechanisms are widely explored, and are not in the focus of this work, though they are often described in mentioned handbooks. Since the international and national handbooks do not deal with linseed oil paints or other drying oil paints, no descriptions of working procedures with these types of paints are provided, and certainly no descriptions are given that describe the painter's quality assessments during the intervention. This is an obvious gap that this research strives to reduce.

In the publication *Äldre järnplåtsarbeten. En sammanställning av uppgifter ur äldre facklitteratur, [Older Iron Sheet Works. A Compilation of Information from Older Technical Literature]* from 1979, the architects Lisinski and Johansson (at the Swedish National Heritage Board) compile Swedish, German, and Danish technical sources (the earliest from eighteenth century) regarding the historic manufacture and use of iron for roofings, and the working procedure for paint treatments (an example of precious sheets is shown on page 32). The information gives a genuine background to the use of linseed varnishes and tars, and pigments, and how sheets were treated at the installation and on maintenance. This research is of relevance for this study since it provides for detailed material specifications and information on use, based on historical sources. However, recommendations for maintenance and repainting are not included. The authors refer to the publication of 1979 in their publication from 1992: *Järnplåt, Anvisningar för underhåll och reparation [Iron Sheets, Instructions for Maintenance and Reparation]*, which emphasises repair of the substrate and examples of damage. The manual from 1992 does not refer to published sources. A brief chapter discusses historical and contemporary painting treatments. The recommendations focus on modern paint systems such as alkyds and caoutchouc paints. Linseed oil paints are a viable option, but the authors state that the contemporary linseed oil paints are not as fat as the historic paints, though fat linseed oil is accessible via importation from Holland (pp. 32–35). The authors' conclusion (p. 35), is still valid and highly relevant to this thesis (my translation):

> *"Paint treatments of steel-sheet roofings is a complex and difficult task. The expectations on paint material and the implementation are demanding. A variety of paint types have been tested with varying results. Repainting with new paint systems containing heavy VOC´s has led to adherence loss of older paint layers. The unpredictable behaviour of new paint types also increases due to unspecified changes in formulations. Many modern paint systems are, due to practical or economic reasons, inappropriate for roofings due to the need of high demands of surface preparations, protection measurements and so on. In the maintenance of valuable sheet works, painting methods must be used that enable repeated maintenance in the long term. It is therefore substantial to always use the same type of paint materials. Earlier maintenance painting with linseed oil paints has generally worked well. The paint type adheres well and does not tend to introduce stresses that will flake the existing paint layers. [..] A cumulative assessment of different factors, strongly suggests continued use of linseed oil paints for the preservation of historic ferrous works".*

Some examples of scientific works that deal with the conservation of ferrous heritage can be found, but they do not give any input regarding authentic-like paints. An example of this is *Corrosion and Conservation of Cultural Heritage Metallic Artefacts* by Dillman et al. (2013). The conservation of metallic archaeological and historic artefacts concerning conservation ethics and science, analytical methods and onsite monitoring are described, and the text also suggests modern solutions such as alkoxysilanes and self-assembling monolayers. No information is provided about the maintenance of outdoor-located objects. Conservator Emmerson describes the conservation of wrought iron as lying in the intersection between conservation and engineering and the gap of evidence-based understanding of solutions in decision-making in her thesis *Heritage Wrought Iron: Towards the Development of Evidence-Based Standards for Coating*, (2015). Five surface preparation methods and three modern paint systems were evaluated after two years of humid exposure in air-tight reaction vessels. Oxygen consumption is used for calculating corrosion rates and the corrosion products are characterised by XRD. Despite the promising title, this thesis does not deal with maintenance or ageing of outdoor-located ferrous structures and objects, nor the principle of using authentic-like fat oil varnishes or paint. The gentle surface preparation methods may be useful for delicate objects, but otherwise, there are no relevant aspects for the present research.

Considerations of using anticorrosive linseed oil paints appear to be absent from the international literature. During the first half of the twentieth century, linseed and oil varnish paints were tested in different types of field tests, for instance in Sweden and the United Kingdom, but when they were replaced with modern paints, this development stopped. Therefore, there is only very sparse contemporary research about the outdoor use of linseed oil paints, and anticorrosive paints, despite the revival of these paints in some countries such as Sweden. Some Swedish test programmes deal with linseed oil paints for anticorrosive purposes, such as those reported by Heale, Palm & Carlsson (2011). In their research study *Jämförelse av tillgängliga rostskyddssystem för kulturmiljövård, [Comparisons of Available Anticorrosive Paint systems for Heritage Preservation]*, they conducted field and accelerated corrosion tests of commercial anticorrosive paint systems, mainly used for bridges. A reconstruction of historic anticorrosive linseed oil paints with red iron oxide primer and unknown topcoat were made after old recipes (not described). The outcome was not successful, and the linseed oil paint layers were too thin to function as effective barriers. This result is interesting for several reasons. It shows that the making of historical concepts is not trivial, and that the paint system thickness plays a vital role in the performance – and that this was not predicted in the research design. Reuterswärd explores the field experiences of different paint systems for steel bridges, makes quantification of critical adhesion of new and old paint layers with pull-off testers, investigates the initiation of corrosion by the introduction of notches on painted steel-sheets and discusses how to deal with old ferrous objects that are primed with red lead paints (2011a, 2011b, 2014). He has provided important evidence reports on the long-lasting performance of weather-exposed armour paints. All these issues are relevant and useful for the management and maintenance of painted ferrous heritage. Reuterswärd´s observations are valuable, and confirm statements in literature and IVA research reports. His results regarding the repainting of red-lead primer paints as a way to reduce pollution to the environment is referred to in **Paper II**.

To summarise, the gap is characterised by a lack of information on the maintenance of and working procedures used for ferrous substrates. This includes a lack of information on the use of anticorrosive oil varnishes and paints, and factors that may affect the results depending on how such treatments are conducted.

2.2 Heritage Architectural Oil Paints, the Painting Profession and Industry

Painting conservator Karlsdotter Lyckman's licentiate thesis *Linoljefärg förr och nu, en studie av ett autentiskt material i förändring, [Linseed Oil Paint Then and Now: A Study of an Authentic Material in Continuous Change],* (2002) and Ph.D. thesis *Historiska Oljefärger i Arkitektur och Restaurering, [Historical Oil Paints in Architecture and Restoration]* (2005), deal with the making and use of linseed oil paints in the beginning of twenty-first century and how the use of them differs compared to earlier usage. These issues are highly relevant for this thesis. Through the compilation of (mainly Swedish) historic written sources and by interviews with 15 senior painting professionals about oil paints the paint components, oil refinements, and use of drying oil paints (with focus on linseed oil paint) on different substrates, indoors and outdoors, are described. Based on the survey and a one-year outdoor exposed weathering test with a reconstruction of white linseed oil paints on wooden substrates, Karlsdotter Lyckman concludes that the relatively short lifetime of modern "boiled" linseed oils is caused by lower heating temperatures, different drier additions and the use of different white pigments. A short chapter describes oil painting on ferrous substrates, and she states (p. 136) (my translation);

> *"It is reasonable that the modernised boiled linseed oil, generated a need for additions of stand oils, quarter tung oil and china wood oil during the 1930s, to gain better durability".*

This statement has relevance to the research questions in this thesis that concern the concept and characteristics of armour paints, and the reasons for adding these highly refined binders are therefore searched in the descriptions of historical anticorrosive paint types. Karlsdotter Lyckman emphasises the importance of practical knowledge associated with the use of oil paints, and she refers to the knowledge of the old Master Painters that she interviewed. This is the only research that has been found, that clearly emphasises the craft aspects. This inclusion is very valuable and inspirational for this thesis. She describes the substitution of linseed oil paints with other paint types, and the revival in the 1980s which was initiated by the critical reactions of damaged wooden architecture due to the use of modern paints (pp. 42–45, 91–92). Due to the knowledge gap of a few decades, raw linseed oils were used instead of boiled oil, inspired by artists' oil paints and the use of (raw) linseed oil pastes during the mid-twentieth century. The polarisation between the contemporary paint industry and the requirements of the needed oil paints is described, as are the consequences of the misunderstandings that linseed oil paints require VOC's for the unwillingness from the Paint Unions to use these paint types. These matters are also highly relevant today, and are of relevance for this work. Because of Karlsdotter Lyckman's work, most of the many myths regarding linseed oil varnishes and paints have received explanations and could be rejected by the public or professionals; still, the myths are very long-lasting. Today, the requests for linseed oil paints are increasing, not only for listed buildings and heritage professionals but also for an increasing number of ordinary house owners. The paint type is currently produced by 12–13 small companies, with quite varying formulations, and is sold in shops specialising in heritage materials or paint shops specialised in heritage paints. This is a frame for the understanding of the increasing use of linseed oil paints in Sweden.

In *House Paints, 1900–1960. History and Use* (2011), painting conservator Standeven describes the context and use of ready-made house paints in England and in the USA, an area that in the publication is described as unexplored and barely researched. There are a wide variety of paint types with many formulations and characteristics, and some have been used for artistic purposes. The survey holds a chapter that describes historical drying oils and their use in the paint industry, and how different types of additives such as resins and driers affect the durability of outdoor oil paints. The descriptions of the development of tung oil and stand oil additions are relevant to this thesis since their function was to improve outdoor paint durability. Standeven gives a description of how the paint industry has changed over time, which is consistent with Karlsdotter Lyckman's description. An interesting and relevant contribution is the description of how multi- or three-layer paint systems were gradually replaced by two-layer systems after intense debate in the United States of America during the 1920s and as a result of rigorous national research (pp. 31–33). This underpinned the development of paint types that could be applied thicker and yet dry well, an analogue to the development of armour paints and other anticorrosive paint types. Standeven gives a perspective on the many additions to paint formula to ready-made paints in the 1920s that should not be considered solely as adulterations but also as experiments to improve can-stability and flowing application. In her work from 2013, the theme is continued, but with a focus on *Ripolin*, a glossy enamel paint that was used on ferrous substrates such as railway wagons. The use of tung oil in *Ripolin* is discussed, as well as the reasons for paint formulation deviations for a certain brand of paint. These are questions that are related to the present thesis since the formulations and use of ready-made paints during the mid-twentieth century are rarely described elsewhere. Standeven describes the difficulty of analysing drying oil additions to linseed oil, such tung oil or other varnishes. This is interesting because chemical analysis of historic paints, or interpretation of historical recipes, are important for the understanding of historic paint formulations. The present thesis uses recipes for the remaking of armour paints, but also undertakes an analysis of aged armour paints (as described in **Paper II** and **Paper III**). The foundation to Standeven's outlined field was put in her thesis *The Historical and Technical Development of Gloss House Paints, with Reference to their Use by Twentieth-century Artists* (2003). This work describes co-development in art and house paints in the early twentieth century, for instance in terms of oil paints.

In two massive publications *Bland pigment och kopaler, Svensk färgindustri under 200 år, del 1 & 2 [Amongst pigments and copals: Swedish paint industry during 200 years, Part 1 and 2]*, the profession of the Swedish paint-makers' and painter's before and during the industrialisation is described by Johansson (2002, 2004), and this is relevant to this thesis. The timeline starts with the small-scaled artisan paint making from the eighteenth century and ends in the 1970s. The consumption of the paint treatments in the society and the painting materials, and formulations are described. The growing paint industry in the nineteenth century is described, with influences from Germany, and this is exemplified by recipe and process handbooks. Johansson's background as a Professor in Economic History is depicted in the useful statistics about the number of painters, industries, production values, and so on that are relevant for the understanding of the transformation of the painting profession.

In the thesis *Tarring Maintenance of Norwegian Medieval Stave Churches* (2003) painting conservator Egenberg deals with the real-world problems of lacking knowledge, insufficient practices, and an absence of quality specifications for "authentic" pine tars for the maintenance of wooden roofings. The materials are different, but there are many similarities between pine tars and oil varnishes. There is some common history in the use of tars for iron objects and sheet roofings, and in the refinement and shielding function for tars and oil varnish paints. Egenberg puts contemporary tars and practices in the light of information from historical sources. Her approach is, like mine, "learning by doing" and participatory observation. Egenberg uses the word "reconstruction" and points out similarities to experimental archaeology. In my work, I gradually concluded that I do not want to use the word "reconstruction", since it can never be confirmed when reconstruction is made (not even if a recipe is followed), and there is nothing to compare it to, there is no universal prototype, and the circumstances are different. I prefer the word remaking instead and try to identify the substantial foundations of the concepts. In my view, I consider that knowledge concerning paint materials and tars cannot be reconstructed; it may be re-searched, re-covered, revitalised, and explored for, and must be practiced repeatedly for a long time in order to be considered as reconstructed. Some of the experiences from Egenberg's work are useful for this thesis, such as the improved weathering resistance by heat bodying (determined by accelerated and natural ageing), the comparisons of pre-industrial and industrial production, and also by her methods of testing weathering resistance and material characterisation. She mentions general classifications and "traditional assessments" such as appearance, viscosity, smoothness, homogeneity and so on, but does not specify these types of sensory quality assessments because this was not the purpose of the thesis. Tarring guidelines are provided with quality assessments of critical steps. Sustainable development and integrated conservation regarded the tangible and intangible aspects of tarring are discussed. These are inspiring similarities between my thesis and that of Egenberg: both use a multiple research methodology approach, combining qualitatively and quantitatively data-collecting or data-generating methods.

To summarise, the gap is characterised by the lack of detailed descriptions of heritage industrial anticorrosive paint formulations, such as armour paints, and the context for their use.

2.3 Oil Paint Chemistry and Ageing in Art Works

The chemistry of drying oils, driers, and pigments for indoor oil paints, such as interior paints or art-works, has been described by many authors. The results of these investigations are very extensive. Despite differences in function, substrates, and deterioration mechanisms, there are similarities between indoor and outdoor oil paints and their ageing. Historical oil varnish recipes and procedures have many similarities to small-scale artist paint or architectural paints. These works are relevant since they describe the chemistry of linseed oils drying and ageing, and analytical methods.

Reconstructions of historical recipes and practices for easel oil painting have been studied in the Dutch research programme MOLART, the HART project, and in the De Mayerne Programme (Carlyle, 2012). This extensive research involves analytical and multidisciplinary chemical analysis of the reaction process, kinetics, and ageing of reconstructed binders and paints, and discussion of conservation issues for historical artworks. Examples of research in these programmes include van den Berg's thesis *Analytical Chemical Studies in Traditional Linseed Oil Paints,* (2002), which is based on extensive investigation of deterioration processes of painted art with spectrographic and chromatographical analytical methods within MOLART, and Alveses' thesis *Molecular Aspects of the Chemical Drying of Oil Paints Formulated in the Period 1890–1940* (2015), which describes the chemistry, raw materials, and composition of artists' linseed oils and paints (linseed, poppy, hemp, walnut, safflower and so on). Alves touches on some historic sources which describe scientific discoveries and oil production. The solid film of Linoxyn is mentioned, but the origin of Mulder and the film characteristics are not described and this is an important issue in the present thesis, which aims to describe the characteristics of a durable film. Dr. Kappelmeyer's stand oil process from 1938 is described by Alves, and the Diels-Alder theory for the chemical structure. This is also of relevance to the present work since the stand oils are important features of anticorrosive oil paints. Izzo's thesis *20th Century Artist's Oil Paints: A Chemical-Physical Survey* (2011) uses different analytical methods to investigate the paint formulations and ageing characteristics of artists' oil paints that have been aged with acceleration and natural ageing. The multi-analytical approach is important to the present thesis since the use of different methods reveals interconnected characteristics that affect the performance of the paintings. The use of different fatty acid ratios is beneficial for the evaluation of characteristics of remade and naturally aged armour paints. Izzo's work is interesting since she investigates the presence of metal stearates. Stearates are also used for achieving the leafing effect of the metallic aluminium pigments in armour paints. Mecklenburg, Erhardt and Tumosa's research on the ageing processes of museum objects and linseed oil paints for art, is extensive. Examples of articles that describe accelerated and natural ageing, in order to describe the chemical deterioration processes, could be found in Erhardt, Tumosa, & Mecklenburg, 2000: Mecklenburg & Tumosa, 2001: Erhardt, Tumosa & Mecklenburg, 2005: Tumosa & Mecklenburg, 2005. In these articles, thermal ageing is compared to natural ageing. The long-term chemical, physical, and mechanical properties of artists' oil paints are described, regarding the influence of pigments, binders, and solvents on the drying and ageing processes. A great number of researchers have used Mecklenburg's Paint Reference Collection at the Smithsonian Center for Materials Research and Education (United States of America), for their own research concerning ageing effects on technical characteristics.

Paint conservator Carlyle conducted extensive research on the artists' oil paints, particularly their ingredients and recipes. Her thesis *The Artist's Assistant: Oil Painting Instruction Manuals and Handbooks in Britain 1800–1900 With Reference to Selected Eighteenth-century*

Sources (1991) searches historic sources regarding oil paint and oil, resin, spirit varnish formulations; preparation of substrates; paint application, and techniques; and deterioration of paintings. Using analytical methods, she investigated the characteristics and ageing of reconstructed oil paints (for instance, Bonaduce, Carlyle & Colombini et al., 2012). The early recipes are relevant to this work, since the making of the small-scale artists´ oil paintings and architectural artisan paintings had many aspects in common. This information is relevant to this work in describing the development of oil varnishes and paints, from the small-scaled to the industrial. The thesis of the technical art historian Kneepkens' thesis; *Masterful Mixtures: Practical aspects of fifteenth- and early sixteenth-century oil paint formulation* (2021), explores the recipes of historical linseed oil paints recipes from an art painter's view. By analysing recipes concerning fifteenth- and early sixteenth-century oil paint formulations such as those used by Jan van Eyck (c. 1390–1441) and his successors, she explores the effect of different paint ingredients by reconstruction experiments. She uses her perception to put into words the types of motives that were behind different formulations for purification and varnish making. The variation's influence on the paint properties is investigated. The purpose of the paint making is different from that of the anticorrosive paints, but the basis of paint making has universal similarities. She investigates the materials as a painter, to reveal new facts – and this is similar to the present thesis. Kneepkens did not have any vocabulary or parlance for describing her practical experiences, and this is one of the intentions of the present work.

Art in oil paintings was conducted on copper plates from the seventeenth and eighteenth centuries, and this is a field of research by, for instance, by Fuster Lopéz, Carlyle, Wadum and Pavlopoulou. In the publication *Paintings on Copper and other Metal Plates* (2017, with editors López et al.) production, deterioration, and conservation issues are reviewed. Pavlopoulou´s contribution *Chemical, Physical and Mechanical Decay Processes in Oil Painted Copper Objects* concerns indoor-located art but also describes some of the factors that influence the adhesion of oil paints on metal substrates and the linseed oil paints´ interaction with the metal for the initiation of defects. The factors that influence the adhesion on copper are also relevant for ferrous substrates. Barrier paint systems are used for wooden substrates too, and is an issue for research based on increasing sustainability demands. An example of research on linseed oils and paints includes Stenberg's thesis *Influence of the Fatty Acid Pattern on the Drying of Linseed Oils* (2004), with a background on the increasing demand for renewable, VOC-free paint and surface treatments of wood. The interactions between the wood and the oils, and different penetration characteristics are interesting but they differ in many ways from the behaviour on metallic substrates. Metallic substrates normally have no, or very limited penetration of paint (or paint binder).

To summarise, research about the ageing processes of oil paints in the art context is extensive. This is not the case for oil varnish paints for outdoor applications on metallic substrates. The gap is characterised by the lack of investigations concerning the making of anticorrosive oil varnish paints and their ageing in natural or accelerated ageing conditions.

2.4 Craft and Sensory Research

The Craft Laboratory is a part of Gothenburg University, Kulturvård. In cooperation with different stakeholders, the purpose of the Craft Laboratory is to document, trade, and develop traditional architectural craft knowledge, which is needed in order to preserve and carry on tangible and intangible cultural heritage. A number of theses have been conducted in the field of craft research, where the researcher is also a craft person – as in the present thesis. Craft research could include, for instance: mapping of evidence-based knowledge; investigation of working procedures; reconstruction of knowledge by studies of written sources, materials, objects; causality mapping; and redevelopment of "authentic" materials and methods (Sjömar, 2017, p. 117). For craft research, many different types of exploratory and explanatory methods are used–video and audio recordings, participation observation, time-geography, and so on. In the background of craft research, practice-led inquiry and craft knowledge are often referred by a large number of philosophers and scientists such as Gibson, 1966, 1979), Schön (1982), Ryle (1949), Ingold (2011, 2013, 2018a, 2018b), Molander (1996, 2017), Rolf (1995, 2017), Sennett (2008), and American Pragmatism philosophers such as Peirce (1839–1914), Dewey (1859–1952) and James (1842-1910). Repetition of those works is unnecessary, however, and can be found in the following presented work of, for instance, Seiler et al., 2021. Relevant research perspectives of those aforementioned philosophers for the present thesis are mentioned in **Paper V**, **Paper VI**, and in chapter 7. Some examples of relevant research associated with the Craft Laboratory, are described below.

In gardener Westerlund´s thesis *Trädgårdsmästarens förökningsmetoder: Dokumentation av hantverkskunskap, [The Master Gardener´s Propagation Method: A Study of Craft Knowledge]* (2017), the implicit knowledge of Master Gardeners is explored and results in the categorisation of plants and propagation descriptions from the craft practitioner's view. She describes knowledge as a type of focused attention, and this is in connection to sensory assessments (that gradually develop into a language in the field). Westerlund uses video recordings, audio recordings, and workshops as a way to undertake participatory observation, where she explores her craft field from the inside. The research methods she uses are relevant for this work, and she is an inspiration in her ambitions to put words into the practitioners' sensory assessments (*sinnliga bedömningar*) and to use the professional collective as a source for the attentive focus, information collection, and categorisation of knowledge. The use of video and audio recordings to observe, analyse, and discuss craft knowledge has relevance to the present work. I consider my colleagues as a highly valuable source for reflective discussions, and for the initiation of a common language for quality assessments, and this is a foundation in my thesis.

In gardener Seiler´s thesis *Management Regimes for Lawns and Hedges in Historic Gardens* (2020), heritage gardening methods are explored by analysing historical sources, by the reconstruction of tools, and by post-analysing video recordings of the practices in action. Seiler uses video as a diary, in combination with speak-out-loud-accounts, and analyses the recordings afterwards. There are similarities in research methods between Seiler´s study and the present study; an alternation in temporality and from details to full views, the remaking of products, and the use of video recordings. A video is a powerful tool to document, discuss, and to catch details of material or human response. It has been used widely in this work and is used for exploration and explanation of my own or other painter´s practices and sensory quality assessments, but it has not been given a major role in the present written thesis.

In Groth´s thesis *Making Sense through Hands: Design and Craft Practice Analysed as Embodied Cognition* (2017), she explores her ceramic practices from the inside, for instance by analysis of video recordings, speak-out-loud accounts, and workshops conducted with blind-folding. Cognitive capacities and embodiment of the touch with materials in craft are co-investigated with neuroscientists. Her findings that the making process involves critical points of problem-solving and attention, decision-making, and risk assessments are relevant for this thesis since these are all relevant issues during the workings procedures of painting treatments.

In Swahn´s thesis *If I Can Taste It, I Want It. Sensory Marketing in Grocery Retail Stores* (2011), he uses a multiple research approach in three different research fields to develop a sensory language regarding food as marketing and communication tools in retailing. The Swedish Alcohol Retail Monopoly (Systembolaget) is an example of a company that uses strategic communication about its products to a wide spectrum of consumers with different experiences. For this research, Swahn uses methods such as RGM (Repertory Grid Method), descriptive analysis, and different types of statistical analysis. Swahn compares how sensory perception and descriptions correlate between those expressed by laymen/consumers and those expressed by expert/trained panels, and he creates a semantic frame to extract keywords for the marketing strategy. Sensory science is defined as a "*multidisciplinary field comprising measurement, interpretation and understanding of human response to product properties as perceived by the senses such as sight, smell, touch and hearing.*" He describes how language reflects and determines how we perceive the world, and that in order to express a product´s sensory characteristic, a conscious act of learning and practice is required. It was found that the layman expresses similar sensory description labels as the trained expert, only less detailed. One of the papers in Swahn´s thesis; *Sensory and Semantic Language Models for Red Apples* with Swahn et al., (2010), inspired **Paper VI** in this thesis, which uses a very similar methodology, and was also conducted in collaboration with Örebro University. The work of Swahn, with his co-researchers, has influenced a part of the approach in the present thesis a lot, and the ambition to establish a language for expressing some of the affordances that painters may assess in the painting treatments. With the methodology and experiences of sensory research and studies, it became possible to perceive linseed oils and varnishes in deeper dimensions than merely 'a coloured liquid.' Moreover, the work of, for instance, Herdenstam et al. (2009), *The Professional Language of Wine: Perception, Training and Dialogue*, describes how the perception of odours affects the language of expressing wine aromas. This has very much in common with the neuroscience and cognition training that is also fundamental also for the work described in **Papers V** and **VI**.

In Eriksson´s thesis *Att gestalta måltider. Mise en place, dukning och servering, [To Represent Meals. Mise en place, Table Setting, and Serving]* (2021), the tacit knowledge of a waiter

(Eriksson) is explored and visualised by auto-ethnography, time-geography, and video recordings (film). One of the research publications is a film, where the tacit knowledge of the waiter and two gardeners is exemplified by video and audio: *The Ways of Tacit Knowing*, referring to Michael Polanyi's quote "*We know more than we can tell*" (Polanyi, 2009, p. 4). I consider this to be an interesting and splendid way to convey complex craft knowledge. Originally, it was intended that the painter′s tacit knowledge should have been included in Eriksson's thesis (based on many of my recordings). Unfortunately, it did not turn out that way. One reason for this was that the material and painter interaction is complex and very subtle, and may be challenging for laymen to appreciate. The work of the Seiler et al. (2021) was, and is, very inspiring to the present thesis, but video and audio recordings are used mainly for post-analysis of paint making and use, sensory profiling and reactions, discussion, documentation, and interviews.

To summarise; craft research is still an underdeveloped field, especially the specification and attributing of practitioner′s sensory quality assessments. There are gaps about how to bring these types of assessments to the surface, so that they may be communicated and discussed. However, the working field of sensory research and studies is well established, with a wide variety of approaches and methodologies. There may not be any large differences as to whether cooking oils are explored, or drying oils.

CHAPTER 3

INTENTIONS

An example of ferrous heritage; An intricate structure of cast grey iron and wrought iron from 1836.
Part of the spire of Riddarholmskyrkan in Stockholm, by Erik Gustaf Göthe. Photo by Sven Olof Ahlberg.

INTENTIONS

3.1 Gaps

The research in the field of atmospheric corrosion and anticorrosive paints is extensive, but the authentic-like paint materials based on drying oils, are not described in the international literature today since they are used only to a very small extent. Artists´ oil paints have been the focus for extensive research for many years, but the environments differ considerably and the anticorrosive paints need to withstand very tough atmospheric conditions for a long time. The artists´ oil paints differ in concepts and formulations compared to anticorrosive paints. The revival of linseed oil paint making in Sweden has been ongoing for almost 30 years, but the practices are focused on wooden substrates. In order to enable the production of adequate alternatives, the elucidation of characteristics and performance of authentic-like paints on ferrous substrates exposed to atmospheric conditions (or simulations thereof), is relevant.

We lack systematic ways to describe, control, and document the maintenance process of anticorrosive paint treatments on ferrous heritage. The anticorrosive paint type is one key to the quality of the paint treatment and the final results. Other keys are the painting skills, the interaction with the materials (including the substrates), and quality assessments during the working procedures.

3.2 Purpose

The inquiry looks at some of the tangible and intangible characteristics of the anticorrosive linseed oil paints that influence the paint layers´ response to atmospheric deterioration (aspects of the paints' improved durability) and the quality of the painting treatments. By using appropriate and authentic-like paint types, in order to continue practicing the associated painting skills, and using evidence-based working procedures and control methods, the chances of creating sustainable maintenance and management increases. The research concerns architectural painting and paint making crafts for linseed oil paints, especially armour paint. Armour paints were used from the early twentieth century to about 1960s, and the paint concept includes red-lead primers with topcoats of micaceous iron oxide and aluminium pigmented linseed varnish paints. Some consideration about which characteristics of paint material and painting skills are important in order to achieve sustainable results in anticorrosive treatments of heritage objects is clarified and exemplified in a working procedure. Through the initiation of sensory vocabularies, the quality assessments could be articulated by traditional architectural painters and paint-makers – and the correspondence between materials and painter could be better communicated.

3.3 Research Questions

The assumption is that the weathering resistance of a paint treatment is dependent on material characteristics, but also on how the treatment is conducted. In order to improve guidelines and working procedures, the explicit quality assessments regarding paint and practice could be exemplified with the assistance of craft descriptions from within the craft. The research areas, questions, and contributions of each of the supplementary papers are illustrated in **Figure 3** and **Figure 4**.

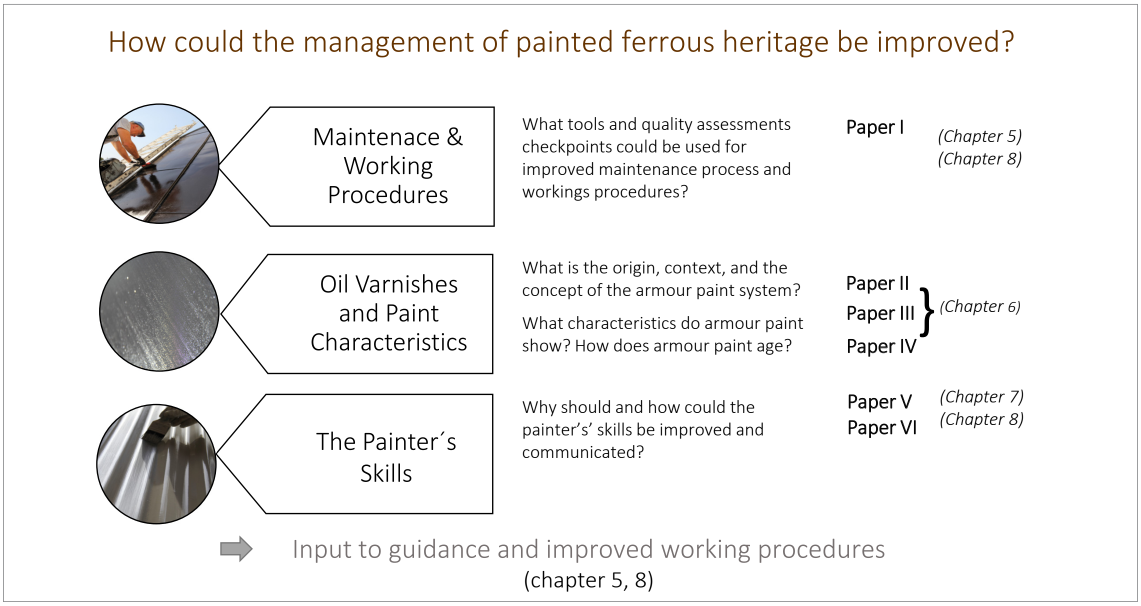


Figure 3: Research areas, questions, and papers (and associated chapters in this thesis).

Objectives and expected immediate results of this thesis are:

- Description of concepts and material characteristics of remade armour paints in both aged and unaged conditions. To put the origin and use of historic armour paints in a wider context.
- Initiation and development of sensory vocabularies, to enable the articulation of quality assessments made by traditional architectural painters and paint-makers.
- Exemplification of how craft and paint-material knowledge could be considered and enlightened in working procedures and guidelines.
- Description of quality control tools and checkpoints in the different phases of a maintenance cycle. This includes a model for a systematic description of working procedures.

The expected long-term outcomes improve the sector´s ability:

- To formulate and inform input to guidance concerning the sustainable maintenance and management of historical objects, constructions, and listed buildings, considering authentic-like linseed oil paint and craft skills.
- To enable commercial paint making of authentic-like or modified oil varnish armour paints for the protective treatment of ferrous heritage.
- To catalyse improvements in terms of increased craft skills, consciousness, and improved communication methods for painting professionals concerning sensory quality

assessments of linseed paint materials and working procedures, for the use on any kind of substrates. Improved communication methods could be used in practice and education, and to highlight the importance of craft skills and evidence-based experiences for the final results.

- To introduce new experimental methods for craft research, through interdisciplinary collaboration from another research field. This includes the involvement of painting professionals.

	Why	Contribution
Paper I	To bridge the communication gap between research and practice and to provide useful tools for quality control, to balance different values, for better decisions.	Systematic descriptions of material characteristics, working procedures and quality control checkpoints. Defining technical, economic, environmental and historical qualities of paint systems. Proposing a model for describing the circular nature of maintenance.
Paper II	To describe the idea, history, function and characteristics of armour paint system.	A concept model is presented. Technical specifications on raw materials and paint recipes are provided. Analysis of paint system from technical, economic, environmental and historical perspectives.
Paper III	To explore the chemical and physical properties of remade armour paints to investigate their durability and the chemical changes that occur following their exposure to natural and artificial ageing.	Introduction of a multi-analytical methodology. Description of remade and historical armour paint ageing characteristics. An approximation of equivalence between accelerated (standardised) and natural ageing (Southern Sweden).
Paper IV	To explore chemical and physical properties of the binders in the remade armour paints (from Paper III). and the chemical changes that occur following their exposure to artificial ageing.	Introduction of a multi-analytical methodology. The reintroduction of the water immersion test on glass plates. Description of some different types of drying oils composition and ageing characteristics.
Paper V	To exemplify why and how the painting craft competence is important in heritage research.	Introduction of the research methodology. Initial vocabularies for olfactory, haptic and visual perception of linseed oils and varnishes.
Paper VI	To formulate an olfactory description for refined linseed oil in order to articulate material and craft skills relevant to heritage.	Application of research methods from sensory science (food and beverage). Formulating an initial vocabulary for olfactory perception of linseed oils and varnishes. Showing that it is possible to distinguish and correlate odours to types of linseed oils.

Figure 4: Research questions and contribution of the supplementary papers.

3.4 Focus and Delimitations

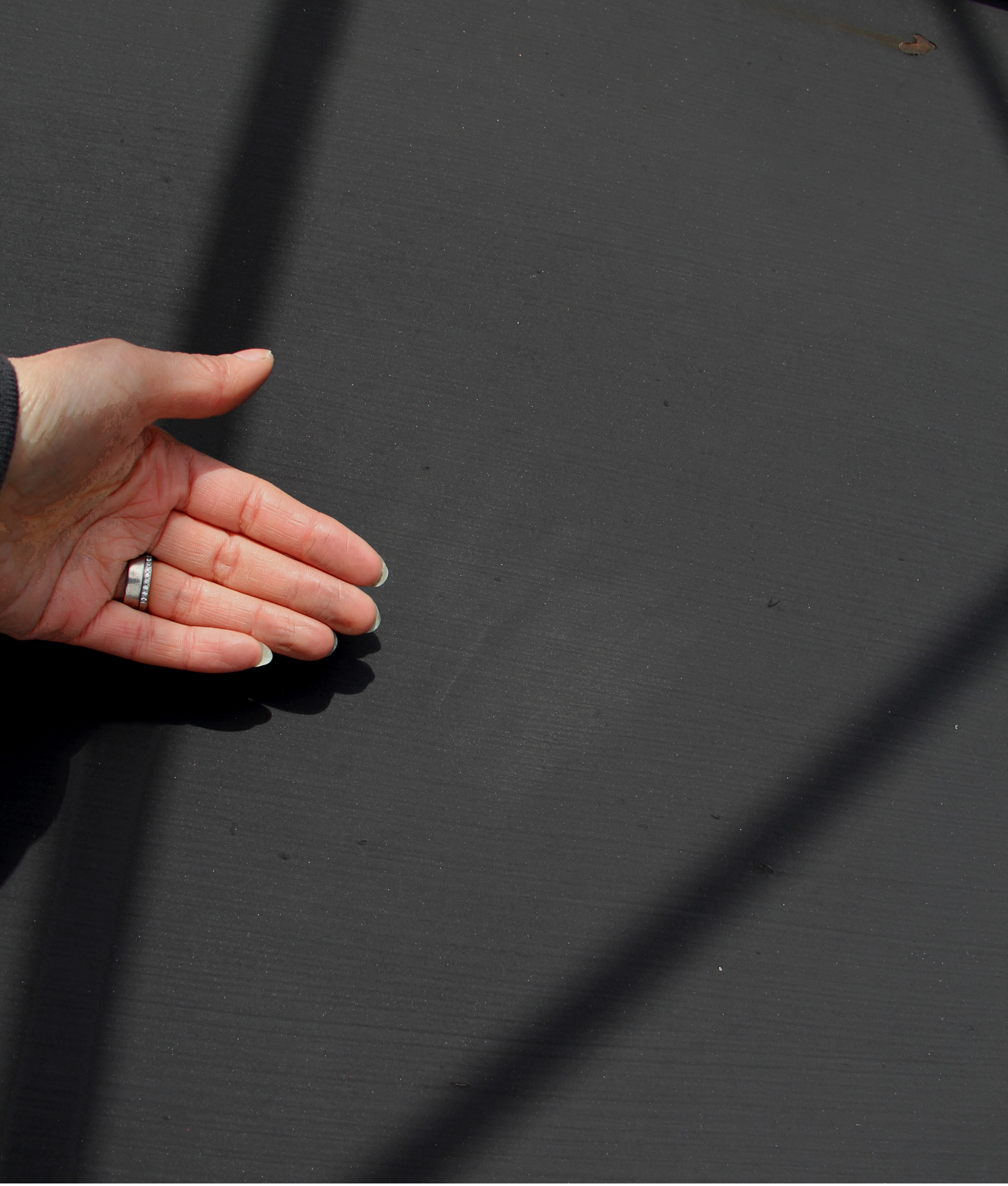
This research focuses on anticorrosive paint treatments used on different types of ferrous heritage in Sweden. For a time, the research was part of another research project concerning anticorrosive treatments of steel-sheet roofings, with different types of forged, hot-rolled, and cold-rolled steel sheets, with or without zinc metallisation. The majority of the cases that I followed were metallised since this is the most common substrate in use today. However, zinc metallisation involves certain challenges connected to whether the painting is conducted on substrates that are electrochemically active or passive. In order to delimit these issues, the focus is on the painting treatments of non-metallised ferrous substrates, regardless of production method, that are always are in an active state prior to painting. Archaeological iron artifacts are not considered in this research; neither are corrosion mechanisms of ferrous substrates, or different types of test methods for this. The complex mechanisms for moisture transport through organic coatings are not treated. There are many ways to repair ferrous structures and objects so that material substitution would be unnecessary, but this issue is not presented further. The study does not go deep into different types of surface preparation/pretreatment methods.

Drying oil varnish and paint formulations with resins, alkyds, or petroleum-based additions are excluded, as are different types of exterior paints for wooden substrates. Contemporary anticorrosive paints types are not ventilated, and the solutions for changing course for using more authentic-like paint systems are further difficult issues that are not included in the present thesis. The very common historical anticorrosive paint types—such as tar paint, bitumen, asphalt varnishes, and so on—are neglected. The research occasionally touches on, but does not go deep into, various pigmentation such as chromates, white-lead, hematite, carbon black, and so on. The main interest is the concept of armour paint, an anticorrosive paint system that was used, like other linseed oil paints, mainly in the period of 1920s to 1960s. The origin of the paint type, however, is older, as are the paint binders. Since the armour paint was a result of engineering and craft traditions, the survey includes older types of linseed oil varnishes and other drying oils (such as tung oils). Moreover, the painted anticorrosive treatment and procedures have an older history, but the needs increased from the industrial revolution and beyond. The concept of armour paint is analysed from different perspectives such as formulation, function, origin, use, and ageing. The complex correspondence between the paint materials and the craft practitioners is essential in this research. Though the correspondence forms the painters' skills and quality assessment, it is usually very difficult to discuss between professionals. Therefore, method transfer from another research field is used for the initiation of some sensory vocabularies for oil varnishes and paints that may be used for attentive learning, discussion, and education. The vocabularies are put in relation to sensory attributes and empirical assessment methods described in some historical sources.

Some aspects of heritage management and maintenance are included in the research, but not aspects of business law aspects or the different strategies that governmental or private organisations apply. Working procedures for anticorrosive paint treatments are exemplified, and take into account painters′ quality assessments.

CHAPTER 4

APPROACH



An example of a field observation during the research; Assessment of the condition of painted surfaces of a steel-sheet roofing, showing chalking due to the ageing and gradual loss of the paint binder.

APPROACH

4.1 Research Perspectives on the Field of Kulturvård and Craft

This study is conducted in the research field of *Kulturvård* (Culture + Care), which also includes research about the tangible and intangible aspects of different crafts (in this case, painting crafts) needed to preserve and maintain different cultural environments. *Kulturvård* lacks strict definitions since it is an ever-changing, complex field involving different aspects of sustainability and cultural heritage. The field uses, adopts, and intersects theories, methods, and research traditions from a variety of areas, in interaction with different actors such as authorities, universities, contractors, stakeholders. *Kulturvård* is based on an integrated approach to conservation described in the Amsterdam declaration (ICOMOS, 1974) and definitions in the Nara Document of Authenticity (ICOMOS, 1994: RED19, 2018). *Kulturvård* is described as "*the art to preserve, develop and in a sustainable way*" relate and evaluate material characteristics and craft practices from the past into the future (RED19, 2018, pp. 6–7). The historic object´s cultural, societal, scientific, and craft aspects are therefore considered and evaluated. I agree with this general description of the field Kulturvård. I find the traditional crafts to be extremely important in order to protect, reconstruct, interpret, or gain new knowledge of the built heritage since without this professional knowledge it would be impossible for built heritage to continue. Craft skills are intimately intertwined with material knowledge. The relation poses a direct impact on the practice and results of any intervention in the short and the long term. This personal view affects the material-practice theme in this thesis. My standpoint is that to protect the ferrous heritage is an act of sustainability in itself, since the heritage, societal, and economical values represented in the structures and objects are carried on. There are many possibilities to improve how the management and maintenance is conducted. From the efforts of earlier generations, we and our children can find knowledge and inspiration to live more sustainably and with respect to nature and all living creatures.

Sustainability is one of the most used (or misused) words today, and there are numerous definitions. The most common definition is that of the UN´s World Commission on Environment and Development in *Our Common Future* (1987, p. 16): "*Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs*." Also, for conservation, the link between safeguarding and future generations is pronounced, as in the following: "*The aim of conservation is to safeguard the quality and values of the resource, protect its material substance and ensure its integrity for future generations*" (Fielden & Jokilehto, 1998, p. 14). The acts of caring about and maintaining industrial heritage essentially meet many of the environmental and sustainability quality goals expressed in *God bebygd miljö, [Good Built Environment]*, decided by the Swedish government in 2012. The goals of preservation, use, and development of heritage are obviously relevant. Sustainable built environments, sustainable community planning, values of infrastructure, economised resources, and environmental impact are other examples of goals that are relevant to the research theme. This is also the case for the Swedish government programme from 2018, *Politik för gestaltad livsmiljö, [Politics for Designed Habitats]*, which emphasises the holistic importance of architecture, shape, and design, and art and cultural heritage, which are grounded in well-designed, long-term sustainable environments (Boverket, 2018). Through transdisciplinary and cooperative management, heritage values are preserved for society and future generations in a responsible and care-taking way. *The New European Bauhaus* initiated by the European Union in 2020, focuses on sustainable and beautiful green living environments, via cooperation and revisiting sustainable, creative, and innovative practices. The cooperation between art, culture, technique, and science is an important key factor. The revitalisation of material and craft knowledge and concepts associated with ferrous heritage could contribute to this. ICOMOS and Europa Nostra promote the *European Cultural Heritage Green Paper, Putting Europe's Shared Heritage at the Heart of the European Green Deal* (Potts, 2021), with beneficial cooperation in order to enable cultural heritage to be one success factor for sustainable development by for instance, by encouraging skilled entrepreneurs to get involved in the renovation of historic sites. UNESCO's work on *Culture and Sustainable Development Evaluation of a Policy Theme* (2015, p. 24), points out that, together, tangible and intangible heritage together should drive sustainable development. Essential cultural components in sustainability include the ability to use senses, imagination, thoughts, and emotions in artistic practices and in historical views, according to UNESCO. Another similarity between sustainability and *Kulturvård* is also the *temporality* – the interconnectedness of past, present, and future. There are essential considerations when safeguarding industrial heritage in sustainable ways, including the safeguarding of: materials and practices which carry on ferrous architecture, structures, and artifacts; sound oil-based anticorrosive painting systems; and particular craft practices and working procedures for sustainable maintenance.

As well as pointing out that tangible and intangible heritage should drive sustainable development, UNESCO's work (2015, p. 24) also points out that the intangible heritage is essential for valuing the physical objects. Cultural components in sustainability include the ability to use senses, imagination, thoughts, and emotions in artistic practices while also considering historical views. The policy theme emphasises that the intangible heritage is essential for valuing the physical objects (the tangible heritage). This is very close to the core values of crafts for instance traditional architectural paint crafts. The craft research into *Kulturvård* has established that the craft practitioner does other, more detailed interpretations of architectural painting than, for instance, those performed by art historians due to their *code competence* – i.e., they are literally practicing the craft (Almevik, 2017, p. 261). The craft research inquiry is conducted by doing, and a condition of craft research is that the researcher is experienced in the craft (Sjömar, 2017, pp. 112, 129). This thesis is not only about painting craft, but it is also written from inside the craft – by me as a traditional architectural painter – and this has an effect upon the research questions. The anthropologist Tim Ingold denominates the immediate situation of the practitioner in the context of active engagement in the craft surrounding as "*the dwelling perspective*", for the active attention or development of skills *in* and *through* the craft (Ingold, 2011, p. 5: 2013, p. 1). The context of this research study is practice, as a platform and method for inquiry into real-world problems, and to learn/experience *by doing* (Dewey 1934/2015, pp. 63–94). To know something about something is not synonymous with being able to practice it and knowing how to do it. As for any crafts, the craft practice and the craft theory are integrated (Molander, 2017, p. 18: Almevik, 2017, p. 261: Sjömar, 2017, p. 129). This research has an open, practical approach with multiple empirical research methods, involving exploratory and explanatory analysis of aspects from several fields such as history, paint materials, painting craft skills, and natural science (to be explained further in chapter 4.2). The practice-led inquiry, with research questions founded on real-life problems and needs, aims to increase the visibility of the craft of traditional architectural painters and to initiate increased awareness of anticorrosive painting treatments. The complex challenges of anticorrosive treatments, cannot be solved by experiments based on the isolation of a few variables, and neither can they be solved by a number of descriptive cases. It is important to appreciate the complexity of the challenges of anticorrosive treatments and to understand the need for useful application of the results. The processes of inquiry and logic follow the philosophy of Charles Sanders Peirce (1839–1914), which is well comprehended by, for instance, Rodrigues (2011) as the philosophy of the American Pragmatism; knowledge is assessed on the basis of its practical applicability, its consequences, and by the most reasonable explanation of the real-world observations. The world around us is not static, but ever-changeable, and could be understood by interpretation. In reflexive methodology, it is recognised that the observer is a part of what is observed and that any research is inseparable from the researcher (Alvesson & Sköldberg, 2017, p. 22). This calls for attention and reflections about pre-conceptions and prejudices, and these ideas have been considered throughout the entire research process.

4.2 Methodology

In the process of inquiry, the characteristics of refined linseed oils and anticorrosive paints (i.e., the phenomena) are viewed from different perspectives. The phenomena are investigated by chemical, physical, and practical empirical data-collecting or data-generating methods (techniques and processes), in order to understand and to describe paints´ weathering resistance, associated craft skills, and practices. Moreover, data and evidence from the literature are reviewed. Quality aspects of materials and skills, for different stages of varnish, oil paint, and paint systems are considered.

The combination of qualitative and quantitative data-collecting (or data-generating) research methods is referred to as a mixed-methods approach or research design (Creswell & Creswell, 2018, pp. 213–246: Åsberg, 2001, pp. 270–292: Amaratunga et al., 2002, pp. 17–31). In quantitative data-collecting methods, numbers are analysed, and in qualitative data-collecting methods, the data is represented by words. Notice that qualitative data-collecting methods could be made quantitative through statistical analysis. The use of mixed or multiple methods is a type of triangulation to study the same (or similar) question of a phenomenon from different perspectives in order to counter-balance the strengths and weaknesses of different methods, and to gain extended insight into a field. The research questions provide the experimental methods and in a convergent study, the aim is to achieve a comprehensive analysis of the research problem. If the research questions vary, a multiple methods research design is being used. In this inquiry, there are both similar and differing questions, thus mixed or multiple research methods are being used to collect instrumental data in numbers and words of practice and perception. Inquiries are made both from “outside” and “inside”, complementary or beneficial to the other, and put in context. This combination of *multiple research methods in a holistic approach* could lead to an opportunity to get technical aspects of material characteristics becoming enriched by craft perspectives and vice versa. The structure of this study is described in **Figure 5**. The paint material characteristics are studied with research methods that generate quantitative or qualitative data, in constant interaction with theories and earlier research results. Interactions through and between disciplines and professions are important for opening up new perspectives, questions, and hypotheses.

A forensic perspective of (craft) research is described by Almevik (2017, pp. 260–261), applied to the interpretation of buildings or procedures, as a way to gain status and to collect as much information as possible through a variety of methods and perspectives used in tandem. A forensic approach could give clues of the paint materials' characteristics by observing details in behaviour. Attention is shifted between details and general perspectives in a hermeneutical way. According to Kokko et al. (2020, pp. 185–189), the scientific methods of *craft amplification, craft elicitation, and craft interpretation* are used in this research. Amplification uses methods from natural science and technology in order to test and quantify the material qualities of craft. Elicitation investigates craft processes such as the details in working procedures and sensory assessment by self and/or participant-observation through the use of interviews, recordings, and diaries. To some extent, this research also involves craft interpretations, where the craft researcher's insider perspective and practice experience are used systematically in order to make meta-analytical observations in a hermeneutical mode. The data-collecting research methods are described for each paper, see **Table 1**.

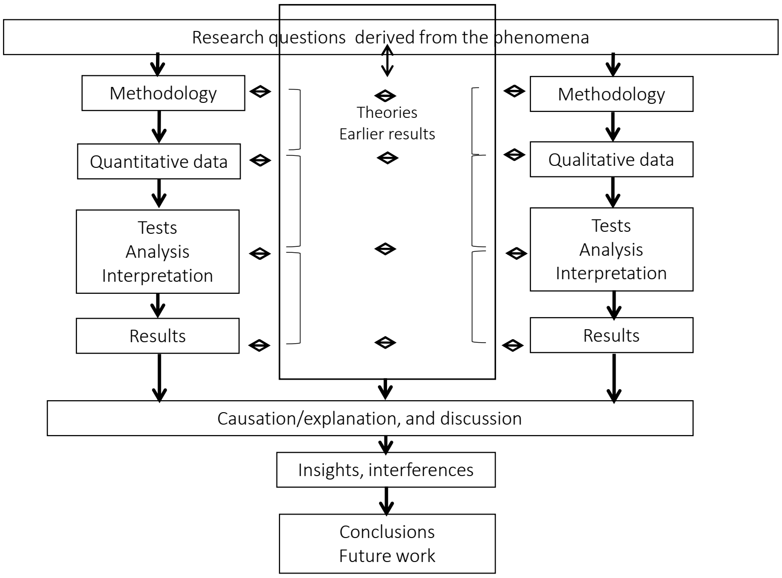


Figure 5: Principal research design, involving mixed/multiple research methods, in a convergent design.

4.3 Quantitative Data-Collecting Research Methods

Different types of methods for characterisation of paint materials and paints are shown in **Figure 6.**

FTIR (Fourier Transform Infrared Spectroscopy)

Analysis of unaged and aged liquid and solid oils and paints, pigments, is carried out by FTIR. Using this method, it is possible to get information about chemical bonding or molecular

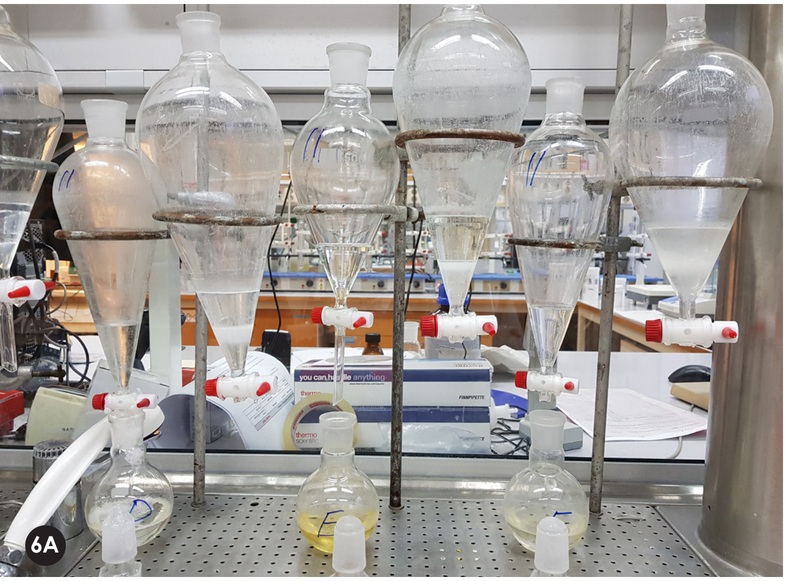
Table 1: Data-collecting research methods for each paper and chapter in the thesis.

Data type	Research Method	Paper I	Paper II	Paper III	Paper IV	Paper V	Paper VI	Thesis chapter
Quantitative data	Material characterisation	-	-	x	x	(x)	-	6
	Natural ageing	-	-	x	-	-	-	-
	Accelerated ageing	-	-	x	x	-	-	6
	PCA	-	-	-	-	-	x	-
Qualitative data	Case/field studies	x	x	(x)	-	-	-	-
	State-of-the-art and literature surveys	x	x	x	-	x	x	6
	Archive surveys	x	x	-	-	-	-	5, 6
	Production of paints	-	x	x	-	-	-	-
	Interviews, questionnaires, recordings, participant observations	x	-	-	-	x	x	7, 8
	Olfactory profiling	-	-	-	-	(x)	x	7, 8
	Haptic and visual profiling	-	-	-	-	x	-	7, 8
	Empirical trials	x	x	-	(x)	-	-	6, 7, 8

structure in organic or inorganic materials, and thus an indication of how the groups deteriorate upon ageing, superficially (Izzo, 2011, p. 34). Details of the method are described further in **Paper III**. The acquisition is done without surface preparation directly onto steel-sheet substrates in absorbed and reflected mode. The reflected mode is used for liquid oil, solid oil, and paint layers and pigments. Liquid samples or dry pigments are placed on the detector. Solid paint is scraped from the steel substrate with a scalpel and placed on the detector. The detector and the tools are cleaned with acetone and ethanol between samples.

GC-MS (Gas Chromatography – Mass Spectroscopy)

The fatty acid profile describes the (bulk) composition of the oil regarding the concentration of saturated and unsaturated fatty acids. This was assessed for the selected drying oils was first conducted by staff in the laboratory of AAK AB, with Gas Chromatography (GC) according to method IUAPAC 2.304. Fatty acids ranging from C6:0 to C24:1 were assessed. The method does not identify -cis or -trans isomers. This assessment did not work well for the stand oils and tung oils, since AAK lacked reference spectra on their complex fatty acid profiles. Therefore, the fatty acid determination was incomplete for these oils. For the analyses in **Paper III** and **Paper IV**, Gas Chromatography combined with Mass Spectroscopy (GC-MS) was conducted by Francesca Izzo at Ca 'Foscari University of Venice. With this method, the sample is decomposed at high temperatures (inert atmosphere or vacuum), and the smaller molecules that are formed are separated by gas chromatography and analysed individually by mass spectroscopy (Izzo, 2011, p. 38). The fatty acid profile, the fatty acid ratios, and the chemical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compounds of paint and selected oils (including stand oils and tung oil) were assessed. Details are described in the mentioned papers and in Supplement 2.

Laboratory Assessments

After a trainee period at the quality accredited oil laboratory of AAK AB in Karlshamn, their staff conducted certain standard test assessments of ten selected drying oils on my request. These chemical and physical quantities are used in the material characterisation of ageing tests and to compare modern and historical linseed oil specifications. Chemical quantities include determination of water content, iodine values, saponification value, free fatty acid/acid value, insoluble or alkaline impurities. Physical quantities include determination of colour, refractive index, turbidity. Some quantities were assessed by Saybolt Sweden AB. The methods and results are summarised in Supplement 2.

König Pendulum Hardness Rocker

The hardness is an indication of the polymer's elastic modulus, yield strength, and strain hardening ability; and the hardness measurement could indicate the relative embrittlement of the aged surfaces, due to oxidation (Irigoyen et al., 2001, p. 59). Common methods such as Vickers, Rockwell, Knoop, or nano-indentation methods should not be used for amorphous polymers due to their viscous-elastic response to indentation (Baltá Calleja et al., 2000). A König pendulum hardness measurement is conducted according to international standard ISO 1522:2006 for all plates at room temperature in the laboratory. This method is widely used for hardness testing of polymers and coatings. The hardness measurement is conducted after an introduction at the material laboratory of IMCD in Malmö. Up to seven measurements were made per sample, and the average and Sd (standard deviation) were calculated.

Natural Ageing

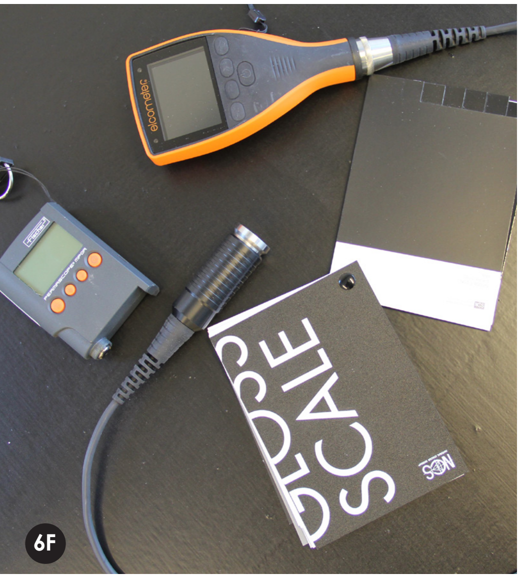
Full-scale tests of selected commercial anticorrosive paints on mild steel sheets (DC01 from SSAB) were started in the city of Mariestad in April 2017 in analogy to recommendations of Hedman, Iverfeldt & Svendenius (1993). About 60 old and new steel sheets were surface

Figure 6A-6E: Different types of quantitative data-collecting research methods were used. From the left: Assessment of saponifiable matter at AAK AB; water immersion tests on glass plates; FTIR analysis of pigment, oils, and films: König pendulum hardness rocker measurements; Weatherometer Atlas Xenotest 440.

prepared (scraping, grinding, pickling, washing, oiling, and so on) and applied with 14 different ready-made anticorrosive paint systems (three of these are remade armour paints). The preparations, painting treatments, quality control, and assessments are documented by video and audio recordings, with speak-out-loud observations and reflections. This included at least three applications for each system, and occasionally more than this, depending on the body of the paint. The sheets are evaluated by visual appearance according to international standard ISO 4628-3:2012 and weight loss. The results from these tests will not be reported here, but some of the naturally aged armour paints are compared to the characteristics of the paint aged in the laboratory. The sheets were treated according to suppliers' working procedures and all paint layer thicknesses are documented.

Accelerated Ageing

There are many methods to accelerate the ageing of paints and coatings. Many of these, such as the well-known Salt-Spray Test (international standard ISO 9227:2017), have a very severe impact on the materials (similar to a harsh marine climate) and may give relative results that are too different from real conditions (Hilton, 2003, p. 42). Actually, there are no accelerated ageing tests that correspond to reality (Lane, 2000, p. 543: Cocuzzi & Pilcher, 2013, p. 984). A common method for accelerated ageing is to use an internationally standardised cyclic test (international standard ISO 16474–2:2013) that does not include salts. It uses three types of exposure, which occur in reality too; UV-radiation, humidity, and high temperatures. The UV-radiation exposure is provided by the use of Xenon-arc lamps with a wavelength distribution similar to daylight (Atlas, 2001). This method was recommended by Atlas, and by RISE in Borås, since it is a common procedure for accelerated ageing within a climate chamber. They have experience on how the standardised testing procedure corresponds to the Swedish climate, as described by Wernståhl (1993). The instrument for accelerated ageing, Xenotest 440 from Atlas (with a black standard panel), is used to age paint samples according to ISO 16474–2:2013, with electromagnetic exposure, humidity, and temperatures specifications in



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cycles according to the standard. All parameters are continuously monitored and recorded in the instrument, including the radiation and efficiency of the Xenon lamps.

Remade armour paints and some commercial anticorrosive paints are applied (thicknesses 30+30 µm, total 60 µm ± 3 µm) to steel-sheets after surface preparation, with monitored thicknesses. These paint layer thicknesses are about half of what are usually applied in practice in Sweden (Corrosivity Class 2 according to ISO 12944–2:1998). The average of 20–30 thickness measurements taken with MI (Magnetic Inductive) instrument, the maximum and minimum thickness range, and the Sd are calculated for each sample. The surface profile (with Sd) before and after the application is measured. Temperature, relative humidity (RH), and observations during application and drying were monitored and protocolled into a diary. Primer layers were left to dry for two weeks before being painted with one layer of topcoat. The red-lead primers are covered with a distanced board so that the samples are not exposed to light to reduce the risk of embrittlement. The topcoat was left to dry for four weeks before the plates were put into the chamber. Three plates (size 75 x 95 mm) of mild steel (DC01 from SSAB) of each variant were tested. The chemical composition percentage of the steel is C 0.12 wt%, Mn max 0.8 wt%, P and S max. 0.045 wt%. The samples were checked and photographed in intervals, and a tape test on microscope objective glass was taken. The plates were removed in intervals, and some were put back again to continue the cycle, after FTIR spectra were collected. The first sample of three was removed when most of the paint surfaces had become matte (exposure 1108 hours, UV-dosage 1623 KJ). The second sample was removed after 5438 hours of exposure (UV-dosage 19575 kJ), when discoloration started to appear in the armour paints; the last was removed when the time schedule ran out for the trials and due to the ongoing pandemic (6293 h, total test duration of approximately 9 months, UV-dosage 22653 kJ). Visible damage, except chalking and some darkening areas, was not seen in any of the samples. The plan was to evaluate any damage by international standard ISO 4628-3:2012, but since no blistering, flaking, and so on occurred, this was impossible. The dosage and the total exposure time for each sample were assessed. Removed samples were stored in a freezer, together with unexposed reference samples. After analysis, they were put back into the freezer. In similar ways (but thinner), different linseed oils were applied to steel sheets and tested (described in Paper IV).

Figure 6F-6I: Different types of quantitative data-collecting research methods were used. From the left: Measurement of surface profile and paint film thickness; field tests in Mariestad; assessment of iodine values; analysis of an aged paint films.

PCA - Principal Component Analysis

PCA is used for correlating the quality attributes of linseed oils during the odour quality profiling. This is a mathematical method for extracting and visualising extensive information from the data, correlating systematic variations between the objects (linseed oils) and variables (odour qualities), and for revealing patterns in the descriptive data sets. The *Unscrambler X*, multivariate analysis software (version 10.5; CAMO Software, Norway) at Örebro University was used.

4.4 Qualitative Data-Collecting Research Methods

Different types of methods for characterisation of maintenance process, working procedures, and craft quality assessments, are shown in **Figure 7**.

Case and Field Studies

The documentation of about 75 steel-sheet roofing painting interventions is studied critically (stated separately in the reference list). These interventions were found via trustees, consultants, governments, and paint-makers. The types of buildings studied were those where steel-sheet roofs have been common: churches, public houses, manors, and residential buildings, and technical buildings. Furthermore, some cases concerning bridges, silos, and other types of objects were studied by provided information from trustees. The age of the building´s spans from the early eighteenth century to the mid-twentieth century. Nine objects were followed physically over time and two cases were subjected to failure analysis. The case and field observations give a picture of how the management and maintenance were organised, how the working procedures were designed and specified, and what information was or was not is documented. Real-life cases provide an understanding of the detailed features of damage on the substrate and paint layers, the detailed features of advantages and disadvantages concerning surface preparation methods, as well as experience on controlling methods, application of paints, and accessibility to roofing (an example is shown in page 54.). The cases give the


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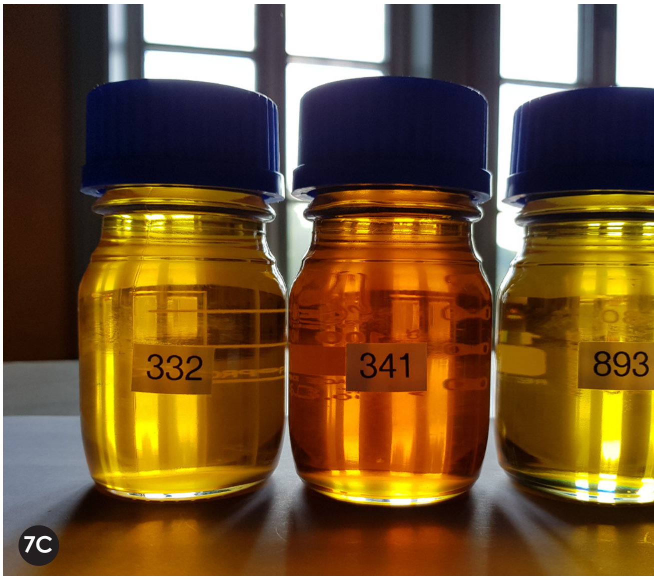
7C

opportunity to participate during the entire intervention process, to observe site affordances, and to discuss with trustees, steel-sheet and paint professionals, and governmental representatives. Five workshops were arranged with stakeholders in order to highlight their perspectives. Empirical trials were conducted in connection to real-life case studies, such as the measuring surface roughness, paint layer thicknesses, and reagent tests for aged paint types. The field studies were documented with video and audio recordings, as discussions with the entrepreneurs. As a part of the case studies, I initiated and co-supervised a Master′s thesis regarding metallographical characterisation of 20 collected roofing sheets manufactured from 1787 to 2017 (Nilsson & Pettersson, 2017).

State-of-the-Art and Literature Surveys

Technical literature was searched in different databases and journals regarding anticorrosive paint treatments and deterioration mechanisms. Other searched themes were chemistry and ageing of linseed oils, tung oils, craft skills, characterisation methods, perception and verbalisation of sensations, and research methods for sensory studies. Technical articles were searched within *Project Runeberg*, a digitalisation database for Swedish technical journals and literature from the twentieth century, and the international source *Gutenberg*. At the “Internet Archive” (archive.org) extensive international historical technical literature was found.

Archive Surveys

The National Archives (*Riksarkiv Arninge, Landsarkiven Göteborg*) were searched for literature, reports, and letters. Newspapers (1880–1950), advertisement prints, and receipes were searched for via the National Archive Database (NAD) and The Royal National Library (*Kungliga Biblioteket, KB*). Archive sources from The Royal Swedish Academy of Engineering Sciences (IVA), and The Royal Waterfall Board (Vattenfall) were searched especially since they conducted extensive corrosion research programs at different geographic locations in Sweden across four decades (1930–1960 and 1923–1960, respectively).

Figures 7A-7E: Different types of qualitative data-collecting research methods were used.
From the left: field observations of interventions; archive studies; assessments of oils and varnish; remaking of armour paints; quality attributes and drying surfaces.

Remaking of Armour Paints

Based on a large number of recipes found in archives, a number of primers and paints were made in cooperation with Wibo Färg AB in Gothenburg. This company is one of the few in Sweden that have traded the knowledge of paint making from the early 1900s, and are thus well experienced. For the full-scale tests in 2017, three variants of armour paints were made; one with MIO (micaceous iron oxide), a second with leafing aluminium pigments (these two according to historic recipes), and a third where MIO and aluminium were mixed. The binders are varying types of linseed oil varnishes and tung oils. In 2019, primer paints red-lead or aluminium-polyphosphate were made with modern "boiled" linseed oil or high temperature boiled linseed oils (the latter also with stand oil and/or tung oil additions). Six variants of armour paints were made with different binder combinations, and some of these were chosen for further analysis. The making was documented using video and audio recordings.

Interviews with Dialogue Approach

Stakeholders with different professions were interviewed on a one-to-one basis, unstructured, or semi-structured open-ended matter with follow-up questions, and a dialogue approach to discuss materials, practice, and quality assessments. Some respondents were interviewed by telephone and some were interviewed in person (some in connection to case studies). The respondents are specified in the reference list. Notes were taken into a diary and interviews are audio and/or video recorded. Self-observation and participatory observation, common in craft research (Almevik, 2017, p. 251) was applied during the preparation of steel sheets for field and laboratory exposure, but also during the sensory profiling sessions. As a participant and organisator of workshops and profiling sessions, I tried to push the painting practitioners to verbalise and to discuss their experiences. Working notes which were written after each occasion into a diary, have helped to identify trends and reflections (as by "reflection-in-action", Schön, 1982). A large number of video recordings from the occasions have been analysed.

7F

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Video and audio recording

Video and audio recording of craft in any form is a common method at The Craft Laboratory, and introduction to this field is given by a professional documentary film-maker. This method has been used during the entire study for documentation and notes to myself. The method enables me to reflect upon my practice, or the practice and reactions of others, and to interview respondents without the need to make notes, thus allowing me to concentrate on the dialogue and assessments painter to painter.

Quality Attribute's Profiling

During a visit to Örebro University, Campus Grythyttan, The School of Hospitality, Culinary Arts and Meal Science with a group of Ph.D. craft research students, the theme of discussions was "*sensorial assessments*." I started to think about their research methods in the field of craft research in *Kulturvård*. The dialogue with ÖU initiated a candidate thesis where the vocabulary of cooking oils was formulated (Kaiser, 2017). I attended as a panellist, and learned the methodology. The same methodology was used in the present research, but the oils were not tasted since they may contain driers. During the olfactory profiling of linseed oils and varnishes, a systematic interviewing technique, RGM, was used, and the responses are reported directly to a database at Örebro University. The different oils are organised in triads (sets of three), where two oils are similar and one differs (the differing samples odour is then easier to distinguish from the others). RGM is very suitable for developing vocabularies for different products in a semantic frame (Swahn et al., 2010.) Interviews of the participants' experiences of the profiling sessions were conducted in a structured manner with open-ended questions via direct reports to a database at Örebro University and were quantitatively analysed by PCA. Haptic and visual quality attributes were assessed by a free-choice profiling method, where the frequency of quality attributes was assessed after semantic coding. Other profiling sessions concerned vocabularies of drying surfaces, rancid linseed oils, and assessing thicknesses of paint layer applications. In total, 15 craft profiling sessions were conducted, involving a total of 67 participants, and documented with video and audio recordings. Working notes on participatory observations are protocolled into a diary. Additionally, three workshops explored:


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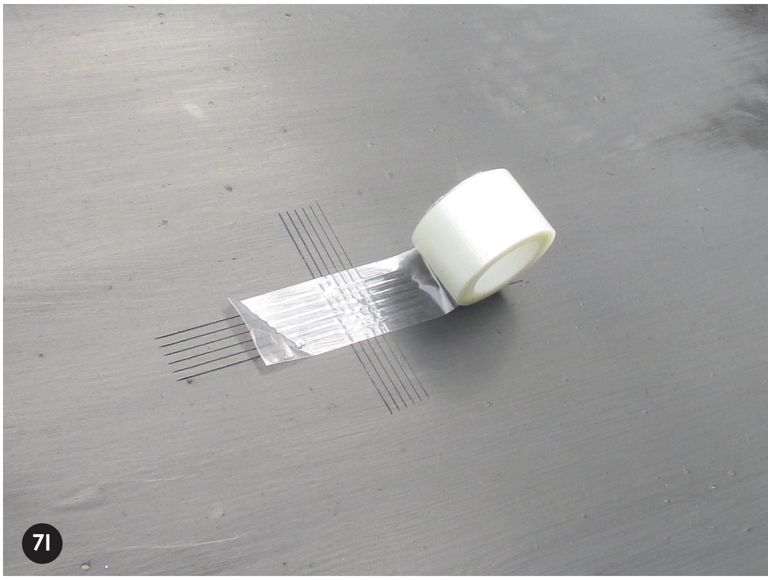
7I

Figures 7F-7I: Different types of qualitative data-collecting research methods were used. From the left: application of anticorrosive paints on substrates; Workshop" How thin is thin?"; surface preparations; checking adhesion of aged paint layers.

- Wet and dry paint layer thicknesses measurements (September 2019)
- Sensory assessments and vocabulary for the drying stages of oil varnishes and paints (May 2019)
- The effects and perception of rancid linseed oils (November 2019).

Empirical Trials on Drying Oils

Approximately 200 steel sheets and about 100 glass plates with different types of oils and varnishes have been applied in my practical work in order to check the characteristics. The substrates were cleaned with solvents before application in thin layers using a finger, a fine nylon brush, a bristle, a glass rod, or an applicator. The drying characteristics, hardness, film-forming ability, and sensory attributes of oils and varnishes were investigated by qualitative and quantitative methods. The water resistance of dry varnish films was tested by a modified glass-plate method described by Magnusson.[4] Observations, temperature, and RH were protocolled in a diary.

During the start-up of the mentioned field tests in 2017, I and my colleague Tom Granath observed large differences in behaviour of the paints regarding odour, viscosity, and applicability, drying power, levelling, and finish. We discovered that we assessed some crucial working conditions differently, for instance, whether or not the painted surfaces were ready for overpainting. In the discussions, which were video recorded, we became aware of how difficult it was to articulate the sensor assessments.

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[4] The method of using glass plates is from Hollander & Eibner (Magnusson, 1939, p. 258). Three droplets of liquid varnish are placed onto glass plates (9x12 cm), on both sides of the short half line, and are applied with fingers along and across for uniformity. The plate is placed horizontally and is then left to dry at 20°C (18-23°C) in diffuse day light for 4 days during summer or 6 days during winter. Stand oils need 7 days. Intense rainy weather may prolong the time by 2 days. After they had died, they were immersed in water for 2.5 days at 20°C. The time taken to make the film milky or, translucent was noted.

4.5 Sources

The written sources for knowledge vary in this research study. Since the making and use of linseed oil and drying varnish binders for exterior paints are not in the focus of scientific reports today, literature mainly from before the mid-twentieth century is important. This does not mean that there is no development in this field, but the information is currently probably held at companies that have no interest in publishing their knowledge. Articles on modern chemical research describe complex lipid chemistry and they usually lack considerations of practical consequences.

Books and digital databases of historical varnish/paint making and working procedures have been viewed in order to answer questions on how the materials and methods worked out historically, what procedures were used, and whether there are any descriptions of quality assessments. Bibliographical information of the authors is searched in order to judge their background and the value of their contributions. Due to the great amount of literature, most efforts have been put into reading original sources of researchers, some of whom are cited in contemporary research. Many researchers such as Mulder, Weger, Hazura, and so on are cited in the technical literature from ~1880-1920 but not today. This research has attempted to critically read and understand the information. Some of the methods for inquiry used in the early technical research have been improved later. In research articles and books from close to the mid-twentieth century, the research methods appear to be technically very sophisticated in terms of process and laboratory routines. Sources that explain research setups were prioritised in order to understand the relations of inquiry, observations, and results. Efforts were made to try to find German, American, British, and Swedish technical sources and descriptions of low-tech and industrial varnish making, in order to find relevant and representative information to enable the construction of a probable timeline of varnish and paint making, and to understand what types of varnishes that were used for different purposes. Since I do not understand French, literature in this language is not considered. However, on many occasions, the work of French researchers was translated, such as Chevreul's research (first half of the nineteenth century) in the German *Dingler's Polytechnical Journal* (Chevreul, 1852). Another example is Mathey´s manual (1852) on varnish making, translated from French to German and finally to Swedish. Since engineering and industrial progress concerning varnishes and anticorrosive paints appears to originate from Germany—for instance, scale armour paints, *Panzerschuppenfarben,* (also called *Ferrubron* in Europe, due to the English mine where the pigment was produced from)—German sources were prioritised, as well as English, from about 1850–1950. The American paint industry was extensive and there are a huge number of published handbooks, often modifications of German and Austrian nestors such as Fahrion, Weger, or Andés. Handbooks and recipe collections were reviewed and a wide variety of procedures for refining varnishes were found, though there were relatively fewer descriptions of how to make anticorrosive paints. The oldest source was Smith's paint handbook from 1687 (*Painting in Oyl...),* though secondary references are often made to older research, or they are interpreted by later researchers. The different varnish-making methods for artist oil paints have been described by, for instance, Carlyle (1991, 1999, 2000), and therefore more efforts are put into the descriptions from the middle of the nineteenth century and onwards, for more industrial production. The most recent painter´s handbook is Söderbergs's from 1964 (*Tekno´s Måleri*), where linseed oils and varnishes were still used. Modern, industrial processes for refining linseed oils differ from the historical procedures in content and scale. The descriptions of the procedures for preparing varnish and varnish paints are numerous, and there is no exact universal procedure but rather a lot of variations, parallel use, or simultaneous technical development. The structuring and labelling of historical information are always over-simplifications in order to enlighten epochs or events, as described by Frängsmyr (1995, pp. 25–26). Therefore, the interpretation and compilation of the published literature in chapter 6 (and partly chapter 8) is of course simplified, and I believe that it would be an impossible task to give a full picture. The compilation is a result of a questioning attitude of the materials and methods: Why? How? What is the effect? For how long? The purpose is not to define epochs, but to understand concepts of oil and varnish- and paint making in order to construct a timeline (see **Figure 13**) and to put the armour paints in this context.

Braenne compiled 130 technical painting handbooks, and he found that the oldest were written in the Middle Ages, for easel and monumental painters (Braenne, 1998, pp. 38–39, 65–67, 241–242). The rise of recipe collections increased markedly during the fifteenth century, in a "new style of science" originating from the context of monasteries, where knowledge on all kinds of subject would be compiled and recorded (Boulboullé, 2019, p. 220). The manuscripts from 1620 of the Dutch chemist and physician Theodore de Mayerne (1573–1655), are often referred to in contemporary varnish reconstructions (for instance, by De Viguerie et al., 2016). The manuscript holds more than 300 detailed recipes and technical descriptions of artisanal mastery and know-how. Boulboullé has studied them in detail and has shown that de Mayerne performed his art-science-practice project using a methodology that originates from the Arabic medical methodology. This he learned at the university, where he was educated in medicine and pharmacology (Boulboullé, 2019, pp. 221-239). The medical tradition included note taking, diagnosis, prescription, and medicine/item production and it was practiced in European universities. The manuscript is a result of a working methodology consisting of systematic and in-depth interviews of artisans and practitioners, and the author′s own experiments and observations at production sites. Just like the German-Swedish scientist Carl Wilhelm von Scheel, de Mayerne wrote his manuscript on individual folded paper sheets that he intended to bind into one scrapbook (Boulboullé, 2019, p. 224: Boklund, 1961, p. 32). Scheele is another example of a chemist, pharmacist, and experimentalist who had a great impact on paint and varnish making. The notes of Scheele are very challenging to read, not only because they are so full of alchemy codes, but also because of the content. The interpretation and transcription of handwritten historical manuscripts are dependent on the knowledge in the field and the pre-conception of the transcriber. This makes it very difficult to follow this type of source. In the example of Scheele, the transcribed section of his discovery of glycerol is read in order to put this discovery into a context but it is not used in order to construct the timeline of varnish making and use. Frängsmyr argues that the scientific progress during the eighteenth century was carried out by practical people and craftsmen, and "*science was seen as a practical part of everyday life*" (Frängsmyr, 1999, pp. 109, 112). Science was an important aspect of economic progress and utilitarianism and organised in academies and new educational programs. Scientific discoveries should not be seen only in the light of innovations and ground-breaking theories; Frängsmyr emphasises the philosophical, organisational, and practical context too. The publishers of the recipe and manufacturing sources used for this study were (as stated in the title pages), for instance, chemists, physics, pharmacists, architects, entrepreneurs, and manufacturers (but hardly a small-scaled artisan or painter), that describe the practical and economical use of specialised technologies. Examples of this type of sources include English and German writers such as Smith 1687, Kunckel von

Löwenstern 1707, and Tingry 1830. Swedish oil paint handbooks are often translations from different European original sources, such as Gütle's publication from 1799/1800, originally in German. Historical sources point out the protection of secrets about varnish and paint making, as material knowledge and craft skills were not intended to be spread since they were the result of long experience and hard empirical work, and possibly also of the restraints of different guilds. Still, the publications give a hint of differences and similarities at different ages and purposes. Brænne points out that copy-right did not exist for this type of "cookery books" for painters, and that information was also re-used and modified for a new printing, and also translated into new languages (Braenne, 1998, p. 66).

The master painters that were familiar with oil varnishes and paint making very rarely wrote descriptions about the painting procedures, and never on sensory quality assessments. In *Hantverkets bok, Måleri* [*The Book of Crafts, Painting*], six master painters wrote chapters (Paulsson, 1934). The content is usually addressed to a well-introduced reader, not from a master painter to another master painter. Not one of the 20 authors of the mentioned *Tekno's Måleri* (editor Söderberg, 1964), was a professional painter; still, the handbook is directed towards professional painters. Back in time, it was common that steel platers and other iron-workers carried out the painting of, for instance, roofings, making the finding of any written sources on the practice written from "within" the craft even less probable. Living painters have been a highly valuable source of information, regarding aspects of the material characteristics and use of paints and working procedures.

The historical descriptions that have been found are mainly written by engineers. The written sensory assessments of paint material and practice are most often very generally described (see, for instance, Rothstein 1856 or Sandberg 1926). Some of the work encountered could be considered as scientifically pioneering, such as Chevreul's trials on driers in 1850 (published 1852) which were known and described in earlier historic sources, so some scientists introduced known empirical rules into the scientific community. Quite often the comments, for instance in archives, on paint ingredients or paints show, as far I can judge from my painting profession, a high level of practical knowledge and inside information. I have wondered over this fact, and have no explanation of it, other than a general impression that *techne* (Greek for art) and art were interwoven closer in the practice and craft skills of making things, than they are today, a fact that also Hendriksen has considered (Hendriksen, 2017, pp. 202, 204). It is likely, that the practice was more common earlier in engineering educations.

On the deterioration mechanisms on metallic or organic materials or material testing, educational and instructive handbooks were prioritised since these works often have a large peer-reviewing editorial committee. Atmospheric corrosion is probably one of the world´s most explored fields and the sources are numerous. Here I have concentrated on contemporary sources, and read historical descriptions critically since the body of knowledge today concerning chemistry, metallurgy, laboratory assessment methods is so large and developed. It is still of interest to understand how the chemists or makers tested and explained their observations. Scientific articles about oil chemistry and anticorrosive paints around 1930–1950 seem to be of very high quality in respect of theories, experiments, and evaluations. The reasons for this are further explained in chapters 6.2.8 and 6.3, due to the establishment of corrosion research and theories.

Archive sources concerning anticorrosive paints, tests, varnishes, working procedures, and contracts have been searched. These sources may give valuable information though they are considered to give some pieces of the puzzle, here and there. Advertising information from manufacturers has been used with caution since advertisements tend to be exaggerated. Still, they do not reveal the composition of ingredients and products. The urge for keeping the details of material and processes details secret is common across time, both historically and today. The archives of Vattenfall were searched for anticorrosive treatments and field tests since these tests were proceeding the establishment of IVA´s Corrosion Committee and test programs. As has been explained by Sundin (1981) and by IVA (2019), the establishment of engineering educations, such as in electro power, created contact between the engineers and the establishment of IVA – to make research in the duty of and for the use of the society. Some state-of-the-art descriptions were found in the archives, written by skilled and devoted engineers. In these sources, I found useful quality specifications and assessment methods of oils, varnishes, paints, and paint ingredients, and also the most accurate sensorial descriptions. An example of this is *Linoljans kemi*, [The Chemistry of Linseed Oil] by Karl Magnusson, probably from 1931, when he was transferred from Svenska Oljeslageriet (SOAB) in Nacka to Mölndal.[5] He was a chemical engineer that later became the R&D head of this company that was the largest oil refiner in Sweden until the 1980s. Another example is *Förslag till föreskrifter vid målning av Statens Järnvägars Person och Godsvagnar* 1926–1928, *[Suggestion to Instructions for Painting of Passenger and Goods Wagons at the Swedish Railway*] by Sandberg and the protocols of the National Railways Chemical Laboratory, who conducted about 1500 material analyses annually (from 1909–the 1960s). It is obvious that there was close contact and updating between Swedish and German engineers and researchers by the referring and discussions of technical findings, facts, and standards. This issue has not been further explored but is mentioned by, for instance, Johansson concerning the chemical paint industry (2002).

As human resources, my own craft experiences, and those as discussed with colleagues, are the base for critical review of historical working procedures. Most often, the information is well consistent with our common intersubjectivity and personal experience despite changes in paint materials and tools. Information from case studies and field observations has been viewed both from an object-specific view but also in a larger context about materials, craft, maintenance, and procedures. I am aware that it is easy to focus on facts that confirm one´s own experiences, preconceptions, or common knowledge, and to ignore facts that contradict those things. It is common to search and extract information differently in the early stages of the research process than is carried out later. All these aspects have been considered in order to try to maintain objectivity, rigour, and precision.

4.6 Ethics

The names of my respondents are given (in the reference list), but are not referred to since they have been very generous not only with describing their experiences of paints and painting craft, but also their failures. No respondent is pointed out in this research. All persons in photographs have given their permission for publishing in this thesis. Photographs have been cropped in order to highlight hands and working scenes, and not persons. Personal data in questionnaires are treated strictly confidentially.

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[5] SOAB (Svenska Oljeslageriaktiebolaget, Mölndal) was the largest manufacturer of linseed oils in Sweden during 1890-2007. They had a plant in Nacka (former Sommelii) and in Mölndal.

CHAPTER 5

MANAGEMENT AND MAINTENANCE

An example of ferrous heritage; Cast grey iron and wrought iron details in a complex structure. Photo: Sven Olof Ahlberg

MANAGEMENT AND MAINTENANCE

The results in **Paper I** show that the establishment of a dialogue process with stakeholders is a primary aim, in order to work out solutions that are vital for the results and the actual considerations about quality and values. The stakeholders consist of a professional group such as trustees, governmental administrators, technical and conservator consultants, material and paint producers, and contractors/paint practitioners), and they have a focus on their respective specialist fields such as economy, laws and regulations, technical aspects, historical values, contracts, and so on. By using systematic tools of *anamnesis* and *diagnosis* in the maintenance cycle, factors that may have a crucial impact on the conditions and the affordances of the actual ferrous structures or objects could be revealed by relevant *control*. From this, the potential for a successful *therapy* and *continuous care* could be enhanced. A systematic way of describing working procedures, in combination with quality assessment tools and checkpoints, as suggested in **Paper I**, could provide for longer intervention cycles and *monitoring*.

5.1 Deterioration of Painting Treatments

As has been described in chapter 1, ferrous substrates are painted in order to protect the metals from atmospheric corrosion.[6] The electrochemical reactions need an electrolyte, that can transport ions and electrons in oxidation and reduction processes. The reactions could be propagated by two different metals or by salts, acids, or bases dissolved in water. Usually, the corrosion types are described as general corrosion, pitting corrosion, crevice corrosion, and bimetal corrosion (Martin & Wood, 2012, pp. 28–32, 133–146). The basic factor needed for causing electrochemical corrosion is the presence of an electrolyte and ions, provided by moisture with dissolved gases. Further descriptions of the complex corrosion processes can be found in Leygraf et. al. (2016). If the causes for corrosion do not exist, the process will cease, as is the case in an environment free of water and oxygen.[7] This is not the case in Nordic outdoor conditions, and this is why the metals are painted. So, as a rule, the purpose of all anticorrosive actions is to prevent the formation of electrolytic cells or to retard the reaction rates (Trägårdh, 1961, p. 16). The paint treatment is deteriorated by atmospheric exposure, and is therefore to be considered as a temporary state where the entropy of the system is handled by the best intentions.

Factors that deteriorate organic coatings outdoors are described in **Paper I**. The main and most important factors are sunlight, moisture, and temperature changes (Berdahl et. al, 2008, pp. 423–433: Talbert, 2008, pp. 89–90). Moreover, weather (like wind, rain, snow), pollution, and biological accumulation are important components. UV-radiation (photons) breaks the

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[6] Wrought iron rusts slower than rolled steel and hardened steel less than unhardened (Nilsson, 1948, p. 1389.). The low-carbon iron rusts faster than the carbon-rich. These categories of ferrous products are usually considered as having about the same low corrosion resistance (Sang, 1910, pp. 94-96: Trägårdh, 1961, pp. 18, 20: Forsyth, 2008, p. 129), though mild steels may corrode quite rapidly. As long as (a correctly designed) paint system is undamaged, the corrosivity of the ferrous substrate is less relevant. The corrosion resistance of the alloy is not revealed until the paint system is damaged.

[7] *"Iron will not corrode in air unless moisture is present, and will not corrode in water unless air is present."* Sang, 1910, p. 62.

chemical bonds of the organic binders, and this results in oxidation, shrinking, and chalking of the paint. Temperature gradients cause expansion and contraction of the paint layers, which could introduce stresses. Further stress formation is caused by hail, snow, freeze-thaw cycles, wind. The resulting increased brittleness and permeability propagate cracking and moisture penetration of the paint layers, thus accelerating the failure. The presence of CO_2, SO_2, NO_2, and other gases form acids in water and deteriorate the materials. Soot and other deposits increase the energy exposure of the paints since the absorption of sunlight increases. **Figure 8** illustrates important variables for the deterioration of painted ferrous substrates.

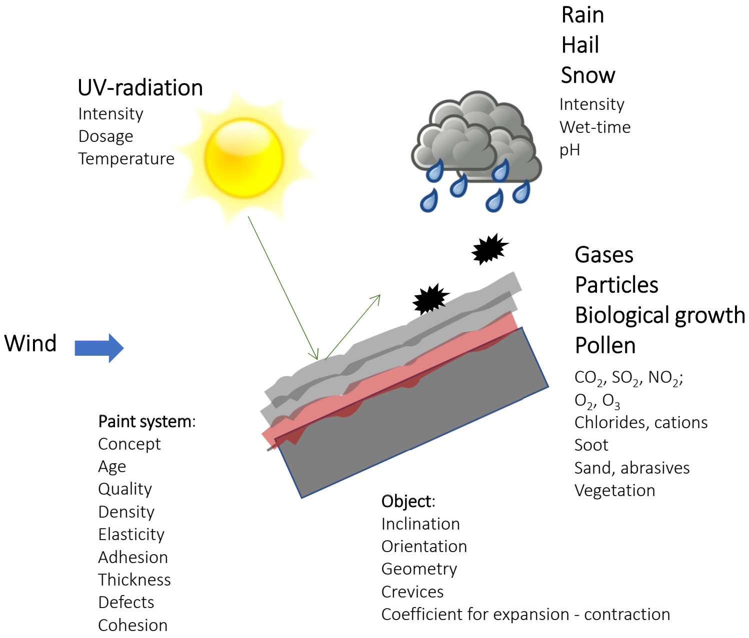

Figure 8: Deterioration of painted ferrous substrates.

> *”A film which cannot remain intact against condensed moisture, snow and ice and despite comparatively wide and rapid changes in temperature (as between day and night, even in rather warm climates) will not necessarily afford very little protection for the steel to which it is applied”.*
> (Toch, 1915, p. 594).

A fundamental function of anticorrosive paints is that they act as efficient, dense barriers between the substrate and atmosphere, for a long time, as illustrated by the quote above. The barrier effect is improved when the total paint system thickness increases (Edwards, 1936, pp. 125–127: Trägårdh, 1961, p. 10). Depending on the geographical conditions, it is recommended that total paint system thicknesses should correspond to stipulations in the corrosivity classes, as described in **Paper I**’s Table 3. Common corrosivity class in Sweden is (as described in the same paper); C2 (i.e., relatively gentle). Frequent reason for failure is due to the thicknesses of the paint layer being insufficient (Edwards, 1936, pp. 125–127: Trägårdh, 1961, p. 10). This has been confirmed also in field observation studies in this research. Substantial paint film thicknesses and high-density paint films retard moisture or water penetration through the painted barrier. New paint may shed for a while, but when the paint gradually ages, the moisture penetration rate increases. The presence of defects in the paint films (capillary porosities, discontinuities, and so on) will be easy points of entry for the moisture, but the most important mechanism is diffusion. Moisture diffuses in and through the paint film, and is then absorbed on the other side (at the metal and paint interface). This causes under-film corrosion that is detrimental for the integrity of the paint system. A failing to use the correct surface preparation methods is a very common cause of rapid deterioration of the paints. A paint system that is successful in one case is not necessarily successful in another, since not only the climate influence but also the handling and how the anticorrosive treatment working procedure is done influences the outcome.

With time, the probability of finding original painted surfaces on weather-exposed ferrous structures and objects reduces, due to the ageing and deterioration of these structures. Still, this happens now and then, and these layers are to be considered as historical documents of materials and craft. Conscious decisions need to be taken regarding how they should be handled. If possible, efforts should be put into protection and documentation, for instance by APR (Architectural Paint Research). But, as described in **Paper I,** this is most often not the case due to guarantee aspects for the contractor, since thick layers pose a risk of stresses and flaking and are therefore totally removed. This is a difficult act of counter-balancing, and must be assessed from case to case, for instance, by practical tests. The historic paint layers should at least be documented by stratigraphical macro- and/or microanalysis.

5.2 The Maintenance Cycle

A framework for management, maintenance, and cooperation between and across different professions in order to make relevant plans is a key factor for the successful care of heritage values (Fielden & Jokilehto, 1998, pp. 1–14). This means that all trustees are aware of the values, and work together according to conservation ethics as expressed by the Venice Charter and other international documents. Specific guidelines are based upon inventory, technical analysis, and risk analysis, work programs are formulated, budgeted, and followed on annual and longer terms. Cultural values and economic values need counter-balancing. Suggestions of historical, economic, environmental, and technical values associated with painted ferrous heritage are given in **Paper I**, and these need to be considered in connection to the specific case.

ICOMOS (2003, p. 2) states that "*The best therapy is preventive maintenance*." A strategy for the maintenance of ferrous heritage could be described as a combination of regular monitoring and preventive measures integrated into a cyclic plan, that is based on a mapping of the values represented in the context and the ferrous heritage. Since the anticorrosive paint layers deteriorate, they need to be renewed. Therefore, the maintenance is cyclic, as described in **Paper I**, and **Figure 9,** and could be divided into different phases such as *anamnesis, diagnosis, therapy, control, and monitoring.*[8] It must be commented on, that the control could be implemented in the full cycle. A suggestion of quality control checkpoints, tools for assessing the status of substrates, and systematic formulation of workings procedures is given, as well as desirable qualities (technical, economic, environmental, and historic) of the paint systems. Complex situations or solutions are usually difficult to control, especially in the interface between tradition and renewed practice (Sjömar, 2017, pp. 104–106). The provided models and tools are aiming for increased control in complex situations. Recording and documentation must be an ongoing process through the maintenance cycle (Fielden & Jokilehto, 1998, p. 26).

It is not possible to point out significant heritage values for ferrous substrates neither as individual structures, objects, or building parts, nor as a ferrous stock, without going into production details and context. Generally, ferrous structures and objects as a result of production

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[8] These stages (except monitoring) are described in the ICOMOS Charter from 2003 (p. 1).

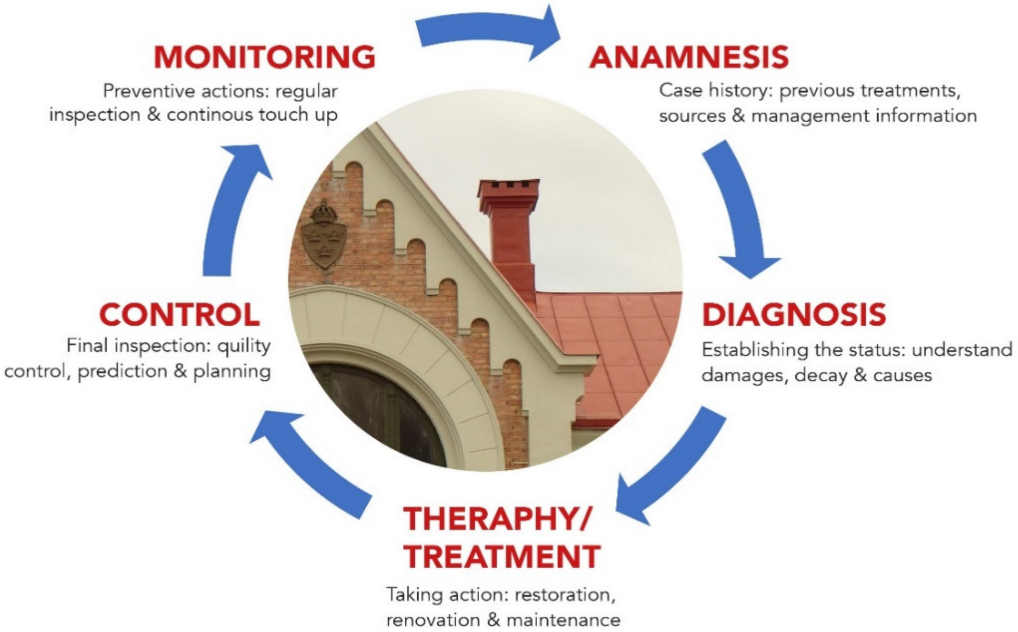

Figure 9: Different phases of the maintenance cycle (Källbom & Almevik, 2020, p. 13).

Figure 10: Ongoing pre-test (left side) of a new paint system for a forthcoming painting treatment of a nineteenth-century steel-sheet roofing.

methods that are no longer in use, have higher cultural values than those produced by contemporary methods, as described in chapter 1.2. For each category of materials or products, it is possible to make prioritisations and grading of cultural significance, as shown by Källbom (2018, pp. 258–262).

The approach of management alongside the stakeholder's participation, as described by van Roy (2018, p. 236), is based on a "continuous care for" and sharing of knowledge in order to preserve the cultural significance of the ferrous structures and objects. Knowledge and skills are very important success factors in planning, decision making, and interventions. Experiences from field observations of current research show that the establishment of a dialogue process with stakeholders is important in order to work out good solutions that consider the objects' values.

In the preface of the research report from 2018 (Källbom, 2018, p. 3), representatives of the National Heritage Board, the Swedish Church, and Gothenburg University (*Kulturvård*) stated that:

> *"Repair and maintenance of steel-sheet roofing on historic buildings is not an exact science, rather an art of assessments. Every preservation situation is unique where different aspects must be considered and interests to be negotiated. The basic ambition in sound preservation philosophy should be, depending on conditions, to develop and to manage the values that exist, no matter how large or small they are.*" [9]

It is recommended that the anamnesis and diagnosis steps are conducted in cooperation with a skilled traditional architectural painter, for enabling relevant site assessments as described above. Detailed knowledge about the substrate materials is essential and in order to give a picture of the case history, the condition of the ferrous substrates, the causes of deterioration, and to conduct pre-tests and to make a plan for the actual anticorrosive treatments as described for steel-sheet roofings in **Paper I**. The pre-tests could be considered as a small-scaled evaluative therapy (which may last for some years) before the final planning and making of working procedures, an example seen in **Figure 10**. Since roofings are very exposed and have small cross-sections, they are often subjected to material substitution, which makes the situation more complex when the value of heritage and the high levels of ambitions for interventions are considered. A component or an object is more rarely substituted, and the options for therapy are usually fewer. If a systematic material-method matrix model for describing the therapy (such as proposed in **Paper I**) is used, it is easier to compare and document the interventions. The matrix should be completed with other substrates (cast grey iron, mild steel profiles, wrought iron) and correlated surface preparation methods, oil and priming treatments, intermediate and topcoats.

Minimal intervention is desired but is mostly not realistic since the risk of guarantee claims on the contractor usually increases if old paint layers are not removed, as described in **Paper I**. Old paint layers could be assets or risks, depending on their status, and considerations of "minimum intervention" (Fielden & Jokilehto, 1998, p. 11) could be difficult to

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[9] *"Underhåll och reparation av plåttak på historiska byggnader är inte en exakt vetenskap utan snarare en bedömningskonst. Varje byggnadsvårdsitutation är unik där olika aspekter måste viktas och intressen förhandlas, Vi talar om god byggnadsvård där den grundläggande ambitionen bör vara, utifrån förutsättningar, bygga vidare på och förvalta de intressen som finns, oavsett hur stora eller små de är."* (Runeby, Dahlberg, and Almevik in Källbom, 2018, p. 3).

make. Well adhering, elastic, and with a low defect level, they increase the substrate protection by increasing the total paint system thickness and barrier effect, and fewer layers are needed when repainting. But on the other hand, they may also lead to premature failure of the renewed intervention. When the barrier of a wooden substrate becomes permeable and deteriorated, the wood does not react with the humidity in the way that is the case for ferrous substrates (but the paint may flake). The ferrous material starts to rust when the humidity reaches the interface, and this accelerates the deterioration of the paint system since the adhesion becomes ruined due to tearing forces when the rust expands in volume. "Maintenance repainting" refers to the overpainting of an existing paint system (Appleman, 1985, p. 87). With the use of relevant quality control methods, at proposed stages of the maintenance cycle, the chances increase for more predictable results, and this will improve the following monitoring. The period for repetition depends on the environment, the type and quality of the painting treatment, the accessibility, and to what degree of deterioration is accepted before a new intervention is undertaken.

The degree of deterioration could be expressed by the use of different systems and comparative assessments scales. The International Standard ISO 4628–3:2012 shows comparators R_{i0} to R_{i5} corresponding to zero to 50% *visible* rust damage on a painted surface. R_{i3} corresponds to 1% and is an appropriate reference if touch-up interventions are a desired strategy. The deterioration of the paint system could be considered as both the cause and the effect of the corrosion of the ferrous substrate. However, in reality, ferrous structures and objects never have the same level of deterioration, since this depends on sunlight and moisture exposure (which varies in different directions). The consequences of leaving too long a gap between maintenance intervals may be severe in terms of corrosion damage, require the total paint removal, and high costs resulting from the damage. Using a repeated strategy of severe deterioration and total paint removal means a risk of severe wear and damage to the substrate. Examples of different actions depending on deterioration are exemplified in **Table 2**, based on the case and field studies in this and previous project (Källbom, 2018). Further examples are given in Källbom, (2018, pp. 116, 144–146).

A structure needs to be maintained in field conditions, and the work must be planned in terms of environmental affordances and accessibility (for instance, different approaches to examples on page 18, 32, 46, 74, 158). Usually, large structures and objects require very detailed planning when it comes to working procedures, the use of paint systems that work, and the need for extensive scaffolding. A movable ferrous object or a vehicle may be brought to a workshop and the maintenance is conducted under more controlled conditions. Annual preventive actions such as cleaning of waterways or traps, as well as the cleaning of dirt, bird excrements, are recommended.

Vattenfall conducted extensive calculations about the number of paint layers and the establishment costs (spot or a total repaint) based on their *in-situ* field tests (Vattenfall, 1933, pp. 13–17). The use of armour paint systems as described in **Paper II** showed the highest establishment costs but also the longest estimated lifetime of 24 years (this was a 1+2 paint system, and 2+2 system should last longer). The paint material cost was 15% of the total costs, and only the highest grade of ingredients and formulations should be used. This type of planning would be beneficial today.

Repainting as a way to save corrugated steel-sheet roofings where the cathodic protection of zinc metallisation is consumed, has been discussed in **Paper II**. The corrugated sheets are

Table 2: Example of different levels of maintenance.

	Total repainting	**Partial repainting**	**Touch up**	**Repainting of the topcoat**
Description	Total paint removal and repainting are needed.	Continuous damaged areas are repainted.	Localised smaller damaged areas are repainted.	Maintenance while the paint system is in good condition in all directions.
Damage	Paint layers missing in most of the areas. With or without corrosion.	Paint damage and/or visible slight corrosion damage. Total layer thickness too low.	Paint damage (and possibly visible primer paint), and/or slight corrosion damage. Total layer thickness too low.	The old paints are chalking but have no visible corrosion damage. The total thickness may be too low.
Surface preparation	Cleaning, total paint removal.	Removal of corrosion to bare metal and relevant part of the paint system, cleaning.		Cleaning.
Application	Inhibitive paint. Intermediate layers and topcoat.	Inhibitive primer paint. Total paint system application on damaged areas. Most often completed with a new topcoat (in order to avoid a mottled appearance).		A new topcoat.

no longer produced equally (in terms of quality) in Sweden and the older sheets could therefore be considered as irreplaceable. Painting of corrugated sheets would mean that the consumed cathodic protection of zinc could be substituted with barrier coatings with a metallic finish. This is a better alternative than the rejection of the sheets.

The following chapters will focus on the interactions (or correspondence, see chapter 7.3) between the paint, the painter, and the substrate, **Figure 11**.

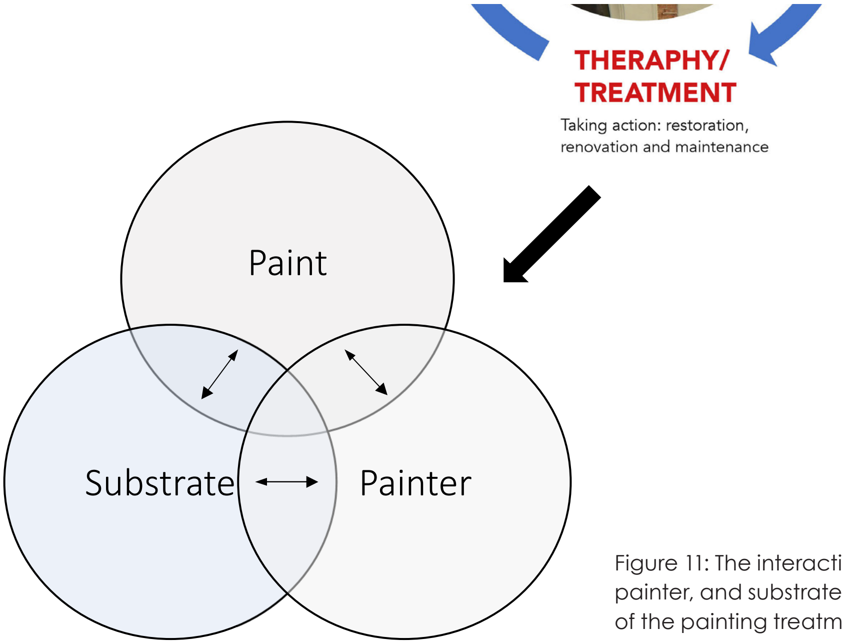

Figure 11: The interactions between the paint, painter, and substrate are crucial for the quality of the painting treatment.

CHAPTER 6

OIL VARNISHES AND PAINTS

Different types of armour paints were made during the research, guided by historical recipes. The photo is showing liquid aluminium-pigmented armour paint.

OIL VARNISHES AND PAINTS

“.. in the dialogue between material and maker, the material has the first word, because it provides us with qualities and potentials, as well as the last word, because it also sets the limitations of what can be done with it. It is material that is the mother of innovation and it is through skill that these innovations are brought about.” (Kuijpers, 2018, p. 886).

The results in **Paper II** and **Paper III** show that the concept of armour paint was successful and could be used for restarting production, guided by the historical descriptions. In both accelerated and natural ageing (Southern Sweden), the paints have proven to function as viable anticorrosive paints, as analysed by multiple methods. Ongoing field tests in Mariestad show so far, that the inhibitive action of primer paints of complex phosphates in linseed oil varnish paints works well and could be a more environmentally sustainable substitution to the original concept´s use of red-led linseed oil paint.

The paint materials, the very base for the craft practitioner’s correspondence, are described in this chapter, and an overview of the production of different oils varnishes, and paints are provided. This is relevant in order to describe what type of paint materials were used for exterior and anticorrosive paints and to put this in relation to viable options for the making and use of anticorrosive oil varnish paints now and in the future. The chemical and physical characteristics of oil paints, their formulations, and the ingredients used (such as pigments and the fat varnish) are shown, with a focus on challenging outdoor exposure. Moreover, how the refining treatments of the varnishes have changed over time is examined, since this led to the development of armour paints. The concept of the armour paint system is described in detail, to highlight successful characteristics of anticorrosive paints and the unique combination of pigments and different types of bodied oils and varnishes. Examples are also given of specifications used by chemical laboratories to control the quality of paint ingredients and paints. The aim is to find out if there are differences in the properties of historical and contemporary oils and varnishes, or if any connection to practical characteristics could be observed.

The introduction of and stand tung oil to anticorrosive paints was not a result of trying to compensate for the changes in linseed oil processing, as will be described in the following chapters. It was a natural development in the background of the chemical-technical industrialisation and commercialisation that started during the last few decades of the nineteenth century. Over time, the chemists were able to master the difficulties of refining raw tung oil into a product that was superior to the weathering resistance of linseed oils. The use of tung oil in early 1920s was a conscious decision to use this as an active ingredient in anticorrosive paints since the kettle-bodied varnishes dried too slowly with a texture that was too soft for aluminium pigmented paints. The spar varnishes, used for extreme exposure in the wooden ships or airplane applications due to their tung oil content, were initiating the use of heat-bodied varnishes for armour paints. In Sweden, the use of a quarter tung stand oil (75% linseed and 25% tung oil, refined together into stand oil) was a result of using the German patent of Dr. Asser. Another example of a German patent was Oljelin, a varnish with stand oil character produced by SOAB which was used for the anticorrosive paints and used also during the Second World War. The tung oil addition made it possible to apply thicker layers compared to linseed varnishes since the drying of the film was rapid and through-drying by polymerisation, and by this characteristic thicker paint layers could be applied than before.

6.1 Paint Making

6.1.1 From Handmade to Industrial Paints

The history of fatty acids originates at least 4500 years ago, to the Babylonian soap-making (Ahmad, 2017, pp. 1–8). Processing and inventions were coinciding worldwide. A chronological summary is provided by Ahmad shows, for instance, the discovery of glycerol by Carl von Scheele in 1779, the discovery of saponification in 1816, discovery of the distillation of fatty acids in 1825, and the discovery of linoleic acid in 1844. The identification of different fatty acids was gradually getting more sophisticated from melting point determination, fractional solubility, and crystallisation, into new technical methods for assessing saponification index (1879) and iodine values (1884), and so on. From the 1880s, the German chemists in particular started to develop laboratory methods, and these were adopted by Swedish chemists (Winbladh & Löfström, 1947, pp. 15–16). The German dominance was kept to the time of Second World War, but from the 1930s the technical influence from the USA, Belgium, France, and other countries increased in Sweden.

Technical inventions and improvements initiated the Industrial Revolution, which had a great impact on the societies across the Western world. This influenced the design and function of different types of buildings, and the development of infrastructure, such as structurally engineered bridges, railways, electricity and radio pylons, vehicles, and so on (Wetterberg, 2020). The technical progress urged for a need for mass-produced paint manufacturing for the surface treatments of these buildings, objects, and structures (Johansson, 2002, pp. 19–20: Standeven, 2011 pp. 11–12). The manufacture of industrialised paint gradually substituted the local paint making that had been executed by painters and small companies. Small-scale individual paint making by the painter went into semi-prepared paints, and further into large-scale industrially manufactured ready-to-use paints. The natural ingredients of drying oils and resins were mixed and gradually replaced by different derivatives and special paints were developed for different purposes (Singer, 1957. p. 3: Standeven, 2011, p. 17). A large variety of paint types, with varying quality, was developed for interior and exterior use. The ready-to-use paints also became available for amateurs and a large variety of customers. Until the 1920s, the raw materials in the varnish industry were mainly natural resins and oils (Johansson, 2002, pp. 91–92).

The painting craft and painting history in Sweden has been described by Johansson (2002). The small-scaled individual paint making was present for several decades at the beginning of the twentieth century (Fallgren, 1934b, p. 137: Laurell, 1942, p. 158: Nylén, 1948, p. 708). When the industrialised milling and rolling was introduced, the need for oil within the paints decreased, and the quality of the paint layers (such as hiding power, applicability, and so on) increased due to the improved dispersion and pigment-binder contact. The painters started to use pigment pastes, based on raw linseed oils, that were diluted to an applicable paint. The small-scale paint making existed parallel to the industrial paint making until the Second World War. Still, painters were fire boiling their own linseed varnish in the 1910s (Braenne, 1998, p. 39). Examples of painted engineered ferrous structures and objects are shown in **Paper II,** such as bridges, masts, and silos. During the First and Second World Wars, different resource-saving oils or substitutions were developed. Linseed oils and varnish paints were still the most important paint type, needed for military vehicles, different transportation vehicles, power plants, agriculture machines, buildings (Pihlblad, 1944, p. 150: Nylén, 1948, p. 651). The oil varnishes got increasing competition from such as nitrocellulose lacquers and phenol formaldehyde varnishes, for example. After the Second World War, the historical oil paints were gradually replaced by other types, and the industrial paint making over-ruled the small-scaled artisan paint making and use. The quotes below give a hint of the effects.

> *“From the leading Swedish paint-makers is nowadays delivered pastes with a declaration of content. This will give an absolute guarantee of the purity of the item. If you buy a cheap item from an unknown supplier, you must understand that the quality might be deficient. To the customer, the Master Painter is not only responsible for the painted surface finishes but also for the durability.“ (Fallgren, 1953, p. 101).*[10]

> *“The consequence has been that the lacquer and paint making, that since ancient times has been a noble craft with jealously kept manufacturing secrets, has transformed into a technical science during the latest decades.” (Berndtsson, 1956, p. 227).*[11]

6.1.2 Paint Formulations with Focus on Anticorrosive Paints

Put simply, paints consist of solid fine-grained minerals (pigments), and a medium that binds to the pigments. Paints are colloidal systems, which means that forces are acting upon (mainly pigment) particles in a surrounding medium (Mewis & Wagner, 2011, pp. 1–2, 325). The size of the solid pigments defines the type of the system, and in anticorrosive paints the particles are suspended. The general components of paints could be illustrated as in **Figure 12**. The nature of the object and the purpose of the painting treatment, mainly determine the type of paint that should be used.

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[10] Translated from *”Från de ledande svenska färgfabrikanterna levereras numera pastor märkta med innehållsförteckning. Denna ger en absolut garanti för varans renhet. Köper man en prisbillig vara från en okänd leverantör måste man ju i alla fall förstå att även kvaliteten kan vara undermålig. Det är ju så att målarmästaren inför kunden har att svara inte bara för utseendet på de målade ytorna utan även för hållbarheten.”*

[11] Translated from: *”Det har medfört att lack- och färgtillverkningen, som sedan urminnes tider varit ett förnämligt konsthantverk med svartsjukt bevarade tillverkningshemligheter under de senaste årtiondena övergått till en teknisk vetenskapsgren.”*

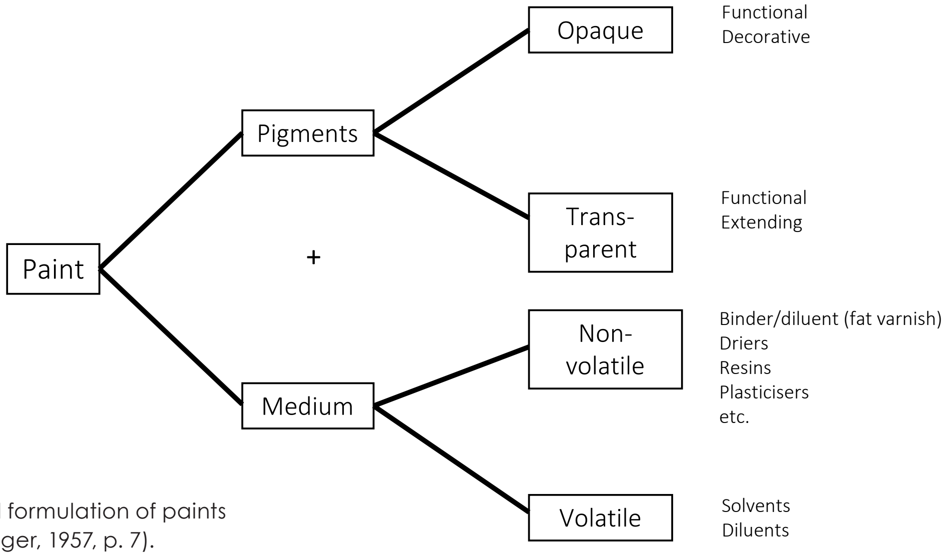

Figure 12: General formulation of paints (modified from Singer, 1957, p. 7).

For anticorrosive paints, the best quality of paint binders and pigments should be used due to the high requirements (Andés, 1900, pp. 95, 201: Magnusson, 1939, p. 264). This is also emphasised by the Master Painter, in the quote below.

> *"An important factor of any paint making is the quality of the ingredients. It is of no benefit for the economy or the profession that inferior materials are used. The paint become not only less workable; it covers badly and extends less; the result is a shabby appearance and the durability is reduced."* [12] (Fallgren, 1953, p. 101.)

The pigments are intimately mixed with the non-volatile and film-forming medium (the binder) into a stiff paste by grinding together the ingredients with a muller and a stone slab or with a paint mill of any kind (Andés, 1900, pp. 192, 267: Uebele, 1913, pp. 328–329*:* Sabin, 1927, p. 180: Magnusson, 1931, p. 58: Nylén, 1942, p. 2). Usually, well-settled raw or raw and fire-boiled linseed oil is used for making the paste. Paste-making requires experience, attention, and skills. The pigments should be added to the binder, not the other way around, otherwise it will form a granular, short/brittle aggregate and not a smooth paste. This is important also in the making of putties. The paste is thinned to "working consistency", depending on the working affordances and purpose, with fire boiled linseed oil or varnish, turpentine oil, or a liquid drier, by the paint-maker in the factory (ready-to-use paints) or by the painter (semi-prepared paint).[13] The viscosity of the paint affects the flowing and levelling characteristics, depending on the viscosity of the binder, the interaction between binder and pigments, and thinners. The full procedure of paint making could, of course, be undertaken by the painter. The mediums

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[12] Translated from: *"En viktig faktor vid all färgtillredning är ingrediensernas kvalitet. Det är varken ekonomiskt eller främjande för yrket att mindervärdiga material används. Färgen blir inte bara mer svårbearbetad; den täcker och sträcker sig längre, resultatet blir ett tarvligare utseende och hållbarheten blir nedsatt."*

[13] Turpentine oil is also called gum turpentine. It is rarely used today; other diluent or solvents are more common.

(binders), and in varying degrees also the pigments, affect the drying of the paint by their nature. Pigments that require a low proportion of oil binder (*lågt oljetal*) usually dry fast and are durable with outdoor exposure (Sandberg, 1926, p. 28).

The binder must not only surround and bind to the pigments into paint and provide internal cohesion of the paints; it must also adhere well to the substrate and together with the pigments give the paint a proper body (Andés, 1900, p. 163: Sabin, 1905, p. 8: Fahrion, 1911, p. 227: Nylén, 1942, pp. 3–4: Nylén, 1948, p. 642). The substrate must always be harder and firmer than the paint layers; i.e., the adhesion must be greater than the cohesion. The paint and the oil binder must be able to follow the expansion and contraction of a substrate due to varying temperatures, and the expansion coefficient of the binder and paint should be similar to the substrate (otherwise stresses and cracks will form). A larger proportion of oil varnish binder results in higher elasticity of the paint film. Historically, there were statements that it was considered as beneficial for the durability if the anticorrosive paint is also a good heat transmitter (Simon, 1897, p. 285: Fahrion, 1911, pp. 245–247).

The organic binder is the weakest link in paint, and its breakdown should be protected by the pigments or other additions in the paint. Chemical changes of the binder result in mechanical changes of the paint layers (Pizzimenti et al., 2021, p. 1912). As a general rule, it is considered as beneficial for the durability if a larger proportion of the binder (to a limit) is consumed by the pigments to form a paint, since the risk for a pigment grain falling out of the solid paint film is reduced (Andés, 1900, pp. 184–188). Each grain should be surrounded by the binder in order to prevent pigments from falling out and leaving a void (the void act as an initiation point for the breakdown of the paint film). Different pigments require varying amounts of binder to form a cohesive and workable paint. Experienced paint-makers and painters know that heavy pigments that occupy small space require less quantity of binders compared to pigments that are voluminous. The pigment volume concentration is a measure of the volume ratio between pigments and binders, described in chapter 6.2.1. Sabin points out that, to a certain extent, a higher concentration of binder is beneficial for the elasticity of the paint (Sabin, 1905, p. 13). If the proportion exceeds the limit, it will rather start to act like a varnish film than a paint, and then the durability will decrease. Where this point is, however, is impossible to say since it varies depending on the varnish or paint-making conditions and between different makers. Smoothness, toughness, chemical attack resistance, and homogeneity are important factors for paint on metals. Moreover, some hardness of the varnish is important.

The pigments increase the paint´s density, body and hiding power, paint film hardness, and durability, thus filling the porosities of the organic film and increasing the resistance to water and gas penetration (Andés, 1900, p. 163: Sabin, 1905, p. 8: Sabin, 1927, pp. 177–178). The pigments may be opaque, transparent or translucent in the media, depending on the differences in their refractive index (Hansen & Jensen, 1991, pp. 34–35). Pigments may also be classified according to their morphology. Solid bodies with a high refractory index or reflexivity, protect the organic binder from deterioration due to UV-radiation exposure. This has been further described in **Paper II** and **Paper III**. Pigments should be permanent, and chemical resistant due to the risk of aggressive environments (Andés, 1900, p. 177). The systemisation of pigments and the scientific work of inhibitive actions of certain pigments in the presence of water was conducted by Cushman & Gardner (1910, pp. 164–179, 219, 223, 265).[14] This is

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[14] Inhibitive; retarding the corrosion processes and putting the iron or steel into a passive state (Cushman & Gardner, 1910, p. 110.

interesting considering that linseed oil is (according to the authors), well known for absorbing water and carbonic acid, and therefore gum or varnish must be required as binders in order to produce dense paint films, in combination with used pigments. Water-soluble pigments were grouped into rust 1) inhibitors, 2) neutrals (indeterminates), and 3) stimulators. Rust inhibitors include, for instance, chromates, some lead compounds, and zinc oxide. Interestingly, pigments such as carbon black or lamp black and graphite (used in anticorrosive paints) act as rust stimulators and should therefore only be used as topcoats. Bone black on the other hand acts inhibitive. Neutral pigments that are contaminated with acidic compounds, such as sulphates in red hematite, may act as corrosive and therefore only natural hematites should be used.[15] The experiences on graphite and hematite seem to have varied a lot (Lowe, 1905, pp. 34–35). Other pigments that were used on architectural ironwork included white-leads, Prussian blue, yellow ochres, and copper acetates (Mitchell, 2016, p. 150). The use of decorative pigments on ironwork such as smalt and mixtures for certain stone colours, Brunswick Green, bronze-green, and so on has been described by Baty (1994, pp. 1–6).

The pigments do not only interact with moisture and metal, but also with the paint binder, and the hydrophobic properties of the paint are beneficial in order to resist water penetration of the metal. Due to the high reactivity of alkaline pigments with oils and varnishes with high acidity, metal soaps may form (sometimes with heavy gelation) (Andés, 1900, pp. 97, 178–179: Uebele, 1913, p. 327: Magnusson, 1931, pp. 57, 68: Tengstrand, 1939, pp. 148–150: Gillian, 2012, p. 20). Therefore, oil varnishes with high acid values are inappropriate for anticorrosive paints. Metal soaps are considered beneficial for the density of the paint film but could cause gelation during storage.[16] Classification of inorganic pigments is also possible with respect to their reactivity with free fatty acids (that separate from glyceride during drying): 1) as soap forming, alkaline; as 2) non-alkaline, positively catalysing; or 3) chemically indifferent with no positive action. To group 1 belongs pigments such as litharge, red-lead, lead white, and zinc oxide. This group is the only group that forms soaps that are durable under atmospheric conditions, and the lead soaps act as a catalyst. The protective action of red-lead primers due to the formation of lead linoleates, and the electrochemically inhibitive action, has been described in **Paper II**. The first known patent with red-lead pigment in a paint formula (with resins, zinc oxide, and copper acetate) is from 1852 as the British patent 1194 by Cookson (Smith, 1981, p. 13). The red-lead pigment favours through-drying of the paint film without risk of *syneresis*.[17] Examples of common main pigments used for anticorrosive paints are graphite (belongs to group 3) (Rothstein, 1856, p. 248) and carbon black (Lisinski & Johansson, 1979, pp. 67–77). Carbon black acts as a UV-absorber and by this act protects from photo-oxidation due to sun exposure (Berdahl et al., 2008, p. 425). Besides for red-lead, red hematite was used for primer paints too (Hawkes, 1979, p. 19). Anodic protection of a ferrous substrate could be achieved by the use of primer oil varnish paint with metallic pigments. This was patented by Mallet already in 1840, and was used before hot galvanising became common (known as *galvanische*

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[15] Sandberg states that the red hematite for anticorrosive use (järnmönja) could be produced also by refinement of specularite/MIO and hematite ore (blodstensmalm) (Sandberg, 1926, p. 35).

[16] Soaps are alkaline compounds of metals and monobasic carboxylic acids containing from 7 to 22 carbon atoms (Schnall, 2012, p. 38).

[17] Syneresis in chemistry: the process in which a gel contracts on standing and exudes liquid, as in the separation of whey in cheese-making or the resoftening and tackiness of a solid oil varnish film due to strong sun exposure (Magnusson, 1931, p. 17).

anstrich) (Lynes, 1954, p. 61: Karmasch, 1862, pp. 609–610). Today, zinc-rich primer paints are very common, but with other types of binders. Modern linseed oil paint may contain 10–15% zinc white (this varies for different paint manufacturers) but the use of lead compounds is restricted to highly valued heritage objects due to environmental concerns. In anticorrosive paint systems, it is usual that the primer paint has a different composition than the topcoats. In the primer paints, inhibitive pigments dissolve and act electrochemically when the humidity is penetrating through aged paint layers (described in **Paper II**). Lamellar pigments form effective barriers and may retard the deterioration of the binder. Extending pigments may be present, depending on the type of primer.

Today, few are aware of the distinction between linseed oil and linseed varnish. In the historical sources, these were absolutely different matters. Linseed oils or other drying oils could be used in the un-refined form as binders in paints (Mulder, 1867, pp. 223–224: Seeligmann & Zieke, 1910, p. 287: Sabin, 1927, pp. 178, 314: Singer, 1957, pp. 13–15). A minimum requirement was that the oils were purified and free from impurities. But even then, raw or boiled linseed oils could not be used for exterior oil paints, since they form a soft, porous, and slow-drying film. So-called "boiled linseed oil" – i.e., heat-treated but without the addition of driers, was not appropriate for high-quality paint making since they dry slowly and are prone to embrittlement and cracking (Mulder, 1867, pp. 223–224). "Boiled linseed oils" were used together with pigments to accelerate the drying (catalysing pigments). In order to act as an efficient binder, the refinement must proceed into a bodied liquid: *oil varnish or fat varnish, made by heat-treating the purified (linseed) oil at high temperatures for a time, with the addition of driers in any form* – i.e., metallic compounds containing oxygen (Fahrion, 1911, p. 182: Sabin, 1927, pp. 44–45, 117). Bodied linseed oils with added driers were called *linseed oil varnishes*. Fat or oil varnishes and volatile or spirit varnishes were distinguished from one other (Standage, 1892, p. 143). The first dry as a result of the varnish constituents; the second by evaporation of volatile ingredients (spirits, naphtha, and so on), and Standage and other authors claimed that the making of oil varnishes required far more skill compared with the other type of varnish. A good varnish should be glossy, transparent, and firm, but still elastic, and forming paint film which is resistant to the atmosphere, as defined by Weger in 1898 (Fahrion, 1911, pp. 215, 245–247). A very important quality criterion is the films' presence of elasticity and non-permeability to gases and fluids – its surface protective action. The application of unpigmented varnish or oil as a final treatment on a ferrous substrate was understood to be wasted and does not affect corrosion resistance due to its water permeability (Cushman & Gardner, 1910, pp. 227, 234–235). Moreover, the use of very fine-grained pigments acts beneficially on the adhesion to the ferrous substrate. These historical statements are important to keep in mind also today, when discussing characteristics of anticorrosive paints and paint ingredients.

At the end of the nineteenth century, great efforts were made by researchers (such as Weger; Engler & Wild; Weissberg; and Osvald) to find out how the driers work chemically (Fahrion, 1911, pp. 195–206: Magnusson, 1931, pp. 4, 33–34: De Viguerie et al., 2016, pp. 46–47). Driers are soluble in oils and catalyses primarily the auto-oxidation reactions – i.e., they accelerate the reaction kinetics by providing undissociated oxygen. The action and the characteristics of the resulting solid film (gel) depend on the metal type, oxide ratio, drier concentration, and the colloidal state of the oil. Different driers promote oxidation, some polymerisation, or both. The driers are described as surface-driers, through-driers, or auxiliary-driers. The oldest types of driers were used in solid form, as fine ground minerals – i.e., metal oxides that form metal linoleates. The term *siccative* is used when the driers are provided in a liquid solution but early statements have been found that say that this term was also used for solid driers (Sabin, 1927, p. 37: Bieleman, 2002, p. 184). Here, they are used as synonyms. UV-radiation exposure and elevated temperatures accelerate the influence of the driers (Fahrion, 1911, pp. 220–221: Bottler, 1912, pp. 45, 47, 64). Higher RH results in a softer film. The oxidation that is induced by the addition of driers continues far after the film has dried (Standage, 1892, p. 145: Sabin, 1927, p. 120). This results in increased hardness and the reduced elasticity of the varnish or paint. Painters refer to this as the "*paint is burning*" due to the action of driers. A good balance of driers and pigments is needed to retard the long-term oxidation rate and increase durability. A skilled varnish-maker uses them very carefully since the driers decrease the durability of the film (Standage, 1892, p. 145). Use of driers that is too excessive is generally unwanted in outdoor paints (Fallgren, 1934b, p. 142) and especially in anticorrosive paints due to their embrittling and premature ageing effect (Anonymous, 1897, p. 389: Strömberg, 1948, p. 390). Varnishes are still needed in order to facilitate reasonable drying rates. Andés states that a varnish used for making anticorrosive paints should dry within 24 hours outdoors, and no additional driers should be used (Andés, 1900, pp. 139–140, 192). If the drying time is longer, the quality was considered as too low due to insufficient processing or falsification.

Resins were used as ingredients to make weather-resistant oil varnishes and enamels in order to achieve rapid drying, high gloss, and hardness, but they were unwanted in anticorrosive paints due to the increased risk of embrittlement and discoloration of the paint films (Mulder, 1867, p. 223: Andés, 1900, p. 74: Singer, 1957, p. 3: Standeven, 2011, p. 17). When exposed to UV-radiation, resins may be rapidly pulverised, which increases the moisture permeability and gives moisture access to the ferrous substrate. Many resins require solvents that are unwanted for anticorrosive paints since they may cause porosity and premature failure (Bergman, 1934, p. 95: Nylén, 1948, p. 643).

Turpentine oil (*Terpentinöl*) in an oil varnish could derive from a liquid drier in the early 1900s, but could occasionally be added in small quantities as a diluent in paint to improve the applicability (Fahrion, 1911, p. 245). Turpentine added to paint decreases the varnish concentration and makes the paint less durable (Andés, 1900, p. 192). It was generally not allowed for outdoor usage (Fallgren, 1934b, p. 138). Turpentine oil acts as a drier due to the content of the hydrocarbon α-pinen catalysing the auto-oxidation through the formation of peroxide and oxygen compounds (Kjellin, 1927, p. 303: Suida & Salvaterra, 1931, p. 136). The turpentine oil was exclusive and was later substituted by other synthetic variants. Turpentine oil and mineral spirit/white spirit (*Lackbensin*) became gradually more common and could be used as diluents for anticorrosive paints in the 1920s and 1930s (Heideck & Leppin, 1933, p. 240: Nylén, 1948, p. 644). The viscosity could also be adjusted by heating the paint before application (Sabin, 1905, p. 42: Sabin, 1927, p. 268: Fallgren, 1934c, p. 247).

At the end of the 1930s, glycerine-phthalic fatty acids and resins were introduced, such as Glypthal and aldehydes (Andersson, 1939, p. 68: Berndtsson, 1956, p. 225).[18] During the Second World War, SOAB ran into difficulties regarding the importation of Argentinian linseeds,

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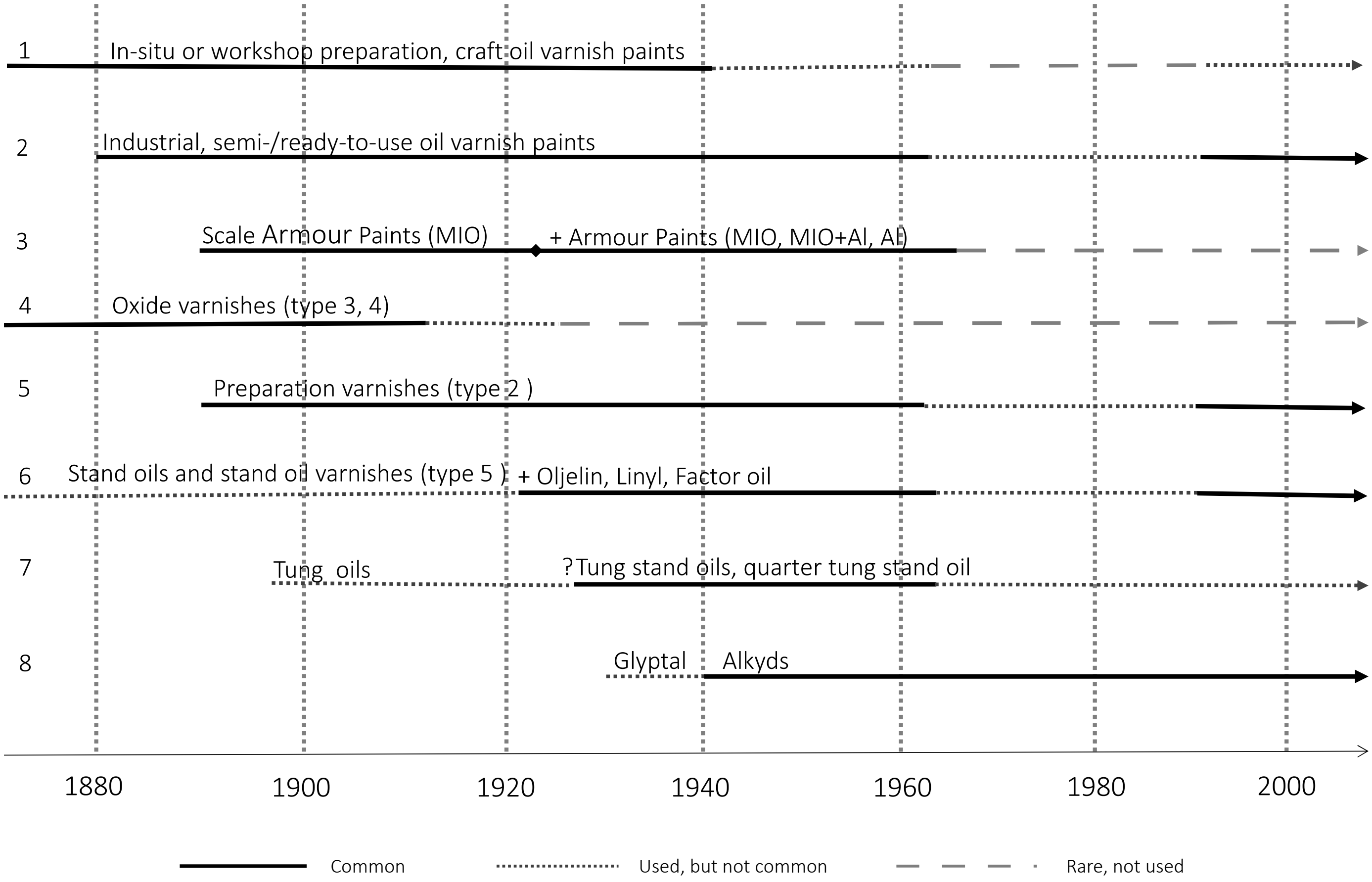
[18] Glypthal was first a modified triglyceride, later an early alkyd, invented by IG Farbenindustrie in Germany in the early 1930s (Suida & Salvaterra, 1931, p. 69).



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3. IVA, 1935, 1961: Edwards, 1925, 1927, 1936: Oskarsson, 1937: Trägårdh 1938: Trägårdh U. 1953: Nylén, 1954: Luneberg & Svensson, 1957
4. Fahrion, 1911: Magnusson, 1931, 1939: Fallgren, 1953: Braenne 1998: Karlsdotter Lyckman, 2005
5. Bottler, 1898, 1912: Andés, 1900: Seeligmann & Zieke, 1910: Kjellin, 1927: Andersson, 1939: Richter, 1941: Nylén, 1948
6, 7. Magnusson, 1931, 1939: Andersson, 1939: IVA, 1935, 1961: Pihlblad, 1944: Berndtsson, 1956: Hansen, 1990
8. Suida & Salvaterra, 1931: Andersson, 1939: Nylén & Andersson, 1957: Hansen, 1990

Figure 13: An approximative timeline showing the use of different product forms of paints and varnish binders.

and so they started a production of alkyds. Long oil alkyds were made from linseed oils, tung oil, perilla oils, fish oils, dehydrated castor oil, and soya oil. These so-called "varnish concentrates" were diluted with VOCs (Andersson & Nylén, 1957, p. 12).

The use of different oil varnishes and anticorrosive oil varnish paint is comprehended in **Figure 13**. Explanations of the types will be given in the following chapters.

6.2 Drying Oils and Oil Varnishes

> *"There are three enemies to fine varnish:*
> *The man who thinks all varnishes are necessary evils.*
> *The man who thinks any varnish will do.*
> *The man who does not think about varnish at all."*
> *(Sabin, 1927, p. 90.)*

6.2.1 The Curing

Oxidation and polymerisation of fatty acids

Drying oils—fatty acids in triglyceride mixtures—are used as binders in historical oil paints. The most important drying oil is linseed oil (from *Linum Usitatissimum*) but could also be poppy, castor, tung oil, and occasionally hempseed, sunflower, walnut, and cotton oils (Varrentrapp, 1848, p. 384: Bottler, 1912, pp. 1–7). For anticorrosive paints, linseed oils and tung oils are the most important drying oils (Suida & Salvaterra, 1931, p. 67). Dehydrated castor oil and oiticica oil are also used in oil paints due to their excellent resistance to moisture and chemicals (Singer, 1957, p. 9).

This group of oils dry when they are exposed to air: they undergo a transformation from liquid oil into a water-insoluble solid polymeric film (gel) when they are exposed to air, by parallel and competitive autoxidative and cross-linking polymerisation radical chain reactions (Erhardt, Tumosa & Mecklenburg et. al., 2000, p. 65: Johansson, Baeling & Ekstedt, 2004, p. 80: Modugno et. al., 2019, p. 2).[19] The rate of auto-oxidation is catalysed by external additions of oxygen-carrying compounds in the forms of driers and/or pigments. Metal cation catalyse the oxidative cross-linking in the drying process (Bieleman, 2002, p. 184). Chemical processes such as auto-oxidation and hydrolysis continue for several years, (especially by UV-radiation exposure and high RH) after the solid film is formed and result in embrittlement, cracking, and breakdown of the film.[20] As a result, the acid value (AV) or free-fatty acid value (FFA) increases.

The drying oils consist of esters formed between one molecule of glycerol and three molecules of various (or same) fatty acids, triacylglycerides (TAG's) (van den Berg et al., 2004, p. 181). Fatty acids are either saturated (no free carbon-carbon bonds that could bond oxygen) and have 12, 14, 16, 18 carbon atoms (lauric, myristic, palmitic, stearic acids, respectively) or 18 carbon polyunsaturated non-conjugated fatty acids with one, two or three double carbon bonds (oleic, linoleic and linolenic acids, respectively) (Lazzari & Chantori, 1999, p. 303). There are other characteristic fatty acids. Typical fatty acid profiles in linseed oils and tung oils are shown in **Table 3** (Schönemann & Edwards, 2011, p. 1174: Carlesi et al., 2015, p. 866). The chemical reactivity is directly related to the fatty acid type (i.e., the unsaturated acids) and concentration.[21] Pure linseed oils dry within 3–7 days, and this could be shortened to one

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[19] The auto-oxidation mechanism of drying oils was first described by Engler & Wild in 1897.

[20] Hydrolysis is a reaction where the ester bonds of the TAG break and a reaction between free fatty acids and cations occurs, leading to the formation of dicarboxylic acids – i.e., metal soaps and hydroxylated fatty acids (Modugno et al., 2019, p 2, 14). This may cause, for instance, moisture sensitivity.

[21] In 1888, Bauer & Hazura discovered that the drying speed is proportional to the number of unsaturated fatty acids bonds and can be described by the iodine value (Fahrion, 1911, p. 163). The drying power is proportional to the concentration of linolenic acid (Bauer & Hazura, 1888, p. 456). The iodine value is an indication of the drying power of a varnish, and was at in 1939 was specified to be at least 170 for raw linseed oils (Magnusson, 1939, p. 255).

Table 3: Fatty acids content (at%) in linseed oils and tung oils (Schönemann & Edwards, 2011, p. 1174, Carlesi et al, 2015, p. 866).

	Palmitic acid C 16:0	**Stearic acid C 18:0**	**Oleic acid C 18:1**	**Linoleic acid C 18:2**	**Linolenic acid C 18:3**	**α-eleostearic acid C 18:3**
Linseed oil	6–7	3–6	14–24	14–19	48–60	-
Tung oil	3	2	8–11	4–15	3	59–86

day or even six hours through the addition of driers (Fahrion, 1911, p. 182). The iodine value is used as a measure of the number of unsaturated fatty acids in the oil.

The drying process phases are initiation (after an induction, waiting period), propagation, and determination (Lazzari & Chiantori, 1999, p. 308: Stenberg, 2004, p. 4: Modugno et al., 2019, p. 2). The curing is characterised by autoxidative radical chain reaction with oxidation and cross-linking (polymerisation) processes that propagate either in parallel or competitively. The free radical chain reaction propagates hydrogen abstraction from unsaturated fatty acids with hydrogen and oxide, hydroperoxide decomposition which could result in either intermolecular cross-linking reactions, or intramolecular chain scission reactions with low molecular weight and easily volatilized compounds – depending on the number of unsaturated fatty acids in the oil. Primary reaction products are, for instance, peroxides and are measured by the peroxide value (PV). Peroxides might be introduced by heat treatment and will increase the crosslinking. Secondary and tertiary oxidation products (mostly low molecular weight and easily volatilized compounds) could be formed such as aldehydes, ketones, and as alcohols, acids, epoxides, and cyclic fatty acids. The chemical reactions are described thoroughly in many sources, for instance, van den Berg (2002), Alves (2015), and Orlova et al. (2021).

The ageing of drying oils and varnishes – or paints where they are used as binders – proceeds by chemical reactions such as auto-oxidation, polymerisation, cross-linking and hydrolysis, as explained in **Paper III** and **Paper IV.** By GC-MS (and FTIR) analysis, constituents such as; saturated (monocarboxylic) acids (myristic, palmitic, stearic); dicarboxylic acids (pimelic, suberic, azelaic, sebacic); unsaturated fatty acids (oleic, linoleic and linolenic acids); oxidative scissored compounds (oxo-, hydroxy- and methoxy- octadecanoic acids) and glycerol could be quantified (van den Berg et al., 2002, pp. 1173-1180: Schönemann & Edwards, 2011, pp. 1173-1180). The sum of of dicarboxylic acids (%D) increase and the proportion of unsaturated fatty acids decrease, as the ageing proceeds. Due to certain high-temperature treatments with restricted air access (during the refinement), cyclic compounds (7-(o-pentylphenyl)-heptanoic acid and 9-(o-propylphenyl)-nonanoic acid) could also be detected. The cyclic compounds are typical constituent in stand oils (see chapter 6.2.5).

The Colloidal State

Parallel to the description of drying by oxidation and polymerisation, it is relevant to describe the colloidal state of the liquid varnish (and paint) since this affects the quality of the formed solid film (i.e., the gel). Dietemann et al. describe that the colloidal aspects of paints and binders are "*forgotten, overlooked, or ignored*" in conservation science (Dietemann et al., 2014,

p. 29). This is strange, since the colloidal chemistry is a well-established and extensive research field today in food technology, nanotechnology, industrial coatings, surface chemistry, and so on.

The colloid chemistry was pioneered by the German chemist Ostwald (1883–1943) in 1910 (Dietemann et. al. 2014, pp. 30–31). Oswald called the phenomena deriving from systems of particles being too small to be seen by microscope but still larger than a molecule, for "*the world of neglected dimensions*." Before Oswald, Graham defined colloids and crystalloids in his work of 1860 about solution passage via membranes. The membranes stop particles with a size of >1 µm and scatter light rays (the Tyndall phenomenon). The colloidal state of the oils influences their characteristics by their content of particles, with different origins and varying sizes (from about 1–10 µm down to nano-meters). Colloid chemistry was emphasised for the controlling and describing paint binders of the first half of the twentieth century (for example, Stern, 1932, pp. 247–341). In SOAB, the process of control was ruled with the aid of theoretical models of the colloidal phase systems of linseed oils (Magnusson 1931, 1939). The theories of colloid chemistry could explain many of the practical aspects and consequences of purification and refining treatments of oils and varnishes, and partly the behaviour of different paints. This has been investigated by, for instance, Eibner (1930).

Fatty oils and drying oils, consist of a *dispersed phase* carried by a *dispersion media* and are *iso-colloids* and *lyophilic* (Auer, 1938, pp. 466–471: Dietemann et al., 2014, p. 37). [22, 23] The dispersed phase coagulates and aggregates (grows) by different mechanisms (i.e., oxidation and polymerisation) and undergoes with the dispersion media a sol-to-gel transformation into a solid film (to gel, gelatinisation), see **Figure 14**.[24] Pre-oxidising or pre-polymerising oils by different treatments will affect the distribution of dispersed phases in the surrounding dispersion media. Gels may be reversible or irreversible, where the reversible is soluble by organic solvents (*peptisation*) and form sols when they are heated.[25] Tung oils have the highest concentration of dispersed phase, followed by linseed oils, and this has a direct impact on the drying power. They form irreversible gels. By heat exposure and the addition of driers the concentration of the dispersed phase increases compared to raw oils. The driers (forming metal soaps) flocculate from the oils with the dispersed phase and accelerate the coagulation. By heat bodying, the dispersed phase aggregates (sticks together) and increases in concentration compared to raw oils. By oxidation (gas coagulation), the dispersed phase incorporates oxygen. An increased concentration of the dispersed phase is initiated by the action of gases, UV-radiation, or other accelerators, and this could cause bodying to raw oils so that they

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[22] Iso-colloidal: The dispersed phase and the dispersion medium have the same chemical composition but different physical characteristics (Auer, 1938, p. 466).

[23] Lyophilic colloid is a system characterised by a strong affinity between dispersed phase and the dispersion media (Auer, 1938, p. 466). Lyophilic ("liquid-loving") and the opposite lyophobic is used to describe whether a surface/film/functional group is wetted or solvated (Shaw, 1991, p. 5).

[24] Sol is the colloidal system of dispersed aggregates in a dispersion media and gel is the precipitation/aggregates surrounded by the dispersion media (Dietemann et. al. 2014, pp. 30-31). Coarse dispersions are suspensions and emulsions, with a grain size of > 200 µm. Dispersed/colloidal systems are in the range of 1–200µm. Molecules and ion dispersed systems are crystalloids: 0,1–1 µm. Peptisation means that the colloid re-suspends (Mewis & Wagner, 2011, p. 11)

[25] Eibner´s test could be used to determine the amount of insoluble (in alcohol and ether), irreversible gel in the dry varnish film. The higher the concentration of irreversible gel, the more durable the film (compare to Mulder´s Linoxyn) (Magnusson, 1931, pp. 20, 76). One weight part of the boiled oil is ground with three parts pure red-lead to form an easily applicable paint, that is applied to a glass plate. After three days of drying, the scraped film is put into ether and shaken. The film should not dissolve and the liquid is allowed to only get a slight orange discoloration.

resemble of stand oils. Fatty acids that are insoluble in petroleum ether (in liquid or solid-state) are the acids of the dispersed phases. The rate of gelatinisation (i.e., sol to gel transformation) could be retarded or accelerated by the addition of different inorganic salts (like driers). This is conducted for tung oils, for instance, by treatment with resins which have been treated with lime (Andersson, 1939, pp. 73–74). Vulcanisation of rubber is a parallel process to oxidation and the colloidal phase system but involves sulphur as accelerators instead (Auer, 1938, p. 471).[26] Heated linseed oils show shear-thinning behaviour— i.e., viscosity increase with increasing shear rate due to the deformation of pre-polymerised molecules (Tirat et al., 2017, p. S42).

When mucilage, also called gum (*slem*), is present in linseed oil, in time they coalesce and form a dispersed phase in the colloidal system (Magnusson, 1931, p. 17). It is easy to check if linseed oil is colloid or not by letting rays of light through the liquid to reveal the Tyndall scattering. If the raw oil is not colloid, it is a crystalloid and will not flocculate with formic acid by Auer's method. Through Auer's method, it is possible to separate the phases as: impurities (the gum, as a bottom layer), the dispersion medium (on the top), and the intermediate layer (the coagulated dispersed phase) (Auer, 1938, p. 467).[27] Examples of visible turbidity and non-turbidity in two different types of linseed oils are seen in **Figure 15**.

Auto-oxidised, blown, or stand oils are iso-colloids, otherwise fresh oils are crystalloids (Magnusson, 1931, pp. 5, 8–9, 19–20, 26–27, 55: 1939, p. 258). In stand oil boiling, and high temperature boiling the transformation from crystalloid to iso-colloid due to polymerisation is detected by assessing the hexabromide value.[10] When the value is zero, the concentration of the low dispersed phase (polymerised unsaturated FA's with a low acid number) is low and the driers are added. Linseed oil requires heating to 230–250°C/32 h or 290–300°C/3 h in a carbonic acid atmosphere to reach a hexabromide value of zero (i.e., when the linolenic fatty acids are consumed). The low drying power of stand oils (including *Linyl* and *Oljelin*, see chapter 6.2.5) was handled, for instance, at SOAB by "boiling" (i.e., heat polymerising) to a hexabromide value of zero and then adding a cobalt drier to the remaining un-polymerised phase, resulting in a stand oil with drying time of 3–4 hours. When a varnish is applied to a substrate it undergoes different stages that could be monitored by Weger's glass-plate method (see chapter 6.2.2), where weight change versus time is stated. *Through-drying* is achieved when the dispersion media is aggregated at an early stage of the drying and the sol-gel formation is completed. The reversibility or irreversibility of solidified films in solvents is dependent on the degree of dispersion in the film (which changes over time).

The spreading of varnish on a clean metal or glass surface is a surface-colloid interaction process (Berg, 2009, p. 217). A polar organic liquid may "wet out" i.e., form a monolayer of the liquid—resulting in an ostensible dry surface. The monolayer retards the bulk spreading of the liquid and excess liquid gathers as drops. The liquid is *autophobic*. Blown linseed oils are

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[26] Sulphur as an accelerator has been used for instance in the making of Factor Varnish, for instance, which is a type of linseed stand oil (Suida & Salvaterra, 1931, p. 68).

[27] One part of concentrated formic acid is thoroughly shaken with one part of the fatty acid oil in a separatory funnel, and after a retention time of several days, three distinct separation layers are formed if the liquid is a colloid (Auer, 1938. pp. 466-472).

[28] The hexabromide value is a measure of the number of different unsaturated fatty acids in a drying oil, and is used as a measure of the aggregation of the oil during boiling (Hehner & Mitchell, 1898, p. 313.).

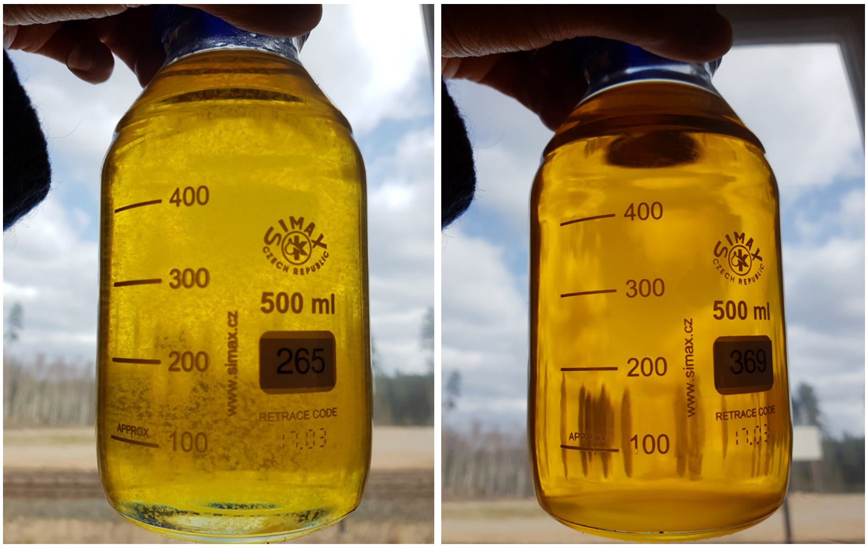

Figure 15: A visible dispersed phase in a linseed stand oil that has been standing in a window for three years (on left) and an absolutely clear, non-turbid raw linseed oil (with slight sedimentation).

known to be polar (Singer, 1957, p. 16).[29] The described phenomenon can be seen in **Figure 16**.

The colloidal state of the solid varnish film is easily revealed by exposing it to water, leading to a phase differentiation (Magnusson, 1931, pp. 4–24, 33–35, 40: Suida & Salvaterra, 1931, pp. 42–52: Payne & Gardner, 1937, pp. 893–894, Magnusson, 1939, pp. 258–259). The drying of oils and varnishes results in a solid gel, with molecule aggregates, bound by cohesive forces into fibril bundles. Short fibrils result in brittle gels and more swelling. The strength, elasticity, and density of gels depend on the size, length, orientation and cohesive forces, and close-packing of the fibrils. Through high vapour pressure, the fibrils could be separated, and

Figure 16: Left: Common behaviour of blown linseed oil varnishes, to "crawl" into thinner and thicker spots shortly after application onto a clean substrate. This leads to the formation of wrinkled surface drying on thicker areas. The crawling effect is eliminated by the addition of 10–20% tung oil to the blown varnish, and this will form nice, and uniform films in analogy to that seen on the right lid. Right: High temperature boiled linseed varnish that forms a uniform film.

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[29] Polarity in chemistry: having a dipole or characterized by molecules having dipoles. Merriam-Webster Dictionary.

liquids or vapour may penetrate through the films. A solid varnish film absorbs water and swells heavily (with a simultaneous decrease in firmness and increase in elasticity) – *imbibition* (see **Figure 17)**. The swelling decrease when the liquid evaporates, but the original state is not reached (*hysterós*). The polarity of the liquid and the solid film are variables that affect the adsorption power. Polar liquids, such as water and alcohol, are more prone to wet polar surfaces and vice versa. Repeated water exposure and drying (and a high tendency for hysterós) result in the alternating expansion and contraction of the painted layers; reduced adhesion, elasticity gloss, and the cracking of the varnish or paint film. A method for the investigation of water resistance is described later in this chapter and chapter 6.3.3. The absorption of water in a colloid or gel is affected by the nature of the dispersed phase and the medium, which in turn is influenced by the varnish-making processes. The driers are soluble in oils, and their action depends on the type of metal, the concentration, and the colloidal state of the oil.

As mentioned, paint is an example of a colloidal sol system, where particles (pigments, extenders) are dispersed or suspended (depending on particle size) in a liquid medium (Berg, 2009, pp. 346, 350, 631: Dietemann et al., 2014, p. 30: Tirat el al., 2017, p. S41: Hodapp, Dietemann & Willenbacher, 2019, pp. 58–66). The pigment to (pigment + medium) volume ratio in paint is described as *Pigment Volume Concentration* (PVC).[30] The critical PVC (CPVC) corresponds to the formulation when there is precisely an enough proportion of the binder, to fill all the interstitials between the solid particles (see **Figure 18)**. The CPVC and PVC affect many characteristics of the system, for instance; applicability, levelling (results a smooth surface), elasticity, and gloss. Glossy paint usually has a PVC of 0.15–0.25 (binder type not stated). The ability to withstand application on vertical surfaces without sagging is connected to the continuous contact between the pigments, the PVC, and the degree of gel formation or flocculation, so that the gravitational forces do not exceed the yield stress in the paint. *Thixotropy* – decreased viscosity (i.e., reversibility of gel networks, the internal structures of the paint) – due to the action of mechanical forces (shear rate) is another phenomenon derived from the colloidal state of paints (or binders).[31] Thixotropy affects the paint′s spreading and levelling depending on application conditions and the paint formulation. **Figure 19** illustrates the formation of the gelating network in a paint slurry. With the exception of the PVC and CPVC, the particle size, shape, and size distribution affect the fluid behaviour of the paints. Despite the same PVC, different pigments may be wetted differently by the binder (Andersson & Nylén, 1957, p. 13). Therefore, a "corrected PVC" could be used.

Colloidal systems could be described by phase diagrams that show the boundaries of thermodynamical equilibrium and could be used to predict the reaction kinetics at different temperatures and phase concentrations of liquids and solids, but phase diagrams and phase models have not been found for drying oil varnishes. These types of models exist for metal alloys, food, chocolate, and many types of materials. Numerous examples describe phase diagrams for polymers and biopolymers, for instance, Amine et. al., (2017) and Keshavarz, Khansary & Shirazian (2015.) For polymers technology, the high molecular molecule model

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[30] To assess the PVC, measurements with, for instance, impedance spectroscopy or fluorescence microscopy are required (Lobnig et al., 2006: Wang et al., 2014).

[31] A thixotropic behaviour of a liquid's is when viscosity decreases over time at a constant shear rate and, but when the shear has stopped, the liquid returns to its initial viscosity (Tirat et al., 2017, p. S37).

Figure 14: Simplified illustration (not to scale) of nucleation, aggregation of fibrils, and interconnected 3D-gel formed in a dispersion medium. This is assumed to be similar to the cross-linked aggregated phase in liquid heat-bodied oils and varnishes.

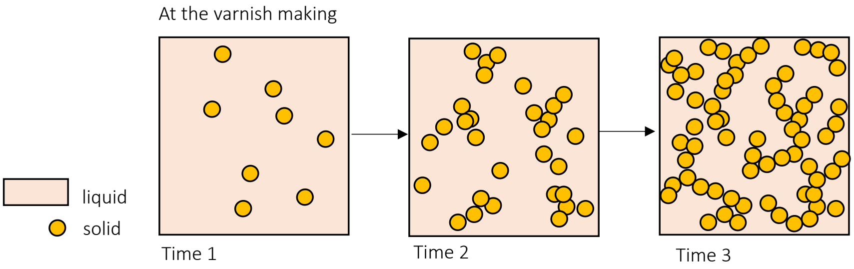


Figure 17: High-density fibrils, cross-linked macromolecules swell to a lesser extent by solvent (for instance, water) and show low hysterós (not to scale, modified from Hirai et al., 2001, pp. 10–11)

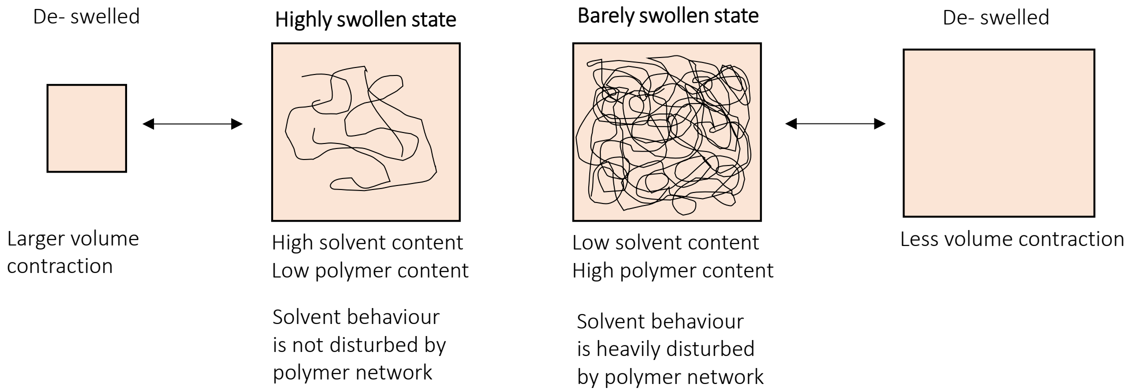


Figure 18: PVC and CPVC in a slurry (paint). Pigments symbolised as simplified spheres (not to scale, modified from Berg, 2009, p. 350).

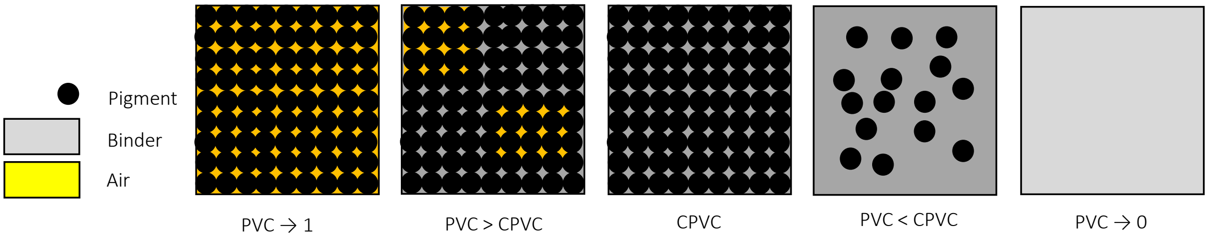
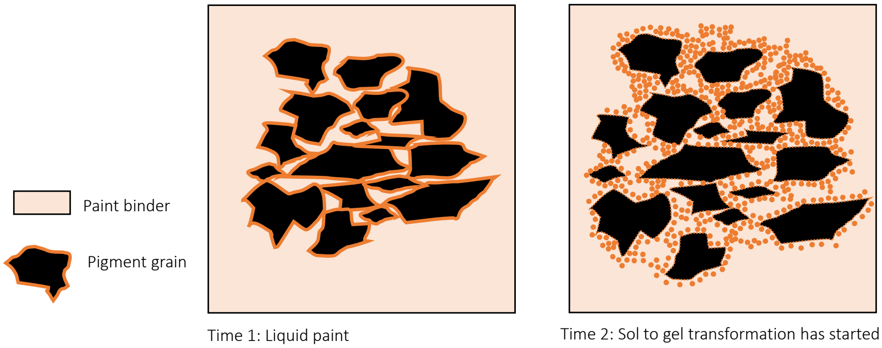


Figure 19: Simplified illustration of paint, not to scale. Left: Pigments are wetted by the binder. Right: The sol to gel 3D network is developing. Voids are either liquid or air depending on the PVC and gelating stage. Drying with air porosities is matte. When the gel network cannot be broken or plasticised, the paint is "dry". (Not to scale, modified from Dietemann et al., 2014, p. 38).



presented by the German chemist Herman Staudinger (1881–1965), is highly used (Mülhaupt, Fell & Morris, 1999). In food science, the colloidal state of oils is investigated in investigations by, for instance, Budilarto & Kamal-Eldin (2015). Colloidal chemistry is occasionally used to explain, for example, hydrolysis connected to RH for artists' oil paints (Modugno et al., 2019). Recent research regarding the deterioration of artists′ oil paints connects closely to the colloidal state of oils and varnishes, but emphasises the difficulty of assessing the polymerisation degree by analytical methods (Pizzimenti, et al., 2021, p. 1913). Nardelli et al. (2021) have shown that oxidation of low-degree polymerisation areas in oil paints results in hydrophilic paint layers.

To Monitor the Sol to Gel Formation

With a Weger′s glass-plate method, the weight increase versus the time in the gel-formation of oils and varnishes could be established, see **Figure 20**.[32] Since the drying rate depends on factors such as temperature and RH, Weger concluded (1897) that comparisons could only be done with a reference sample (*Normalfirnisse*).

Different stages of curing could be assessed in a Weger curve (Magnusson, 1939, pp. 257–259: Nylén, 1948, p. 653). The length of the induction period (i.e., before any change is detectable) is dependent on the purity and the siccative content since it determines the initiation of oxygen absorption. During the second stage, the oxidation of the unsaturated fatty acids continues and the adherence point is reached. During the third stage, the film gets tacky. During the fourth period, the weight increase reaches its maximum and the film is no longer tacky (it is *dust-dry*). If a glass rod is slowly pulled over the film does not result in a continuous indentation but a line: the moment of *point-drying* has been reached. This stage determines the adherence of the film, to the substrate. The relative weight increase to this point is termed "the weight increase value". During the fifth stage, the film dries through and starts to age.

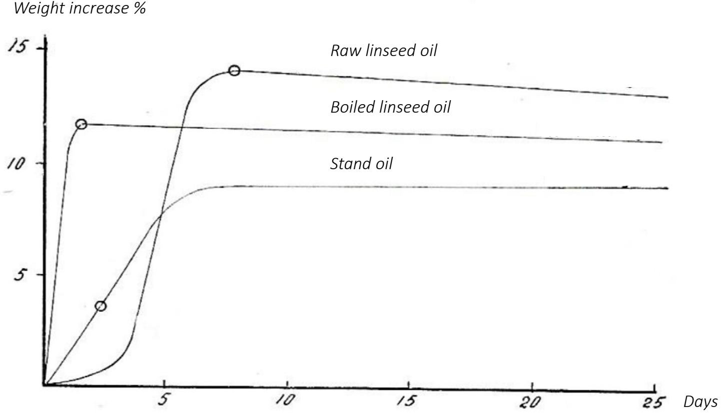


Figure 20: Weger curves, showing the weight increase during drying for raw linseed oil, boiled linseed oil, and stand oil (Nylen, 1948, p. 654). The circles indicate when the film gets tacky (the adherence point). Translated by the author.

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[32] For Weger's glass plate method, 9 x 12 cm glass plates are used, with the addition of three droplets of liquid varnish (3 mg oil per cm2) on both sides of the short half line, applied with fingers along and across to uniform thickness (Sandberg, 1926, pp. 10–14: Magnusson, 1931, pp. 37–38: Magnusson, 1939, pp. 257–259). The plate is placed horizontally and is allowed to dry at 20°C (18–23°C) in diffuse day light for 4 days in summer and 6 days in winter. The weight increase is measured every half an hour during the induction period and then every hour until it is dry, then once a day, identifying five drying stages in total. The relative weight increase to this point is termed 'the weight increase value'. When a glass rod that is slowly pulled over the film does not result in a continuous indentation but a line, the moment of point-drying (almost dry) is reached.

In the interface of the two last stages (the elasticity is decreased and the film starts to crack), there is a critical region of re-softening due to the ratio of the high and low dispersed phase. Too high a level of siccative or very strong sunlight may result in solid films that are too soft. Some standardised methods for drying stage assessments are described in Supplement 2.

6.2.2 The Quality of the Solid Oil Varnish Film

> *"Linoxyn is the most import fundamentum of all linseed oil paints and the product of the drying linseed oils".*[33] (Mulder, 1867, p. 97).

The solid linseed oil varnish film, formed from varnish that has been heat-treated and has had the addition of a litharge drier (3–4%), was termed *Linoxyn* by the pioneering Dutch chemist G. J Mulder (1802–1880) in 1867 (Mulder, 1867, pp. 78, 81–86, 92–102, 168, 182–184, 223–224: Mulder 1869, pp. 164–165: Andés, 1901, p. 10: Macintosh, 1904, pp. 23–24: Lowe, 1905, p. 9: Seeligman & Zieke, 1910, pp. 277–294: Fahrion 1911, pp. 244–252: Sabin,1927, pp. 2, 20-21, 35: Andersson, 1953, p. 40). The quote above describes the importance of the Linoxyn on oil varnishes and paints. Mulder's *Linoxyn* is described as a firm, transparent, and either translucent, whiteish, or with colour ranging from deep yellow to brown depending on the refinement of the linseed oil from which it was made.[34] The mass is an elastic, amorphous mass, with elasticity similar to leather or Gutta-percha (known as Caoutchouc or Indian rubber) (especially after swelling). Linoxyn is hygroscopic (after a long time of immersion, 4–8 days) but highly resistant to water and carbonic acid vapour. The specific weight of Linoxyn is larger than for water. It is insoluble in water, lime salts, weak acids, and carbon disulphide. Linoxyn is almost insoluble in ether and chloroform, petroleum naphtha, and acetone. The film becomes gelatinous by turpentine oil but is not (or almost not) dissolved. Solvents increase the transparency of the mass. When the rubber-like substance driers separately from the solvent it remains elastic and is friable between (rubbing) fingers, forming into particles that are not reunitable. The dissolved and reevaporated fraction resembles of cement. It is dissolved in ammonium, potash, or soda solution, but only after a long time of boiling, and it forms a red compound. When boiled in alcohol, or dissolved in strong hydrochloric acid, a red compound is formed. It is described as heat resistant, with a melting point close to 100°C. Mulder states that the key point of the formation lies in the reaction between linolenic acid and alkaline metals (*Metallbasen* – i.e., metal oxides that are alkaline in the presence of water, especially litharge) which forms soaps when the oil is heated to temperatures over 250 °C.[35] Linoxyn contains some saturated fatty acids, that Mulder concluded would enhance the elasticity of the film. The use of pyrolusite drier does not result in Mulder's desired Linox-

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[33] Translated from: *"Linoxyn ist die wichtigiste grundlage aller Leinölfarben und das Produkt des trocknenden Leinöls."*

[34] Varnishes are somewhat transparent, but black and almost opaque varnishes also exist (Bottler, 1912, pp. 176-177: Sabin, 1927, p. 2). Black oil varnishes are used as, for instance, as patent leather varnishes with iron blue pigments as drier.

[35] Later, Bauer and Hazura proved that the part of Linoxyn that is insoluble in ether is not an anhydride but glyceride, and that the film is a saponification product of linolenic acid and lead (Bauer & Hazura, 1888, pp. 455, 458). An anhydride is formed after long exposure to air or exposure to an elevated temperature.

yn. When in contact with light and from the influence of driers, Linoxyn transforms from an elastic state to a more brittle and hard state. Mulder states that the leather-like Linoxyn is the real basis of the valuable characteristics (such as durability, hardness, and elasticity) of all oil varnishes and paints. Boiled linseed oils – i.e., produced without the addition of driers are not appropriate for paint making due to their low drying power and brittleness. Blown oil varnishes are, in contrast to lead oxide varnishes, completely dissolved in petroleum ether (Seeligman & Zieke, 1911, p. 285).

The term *Linoxyn* has been used later, by many authors, to describe solely the solid film of linseed varnish in general terms (such as Andersson, 1953, p. 40). Most sources do not attribute the Linoxyn to lead oxide varnishes (or oxide varnishes). The term is associated with the thick product used for Linoleum flooring and with the pioneering invention of Walton (1863) and successors (Sabin, 1905, pp. 20–21: Mattson, 1939, p. 157).

The German chemist M. Bottler (1847–1929) and the British chemist H.C Standage (unknown biography) describe the requirements for high-quality varnish based on vegetable drying oils, which cures into a hard, yet elastic, transparent, and protective film (Bottler, 1912, pp. 1–7: Standage, 1892, p.143). First of all, the drying power should be high. The dry film must be uniform, hard and lustrous (glossy or shiny), and formed without cracks or other flaws. It should be sufficiently elastic to manage any bending of the (metallic) substrate. The film is durable and resists atmospheric exposure well. The French chemist A. Livache (1846–1902), was one of many, that researched the liquid to drying mechanism of linseed oils. He concluded that the drying power (i.e., drying speed) of drying oils is dependent on the purity and age of the oil, their storage conditions, the temperature of heating, and the addition of driers (Andés, 1900, pp. 132–133). Not only higher treating temperatures but also longer retention time will improve the drying power. Storage with or without air access will improve the drying power. The drying power is an important measure of the quality of varnishes. A drying time of 24 hours is commonly stated as a minimum criterion for a linseed oil varnish (Anonymous, 1856, p. 452: Andés, 1900, pp. 139–140, 265–268: Lueger, 1908, p. 134: Seeligmann & Zieke, 1910, p. 287: Fahrion, 1911, p. 207: Sabin, 1927, p. 117). This is also the case today (ISO 150:2006 and ISO 150:2018). It is desirable for varnishes to dry fast, but as a rule, varnish-makers consider that a slower drying rate will increase the durability (Sabin, 1927, p. 95). High hardness *and* toughness, usually anti-poles, could be achieved in a fat varnish by a skilled varnish-maker. Viscosity (body) and colour are other characteristics that are ruled by refinement treatments (Standeven, 2011, p. 18).

At the time close to the new millennium of 1900, a number of statements claimed that the qualities of Mulder´s Linoxyn had changed. In 1898, Trumann conducted outdoor tests on Linoxyn, with water exposure and on different substrates (Fahrion, 1911, pp. 246–249). The unpigmented film could last for a while but the conclusion was, of course, that a paint film lasts longer and that the performance of the paint film is dependent on the concept of the paint. If the pigment content is lower, the durability will decrease. Some years later, Dudley came to the conclusion that Linoxyn is water permeable, and the permeability decreases with increasing pigment content. Treumann, Dudley, and Weger (1898) conducted weight measurements versus time, in combination with varying RH, and they came to the conclusion that Linoxyn was strongly hygroscopic. Light exposure and air embrittle the Linoxyn, inducing, for instance, peroxides and hydroxyl-groups transforming to water released by hydrolysis. Mulder found out (at the beginning of 1900) that his definition of Linoxyn from 1867 had changed, and only 80% of the Linoxyn was insoluble in ether (in oil paint). It is not stated whether this was the new way of making varnish (*preparation varnishes*), but comparisons are made with linoleum manufacturing (using air-blown linseed varnish). Simon tested the water permeability of anticorrosive paint films applied to glass in 1897. The paints manufactured from linseed varnish (probably preparation varnishes) are described as soft, twistable, and elastic (Simon, 1897, pp. 286–287). By removing the paint films from the glass and observing the migration of added aniline dye on the backside, he could conclude that the paint films were permeable to water and gases, in a diffusion process reminiscent of the passage of a dialysis membrane. The water-saturated, swelling film is described as animal skin in appearance. He concludes that a ferrous substrate may therefore become sensitive to under-film corrosion due to dew formation or vapour exposure induced by temperature variations, and that a bodied paint with a higher concentration of binder is beneficial for the film's water penetration resistance if a proper adherence to the substrate is assured. Toch started a 17–month field exposure test in 1914 in order to study the deterioration of 52 binders for anticorrosive tests (Toch, 1915, pp. 592–595). Surprised, he states that despite an extensive literature search, he has not found any tests 20 years back on the anticorrosive paint binders (only on pigments). The varnish test was conducted close to New York. The film thicknesses were not measured (described as "*appreciable thickness*"). The substrate was cutlery steel, known for its rapid corrosion. A kettle-boiled varnish, and spar varnish managed the best; they were almost unchanged after the exposure, together with a bodied China wood oil.[36] The high-density, kettle boiled linseed oil (not to be confused with "average commerce oils" – i.e., preparation varnishes, blown oils) was made with the 5% litharge addition and the varnish-making took a day, resulted in a "*slow drying*" but long-lasting flexible film. Inappropriate binders in anticorrosive paints were concluded as raw linseed oils, resinated linseed oils, soya bean oil, and blown linseed oils. Toch state that the air-blown oils are *"not nearly as waterproof and resistant to severe weather conditions as that formed by boiled or polymerized oils".* Edwards states that linseed oils give quite permeable films, compared to spar varnishes (Edwards, 1936, pp. 125–127).

6.2.3. Refinement

The historical and modern descriptions of the refinement treatment of linseed oils are many, both consistent and differing. The basic steps follow the compiled scheme in **Figure 21**.

The quality of the produced linseed oil for varnish-making is not only dependent on the production process, but also seed types, climate, and soil (Fahrion, 1911, p. 208: Magnusson, 1939, p. 255: Richter, 1941, pp. 46–47). In a warm climate, the iodine value is decreased, or if the soil has been treated with lime, potash, or phosphoric acid (Magnusson, 1939, p. 256). In a colder climate, more of the linoleic and linoleic fatty acids are formed. The maturity and time of harvest both influence the water content of the seeds and the concentration of impurities that must be removed (Andés, 1900, pp. 132–133: Fahrion, 1911, pp. 46–47). Unripe and humid seeds produce an oil with a high concentration of gum, despite the clear appearance of the oil.

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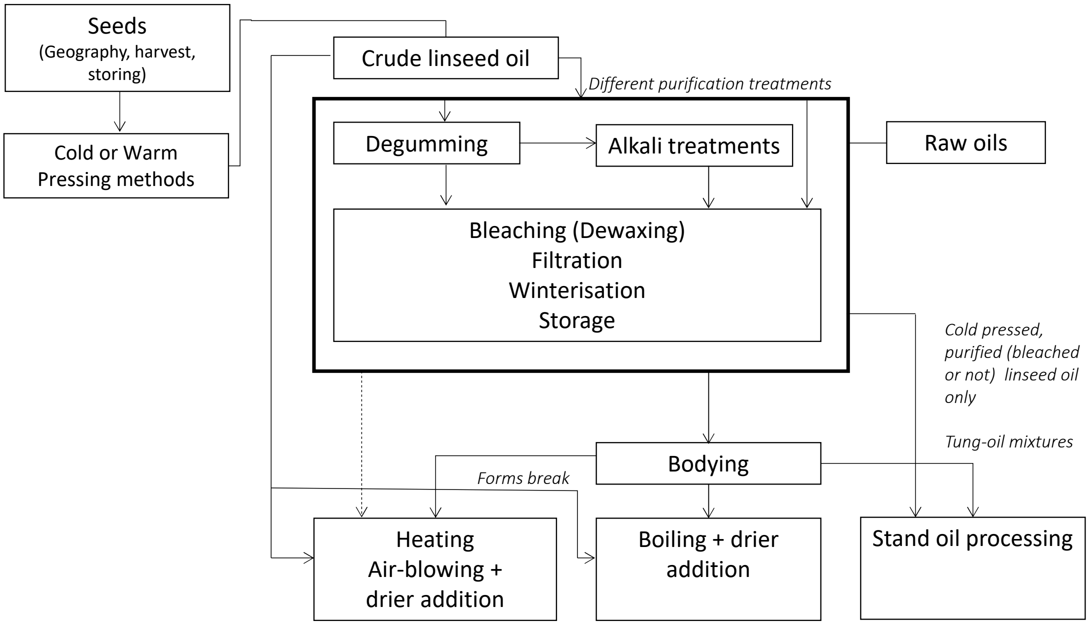
[36] Spar varnishes were typically used for tough exterior paints, such as marine applications (Singer, 1957, pp. 124-125). They usually consisted of a combination of co-polymerised heat bodied linseed oils and tung oils, possibly also with a resin addition.



References:
Bottler, 1912, p.76-81: Bergman, 1934, p. 84: Magnusson, 1939, p. 253-266: Richter, 1941, p. 48, 61-65: Nylén, 1948, p.647: Andersson, 1953, p 39-40: Andersson & Nylén, 1953, p.11-15: Stenberg, 2004, p. 3: Gupta, 2017: Watson, 2018.

Figure 21: The modern and historical production of linseed oils and varnishes follows a process flows similar to this model, but variations exist. The crude oil is cold or warm-pressed (oils extracted by steam and solvents existed also), today dominantly cold-pressed. Purified cold-pressed linseed oil was considered a luxury product in the 1930s in Sweden, and it was mainly used for the industrial production of fine varnishes and paints, including the refined varnishes for anticorrosive paints. The warm-pressed oil, produced into "boiled oil" was used for small-scaled paint making by architectural painters. Purified warm-pressed linseed oil (bleached or not) could be used for stand oil production in the 1930–1950s.

Further descriptions on this issue are found in Seeligmann & Zieke (1910, pp. 230–248), Jerer & Karlsdotter Lyckman (1995, pp. 12–19), Johansson et al. (2004, pp. 68–72).

For the Swedish production of linseed oil, linseeds were imported and pressed industrially (Magnusson, 1939, pp. 253–255, 262, 266: Nylén & Andersson, 1953, pp. 11–15). After storing and post-maturing at SOAB, the seeds are ground and screw-pressed. The cold-pressed oil is used for the production of special linseed oils, stand oils, and oils for lacquers and varnishes since they are purer. The raw material could be (hydraulically) pressed again after treatment with hot steam and solvents, to warm-pressed oil. The warm-pressed oil is used for "ordinary boiled oil" and linoleum fabrication. The cold- and warm-pressed oils are turbid after the pressing due to the content of gum and crop particles. Gum could be removed by various methods, such as winterisation, breaking (precipitation by rapid heating to 250–300°C), and cold storing as well as by centrifugation, filtering through bleaching earth or activated carbon. The cold-pressed oils were purified by hydration (water-salt flushing) and vacuum drying. The gum in warm-pressed oils was not removed in the 1930s since the sediment was used in putty paints and the impurities were considered as wetting agents, the gum repressed the turbidity and that commonly associated with the use of lead driers.

6.2.4 Purification Treatments

Purified and stored cold-pressed oils (linseed, poppy, or nut oil) should be used in the production of high-quality oil varnishes (Varrentrapp, 1848, p. 384: Seeligmenn & Zieke, 1910, p. 287). The oil should be pale and clear, mild and sweet-tasting, without a strong smell, and it should be old or stored (Winckler, 1859, pp. 77–78). Linseed oils cannot be used for varnish making without being purified. If the impurities are not removed, they will break during the heating stage connected to the boiling process. The impurities will then settle at the bottom of the kettle where they are charred, resulting in dark oil or varnish (Hausluck, 1905, pp. 20–27, 123, 154). If impure oil is used, this will result in a soft, slowly drying, and poorer quality varnish (Mathey, 1852, pp. 19–21: Wiederhold, 1866, p. 159: Fahrion, 1911, pp. 48–49: Richter, 1941, p. 53).

Despite this, ordinary “boiled linseed oils” were produced by heating warm-pressed linseed oils without purification, especially during and after the Second World War (Fallgren, 1934b, pp. 138–139: Magnusson, 1939, p. 254: Nylén, 1948, p. 647: Magnusson, 1949, p. 829). There were complaints from the traditional architectural painters about the quality and the purity of the cold-pressed linseed oil, which had been changed in the 1930s in Sweden, and the quality that was accessible in the market was described as far from that of the 1880s. The older oil varnish was described as “*fatter*” by older master painters. Fallgren blames the industrial production methods for this, especially the “*boiling*”. The old master painters claimed the reason for this was that a higher pressure during the pressing gained more impurities. In 1933 the IVA Corrosion Committee called for improvements of methods of the refinement of linseed oil seeds, that could have been damaged due to incorrect harvest or storage (shows higher acid values and lower iodine values than before). Extensive technical laboratory assessments at SOAB showed that the modern pressing resulted in a higher concentration of gum (*slem*) and antioxidants in the warm-pressed oils decrease the film quality and drying power, and increase the water sensitivity of the oil (see chapter 6.2.5). The gum also functioned as pigment wetting agents and repressed the turbidity due to the precipitation of liquid lead driers. The gum was not removed from the warm-pressed linseed oils since the sediment was used in the making of putty paints, but it appears as routines were introduced in the 1950s which saw the warm-pressed oil was filtered and stored in containers before boiling (Nylen & Andersson, 1953, p. 13). Gum is not allowed in the production of finer varnishes since it retards the drying and will result in veils and discoloration of stand oils (Magnusson, 1931, pp. 4, 9). Therefore, this was not the case for binder production for anticorrosive paints. This is relevant in order to understand the common picture that the oil varnishes from the 1920s were of poorer quality, which coincidences with the increased use of air-blown, so-called preparation varnishes that were heated to about 130–150°C (as described, for instance, by Karlsdotter Lyckman, 2005, pp. 89, 93).[37] This temperature was too low for the impuri-

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[37] Test programme of paints for wooden substrates, were conducted by Nylèn & Andersson from 1944 to early 1960s, including about 2000 paint concept combinations (Andersson & Nylén, 1957: Andersson, 1961). For wooden substrates, the absorption power and adhesion of the primer is different compared to metallic substrates, as well the use of pigments and VOCs. Still, best results were obtained for finishing paints with binder of “boiled” linseed oil and stand oil (app. 15%), which more than doubled the life-time compared to paint without stand oil. The stand oil results also in better out-floating of the paint film. Many of the tested paints show a substantial dilution with VOCs, which is known to produce porous paint films. There could be many possible explanations to many of the results: such as the blown oils, cobalt driers, VOC´s, wood quality. Despite the reports of bad performance of preparation varnishes with cobalt driers, this is not mentioned as a cause of the bad behaviour of oil paints on wooden facades in this the very extensive test programme.

fied oils' purification by precipitation during the heating process, as will be described in the following sections. Many varnishes at this time contained about 5% resins (added via the drier) and this was known to reduce the durability of the film (Magnusson, 1931, pp. 39, 40, 53). Cobalt driers were known to reduce the durability of the paint film. The quality of the preparation varnishes could vary. Depending on the varnish-making process, the preparation varnishes could be similar to the older lead and manganese oxide varnishes (as shown by the glass-plate method, described in chapter 6.2.8). The varnishes in the common market were not customarily the highly demanding anticorrosive paints, due to their lower level of performance. SOAB states that high-temperature boiled varnish with lead and/or manganese oxides driers, as well as stand oils, were used for anticorrosive paints and the raw material for this varnish was purified (Magnusson, 1939, pp. 264–265). Laurell describes that during the Second World War, the use of linseed oils and varnishes was highly regulated by the governmental industry commission (Laurell 1942, p. 157). He states that "*since the linseed oil must be considered as more irreplaceable for anticorrosive treatments than for architectural paint treatments, the building industry has been forced to seek for surrogates and make modifications*".[38] The use of linseed oil products was permitted only for the paint industry and for professional painters. For different anticorrosive treatments such as steel-sheet roofings, it was recommended that only the laps should be repainted in order to postpone the maintenance until the crisis was over. Rolf Hansen´s master painter's biography (1990) confirms that high-temperature boiled varnishes were accessible for painters, at least in Gothenburg where SOAB was located. This shows that varnishes with the highest levels of qualities were reserved for the anticorrosive paint treatments even during the war.

Types of impurities

Components of vegetable oils are separated into major and minor non-triglycerides (Gupta, 2017, pp. 11–18, 41–78). Examples of compounds in the major group are phospholipids, free fatty acids, diglycerides, and monoglycerides. In the minor group are compounds such as tocopherols and tocotrienols, sterols and sterol esters, colour compounds, trace metals, and triglyceride decomposing products. Some of these compounds are formed during processing or derived from the initial steps of processing. Phospholipids, called phosphatides or gums are essential in vegetable cell structures.[39] Gums may deposit in the handling of oils, and they can reduce the efficiency of other refinement operations and decrease the quality of the final product. Today, they are usually expressed as parts per million (ppm). The gums are categorized into five different groups, some hydratable or non-hydratable (not specified here). Hydratable compounds are removed by water treatments. Non-hydratable compounds are treated with acids in order to transform them into hydratable forms. Process variables include, for instance, oil temperature, the concentration of additions, retention time, and agitation in the tank. Free fatty acids (FFA) are formed from the decomposition of triglycerides during storage. FFA's could be formed during the crushing and handling of plant seeds or crude oil. Deterioration into FFA´s is always associated with mono- and diglyceride formation, having emulsifying characteristics. Tocopherols are natural antioxidants in vegetable

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[38] Translated from: *"Enär linoljan måste anses vara oumbärligare för rostskyddsmålningenän för måleriet inom byggnadsindustrien, har byggnadsindustrien i främre rummet fått se sig om efter ersättningar och vidtaga modifikationer".*

[39] Gums are often called mucilage, slem in Swedish sources.

oils, and there are four different types: alfa, beta, gamma, and delta tocopherols, with varying abilities to protect the oil from auto-oxidation (i.e., rancidification, initiated by the free radical formation of unsaturated fatty acids). Ɣ- and α-tocopherols protect against auto-oxidation that could degrade oils in absence of visible light. Trace metals (like Fe, Ca, Mg, Cu) reduce the storage lifetime of oils and are usually removed from oils by bleaching clay or the use of citric acid. Another group of effective antioxidants is tocotrienols. Sterols and sterol esters are antioxidants found in ppm concentrations. Colour compounds are usually carotenes and chlorophylls. Oils may dissolve 0,1–0,2 wt% water without any visible effect on clarity (van den Berg et al., 2004, p. 181).

Storing, standing to settle or to precipitate

By leaving the oil or varnish to stand in a container—i.e., being stored before and after other refinement treatment—a separation of unwanted phases could be initiated (Mulder, 1867, pp. 167–168: Fahrion, 1911, pp. 48–49, 208: Heckel & Carlbom, 1925, pp. 18, 35). The storing induces sedimentation of solid impurities and vaporisation of volatile compounds. Storing time varies. When oil is stored for one to two years, this results in a clearer and purer oil with increased drying power. As an example, a raw linseed oil that has been stored for four years (with access to air), will dry to a film within three days (Mulder, 1867, pp. 167–168). Storing could be made in many different types of containers: glass, metal, or pottery. Varrentrapp recommended storing in long and not so wide containers, preferably in the sun (Varrentrapp, 1848, p. 384). For smaller-scale production, other types of flat containers or cans, or wide glass bottles, covered by a loose lid such as a thin Pergamene paper are suitable, preferentially to be exposed to sunlight (Mathey, 1852, pp. 19–21: Wiederhold, 1866, p. 159: Fahrion, 1911, pp. 48–49). Many industrial bleaching methods are described by Seeligmann & Zieke (1910, pp. 254–266).

Winterisation

The oil could be generously mixed with snow or water, then left to freeze before separating the water in a hot place, and repeating this procedure several times (Varrentrapp, 1848, p. 384). A drawback of winterisation is that some of the unsaturated fatty acids are lost, such as linolic acid, and this will reduce the drying power (Magnusson, 1931, p. 7). Moreover, saturated fatty acids are lost, and this will reduce some of the elasticity of the dry film.

Mixing the oil with solids or liquids

Gum is water-soluble and is therefore often separated from the oil by water treatments (Carlyle, 1999, p. 70). The oil could be flushed with hot soft water (1:1), in a combination with continuous agitation (Mathey, 1852, pp. 19–21: Varrentrapp, 1848, p. 384: Sabin, 1927, p. 33: Magnusson, 1931, p. 9). The gum floats on the oil and can be separated from it, with or without an addition of common salt to form a brine. Moreover, the addition of Na/Ca/MgCl under intense agitation and following retention time for separation is very efficient. The turbidity may be removed by adding calcinated iron or zinc sulphate, which also acts as a drier. The procedures are often repeated several times. Gum could be separated by mixing the oil with cold water and alcohol (Anonymous/Livache, 1883, p. 302: Fahrion, 1911, p. 50). The gum forms an emulsion with water and could be separated by repeated shaking of oil and water, as reported by Sheldrake in 1799 (Carlyle, 2000, p. 30). Washing the oil with water removes antioxidants and produces a more crosslinked structure, with fast-drying (Bonaduce et al., 2012, p. 12). Sulphuric acid was and is still used as one of the most important washing chemicals used for removing free fatty acids. Mulder experienced that linseed oil that is treated with sulphuric acid for 24 hours and where the acid is removed with water, dries faster (Mulder, 1867, pp. 145, 182). The acid procedures involve agitation of the oil with strong sulphuric acid, followed by resting time (usually 1–12 hours) (Tingry, 1830, p. 168: Varrentrapp, 1848, p. 384: Mathey, 1852, pp. 19–21: Mulder, 1867, pp. 145, 188–190: Andés, 1900, pp. 132–133: Hausluck, 1905, pp. 20–27, 123, 154: Seeligmann & Zieke, 1910, p. 354: Bottler, 1912, pp. 40–41: Sabin, 1927, pp. 40–41). Diluted potash or caustic soda may be used in connection with the acid treatment, which will improve the drying power. The acid treatment may be combined by treatments containing Fuller's earth, lime, and water. Crushed or new burnt charcoal is mixed with water (1:30) and agitated for 10–12 days for purification of the oil (Wiederhold, 1866, p. 159). The oil is then filtered through a linen cloth. Combined purification or sedimentation and bleaching are beneficial for making almost colourless varnishes (Bottler, 1912, pp. 40–41: Sabin, 1927, p. 41: Singer, 1957, pp. 13–15). For this iron or lead sulphate is added and intermittently shaken in containers stored in sunlight for four to six weeks. By treating raw linseed oil with alkali, free fatty acids are neutralised and soaps are formed. When water is then added to the oil, and a "break" (a mixture of the water-soluble soaps and gum) is formed and settled, and the break could be separated from the oil by filtration. The resulting oil has a low acid number and could be used with any pigment without interacting reactions. The alkali refined oils are refined further into kettle-bodied (-boiled) oils. The described treatment procedures are numerous.

Breaking

Rapid heating of oil to temperatures exceeding 175°C, will break out and coagulate impurities in a frog spawn-like manner, and thus could be separated from the oil (Andés, 1900, pp. 143–144: Bottler, 1912, p. 313: Fahrion, 1911, pp. 48–49: Nylén, 1948, p. 647). This phenomenon is referred to as "*breaking*" (*brytupphettning*) in the technical literature. Since warm-pressed linseed oils contain more impurities than cold-pressed oils, breaking is more common for this type of oil.

6.2.5 Bodying Treatments

> *"By boiling, any drying oil´s drying power could be improved and its gloss enhanced, the higher boiling temperature is used, so that it finally will start to burn, and perform the effect of boiling for as long a duration as possible."* [40] *(Mulder, 1867, p. 168).*

Two major principal methods are used for giving the drying oils a higher viscosity or a body—*air-blowing or heating*— and they are most often combined (Standeven, 2011, pp. 18–19: Singer, 1957, pp. 15–17). Air-blowing promotes pre-oxidation and heat exposure promotes pre-polymerisation (cross-linking). Neither of these methods alone is sufficient for producing

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[40] Translated from: "*Durch Kochen wird dann jedes trocknende Oel mit einem grössern trocknenden Vermögen ausgerüstet und wie es scheint um so grösser, je länger man bei höherer Temperatur kocht, so dass man für gewisse Zwecke schliesslich das kochende Oel in Brand gerathen lässt und dies einige Zeit forsetzt, um den Einfluss des Kochens so stark als möglich aufzuführen.*"

well-functioning varnishes (Vincent, 1871, p. 67: Anonymous, 1898, p. 284: Fahrion, 1911, pp. 211–213.). Driers are needed in combination with the principal methods in order to catalyse the auto-oxidation reactions, otherwise the drying power would be impractically low. The levels of pre-polymerisation and pre-oxidation (catalysation) influence the kinetics of the final drying and solid film (gel) formation. The holding temperature and time determine the level of the liquid´s heat-induced polymerisation, and the liquid´s pre-oxidation is determined by the oxygen reactivity. Polymerisation produces molecules with dominantly carbon-carbon bonds, and these are more stable and stronger than the carbon-oxygen bond that is produced by oxidation (Andersson, 1953, pp. 39–40, Johansson et al., 2004, pp. 78–80). UV-radiation could contain so much energy that a radical polymerisation may be induced. It is only the unsaturated fatty acids that are involved in the polymerisation and oxidation processes. Saturated fatty acids react very slowly. The use of lead compounds as driers is a very old technique, and it forms lead-linoleates, as already stated in the nineteenth century (Standage, 1892, p. 144).

Heat bodying of drying oils is conducted in metallic kettles of varying sizes; from small batches of a few litres over an open fire, to electrically heated closed vessels containing several cubic meters (Power, 1950, pp. 468–472). The holding temperature is usually 230–330°C, depending on the oil type, its state of conjugated fatty acid arrangement, and the desired viscosity. For paints and varnishes for outdoor use, the weathering resistance is considerably improved for bodied oils than for unbodied oils. In order to start the radical chain reaction, a certain amount of oxygen is first required, but the sites of oxygen bonding are initiation points for deterioration. Therefore, bodied and polymerised oils reduce the need for oxygen (for auto-oxidation) and improve the stability and durability of the paint or varnish. It is beneficial to use already bodied oils for the under-cooling of superheated oils during the heating process. The arrangement of which fatty acids that are attached to glyceride is considered to have a minor impact on the results. With the increasing temperature, double bonds migrate and form conjugated molecules (i.e., *isomerisation*) that are far more reactive than non-conjugated fatty acids. The conjugated double bonds are transformed into cyclic reaction products with six carbon atoms and one double bond. When glycerides are added, the viscosity increases. At a given temperature, the viscosity is almost logarithmically proportional to time. In natural oils, with monounsaturated fatty acids, the molecule size can reach only a certain point. Over-heating (over 300 °C) may result in exceedingly large molecules and the formation of an insoluble and infusible gel. Powers states that if two-thirds of the fatty acids in the oil are not reactive, the oil is not considered as a drying oil (1950, pp. 468–472). Tung oil, with its high concentration of conjugated, tri-unsaturated fatty acid, is the most reactive of any drying oil. Some compounds, *catalysts*, accelerate the bodying rate of oils, as already mentioned. Isomerisation is usually a rather slow stage and if it is accelerated, the total treatment is accelerated. Compounds that strongly accelerate the polymerisation are different quinones, sulphur dioxide, aluminium chloride, sulphuric acid, and other acids, and boron fluoride.

In order to comprehend the numerous descriptions of varnish-making methods, the procedures after the maximum holding (treating) temperature are categorised and exemplified in **Table 4** and **Table 5**, where the references are stated. The procedures for varnish making are in many sources described as jealously kept secrets (Vincent, 1871, pp. 65–66: Sadtler, 1891, p. 70: Andersson, 1939, p. 68), and there must, of course, have been a great number of varieties. Suida & Salvaterra (1931) and Bottler (1912) provide useful descriptions of varnish making, including equipment and terms.

The boiling temperature (T_B) of linseed oil is stated in many sources as about 285°C (for instance, Karlsdotter Lyckman, 2005, p. 33). Practically, the boiling temperature is so close to the auto-ignition point (341°C), that the boiling point does not really exist (Kneepkens, 2021, n.p.: Johansson et al., 2004, p. 73). Before this point is reached, the oil is pyrolysed. The following description of the varnish-making procedures stipulate a boiling temperature of 285 °C and states the different methods relative to this. It starts with the oldest, and the references are stated in **Table 5**, unless otherwise specified. The terms refer mainly to those used in Bönisch, Chwala & Grün, 1937 (p. 216) and Suida & Salvaterra, 1931 (pp. 62–67).

Table 4: Classification of oil varnish-making procedures and varnish types

Type	Holding temperature (T_H) in relation to boiling temperature T_B	Term
1	Room temperature or < 100°C: 0.1–0.3 $\cdot T_B$	Cold prepared varnishes
2	120–150°C: 0.4–0.5 $\cdot T_B$	Preparation varnishes or blown varnishes
3	150–200°C: 0.5–0.7 $\cdot T_B$	-
4	200–285°C: 0.7– 1 $\cdot T_B$	Fire/kettle boiled varnishes or oxide varnishes
5	280–330°C: 1– 1.15 $\cdot T_B$	Stand oils and stand oil varnishes

Type 1: Cold prepared varnishes

The procedure of keeping raw linseed oil in containers for a time, in order to improve their performance, is very old (Rothstein, 1856, p. 247: Winckler, 1859, pp. 77–78: Cronqvist, 1871, p. 102: Linder et. al., 1881, p. 1161: Stadtler, 1891, p. 102: Fahrion, 1911, p. 106: Standeven, 2011, p. 19). During this procedure, impurities will settle and can be separated, and the body of the oil increases, which will improve the drying power of the oil. If the container is made of glass, the oils are affected by the energy transmitted by sunlight/photons and the retention time could be for several months or longer (preferably in summertime). The photon/energy exposure will bleach the oil, improve the drying power and increasing the viscosity. Moreover, the gloss of the solid film increases. The increased drying power is amplified when different types of driers are added. The container may be of lead, or the oil could be stored in contact with pieces of a metal, which improves the drying power. Further, drying power of a paint may be improved by mixing type 1 varnish with catalysing pigments. There are similarities between the cold-prepared, intensively sun-bleached varnishes, fire-boiled oxide varnishes, and stand oil varnishes, types 4 and 5. Sun-exposure could also be practised after bodying treatment.

Examples:

Linseed oil is mixed with about 10 wt% of lead acetate and left for eight days (Varrentrapp, 1848, p. 390.) Water may be added (it will vapourise). The varnish becomes almost colourless and thin, and dries slower than lead oxide varnishes. Litharge and oil are mixed and agitated two to three times a day over a period of two weeks, without heating (Tingry, 1830, pp. 157–167). A pale varnish is produced by maceration of linseed oil in lead acetate (Meyer, 1906, p. 589). Lead acetate may be pre-mixed with oil or varnish and added at temperatures like 30–40°C, under constant agitation for several hours (Sabin, 1927, p. 116). Litharge may be added in the same manner.

Table 5: Overview of oil varnish-making procedure types.

Type 1A: 0.1 · T_B	
Holding temp.	Room temp. or slightly elevated.
Retention time	3–14 days to months or years.
Driers	Litharge, massicot, red-lead, lead acetate, metallic lead, white lead, pyrolusite, Mn borate, Mn oxalate, slaked lime, alum, copper acetate, potassium -permanganate, zinc/iron/copper or lead sulphate.
Auxilary	May have additions of acids, water, salt, chalk, ash, sand, urine. Sun exposure.
Benefits	Combined purification. Easy method. Slightly bodied. Flexible use. Pale. Driers that are sensitive to thermal decomposition may be used. Improved drying compared to raw oil. Use with catalysing pigments for increased drying power.
Drawbacks	Softer film and slower drying than for heat-treated varnish.
Comments	Probably the oldest method. Used also without additions. Containers of clay, metals, glass. Intermittent agitation. "Cold varnish making".
Sources	Smith, 1687, p. 20: Gütle, 1799, pp. 11–18: Varrentrapp, 1848, p. 390: Anonymous, 1856, p. 452: Rothstein, 1856, p. 247: Widerhold, 1866, p. 159: Mulder, 1867, pp. 143, 165: Cronqvist, 1871, p. 102: Linder et al., 1881, p. 1161: Sadtler, 1891, p. 102: Meyer, 1906, p. 589: Seeligmann & Zieke, 1910, pp. 251–252: Bottler, 1912, pp. 40–41: Sabin, 1927, pp. 15, 33, 35–36, 116: Kjellin, 1927, p. 303: Gaugin, 1947, p. 243: Carlyle, 1999, pp. 70–71, 73–74: Carlyle, 2000, pp. 32, 41–44: Standeven, 2011, p. 19: Vigureie, 2016, pp. 47–49.
Type 1B: 0.3 · T_B	
Holding temp.	< 100°C
Retention time	2 hours to years.
Driers	Litharge (silver/gold), metallic lead, photons (light). Also manganese borate, borax, or lead white.
Auxilary	Sulphuric acid, iron sulphate, water. With/with-out air access.
Benefits	As Type 1A. Especially pale. Bodied. Oxidised if air-access. Good drying power. Glossy films. Elastic films.
Drawbacks	Long retention time.
Comments	Glass containers. May be intermittently agitated. Artist purposes. "Sun bleached oil/varnish"
Sources	Gütle, 1799, pp. 11–18: Barruel ,1853, p. 376: Rothstein, 1856, p. 247: Jünemann, 1865, p. 460: Mulder, 1867, pp. 148–154, 174–179, 203: Linder et. al, 1881, p. 1161: Andés, 1900, pp. 190–191: Fahrion, 1911, p. 208: Sabin, 1927, pp. 35–36, 116: Carlyle, 1999, pp. 71–72: Johansson, et al., 2004, p. 80: Vigureie, 2016, pp. 47–48
Type 2A: 0.4–0.5 · T_B	
Holding temp.	120–150°C.
Retention time	1-8 hours.
Driers/ Auxilary	Pb/Mn/Co compounds in liquid oleates /linoleates/ resins may also be added to at room temperature. 1.5–5% resins. 0.3% Pb, 0.02–0.05% Mn or Co. Lead acetate, manganese borate, Ca/Ba/Cu/Zn resins. Air- blowing.
Benefits	Bodied. Pale. Pre-oxidised. Rapid drying (24 h). Smooth paint films. (Gloss and luster, usually after storing). Increased viscosity /gelation during storing (may be good/bad). Good wetting to pigments, used for emulsions.
Drawbacks	Less viscous. Soft film. Hydrophilic/polar. Strong imbibition, swelling. Less elastic films. Sagging risk. Settling risk. Yellowing risk. Could turn to jelly when stored for a long time. Films swell heavily with moisture. Saponifies less. Risk of premature embrittlement of films. May be very sensitive to UV-light.
Comments	"Unboiled linseed oil varnishes". "Cold prepared varnishes"." Blown oil". "Double boiled linseed oil/varnish". "Linolate firnisse". "Resinat firnisse". "Siccativated raw linseed oil" (when not heated). ca 1885/1890 ff. ca 1885/1890 ff.
Sources	Varrentapp, 1848, pp. 385–390: Anonymous, 1898, pp. 283–287, Bottler, 1898, pp. 70, 72: Andés, 1900, pp. 130–131, 138: Anonymous, 1902, p. 140: Hausluck, 1905, pp: 20–27, 123, 154: Lueger, 1908, p. 134: Seeligmann & Zeke, 1910, p. 252: Fahrion, 1911, pp. 32, 188–191: Kjellin, 1927, p. 303: Sabin, 1927, pp. 42–43, 117–118: Suida & Salvaterra, 1931, pp. 62–64: Magnusson, 1931, p. 20: Magnusson, 1939, pp. 260–262: Crebert, 1939, pp. 674–675, 686: Nylén, 1948, p. 648: Strömberg, 1948, p. 388: Andersson, 1953, p. 39: Westholm & Bergman, 1965, p. 3: Fischer, 1966, p. 469: Bieleman, 2002, pp. 184–188: Standeven, 2011, pp. 18–19.

Cont. Table 5.

Type 2B: 0.4–0.5 · T_B	
Holding temp.	120–150°C
Retention time	A few hours.
Driers/ Auxilary	Pb/Mn/Co- naphtenate (liquid) octates, neodecanoates, ethyl-hexanoate and other acids, Co/Mn/Ca/ Zr driers. 0.02–0.3 wt %
Benefits	As type 2A.
Drawbacks	As type 2A.
Comments	As type 2A. ca 1925–1930 ff.
Sources	Nylén, 1948, p. 648: Strömberg, 1948, p. 388: Singer, 1957, pp. 45–46: Fischer, 1966, p. 469: Bieleman, 2002, pp. 184–188: Johansson et al., 2004, p. 74: Schnall, 2012, pp. 39, 41
Type 3: 0.5–0.7 · T_B	
Holding temp.	150–200°C.
Retention time	1-8 hours.
Driers	Pb, Pb-Mn, Zn, Zn-Co dissolved in oil or liquid fatty acids, resins. Manganese borate.
Auxilary	Air-blowing. Steam
Benefits	Few descriptions. Very pale if heated by steam. Lowered temperature compared to type 4.
Drawbacks	-
Comments	”Unboiled linseed oil varnishes”. “Metall-resinat-firnisse”. ca 1885 ff.
Sources	Anonymous, 1856, p. 452: Bottler, 1898, pp. 70–72: Andés, 1900, pp. 139–140: Hausluck, 1905, pp. 20–27, 30–31, 154: Bottler, 1912, pp. 338–339: Sabin, 1927, p. 116: Suida & Salvaterra, 1931, pp. 62–64, 76–81: Magnusson, 1931, pp. 31–33: Nylén, 1948, p. 648.
Type 4A: 0.65–1 · T_B	
Holding temp.	180–285°C.
Retention time	2–48 h.
Driers/ Auxilary	Litharge (1–2, 3–4, 2.5–8 wt%, 1–20 wt%), red-lead, lead acetate, lead nitrate, lead borate. May be further additions of metallic lead or tin, white lead, zinc sulphate, zinc oxide, iron oxide. Combined Pb-Mn driers were also used. Driers are solid, pulverised but may also be liquid, dissolved in oils, fatty acids, or resins. Occasionally combined with air-blowing in order to reduce processing time.
Benefits	Bodied. Sticky (like plaster). Pre-polymerised. Excellent drying, usually overnight or even at 8 hours. High gloss. Colour retention. Smoothing. Weathering resistance. Hydrophobic. Long-term elasticity. Less hygroscopic/ low swelling when immersed. Dries into Mulders’ “Linoxyn”.
Drawbacks	Varying characteristics. Turbidity risk. Charring risk. Dark varnish. Loose gloss rapidly. May gelate heavily with alkaline pigments if acid value is high or there is too high a concentration of drier; therefore preferred alkaline treated oils as raw material.
Comments	“Oxyd-firnisse”/Oxide varnish. “Lead varnish”. “Kettle-boiled oil”. “Fire-boiled oil”. “Double boiled linseed oil/varnish”. Most common type until ca 1885 in Austria, 1890 in Sweden
Sources	Smith, 1687, pp. 38–39: Kunckel von Löwenstern, 1707, p. 20: Gütle, 1799, pp. 11, 25, 44–48: Tingry, 1830, pp. 105, 157–167: Varrentrapp, 1848, pp. 385–388: Mathey, 1852, p. 6: Chevreul, 1852, pp. 57, 135–136: Anonymous, 1856, p. 452: Rothstein, 1856, p. 247: Winckler 1859, pp. 77–78:Mulder, 1867, pp. 148–154,172–174, 177, 179, 182, 203: Linder et al., 1881, p. 1160–1162: Cleve, 1883, p. 112: Sadtler, 1891, pp. 95–97: Standage, 1892, p. 167: Anonymous, 1898, p. 283: Andés, 1900, pp. 130–132, 139–140, 178–179, 190–191: Anonymous, 1902, p. 140: Hausluck, 1905, pp. 123–126: Meyer, 1905, p. 589: Lowe, 1905, pp. 29, 32: Meyer, 1909, p. 462: Seeligmann & Zieke, 1910, p. 287: Fahrion, 1911, pp. 182–185, 208: Bottler, 1912, pp. 76–83, 158: Heckel & Carlbom, 1925, pp. 38–38: Kjellin, 1927, p. 303: Sabin, 1927, pp. 19–20,44–45, 117: Suida & Salvaterra, 1931, pp. 62–64: Magnusson, 1931, p. 30: Bergman, 1934, p. 87: Magnusson, 1939, pp. 260–262: Gaugin, 1947, p. 243: Nylén, 1948, p. 648: Singer, 1957, p. 16: Vigureie, 2016, pp. 47–49

Cont. Table 5.

Type 4B: 0.65- 1 · T_B	
Holding temp.	180–285°C.
Retention time	2-15 hours.
Driers / Auxilary	Pyrolusite (1–2.5%, 5, 10–15 wt%), umbre, manganese oxides/ hydrate/ carbonate/ borate/ oxalate/ sulphate/ nitrate, ferric oxide, combined Pb-Mn, zinc oxide. Driers are solid, pulverised but may also be liquid, dissolved in oils, fatty acids, or resins.
Benefits	As type 4A. Often used for pale/white paints. Borate or hydrate produces the palest varnishes. Less addition is usually needed compared to lead compounds.
Drawbacks	Varying characteristics, many common to above. Varnish could be pale or dark.
Comments	"Linseed oil varnish". "Kettle-boiled oil". "Manganese varnish". Oxide varnish. Most common until 1885 in Austria, 1890 in Sweden. Still used in the 1940s. Manganese borate from 1864, common in the 1890s and ff.
Sources	Chevreul, 1852, p. 57: Anonymous, 1856, p. 452: Anonymous, 1864, pp. 165–166: Mulder, 1867, pp. 172–173, 182: Sadtler, 1891, pp. 95–97, 102: Andés, 1900, pp. 130–132: Anonymous 1902, p. 140: Hausluck, 1905, pp. 123–126: Meyer, 1909, p. 462: Fahrion, 1911, pp. 208–209: Heckel & Carlbom, 1925, pp. 38–38: Kjellin, 1927, pp. 303, 671: Sabin, 1927, pp. 36–37, 44–45: Suida & Salvaterra, 1931, pp. 62–64: Bergman, 1934, p. 87: Magnusson, 1939, pp. 260–262: Nylén, 1948, p. 648: Singer, 1957, p. 16.
Type 4C: 0.7- 1 · T_B	
Holding temp.	200–285°C
Retention time	≥ 8 hours. Depends on the desired viscosity.
Driers / Auxilary	Driers added by the painter. Could also be used with catalysing pigments.
Benefits	Bodied.
Drawbacks	Dries slowly without driers or catalysing pigments.
Comments	"Boiled linseed oil". "Målarefernissa". 1100 ff.
Sources	Gütle, 1799, pp.9–10: Mulder, 1867, pp. 223–224: Fahrion, 1911, p. 207: Hawthorne & Smith, 1963. p. 28.
Type 5: 1,0–1,15 · T_B	
Holding temp.	280–330°.
Retention time	2 h to a few days.
Driers	Driers were not added or done by paint-makers. Also siccativated and/or air-blown variants.
Auxilary	Air/gas/steam blow. Siccative. Sulphur treatment. Tung oil additions.
Benefits	Highly bodied. High wetting capacity. Lower binder need. Weathering resistance. Hydrophobic. Gloss. Non-yellowing. Smoothing. Long term elasticity. Works with any pigments, no gelation risk. Air-blown have improved wetting capacity to pigments and may reduce the binder need by approx. 20%.
Drawbacks	Post-tackiness if not prevented by processing treatments.
Comments	"Stand oil". "Stand oil varnish". Dicköl. Bisöl. Bisfirnis. Linyl. Linylen. Oljelin. Factor oil. 1830 Holland. Industrial revival 1900–1920 ff. Quarter tung stand oil 1920 ff.Partial process pressure could be up to 4–5 atmospheres.
Sources	Varrentrapp, 1848, p. 390: Mulder, 1867, pp. 170–172: Fahrion, 1911, p. 18: Bottler, 1912, pp. 142–146: Sabin, 1927, p. 42: Suida & Salvaterra, 1931, p. 68: Magnusson, 1931, pp. 12, 27–29: Helmersson, 1996, n. p: Heideck & Leppin, 1933, p. 244: Magnusson, 1939, pp. 258, 260–264: Richter, 1941, pp. 61–65: Pihlblad, 1944, p. 150: Nylén, 1948, p. 651: Andersson, 1953, pp. 40–41: Singer, 1957, p. 16.

Type 4: Fire boiled/Oxide varnishes

High-temperature holding in combination with any oil-soluble solid, pulverised metal oxides, is an oil varnish making method that has been used for a long time and is considered to be archaic (Mulder, 1867. p. 79: Lindner et. al, 1881, pp. 1160–1162: Sadtler, 1891, pp. 95–97: Hausluck, 1905, p. 123: Bottler, 1912, p. 83: Uebele, 1913, p. 270: Magnusson, 1939, pp. 260–262: Powers, 1950, pp. 468–471). A temperature of at least 235–245°C is needed to produce well-drying varnishes according to Bottler. The heat/energy exposure results, as described, in conjugated molecular bonds and the oil becomes more viscous (with losing about 1/6 of weight, becoming "thick and glutinous"). This varnish is similar to stand oils, with high levels of elasticity, gloss, and resistance to sunlight and moisture. The drawbacks were that the drying power could vary depending on the solubility of the driers and heating temperature (and time) control. High temperature and/or air access at high temperature turns the oil dark. Boiling for too long at a high temperature results in a varnish that will not dry due to the formation of degeneration products. Charring—i.e., overheating of impurity break or settled driers – will darken the oil and reduce its quality. The presence of impurities may cause slow drying and weak varnishes. The level of free fatty acids and the formation of polymerised fractions could lead to gelation with alkaline pigments.

Examples:

Mulder states that *Leinölfirnis* – which has a good body, elasticity and drying power and therefore leaves nothing more to wish for, and which is also suitable for anticorrosive paints—should be boiled, in contact with air, with 3% red-lead or litharge for two hours (Mulder, 1867, pp. 148–154, 174–179, 203: Andés, 1900, pp. 190–191: Fahrion, 1911, p. 208). After cooling, the lead soaps and gum (*Schleim, slem*) should settle and then be filtered.

The industrial method of producing very pale varnishes varnish by heating with water vapour or over-pressure was patented by John Webster in England 1853 (Webster, 1855, pp. 457–458: Vincent, 1871, pp. 65–66). A covered copper vessel is filled up with preheated clarified oil by pumping from a separate tank. The interspace between the vessel and coverage is filled with water vapour, and the heating speed to boiling temperature is accelerated by the over-pressure of the vapour. The agitation of the boiling oil is conducted with roto blades and fumes are collected and transported out. The oil is skimming due to volume expansion, and the dark brown colour turns to pale yellow. The over-pressure is kept for half an hour to homogenise the temperature of the oil. Then the fine ground driers are added, mixed with oil, through the vapouriser that lets in air. If a dark oil is wanted, litharge is used. After four hours of treatment, the drier excess has sedimented and may be drained by a bottom pipe.

The "Hollandic boiling method" was dominantly used in Sweden until about 1890 but was still used by SOAB in Gothenburg right up until just before the Second World War (Magnusson, 1931, p. 30: Suida & Salvaterra, 1931, pp. 62–64: Magnusson, 1939, pp. 260–262: Singer, 1957, p. 16: Hansen, 1990, p. 7). The method was common in Germany in the 1930s and is also described as in use in the United States of America in 1959. The Swedish description of the "Hollandic method" is that cast iron kettles were filled with raw linseed oil to two-thirds and put over a fire. At about 100°C vivid foaming started, and the foam was removed. After the foaming ended, finely ground litharge/red-lead and/or pyrolusite were added under constant agitation and the temperature was increased to about 240°C. When the oil became more viscous, the temperature was increased to 280°C and heavier vapours were formed. The oil was heavily agitated until the gases disappeared and after three hours of boiling the varnish (so-called “double-boiled varnish”) was finished and the fire could die. When the oil was cold it was cast out in containers where it was stored until it was absolutely clear and glossy, similar to stand oil. Suida & Salvaterra describe that it was only pyrolusite that was used in the Hollandic, double-boiled varnish (1931, pp. 62–64). If the metal oxides settle at the bottom of the kettles, this may decrease the quality of the varnish, therefore agitation from the bottom upwards is instructed (Bottler, 1912, pp. 338–339). Charring and overheating must be avoided, for instance by supercooling the bath with type 1B or type 4 additions, avoiding any splashing to the vessel walls, and using temperature indicators or thermometers (Varrentrapp, 1848, p. 385: Bottler, 1912, pp. 83, 338–339).

So-called “German stand oil” was produced in enamelled kettles, with or without superheated steam, to produce very pale varnishes, known for their high gloss (Bottler, 1912, p. 158). This viscous varnish, produced from well bleached and purified cold-pressed linseed oil, produces films of high gloss, used as a varnish or in (enamel) paint.

Type 2: Preparation varnishes

New types of driers were introduced in Germany from the 1880s that did not require holding temperatures close to the boiling temperature (which was the custom, type 4) and with more accurate control of the drying times (Anonymous, 1898, p. 284: Sabin, 1905, pp. 20–21: Fahrion, 1911, pp. 127–128, 132, 211–213: Bottler, 1912, pp. 70, 72, 151–158: Uebele, 1913, p. 270: Magnusson, 1939, pp. 260–262: Mattson, 1939, p. 157: Richter, 1941, p. 48, Singer, 1957, pp. 16, 22). These driers are different metallic-oxygen compounds that are dissolved in media such as oils, fatty acids, resins, and later, naphthenic acids (tall oils). Many decades before this, the introduction of water steam or airflow had been introduced to the treatment of drying oils, such as the Linoxyn-making (air-blowing at 100°C) for Linoleum products by inventors such as Walton in 1860 and others. By blowing air through the oil, the reaction surface and reaction rate increase significantly and the induction stage in the drying process is eliminated. Air-blowing alone is not sufficient to produce a usable varnish. Over-blowing (i,e., blowing too long time) results in a varnish that has difficulty drying, is extremely insoluble, and which is too viscous, which adversely affects the varnish´s usefulness and applicability. The holding temperature is below the temperature that is needed for resulting in a break of impurities, and the raw oil must therefore be of high purity, but sometimes it was not purified. The presence of gums and other impurities may cause slow-drying, weak varnishes. It is the combination of pre-oxidation (by air-blowing and by the addition of driers) that makes the characteristics of this varnish type: a paler and less viscous varnish. This varnish type was also called “double-boiled” in Sweden (as the Hollandic method), or Germany *Präparatfirnisse*. The varnish needs to be stored at room temperature in order to increase the gloss and viscosity, but it is reported that too long storage may cause gelation. White paints yellow in darkness and moisture, and are sensitive to UV-radiation (it cracks easily). The dry varnish film and paint film swells heavily in water and absorbs moisture. Blown oils are frequently stated as being too soft to produce weather-resistant paint films. Blown oils usually wet pigments very well, and it is because of the wetting characteristic that these oils are also used for making emulsion paints.

Trials made by Magnusson show that practically no heat-induced polymerisation occurs at 150°C (1931, p. 31). This was confirmed by Kneepkens´ trials (2021, n.p.)

These varnishes were discussed at the German Association for Material Testing meeting in Frankfurt in 1897 (Anonymous, 1898, pp. 283–287). The numerous variants and their diversity in drying characteristics, falsified products, and the lack of relevant testing methods were in focus. The problem was especially relevant in the use of anticorrosive paints for the national railway. The commission decided to collect and analyse commercial anticorrosive paints and established that the experiences about these varnishes were ambiguous. The varnish produced by these "cold methods" is paler and not as viscous as those produced by older methods. Landolt claims these varnishes are to be considered as falsifications which are inappropriate for protecting ironworks, and that impurities that would normally be removed by heating (i.e., breaking), remain in the unheated oils (Andés, 1900, p. 141). Gardner described a fresh linseed oil varnish paint as a porous, water-permeable membrane, depending on the type and concentration of pigments (Gardner, 1910, pp. 18–19). Sandberg states that "boiled oils" should not be used for anticorrosive paint treatments on the Swedish Railway since they are too hygroscopic, especially during the drying stage (Sandberg, 1926, p. 34). Master Painter Fallgren states that these varnishes were inconsistent in quality and could not compete in technical characteristics with those made "traditionally" in Sweden (Fallgren, 1953, pp. 102, 105). The older linseed oil varnishes were described as "*fatter*". He states that some factories still make the older product that was used before, on request. Fallgren complains about the increased use of liquid siccative such as Xerotin, and that the old master painters considered a 2% addition (at room temperature) to be "*more than enough*".[41] He describes the difficulties in making puttying paint and points out that when hard-boiled, stored, or thick-oil (stand oil) is used, the problems with lacking emulsion between oil and glue are not there.

Examples:
In 1911, the resinate oil varnish at Sommelii (later SOAB) in Nacka was made by heating 5000 litres of raw linseed oil for one hour after it had reached 100°C (Magnusson, 1931, p. 32). 7 kg of litharge was added, and the air-blowing was reduced to a slight movement on the surface (retention time four hours). The air is shut off and 100 kg of lead resinate and 40 kg of manganese resinate are added. One hour after this addition, the air-blowing starts gently again for one hour. The oil is heated to 120–140°C for one additional hour and is then finished. The oil is constantly agitated during the entire procedure.

A high-class varnish in 1926 was prepared by Sommelii/SOAB in Nacka, by heating 5000 litres of raw oil to 100°C by steam (Magnusson, 1931, p. 33). Then an air-blow started, and the steam was turned off at 135°C, while the air-blow continued and the temperature exceeded 150°C. The air was turned off until the oil had cooled, and the intense air-blowing continued for seven hours. 95 kg lead resinate and 35 kg manganese resinate were dissolved in a separate furnace and added to the bath and agitated for one hour. The air-blowing procedure was random and the results varied (Magnusson, 1939, pp. 261–262).

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[41] Xerotin was introduced in Sweden by Wilhelm Becker in 1873 (Westholm & Bergman, 1965, p. 3). It was added by the painters at the time of painting. It resulted in a drying time of 4–5 hours instead of the typical 16 hours.

The following SOAB procedure was introduced for SOAB varnish making in about 1930. The steam is turned on when 3000 litres (of 5000) have filled the apparatus (Magnusson, 1931, pp. 31, 40, 72). The preparation pan is also filled with 50 litres and the steam is turned on, 50 kg Pb-Mn driers (crushed into 3 cm pieces). When the large pans reach 80°C, the air-blowing starts and is proceeded for exactly 80 minutes and should be as intense as possible. The driers (2.5 wt%) are added at 140°C and the batch is agitated for one hour at the highest possible temperature (156°C). The steam is turned off and the oil is tapped and samples are taken to the laboratory for testing the drying power and clarity, and so on. If the oils are heated until the hexabromide value is zero (renders so-called *stand oil character*), and then linoleate/resinate driers are added in batches, as quality as good as that of the oxide varnishes could be achieved (confirmed, for instance, by the glass-plate immersion method). It appears as the quality of this type of varnish may vary considerably.

Type 3: TH = 150–200°C: 0.5-0.7 · TB
This is process type could be described as a hybrid between types 2 and 4. If the oil contains gum, it will break at temperatures around 175 °C. Therefore cold-pressed and purified oils are preferred (Andés, 1900, pp. 139–140, 143–144: Fahrion, 1911, pp. 48–49: Bottler, 1912, pp. 76–81, 313: Nylén, 1948, p. 647).

Bottler explains that the products were called "unboiled linseed oil varnishes" (*ungekochten Leinölfirnissen*) and he refers to a material laboratory reigned by the German Painters Association in Kiel and by the researcher Amsel (Bottler, 1898, pp. 70–72). The metal resinate varnishes (*Metallresinatfirnisse*) are produced at a temperature of 150–180°C. The resinates use colophonium dissolved in warm-pressed oil as a base for the lead, manganese, and zinc compounds. The quality (drying speed, gloss, transparency, and durability) was described as equal to the varnishes and lacquers produced with ordinary methods (i.e., heating linseed or poppy oil with metal oxides to a temperature of about 225°C). The liquid driers could be used as additions at room temperature (Suida &Salvaterra, 1931, pp. 62–64). Varnishes produced by temperatures such as 180°C, and produce firm, untacky films with drying times of eight hours when applied on glass, are reported as extremely valuable for the production of anticorrosive paints (Cushman & Gardner, 1910, p. 273).

Examples:
Pulverise pyrolusite or umber pigments until ground as fine as gunpowder and half fill a water-pail with it (Bottler, 1912, pp. 338–339). Fill the rest of the pail with water and stir well, let it stand for about 7 minutes before carefully pouring off the water (repeat three more times with 4- and 2-minutes of contact time). Dry the powder by a slow fire under continuous agitation, and let it dry flat. Place purified, bleached linseed oil in an iron kettle and heat it slowly to 160°C, then add the manganese drier by slowly sprinkling it (80 gallons oil and 30 lbs drier). Stir for four hours, from the bottom and upwards so that the drier will not settle and burn at the bottom. Remove from the fire and continue to stir for half an hour. Can up the light brown varnish while it is still hot.

Stored and clean oil is usually used and is heated steadily to about 170–175°C (Bottler, 1912, pp. 76–81). Water vapour leaves as bubbles at 100°C. At about 150°C, the oil gets paler when colouring agents are decomposed. At 175°C, the gum breaks and is separated from the oil, and is partly decomposed by the heat. The oil is held at this temperature until the foam has vanished, and this usually takes 2.5 – 4 hours. Ground driers are added (usually manganese and/or lead compounds) when the foam is gone. The additions cause more foam and therefore this needs to be undertaken gradually. After the driers are dissolved, the varnish is ready to cool and settle. If a thin film is formed on the side of the kettle or partly over the oil surface, this is a good sign regarding the quality of the varnish.

Artificially aged and bodied oils were air-blown, with small effects on the drying power unless the air and oil were not heated (Sabin, 1927, pp. 42–43). "Ordinary" bodied oil is heated to 120–150°C with blowing of cold air. The vapourised air is evacuated through a steam jacket with a pipe. The heat caused by the exothermic reaction is controlled either by stopping the process or by using the steam-jacket as a heat exchanger in the temperature interval of 180–200°C. After a few hours, the oil will foam intensely, and this is whipped down or blown down with hot air. Steam-heated varnishes are very pale (Andés, 1900, pp. 139–140: Hausluck, 1905, pp. 30–31).

Type 5: Stand oils and stand oil varnishes

Fatty acids with conjugated double bonds could be treated to form stand oils, such as linseed oils, tung oils, and oititica oils or isomerised[42] or fire boiled linseed oil (Nylén, 1948, p. 655: van den Berg et. al., 2004, p. 182: Carlesi et. al., 2015, p. 866: Alves, 2015, p. 30:). The Diels-Alder reaction that takes place during the stand oil production process results in cross-linking and increase in molecule weight, high viscosity, and an increased acid number due to diene double bonds that are rearranged into a conjugated state of cyclic fatty acids with carbon-carbon bonds.[43]

Linseed stand oil was invented in Bennebroek in Holland in 1830 (Varrentrapp, 1848, p. 390: Mulder, 1867, pp. 168, 170–172: Linder et al., 1881, pp. 1160–1162: Fahrion, 1911, p. 111: Sabin, 1927, p. 42: Suida & Salvaterra, 1931, pp. 65–67, 270: Magnusson, 1931, pp. 28–29, 40: Magnusson, 1939, p. 832: Magnusson, 1939, pp. 263–264: Richter, 1941, pp. 60–61: Nylén, 1948, pp. 648–656, 716: Andersson, 1953, pp. 39–40: Standeven, 2011, p. 19). The term *stand oil* derives from Van Hopman, 1856. The English term is "burnt oil" and in German *Buchdruckfirnis, Lithographenfirnis* was used due to the initial primary usage of the oil. Book maker's ink is described by Varrentrapp as "short" – i.e., it should not be pulled off with a string formation but should still be very thick, and should not leave fat stains on a paper. Stand oils became more widely used in the 1920s. Purified and bleached raw cold-pressed linseed oil was most commonly used as raw material. The processing temperature for high-temperature treatments is about 250–320°C in covered metallic kettles with limited air access under a carbonic acid lid or in a vacuum. The duration of the process may last for several days. With an increasing process temperature, the risk of decomposing product formation increases, and this may result in stand oil with poor drying characteristics, long tackiness, and high brittleness—the varnish becomes "dead boiled". Originally, the stand oils were not siccativated, but when this was introduced, the term was linseed stand oil varnish (*Leinölstandfirnis).* A pale oil (that may

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[42] In the 1930s, it was discovered that saponification transforms double bonds into a conjugated state. With the treatment of an alkali and alcohol in combination with a high-temperature heat treatment, an isomerised activated linseed oil was obtained, which dries fast and has high water resistance (Nylén, 1948, p. 658). See the patent of Bradley (1941) for more information.

[43] Diene is a compound containing two double bonds between carbon atoms. Merriam-Webster Dictionary.

have a green tint) with high levels of viscosity and body (syrup-like) is produced and it dries to a high and long-lasting gloss. The characteristics of this oil are similar to the historically fire-boiled linseed oil. The characteristics of this oil are similar to the historically fire-boiled linseed oil. The stand oils dry slowly, but the films are very elastic. Siccativated stand oils are especially recommended for applications exposed to strong variations in light and temperature. Stand oil paint have excellent durability, and stand oil was used in high-quality outdoor paints, lacquer paints, and enamels, gloss oil additives, or as an addition to topcoat. Stand oils are used for priming on absorbent substrates, enamel paints, and anticorrosive paints. For anticorrosive paints, an addition of 20% of special stand oil to linseed varnish paints, is beneficial. Tung oil could be processed into tung stand oil, which is highly valued due to its water resistance. For tung oil, the heating temperature is lower than for linseed oils due to the high speed of gelation. A SOAB procedure of tung stand oil included a holding temperature of up to 240°C (when the desired viscosity is achieved the temperature is lowered to 200°C). Linseed oil and tung oil were also mixed in order to prevent the rapid gelation of tung oil, into a stand oil called thick-oil (*Dicköl*). By mixing linseed oils and tung oils in different proportions (typically 20–25% tung oil), useful compromises of drying rate, hardness, water resistance, and weathering resistance are achieved. SOAB´s special stand oils were made by adding 20–25% of tung oil to an ordinary linseed stand oil and the boiling process was continued until a suitable viscosity was achieved. This quarter tung stand oil was used as binders in armour paints. This was an oil mixture of 75% linseed oil and 25% tung oil, co-processed into stand oil.

SOAB received a license from Dr. Erich Asser to produce patented methods in 1936 (Helmersson, 1996, n. p). Asser was working at A/G Gustav Ruth Temperol-Werke, Chemische und Lackfabrik (Wandsburg, Hamburg). With his invention, the *Thermodux* cooler, it was possible to combine high-temperature treatments with, for instance, air-blowing. Examples of licensed methods that were transferred to SOAB are the following.

- *Olo*-linseed oil is made by heat-treating a cold-pressed, degummed oil at 300°C and air-blowing it. This results in a product suitable for the production of ready-ground paints since the oil absorbs or wets 20% more pigments than ordinary linseed oil, resulting in better hiding power and durability.
- *Bisöl:* a rapidly drying gas/air-blown stand oil, may be used with an added solvent such as white spirit (*lackbensin*) or turpentine oil, or without. It is sold by SOAB as *Linyl*, and siccativated as *Linylin*. Linylin could be used wet-on-wet, applied with a spray gun or brush, and reapplied within 1.5 or 4 hours respectively.
- *Bisfirnis* or SOAB´s *Oljelin:* a resin-free siccativated linseed stand oil, which is easy to apply (with 2–5% solvent concentration) and does not have any post-tackiness.
- Stand oil of combined linseed oil and tung oil, boiled with the *Thermodux* cooler.
- Special stand oils such as *Tidol, SOAB-Ol* (similar to tung oil), and *Apprimol*.

The air-blowing during the processing of Linyl causes a rapid reaction speed and heat formation with a simultaneous increase in viscosity (and acid value) (Magnusson, 1939, pp. 258, 263–264: Richter, 1941, pp. 61–65: Laurell, 1942, p. 159: Pihlblad, 1944, p. 150: Nylén, 1948, p. 653). It is explained that stand oils are considered as iso-colloids; the formation of cross-linked/ polymerised macromolecules (formation of the so-called *low dispersed phase*), that are dispersed in the surrounding medium of unpolymerised oil (dispersion medium), with high and low drying power respectively. The ratio between the phases determines the extent of waterproofing, elasticity, yellowing power, and tackiness. The air-blowing of Linyl reduces the un-polymerised phases in the stand oil process. A stand oil with a low content of un-polymerised phase is very pale, high levelling capacity, and dries into non-yellowing, glossy, and durable weather-resistant paint varnish (also for *Bisfirnis/Oljelin*). The drying power is better than that of stand oil and is similar to quarter tung stand oil. The process also creates conjugated double bonds. The characteristics correspond to those of stand oil, but Linyl dries faster, and it can be used in paint without solvents. Linyl is cheaper than stand oil and Linyl and Oljelin were used during especially demanding paint jobs, such as anticorrosive painting (like armour paints) or on surfaces exposed to tough conditions, such as railway wagons. Linyl and Oljelin have a substantially higher level of hydrophobicity than non-treated linseed oil but have a slight polarity. Linyl (and other air-blown linseed oils) have a high wetting power, which is beneficial in respect of the wetting of pigments which reduce the amount of binder needed to about 1/3—i.e., more than a 50% reduction in the total amount of binder needed. The increased wetting reduces the risk of crack propagation in connection with pigment/oil interface voids.

In the 1930s linseed oils started to be heat treated with sulphur- or sulphur-chloride compounds with inspiration from the Caoutchouc industry (Fahrion, 1911, p. 18: Suida & Salvaterra, 1931, p. 68: Heideck & Leppin, 1933, p. 244: Pihlblad, 1944, p. 150: Nylén, 1948, p. 651). The discovery was made by Henriques in 1893, and he named it as white or brown *Faktis*, a Caoutchouc surrogate. This produced an elastic binder, similar to stand oil, called *Factorfirnis – [factor varnish]*. The high drying power makes it possible to repaint wet-on-wet—in other words, only an hour after the first application. It was diluted with turpentine. Factor oil was used as a binder in anticorrosive paints. Factor oil was used as a linseed oil substitute mainly during the Second World War, and with this stand oil type, paint could be produced with a substantially lower binder need (15–17%, compared to 30–35% for industrial paints and 50% for paints manually produced by painters). Linylin and *Factorfirnis* were used as common painters′ varnishes (*målaroljor*) during the Second World War, beside blown linseed varnishes (Laurell, 1942, pp. 157, 159).

6.2.6 Driers

As has been earlier described, raw linseed oil with driers will form a soft, somewhat porous film in several days, while the addition of driers transforms it into a dense and firm film within a day.

Some basic requirements of driers (i.e., positive catalysts) are that they should be *soluble* in the liquid oil so that they can *transmit oxygen* to the unsaturated fatty acids (Singer, 1957, p. 47: Fischer, 1966, p. 469: Schnall, 2012, p. 38). By being oxidisable and *multivalent* they can accelerate both the repeated oxygen transmission to the organic molecules and accelerate the peroxide decomposition. They also counteract the influence of naturally occurring antioxidants (negative catalysts). Driers are metallic compounds, that are added in solid or liquid form to form carboxylic acids, metal salts/soaps of lead, cobalt, manganese, calcium, zinc (and glyceride), that catalyse the drying reactions. The formed soaps should be *water-insoluble* in the formed solid film, for usage in paints (Schnall, 2012, p. 38). Already in 1897, Weger showed that for each drier there is a maximum concentration that will give no further decrease in drying time (Fahrion, 1911, pp. 223–225). The drying time is proportional to the concentration, up to the maximum concentration plateau.

Driers change the reaction kinetic of the drying process for a specific oil, not the reactions themselves (De Viguerie et al., 2016, pp. 46–47). Driers strongly reduce the length of the induction period of drying, for instance, 5 wt% litharge has been found to reduce it by four times. Multivalent metals act as *surface driers*, with the ability to promote also reversible reactions from the paint surface and downwards through the layers. Examples are cobalt and manganese driers that tend to leave the subsurface soft. *Through-driers* promote drying effectively through the entire film, such as lead driers. These films are characterised by a good compromise in hardness, toughness, elasticity, and chemical endurance. Secondary, or *auxiliary-driers* favours phase cohesion during drying, having one potent oxidation state. These are known, for instance, zinc, calcium, potassium, lithium, or sodium compounds. Driers could also be classified whether they promote oxidation or polymerisation of the oil. The secondary driers promote polymerisation, the others primarily oxidation (primer driers such as cobalt and manganese compounds). Lead compounds are considered as promoting both. There are other classifications of driers.

Different generations of driers have been used, as described in **Table** 5. Detailed descriptions of driers can be found in, for instance, McIntosh (1904, pp. 84–93). The oldest types were added to the oil in solid form, in fine fractions. These compounds react when they dissolve and form soluble linoleates, oleates, and so on, and then act as driers (Singer, 1957, pp. 45–46: Schnall, 2012, pp. 38–40). The main types were lead and manganese oxides, but also different lead and manganese salts that form lead or manganese linoleates in the oil. They could be used solitarily or in combinations. When correctly used, these were very potent driers. The challenge of controlling the refinement process could lead to unreacted, settling driers that could not only not fulfil their function but could also be overheated— conditions that would lead to undesirable and non-reproducible results. This led to the industrial development of fused driers: the metallic compounds (mainly of lead, manganese, and cobalt) were dissolved in oils or free organic fatty acids (oleic acid, linolenic acids, resins) and then added in calculated proportions to the varnish-making process.[44] By this, the solving temperature was lowered, resulting in paler varnishes, bodied by air-blowing. The third generation of driers – precipitated by the double decomposition process— where a water solution of the metal drier salt/soap reacts with water-soluble solution (the latter consisting of a soluble metal salt of the fatty acid, another inorganic salt such as naphthenes/tallates, octoates, neodecanoates or other synthetic acids). The most common driers used in linseed oils today are cobalt and zirconium compounds (Johansson et al., 2004, p. 80). In the following, some of the most important driers are briefly described.

Lead compounds

Litharge and white lead were known for their drying effect on linseed and other oils in the second century, as described by Galen (Sabin, 1927, p. 36). In the fourth century, Marcellus advises boiling the oil over a fire with a little-by-little addition of well-ground litharge until the oil thickens. In an early twelfth-century recipe by Eraclius, oils should be boiled with

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[44] The making of metal soaps, such as manganese or lead linoleate are described for instance by Sabin (1927) and Braun (1932). Another good description of driers is provided by Fahrion, 1911, p. 185.

lime and ceruse (white lead) and places in the sun for several months or more, with frequent agitation (Merrifield, 1849, p. 232: de Vigeurie, 2016, pp. 47-48). De Viguerie states that oil varnish driers during the Renaissance were litharge, red- lead, or zinc sulphate. Manuscripts of the Swiss chemist Turguet de Mayerne (1573–1654) describe the frequent use of litharge as drier. The British clockmaker J. Smith describes how to make durable “Oyl paints” for outdoor use by boiling linseed or nut oil with litharge (Smith, 1687, pp. 38–39).[45] The French chemist M-E. Chevreul (1786–1889) published several scientific results where he described his experiments with oils and driers. In 1850 he discovered that a linseed oil applied on a metallic lead surface, will dry very fast (Chevreul, 1852, pp. 57–58: Andés, 1900, pp. 135–136). If a raw linseed oil is boiled without drying additions, this will not result in good varnish. If lead compounds are added to raw linseed oil, the drying power of the oil increases even without heating. The combination of heating with the addition of driers will result in an oil varnish and a painting medium with high drying power. The catalytic effect of lead was published by Livace & Weger in 1883 and 1889 as pointed out by Fahrion (1911, pp. 139–140). Chevreul noticed that the nature of the substrate affects the drying rate of the paint film; for instance, it is improved when applied on a lead or an existing paint layer (Chevreul, 1852, p. 57 ff). An existing paint layer absorbs oil from the over-painting and also provides it with siccative. The reason why the application to a metallic substrate such as lead increases the drying power is that the fatty acids dissolve in the interface and form lead-linoleates (Magnusson, 1931, p. 34). Recent research has confirmed the influence of catalysing substrate, which Chevreul had previously described (Fuster López & Mecklenburg, 2017, p. 97). The migration of metal ions between paint layers is especially prone when the layers are hydrolysed. Mulder concludes that red-lead is the best dryer, followed by litharge (Mulder, 1867, pp. 172–175, 208). He states that lead acetate will not give a good elastic varnish or paint. Lead acetate was usually added in low temperatures, in order to avoid the formation of acetic acid at higher temperatures (Fahrion, 1911, p. 183). Lead acetate was a common drier in artists´ oil paints (Carlyle, 2000, pp. 40–46). The drier is made by dissolving metallic lead in acetic acid (vinegar) and by evaporation of the liquid (Standage, 1892, p. 30).

Manganese compounds

De Mayerne describes additions of umbre to oils in 1622, in a letter correspondence with his brother (Sabin, 1927, p. 37). Cheuvreul was the first to scientifically state that varnish could be produced by the addition of pyrolusite (Mulder, 1867, pp. 172–173, 182: Andés, 1901, p. 9). He described that varnish boiled with litharge or pyrolusite will get a further enhanced drying speed when carbonated zinc oxide is added to the paint (of lead white). Manganese compounds are described as more potent driers than lead compounds. He stated that litharge and pyrolusite added together are more reactive than the pigments alone, and that these oxides added as pigments acted as driers even to boiled linseed oil when mixed to a paint. The use of lead oxides results in a more elastic but softer film, and the manganese oxide is a harder, firm film with more “snap and promptness” (Sabin, 1927, p. 117). The proportions of the driers may differ, but, usually, the concentration of lead oxides is about ten times higher than manganese

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[45] The German engineer J.C Gütle (1747–1827) from 1799/1800 and the British chemists and pharmacists P.F Tingry (1743-1821) also give descriptions about how to prepare a well drying oil of lead compounds such as litharge and red-lead for finishing purposes. (Gütle 1799, pp. 44–48.: Tingry, 1830, pp. 104–107, 157–167). Mathey (1852) and the German Chemist Varrentrapp (1848) describe boiling with addition of lead compounds.

oxides. Cheuvreul is considered as the introducer of Pb-Mn varnishes, though the breakthrough of this finding was published by Weger & Lippert in 1897. Japanners gold was an artist′s oil drier with a very high drying power, and it was described by, for instance, Field already in 1835 (Carlyle, 2000, p. 37). It consisted of a combination of litharge or red lead and burnt umber or manganese. Many types of Japanese driers existed, but they were considered too potent for use in anticorrosive paints, resulting in brittleness (Cushman & Gardner, 1910, p. 273). Liquid Pb-Mn driers (such as Xerotin) consists of lead and manganese oleate or resinate (2:5 ratio) in neutral linseed oil, and they can be diluted with turpentine or benzine (Heckel & Carlbom, 1925, pp. 13, 38–38).

The favouring of manganese borate (before pyrolusite) started in the 1860s, after the work of Barruel in 1853 (Barruel, 1853, p. 376: Anonymous, 1864, pp. 165–166: Mulder, 1867, pp. 171, 183–184). It is described as the most useful and efficient of all manganese driers (used in concentrations 0.01 to 0.15 wt%), resulting in a quick-drying and hard varnish with good resistance to moisture (Anonymous, 1856, p. 452: Standage, 1892, pp. 8, 16: Andés, 1900, pp. 137–139: Meyer, 1906, p. 589: Seeligmann & Zieke, 1910, p. 287: Bottler, 1912, pp. 45, 65–67: Sabin, 1927, p. 116). It is prepared by boiling iron-free manganese oxides with sulphuric acids and then mix this with a borax solution. There are also other procedures for the preparation. The borate is added as a powder or is mixed in oils. Manganese borate decomposes to boric acid at high boiling temperatures (used for the solving of lead and manganese oxide driers). Manganese borate is usually added at temperatures of ≤ 170°C, possibly in combination with air-blowing. A very pale, sometimes reddish varnish could be produced by short retention times, and the film dries to a hard within 24 hours.

Cobalt Compounds and Zinc Oxides

Carlyle states that cobalt is mentioned as a drier for artists’ oil paints by Riffault et al., in about 1852 (Carlyle, 2000, p. 52). Barruel (1853, p. 376) discovered that protoxides[46] of cobalt, manganese, and to some extent, iron, function as efficient driers in varnish making. Mulder reports that linseed oils that have been boiled with smalt (a cobalt glass), dry within 48 hours (Mulder, 1867, p. 185). Zinc compounds, such as oxide, sulphate, or resinate are used to produce pale varnishes, often in combination with manganese borate (Bottler, 1912, pp. 45, 65–67). The breakthrough for cobalt driers came when they were developed as oleates and resinates (Heckel & Carlbom, 1925, pp. 13, 36–38: Magnusson, 1931, p. 40).

Magnusson at SOAB describes extensive trials on cobalt, lead, and manganese liquid driers (linoleate, resinate) (Magnusson, 1931, pp. 34–48). All driers influence the quality of the film and its ability to absorb liquids such as water and solvents. He rejected all the resins since they embrittle the film and deteriorate rapidly. With the exception of the different basic behaviours of the driers (cobalt and manganese driers act as surface driers and lead driers as through-driers), they also have different solubilities in the oil, and therefore have different process temperatures. Lead driers are known for causing turbidity and sediments, especially in cold storage, while other driers did not. The manganese varnishes are described as unstable, unpredictable, and as drying unevenly, and after the application they tend to crawl into droplets. This phenomenon is called *Bocken* in German, “being stubborn”. The cobalt varnish-

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[46] The one of a series of oxides that has the smallest proportion of oxygen. Merriam Webster Dictionary. (Comment: This is an uncommon chemistry term today).

es produce the most ductile films (followed by manganese varnish), but they are easily embrittled by UV-radiation. The lead varnish films show no reduction in elongation but in tensile strength. The Pb-Mn varnishes had the most advantages, such as being fast and through-drying, with no discoloration of white paints (but they tend to turn white paints a greyish-white).

Zinc white, different compositions, and morphologies of zinc oxide was introduced in the 1780s in order to find substitutions for lead white (Andersson & Nylén, 1957, p. 10: Estaught et al., 2008, pp. 406–407: Standeven, 2011, pp. 34–36: Osmond, 2012, pp. 20–22, 25). Zinc oxide became common in the middle of the nineteenth century and was used in oil varnish paints. It transformed the ready-made paint industry due to its good suspension characteristics. Zinc oxide paints were especially appreciated for their bright, durable, and glossy finishes for indoor and outdoor use. Zinc oxide saponifies with fat oils and varnishes and is used as an additive for improving the weather-resistance of exterior paints due to its ability to protect against UV-radiation, though there are also reports on embrittlement and premature failure attributed to zinc oxide. Zinc oxide is an inhibitive pigment which is amphoteric (may neutralise acidic and alkaline surroundings), and it is therefore an important addition in anticorrosive paints. (Cushman & Gardner, 1910, pp. 164–175: Smith, 1981, p. 13: Osmond, 2012, p. 23). Zinc oxide is mainly used as a catalysing and zinc soap forming pigment in some linseed oil paints today, in additions of typically 10–15 wt%.

6.2.7 Tung Oil

> *"China wood oil is due to the great durability and water-resisting qualities of some of the best varnishes manufactured in the world."* (Vandermyn, 1921, p. 38).

The quote of Vandermyn describes the superior performance of refined tung oil. Tung oil, also known as China wood oil, is a pale oil refined from nuts from tung trees of different *Aleurites* and has been known outside of China, the original site of the trees, from 1760 (Jordan, 1929, pp. 847, 849). It was introduced to paint making in the late nineteenth century (United States of America in 1896, Germany in 1897, and the United Kingdom shortly after this). The American Tung Oil Corporation was established in 1923 in order to provide for American production and use of tung oil. Henry A. Gardner, the legendary metallurgist and paint researcher, and the director of the American Paint Research Institute, was the Vice-President and General Manager of the corporation. Cold-pressed tung oil is clear and pale yellow, with a slight (deodorised) almost neutral odour or resembling of castor oil, and it is tasteless (Andés, 1900, p. 156: Fahrion, 1911, p. 263).

Tung-oil was used in oil paints from the late nineteenth century (Andés, 1900, p. 159: Suida & Salvaterra, 1931, p. 57: Andersson, 1939, p. 68: Nylén, 1948, p. 656: Strömberg, 1949, p. *Träolja*: Standeven, 2011, pp. 21–22). In the 1900s, tung oil was far more expensive than linseed oil, and therefore was not considered as a cheaper substitute. It was used as a linseed oil surrogate for paint making during the First World War. It became an essential ingredient in the production of linoleum and for floor varnishes. It was discovered that the addition of tung oil made it possible to exclude resins. Due to its rapid through-drying and waterproofing characteristics, tung-oil quickly became used in varnish in paint-making industries in the 1920s. During the

Second World War it was used for outdoor paints such as aeroplane resin-free varnishes, and as spar/long oil varnishes (Statton & Walker, 1920, pp. 1–5: Zimmermann & Irwin, 1924, pp. 1–5).

At the beginning of 1900, the use of unrefined tung oil was limited since the technical benefits of the tung oil were not yet discovered (Fahrion, 1911, pp. 263–273: Andés, 1900, pp. 156, 161). Andés states that no other drying oil will supersede linseed oil varnish, but the superior drying power of tung oil could be very useful for the development of anticorrosive paint (Andés, 1900, pp. 122, 156). It was revealed that light-exposed tung oil (without oxygen access) rapidly forms a solid gel (not soluble in any solvent, and not saponifiable) by polymerisation, despite its low iodine value. The high polymerisation power is caused by a high content of α-eleostearic fatty acid (C18:3), having conjugated double bonds, which makes the oil very reactive and results in rapid through-drying. Normann, Cloez, Kitt, and Bock are examples of American scientists that started extensive development in order to control the reaction kinetics of rapid coagulation. Kettle boiling at 180°C drives off moisture and impurities, increases the viscosity, and alters the characteristics beneficially for paint making (Andés, 1900, pp. 122, 158: Uebele, 1913, pp. 279–287). Kettle boiling with litharge produces a varnish that dries rapidly into a clear and bright film, but the drier addition is unnecessary. The varnish with litharge dries uniformly throughout, including the thicker layers. Its fast gelation speed at high temperatures (> 200°C) requires special caution and procedures. Within a few minutes, a temperature of 280–285°C, causes rapid gelation (*monkeying*) due to polymerisation (Suida & Salavaterra, 1931, p. 58: Singer, 1957, p. 20).

Tung oil is not used in an unrefined condition, and not on its own since it dries unevenly and forms a soft, matte, and porous film (Uebele, 1913, pp. 279–287: Magnusson, 1931, p. 29: Singer, 1957, p. 20). The low-refined oil dries with a porous ice fern appearance that is unbeneficial for paint products. The reason for the severe skin formation in tung oil is a colloidal phenomenon that could be prevented by linseed oil mixing (maximum 30%) that will change the polymerisation reaction kinetics. Tung oil should always be used in the bodied condition, and will, with correct refinement give a glossy, hard and tough film. The addition of tung oil to linseed oils significantly improves the drying power, film toughness, and water resistance of the linseed oils and paints (Uebele, 1913, pp. 279–287, Suida & Salvaterra, 1931, p. 67: Fallgren, 1934b, p. 141). Tung oil is superior in anticorrosive paints compared to the use of solely linseed oil (Vandermyn, 1921, p. 37). It is used, for instance, for high-quality enamel oils and paints (Rowe, 1938. p. 45: Nylén, 1948, p. 657). Tung oil is never used in order to cheapen the paint; indeed, the opposite is true (Andés, 1900, p. 159: Vandermyn, 1921, p. 39).

Refined, bodied tung oil dries fast to an elastic and hard, hydrophobic film without the need of drier additions (Andés, 1900, p. 122: Uebele, 1913, pp. 279, 287). The pale, lustrous paint film is durable with excellent water-repelling characteristics, thus its high chemical resistance. Tung oil is the most rapidly drying oil that exists, with the best alkali and solvent resistance (Singer, 1957, p. 20). Tung oil is beneficial as a co-binder in paints containing metallic pigments, which may be sensitive to acidity (Uebele, 1913, pp. 279–287).

SOAB used tung-oil for producing stand oils (Magnusson, 1931, p. 29. Helmersson, 1996, n. p). The stand oil procedure with tung oil has been described earlier. Tung stand oil was considered as extremely valuable due to its resistance to water (Magnusson, 1931, p. 29). The gelation during processing is inhibited by additions of linseed oil (or oxidised oil turpentine and so on). The stand oil holding temperature is up to 240°C (when the desired viscosity is achieved the temperature is lowered to 200°C).

6.2.8 Quality Assessments of Oils and Varnishes

> *”Paints should be tested out by the chemist.....In order to ensure the most desirable results, the chemist should do his own testing out, and this involves a practical painting knowledge that can be gained only under experience and under the guidance of an able master painter”. (Holley & Ladd, 1908, p. 107).*

The quote above was stated at a time when the technical innovations of drying oils and varnishes, with associated paint making, were an issue of intensive research and development. It indicates that a combination of technical and empirical methods were considered to be necessary for the required quality assessments. At the beginning of this research, one expectation was to try to reveal some of these assessments in order to provide information about the characteristics of durable paints. This is commented on later in this chapter and chapter 9.

The history of paint chemistry originates from ancient times and was based on the knowledge of the alchemists and pharmacy (Johansson, 2002, pp. 31, 41–46: Friedstein, 1981, p. 291). During the eighteenth century, many discoveries of pigments and other paint materials were made in expanding knowledge of chemistry. In the 1860s, the chemical industry was initiated in Sweden, and the trade of domestic and imported products was first located to pharmacies. The pharmacies were natural trade points due to the intimate and interdisciplinary connections between art and sciences. In the 1870s, the English industry was influential, but in the 1880s and beyond, strong influences of paint manufacturing were originating from the chemical industries of Germany and Switzerland. Institutes were opened for paint technology and craft, for instance, *Versuchsanstalt und Auskunsftstelle fűr Maltechnik* was located in Műnschen, as well as other laboratories in Charlottenburg, Weimar, and Wien (Lenander, 1923, pp. 95–95). Germans or Swedes studying in Germany, such as Carl Wilhelm Becker, Ferdinand Leidig, Herrman Gentele, Victor Bäcksin, and Frans Gustav Klimt were involved in the growing new paint technical-chemical industries (Johansson, 2002, pp. 43–47). German engineering and science influenced the technical education system in both countries. German technical handbooks were translated, and engineers worked theoretically and experimentally with the newest technical procedures. In an article from 1899, Rosenberg (professor at the Technical University in Stockholm) refers to the pioneering research works of Mulder (1867) and Hazura (1883), as well as his contemporaries Andés (1898), Amsel (1897), and Livache (1897). The chemical laboratories at the Royal Academy of Engineering Sciences (IVA) were initiated in 1919 (IVA, 2019) and the Royal Institute of Technology (KTH) was built between 1917–1921 (Enström, 1929: pp. 137–138: Sylwan, 1929, pp. 337–340). The metallurgical industries had their own research laboratories before this, and the technical field evolved scientifically during this time, as described by Sundin (1981). After the First World War the engineering sciences focused intensely on the technical and economic aspects of materials for building societal prosperity.

During the decades before and after 1900, paint ingredients and paints were often falsified by different other additions (Rothstein, 1856, pp. 246–247: Cronqvist, 1871, p. 86: Andés, 1900, pp. 74, 119, 143–155: Lueger, 1908, p. 133: Fahrion, 1911, pp. 53–105, 230: Uebele, 1913, p. 271: Lueger, 1914, p. 418). It could be falsifications or dilution with extenders, resins, petroleum products, or non-drying oils. A number of physical, chemical, and empirical tests were developed in Amsel at the German Painters´ Association in Kiel, but also by different researchers (Andés, 1900, pp. 143–144). This was a time when the use of paint materials and ferrous structures was immensely diversified, and a lot of the knowledge of metallurgy and technical science was progressing (Sundin, 1981: IVA, 2019: Wetterberg, 2020). The methods for characterising metals and corrosion testing materials were introducing standards that are still used today. The literature on this is extensive (for instance, Andés, 1900: Mcintosh, 1904: Walker, 1910: Bottler, 1912). There was a combination of chemical and physical laboratory methods, empirical methods, and sensorial methods such as colour/brightness, taste, and smell.

For anticorrosive paints, the best raw materials and paint were required. The importance of the paints' quality and long-term characteristics was negligible compared to the cost of it, and to the costs of maintenance or damage on the ferrous structures (Andés, 1900, p. 93: Vattenfall, 1933, pp. 13–17). The best linseed oils and oil varnishes were required, and the pigments and other ingredients were not to be diluted or falsified. Not only in Sweden, but also in Europe did the railway and governmental organisations experience falsifications which resulted in expensive and dangerous effects on anticorrosive treatments. This resulted in the development of testing methods and the specification of standards in order to control the quality and costs of the contracted products at (for instance) the Swiss Institute for Testing the Strength of Materials. The Swiss and Bayer's Railway conducted tests on the drying capacity, elasticity, and mechanical characteristics of anticorrosive oil paints (Anonymous, 1898, p. 283-297: Andés, 1900, pp. 262–268). Test methods were evaluating the chemical composition, paint consumption/area unit, drying rates, weight changes post-drying, adherence and toughness, covering power, and resistance to acids of anticorrosive paints (Andés, 1900, pp. 262–253).

The chemical laboratory of The Swedish Royal Railway Board, the governmentally owned railway (*SJ*), was organised under the Workshop department (*Verkstadsbyrån*) and was started in Stockholm in 1906 (SJ, 1931, pp. 527–529), see **Figure 22**. Before this, laboratory analyses were purchased. The chemical laboratory tested all sorts of materials from different manufacturers that offered their products for purchase. The products that fulfilled given specifications and showed high levels of quality were purchased by costs that were most beneficial to the board for the use on mediums, railway buildings, pylons, steel bridges, and so on. If a product showed superior quality, it could be bought despite its higher costs. The staff also carried out revisions on older material specifications, developed new testing procedures, and handled reclaims.

The major material groups were charcoal and their products, mineral oil, fat oils (with soaps and tallow), tars, and textiles, but also pigments and other painting stuffs, metals, and alloys. Some paint materials were delivered in a ready-to-use state (such as linseed oil varnishes, lacquer paints, and tars); others would usually be prepared to be usable in the organisation. The staff at the railway laboratory were used for material consulting in the organisation, and the number of annual material examinations was between 1200–1600 (SJ Annual reports, 1906–1935). During the First World War the laboratory performed experiments in order to substitute materials that were not accessible. In 1918 in particular, a large number of linseed oil substitutes were examined. During the years 1919–1921, anticorrosive paints were tested in the laboratory. The laboratory used technical specifications, but also high-quality reference samples to compare the tested materials (*provvätska*) to reference material (*standardprov*) (SJ, 1906–1935: Sandberg, 1926, pp. 12–26). The testing procedures are mainly refer-

437. Statens järnvägars laboratorium år 1906.

Figure 22: SJ´s Chemical Laboratory in Stockholm, 1906. (SJ, 1931.)

ring to German literature, and the product types often by their English designation. Paint materials were investigated in a liquid state, a drying state, and after complete drying. The main focus was on the quality of the products that should not be diluted or falsified. Paints and pigments were investigated regarding their chemical composition, hiding power, drying time, and coarseness. Outdoor durability was made through time-consuming field tests that were checked every third or sixth month. At this time, chemical analyses such as gas chromatography or mass spectroscopy could not be performed. The instructions stated that an integrated balancing of available chemical, physical and practical aspects must be done. In this, sensorial assessments are also included. The authenticity, purity, turbidity, colour, and drying capacity were assessed. Liquid fat oils were characterised by technical quantity assessment numbers according to the technical handbook of Seeligmann & Zieke (1910). For liquids, practical profiling includes colour and turbidity, specific weight, density, and viscosity. For drying films, it includes applicability, hiding power, and drying capacity. After complete drying, the practical profiling includes measuring the hardness, elasticity, adherence, and durability. The product tests were protocolled annually (1935–1961 are kept at Riksarkivet Arninge), and random examples were investigated (SJ reports 1935–1961). In the reports from the 1930s, linseed oils were investigated, but not in the late 1940s and so forth. Moreover, the paint treatment sections of documents for required offers to the manufacturing of vehicles were also investigated

The specifications were quantifiable but also commented on by perception of vision, odour, and taste. Typical usage and painting or other characteristics were commented on. The mixing of pigments in different paint binders is commented on, and the chemists were well aware of what nuances the organisation were or were not accepting. For instance, boiled master oil

Table 6: Comprehension of quality attributes of linseed oils used for paint making by the Royal Swedish Railway Board between 1926–1928 (Compiled from Sandberg, 1926).

Characteristic	**Raw**	**Alkali-refined**	**Acid-refined**	**Boiled**	**Test method**
Density, 20°C	0.924–.,931	0.924–0.931	0.924–0.931	0.926–0.948	ISO 2811–1, 3 Pycnometer
Colour	13	4	6	Agreed	ISO 4630–1, 2 Gardner or Lovibond
Clarity	No sediment at 65°C	Slight turbidity is allowed. After short heating up to 45°C, the turbidity shall disappear and the oil shall stay clear after cooling to r.t		-	Clause 8
Refractive index, 23°C	1.478–1.483	1.478–1.483	1.478–1.483	-	ISO 5661 ISO6320
Water content, wt%	0.20	0.10	0,10	0.30	ISO 8534 Karl Fischer
Acid value, mg KOH/g	4	1	9	8	ISO 2114 ISO 660
Saponification value mg KOH/g	188–195	188–195	188–195	188–200	ISO 3681 Titration
Iodine value, min	175	175	175	-	ISO 3961 Titration (Wij) or composition
Drying time, max	-	-	-	24 h (15-20°C) 15 h (25-30°C)	ISO 1517 Ballotini
Composition	Mass % Myristic acid (C14:0): 0–0.4%, Palmitic acid (C16:0): 4.5–7.1, Palmitoleic acid (C16:1): 0.1–0.3%, Stearic acid) C18:0): 2.3–5.8%, Oleic acid (C 18:1 cis): 17–23.5, Elaidic acid (C 18:1 trans): 0.6-1, Linoleic acid (C 18:2): 13.8–17.5, Linoleic acid (C 18:3): 50–60, Arachidic acid (C20:0): 0.2–0.6				ISO 12966

(*mästarolja*) is commented for the making of white zinc oxide paints; where the oil should be light, and the paint should dry purely white without a fatty appearance (SJ lab report 17494 and 17602, 1935). Moreover, craft oil (*hantverksolja*) was delivered. The chemists appear to have been well aware of the methods for in-house paint making at the workshops. The chief engineer does not only comment on whether the colours are ugly or inappropriate for the needs; he also describes how falsifications could be revealed by bad smells or tastes. The judgements could be either hedonic or specified. Specifications often refer to everyday items such as food. It is clear that the governmental engineers at the laboratories combined chemistry theory with experimental theory, involving sensorial profiling of the quality of paint materials and products. The Royal Railway Board had the competence to judge what products corresponded to the specifications and quality goals that were pre-determined. A written proposal instructing the painting person and goods vehicles at SJ, dated 1926–1928, was found at Riksarkivet in Arninge (Sandberg 1926). It describes painting procedures, materials, and quality requirements and testing methods. Quantifiable laboratory methods are combined with sensorial and practical profiling, see **Table 6**. Varnish making results in: increased viscosity,

Table 7: Standard specifications according to ISO 150:2006 and ISO 150:2018.

Quality attribute	Cold-pressed	Warm-pressed	Extracted	Boiled (130°C)	Comment
Turbidity	Clear, glossy	Not specified	Not specified	Clear	Assessed as clear, less clear, turbid, opalising.
Colour	Golden yellow	Yellow-brownish	Yellow with a red or green tint	Yellow-brownish	Comparing standard solutions. Colorimeters.
Smell	Less unpleasant	Unpleasant	Like garlic or whale-oil	Could be unpleasant, but not stinking	-
Taste	Less unpleasant	Unpleasant	“	As cold-pressed oil	-
Drying time at 20°C	2 days dust-free + 3 days through-dry.	5–8 days	>5–8 days	6 h + 12 h	On glass plates, expressed in hours, temperature, and humidity.
Specific weight at 15°C	0.930 – 0.936	Not specified		0.935–0.950	Important for judging authenticity.
Acid Number	2–5			Maximum 10	If ≥ 12 the origin is doubtful, if >15 it is falsified.
Saponification Number	188–197			185-187	-
Iodine Number	170–197			Slight below the used raw	-
Hexabromide Number	50–60			Not specified	-
Usage	For polishing, paints, waterproof treatments. Should be stored 1–2 or bleached by earth.	-		As varnish or in paint making. No sedimentation is allowed. Sensitive to humidity in the atmosphere. Stand oils are also used for paint making.	-

specific weight, refractory index, viscosity, and acid value; a decreased iodine value and hexabromide number, compared to the raw linseed oil (Richter, 1941, p. 60).

The specifications in **Table 7** could be compared to the armour paint standards (see Table 4 in **Paper II)**, and today's standards. Today, boiled linseed oils are defined as *"oils obtained by incorporating driers in raw linseed oil or refined linseed oil and heating alone or while blowing air or oxygen through the oil"* (ISO 150:2006)—i.e., no heating close to boiling temperature is required. The specifications are similar in all mentioned sources.

The Royal Waterfall Board was started in 1909 in order to provide the industries and railway organisation with electrical power (Vattenfall, 2014). An important category for painting purposes was power pylons for the transportation of electricity, power stations, and dams. Vattenfall purchased laboratory analyses (of mainly anticorrosive paints) for instance, from external laboratories such as *Statens Provningsanstalt*, *Chalmers*, and *Ferrolegeringar AB* (Laurell, 1937) (Vattenfall, 1923a, 1923b, 1923c). A number of archived paint investigation reports are examined (1923a, 1923b, 1923c). All paint materials were thoroughly analysed at laboratories, such as pigment composition and binder qualities (Vattenfall, 1933). The pigments were mixed and rolled once or several times at the paint factory that Vattenfall had. This shows that Vattenfall had control of the paint quality and was also able to manufacture their own paints (at least in the 1920s). Vattenfall began the first corrosion tests 1922–1923, as has been reported in **Paper II**, and when cooperation started with IVA's Corrosion Committee, the corrosion tests were later extended.

Comparing technical quantities for drying oils and varnishes today

Fourteen available linseed oils from the Swedish market were profiled by sensorial methods and by technical laboratory methods, as described in **Paper V** and **Paper VI**, Supplement 2. Ten liquid oils and varnishes that have been analysed, generally manage the historic and modern standard intervals. The chemical composition and characteristics of some of these have been analysed and commented on in **Paper III** and **Paper IV**. The purpose was to get an explanation of the different behaviours of different oils and varnishes, as described in **Paper V**´s **Figure 16** and **Figure 17**.

Two of the analysed raw oils have acid values that are a bit high according to the mentioned ISO standard. Peroxide values are also high (probably depicting initiated rancidification). Their refractive index for the raw oils is slightly lower than is standard. The boiled varnishes manage the drying time specifications, but the time does not tell anything of the characteristics of the formed films. The heated varnishes (preparation varnishes) tend to be autophobic when applied onto cleaned steel sheets or glass plates, and the boiled (oxide varnishes) do not show this tendency (exemplified in **Figure 16**). The iodine values are normal for all samples and, as expected, are lower for the stand oils since a majority of the double bonds have been consumed for conjugation and cyclic compound formation. As has been shown in **Paper IV** also high temperature boiling may result in cyclic compounds. It is clear that the iodine value does not function as a measure of drying power. The iodine values are comparable for the raw oils and the heat-treated varnishes but the drying time is up to 5–14 days for the raw oils and stand oils, and considerably shorter for the heat-treated types (at comparable film thicknesses). For raw linseed oils. it is reasonable to conclude that the fatty acid profile and purity both influence the drying power. The iodine value does not take into account the influence of the fatty acid profile or conjugated bonds, such as those which are produced by isomerisation or which are typical of tung oil (Andés, 1900, pp. 152–155: Andersson, 1939, p. 38: Richter, 1941, p. 60: Singer, 1957, p. 21). The iodine value includes the oleic acid, which does not contribute to the drying power. The drying is catalysed by the addition of different types and concentrations of driers and this affects the drying rate of varnishes considerably. Different drying oils (having the same iodine number), may have different compositions or distributions of fatty acids attached to the glyceride molecule. The result could be that one oil is drying, and the other is not (Magnusson, 1949, pp. 830–831). Different seeds and growing climates could affect the fatty acid distribution and fatty acids may be rearranged in industrial processes (re-esterification). It is experienced that some attributes are not described by these values, such as the sedimentations of sedimented mucilage/gums. After three years of storing, there are sediments in all glass jars, except for some of the raw oils. Impurities could be described by the content of unsaponifiable value or insoluble impurities. The heated varnishes show some sedimentation, and that is not depicted in the technical values. It is experienced that the acid value of about 6 for the stand oils is high enough to etch a clean mild steel surface, and remaining marks at the application can be clearly noticed. Viscosity data could indicate the colloidal pre-aggregation (pre-oxidation or polymerisation), but for several reasons this was not assessed for the selected oils and varnishes. Specific weight, assessed with four decimals, also indicates the pre-aggregation state. It is concluded that the technical quantities are consistent with historical specifications in **Table 6** and **Paper II.** Several paint-makers use the standards for selecting binders in their paint production. The quantities do not give a clear picture of the sensorial characteristics of the oils and varnishes (for a layman, at least at my level of experience), but make it possible to distinguish for instance stand oils from other oils. According to Alvès, the technical quantities are not able to describe oxidation in linseed oil artist paints, but no further information is provided (Alvés, 2015, p. 63). Likely, the differences could partly be explained by different degrees of heat bodying, drier additions, and different purification treatments. The results in **Paper IV** also showed that commercial varnishes may have additions of other vegetable oils, that are not declared. With the background on what has been explained in chapter 6.2.1 concerning the iso-colloidal state of oils and varnishes, two oils with similar technical quantities since their sol-to-gel formation kinetics may still vary, due to variations in characteristics of dispersion media and phase. In order to reveal these complex connections, an extensive research project is probably needed that is capable of determining the colloidal state, quantifying the reaction kinetics and film formation, and correlating this to the chemical and physical characteristics. The correlation between oils and varnishes, with the practical use of a traditional architectural painter (as described in **Paper V**´s **Figure 16** and **Figure 17**), remains to be explored. As described in **Paper III and IV**, the fatty acid profile (assessed by methods such as GC-MS) could provide some information about the characteristics, for those that are experienced in those types of interpretations.

Potential Empirical Test Methods

In the following, some empirical testing methods are described because they indicate some differences between different types of oils and varnishes and also because the methods could inspire modified quality assessments by paint-makers or painters.

In order to detect gum in liquid oil or varnish, the liquid is placed in a test tube (two-thirds of the volume, at least 50 cm^3) after the tube has been exposed to an exhalation for the evaporation of the walls, and it is then rapidly heated with a large flame to 300°C without agitation, and impurities will break (Bottler, 1912, pp. 240–245, 311: Magnusson, 1931, pp. 9, 63, 75). The gums should be light or slightly brown, not dark brown, and should have a consistency like jelly, not powdery or granular. Without exhalation and rapid heating, the oil will dry despite the fact that it contains mucilage. This may occur even if the impure oil (or varnish) has been air-blown and stored. The presence of gums is checked by letting a litre of the oil stand in a clear glass bottle for eight to 14 days. The highest grade of oil should not show any turbidity, veils, or foots after this time (Andés, 1900, pp. 152–155: Bottler, 1912, pp. 240–245, 311). It is also beneficial prior to the bottling to heat the oil to 100°C. Turbidity could be checked by leaving about 25 cm^3 of the oil standing for two weeks in a graded 1-cm diameter glass tube at 15–25°C (the oil should be perfectly clear after the time) (Bottler, 1912, pp. 240–245, 311). Moisture and volatile matter in liquid oil are checked by weighting the sample before and after heating to 105°C for 45 minutes (though some oxidation will occur). Moreover, the ash content may be checked by heating up to the point of combustion and calculate the remaining weight. Elasticity and adherence of the dried film as described on glass plates are tested by rolling round a notch (similar to glass cutter notch) on the films and studying the deformation characteristics (Sandberg, 1926, p. 15). A brittle film is profiled by a groove with "flattening". The body of the film can be characterised by its appearance, and sharp distinctive grooves. Falsifying the additions of rosin or mineral oils were revealed by applying the oil onto a black painted glass plate (Uebele, 1913, p. 271). If bloom or iridescence occurred, this was a sign of falsifications. They dry slowly, to soft films (Holley & Ladd, 1908, pp. 45–47).

In the requirements of the Swiss NE Railway of dark grey MIO armour paint, it is specified that; only well stored and acid-free linseed is allowed as a base for the varnish making (Andés, 1900, pp. 265–268). The density of the varnish should be at least 0.93 (only two decimals) and when spread out on glass plates it should dry within 24 hours. The armour paint should be easily applied, with good coverage on primed or un-primed iron. It must also be tough and elastic without peeling. It should be free of "*all turpentine, benzine, or other hydrocarbon diluents, and of all liquid driers*". It should also be waterproof (set-to-touch) within 12 hours, and have dried hard in 24 hours. It is assumed that by "waterproof", is meant that a light rainfall will not affect the freshly painted surface negatively. The paint must be acid-proof and free from compounds with solubility in water with atmospheric carbon dioxide or sulphuric acid. The paint is tested by applying it in two layers on an un-primed iron substrate and then exposing it for 48 hours to 5% sulphuric acid and the varnish film should manage water immersion tests (time not specified) without showing milkiness.

Water immersions tests of solid varnish films seem to have been an important method of testing the quality of the varnish and the formed films. A solid varnish film absorbs water and swells (simultaneous decrease in firmness and an increase in elasticity) (Magnusson, 1931, pp. 4–5, 9, 14, 19–24, 45–46, 63: Magnusson, 1939, p. 258: Nilsson, 1948, p. 1390). The swelling is decreased when the liquid evaporates, but the original state is not reached. The swelling value describes the water uptake (in gram) that one gram of dry matter absorbs. The solid film of linseed oils swells to a certain limit (i.e., there is not endless swelling, as some systems show). Magnusson made trials on water absorption on films applied on glass plates by a method from Hollander & Eibner, as is described in chapter 4.4. After the films were dry, they were immersed in water for 2.5 days at 20°C. The time taken to make the film milky or translucent was then noted. Some of the results that Magnusson describes are interesting even today because they reveal the positive effect of stand oil and tung oil additions on the quality of the film quality and they show the great effect that the driers had on the quality of the varnish. For instance, the low levels of water resistance of ordinary boiled linseed oils could be improved by adding high-temperature boiled oils, such as Oljelin or Linyl, or ordinary stand oils.[47] An addition of 10% of Linyl to oil paints is concluded to work brilliantly for this purpose, while an addition of 10% of "ordinary" stand oil may leave the solid film tacky. A three-day old solid film of cobalt-resinate (0.03% cobalt) shows a volume increase of 92% of water (20°C) in 24 hours. In a stored Pb-Mn varnish with 20% of stand tung oil-linseed oil (20% tung oil), the uptake is only 25% water. Another trial for pure (20%) stand tung oil-linseed oil

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[47] Payne & Gardner confirm that a linseed varnish similar to *Oljelin* (boiled with air access) is not water soluble and show relatively low permeability of water vapour through the film (Payne & Gardner, 1937, p. 898). This demonstrates that the film is not polar (water is a polar liquid). It was also shown that the thinning of the varnish did not, as was expected, increase the permeability of the varnish film.

which had dried for four days and then stored in water for 2.5 days had 25% water absorption. Magnusson concluded that 2.5 days of water immersion was too long for the fresh stand oil films, which will release water-soluble constituents. When the stand oil film is allowed to dry for seven days, it is absolutely clear, and also managed Eibners′ red-lead test excellently (see chapter 6.2.1) (i.e., the stand oil needs a longer time for drying). Tests with air-blown varnish (blown for up to 80 minutes) (cobalt-resinate) turned opaque after only two hours. Their varnish (2% Pb-Mn siccative) turned whiteish after 24 hours, and a stored Pb-Mn varnish from the Sommelii factory in Nacka turned semi-whiteish after 2.5 days. An air-blown Pb-Mn varnish from Dorch, Bäcksin & Co and a stand oil was slightly turbid after 2.5 days. A Sommelii varnish (stored for a year) was almost clear, and this oil with an addition of 20% tung oil was absolutely clear at the same time interval. Nilsson (1948) states that an ordinary linseed oil paint could absorb up to 20 times more moisture per area unit compared to specially treated stand oils produced for anticorrosive paints. Another type of test that SOAB conducted was on applied zinc plates that were allowed to dry for four days, immersed in a copper sulphate solution. The Sommelii varnish with a 20% tung oil addition showed no copper deposit. These observations show that the Pb-Mn varnish is superior to the cobalt-resinate varnish, and is further improved by additions of stand oil, tung stand linseed oil, or tung oil. Moreover, storing improves the water resistance. The water immersion resistance between different varnishes varies considerably.

Similar tests as described by Magnusson above were undertaken in this work, and has been described in **Paper IV**. For this, some of the varnishes has been used in the armour paint formulations as described in **Paper III** has been used, with some additional varnishes. The results confirm the high level of water resistance of litharge varnish, stand oil, different varnishes with a 20% tung oil addition—which are all equal. The litharge varnish and tung oil added modern varnishes are about equal. But none of these are as superior as the Pb-Mn resinate varnish used in the 1930s, as reported by Magnusson above. The relatively low resistance of the modern blown varnish was expected: it is similar to ordinary "boiled oils" (with cobalt drier) of the 1930s. The result of a manganese borate varnish behaved better than expected (considering it is a modern varnish). It seems that the already mentioned historical statements of the efficiency of manganese borate have some relevance. The results show that fire-boiled oil varnishes with manganese driers are prone to imbibition (have very low water-resistance), despite that they are heat-bodied and pre- polymerised. Other observations connected to these tests could be mentioned. When droplets of distilled water were added to the surfaces of six different armour paints (with the same recipe but different types of binders) for a duration of 1, 2, 3, 4, 6 hours, this resulted in "blindings" in all surfaces. The blindings (i.e., surfaces with slightly deviating colour) almost disappeared a while after the water being wiped off, and the variants with stand oil and/or tung oil managed best. Another observation is that the addition of 20% tung oil produces glossy films, but commercial products give matte films.

6.3 Armour Paints

6.3.1 Needs and concept

About 100–120 years ago, the anticorrosive treatments of iron and steelworks relied mainly on empirical work. Uebele states that scientific researchers were quite busy discovering and formulating theories on how the metals corrode and how to paint them (Uebele, 1913, p. 327). He says that "*As we cannot wait for them, however, we will have to work on what we know from experience...*". Today, we know a lot about the mechanisms of different types of corrosion, but instead we have a lot to re-discover about the concepts and characteristics of high-quality oil varnishes and paints. With the exception of the pioneering work of the engineer Robert Mallet (1810–1881), who conducted extensive, ground-breaking, and systematic research between 1837–1840 on behalf of the British Association for the Advancement of Science due to the increasingly number of "*harbours, ships, bridges, railways,*" the nineteenth century has been called the "*Dark Ages of Corrosion Research*" (Lynes, 1954, pp. 59–62: Smith, 1981, p. 13).

During the nineteenth century, scientists such as Thénard, Davy, and Faraday formulated and proved theories about the electrochemical nature of corrosion (Cushman & Gardner, 1910: Lynes, 1954, pp. 1–8: Habashi, 2003, pp. 90–92: Leygraf et. al., 2016, pp. 1, 100). Arrhenius, Whitney, and Gardner and Cushman rediscovered, proved, and published scientific work about the electrochemical process of corrosion in the early 1900. Cushman and Gardner researched and published their formulations of inhibitive paints in 1910, and this had a strong influence on the scientific work regarding formulations of anticorrosive paints.[48] Moreover, anodic protection by zinc-pigmented primer paints was introduced. Vernon started systematic work about atmospheric corrosion in the early 1920s (described by Leygraf et al.). Until the First World War, most of the research was conducted in university laboratories, but after some serious industrial corrosion breakdowns, more extensive outdoor research programs were started by, for instance, the British Institute of Metals, as well as in America. In Sweden, Vattenfall and IVA started their research field tests with anticorrosive paints for the needs of protecting bridges, masts, and industrial facilities, as described in **Paper II** and **Paper III**. The tests continued for almost four decades. With the development of corrosion and paint research, the knowledge about the function and specifications of anticorrosive paints gradually developed in relation to the needs for ferrous structures and objects in society. The concept of a well-functioning anticorrosive oil varnish paint, such as the armour paints, was the result of these efforts. Armour paints and aluminium paints were also used for decorative purposes, such as architectural cast iron (Sheppard, 1945, pp. 48, 52). The possibility of zinc metallising large objects in the 1960s coincided with the diminishing use of oil varnish paints, and there was no longer a general use of the concept. The 2+2 (or 1+2) Armour paint concept, described in **Paper II** and **Paper III**, is concluded to be as a synthesis of several traditions, see **Figure 23**. An understanding of the "*values and aspirations that drove its makers*" enhances the understanding of the tangible and intangible values of armour paints (Unesco, 2015, p. 24).

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[48] *"Out of this mass of tentatively accepted facts has developed a provisional theory along which the more advanced manufacturers are now engaged in working out a new mode of procedure in the painting of steel. The theory is that rust-stimulating pigments should never be placed in contact with the steel surface, but that an inhibitive priming coat should always intervene. Over this priming coat the air – and moisture – excluding coats can be safely applied; these coats being designed for protection only, with regard to inhibitive qualities"*. Heckel, Railway Gazette, cited by Cushman & Gardner, 1910, pp. 174-175.

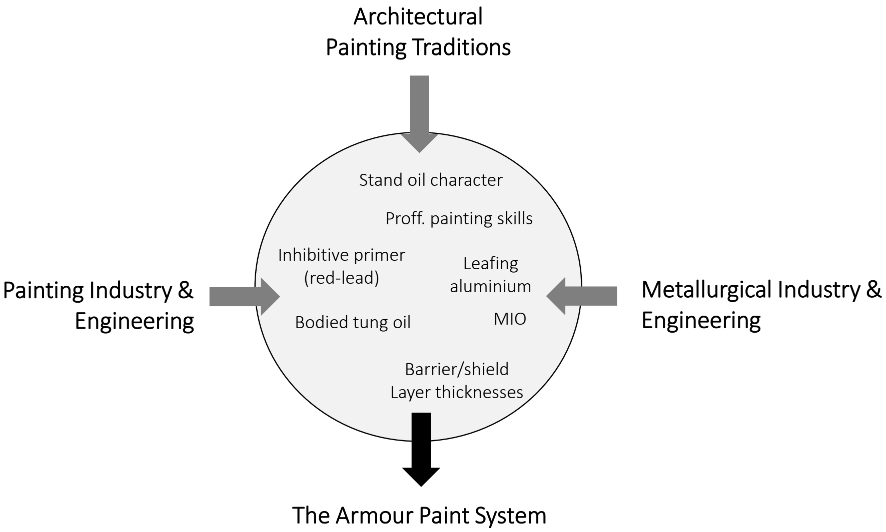

Figure 23: The Armour Paint concept and system is a result of expert knowledge from several fields.

Architectural Painting Traditions – ensured that high standards were kept in the chain of actions leading to the final results. The development of the varnish and paint making evolved from small-scaled artists and the paint of artisans to the architectural painters who made and adjusted the paint ingredients and paints themselves, depending on affordances and purposes. This tradition continued with the growing industry of paint making, particularly semi-prepared and ready-to-use paints. After the Second World War, the industry made the new paints accessible, and when the older types of paint were not requested or used, the continuity of practical knowledge in this area became partly weakened. Scientific research of paints and technical quality assessments became intertwined for the development and application of the products for different needs by the *Painting Industry and Engineering*. Crafts institutes and laboratories were started in cooperation with industry and universities in order to increase the foundation of knowledge in this field. This led to the development of highly polymerised, bodied oil varnishes for the use as successful binders in anticorrosive paints. *Metallurgical Industry and Engineering* – the long history of mining and metallurgy, adaption to industrial and large-scaled needs of rolled sheets and profiles, castings. From this research, the use of inhibitive pigments in the primer layer was introduced as a part of the success concept. Pioneering industrial production of new metals like aluminium was conducted, to be used in new products such as fragmented fractions for paint pigments that were based on the scale armour paints (with MIO). By combining empirical and theoretical knowledge—the beginning of research laboratories— led to the formulation of requirements of extending engineered anticorrosive actions. From the clever combination of engineering and these painting traditions developed the formulation of armour paints; the use of UV-radiation reflecting pigments to the protect the bodied, elastic paints binders from deterioration and the use of inhibitive primer paint layers. The building of the modern society, with the need for infrastructure (such as railways, bridges, masts, and so on) was made possible due to the accessibility of the knowledge of the industry. The government; IVA, Vattenfall and SJ were highly ambitious and worked to ensure a high quality of products to best available costs over time. All these aspects led to the formulation, testing, and use of armour paints. Their investigative mindset and their knowledge of what they were investigating and why, with preventive management implemented in the organisations in order to exchange the cost of investments over the longest possible time, is in many ways a lost treasure. With this, valuable knowledge is developed over time.

6.3.2 The concept of Armour Paint System

Armour paints are described in **Paper II**, **Paper III** and **Paper IV**, in terms of concept, history, use, paint formulations, and ageing. Some additional information on armour paints is given below.

Andés describes the analysis of some early Swiss and German patents of scale armour paints (Andés, 1900, pp. 162–182, 204–221). The paints consist of MIO pigments in a high-quality linseed oil varnish that is neither acidic nor alkaline. The pigments should not contain any sulphur compounds that may influence the risk of corrosion. The varnish will become more acidic if it is mixed with pigments which contain sulphur. After the paint is stirred, it should be reduced with the best, quick-drying linseed oil varnish. When the scale armour paints are correctly designed, they have high hiding power, are acid-resistant, and form durable paint films. The MIO pigments result in a sparkling appearance in sunlight (Fuller, 1988, pp. 769–791). Some years later, the varnish in the Graf & Co's Scale Armour Paint is said to contain a new binder: *Panzerfirnis*, called *Panzerit* (Anonymous, 1930, pp. 525–528). The composition is not revealed, but the varnish is opposed and compared to linseed varnish; this binder dries from throughout the layer, it could be applied in thicker layers, and it has a high level of weather-resistance. This description suggests a tung oil component. “Linseed varnish” is described as water permeable and with low chemical resistance (indicating reference to type 2 varnishes).

Edwards states that the most important requirement of the aluminium paint binder is that it has a proper *body and viscosity* (syrup-like), in order to flow and level the paint properly, and to form tough films (Edwards, 1936, pp. 7–9, 47–52, 201–202).[49] Without body, the paint will be too thin to produce thicker paint layers, and will not have enough hiding power. If it is too thick, it will, with difficulty, be spread out to a uniformly and with desired thickness. The body of the paint must also be so high that the paint will not “*run, sag or break*” on a vertical surface, and therefore the plasticity and viscosity of the paint must be correctly designed. For instance, a binder with low viscosity such as raw linseed oil will result in a paint that runs on a vertical surface. Kettle-boiled linseed oil varnishes are durable binders for aluminium paint. The driers should be added during the “boiling” of the linseed oil, but still, the drying time is still considered to be too long and as resulting in films that are too soft. “Ordinary” boiled linseed oil (type 2) is considered by Edwards considered as not viscous enough: the oil must be bodied by other methods such as high-temperature treatment or air-blowing. Long-oil spar varnishes are appropriate as binders, and their tung oil content makes the paint layers very dense and resistant to moisture penetration in severe atmospheric conditions. The spar

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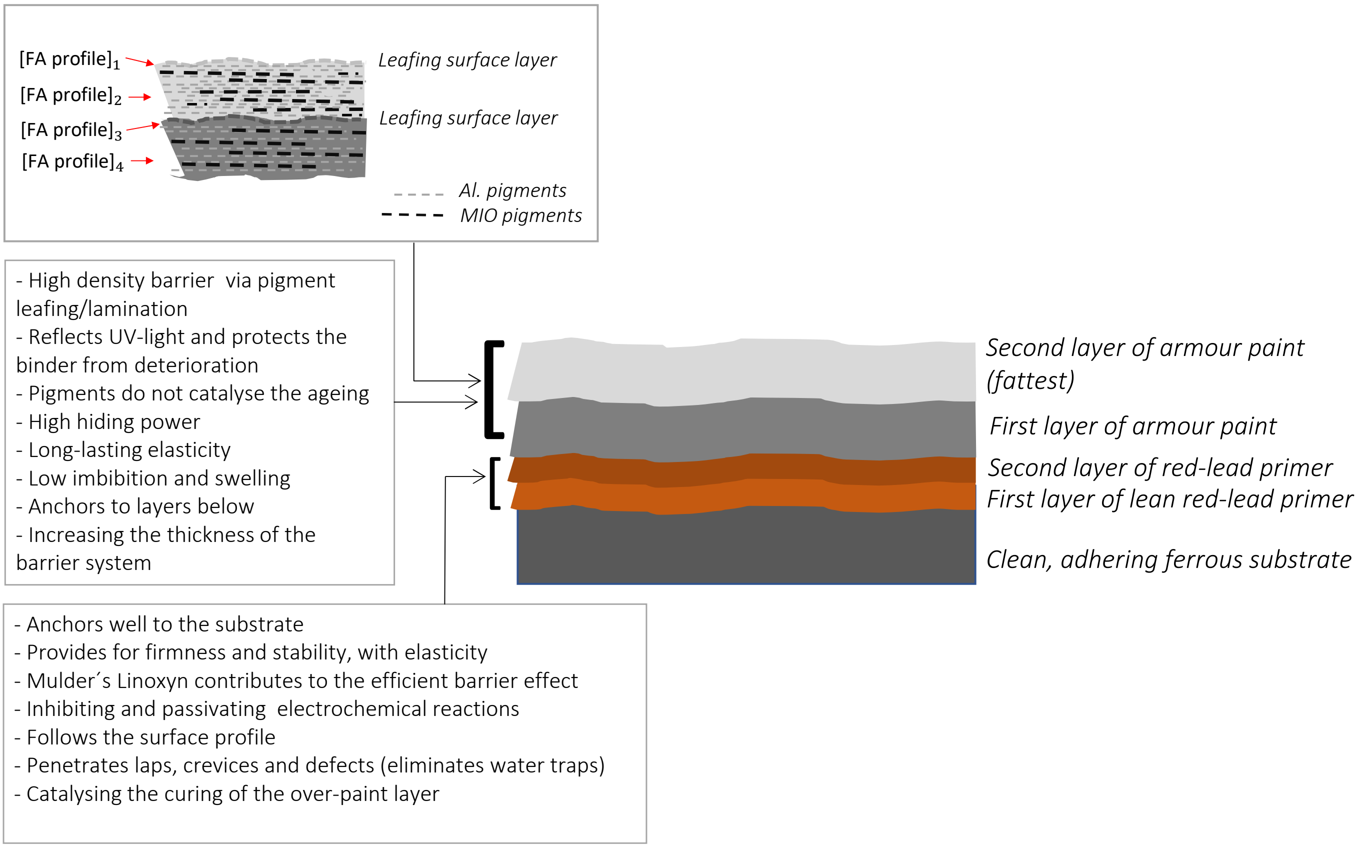
[49] The appropriate viscosities of armour paints for the use of anticorrosive treatments of power pylons at Vattenfall were determined with Ford-cup (Vattenfall, 1952, app. 2) to 2 minutes. The method measures the time for a certain volume of paint to flow out from a cup with an opening at the bottom. Further descriptions of viscosimeters are found in Talbert, 2008, p. 169.

varnishes show excellent spreading and covering features. Since spar varnishes are originally designed for wood protection, they are adjusted in order to be used as aluminium paint binders, since thinners (due to resin content) impair the paint film and are therefore undesired. The requirements on long oil varnish binders (i.e., only a small fraction of resin in a fat varnish) and aluminium paints were very similar; they should “set to touch” in a maximum of six hours and “dry hard” and to a firm, elastic and durable film in about 24 hours at a temperature of 20°C. When the resin content of spar varnishes is reduced, there are strong similarities with the characteristics of kettle-boiled varnishes. Kettle-boiled linseed varnishes (considered as varnish bases or “all-oil varnishes”) could include tung oil or perilla oil, making the similarity to long oil varnishes even more striking. Tung oil in a bodied linseed oil results in the entire film drying through in a faster rate, and this results in harder and denser film, which are advantageous as binders for aluminium paints. Viscous varnishes with a body, a high content of non-volatile binder, forms thick, tough films that make them more weather-, smoke-, and impurity-resistant. Viscous varnishes without VOCs, such as bodied linseed oil varnishes (kettle-boiled or blown varnishes), spar varnishes, and other long oil varnishes are all very suitable binders in aluminium-pigmented paints. The manufacturing of long oil varnishes was considered as a skilled art with a long tradition, but in order to determine the weathering resistance the varnishes are dependent on the experience of the varnish-makers and on the result of different empirical tests.

The results described in **Paper III** indicate that cold-pressed, highly refined blown varnishes could work for armour paints, at least for a short period. We do not know the impact of, for instance, binder polarity or wettability or the reflexive protective effects of aluminium pigment leafing or MIO. Blown oils are, as mentioned earlier, polar and therefore attracts water (Singer, 1957, p. 16). This may have effects in a later ageing stage.

Tinting of aluminium paints requires quite a high concentration of pigments with a high refractive index and/or colouring power (Edwards, 1927, p. 14). 10% red iron oxide to 20% aluminium paint will result in a rose, metallic tint. Moreover, brown iron oxides, chromium yellow, and chromium oxide greens were used. We know that different grey, blackish, or green colours were used for Swedish armour paints (described in **Paper II**). Two different grey and three green colours were common (Nilsson, 1948, p. 1391). It is important that the binder does not interact in a negative way with the leafing aluminium pigments. The oil properties, driers, and boiling of the varnish, and the additions of thinners or resins are important for determining the armour paints′ characteristics. Since aluminium is amphoteric, the acid number of the binder should be ≤ 7 (Edwards, 1936, pp. 13, 51, 67: Fergusson, 1988. pp. 788–798). Leafing pigments made from ultra-pure base metal, are used in the automotive industry due to their high acid and alkali resistance. Varnishes with lead driers should be avoided, since they may harm the metal colour and the brilliance of the leafing aluminium pigment. Too long shelf-life may lead to the leafing effect being ruined or the darkening of the paint. If aluminium paste is used, the viscosity of the binder should compensate for the thinning effect of the mineral spirits in the paste. Polar solvents will ruin the leafing effect and also the hydrophobic (and oleophobic) nature of the leafing aluminium pigments. Moisture condensation is unbeneficial since this may release hydrogen gas when the aluminium pigments react with oxygen.

The concept of a well adhering, elastic, inhibiting, and dense primer paint forming Mulder′s *Linoxyn*, preferentially in multiple layers, followed by multiple layers of dense, UV-radiation protecting, and elastic intermediate and topcoat (see updated model in **Figure 24**),



- High density barrier via pigment leafing/lamination
- Reflects UV-light and protects the binder from deterioration
- Pigments do not catalyse the ageing
- High hiding power
- Long-lasting elasticity
- Low imbibition and swelling
- Anchors to layers below
- Increasing the thickness of the barrier system

- Anchors well to the substrate
- Provides for firmness and stability, with elasticity
- Mulder´s Linoxyn contributes to the efficient barrier effect
- Inhibiting and passivating electrochemical reactions
- Follows the surface profile
- Penetrates laps, crevices and defects (eliminates water traps)
- Catalysing the curing of the over-paint layer

Figure 24: The concept of armour paint (updated from the description in **Paper II**). As described in Paper III, the surface of armour paints is oxidised, but beneath the leafed, "armoured" surface, the paints are still "young" and immature (i.e., there is still a high proportion of unsaturated fatty acids and a lower proportion of carboxylic acids) beneath the leafing surface layer. It is suggested that this will contribute to the long-lasting elasticity of the armour paint system.

Figure 25: Water droplets on a non-wetting armour paint surface.

has been proven to work (in the field) very well for the armour paints. Durability is dependent on the toughness or elasticity of the paint film (Edwards, 1936, p. 51). The need for long-lasting elasticity and water resistance is prevailed by the use of highly polymerised drying oils. The paint film should stand the attacks of sunlight and weather, smoke, and corrosive environments of industries. In other words, the paint system should function as an impermeable membrane for a long time. It is assumed that since the (oxidised) aluminium pigments and the MIO pigments are very stable chemically (as described in **Paper II**), and not multivalent, or soluble in the binder (or in water) – they are not expected to not catalyse the drying of the armour paint. For the same reasons, the pigments are not expected to accelerate the ageing processes. The ageing characteristics of two different remade armour paints have been analysed by a multi-analytical approach (described in **Paper III**). The composition and ageing characteristics are coherent to what we already know about paint with drying oils (or varnishes). The results shows that the values of %D is generally 35 wt% higher, the A/P ratio is >1, and the O/S ratio is lower for all the analysed historical paints (compared to the remade armour paints). It is not possible to determine whether tung oil was also present in the original armour paints, since the characteristics of oxidised unsaturated fatty acids are quite similar in linseed oil varnishes and tung oils. It is shown that %D (sum of the dicarboxylic acids pimelic, suberic, azelaic, sebacic) and the ratios of A/P and O/S also differ within the paint system. The oxidation/ageing state of the remade armour paints is generally higher at the surface (with higher %D and lower proportion of unsaturated fatty acids) compared to the state of the subsurface. Result from **Paper IV** confirms that the stand oil used in one of the remade armour paints has a higher resistance to ageing, compared to the other varnishes. The stand oil produces less dicarboxylic acids (mainly less azelaic acid, depicted in lower %D and A/P ratio) upon ageing. The fatty acid profile of liquid, solid, and aged oils and varnishes are shown in Supplement 2.

The investigated remade armour paints age in similar ways as the historical ones, as shown in **Paper III**. The fresh surfaces of armour paints are hydrophobic, see **Figure 25**. Armour paints start to chalk when they are weather-exposed, and may show some yellowing depending on their fatty acid profile and the concentration of unsaturated fatty acids. It has been shown that 5500 hours of accelerated ageing according to ISO 16472–2:2013 corresponds to about four years of ageing of the armour paints at the field test ageing station in Mariestad. Considering the already reported findings of armour paints from the early twentieth century, the length of the testing in the present research is very short. It is not known how the used different binders may affect the ageing over longer periods. It is indicated by the glass-plate tests (in chapter 6.2.8), that the preparation varnish with cobalt driers has poor resistance to water penetration, but this tendency may be retarded by the protective action of the pigments.

From an environmental perspective, the run-off of ions from deteriorating structures and objects may be retarded by the painting treatments. A lack of repainting maintenance intervals increases the risk of spreading the red-lead paint flakes that may pollute the surroundings. The historic use of red-lead primers is a problematic issue regarding anticorrosive paints and some aspects of this have been dealt with in **Paper II** and **Paper III**, for instance, isolation by over-painting. It is unfortunate, that the superior inhibitive action of red-lead paint also means the use of toxic pigments, and that the use of litharge in varnish making could produce the most durable paint binders (see chapter 6.2.5). It is important to understand how the paint systems work, in order to find inspiration from the past for alternatives such as complex phosphates or other types of driers.

6.3.3 Practical Experiences so far

In total, nine armour paints with different formulations have been produced in this research, guided by historical recipes and by the assistance of an experienced paint-maker (an example of armour paint with metallic finish is shown on page 84). Four of these are presented in **Paper III**. The remade armour paints have been used for applications on steel and glass. All armour paints with a tung oil content rapidly form a heavily wrinkled, thick skin in the can (exemplifed on page 186). Underneath the skin, the paint is in perfect condition for several years. During use, the paints need to be agitated repeatedly often due to sedimentation of the pigments. It has been noticed during use, that the paints release gas in the can during the use, which is observed as small "needle sticks" in the liquid paint surface. The liquid paint smells some white spirit but most distinct and dominantly of aluminium (an intense sharp and heavy odour associated with industry, metal working, lubricants), and white spirit.

Experiences of the remade armour paint show that they are easily applied and spread rapidly and smoothly. Brushing should be performed evenly and in the natural length direction. There is a slight difference in the body for different binders: those with more viscous, bodied oils give the paint more body. If the paint has a very high body, it will easily give a slightly striped appearance due to a reduced ability to level/smooth out after application. This is the case in the combination of varnishes which are high bodied and with a high content of leafing aluminium pigments, such as tung oils and stand oils. These versions require slight heating, diluent addition, or a finer application brush than a black pig bristle. A paint with body builds thicker layers but despite quite thick applications of between 50–75 µm, the paints dry within a day (however, 'ample drying time' would be considered a few days, or preferentially a week). The paint layer must dry properly before it is over-painted. The effects of a substantial and poor paint body have been described in chapter 8.2.7. Depending on the binder used, the gloss varies. If the armour paint contains stand oil, the level of gloss increases. For the same paint formulation, the armour paints with modern blown linseed oils are experienced as less bodied and less fat. Edwards describes that the leafing compensates for brush strokes and helps the levelling of the paint layers (Edwards, 1936, p. 86). The "ball up" tendency that Edwards describes, as a result of excessive brushing, has not been observed. But on the other hand, excessive brushing has not been needed. As described in **Paper II**, the armour paint forms a dense metallic floating surface layer and layers beneath, making it sensible to shear stresses.

Efflorescence is a colloidal phenomenon and is prevented when the solid paint film acts as a dense membrane that does not allow the bituminous substance to pass (Magnusson, 1931, p. 59). Edwards treats this ability to stop efflorescence, as a benefit of aluminium paints (Edwards, 1925, p. 11). Experience confirms that armour paints effectively retard efflorescence of tar staining through ordinary linseed oil paints. This was discovered when old corrugated stained sheets were repainted. Two applications of grey armour paint will stop the through-bleeding quite well, but the results should be even better with aluminium paint.

From the workshop "How thin is thin?", where ten traditional architectural painters applied linseed oil paints (dry matter content 98%) onto steel sheets, it was shown that normal WFT/DFT varies between 20–30 µm. How thin historical traditional architectural painters applied varnish paints could be determined from APR, but this has not been investigated further. It is very likely that the high performance of armour paint is a combination of the pigment and binder interaction, and bodied, polymerised varnishes that enable relatively thick paint layer applications. All this provides for an efficient barrier due to thicker paint layers and high levels of waterproofing, and low imbibition.[50] The tung oil addition made it possible to apply thicker layers (40–60 µm) compared to linseed varnish, due to rapid polymerisation kinetics that enables high drying power through the entire film. Since bodied oils were used, such as stand oils, it was difficult to apply layer that are too thin. The barrier properties are further improved by the lamellar pigments, that close-pack the paint film and protects it from deterioration. The finest lamellae sizes provide the highest hiding power and protection of the substrate.

Despite the historic specifications and formulations of the armour paint systems provided in **Paper II**, a restarted production is not trivial since oil varnish paint making is complex and requires a lot of experience. The effect is that the protecting power may vary depending on paint quality in short and long time-span, as has been indicated in **Paper III** and **Paper IV;** such as differing wettability of painted aged surfaces the same paint recipes (with different binders). Short-term aspects include that the paint should easily leave the brush and be applicable, have a sufficient body for giving the desired layer thicknesses, and adhere well also to a vertical substrate. Long-term aspects include the use of a protective mixture of pigments and extenders, weather-resistant, elastic binders that behave well in the atmospheric exposure for long time. To read a recipe and try to make a product is not sufficient to reconstruct the tangible and intangible aspects of the tradition. This is valid for cooking as well as for paint making. The raw materials are almost impossible to replicate, and are seldom specified in detail. And even if the raw materials are specified, the working procedure for the paint making holds a number of moments that could be performed in different order and with different quality assessments. As for any craft, the practice needs to be repeated over and over again in order to develop the skills that are required to achieve the product that the painter wants to use, as illustrated by the quote below. Still, the reproduction of nine armour paints shows that it would be possible to restart an armour oil varnish paint production. At the remaking of the armour paints, it was experienced that bodied tung oil and tung stand oil are very difficult for a small paint-maker to buy from the European industrial oil- and varnish-makers. The same is the case for linseed stand oils with a viscosity below 50 dPa·s. This makes it difficult to produce armour paints with formulations as the historic, which also contained quarter tung stand oil; a co-processed product of refined linseed oil and tung oil, which is not produced any longer. At least, no producer has been found.

> *”Two paint-makers, who use the same raw materials and apparently the same procedures, could deliver different products, and vice versa could two paint-makers with different starting materials and different processes be able to release products to the markets that appear to be of the same quality.”*[51]
> (Heckel & Carlbom, 1925, p. 54).

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[50] As a comparison, the life-span of an anticorrosive painting treatment with a total paint layer thickness of 80 µm is estimated to last 15 years, compared to 10 years for paint with thickness of 60 µm (Trägård, 1961, p. 53).

[51] Translated from: *“Två fabrikanter, som använda samma råmaterial och till synes samma förfaringssätt, visa sig leverera olika produkter, och vice versa två fabrikanter med olika utgångsmaterial och olika processer kunna utsläppa produkter i marknaden av synbarligen samma kvalitet.”*

CHAPTER 7

PROFESSIONAL PAINTING SKILLS

Anders Brodin (1840–1923) was a Master Painter in Hälsingland, Ovansjö parish, Sweden. He is an example of a traditional painter who tailor-made his paints for different purposes, but occasionally also used semi- or ready-made paints.

PROFESSIONAL PAINTING SKILLS

The results from **Paper V** and **Paper VI** show that by using research methods from sensory research, it is possible to articulate sensory perceptions of drying oils and varnishes, and that a correlation has been found between different types of products and quality attributes. Through attentive and active training, this ability could be improved, as for any field that involves consumers/painters and intimate correspondence with the materials and the actual affordances. The value of this result is that the initiated vocabularies, or the methods for generating other paint material or substrate characteristics, may be utilised in education and professional communities of mutual or individual attentive learning and for further development of material intelligence and painting skills.

This chapter briefly describes the profession of traditional architectural painters, historically and today. It reviews some of the factors that are considered as crucial for developing craft skills and attentive learning that is important for conducting working procedures. The initiation of sensory vocabularies for linseed oils and varnishes is presented and some comparisons are made with historical descriptions.

7.1 The Painting Profession

The craft organisations in Sweden that regulated the establishment of professional painter's and the quality of products (i.e., the craft guilds [*skrån*]) were abolished in 1864 by the regulation for the freedom of trade (Fridell Anter & Wannfors, 1997, pp. 146–148, 231: Johansson, 2002, p. 9). The traded knowledge of the guilds was replaced by vocational and evening schools in the 1920s which traded and developed the professional knowledge. When people became free to take employment or start businesses where they wanted, urbanisation began. Industrialisation grew, as well as the expansion of the public and the transportation sector, with increasing needs for decorative and functional painting treatments. The painting profession was affected by the development in the painting industry, as described in chapters 6.1.1 and 6.3 and the small-scaled craft paint making existed on parallel with the industrial paint making of the early to the mid-twentieth century, when the modern paints were introduced. When the older paint types were no longer requested by the customers, who had begun to paint for themselves, the competence space of the painters gradually diminished.[52] The number of professional painters was about 500 in 1820 and 15,000 in 1910 (Fridell Anter & Wannfors, 1997, pp. 146, 228–235). In 1932 it was agreed by trade unions, that other professionals had the right to paint: such as sheet metal workers got the right to paint steel-sheet roofings. From the mid-1950s, a common 'do-it-yourself' house painting movement grew, with mostly modern paints. In 1965 the first female painter graduated.

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[52] The competence space describes the possibility for the craft practitioner to implement practical knowledge of action (Sjömar, 2017, p. 85). The competence space is decreasing when the competence is not requested by customers. Finally, there is no need to hold the materials or tools since they are no longer desired, and thus the competence is not traded any longer and the craft traditions are diminished or become extinct.

The traditional architectural painters' education first involved being a painter´s attendant (*dräng*), followed by five years as an apprentice (*lärling*), then a few years as a journeyman (*gesäll*) under the supervision of a master painter, before finally becoming a master painter (as exemplified on page 146) (Hansen, 1990, pp. 1–2: Fridell Anter & Wannfors, 1997, pp. 231–235). A four-year education was established in 1944 by the painters´ trade union and the employers. Today, the painter's education is usually three years + two years as an apprentice, but the education is focused on modern painting materials and methods. The traditional architectural painters and decorative painters of today have received different specialist educations of one to two years, have worked as apprentices for experienced painters (who may have learned to conduct tasks from earlier generations), or are self-taught. Of course, this means a difference in the level of competence between the older and the contemporary architectural painters, but also in comparison to the modern painters. There are no (or few) old painters left who were active before the 1960s and who could show or tell us about how they experienced the historical paints and especially how the (anticorrosive) oil varnish paints were made and used. Only two oil paint-maker companies in Sweden have a continuity that goes to the early twentieth century; all others started in the late twentieth century. Today, the traditional architectural painters usually use ready-made paints for outdoor painting treatments, but may make their own oil paint for indoor use or for small outdoor works.

It was through the personal master-apprentice relation that the painting professions were learned until a hundred years ago, which could be described as a continuous cultural trading of content over generations (Rolf, 1995, pp. 140–150). Strong traditions are supervised and the quality is assessed by some sort of institution and social structure (such as the craft guilds), and when the master´s vocabulary, material, and working procedures have been transferred to new generations over time. The criteria for quality assessments are intersubjective. In weaker traditions, the extensive supervision does not exist and the knowledge is legitimised by its use. Teaching and actions are still conducted according to transmitted praxis, procedures, and norms, as expressed by Sjömar (2017, p. 104), though todays paintings traditions could be considered as weakened compared to the time before the Second World War. We, the painters and paint-makers, still make and use lime paints, different types of vegetable and animal glue paints, emulsions, and drying oil paints, and we still also make/repair decorative paintings such as wood graining, marbling, stenciling, guilding, and freehand paintings in different media. The traditional architectural painters make and repair substrates of materials such as ceiling and wallboard (*spännpapp), jute fabric (juteväv), linen board (linne/grålumppapp)* and so on. Depending on the size of the object, the ageing conditions, and the costs and experiences, paints may be achieved ready-made or made by the painter. Today, the painters work also with different types of "natural" paint types, such as modern hybrid paints for eco-building. No craft traditions are static—materials and methods, substrates, and ideals have evolved from the very first paintings by humans right up until today. The painters´ profession could—as for many professions active in the care of built heritage—be described by Pye's expression "*workmanship of risk*". By this, Pye means "*workmanship using any kind of technique or apparatus, in which the quality of the result is not predetermined, but depends on the judgment, dexterity, and care which the maker exercises as he works*" (Pye, 1968, p. 4-8). The number of traditional architectural painters is uncertain today, but an estimation can be found in **Paper II**. It appears to be close to the number of painters in the early nineteenth century. In the same paper, the profession of linseed oil paint-makers has been further described.

7.2 Practical Knowledge

Rolf describes some of the factors he considers to characterise professional and practical knowledge (2017, p. 53). To "be skilled" is to be able to do something in a particularly skilled way, compared to others that are not professionals. This appears as a very coarse and blunt description of professional craft knowledge. Skills could also be described as a result of ecological relations; perception and action by the human situated in an environment (Ingold, 2011, p. 5) or as sensory reading of the materials (Kuijpers, 2018, p. 864). Therefore, Ingold refers to skills not as something which as traded between generations or across social contexts, but as results of training and experience of the individual in the frame of the task´s *modi operandi* (Ingold, 2011, p. 5: Ingold 2018a, p. 161). Skills are described as the initiation of all knowledge, and the words connected to skills as "*among our most treasured possessions*." Ingold describes skill as involving "*...both movement and feeling, [skill] is never still or silent*." My standpoint is that knowledge may be tacit, as Polanyi refers to it (2009, p. 4), but we can be trained to observe, describe and communicate parts of it. The more we train the better we get. The groundbreaking influence of James Gibson (1966) on the perception of the environment by our senses, and the ability for active, attentive training has been explained in **Paper V**. In this paper, it is described such training might also be given in shorter time perspectives. The affordances may result in many possible results, depending on recognition and sensorial response to the qualities and constraints of the material (Kuijper, 2018, p. 881: 2019, p. 609). Skills develop where the material and the practitioner meet, in a cognitive knowledge. Rolf denotes professionalism with "action competence" (*handlingskompetens*) and metacognition (Rolf, 2017, pp. 58–64). The former means to do the correct actions at the right occasion and is usually based on procedures passed down in a professional tradition. The professionals are able to *make* quality improvements and have the authority to do so. Metacognition means (self) conscious request of inquiry, reflection about the practical knowledge, re-evaluation, and/or some type of validation, in order to improve. So, professional knowledge could be described as being able to play the game (do the craft) and to discuss and change the rules of play (craft).

Theory and practice are closely related and hard to distinguish (Rolf, 2017, pp. 66–71). Both are well-grounded, rooted in systemisation, mental and embodied representations, actions, and assessments. Practical/practice-led knowledge could be considered as a tool to reach a practical result or goal, like being able to perform a working procedure; it always involves some sort of action (Sjömar, 2017, pp. 85–102). Practical knowledge includes competence: to implement knowledge into action and to take actions at the right time for a certain achievement. The concept 'craftiness´ (*hantverklighet*) is meant practical problem solving by skilled use of material, methods, and aesthetics. This is the ability to adapt and adjust the implementation to the affordances. To know something about a craft is not synonymous to having the ability to conduct it. To know how to conduct a working procedure, and how to control the results, is significant for the professional knowledge. This can only be achieved by repetition over a long time, in order to develop experience and understanding of the craft (the profession).

7.3 Material Intelligence and the Art of Correspondence

"Material intelligence" is a term that is used in different contexts such as design or technologies. For instance, Adamson has described it in relation to art and craft (2007) and material culture. Material intelligence refers to a conscious awareness about the nature, handling, production, and behaviour of materials that we meet in everyday or in our professions. The term "material intelligence" could therefore be used to describe an understanding and connection of the metallurgical and industrial properties and values of different types of metallic materials, but also the connection of historical anticorrosive paints and associated painting crafts. Material intelligence involves an active perception that trains attention and leads to enhanced knowledge of the material characteristics. This develops the necessary knowledge and craft skills for, for instance; the making or adjusting of anticorrosive paints, or the adjusting of substrates or tools, and for problem-solving. To have material intelligence is to be a step ahead of the material—what Sennett refers to as *anticipation* (Sennett, 2008, p. 175). For me, to have anticipation is to search through the earlier experiences that formed embodied and mental material models and try to predict the material′s response to possible actions and alternative scenarios. Every material interaction and every act of problem solving or decision-making influences the plasticity of the brain (Hari & Kujala, 2009, p. 470: Seitamaa-Hakkarainen et. al., 2016, pp. 4–5). Ingold describes being among and putting the pieces, the tasks, the materials, and actions together, as a type of *correspondence* or as an *art of correspondence* (2013, pp. 69, 72, 85). The boundaries between the practitioner and the material and tasks blur and merge gradually. Through correspondence, the touch and observations come close to our being and the surrounding and interacting materials. Ingold describes this with the following quote:

> *"To describe a material is to pose a riddle, whose answer can be discovered only through observation and engagement with what is there. The riddle gives the material a voice and allows it to tell its own story: it is up to us, then, to listen, and from the clues it offers, to discover what is speaking. [...] to know the materials we have to follow them— to 'follow the matter-flow as pure productivity' — as artisans have always done. Their every technical gesture is a question, to which the material responds according to its bent. In following their materials, practitioners do not so much interact as correspond with them."*
> (Ingold, 2013, p. 31).

Traditional architectural painters correspond constantly with the materials; interpret the texture, the strength, the cleanliness, and the absorbance of the substrate, as well the response to consolidation and application efficiency, paint drying stages, paint ingredient and paint qualities by smelling, touching, listening, and seeing, as exemplified in chapter 8. The interaction with and active attention towards the environment—the correspondence— between the painter and the materials is trained and developed throughout the painter′s professional lifetime. By paying active attention to the complex relationship between material, skill, and quality, the practical knowledge increases (Kuijpers, 2018, p. 887). Improved material intelligence is needed for paints and substrates in order to make sustainable measures. "The art of correspondence" is multiple since it is not only delimited to the paint and painter, but also the nature of the ferrous substrate and the atmospheric exposure.

7.4 Selective Attention and Associative Learning

The human perception systems' interaction (or correspondence) with the surroundings is described in **Paper V**. Humans continue to develop the nerve system and cognitive capacity throughout their entire lives (Gibson, 1966, p. 266 ff.: Barsalou, 1999, pp. 579–585). In selective attention and associative learning, perception and cognition are intertwined due to shared neural systems, with simultaneous functions in the same mechanisms. Perception is stored in a long-term memory (in the form of conscious and unconscious symbols, that develop cognition). Symbols are records of the neural unconscious states that underlie perception; they reflect the experience that created the memories. The neural system that represents, for instance, perceived colour, also represents the colour of objects in perceptual systems. Later, the perceptual memory may function symbolically for associative recalling of components of the world. This is very similar to so-called mental imagery (mental models), used for recalling physical objects or experiences in their absence, to simulate event sequences across different attribute domains such as vision, touch, and olfaction or proprioceptive (bodily) experience (Barsalou, 1999, p. 585: Palmiero, Di Matteo & Belardinelli, 2014, pp. 144–147). Visual imagery and auditory imagery and thus verbalization are easier to form than odour representation. When humans can remember, identify, and name (for instance) sensory stimuli, this is based on associative learning and neurological connections between emotions and memories and semantic meaning (Barsalou, 1999, p. 579: Zucco, Herz & Schaal, 2012, pp. 97, 117: Keller & Vosshall, 2016, p. 12).

Language substitutes things for words, as codes or symbols for associated perceptions, as schematic memories of spoken or written experiences (Gibson, 1966, p. 281: Barsalou, 1999, p. 585: Rolf, 1995, p. 21). The linguistic code represents different meanings, depending on the lexicon; the code of the group, culture, or social context. Languages have grammatical rules and are able to express predictions in sentences learned by convention from earlier generations (even though values, context and meaning may have changed). This makes it possible to generate a mental image from a verbal description, or to generate a mental image from a semantic description (Palmiero, Di Matteo & Belardinelli, 2014, p. 144). Metaphors may be considered as representations of abstract concepts. Communication could also be transmitted through gestures, facial expressions and mimicry, images, writing, and so on. (Gibson, 1966, p. 27). An introspectively trained person could learn how to detect, differentiate, and evaluate the input of the perception system (Gibson, 1966, pp. 283, 319). *Extero-sensitive perception* refers to self-guiding and self-tuning, when observing a material or reacting to an action/event (Gibson, 1966, p. 275). Molander (1996, p. 143) points out the importance of *focused attention* in craft situations. Humans learn how to observe critical features, distinctive variations, characteristics of substances, textures of things, and so on. *Affordances* refer to what the situation or object offers the observer, the craft practitioner (Gibson, 1966, p. 285).

7.5 Reflection and Action

A craft person learns how to observe and differentiate critical features, distinctive variations, characteristics of substances, textures of things, and so on (Gibson, 1966, p. 282). A curious person can always observe more properties than he or she can put into words. This is close to the concept of tacit knowledge, launched by Polanyi (2009, p. 4) in "*we can know more than we can tell*". The perceptual experiences are characterised by thoughtful activities, in order to make sense (Noë, 2008, p. 664). Perceiving sensations and remembering are actions which are inseparable from the past, presence, or future, making mental comparisons in self-consciousness (Gibson, 1966, pp. 234, 275). It is not possible to say when perception starts and memory ends. Mental comparisons (or images are) involved even in the easiest abstract connection of cause-and-effect. Experiences may be pointed out by a second person, as a type of mediated perception. Knowing how (in contrast to knowing that) may be considered as practical knowledge, which is not necessarily expressed (Ryle, 1949, p. 25 ff.: Molander, 1996, p. 48). These standpoints are grounded in American pragmatism. Husserl (1859–1938), Heidegger (1889–1976), and Merlau-Ponty (1908–1961) were philosophers pointing out the connection between mind, perception, and living experiences. Dewey and Schön explain embodied knowledge as reflection-in and reflection-on actions (Dewey, 2005: Schön, 1982). Groth describes how the cognitive, embodied mind interacts with the environment in an enactive approach (Groth, 2017, pp. 20–21). In this, the body is integrated in all knowledge since learning is a result of activities and experiences that are accumulated in the body. Thompson & Pascal (2012, p. 317) point out the neglected importance of language and meaning. They suggest that practice should be critically paired with self-analysis and introspection, for the development of a language and dialogue. When humans interact socially, these actions are internalised and the language and cognition develop through reflective practice progress in cyclic ways (Collin & Kasenti, 2011, pp. 572–574). Reflective practice is described as an individual process without consideration of the importance of social verbal interaction, called reflective conversation. The collective dimensions of reflective practice stimulate us to verbalize and share individual reflections and *a priori* knowledge, to consider attitudes, and to shape and reshape theories. These things can be reinvested into professional actions, for instance, in teaching situations.

When the materials look similar but behave differently (such as oils and varnishes), active attention to characteristics and details becomes important. This helps to create “mental model” of the nature of the material and how it might behave in different situations. A similar “inner image” is described by Molander (1996, pp. 115–116), concerning a meteorologist who is predicting the weather forecast based on theory, abstract parameters, experiences, and so on.

7.4 Sensory Vocabularies for the Characterisation of Oils and Varnishes

> *“The nose is a very useful factor in testing of oils, and no opportunity should be lost in training and exercising it in duties in this respect. But one must not be led away even by a smell into the fields of imagination; one must not imagine himself into Dantés Inferno every time one smells sulphur.”* (McIntosh, 1904, p. 94).

The quote above, and also the statement from Andés *“..that for the painter and lacquers, the senses of taste and smell are the best ways of testing the linseed oil quality, that rarely fail after some training*”, supports a picture that our senses are useful tools for the quality assessments of oils and varnishes (Andés, 1922, p. 28).[53] It has been explained in previous sections how the complex correspondence between materials, skills, and quality could be addressed with the aid of a vocabulary, which might help to put focus on details and *being with* the materials. To dwell on the situation, on the materials, and on the perception makes it possible to verbalise and expand knowledge. This could enable communities of mutual learning, with discussion based on observations, reflections, and experiences, therefore increasing the material knowledge/intelligence. Through this, the action competence of the traditional architectural painter could be improved as described in **Figure 26** and **Paper V** and **Paper VI**. Utilising such vocabulary, the traditional architectural painters may be able to define their practices. In

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[53] Translated from: “*...men för målaren och lackeraren äro smak och lukt de bästa prövningsmedlen, vilka efter någon övning sällan svikta*”.

the longer term, this will also have an impact on the intersubjectivity and quality assessments in the painting craft. This will improve the possibility that the craft will be continued.

Examples of professional painters´ everyday sensorial assessments (as reported in Part 3 of the Research Design, **Paper V**); controlling or adjusting the viscosity of made paints (vision, touch, or resistance), detect whether the paint or paint ingredients are rancid or defective (odour, vision, weight, colour, drying capacity by time and touch), having knowledge of paints´ drying power, adherence or hardness (sound, odour, haptic touch, nail scraping), checking the firmness and absorption of the substrate (vision, touch, temperature), checking colour combinations or adjustments (vision), review complaints or default equipment.

In the following, the sensory attributes of oils and varnishes in some historic sources are described, in order to enable comparisons with the present result. Usually, the written descriptions of oils and varnishes are very brief, and only states that the painters or paintmakers used to smell the linseed oil or oil varnish before use, but the sources very rarely specify the quality attributes (for example, Karlsdotter Lyckman, 2002, p. 1).

An odour test of oils and varnishes could be performed by placing the oils between the balms of the hands and rubbing intensely (McIntosh, 1904, p. 94: Uebele, 1913, p. 271). This will warm up the liquid which increases the intensity of the emissions. Falsification additions are easily revealed, for instance, by the smell of resins. By rubbing or holding the oil or varnish between the thumb and forefinger, the viscosity is estimated, and the odour of additions may be revealed by holding the liquid in the balms of the hands (Bottler, 1912, p. 147). Moreover, turning proof-glasses are used, but it is not described how it works. Possibly, it refers to placing the liquid between the glass plates, that are turned relative to each other 180 degrees. For instance, for the printer's ink (stand oil), the varnish should be tough and stringy, but not sticky. The turbidity of the varnish during making is checked by putting drops on a glass plate (Hausluck, 1905, pp. 10, 54). It is assumed that the glasses are held against light to reveal turbidity. Putting the oil between a finger and thumb and drawing them apart should form strings and the varnish should be very elastic. The greasiness of oils is also telling as how two surfaces can adhere together but still slip apart, like the effect of a lubricant. They should not be mixable with water and should be hydrophobic, but it is not described how this is assessed. It is assumed that the oil or varnish is placed in a jar and shaken, and when settling then should separate into different layers. The "string test" was used during varnish making (Macintosh, 1904, p. 63). A fraction of the varnish is removed with iron spatulas and cooled by rapid agitation. A droplet is placed and pressed between the thumb and finger. The fingers are drawn apart as wide as possible and the length of the longest thread that could be formed without rupture is a measure of the quality.

Cold-pressed raw linseed oil is described in historic sources as a *very clear, yellow or golden yellow oil, with a mild/tasteless or peculiar taste and mild/almost neutral smell,* **Table 8** (Winckler, 1859, pp. 77–78: Andés, 1900, pp. 140–142: Luger, 1908, p. 134: Fahrion, 1911, p. 263: Bottler 1912, p. 39: Ubbelodhe 1920, pp. 378, 397). Raw warm-pressed oils are described as *dark, brown brownish-yellow, amber with a strong less agreeable smell and intense, harsh (amper), bitter-sweet taste.* Descriptions of blown varnishes have not been found at all. Fire boiled varnishes are described as *yellow, light green, yellowish-brown or pure brown with a bitter taste.* The odour of fire-boiled varnishes is described by an explanation of how it should *not* smell: as they should not be; *maladorous, empyreumatic, pungent, strong.* A good varnish is similar to raw linseed oil, but there are "empyreumatic" *aromas* i.e., from burnt or charred organic matter as a result of decomposition at high temperatures (Andés, 1900, pp. 140–142).

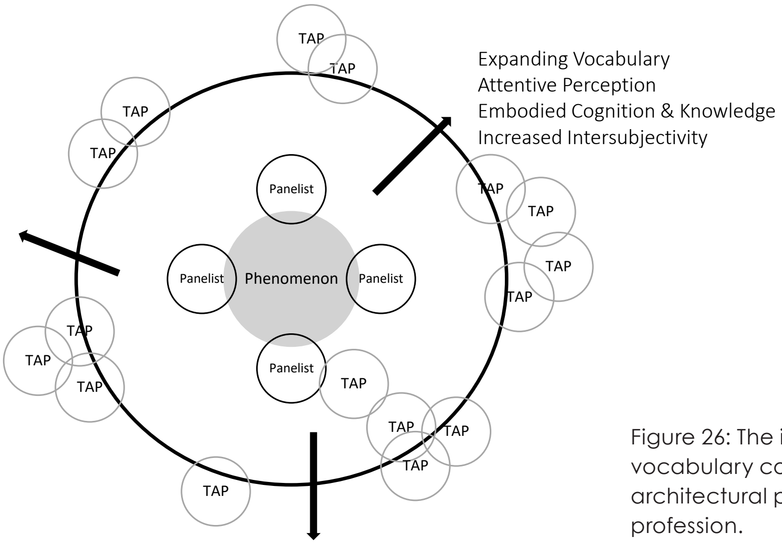

Figure 26: The initiation and use of a sensory vocabulary could expand to other traditional architectural painters (TAP) and revitalise the profession.

The smell may be *unpleasant* but not *malodorously bad*. Overheated varnish is blackish brown and smells empyreumatic. Holley & Ladd state that the smell of varnish will often tell much of its value (1908, p. 269). Attributes indicating the quality of a fine varnish include a "*good, wholesome and gummy smell*"; those of a poorer quality include a "*strong, raw, pungent odour*". The after-smell that occurs when the varnish has been in a small container or beaker for 3–5 minutes and then poured out could also be used to describe the odour qualities of a varnish. More nuanced descriptions and specifications were written by Karl Magnusson, R&D leader at SOAB, who describes the odour for raw, bleached or refined linseed oil as *flowery* or *cucumber*-like (Magnusson, 1931, pp. 65–68). He in return was inspired by the German specifications for oils and varnishes (*Deutscher Reichnusschuss Fur Lieferbedingungen*) which also describes the odour in this way. Rancid oils and varnishes could be assessed by a method described by Cronqvist (1871, p. 86). The suspected oil is mixed with water that settles, and if this water has a sweet taste, it is a sign of glycerol. Another indication of glycerol is when a burnt water droplet smells like a *recently quenched oil lamp* or *tallow candles* (glycerol). The rancidification will increase the acid value of the oil, FFA, Peroxide, or p-Anisidin value.[54] A method that is used in edible oil technology (heating 60°C/60 h with air access) was applied for drying oils in this research, with the result that the intensity of their odour attributes diminished.[55]

Compared to the historic sources, the results from sensory assessments in this study are more nuanced and could be correlated to different types of oils and varnishes. The attributes of colour and turbidity are fairly similar in the vocabulary used historically and in the sensory vocabulary used in the present study (**Paper V**). The odour attributes of *mild*, *flowery*, and *cucumber*-like are coherent with attributes in the olfactory description of oils and varnishes (**Paper VI**). The *non-empyreumatic* odour is a new, and useful word from historic sources. It is obvious that the oils and varnishes were tasted historically, but this we do not do due to the content of driers. The viscosity descriptions of fire-boiled varnish are more consistent with stand oils, and this confirms the earlier-mentioned descriptions of high-temperature heated

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[54] At rancidification, the unsaturated FA´s undergo free radical chain reactions that promotes the breakdown of unstable hydroperoxides into different types of compounds, which causes rancid odours and flavours. This occurs to free and bind FA´s (to TAGs). Alvés, 2015, p. 54.

[55] Used by sensory experts employed at AAK in Karlshamn, November 2019.

varnishes with *stand oil character*.

The written academic format makes it very difficult to communicate the subtle nuances of sensory quality assessments, even to professional painters. It has been experienced during the research that it is difficult to verbalise sensory quality assessments if not being present in the actual situation—and even then, it might be hard. This can be observed when video recordings are analysed. The personal, embodied knowledge of traditional architectural painters differs from that of the next, since we all have different experiences and also perceive the world differently depending on the social context (Hari & Kujala, 2009, pp. 458, 460, 470). Despite this, it is possible that individuals have similar perceptions when sharing similar experiences, leading to intersubjectivity. This could be partly explained by the so-called mirroring in social communication. The initiated vocabularies are directed to persons that have corresponding craft skills because they have a preconception of the perception of the materials. To hold a protocol for wine-tasting does not make you a sommelier, and it takes time and continuous, active training with correspondence with the materials to gain skills. This is also the case with sensory assessments of paint materials. My experience is that the difficulty in expressing perception and assessments of the quality of the craft is a result of lacking reflection on, attention towards, and discussion of situations. During the profiling sessions, it has been clear that there is a difficult threshold to pass through in the verbalisation of the sensory assessments, but it is possible to do so through training, even in a short timespan (with the repertory grid method). A summary of the panellists´ experiences of the profiling are found in Supplement 4.

Table 8: Quality attributes of fat oils and varnishes in some historic sources.

	Raw cold-pressed	**Raw warm-pressed**	**Heated/ preparation varnish**	**Fire boiled varnish**	**Other**	**Reference: page**
Colour	"Very clear" yellow golden yellow pale and clear Colourless Brown-yellow	Dark Brown Brown-yellow Amber	Not found.	Yellow Light green Yellow-brown Pure brown Port wine	Mineral/resin: green-tint bloom on black background. Cottonseed oil addition: flaky matter	Winckler, 1859: 77–78 Andés, 1900: 156 McIntosh, 1904: 94–95 Lueger, 1908: 134 Fahrion, 1911: 263 Bottler, 1912: 39 Ubbelode, 1920: 378, 397
Smell	Mild Almost neutral Like castor oil	Strong Less agreeable	Not found.	Gummy Unpleasant Not stinky Not empyreumatic* Not pungent		Bottler, 1912: 39 Andés, 1900:140–142, 156 Holley & Ladd 1908: 269 Fahrion, 1911: 263
Taste	Mild Peculiar Characteristic Sweet Tasteless	Intense, Peculiar Harsh/(amper) Bittersweet	Not found.	Bitter (Irritating)	Old: acrid Resin: bitter, biting, acrid, nauseous, persistent	Fahrion, 1911: 263 Bottler, 1912: 39 Standage, 1892: 23 Andés, 1900: 140–142 McIntosh, 1904: 94–95 Ubbelode, 1920: 378, 397
Viscosity	Not found.	Not found.	Not found.	Syrup Molasses "Treacle that comes from sugar"		Smith, 1687: 38–39 Bottler, 1912: 158 Edward, 1924: 7–9

CHAPTER 8

WORKING PROCEDURES

An example of a sound management strategy and repainting maintenance, with planned seven-year repainting intervals (using linseed stand oil paint). Ulvåsa Egendom.

WORKING PROCEDURES

In order to draw attention to the importance of details of how the painting treatment is conducted, some of the material correspondence and critical quality assessments that traditional architectural painters conduct during the working procedure are exemplified. The description attempts to articulate sensory quality assessments, as a part of the continuous correspondence between the materials and the painter. Today's procedures are put in relation to some of the historical descriptions, and the assessments that painters may carry out are described. This information could be used in order to improve future guidelines and working procedures.

8.1 From General to Specific

> *"There is hardly any work that demands more attention and accuracy than the implementation and the choice of materials to achieve the desired effect – for the highest possible protection against rust."* [56] (Fallgren, 1934c, p. 245, on anticorrosive treatments).

The quote above (by a Master Painter) describes how traditional architectural painters consider the challenges of conducting anticorrosive working procedures. The purpose of the painting treatment of a ferrous substrate is to provide for an efficiently long-lasting, easily maintainable, protective organic barrier between the atmosphere and the substrate. Some crucial requirements of oil varnish paints have been described in chapters 5.1 and 6. A high-quality paint is not sufficient; furthermore, it needs to be applied to the substrate in a manner that relies on practical experiences and validated best practice. Therefore, even with a sound working procedure, the outcome could differ – depending on the correspondence between the painter, paint and substrate as indicated in **Figure 11**, but also on weather conditions.

A working procedure could be specified to a limit, for instance, by the material and method matrix system presented in **Paper I**. A working procedure is a specification and a description, yet an approximation, of the chain of conscious actions that consider the continuous quality assessments adapted to situation affordances, from the start to the end of treatment (or intervention) in order to achieve the desired end-result. Each step is assessed as successful before the next one starts, though planning actions may be performed in tandem with ongoing steps, depending on the experience of the traditional architectural painters. At *critical incidents*, problems or difficulties that are overcome – or the way of conducting the sequence are changed (Groth, 2015, p. 15). In addition to this, I would like to describe critical incidents as steps of critical quality assessments that the painters conduct on-site during the work and that can more or less be communicated. This is a type of procedural knowledge (Rolf, 2017,

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[56] Translated from: *"Det torde knappast finnas ett arbete som kräver mera omsorg och noggrannhet vid utförandet och valet av materialier för att den avsedda effekten ska uppnås, ett i möjligaste grad effektivt skydd mot rost".*

p. 51). There is no universal way of conducting an anticorrosive painting treatment, but some basic steps are always the same. Every situation is unique and affordances and conditions vary for every object. A specific step or goal is proceeded by a diagnosis, a prognosis, an intention, and a choice of known or novel actions (Sjömar, 2017, p. 180). The results are evaluated and put in the experience bank of the practitioner.

Typically, the *historic working procedures* advise for thorough working and cleaning of the ferrous substrate before priming with red-lead oil or varnish paint (Karmasch, 1862, p. 609: Mulder, 1867, p. 221: Simon, 1897, pp. 286–287: Andés, 1900, pp. 162–182, 204–221, 256–268: Sabin, 1905, pp. 12, 14–15, 40: Uebele, 1913, pp. 327–330: Lisinki & Jonsson, 1979, p. 69: Fuller, 1988, p. 769). After ample drying times of up to two weeks, additional thin layers were added of different types of oil varnish paints. The required high adhesion and elasticity of the paint films are emphasised. About 1% oil turpentine could be used for adjusting the applicability of the paints, but this is usually not recommended. The number of paint layers should be at least four, and this gives the painting treatment a lifespan of between five to ten years. After applying the topcoat, a fine sand may be dusted over the surfaces. For ferrous structures prepared at a workshop and mounted *in situ*, an easy-flowing red-lead primer of linseed varnish is applied with stiff brushes to ensure penetration to all contact surfaces and irregularities. A final red-lead primer is added after mounting, touch-up and puttying (usually a mixture of red lead, white lead or zinc grey with linseed oil, or asphalt putty). Alternatively, a paint consisting of 90 wt% thin quick-drying varnishes and 10 wt% of zinc-white could be used as the primer, or a natural red iron oxide linseed oil primer. Advice for warming up the oils and paints, or objects before priming was common. Then, thicker layers were applied in two to three additional coatings with a proper ample time in between each layer (at least a week). Moreover, descriptions of fewer paint layers exist as well as the use of neutral or no special primer paints (Rothstein, 1856, p. 248: Lisinki & Jonsson, 1979, pp. 73, 75). These descriptions without designated primer paints and fewer layers often state very short repainting intervals. The importance of skilled practitioners for conducting anticorrosive painting treatments is stated by Andés´ quote; *"The painting should be done by skilled workmen and not by day labourers"* (Andés, 1900, p. 268).

> *"In the question of protecting iron from rusting, the use of an oil paint, made from good materials, properly laid on and renewed in good time, is still the best means available for this purpose on iron structures. Moreover…this will I long continue to be the case, for he [the author] cannot conceive any other coating endowed with the same qualities and so easy both to apply and renew".* (Andés, 1900, p. 58).

Three applications of paint is generally considered as the common painting practice *today* but the required thickness for anticorrosive treatments depends on the corrosivity class, the substrate, the paint system, and the application mode. Three layers on a fairly even surface normally correspond to approximately 120 µm: one layer of primer and two location paints, and this is common for zinc metallised surfaces in C2 (as described in **Paper I**). This should correspond to a minimum paint film thickness of 40 µm for each layer (Trägårdh, 1961, p. 62). For non-metallised ferrous substrates, at least four layers are needed, corresponding to about 160 µm (Fredriksson, 2007, p. 21). Martin & Wood state a minimum DFT of 150–200 µm, referring to modern coating systems (2012, p. 188). The application of two layers of inhibitive primer is beneficial for non-metallised substrates. Three layers of linseed oil varnish paint without inhibitive primers on ferrous substrate lasts for about three years without visible rust spots due to under-film corrosion in Southern Sweden (Törnblom, 2009, p. 3). It is experienced in present projects that when a priming, intermediate, and topcoat application procedure is used, the paint film thickness is usually applied by brush in thicknesses of 30–60 µm.[57] Therefore, if a minimum of 120 µm is required, four applications (or five applications for 160 µm) are needed due to thickness variations. An individual paint layer thickness of approximately 100-120 µm of linseed oil varnish paint, usually results in skin drying. In anticorrosive painting treatments, the control of painting thicknesses is a crucial variable for the weathering resistance and the lifetime of the painting system. The lifespan of a painting treatment with a total paint layer thickness of 80 µm is estimated to last 15 years, compared to 10 years for 60 µm (Trägård, 1961, pp. 53, 62–63). Unfortunately, the total paint film thickness is rarely controlled. As described in **Paper I**, a wet film comb and MI (Magnetic Inductive) devices could be used for measuring WFT and DFT. The film thickness could be calculated on the basis of consumption per m^2, but the surface profile must be considered. A rough surface absorbs much more paint, and if the paint contains VOCs, this must be taken into account (since this will reduce the DFT when the VOC evaporates).

8.2 Critical Incidents of Traditional Architectural Painters' Quality Assessments

> *"The specified requirements exacted of rust-preventing paints in different quarters vary considerably in important particulars, as do also the results obtained with one and the same paint. This divergence in results is by no means strange when differences in methods of treatments, and external local influences, are considered; and they merely offer a fresh confirmation of the old-established facts that nothing is universally good."*
> (Tetmayr, cited by Andés, 1900, pp. 119–120).

This section exemplifies some of the subtle quality assessments that traditional architectural painters may carry out during the anticorrosive painting treatments (and which could be described as *maxims*). The effort to try to put words to empirical and sensory assessments is an attempt for what Ingold refers to as "*guided rediscovery*" and a possible path for other traditional architectural painters to follow (Ingold, 2013, p. 110). There are always multiple ways of conducting and assessing the steps, and there is no absolutely "right", as illustrated by the quote above. Procedures vary depending on the object type, the size, and other conditions of the intervention. The description is a synthesis of my own experiences as a painter (and from field observations), or of professional painters´ as expressed in painter-to-painter interviews. The resolution of the assessments is limited and in order to make detailed assessments, a real situation is needed. This section combines footnotes (additional information or written verification of experiences) and text references (statements and facts that support a theory or explanation). The exemplifications are described in themes and are connected to the steps

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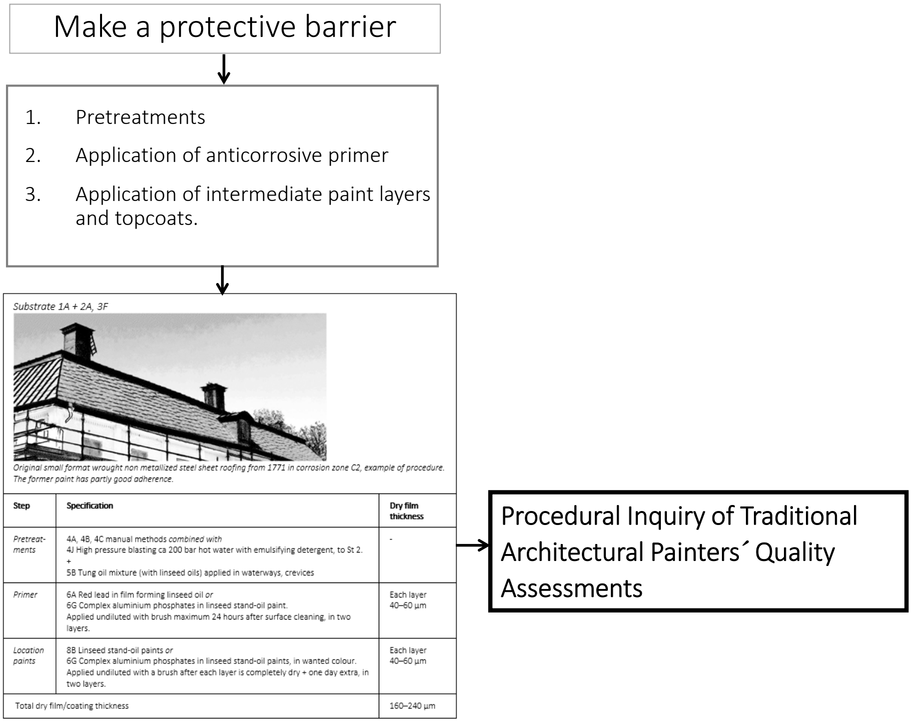
[57] Paint layer thicknesses are not stated in the report by Törnblom (2009). It is expected that the total thickness is > 100 µm. Location at Karlsborg, probably Corrosivity Class 2.



Substrate 1A + 2A, 3F

Original small format wrought non metallized steel sheet roofing from 1771 in corrosion zone C2, example of procedure. The former paint has partly good adherence.

Step	Specification	Dry film thickness
Pretreat-ments	4A, 4B, 4C manual methods *combined with* 4J High pressure blasting ca 200 bar hot water with emulsifying detergent, to St 2. + 5B Tung oil mixture (with linseed oils) applied in waterways, crevices	-
Primer	6A Red lead in film forming linseed oil *or* 6G Complex aluminium phosphates in linseed stand-oil paint. Applied undiluted with brush maximum 24 hours after surface cleaning, in two layers.	Each layer 40–60 µm
Location paints	8B Linseed stand-oil paints *or* 6G Complex aluminium phosphates in linseed stand-oil paints, in wanted colour. Applied undiluted with a brush after each layer is completely dry + one day extra, in two layers.	Each layer 40–60 µm
Total dry film/coating thickness		160–240 µm

Figure 27: Specification levels of working descriptions. Example of general specification for steel-sheet roofing treatment (according to the matrix system) from Paper I.

taken in working procedures as illustrated in **Figure 27** and **Figure 28.** The main steps are as follows (in chronological order):

1) Surface preparation/pre-treatment;
2) Primer paint application;
3) Intermediate and topcoat application.

My standpoint is that when the substrate, the paint, the tools, and the body work together (or towards) the same goal – the conditions are fit for the affordances, and the critical incidents of a working sequence are passed in a flow. If not, something in the specific conditions needs adjustments. This concerns not only oil varnish paints but to any paint type.

8.2.1 Do the Preparations

The intervention starts a long time before the actual occasion of preparing the substrates and applying paints. It starts when the practitioner visits the objects; in connection to the contractor agreement and at the inspection and planning. The craft practitioner is obliged to assess whether or not the proposed general working procedure is reasonable. If the results from the *anamnesis* stage (**Paper I**), the planning and pre-test phase, are not satisfactory, this must be discussed and further pre-tests should be carried out. In particular, this includes the assessments of a paint system´s compatibility and appropriate surface preparation methods.

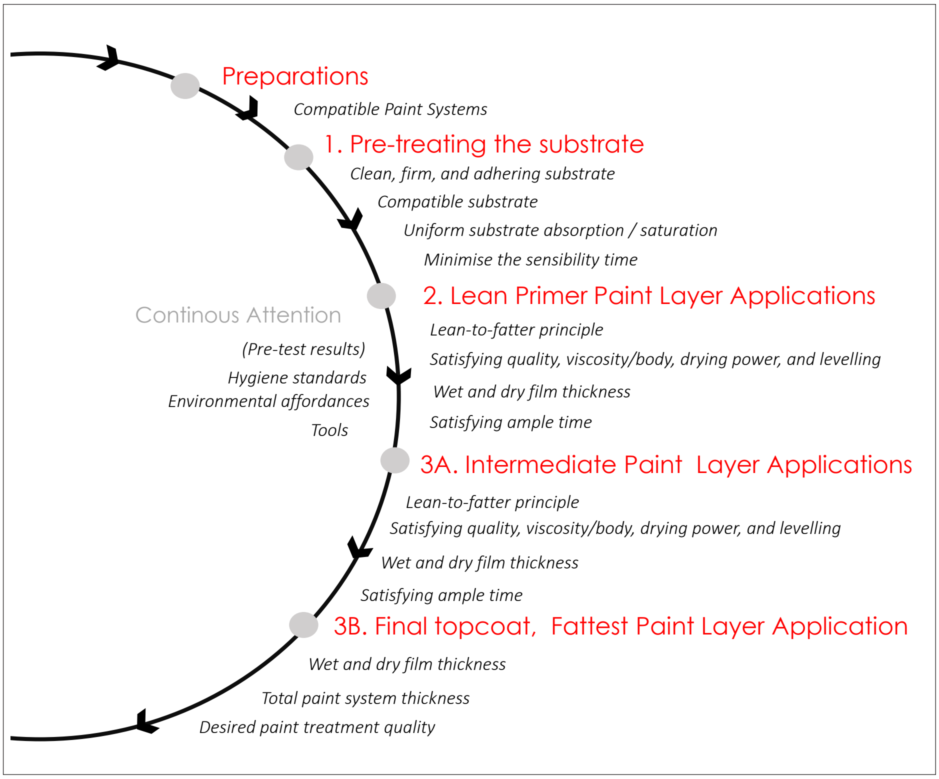


Figure 28: Overview of the major steps and craft quality assessments connected to an anticorrosive painting treatment. Each of the points and sequences could be considered as critical incidents, as described.

It is recommended that a stratigraphic paint investigation and documentation is conducted if there is any suspicion of historical layers.[58] The arrangements for safe and efficient work need to be planned in an early phase. Depending on the object type, this includes, for instance, weather protection in order to ensure dry working conditions, planning for the collection of left-overs, establishing the type of tools to be used. The quality control tools and checkpoints in **Paper I** (and its Table 6) should be considered, and especially the documentation and weather conditions.

8.2.2 Keep High Hygiene Standards

An important part of being a professional is to have a high awareness of hygiene standards, and for ensuring that the necessary routines for upholding those high standards of hygiene are performed at every step of the working process: in handling paint and paint ingredients, in every action, and especially in the surface preparation steps. Insufficient hygiene may corrupt the paint materials, ruin the paint layer adhesion or cause under-film corrosion, or cause defects that may initiate break-down of the paint system, or disgrace the work. High standards of hygiene are also important for the personal safety of the painter. All cans, sticks, cloths, brushes, or other applying tools must be held clean so that moisture or dirt does not contaminate the paint or substrate. Moisture may be a source of microbiological activity that may cause rancidification or fungi deposits on painted surfaces. All items should be stored in

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[58] Recommended also by Trägårdh, 1961, p. 120.

dry and safe conditions. Lids should be replaced on the cans after use, and fresh consumption of materials may be necessary.[59] Dripped paint on the sides of the can will need to be brushed down to the liquid paint in order to prevent skin formation that may end up in the paint. Any skin which has formed on the surface in the can will need to be gently cut off with a knife at the can periphery, and lifted up. If the paint has been contaminated with skin fragments, it is common to filter it through, for instance, a nylon stocking. The paint surface could be covered with some water (that will be decanted prior to the paint's use). A common and important routine is to count the number of used cloths during and at the end of the working day, so that no forgotten cloth may cause fire ignition during the exothermic reaction during the drying of oils and paints.

8.2.3 Consider Environmental Affordances and Paint Adherence

> *"In no case shall any paint be applied out-of-doors in freezing, rainy, or misty weather, and all surfaces to which paint is applied must be at the time dry and clean; and all work must be done in a thorough, neat, and workmanlike manner. If it is necessary, in cool weather, to thin the paint, this may be done only by heating it; and this may be required by the inspector."* (Sabin, 1905, p. 42).

The quote of Sabin illustrates some of the complex quality assessments associated with weather, substrate, and paint. Any damp must be prohibited before painting, or the paint will not adhere to the metallic substrate.[60] Moreover, any remaining rust after cleaning operations may bind moisture, which may be released later, leading to lost adherence of the primer layer.[61] Moisture under the paint film may cause under-film corrosion, and the expanding corrosion products may lead to blistering and flaking. The dew-point is dependent on the RH and the surrounding temperature (Hult & Persson, 2015, pp. 57, 73–75). Of course, this is also assessed by touch, in order to check temperature gradients and moisture levels. A common rule is that anticorrosive treatments should not be executed at RH < 60%, which is a critical point for corrosion initiation. The temperature of the metal should be at least 3°C higher than the dew point of the surrounding. Usually, +5°C is stated as the lowest temperature for anticorrosive painting, but for Nordic conditions, this is considered too low due to the risk of dew and relatively long drying times of oil varnish paints. An empirical rule is that a temperature increase of 10°C, doubles the drying rate – i.e., the drying time is halved (Magnusson, 1931, p. 37). Therefore, a minimum of 10°C is preferred as the lowest temperature possible for outdoor application. The RH and temperatures are assessed by using a hygrometer and thermometer, and the point could be calculated. Hot days and cold nights, like those typically experienced in August and onwards, require special attention due to cold ferrous surfaces at night, and large temperature gradients daytime. Painting treatments of ferrous substrates must always be performed on substrates which are completely dry and should therefore be executed in

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[59] A ready-made oil paint that has been standing for a long time in open containers, will be thick and difficult to use, easily running off vertical surfaces (Fallgren, 1934b, p. 138).

[60] Verified by Andés, 1900, p. 63. After cleaning, a metallic surface will immediately after cleaning form a hydroxyl layer on the surface which is invisible to the eye and prone to adsorbing moisture and corrosive gases (Leygraf et. al., 2016, pp. 8-18). This may form a layer of corrosion products, which is not visible to the eye.

[61] Pointed out already in 1867, by Mulder (p. 216).

clear sunlight and stable warm weather (Andés, 1900, p. 268: Fallgren, 1934b, p. 125: 1934c, p. 247). In strong sunlight, the drying may be too rapid and thus disadvantageous for the result (Sandberg, 1926, p. 8).[62] This may increase the risk of blistering. During hot days, an increased RH is disadvantageous for the drying power of the paint.

The act of preheating could be considered on small ferrous objects themselves, or to the paint – for instance, to +50 to 65°C. If the object is heated, the surface humidity will evaporate and the paint will penetrate crevices and porosities (Sabin, 1905, p. 42: Sabin 1927, p. 268: Fallgren, 1934c, p. 247). Moreover, the paint could be preheated, for instance, in metal pails in a hot water tank. Heating the paint will reduce its viscosity, which is beneficial for applying viscous paints, and it will adhere and penetrate better. On the other hand, it must be considered that this may result in a thinner layer than under normal conditions. This is also the case if the outdoor temperature is high. Slight humidity (that dries off) on, for instance, the intermediate layer will usually result in matte surfaces that normally do not have any practical impact on the results. This is typical, for instance, with steel-sheet roofing painting in August, when the cold nights enter. If the final finishing layer is exposed to dew or humidity during drying, it should be ground and repainted. If a heavier rain hits a drying surface, this may result in depressions and uneven film thicknesses that may affect the total film thickness variation that could influence the barrier properties of the paint system.[63] The Nordic painting season is short and if an object cannot be finished in the autumn due to environmental obstacles, intermediate and topcoats could be applied in early spring after thorough washing off the surfaces. Early spring is an appropriate time for many outdoor painting operations.

8.2.4 Use Appropriate Tools

The tool used act as the media for perception with the environment, for instance in surface preparations and paint applications. The tool needs to be right for the purpose, but a large variation exists in the use of different types of tools (as exemplified on page 158). The effect of different tools for paint application includes a substantial aesthetical aspect, but also has an impact on the durability of the paint, through variables such as paint layer thicknesses and defect levels. It is a common craft rule that the penetration and spreading of the paint are depending on the tools that are used. Depending on the geometry and size of the object, but also on the paint characteristics, different tools could be used. Each tool has advantages and disadvantages, and it is common to combine tools after preferences. The use of the appropriate high-quality tools for the application of varnish or paint is very important. A brush offers good penetration and coverage of the paint into difficult geometries, crevices, and irregularities.[64] A round or oval paintbrush of pale or black pig′s bristles (in a steel ring, prewrapped by yarn) has a high capacity to hold and to spread the paint (Fallgren, 1934b, p. 127: 1934d, p. 269: Söderberg, 1964, pp. 356–357). These brushes are especially beneficial for low-viscous paints. Thick paint mottlers (bound in a steel sleeve) are also commonly used. A well-worn brush with short and firm black bristles works well for working out a lean primer. Sometimes a thin mottler is preferred in order to really work the paint into close contact with the substrate.

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[62] Due to radical polymerisation induced by the photon energy of UV-light, Johansson, Baeling & Ekstedt, 2004, p. 80.

[63] Verified by Andés, 1900, p. 92.

[64] Brush application must be considered as the most appropriate and authentic-like method for architectural ironworks or rubbed on by rags according to Mitchell, 2016, pp. 163-164.

Some firm synthetic mottlers and bristles work well for this type of painting treatment. All application brushes and tools should be pre-washed in water and a pH-neutral detergent and dried before use in order to eliminate dropping particles and contaminations.

A commonly shared ideal of painters is that the finished surface should be neat, should have a uniform gloss, and should be smooth and without any defects, and that brush marks should only be seen as a slight surface variation, not a striped effect.[65] Brushes may give a striped appearance that is desired for aesthetical reasons, but attenuated striping also entails significant variation in layer thickness. This is usually accepted for large structures that are viewed from a distance, such as steel-sheet roofings and so on. Attenuated striping involves a risk of corrosion initiation at the bottom of the brush stripe indentation. Commonly, fluent paint application, by a less experienced painter, could induce unwanted surface skin formation at the top of the elevation, when drying oil varnish paints are used. Generally, the application starts with spreading out puddles of paint, that are brushed in a particular direction and then the perpendicular opposite, and finishing with long strokes in the length direction.[66] By extensive WFT and DFT and surface profile measurements in the study, it is experienced that the profile does not decrease with an increasing number of layers. In fact, the opposite is true, unless the surface is post-smoothened with a fine brush and/or with a light touch when the surface has started to settle slightly.[67] This depends on the type and size of the object. The efficiency of brush application may be increased by first rolling out the paint and then smoothening the layer with a brush. The surface finish after rolling depends on the type of warp and size of the roller (a short hair mohair pile is often used). Standing laps of a steel-sheet roofing could be pre-applied with a smaller (like radiator) brush or a small, short-hair piled corner roller, and then smoothened with a (paint-filled) brush. The spraying of thinned paint is conducted on (for instance) steel-sheet roofings, but this method does not penetrate and cover surfaces that are not easily accessed. Experiences from case studies involves the risk that spray applications are too thin. For smaller objects that are viewed from a close distance, and certainly in cases when there are esthetical requirements and expectations additional to the technical requirements, the applied paint may be post-smoothened/levelled with a soft and long-haired flat brush for a high surface finish (especially on vertical surfaces) and no visible paintbrush marks. For small objects, it is advisable to exclude the risk of contamination from surroundings by lifting the object to distances. Only high-quality tools should be used and the care of them is important for keeping paint treatments at a high standard of quality. Paint should not be allowed to dry in the tools, because this will cause problem with the finish and may induce defects. A common procedure carried out by painters is to scrape off the excess paint with a knife (or a special knife for rollers), and put the brush in raw linseed oil overnight. Rollers may be placed in a plastic bag overnight, where the air is pressed out and the plastic is wrapped hard around the roller.

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[65] Unwanted defects are for example dirt, sagging, curtains, peeling, un-painted spots (*friställ)*, non-uniformity (skäck), dripping edge effects. Skäck appears as a difficulty to touch up an already painted (but still not dry) surface that might have started to settle, resulting in deviating gloss or the structure of the touch compared to the surroundings paint. It has been described as a darker flame on a glossier surface (Fallgren ,1934b, p. 140). It is likely that this is a colloidal phenomenon.

[67] Described, for instance, by Sandberg, 1926, p. 8.

[67] The levelling capacity of paint depends also on the surface profile of the substrate and factors such as paint formulation, viscosity, surface tension, temperature (Bosma et al., 2006, pp. 97-98: Tirat et al., 2017, p. S41).

8.2.5 Assess a Clean, Firm, Rust-free, and Adhering Substrate

To be capable of interpreting and assessing the substrate quality before painting (or repainting) is one of the major challenges in traditional architectural painting craft, and of crucial importance for the final results. This is a capacity that must be trained and repeated, in order to manage different affordances in a skilled way.

> *”The surface of a structural steelwork that is about to be treated with anticorrosive paints, is never in such a state, that it could be painted directly without pre-treatment. The pre-treatment is exceptionally important because if it is conducted in an inappropriate manner or without sufficient accuracy, the rust protective ability will be substantially reduced. Even a painting conducted with the best of paints will deteriorate very rapidly at an insufficient or inappropriate pre-treatment.”* [68] (Trägårdh, 1961, p. 30).
> *“Nothing is more inimical to the durability of paint on iron than an insecure adherence of the first coat to the metal.” (Andés, 1900, p. 61).*

The quotes above describe the crucial impact on the quality of the paint systems and the important correspondence between a prepared substrate and the first application of a liquid paint (or sometimes a varnish). At the surface preparation stage, the substrate is treated with a combination of methods: to a clean, firm, rust-free and adhering substrate, with a uniform capacity of liquid absorbance or saturation. A main rule of the painter is that the surface preparation is as important as the painting treatment itself because the primer paint adhesion is substantially improved if the substrate is clean and has some surface profile for mechanical anchoring. If the primer does not adhere, this will adventure the entire painted barrier. Proper surface preparation will reduce the risk of defects such as under-film corrosion, blistering, and flaking, and the paint system will perform more robustly and will remain durable. Paint adheres to the metallic substrates by different types of chemical bonds and/or mechanical/physical bonds, and the main purpose of the surface preparation is to strive for the optimisation of these bonding mechanisms (see, for instance, Bayliss & Deacon, 2002, p. 20: Sørensen et. al., 2009, pp. 149–150).[69] There are no universal cleaning methods, and it is almost always necessary to combine different methods.[13]

It is important to check the type, condition, and adherence of existing paint layers. If this is not conducted in advance, then it is usually assessed during the initial washing. The painter must assess whether the old paint layers have the strength to carry further re-painted layers without developing injurious stresses. This is dependent on the age characteristics of different paint types and the assessment requires experience also in long-term performance (**Paper I**´s Table 2 and Figure 2 could assist). Aged, brittle layers and thick layers are removed since

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[68] Translated from: *”Ytan hos en stålkonstruktion som skall rostskyddsmålas befinner sig praktiskt taget aldrig i sådant skick, att den kan målas direkt utan förbehandling. Förbehandlingen är utomordentligt viktig, ty om den är utförd på olämpligt sätt och med otillräcklig noggrannhet blir målningens rostskyddsförmåga betydligt nedsatt. Även en målning utförd med de bästa färger fördärvas mycket snabbt vid bristfällig eller olämplig förbehandling”.*

[69] The very importance of an absolutely clean, anchoring surface was described already in 1867 by Mulder (pp. 217-218) and later by Cushman & Gardner, 1910, p. 225.

[70] For more information about specific surface preparation methods, see Källbom, 2018, pp. 110-130, and on working procedures for unmetallised steel-sheets, see pp. 238-239, 242 (or Forsyth, 2008. pp. 148-151: Martin & Wood, 2012, pp. 196-207: Hult & Persson, 2015, pp. 33-46).

these pose a risk of the formation of high stresses formation and reduced paint adhesion. Old linseed paint layers usually do not peel off, since they dominantly age by chalking. Other paint types are usually possible to peel off and the elasticity is tested by bending a flake (cracking and elasticity/promptness are assessed). If the existing layers are in good condition and well-adhering, they could be repainted. Recommendations for ready-made paints should always be followed. For modern industrial coatings (for instance on a substituted steel sheet), it is advisable to make an overpainting test in order to reveal whether any plasticisers (from modern paints) are migrating from the coatings. If so, the over-painting will not dry within the normal time and will result in a soft paint film. In the presence of plasticisers, an insulating special primer paint must be used. A pre-test application will also reveal whether the substrate is fat/contaminated (the paint will crawl) or highly absorbing (correction of binder content in the first layer will be needed).[70] Methods for correcting a substrate which does not absorb uniformly are described in chapter 8.2.6. If the existing paint layers have been applied to a rusty surface, or if under-film corrosion has started, the layers must be removed in order to avoid future flaking and failure.[72] Rust impairs paint adhesion to the metallic substrate and may also contain salts and other impurities. The substrate must be absolutely clean from rust, oxides, dust, grease, particles, salts, and moisture before priming in order to secure the adherence of the paint film to the substrate.[73] The nature of the rust and contaminants rule the type of cleaning operations are required. Today, the condition corresponding to international standard ISO 8501–1:2007 for mechanically cleaned St 2 or St 3, respectively, blasted Sa 2, Sa 2½, or Sa 3, are considered as appropriate surface preparation grades.[74]

If total paint removal is not in question, washing/cleaning is usually undertaken before any mechanical cleaning starts, in order to avoid the spread of contamination. The need to wash (with detergents) and rinse (with flowing clean, preferably hot water) the surfaces is always valid, and it is necessary to repeat this several times so that this is the final treatment immediately before priming, regardless of whether the substrate is metallic or consists of old paint layers. When the metallic surface is wetted, actions must be taken for it to dry rapidly, so corrosion is not initiated (flash corrosion). The purpose of the initial cleaning is also to assess whether the remaining paint layers are adhering, by stressing through scraping and/or with the use of a knife. Tough scraping should proceed with clean steel brushes (to avoid spreading contamination).[75] Moreover, grinding with nylon wool and water addition, and extensive rinsing, could be used in order to remove any contamination. Washing (for instance with emulsifying alkaline detergents) should be conducted before pickling since acids (or alkalines) are not effective at removing fat and grease. It is common to assess the condition of a

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[71] Crawling (*krypning or pärling*) occurs due to high surface tension or high fatness of a drying oil or paint (or substrate), or if a glossy paint is applied on another glossy surface, apparent as a tendency to draw up in to droplets or globules shortly after application (Heckel & Carlbom, 1925, p. 42: Zanichelli, 1950, p. 231: Singer, 1957, p. 19). The liquid spreads unevenly, especially when the absorption power of the substrate is low or during the initial drying stages. The pigment may separate from the binder in the wet paint film, or turn to blobs in local areas as islands on the dry surface. The causes may be impurities, fats, moisture or a very low surface profile. Crawling may also occur due to the temperature of the paint or substrate being too low paint or substrate temperature, or too long time between overpainting. Crawling could be remediated by degreasing or washing of the substrate, some small addition of soap or detergent to the paint, or by increasing the temperature. It is also experienced that rancidity may cause the oil to separate and to crawl. In that case the oil could be decanted and substituted, or a thickening filler could be added.

[72] Verified by Edwards, 1936, p. 85: Trägård, 1961, p. 34.

[73] Verified by Andés, 1900, pp. 61, 267: Sabin, 1927, pp. 249-250: Edwards, 1936, p. 84.

[74] Verified by Söderberg, 1964, p. 351. ISO 8501-4:2017 may also be used.

[75] Verified by Sabin, 1905, p. 26.

substrate by using a cemented tungsten carbide scrape, but this is somewhat wasted on metallic surfaces due to their firm nature, since it is possible to remove any paint layers, (if enough force and firmness are applied). Therefore, a knife may be used for smaller objects, since paint removal with a knife requires more effort than a scrape, and will reveal whether any previous surface preparation was insufficient. This is revealed by impaired adherence, visible under-film corrosion, or contaminations at the interface. Another way is to use a scrape but to use it from many different directions. The blade should slide (not bump) over ridges if the adhesion is good. After washing, there may be a need for scraping and/or grinding of paint edges that have raised due to the moisture exposure. Cross-cut tests or pull-off testers may be used to check the remaining paint adhesion. Another way to check the adhesion and stability of thick painted layers (on a restricted surface), is to put the fingertips on the surfaces and to push the surface resolutely. The slightest movement is detected by the fingertips and reveals whether the old paint layers are stable and adhering to the substrate.

In order to assess whether a metallic surface is clean, a combination of sensorial and empirical tests is used (on several inspection spots). There are standard methods too.[76] The most common method is to make an ocular inspection (uniform gloss, colour variation or changes, and so on) in combination with a haptic touch in order to feel whether there are any small gritting particles or fats/grease left. The "clean" touch is described as matte, dry (dry as wheat), and recalcitrant with a very limited porosity. A skilled painter describes it as the difference between porcelain that has been machine-washed or hand-washed, with the slightly harsh, gripping, and un-greasy touch of the former. A small magnifier could be used in order to reveal contaminants. Wiping off the surface with a white, clean cloth reveals the presence of soot or other contaminants. When distilled water droplets are spread over the surface, it can be assessed whether or not the droplets are pearling, in order to reveal fat and grease (water will be repelled). Organic matter may be detected by the use of UV-light lamp at dusk or dawn, and organic matter on the surface will turn fluorescent. If a clean metallic surface is overpainted with white emulsion paint as a test, pitting with salt contaminations could be easily detected as rust spots when the paint dries. Pittings are very difficult to clean due to their depth, which traps corrosive salts. A pitted or porous metallic surface is especially susceptible to trapping water or condensation. Small objects could be heated before varnish or paint application. If particles are found at the surface, they are washed, wiped, or brushed away before application. A dust-off check or treatment (*avdamning*) before application is essential.

Any pickling fluids must be removed and neutralised by their counterparts and well washed so the risk of under-film corrosion is decreased.[77] It is very important to neutralise and remove any traces of alkaline substances from the surface, in order to prevent hydrolysis and further saponification that will deteriorate the paint film (Johansson et al., 2004, p. 77). It is experienced that alkaline impurities may cause discoloration and heavy chalking in linseed oil varnish paint surfaces. If washing is sometimes avoided due to intricate water-trapping geometries and/or cold weather that will postpone the drying of the surfaces, wiping off the surface of small objects with pure ethanol is practiced. The use of pure alcohol is used as a regular washing treatment for smaller objects, and the priming is undertaken immediately

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[76] Such as described in ISO 8502-2:2015, ISO 8502-2:1994, ISO 8502-3:1992, ISO 8502-4:1993.

[77] There are many historical examples of this, for instance Sabin, 1905, p. 25, where there is a description of pickling with sulphuric acid with hot lime milk, then rinsing with water. Also, by Andés, 1900, p. 62. Diluted ammonia is also used today in order to neutralise acids. In order to neutralise alkaline pickling, diluted acetic acid may be used (and rinsed).

Figure 29: Proper planning of working sequences. From left, washing, drying and on the right side, priming.

after the evaporation. The alcohol is applied flowingly with a cloth. After cleaning treatments, and especially after operations such as blasting or pickling which leave the ferrous surface highly reactive (active), it is very important that the priming should be undertaken immediately after and within 24 hours (even when the RH is below 60%) – i.e., the sensibility time should be short (Vattenfall, 1933, pp. 17–18). Sabin states the sensibility time should be as short as two hours (Sabin, 1905, p. 36). When planning the sequence, it should be limited to areas manageable within 24 hours after the final rinsing operation, see **Figure 29**. If the surfaces are exposed to sun or wind, the drying after washing and rinsing proceeds very fast. Washing and rinsing operations are preferentially carried out in the morning, so the surfaces will dry faster.

The grades of preparation after blasting or manual cleaning are, as earlier described, checked to the comparators of ISO 8501–1:2007. A degree of surface roughness is needed in order to provide for mechanical anchoring of the primer layer to the substrate. Significant variations in the profile of the surface will result in paint layers that are too thin on the ridges, and which are consequently initiation points for corrosion. A rule of thumb is that the median surface profile, R_a, should be a maximum of one-third of the paint layer thickness (Bergman, 1968, p. 72). The surface profile is either measured with an electrical device or assessed manually. If a metallic surface is very shiny (i.e., having a very low surface profile), the *cleaned* surface should be roughened by any appropriate method since it will otherwise not provide for mechanical adherence of the paint. Therefore, it should be ground with fine sandpaper, steel wool, or nylon wool (scrub cloths). Most often, the roughened surface still feels very smooth, like very fine sandpaper, like 180 grit (to 240 grit) to the hand. If the profile is too large, the paint layers easily become too thin on the ridges. Pickling could also be used for roughening the smooth steel surface.

8.2.6 Follow the Lean-to-Fatter Principle

A common craft rule is that the paint layer sequence should go from lean (meager) to fatter paint, and should not alternate between the fattiness (i.e., do not apply lean paint, then fatter, and then lean paint again).[78] If this rule is not followed, it may result in ruined adhesion and/or premature cracking of the entire paint system. The lean-to-fatter principle means that the leaner substrate will always absorb some of the binder in the fatter over-painting due to some binder deficit. If a paint layer is too fat, the next, over-painted layer will have difficulty adhering and could crawl, crack, or peel off.[79] The primer paint for ferrous substrates must be firm, lean, and be overpainted by a fatter paint for durable results.[80] A firm, less porous, or less absorbent substrate usually requires a thicker, more viscous, and elastic paint compared to the case when the substrate is more porous and absorbent (Lowe, 1905, p. 20: Fallgren, 1934b, p. 138).

The weather-resistant characteristics of fat oil varnishes have been described in previous chapters. "Lean" paint refers to paint that has a low concentration of an oil varnish binder (and is high in pigment concentration – i.e., a high ratio between the concentration of pigments + fillers versus the concentration of non-volatile binder; chapter 6.2.1 for a description of PVC). For a given PVC, a leaner paint could also be obtained by using a less bodied, less fat oil varnish binder. So, a lean paint could either have a low binder content (high PVC), or a less bodied/fat binder (or both). The consequence of inappropriate use of diluters or solvents, which spoil the lean-to-fatter principle, may lead to a paint system failure.[81] This is a main reason why the recommendations for ready-made paints should be followed. Most ready-made paint systems have products that have proved themselves as reliable (and compatible) over time. Depending on the nature and size of the object, and the purpose of its paint treatment, traditional architectural painters may produce the paint. When a painter is adjusting or producing the paint, they take over the responsibility as paint-makers—something that could be of significance for issues of guarantee. The quotation from Andés below is a hint at the different requirements that the paint-maker should handle. To this is added the need to provide increasing fatness of each layer. An example of this is given in **Figure 30**, with the caption.

> *"...to prepare a suitable painting material which will fulfill all the requirements of the case. Viz., quick drying, sufficient tough and elastic, adhering will to the iron, able to absorb and unite with succeeding layers of paint, and exerting no injurious influence on the metal."* (Andés, 1900, p. 70).

So-called "early-cracking" (*tidigsprickning*) may occur shortly after application due to a paint formulation using pigments with low specific weight and a too narrow grain size normal-distribution (Sandberg, 1926, pp. 10–11: Magnusson, 1931, pp. 59–60: Magnusson, 1939, p. 259). This defect could be avoided by using a varnish with limited weight increase during drying, such as high temperature bodied oils (similar to the historic *Oljelin*) i.e., with *stand oil character*, or assure to always go from lean-to-fatter paint layer sequence (and finishing with

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[78] Verified by Andés, 1900, p. 91: Sandberg, 1926: pp. 8-9: Palmær, 1953, p. 134.

[79] Verified by Andés, 1900, p. 77 or even as early as 1845 by Tripier-Deveaux, p. 301. In combination with humid substrate at the application the effect is very severe.

[80] Verified by Andés, 1900, p. 84: Magnusson, 1939, p. 259.

[81] Verified by Jönsson et al., 1964, p. 363. It must also be repeated that solvents will impair the paint film quality.

Figure 30: Master Painter Thom Olofsson at the Swedish Railway Museum in Gävle describes the procedure of treating the chassi of a train wagon from the 1920s with linseed stand oil paint. The train is uplifted on trestles for enabling the anticorrosive paint treatment after surface preparation. Two lean red-lead oil paint primer applications, each fatter than the previous, are followed by four location paints. The location paint is prepared in situ by gradually increasing the dilution of a milled black carbon (raw) linseed oil paste with a high temperature boiled linseed oil varnish, and pale, medium-viscous German stand oil. The drying time is adjusted according to the increasing fatness of the paint layers. Leaving too much time between the applications, especially in connection to the topcoat is crucial, is a problem because too much time may lead to failed adherence due to crawling.[82] Video interview and discussion of sensory assessments.[83]

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[82] Andersson, 1961, p. 28: Jönsson et al., 1964, p. 363 also emphasises the urge for caution regarding ample time. If the time is too long, it may be contaminated or result in chemical changes ("getting fat"), which in turn results in insufficient adhesion.

[83] Video recording 2017-11-13:00215.

fatty oil paint with an addition of stand oil). It is also important that the drying time is not too short. Magnusson emphasise the use of a varnish that is sticky (*klibbig*), as it will adhere well to a neutral substrate and this is beneficial in order to avoid premature cracking.

A lean primer paint layer is matte, and feels dry, sometimes a little over-dried, and slightly porous, or powdery. It should never smear (*smita)* on to fingers when it is touched because in that case, it lacks binders and this means a high risk that there will be a lack of adherence for the next paint layer. The fatness and viscosity should be highest in the final topcoat. Master Painter Fallgren states that the viscosity of the topcoat should be very high and illustrates this with an agitation stick that should stand up when placed vertically in the paint can (Fallgren, 1953, p. 106). A fatter anticorrosive paint contains a higher fraction of a bodied oil, and also feels fatter, usually shows a higher gloss. It is experienced that a fatter surface often dries with more friction (for a longer time) between finger and paint, and this may cause a screaming sound that finally disappears when the layer is dry.

An aged, weathered oil varnish painted surface is also lean and has the same sensory characteristics as described above. An important difference is that it chalks (and smears) due to the deterioration and loss of organic binders. Chalking material must always be removed before the surface is painted. An old paint layer may also be porous and absorbent due to saponification, due to (for instance) remaining alkaline matter from washing treatments. A saponified surface is often discoloured. A local, lean, absorbent surface is also detected on fresh paint layers, as matte spots (*mattfläckar*), as in the case of over-painting of previous defects with paint loss or in former rust spots that have not been cleaned to a metallic lustre. Matte spots should never exist in a fresh topcoat since this means that the lack of binder will cause a higher rate of deterioration.

What kind of lean paint (or varnish) should be used closes to the metallic substrate? The quote of Andés below, gives an answer to this.

> *"Hence it is sufficiently evident that the first point of issue is not 'which paint is best adapted to overlay paint?' but rather 'which paints adhere most firmly to iron'? "* (Andés, 1900, pp. 78–79).

For *wooden substrates*, it is common to undertake the first treatment with penetrating, boiled (less bodied) oils in order to reduce the binder absorption of the substrate from the primer paint layer and to improve the adherence of the paint layer to the wooden substrate.[84] In *metallic substrates* the absorption is very limited, unless there are particularly absorbent surface materials, such as old, weather- exposed, and out-meagered (*utmagrad*) paint layers. It was stated already in the nineteenth century that a linseed oil (i.e., not a varnish) on ferrous substrates will not produce films that are hard enough, and this may be harmful to the adherence of the following painting treatments (Mulder, 1867, p. 217: Cronqvist, 1872, p. 123: Jones, 1891, pp. 13–14: Lowe, 1905, pp. 17–19). Instead, it is recommended that the first application on the ferrous substrate is performed with a lean oil varnish primer *paint* (less fat than the over-paint) that must get in close contact with the metal and attach firmly by thoroughly rubbing it into the metal (or ragging it off after the application). If the ferrous object is heated, any moisture is vapourised and the paint adheres firmly (Cushman

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[84] Excessive oil/varnish saturation (wooden substrates) was considered as questionable due to the hydrophilicity and large imbibition of linseed oil varnishes at the time (Magnusson, 1931, p. 28: Nylén & Andersson, 1953, pp. 23–24).

& Gardner, 1910, p. 233). It is pointed out that for metallic substrates the oil varnish paints need to be *stickier and more adhesive*, compared to the more penetrating oil varnish paints used for wooden substrates (Andés, 1900, pp. 58, 77–78: Jones, 1891, pp. 13–14). High *adhesion ability* is a primary requirement for the primer paint, and also for the ferrous substrate. An anticorrosive (especially the primer) paint must have closer contact with the substrate than is necessary for wood painting (Uebele, 1913, p. 320).[85] Sticky and adhesive characteristics are, as shown in the chapter 6.2.5 and **Paper IV**, significant for highly polymerised, bodied varnishes. (Trägårdh, 1961, p. 18). Grinding the still-wet primer paint with pumice (*pimpsten*) was a common method for achieving an intimate contact between the substrate and the paint (and a neat finish) on ferrous objects (Sandberg, 1926, p. 6).

Historical sources state that using a rag to apply a very thin film of a well-bodied fast-drying linseed oil *varnish* is not harmful as a first layer, especially when applied hot or onto a hot iron (metallic) surface if the excess liquid varnish is removed (i.e., a solid film is not formed) (Andés, 1900, pp. 78–80, 268: Lowe, 1905, p. 17). On a vertical surface, this is not possible (or difficult) since the varnish will run off. Historically, (oxide) oil varnishes were used (with or without pigments) on the back and over-side of black iron sheets, preferably when the sheets were fresh and hot, not yet mounted (Lisinski & Johansson, 1979, pp. 70–74). As already stated, raw or boiled linseed oil (i.e., *not oil varnish*) should not be used as the first layer on metals since they dry into soft, dirt-collecting gummy films which require a long drying time, and are therefore an inappropriate foundation (Mulder, 1867, p. 217: Cronqvist, 1872, p. 123: Sabin, 1905, pp. 35–36). The purpose of an oil varnish treatment could be, for instance, to protect rivets, bolts, or other parts with crevices, or to ensure capillary varnish penetration to crevices/water-traps, before a later puttying and priming *in a workshop* (i.e., the varnish treatment is also conducted in the workshop). The formed varnish film must be very thin and firmly adhering to the substrate and the following primer paint layer (Andés, 1900, p. 81, 268: Holley & Ladd, 1908, pp. 108–116).[86] It should be preferably be pigmented so that it could be easier to detect if insufficient penetration has occurred (Lowe, 1905, p. 18). Andés described the painting procedure of eight European national railway organisations at the end of the nineteenth century (Andés, 1900, pp. 256–268, and also Mulder, 1867, p. 217). The ferrous components, or the primer paint, were warmed up in the workshop so that the *low-viscous* primer paint (with a slight excess of oil varnish) that was applied thinly with stiff brushes would penetrate all contact surfaces and crevices. After puttying and repeated priming, an additional 2–4 thicker layers of paint were applied (with ample time was given for drying: 2–14 days). Wrought bridges were treated in similar ways (Welkner, 1853, p. 308). Low-viscous paint is, also advantageous for clean sand cast iron or steel surfaces, which are usually porous and uneven due to impressions from the sand mould material, in order to improve the adherence of the varnish paint (Mulder, 1867, p. 221). The reason for this type of low viscous varnish or paint treatment on cast iron is described in *American Architect and Architecture 1891* as below. The iron com-

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[85] An anticorrosive paint should supress the anodic reaction and give a high resistance to ion transportation, and a very close contact between primer and substrate is necessary. The primer should wet the clean substrate in order to adhere (Trägårdh, 1961, p. 18).

[86] Vattenfall applied oil varnishes to power pylon prior to painting treatment, but this procedure was abandoned due to the risk of too long time period before the priming. The oil varnish is hygroscopic and could attract moisture, which could lead to under-film corrosion. If linseed oil varnishes are used on metallic substrate, the priming must be conducted immediately after it has dried solid (at the same day, and preferably in workshop) (Vattenfall, 1933, pp. 7, 16).

ponent or the oil is heated so that the oil starts to fume (Anonymous, 1890, p. 648: Anonymous 1891, p. 648).

> *"A thin coat of hot oil will penetrate every porosity, displace all adhering dampness, and stick to the metal so closely that no exposure to air or moisture will ever cause it to separate. To such an oiled surface paint adheres well; and when this process is adopted, we never find the paint falling off in large flakes, owing to moisture having crept into some crack and gradually producing a thin layer of rust between the paint and the metal."* Anonymous, 1891, p. 648.

It is always preferable to use *primer paint* on dense, metallic, clean surfaces.[87] Sometimes this is not possible, because the rust must be removed with machine power. It is inappropriate to paint on rust, for reasons already mentioned. Today, oil varnish pre-treatments on the ferrous substrates may be used on, for instance, forged or cast old objects (that are not cleaned to the ideal surface preparation grade St 3 or Sa 3, and hold some porosity and oxides on the surface), existing cleaned black iron sheets for proper penetration into crevices, laps, or in waterways before priming. The used varnishes are high-temperature bodied with the addition of linseed-tung oil (about 20 wt%) or stand oil (about 10–15 wt%) addition, or linseed long oil alkyds, all known to be very good at penetrating and drying to a *firm, stable* varnish film. These types of penetrating fat varnishes are also used when (cleaned) weather-exposed lean paint layers need to be consolidated, by adding the lost binders, or when a shining metallic surface cannot be obtained after cleaning (surface preparation grades St 2, St 2½, Sa 2 instead of the desired St 3 or Sa 3)— i.e., there is still a slightly absorbent layer of oxide residues or if the surface may be expected to show some porosity (such as some castings) or crevices. If a penetrating oil is used, the consolidated surface should be assessed as firm and stable after drying, which is usually checked by scraping with a fingernail and/or by firm pushing with fingertips. The solid film gloss will vary depending on the surface absorption and profile, and the characteristics of the oil varnish. Many painters state that the over-painting of a glossy varnish surface is not harmful, but if it is simultaneously greasy/fat, it should be wiped off flowingly with pure alcohol before priming. The haptic touch of the solid varnish film should have some very slight *tackiness* (see Supplement 3), with *grip, bite* after 24 hours of drying time. Some very skilled painters use a linseed-tung oil varnish mixture for slightly wet-on-wet over-painting with good results and coverage. The adherence is excellent and the tung oil addition seems to ensure through-polymerisation. This wet-on-wet procedure is generally not recommended, since the experiences of performing it vary.

Well adhering, old, weathered paint layers could be over-painted with an oil varnish *primer paint* diluted with some added oil varnish to compensate for the under-layer absorbance (see **Figure 31**), or it could be painted twice with the oil varnish primer paint.[89] Chalking, loose-surface pigments must of course be removed before the application.[90] In order to make a lean (pigment-rich) primer applicable, it could be slightly warmed. If the object is small, the object may be warmed. The tendency of the oil varnish paints to chalk is a plausible expla-

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[87] Even then, the paint has practically no penetration (Andés, 1922, p. 8).

[89] Verified by Andés, 1900, p. 96: Jönsson et. al., 1964, p. 383. Boiled linseed oil could be used prior to primer paint.

[90] Chalking (*kritning*) is a result of binder loss due to ageing and an enrichment of unbound pigment grains on the surface. The phenomenon is dependent on characteristics of the binder, pigments, and exposure (Zanichelli, 1950, p. 210).

Figure 31: Making oil paint for repainting a lean substrate. The Master Painter makes the oil varnish paint for the steel-sheet roofing, as he has been taught, for this purpose. Raw and heated linseed oils of high quality are mixed 1:1 and after this, it is poured off some litres into a 15-liter high pail to make the pigment paste (otherwise the pigment will stick to the bottom). To the oil is added about 1 dl oil turpentine so that the pigment will wet to the varnish properly. To this is gradually sprinkled bone black pigment and oil until they form the desired volume of a very viscous paste. The paint is intensely worked with a drilling machine equipped with a beater/dissolver at 600 rpm for at least 45 minutes so that the viscosity decreases and the paste becomes more homogenous. This is quite tough physically, so it is necessary to have a good working position. Then is added 10 vol% zinc oxide and 5–10 vol% stand oil for a stronger and more durable film formation. The paint is worked to the right consistency and additional varnish is added if needed. The proportions are 1:1 between varnishes and pigments, but at the end, some extra varnish is added since the substrate consists of an eroding, chalking oil paint (and therefore lean, absorbent). The proportion of oil turpentine is about one dl to 10–15 l oil. This is so little that it cannot be smelled. The paint is left to rest for 24 hours or overnight and whipped up for several minutes before use. The drying time is 48 hours and the paint is not prone to sediment. The application of the paint on the roofing is made with a modified watering pot, so it can be sprinkled on the clean and warm substrate before it is distributed. It is rolled out thinly with a 43 cm mohair roller and then post-brushed with a 20 cm lacquer dispenser, both with a shaft. The maintenance repainting is carried out after seven years. Video interview.[88]

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[88] Video recording 2016-06-03: 0009 and 00024.

nation for the cleaning and repainting actions of roofs and other weather- exposed painted substrates after only a year (or some years) after the establishment, as described in several sources from the eighteenth, nineteenth and twentieth century (Lisinski & Jonsson, 1979, pp. 67–73, 75). The weather-exposed lean substrate was suitable for additional paint layers, for achieving an increase of the final paint system thickness without the intermediate layers becoming too fat at the time of establishment. The paint system was then maintained regularly without the need for complete removal of the paint.

As pointed out earlier, a substrate with a metallic lustre should preferentially be painted with a lean (pigment-rich) oil varnish primer, for obtaining not only good adherence to the substrate but also a cohesive paint film strength. Painters experience that the pigments fill microscopical porosities, contributing to the anchoring of the paint to the substrate.[91] It is considered that paint with a high body (with a high pigment to binder ratio, high PVC – i.e., lean paint) should be applied very thinly on a substrate like this.[92] For this, a stiff brush high-quality brush and a rather short brush are useful and may be used in combination with the heating of the paint or the substrate if possible. Adding varnish too extensively to the paint will leave the primer layer too glossy and it will not be as functional for the following layer to adhere to. The primer must have enough time to dry before applying an over-paint layer, especially if quite thick layers (like ≥ 40 µm) are applied. It is important to assess how much drying time to leave before the middle coat is applied, since this is the interface between the foundation and the protecting/finishing coats. The lean-to-fatter principle means that the pigment to binder weight ratio should decrease—i.e., the first layer should have a higher concentration of pigments and fillers and a lower concentration of paint binder.[93] The middle coat should have enough viscosity to penetrate slightly into the primer layer (i.e., the primer paint should be leaner). For every application, the absorption of the over-painted layer decreases to saturation. The finishing layer requires an addition of oil varnish to achieve high elasticity, and the finishing layer should be applied smoothly and evenly, and should be brushed out thoroughly. It is common for a skilled painter to make a small addition of spar varnish, stand oils, or bodied tung oil to the final paint layer if the paint is not ready-made with this. When stand oils are used in anticorrosive primers, the location paints should also contain stand oils (Strömberg, 1948, p. 390).

The recommended use of oil varnish or primer is explained in **Table 9**. Make a pre-test before large-scale decisions. Penetrating oil varnishes must be used with caution and the need judged individually for every ferrous object, depending on its production method, history and condition.

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[91] Firm and non-absorbent substrates should be primed with a thicker (more viscous) paint, as stated by Fallgren, 1953, p. 101. Lowe (1905, pp. 16-17) describes that lean (pigment rich) primer paint should be used closest to the metal. Nylén states that the primer paint has three important functions: to increase the adherence to the following layers, to increase the firmness of the substrate, and to seal porosities (Nylén, 1942, p. 4).

[92] Verified by Lowe, 1905, pp. 16–17, 44 and Andés, 1922, p. 9. The primer should be "*an unyielding foundation*", should *dry firm and fast*, and should *be less elastic than the over-paintings*.

[93] The paint-makers usually base recipes on weight percentage, and the result may vary depending on the wetting power of the oil. The oil fraction cannot be calculated for a paint, based on the oil number of the used pigments (Andersson & Nylén, 1957, p. 13).

Table 9: Recommended use of oil varnish or lean primer paint.

	Metallic Sa 3, St 3 on steel grade B, C.	**Slightly porous Sa 2, 2½, St 2 on steel grade B, C.**	**Old weathered paint**	**Comments**
Surface preparation by a firm oil varnish application	No. Risky. Possible if it is ragged off.	Possible. Rag off.	Possible, for consolidation.	Preferentially sticky, bodied varnish that dries to a firm, waterproof and elastic film. Heat the paint or substrate slightly. Avoid VOCs.
Lean primer paint application	Yes.	Possible, the viscosity may be adjusted by a small addition of varnish.	Yes. eventual. addition of varnish or apply primer paint twice.	Sticky and bodied varnish. High PVC to make the primer paint lean. Heat the paint or substrate slightly. Avoid VOCs.

8.2.7 Balance the Paint Layer Thickness, Viscosity and Drying Power

The lean-to-fatter principle was previously described from a painter's view. This is closely connected to other paint characteristics, like the body of the paint. The body in turn affects the applicability (how easy or difficult it is to apply the liquid paint with a satisfying result—i.e., smooth and defect-free surfaces) and how thick the wet film can be whilst retaining a satisfying drying power. With a substantial body, it is possible to apply thicker layers.[94] With a paint with a poor body, this is not possible. In this case, a higher number of layers must be applied in order to reach a given total paint system thickness. Historic sources emphasise the importance of many thin layers in order to enable fast and good drying, to build the total thickness, and to achieve a neat and durable result.[95] The following quotes describe how difficult it was to apply thin coats (though it is rarely specified "how thin is thin?" and also consider other important conditions for multiple layer applications.

> *"The most difficult skill of the painting art is to learn how to apply thinly."* [96] (Magnusson, 1931, p. 38).
>
> *"There is no damage to fear from a large number of coats, provided a sufficient interval be allowed to elapse after each coat before applying the next because the individual layers will coalesce properly, and the greater the total thickness the greater the degree of impermeability secured."* (Andés, 1900, pp. 95–96).

These important and subtle interconnected rheological variables were very clearly demonstrated during the start-up of the field tests in Mariestad 2017 when a large number of anticorrosive paints were compared (and could exemplify this issue).[97] A paint which is characterised by high viscosity (substantial body) and high drying power, such as that of vinyl primer paint, makes uniform application very hard (without the use of VOCs, which were not allowed for this specific paint). This is in contrast to the characteristics of oil varnish paints, where the time needed for thorough application is many hours, and in combination with the use of appropriate tools and pre-heating, which enables a high-quality result. Depending on

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[94] Verified by Sabin, 1927, p. 178.

[95] For instance, by Sandberg, 1926, pp. 5, 30.

[96] Translated from: *"Målarkonstens svårlärdaste knep är också att lära sig att stryka tunt."*

[97] Paint rheology is described, for instance, by Armelin et. al., 2006 and Bosma et. al., 2006.

the body of the paint, it is possible to apply a certain wet film thickness if a reasonable drying time is desired. A paint with a poor body will, in the worst cases, only be able to result in ≥10 µm thickness: the same is the case for an unpigmented oil or varnish. If the recommended minimum thickness of a total dry film (i.e., 160 µm for non-metallised iron or steel) is to be reached, the possibilities of using such poor-bodied paint would be unrealistic because this would require too many applications. A poor-bodied paint combination with low drying power, would be inappropriate for its purpose, and it would also be a challenge to keep up the lean-to-fatter principle without reaching a state when the surface will be too fat (to be overpainted). On the other hand, a paint could dry in reasonable time and still enables layer thicknesses of 40-60 µm DFT of each application, is usable. Paints that are quite dry within 1–1.5 day´s work well for anticorrosive paint treatments outdoors during the right paint season, and enable the working steps to flow well. It will be explained later how the drying stage could be assessed, and the recommendations about what will constitute "ample time". An example of a low-bodied paint is the MIO armour paint (that was tailor-made for the field tests in Mariestad), and which is hard to apply in thicker layers than ~15–20 µm without sagging and curtain formation. Since MIO pigments have a very low binder-need it is practically impossible to make a useful paint without the use of other bodying additions. This paint flows out well on horizontal surfaces and dries smoothly (despite the gritty influence of the MIO-pigments) but may sag on vertical surfaces. Another similar example of this is a red-lead primer oil paint, which often has low PVC due to the characteristics of the pigment (low binder need).[98] The opposite is experienced for the leafing aluminium pigmented armour paint which has a metallic appearance (described in **Paper III**, variant F Al). The rich body easily enables a DFT of 60–80 µm for each application; but a flowing application and smoothening of the paint were more difficult to make—this results in a slightly striped appearance with the same brush. In order to avoid the striping, the PVC could have been slightly lower (diluted with a bodied oil varnish), or the paint could have been warmed.[99] Due to the combination of different types of driers, this highly bodied paint was still through-dry within 24 hours. As described earlier, the drying power is dependent on factors such as environmental conditions, paint formulation, substrate absorption, and paint layer thicknesses.

Chevreul states that the oil varnish paint should be so "liquid" that it could be dispersed by a brush, but so tacky and viscous that it will adhere at the required thickness also on vertical substrates without sagging (Chevreul, 1852, p. 55).[100] The paint must solidify and cure after application, with proper adherence to the substrate. These stipulations could be adjusted by the skilled painter, and the viscosity should be different for each paint and type of project. With the ready-to-use paints, this should be foreseen and described by the paint-maker's recommendations. The art of paint-making, taking these considerations into account, has an extensive scope that will not be further described in this context.

Historically, solvents or oil turpentine were strictly discouraged from use in anticorrosive paints in order to adjust the viscosity and applicability, since their addition would make the

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[98] In order to prevent sagging on vertical surfaces due to the high density of the pigment, filler pigments are often added to the red-lead paint (Sandberg, 1926, p. 34).

[99] Warming the armour paint in a water bath (maximum 50°C) is recommended by Vattenfall (1923b, p. 1.).

[100] This is synonymous to "curtaining", "curtain formation" (*gardinbildning, gardiner*), a term used by painters to describe the defects that are caused by too fluent an application of a paint without enough body on a vertical surface (Zanichelli, 1950, p. 220).

paints leaner (i.e., less fat), more porous, and less durable (Andés, 1900, pp. 127, 192: Sandberg 1926, p. 9). The use of solvents for anticorrosive treatments was considered as a type of falsification and was thus not allowed (Fallgren, 1934b, p. 138: Fallgren, 1953, p. 101: Hansen, 1990, p. 5). Some sources occasionally allowed for a very small concentration of oil turpentine as a diluent (Fahrion, 1911, p. 245). Gradually, the acceptance for oil turpentine and mineral spirit/white spirit (*Lackbensin*) were accepted as active diluents/catalysts for anticorrosive paints in the 1920s and 1930s (Heideck & Leppin, 1933, p. 240: Nylén, 1948, p. 644). White spirit was not introduced to the painters in Gothenburg in the 1930s, and oil turpentine was used only in very small concentrations for indoor priming (Hansen, 1990, p. 5). Closer to the mid-twentieth century, and especially during and after the Second World War, the use of solvents became more common due to the use of transformed linseed paint formulations (raw linseed oil paste and stand oils) and alkyds, but this was not recommended since the durability decreases (Andersson & Nylén 1957, p. 12). Today, some paint systems recommend the use of different VOCs. This is not desired either for painters´ working conditions, for the density and the quality of the paint films, or for environmental reasons. As already mentioned, some painters may add a percentage of oil turpentine to wet pigments when they make a paint paste and in order to improve the applicability. The addition should be so low that this cannot be smelled (like 1–2 wt%). The use of a large proportion of VOC in the paint is a modern concept and should be avoided. Since the VOCs evaporate, this must be compensated with a thicker wet film, in order to produce a specified total dry film thickness. If the viscosity and body is lowered too much, the durability will also be decreased (Welkner, 1853, p. 308). Fire-boiled/bodied linseed oil could be used in order to adjust the paint viscosity before application (Cronqvist, 1871, p. 102: Uebele, 1913, p. 328).

A common rule of practice is that linseed oil paints should be applied thinly and in multiple layers, so the layers dry-through and harden firm (by efficient oxygen diffusion and polymerisation) in order to carry the next layer (without large expansion).[101] In this way, the beneficial effects of the paint layers´ elasticity could be utilised. After sufficient curing, over-painting can be undertaken. If the film thicknesses increase, the diffusion rate of oxygen and other gases is retarded. When linseed oil paints are applied in layers that are too thick, a characteristic surface wrinkling phenomenon (*skinntork*) occurs while the drying process has started.[102] Layers which are too thick will prevent oxidation and will prolong the drying time by excluding air access (Mulder, 1867, p. 159). For industrial applications, application of many thin layers in order to produce a substantial total paint system thickness was considered as an uneconomic procedure, as illustrated by the following: "*Professional painters always advocate thin and repeated applications, which is, of course, better but which is not economically feasible for power pylons.*" (Vattenfall, 1924, p. 1.).[103] Therefore, the layers were applied thicker and in fewer numbers. For making this possible, siccative was used, but the long drying rates of armour paints were considered in the working procedures.

Experiences from sample preparations and workshops in the present study have shown that painters usually apply wet film thicknesses of about 20–25 µm.[104] The over-painting

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[101] Verified by Andés, 1900, p. 92: Magnusson, 1931, p. 38: Seeligman & Zieke, 1910, p. 287.

[102] The mechanisms are described for instance by, for instance, Nylén, 1948, p. 654: Magnusson, 1939, p. 258.

[103] Translated from: "*Yrkesmålare förordar ju alltid tunna strykningar, men stryks de istället flera gånger, vilket givetvis är bättre men ekonomiskt oförutbart på kraftlinjestolpar*".

[104] For instance, at the "How thin is thin" workshop in Mariestad in September 2019.

is repeated until the desired total paint layer thickness is reached, and until no matte spots could be observed after drying. These spots are usually predicted and the areas are spot-primed before the overall priming (or before the intermediate layer when the spots are visible). Two layers of primer could make it easier to add multiple layers and at the same time to keep up the lean-to-fatter principle. If several topcoats are used instead this will increase the risk of achieving substrates that are too fat. When the painted surface has an even gloss, and the total paint film thickness is as required, the painting is finished. If the final topcoat has a colour deviation compared to the under-paint, this is beneficial since it reduces the risk of unpainted spots.

8.2.8 Assess the Quality of Used Paint or Varnish

The quality of the paint is usually checked *in situ* when it is stirred prior to use. After intense stirring for 10–15 minutes, no sediments should remain on the bottom, and the ingredients should not separate after a short standing time. Five-litre pails are stirred for about the same time, but with a dissolver and drilling machine for uniformity. Heavy pigments often sediment during work, even in a bodied binder, and the paint needs to be regularly stirred. The viscosity is assessed by observing the paint running off the stick used for agitation. Most painters describe that it should run off easily for 15–20 seconds, then start to drip. The desired viscosity for the topcoat is usually described as creamy, like yoghurt or sour milk. Paint with a high body could be diluted with varnish or be heated to a viscosity that enables good applicability and levelling, still with the lean-to-fatter principle in mind. A historic description is that the paint should leave the brush in tough droplets (Rothstein, 1856, p. 246). During use, the paint is also checked so that it is not contaminated by particles, skin, or similar contaminants.

A common sensory assessment, stated by the painters and demonstrated by many video recordings in this study, is to smell the paint or paint ingredient after the capsule or lid has been removed. The impression is that the painters that participated in the sensory profiling sessions quite easily find the word for describing their perceptions. They check if the odour is rancid, or typical for the stated paint binder (**Paper V** and **Paper VI**). There is scepticism for unfamiliar odours, but high intensities of strong or acrid odours are usually accepted if they are attributed to highly bodied linseed oil varnishes. The smell of stand oils or tung oils in the paint is usually easily detected. A rancid paint or varnish should not be used since it may cause that the paint does not dry or harden, or could take months for it to dry (as happened during a workshop).[105] Another effect of rancidification is that the paint could separate—i.e., the pigments and binder physically creep and disintegrate from each other immediately or a while after application, or the paint could creep from the substrate. A paint that sags off a while after being applied to vertical surfaces could be rancid (or have a too low body). Sometimes a rancid paint could be used again after the binder has been decanted and replaced by a high-temperature bodied, reactive varnish. The paint may also lose its body or gelate with pigments such as zinc white. The causes are that fatty acids are separated from the glyceride, and become free together with volatile decomposing products (depicted by the acid value, free fatty acid value, peroxide value, or p-anisidine value) (Gupta, 2017, pp. 326–328). The phenomenon could occasionally occur due to auto-oxidation, photo-oxidation, hydrolysis, and thermal deterioration. Crucial factors are moisture, presence of microbiological activity (for

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[105] Verified by Andés, 1900, p. 142. “How thin is thin?” workshop September 2019.

instance, under storing).[106] Insufficient purification and mucilage could cause rancidification due to the presence of chlorophyll and phospholipids. Different enzymes, trace metals, and driers may initiate rancidification. Some deterioration types are promoted or inhibited by light and air. Examples of preventive actions include keeping good hygiene routines (avoid moisture and dirt), storing products in dark and coolish spaces, minimising the air volume in containers, and avoiding condensation in cans. If possible, pour the oil or varnish that is about to be consumed into a separate packaging. When linseed oils and varnishes get rancid, they may either lose their odour intensity considerably or be likened to oats (*havre, gryn*), chipboard (*spånskiva*), sour dishcloth (*sur disktrasa*), stale or musty (*fadd, unket*), motor oil (*motorolja*), Chinese food or frying oil that is old or has gone bad (*kinamat, dålig frityrolja)*, bone infusion/collagen (*benavkok/kollagen*), newly swabbed old linoleum floor (*gammalt nyskurat linoleumgolv*), modeling clay (*modellera*), red beet (*rödbeta*).[107] In addition to rancidity, the varnish is observed for turbidity which might indicate dispersed water or gums, which in turn could impair the drying and film-forming characteristics of the varnish.

8.2.9 Assess the Drying State and use Satisfying Ample Time

A common painters' rule is (as mentioned) that if a paint layer is over-painted before it has reached a high state of drying, its further drying rate will decrease because of the limited further access to light and air (important for the auto-oxidation and polymerisation).[108] The effect may be that the mismatch of drying expansion and contraction between the layers causes stress and cracking of the paint layers (Fallgren, 1934b, p. 125). This may further lead to flaking and initiation of under-film corrosion. Painters commonly consider that insufficient drying may introduce instability to the paint system that is unbeneficial for the system′s lifetime.

A durable result is dependent on allowing "ample time" (sufficient curing time) for each layer to dry satisfactory before application of the next layer (Sabin, 1905, p. 38: Edwards, 1936, p. 87.) Too much time is not appropriate since this could cause contamination of the surface, or in some cases embrittlement.[109] As described in chapter 8.2.6, too much time between the applications may lead to the formation of surfaces that are too "fat" and which must be degreased prior to over-painting in order to achieve proper adherence.

The drying power of each layer depends on a number of complex variables, such as the substrate, the varnish paint composition (varnish type, pigments, driers), the environment (temperature, RH, photo dosage), and the film thickness. This makes it impossible to state exactly where the appropriate over-painting point is for a certain oil varnish paint. Through sensorial assessments and measuring the oxygen value, Weger showed that *rapidly drying* varnish is not synonymous to *well drying* (Fahrion, 1911, pp. 214–216). It is considered as irrelevant to state the drying time unless the drying temperature is also stated (Magnusson, 1931, pp. 37–38). For an exterior paint layer, it must dry enough within 12 hours in order to avoid moisture penetration to the substrate (Andés, 1900, p. 268). Some painters state that "set-to-touch" drying is an important quality criterion for anticorrosive paints and that this differs for different paint systems. This is important due to the risk of dew or rain that may initiate under-film corrosion. It is, in most cases, desired that an anticorrosive paint layer dries within

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[106] Described also for instance by Mulder, 1867, p. 92: Cronqvist, 1871, p. 86, Fahrion, 1911, p. 106.

[107] Examples of suggested attributes from a workshop in Vekhyttan in November 2019.

[108] Verified by Andés, 1900, pp. 89, 92: Magnusson, 1939, p. 259.

[109] Verified by Söderberg, 1964, p. 363.

24 hours in the Swedish climate, in order to be able to plan and conduct the work.[110] The correlation between the drying stages of different types of linseed oils and varnishes is described in chapter 6.2.1.

A preliminary drying sensory vocabulary is described in Supplement 3. A through-dried lean oil varnish paint feels differently than a through-dry fat oil varnish paint. Most painters seem to agree that a paint layer is ready for over-painting when the touch of a hand and fingers is met with slight friction, and feels a bit harsh. This stage varies between dust-dry and through-dry and should be similar to when a hand touches a rubber balloon; some harshness, rubber resistance, only with a small amount of flexibility. If the layers are very thin, this feeling is more difficult to perceive and thick layers are more elastic. Some painters assess the haptic touch before over-painting as a firm, a bit tacky, with "bite" and grip. If the layer is not mature for over-painting, the next application may crawl, pearl, and the application is heavier and will demand more muscle work. When a paint layer is through-dry there is no friction or resistance to touch, and it feels like any other room-tempered surface. When a finger is pulled hard over the surface it does not "scream" anymore (make a loud noise due to the friction) and does not "bite" any longer. The screaming sound is analogous to the assessments that guilders conduct when they pull the blade metal over the paint layer. Even if it resists pressure for instance by a thumb without plastic deformation it may not have dried completely. When it is firm and the warmth from a holding hand (for a while) does not soften the film, it has dried harder (Andés, 1900, p. 82). Commonly, it is recommended to wait at least an extra day when the rubber-balloon stage is reached. Many painters use drying time of a week, even under beneficial drying conditions during summer (this varies for different paint-makers and painters, with some waiting only a couple of days).

It is experienced in this study, that if the paint has not dried through this is easy to reveal with a coating drill. The drill results in the shear of the immature film, and this is observed as torn edges in the magnifier. When the film is through-dry, the drill makes a distinct, circular deformation, see **Figure 32**. The use of an electrical surface profile or a MI device to measure thickness easily reveal when the through-dry state has passed, since the measurement does not make a clicking sound any longer.[111]

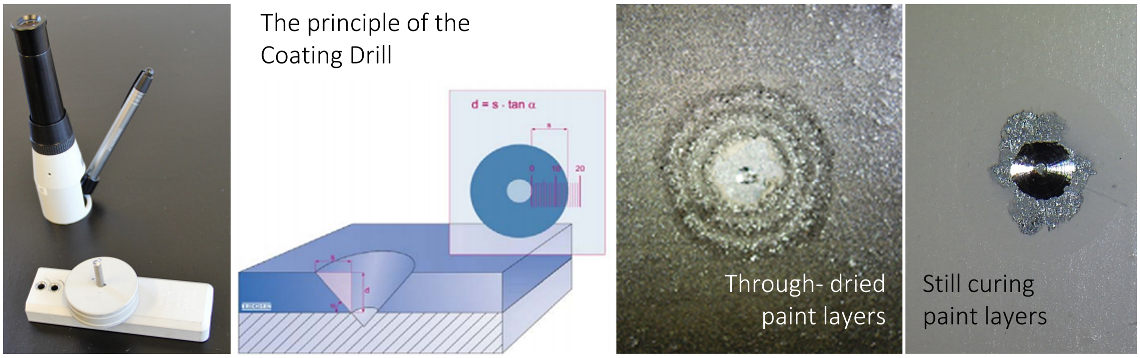

Figure 32: A Coating Drill may reveal if the paint layers are through-dry, by the formation of distinct circular interfaces (viewed from above). When this is not the case, the layers are torn into irregular interfaces.

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[110] For the painting of power pylons at Vattenfall, a slight rain after the application of armour paint with stand oil is not a catastrophe, since the fat binder makes the surface hydrophobic (Vattenfall, 1933, p. 10).

[111] Video recording 2017-04-04:00235.

CHAPTER 9

DISCUSSION AND CONCLUSIONS

Example of a characteristic of a fat oil varnish paint with a tung oil addition (15-20 wt %); it forms heavily wrinkled surface skin in the can due to its high reactivity and volume expansion at the sol to gel transformation. The high polymerisation rate of tung oil is beneficial for rapid through-drying of the anticorrosive paint.

DISCUSSION AND CONCLUSIONS

9.1 Summing up

What tools and quality assessment checkpoints could be used for improved processes of maintenance and working procedures? It is concluded that the durability of anticorrosive paint is affected by:

1. The geographical location of the ferrous structures and objects;
2. Leaving too long between maintenance intervals, meaning the painting treatment is not renewed at the right time which can lead to damage which is too severe to correct;
3. Type and condition of the ferrous substrate or previous paint system;
4. The quality of the anticorrosive paint and its chemical and physical characteristics;
5. The number of applied paint layers, and their thicknesses;
6. The skills of the painter and the affordances of the application, which affect the quality of surface preparations, the firmness and adhesion of the primer paint, the application, protection from moisture during drying, the necessary length of time between the paint applications, and the film thicknesses;
7. The atmospheric conditions at the time of working, such as RH and temperature.

The establishment of efficient barriers to protect ferrous substrates against weathering is a matter of multiple ongoing strategies and concepts. The maintenance strategies for a highly valued ferrous structure or object need to be adapted according to, amongst other things, geographical factors and exposure. All the factors listed above could be considered for improving the management of painted ferrous heritage. Different strategies and repainting intervals should be formulated depending on the conditions, the ambitions of the project, the object type, and accessibility. The overall management and the quality assessments for controlling and designing the site affordances are of major importance for the results. When establishing these strategies and concepts, the stakeholder should also plan what interventions must be undertaken, the forms for the contracts, and when to carry out the intervention according to need and weather conditions. For heritage structures and objects, this may be especially delicate since many factors must be considered which have to be negotiated alongside the heritage values represented.

A suggestion of a model for improved management strategies and guidance, systematic quality tools and checkpoints, and general working procedures for anticorrosive paint treatments of non-metallised ferrous substrates has been provided (chapter 5 and **Paper I**). A model for the circular nature of maintenance based on the stages of *anamnesis, diagnosis, therapy, control, and monitoring* has been proposed. Descriptions of technical, economic, environmental, and historical qualities of paint systems have been proposed, and for each object, it has to be decided which of these factors that is/are the most important. The results could be used for the initiation of guiding standards on the maintenance of ferrous heritage.

The oil varnish paint formulation, with different characteristics and interactions between the binder and pigments, is a key factor for the establishment and success of efficient barriers.

But, just as crucial as the concept of the paint system is how the system is used. In the general working procedures should be established the intervention frames; sequences of actions, use of different products, total barrier thickness, and quality control checkpoints. The skills of the painters should be considered in the design of general and specific working procedures, as exemplified in chapter 8. When this is the case, the documentation could be facile and relevant, and useful for the next maintenance cycle and the long-term evaluation.

What is the origin, context, and the concept of the armour paint system?
What characteristics do armour paints show? How does armour paint age?

The factors that influence the qualities of oil varnish paints have been enlightened, as well as the concept of armour paints (chapter 6**, Paper II, Paper III, Paper IV**). An efficient anticorrosive paint system is a sophisticated formulation and complex interaction of pigments, fillers, and binders which need to be used in a way that enables the paint system to function to its potential as a shield on ferrous substrates. The complex correspondence of the paint's body, viscosity, and applicability is described in chapters 8.26 and 8.2.7. A sum-list on relevant characteristics of binders, pigments, anticorrosive paints, and anticorrosive painting treatments is suggested in Supplement 5. The results from Karlsdotter Lyckman's thesis from 2005 regarding the production and use of oil varnishes and paints are confirmed in general but diversified concerning the formulations and function of anticorrosive paints.

Armour paint concept and context: It is clear, that the demands on paint materials and paint skills were very high due to the challenging applications. The concept of a 2+2 armour paint system is as follows; the use of two layers of an inhibitive lean and firm primer linseed oil/varnish paint with additional two layers of dense, effective barrier layers of UV-radiation reflecting armour paints with MIO and leafing aluminium pigments in a multi-varnish mixture with long-lasting elasticity and adherence. The concept is a result of the clever combination of engineering and painting traditions, to be used in the development of modern society´s need for infrastructure and industries until the 1960s. When it became possible to produce aluminium in the early twentieth century, the blackish-greyish scale armour paints (MIO pigments and type 4 varnishes) were used with the addition of aluminium pigments. The lamellar pigments act as integrated UV-stabilators, additions that are common in many other paint types today. When it became possible to produce paint binders of *stand oil character* (in a larger scale), these binders were used in the anticorrosive paint formulations in order to produce paints with higher elasticity and keener waterproof capacity.

Outdoor linseed oil-based paint formulations: It has been shown that the nature of the paint binder plays an important function in the behaviour and the durability of the paint and the formed paint film. The correspondence with the other components and pigments is complex, and the components cannot (of course) be used separately to gain durability. The quality of the formed paint film depends on a number of interacting variables such as the oil seed type (and the "terroir"), the storage, and the many steps of different refinement treatments. The influences of multivalent ions (positive or negative catalysts), energy exposure (temperature x time at the heat bodying), and molecular pre-agglomeration, and gel formation significantly affect the results. The refinement treatments of drying oils require advanced skills to produce varnish and paint with a high film-forming capacity, i.e., with sufficient body, that allows the liquid to solid transformation (gel formation) to proceed to characteristics such as uniform spreading without defects; high levels of adhesion, cohesion, drying power, and elasticity; high waterproof capacity (low imbibition and *hysterós*); and high resistance to ageing. These characteristics cannot be achieved with an unrefined drying oil. A varnish requires heat treatments with the addition of driers to produce durable films. Mulder's *Linoxyn* is achieved by the use of fire-boiled lead oxide varnishes which result in an irreversible, lyophobic, and hydrophobic gel, with high resistance to water penetration and solvents. From about 1900 and onwards, the weather-resistance of films made from commonly used fat varnishes changed, as stated in Swedish and international technical literature. These changes were probably connected to different varnish-making procedures, but also changes in purification methods.

Anticorrosive linseed oil-based paints: Did the reduced performance of type 2; air-blown oils (preparation varnishes) motivate the additions of highly refined stand oils and tung oils, to anticorrosive paints? The answer appears to be no, since air-blown oils were not generally used for anticorrosive paints. There was a consciousness at the time (1920–1960s) that *anticorrosive paints* need pure and heat-bodied (polymerised) varnishes, and these were provided by many paint-makers. For this purpose, varnishes of *stand oil character* were used, as stated by, for instance, Magnusson and Laurell.[112] The finest fat varnishes with *stand oil character* were saved for anticorrosive paint purposes during the Second World War thanks to governmental restrictions. It was possible for master painters to get access to, for instance, *Oljelin*, *Linyl*, *Linylin*, and *Factor Varnish*, all with *stand oil character*, during the war. For armour paints, the use of stand oils and tung oils were chosen due to their own attributes, since they were superior compared also to the oxide varnishes (as described in chapters 6.2.5, 6.2.7, 6.3.2).

Through the (historically recurring) term *stand oil character* is stipulated varnishes of characteristics similar to stand oils, though the colour of the liquid may vary depending on production methods. The haptic experiences of liquid varnish with stand oil characteristics (as described in **Paper V**) are associated with *fatness, oiliness, stickiness, butteriness, smudginess, "long" touch" (stringiness), smoothness, thickness/body, high viscosity*, and *elasticity*, and from the historic sources, it can be stated that it should be *clear (non-turbid)* and *pure* and *with high capacity to wet pigments*. The odour should correlate to the right side of the PCA biplot in (in **Paper VI**). Other relevant stand oil characteristics to mention include, for instance, low level of weight increase during drying, low imbibition (indicated by the ability to withstand water immersion ≥ 24 hours without milkiness) (see chapter 6.3). *Stand oil character* is related to varnishes that results in a glossy or shiny durable film with (long-term) elasticity. The character is produced by sun-bleached and bodied oil varnish (type 1), fire-/kettle-boiled and heat-bodied oil varnishes, especially Mulder's *Linoxyn* (type 4), and by different types of heat-bodied linseed/tung stand oils (type 5). The qualities for especially types 1 and 4 varnishes in particular may vary regardless of whether they were made manually or industrially, and the number of recipes and procedures are numerous.

The historic sources state that the use of type 5; bodied tung oils and linseed stand oils, and also the combination of tung stand-linseed stand oil, were used; not because the preparation varnishes were so bad—but because these oils have so many beneficial effects on durability for anticorrosive paints. The introduction of tung oil was not a result of trying to compensate for the changes in linseed oil processing, but a decision based on their superior quality

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[112] Magnusson, 1939, pp. 264–265: Laurell 1942, p. 157.

characteristics for outdoor use. The tung oil addition was a natural development in the background of the chemical-technical industrialisation and commercialisation that started during the last decades of the nineteenth century. By that time, chemists were able to master the difficulties of refining raw tung oil into a product that was superior to the weather-resistance of linseed oils. The decision to use tung oil as an active ingredient in anticorrosive paints in the early 1920s was taken consciously since the kettle-bodied varnishes dried too slowly and were too soft for aluminium pigmented paints. Lead oxide varnishes or varnishes with high acid values were not recommended as binders for armour paint due to the risk of discoloration of the aluminium pigments. When the resin was reduced in spar varnishes, they provided for a durable paint binder for aluminium paints. In Sweden, the use of a quarter tung stand oil is highly likely to be a result of using the German patent of Dr. Asser. The tung oil addition made it possible to apply thicker layers compared to linseed varnish since the drying progress was rapid and through the entire film by polymerisation. It appears as the material knowledge and science were excellent up to the time of the Second World War, but today we have forgotten almost everything.

Stand oils became popular in *wooden* exterior paints later than for ferrous substrates (after the Second World War according to the described trials of Andersson & Nylén, 1957 and Andersson, 1961). Andersson & Nylén state that the historic information regarding the introduction of stand oil paints for wooden substrates is hard to find, though this was used as a way of reducing the necessity for binder in paint formulations during the Second World War.[113] However, stand oil additions were used for anticorrosive paint formulations in the 1920s, as described by, for instance, Suida & Salvaterra (1931).

The extensive need for quality assessment methods for varnishes and paints, extensively described in historical sources, shows that there were many products with varying quality for outdoor use. The use of preparation varnishes (type 2), and especially with liquid cobalt driers did reduce the durability of outdoor painted surfaces.[114] For those varnishes, an addition of stand oil or tung oil would of course be beneficial. It appears as an oversimplification to say that all the linseed varnishes from the 1920s were of low quality or that all preparation varnishes were sensitive to UV-radiation or moisture. This is indicated, for instance, by the book om Magnusson, 1931, where he shows how he uses the glass-plate water immersion test to check the water resistance of different varnish films (and Pb-Mn resin varnishes managed very well). Both good and bad examples of the quality and durability of preparation varnishes exist, as also indicated by the glass-plate method in this study. The glass-plate water immersion test, used in **Paper IV**, indicates that the addition of (10 wt %) stand oil or (20-25 wt%) tung oil to different types of linseed oil varnishes results in similar water resistance capacity as if litharge varnish is used. By weather-induced ageing, stand oils produce less dicarboxylic acids, compared to other types of linseed oil varnishes, as shown I **Paper IV**. It is also shown that high-temperature treated pyrolusite varnishes (type 4) may contain cyclic compounds similar to those that are characteristic of stand oils, but despite this, the imbibition is high.

Armour paint ageing: A number of armour paints and primers have been remade (from recipes from the 1940s) and applied on ferrous substrates without problems. Ageing processes

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[113] Andersson & Nylén, 1957, p. 12.

[114] As earlier reported by Karlsdotter Lyckman, 2005, p. 89.

in natural and accelerated aged armour paints have been described through a multi-analytical approach, in **Paper III**. The remade armour paints age by becoming matte, darker, harder and more brittle. The painted surfaces may also show some yellowing. With ageing, the wettability of the surfaces change. It has been found that their surface is oxidised but beneath the leafed subsurface, the paints are still "young" and immature (i.e., there is still a high degree of unsaturated fatty acids, and less dicarboxylic acids compared to the surface) after a period of about four years in field. A hypothesis is that the dense leafing layer retards oxygen access and oxidation of unsaturated fatty acids for a long time. As long as there are unreacted fatty acids in the film, it will keep more of its elasticity since the embrittlement caused by oxidation is postponed. This is beneficial for the hard ("armoured") topcoat. For the intermediate armour paint layer, the oxidation during curing may be partly catalysed by the red-lead primer. Therefore, an armour paint system that has a leaner and faster drying intermediate paint, and a fat topcoat with the character of stand oil could be useful. This is confirmed in **Paper II**´s Table 2 where the paint formulations of Vattenfall (1933) are described. In the same paper it is described how the armour paints containing a quarter tung stand oil could need weeks for drying if driers are not added—but for a topcoat this is not a problem if the application is done during appropriate weather conditions. This type of topcoat will likely show a long-lasting elasticity, which is a beneficial feature of the paint.

Remaking of armour paints and anticorrosive oil varnish paints: The results confirm beneficial anticorrosive characteristics and that it is possible for a skilled paint-maker to initiate a production of armour paints based on the provided recipes. Remade armour paints could be used for the maintenance of ferrous heritage originating between the 1920s–1960s, because the paint type existed in that period. For objects from the time before this, the scale armour paints could be remade, with binders of stand oil character for the production of elastic, weather-resistant, and durable paint films. To enable thicker paint layers, bodied binders are needed in the paint formulation There are indications that also cold-pressed, highly refined blown varnishes could work for armour paints, at least for a short time (descried in **Paper III**). We do not know the impact of, for instance, binder wettability or the reflective protective effects of aluminium pigment leafing or MIO. All the remade armour paints (with different formulations), aged artificially and under natural conditions, manage the weather-exposure very well. The pigments and binder interaction is complex and affects the ageing behaviour of the paint. As a primer oil paint, inhibitive complex phosphates could be used for environmental considerations, as described in **Paper II**. So far, this has worked well in the field tests in Mariestad. Two layers of red hematite could probably also manage satisfying (without the inhibitive action) with two layers of armour paints. The armour paint could be over-painted with a topcoat of a coloured oil varnish paint if the metallic or dark finish is not wanted. This will take advantage of the dense moisture barrier effect of armour paint system, but not the high reflectivity of UV-radiation that protects the organic binder.

For objects where no type of armour paints is wanted, anticorrosive paint formulations with pigments such as carbon black, bone black, graphite, natural red hematite, and binders of *stand oil character* could be used.

Why should and how could the painter's skills be improved and communicated?

Vocabulary and language tools have been initiated for the sensory quality assessment of different types of oils and varnishes in the forms of olfactory, visual, and haptic vocabularies; **Paper V** and **Paper VI**, Supplement 3. They have been tested in workshops and have been proven to be valuable. Now the vocabularies need to be further used and refined by the painters and paint-makers.

In order to develop professional skills and material intelligence, repetition and focused attention are necessary factors for success. The correspondence between the materials and the painter develops into experiences about their nature and behaviour – the knowledge that is needed in problem solving to control the results and quality of the actions. Sensory vocabularies to be used as tools for attentive reflection and learning have been initiated and it has been possible to correlate to the different types of oils and varnishes that are used in the profession of traditional architectural painters. The complex correspondence between materials, skills, and quality could be assisted by a vocabulary, that helps to put the attention on details and *being with* the materials. The quality attributes have been found to correlate to the profiled products; still, it cannot be concluded that the results are generalisable to all products. An example of a procedural inquiry (chapter 8) and quality assessments are given in (**Paper V** and **Paper VI**). The vocabularies could enable communities of mutual learning, with discussion with a basis of observations, reflections, and experiences, and could increase the material knowledge/intelligence. Through this, the action competence of the traditional architectural painter´s craft could be improved, and in return, the traditional architectural painters may be able to define their practices together. In the long term, this will have some impact on the intersubjectivity and quality assessments of the craft of painting which will improve the opportunities for the craft to be continued.

9.2 Recommendations and Suggestions for Implementation

Within this work, stakeholders at any organisation may find relevant aspects to apply in their work in preserving ferrous heritage.

- Vattenfall and IVA had national strategies for how the anticorrosive paint treatments of ferrous structures should be managed. For instance, no paint materials with unknown formulation or specifications should be used, and results of interventions were evaluated systematically and from a life cycle cost (LCC) perspective. They were not in the hands of material and paint producers; they were in charge of what they needed and analysed ready-made paints so that they were sure that the requirements were fulfilled, and they had an ongoing dialogue with paint-makers about the anticorrosive paint formulations. The formation of a national independent specialist group that works on preservation issues of ferrous heritage would be very useful, and guidelines and results could be implemented across various authorities and organisations, and other vital decision-makers.
- Governmental conservators and other trustees could make inventories and priorities regionally about which valuable objects need special care and attention, and work out sound strategies for the management and maintenance.

- The implementation of the suggestions concerning management and maintenance that are described by Fielden and Jokilehto (1998) is recommended. These suggestions include the need for competent consultancies and traditional architectural painters to be involved in the different stages of the maintenance cycle. The responsibility to safeguard the paints and the skills of the traditional architectural painters as tangible and intangible heritage is one which all stakeholders should be involved in.
- This research could inspire start-ups of pilot projects which could implement the results presented in this study so far. This could, for instance, be made on a platform or other small, easily accessible roofings or objects. There is a benefit of working with real objects compared to field tests of new or old sheets since this will deal with the complexity of anamnesis, diagnosis, therapy and control. This would provide the opportunity to formulate paint with heat bodied varnishes of *stand oil character*, but also the chance to understand how the paint treatment is actually conducted, with focus on quality assessments and documentation. It is suggested that video recording is a complementary documentation method, and that critical incidents as well as quality assessments are highlighted.
- Paint-makers may direct their attention towards raw material specifications and qualities in order to increase the alternatives for making anticorrosive paints with heat-bodied varnishes of stand oil character. The production of armour paints is initiated as a result of the work, and hopefully additional paint-makers will follow.
- Chapter 8 could be refined into a film manuscript that will have the pedagogical value of transmitting and exemplifying details and context visually to the receiver. It could show not only the intertwining of material with the painters' assessments, but also the intertwining of theory and practice. This recording could be used for educating trustees and traditional architectural painters.
- A new education programme could be implemented: Traditional Architectural Painters, who would specialise in anticorrosive paint treatments of ferrous heritage. Modules with and for expert consultants would be included. The programme Could also include repairing methods which involve minimal intervention of ferrous structures and objects, for instance, plating, riveting, and welding. Alternatively, these latter suggestions could form another specialist education programme.
- For the traditional architectural painters and paint-makers, the results in this work may offer increased material knowledge and sensory quality assessment tools to be used in the profession's attentive reflections and discussions, and in education. This could revitalise the subject and offer increased competence space for the heritage field and those working within it. For craft research, new tools for material characterisations are provided.
- The research could help to establish a platform or hub for traditional architectural painters and the paint-makers' community of mutual learning and communication. This could strengthen a somewhat weak profession (regarding oil varnish paints) which has very little in common with conventional painters.

9.3 Methodological Reflections

The multiple research approach has been fruitful, but also challenging and the work took a new direction many times. Referring to Ingold, again, he inspires me to consider my research as pathfinding and driven by curiosity, as a way to train care and attention (Ingold, 2018b). In a world that is under constant transformation, facts lead us to new information: we follow and re-search. Molander's insightful statement that knowledge is growing in the intersection between the familiar and the strange, the known and unknown (2021), is true. It has not been difficult to distinguish between data and information generated by different types of methods, but it is sometimes a bit tricky to triangulate the observations and conclusions from various sources.

Reflective dialogues without prejudice, as enjoyed in the profiling sessions and discussions within the workshops, have really brought up interesting thoughts, details, and different views on the materials and the use of them. A valuable base for collegial experience exchange has been founded through the research. Material clues can give a broad view of the type of materials used, but repetitive loops in the skill are needed to get close to the original product. To reach an authentic-like product requires skills that correspond to those of the original maker. This is very difficult without taking the required time to repeat and develop skills and material correspondence over and over again. The production machinery may not be accessible, materials have changed, and different tasks could be solved in several ways. But for each loop, deeper hypothetical questions may be formulated (perhaps to the bypassed original makers), as is the ability to make different critical quality assessments.

The methodology of combining different types of experimental and analytical methods is promising and has the potential for improvements. For instance, the steel sheets for accelerated ageing could have been notched, so that clues about paint adhesion and cohesion could have been gained. The accelerated ageing was chosen because it would resemble real conditions and would not introduce irrelevant deterioration mechanisms, but as a consequence of this, the results appeared quite gentle in exposure and ageing rate. The standards for describing paint damage could not be used for the evaluation. It is, as described in the introduction, difficult to overcome the time-lag for testing weather-exposed paints. The armour paint films were too brittle for enabling the preparation of cross-sections, and the steel-sheet substrate caused difficulties for the grinding and polishing of layers with large deviations in hardness. This could be improved by applying experimental paints on a flexible, removable substrate that could enable microscopic preparation and even micro strain-stress testing. The intention was to determine the PVC of the produced and aged armour paints, but this was not conducted since the metallic pigment would probably have melted in the valuable platinum crucibles. Some other methods would be needed for this.

An insight that has developed during the research is that material analyses could indicate, but not tell us how to reconstruct the material because we will only get clues of the production methods and the tangible knowledge connected. There are quite a few examples of this, and I had an initial wish that the historic specifications could lead us closer to the historic varnishes. That was one reason why a number of oils and varnishes were analysed at AAK AB in Karlshamn. In a way, the fact that the specifications of the historical and contemporary data neither showed a big difference nor gave clear answers on the material-skill correspondence says something. The multi-analytical approach used for the analysis in **Paper III** and **Paper IV** gave some useful insights, especially GC-MS when skilled professionals like my

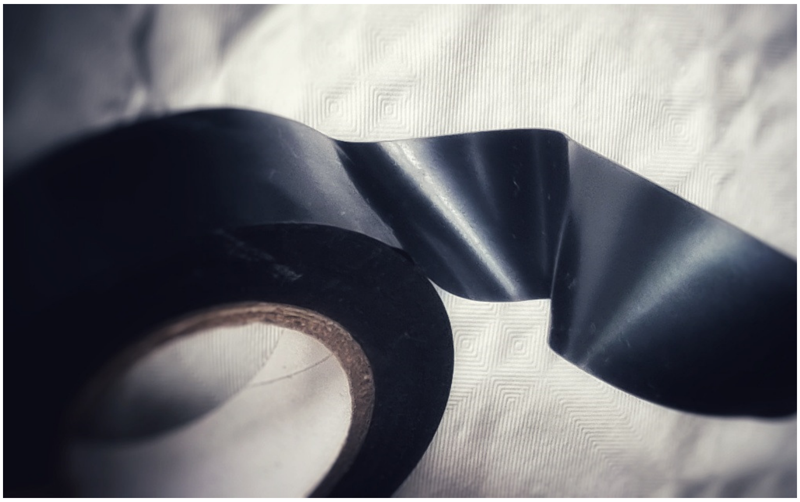

Figure 33: A role model for anticorrosive paint; a piece of a tough but firm mounting tape; very sticky and well adhering to a clean metallic substrate or the next paint layer, with a pronounced elasticity and cohesion, and a smooth water-repellent surface of uniform thickness.

co-authors are in the lead for interpretation. Still, the individual material, the combination of materials, application, deterioration—are all very complex. Data on general or specified bulk composition on paint binders or paint, is very difficult to connect to practical use or ageing response. Rancidity, high acid values and impurity content are quite easily revealed in practical work, which has been described. The colloidal state of different varnishes is a plausible explanation for why some matters may have a similar chemical composition (and similar technical quantities) and yet still behave very differently. Due to differences in aggregation (oxidation and polymerisation,) the proportions and characteristics of the dispersed phase and dispersion media, driers, may differ but still have the same or very similar composition, density, refractive index, and other technical quantities. It is also very difficult to connect the technical bulk data to the results from other (bulk) methods, such as GC-MS. Further connections to practical painting use are very complex and could possibly be assisted by, for instance, PCA.

I have been *with* the varnishes, pigments and paints, the substrates/objects, and I have studied them attentively and actively using empirical and laboratory methods. This intimate connection to the materials in my practice over a couple of years has formed my view of them, though I have struggled to ensure I do not become disconnected from the craft by the academia. Referring to the preface, I find myself working in a similar mode to that of Master Painter Olofsson, but over a wider subject. A physical role model that I am currently using for the understanding of the solid requirements of fat varnishes and anticorrosive varnish paints is shown in **Figure 33**. The representations of different oils and varnishes make it possible (better than before) to articulate the perception of them and to discuss their characteristics with other traditional architectural painters. My role models of oils, varnishes, and tars are constantly evolving and now include an addition of colloid chemistry that I feel should be explored further. I find that the use of colloid chemistry, as used for describing and controlling the characteristics of oil varnishes, is rarely used anymore. The most reasonable explanation is that when the linseed oil varnishes were substituted by other materials, there was no need to conduct further research into the colloid chemistry. Colloid and surface chemistry, rheology, are extensive research fields that apply to many other fields, including coating technologies.

CHAPTER 10

FURTHER RESEARCH

A closer look into possible further research. Street art on a concrete bridge, with the use of an alumininum-pigmented paint.

FURTHER RESEARCH

The ambition of present research is to identify and relate to our society's need for research in the field. Different aspects of this have been brought up to the surface by dialogue and discussions with governments, organisations, professions, other researchers and students but also during field observations, workshops and seminars, trainee periods, and so on. This final chapter highlights some of the issues that could be useful for further research regarding anticorrosive painting treatments of ferrous heritage.

The general problems described in the introduction are many and difficult to handle in academic research projects. A research approach could study the impact of using skilled painters and other craft persons in the anamnesis and diagnosis phase, in order to provide for more adequate working descriptions. Another field is to evaluate the use of different gentle blasting methods and materials, especially for the cleaning of black sheets or ferrous substrates with intricate shape. Also, each of the maxims suggested in Supplement 5 could be critically investigated and viewed.

An ambition in the work was to systematically test and evaluate oil varnishes and commercial anticorrosive paints, and to use PCA to correlate the results to different characteristics. For this, a setup of empirical, physical, and chemical methods would have been needed. A large number of ageing tests of oil varnishes and paints were conducted in the weatherometer, but were not evaluated due to lacking access to equipment and resource persons. This could be performed in a future multidisciplinary research project that includes an evaluation of ageing performance. A multi-analytical approach, as described in **Paper III**, could be used for the analysis and interpretation of the ongoing field tests of anticorrosive oil paints in Mariestad.

During the work, I have met the research of outstanding yet bypassed engineers and researchers, and the work of skilled painters. Despite some findings in the present thesis, questions remain about who formulated the concept of armour paint. Was it IVA, Vattenfall, or SOAB together, as some people were involved in several of the organisations (like Kurt Fr. Trägård). I would particularly suggest further work on SOAB and the work of Karl Magnusson, a talented and bright engineer who worked for decades of Sweden's largest oil refineries and produced several technical patents. The archives of SOAB are kept at several places in Gothenburg, and could shed further light on the production of oils, and on the required skill to produce different oils and varnishes – certainly the stand oils and stand tung oils. With the exception of the oil and varnish production of SOAB, there were also smaller similar companies such as Dorch, Bäcksin & Co AB in Gothenburg. Paint-makers that produced armour paints included, for instance, Färg- och Fernissfabriksaktiebolaget Standard/Firman Standtard in Trelleborg, Wedevåge Bruks AB, and Ahlfort & Cronholms. "Pansarfärg 280, Tre Kronor" is stated in Vattenfall's very first field trials in Sweden, in 1923, and I would like to know which company (Tre kronor) delivered this product (Vattenfall, 1922). There could be the possibility of finding living tradition carriers to interview. It is possible that IVA may still keep their archives on the work of the Corrosion Committee, and could perhaps give some clues about this. It is interesting to get more information about the domestic production of oils and varnishes, and how much was imported in order to get a picture of the characteristics of oils and varnishes. It appears that the linseeds for pressing and further refinement were imported (i.e., they were not produced in Sweden), and the influence of binders with a stand oil character came from Germany and the United States of America. It would be interesting to get a picture of which drying oils other than linseed oil and tung oils were used for high quality ready-made paints, such as perilla and oiticia oil (as described by Standeven, 2011).

Gerardus Johannes Mulder's experiments with Linoxyn, described in his work from 1867, would be interesting to repeat, but with the aid of modern analytical methods for evaluation within multidisciplinary research. It is interesting to compare tests of Mulder's Linoxyn with heat-bodied varnishes with other catalysts, such as zinc oxide and manganese borate. It could be investigate if a partial dissolving takes place at a metal interface when Linoxyn is applied, that could explain it superior adherence to metallic substrates. The use of the Teas chart is interesting for the stressing of Mulder's Linoxyn—it describes the polarity of different solvents with the aid of a ternary section (see, for instance, Izzo, 2011, p. 38). The glass plate immersion test method could be used with other solvents than water. The glass plate immersion method in combination with anilin dye, described by Simon 1897, could be used for evaluating ready-made anticorrosive paints. The immersion tests method could be utilised also in the evaluation of the reversibility of Nordic pine tar films.

The surface and colloid chemistry of paints could give many answers to the behaviour of varnishes, paints, and pine tars, and would be a very interesting topic for further research and rediscovery. The work of A. Eibner (1923, 1930) and A.V. Blom (1954) could serve as a starting point for this, in cooperation with the aid of modern analytical methods for evaluation within multidisciplinary research. The measurement and control of films and gels are common in the food, pharmaceutical, cosmetic, and packaging industries (and so on), and collaboration could be interesting. A deeper penetration on the characteristics (including their colloidal behaviour) of different types of stand oils would improve our knowledge and understanding of heritage paints. The glass-plate water immersion test can be developed further to assess and indicate the quality of varnishes.

There are still questions about the armour paint systems and formulations, for instance, to investigate and compare the catalytic effects of inhibitive and soap forming primer paints and to compare the wettability effects of different types of binders. The characteristics of stand oils and linseed + tung oil combinations could be further explored. For instance, how sensitive are the stand oils to deterioration caused by small additions of solvents?

Railway organisations and other industries had access to tinted armour paints. There were several grey paints and some greens in Sweden. An armour paint colour palette, similar to that used in Germany (*DB-Farbtonkarte*), could be useful for heritage purposes. It is likely that the colour palettes that were used for, for instance, SJ, Vattenfall and other organisations could be found and made the subject of research. It would be fun and interesting to investigate the use of tinted armour paints on industrial heritage and to investigate the limits and perceptions of tinted shaping.

It is highly interesting to look further into alternatives to replace the red-lead primers. Initial electrochemical trials with Elisabeth Ahlberg and Alberto Visible at GU Chemistry confirm the superior protection of red-lead linseed varnish paints. Complex phosphates work in a similar way but may need improvements, such as additional and thicker layers, with a varnish of stand oil character and with low imbibition susceptibility. There is a large variety of complex macro-phosphates with different pH solubilities, and a state-of the art survey is needed. The work was not continued since a paint application mode was needed that could produce completely defect-free and uniform paint film thicknesses in order to achieve higher reproducibility. Different applicators were tested, but none of these met this requirement. The work of Robert Mallet from 1838–1840 is interesting. Zinc primer paints were used for half a decade before the industrial breakthrough for galvanising, and Mallet attempted to find out how would they work with a varnish of stand oil character (without the formation of zinc carboxylates due to hydrolysis). Moreover, the use of lean zinc oxide oil varnish primer paints has been shown in some historic sources, as well as zinc oxide additions to red hematite. The art of making putties for different purposes, appears to be quite forgotten. This is an important field for ferrous heritage painting treatments, since this is a way to eliminate water-traps. The knowledge of preparing putties and putty paints is rarely practiced by painters. As a base, the recipes for metallic substrates of Thon 1887, and Karmasch 1862 could be used as a foundation for practical work.

A research field should be to continue the intertwined development of quality assessments, material knowledge, and craft skills, for painting craft professionals and to adapt this to research about the Nordic pine tars.

What struck me many times during the research was the absence of women in history; always male engineers, researchers, painters, except for two female engineers at Vattenfall and probably at KTH. I would like to find out whether the first female graduated painter of 1965 is still alive and hear her talk about her experiences. There is a need to meet and interview traditional architectural painter tradition carriers about their material intelligence and correspondence.

Painters on a steel-sheet roofing, in the early twentieth century, Stockholm. "Två målare på plåttak" 1905-1920.

Photo: Axel Swinhufvud. Picture: ASW 2140. Stockholms stadsmuseum, Sweden. License: BY-NC-SA.

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Main Respondents 2016–2021

Bernth Adolf. TAP.
Andersson, Björn. Master TAP.
Beischer, Stefan. Plater
Berg, Anna, TAP.
Bergmark, Staffan. TAP technician.
Bilker, Marcus. Master TAP.
Blomgren, André, TAP.
Boredal, Rolf. Master TAP.
Bratt, Helena. TAP.
Eriksson, Maria. TAP.
Falk, Kurt Allan. Master Plater and tradition carrier. Källbom & Hugo Larsson recorded interview.
Friberg, Cajsa. TAP.
Granath, Tom. Master TAP, teacher.
Gyllensvaan, Marie. TAP.
Göransson, Anders. TAP.
Hafvenstein Lenzer, Frida. Paint-maker.
Hansen, Dan. Paint-maker.
Hansen, Carl. Paint-maker.
Helmvee, Marietta, TAP.
Håkansson, Anne. Master TAP.
Ivarsson, Milis. Paint-maker.
Johansson, Leif. TAP, anticorrosive spec.
Järpedal, Cristina. TAP.
Kjellberg, Lars. Paint-maker.
Larsson, Anders. Surface and colloidal chemist.
Lefvert, Fredrik. Plater.
Lindberg, Fredrik. TAP.
Ljungdahl, Tomas. TAP.
Löwall, Richard. TAP.
Magnusson, Johannes. Master TAP.
Moilanen, Outi. TAP
Monsen, Johan. Master TAP and Paint Conservator.
Norling, Rasmus. TAP and Building Conservator.
Nyander, Nanne, Master TAP.
Olofsson, Thom. Master TAP.
Olsen, Björn. Paint-maker repr.
Oskarsson, Elisabeth. TAP.
Palm, Mija Maria. TAP.
Patrik Reutersward, FROSIO Inspector.
Rådesson, Marie. TAP and Paint Conservator.
Sandner, Herbert. Master TAP.
Schneider, Claes. Linseed oil producer.
Sillén, Sven, TAP.
Skoglund, Viktoria. Paint-maker repr.
Skoglund, Olof, TAP Technician.
Svensson, Gösta. Paint engineer, tradition carrier. Källbom, & Granath recorded interview.
Tigerhielm, Ludvig. TAP.
Tunberg, Britta. Restaurator.
Westerlund, Ola. Master TAP.
Zetterström, C-O. Metall Restaurator.

Field studies and Cases

Examples of field studies

Askeryd Church, 2017
Flisby Church, 2016
Habo Church, 2015, 2021
Huskvarna Slottsvilla, 2014, (2021)
Idelunds Snickerifabrik, 2014
S. Solberga Church, 2017.
Ulvåsa Estate, 2016
Valdshult Church, 2017
Åkers Chuch, 2020

Maintenance of painted ferrous heritage, mainly steel-sheet roofings.

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SUPPLEMENTS
RESEARCH PAPERS AND ADDITIONAL DATA

SUPPLEMENT 2: Laboratory Assessments

Some technical quantities were assessed in laboratory, for selected drying oils and varnishes. The results are assessed with a relative Sd of a maximum of 0.5%, and blank references and control references are used in connection to the investigations.

Methods

Density (specific weight): The density is assessed with an electronic density meter (DMA 4500M Anton Paar) at 20°C and 60 °C, with an uncertainty of ± 0.03 %.

Refractive index: The refractive index is assessed by an automatic refractometer (BS RFM 340+) with an uncertainty of ± 0.01 %.

Water content: The water content is assessed according to the Karl Fisher volumetric titration method (The American Oil Chemists' Society method AOCS Ca 2e-84 with an uncertainty of ± 15 %).

Turbidity: A cold test is assessed by a specific AAK method, in order to assess the turbidity. The liquid is put in a glass bottle, that is placed into a water bath (Lauda Eco Silver E15), with a temperature of 0 °C. The retention time is six hours. The turbidity of the sample is assessed visually, according to a given scale.

Colour: The colour is assessed by measuring the absorbed wavelengths of the light, with an automatic tintometer (Lovibond PFC995). The used method is consistent with the Lovibond method, described by The American Oil Chemists' Society method AOCS Cc 13j-97 (with an uncertainty of ± 25 %).

Iodine value (IV): The iodine value expresses the amount of unsaturated fatty acids in the oil. The value expresses the number of grams of iodine that reacts with the double bonds in 100 grams of fats or oils. It is calculated from GC-results according to The American Oil Chemists' Society method AOCS Cd 1c-85. The iodine value for stand oils and tung oils are assessed oil laboratory of Saybolt Sweden AB according to international standard ISO 3961, Wij´s titration method, 0,1 M with repeatability r=3,5 (equipment variation) and reproducibility R=5,0 (technician variation).

Saponification value (SV): The saponification value expresses the number of milligrams of KOH which is required for the saponification of one gram of the oil. Unsaponifiable matters are considered as impurities (Singer, 1957, p. 11). The value is assessed with titration of KOH and bromide cresol green, and with phenolphthalein as an indicator, according to The International Union of Pure and Applied Chemistry Commission method IUPAC 2.202 (with an uncertainty of ± 2%).

Free fatty acid (FFA)/Acid value (AV): The (free fatty) acid value expresses the degree of lipid oxidation—rancidification, (stated as a percent of free fatty acid with an average molecular weight of 282). The acid value is the number of milligrams of KOH which is required in order to neutralise the free fatty acids in 1 g of oil. The value is assessed with titration of sodium or potassium hydroxide, and with phenolphthalein as an indicator, according to The International Union of Pure and Applied Chemistry Commission method IUPAC 2.2001 (with an uncertainty of ± 3%). It is also possible to recalculate FFA into an Acid value, by multiplying the FFA value by 1,99 (Gupta, 2017, p. 21).

Peroxide value (PV): The peroxide value expresses the degree of primary auto-oxidation of unsaturated fatty acids (i.e., rancidification) (Gupta, 2017, p. 21). The value is expressed as units of milli-equivalents (meq) peroxide per 1000 g of oil. The value is assessed with titration according to the American Oil Chemists' Society method AOCS Cd 8-53 (with an uncertainty of ± 15%). The PV is calculated from the concentration of the consumed sodium thiosulphate indicator, in the titration of potassium iodide and starch.

Insoluble impurities: Insoluble impurities consist of dirt, minerals, alcohols, sterols, pigments, hydrocarbons (Gupta, 2017, p. 25). The oil is dissolved in petroleum-ether and filtered through a glass-fiber filter (Munktell MGC, diameter 5,5 cm) according to The American Oil Chemists' Society method AOCS Ca 3a-46 (m) (with an uncertainty of ± 20%). The filter weight before and after filtering is assessed with an accuracy of four decimals, and the weight of the impurities is calculated in wt%.

Alkaline impurities: In order to determine the content of alkaline impurities in the liquid oil, the number of ml that is needed to neutralise 0,01 M HCl is assessed according to The European Pharmacopeia method EP2.4.19.

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Results

The results for three raw linseed oils, two heated varnishes, two boiled (high-temperature treated) varnishes are described in **Tables S2:1** and **Table S2:2**. The fatty acid profile was assessed with GC and GC-MS. The GC is conducted according to The International Union of Pure and Applied Chemistry Commission method IUPAC 2.304, with an accuracy of ± 4% for C18:3, ± 7% for C16:0, C18:1 and C18:2. No ratios are calculated. FA profile of the analysed solid oils and varnishes in Paper III and IV is shown in **Table S2:3.** The FA ratios are described in Paper IV.

	unit/at	at	Uncer, %	**Raw A**	**Raw B**	**Raw C**	**Heated A**	**Heated B**	**Boiled A**	**Boiled B**	**Stand oil A**	**Stand oil B**	**Tung oil A**
Density	g/cm3	20°	-	0,9295	0,9299	0,9289	0,9334	0,9339	0,9370	0,9347	0,9554	0,9575	0,9391
Refractive index		20°	±0,01	1,4812	1,4811	1,4667	1,4828	1,4826	1,4823	1,4824	1,4888	1,4907	1,5194
		60°	±0,01	1,4668	1,4667	1,4811	1,4684	1,4682	1,4679	1,468	1,4744	1,4763	>1,5000
Coldtest		6 h	-	2	2	2	2	2	2	2	2	2	2
Insoluble impurities	%		20	<0,01	0,01	0,02	<0,01	<0,01	0,01	0,02	0,02	<0,01	<0,01
Alkaline impurities	ml		-	<0,01	<0,01	>0,01	0,10	0,15	<0,10	<0,10	<0,10	<0,10	<0,10
Water content	%		±15	0,05	0,05	0,05	0,06	0,06	0,10	0,07	0,01	0,03	0,04
Iodine value		GC	-	189	188	191	194	196	177	181	54	37	161
Saponification value	mg KOH/g		±2	189	189	189	188	188	191	188	193	192	192
Free fatty acid		282	±3	0,77	3,3	2,1	0,59	0,94	1,7	1,9	3,3	3,1	1,7
Acid value	mg KOH/g		±3	1,52	6,50	4,24	1,18	1,87	3,41	3,8	6,63	6,24	3,3
Peroxide value	meq/kg		±15	25	34	7,8	26	2,6	6	1,7	2,9	3,3	5,6
Colour	Yellow		±25	45,0	60,0	45,0	90,0	130,0	140,0	n.k	70,0	40,0	60,0
	Red			5,0	6,0	5,0	10,0	20,0	14,0	n.k	6,0	3,0	7,0
	Blue			0,0	0,0	0,0	0,0	0,0	0,0	n.k	0,0	0,0	0,0
	Total			95,0	120,0	95,0	190,0	330,0	280,0	n.k	130,0	70,0	130,0

Table S2:1: Chemical and physical profiling of selected liquid linseed oils and varnishes. Stand oil A: viscosity 20 dPa·S, Stand oil B 45 dPa·S.

Table S2:1: Chemical and physical profiling of selected liquid linseed oils and varnishes. Stand oil A: viscosity 20 dPa·S, Stand oil B 45 dPa·S.

	Fatty acid	**Raw A**	**Rax B**	**Raw C**	**Heated A**	**Heated B**	**Boiled A**	**Boiled B**
C6:0	Caproic	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C8:0	Caprylic	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C10:0	Capric	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C12:0	Lauric	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C14:0	Myristic	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C14:1	Myristoleic	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C15:0	Pentadecyclic	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C15:1	Pentadecenoic	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C16:0	Palmitic	5,2	5,3	5,2	5,4	5,4	6,2	5,9
C16:1	Palmitoleic	>0,1	>0,1	>0,1	>0,1	>0,1	0,1	0,1
C16:2		>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C16:3		>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C16:4		>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C17:0	Margaric	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C17:1		>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C18:0	Stearic	2,4	3,0	3,1	2,6	2,5	4,6	3,3
C18:1	Oleic (cis)	20,8	20,5	17,2	17,8	17,6	21,7	18,8
C18:2	Linoleic (cis)	15,8	15,6	19,5	5,7	15,6	16,7	22,9
C18:3	α/ ϒ Linolenic	54,7	54,6	54,4	57,9	58,6	49,3	47,6
C18:4	Stearidonic	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C18 isomer other		>0,1	>0,1	>0,1	>0,1	>0,1	0,1	>0,1
C20:0	Arachidic	0,1	0,1	0,1	>0,1	>0,1	0,2	0,1
C20:1	Paillinic	0,2	0,2	0,1	0,2	>0,1	0,2	0,4
C20:2	Eicosadienoic	0,1		>0,1		0,2		
C20:3	Mead	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C20:4	Arachidonic	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C20:5 EPA	Eicosapentaenoic	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C21:0	Heneicosylic	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C21:5		>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C22:0	Behenic	>0,1	0,1	>0,1			0,2	0,1
C22:1 total		>0,1	>0,1	>0,1	>0,1	>0,1	0,1	>0,1
C22:1 Erucic	Erucic	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C22:2		>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C22:3		>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C22:4		>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C22:5		>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C22:6 DHA	Docosa	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1	>0,1
C24:0	Lignoceric	0,2		>0,1			0,1	
C24:1	Nervonic		0,2	0,2	0,2	0,1		
Unknown		0,4	0,5		0,3		0,5	0,5
Known		99,5	99,6	99,8		100	99,5	99,2

Table S2:3: Fatty acid profile of some solid oils/ varnishes analysed by Francesca Izzo.

OH = Heated A
WHT = Boiled A
WS = Stand oil A
WT = A mix of WHT with 20 wt % Tung oil A.
L = Liquid
S = Solid, unaged
A1 and A2: accelerated aged.

Sample		**Unsaturated FA**				**Monocarboxylic FA**			**Dicarboxylic FA**				**Glycerol**	**Total**
Paper IV	Synonym	Linolenic	Linoleic	Oleic	Mix 2	Myristic	Palmitic	Stearic	Azelaic	Suberic	Sebaic	Pimelic		
OH - L	Heated B	51,00	10,27	9,80	0	2,50	4,20	3,00	1,24	0,08	0,07	0	17,85	100,0
WHT-L	Boiled A	23,91	36,65	10,95	0	1,44	8,00	3,13	0	0,19	0,25	0	15,47	100,0
WS-L	Stand A	21,00	32,16	12,29	0	2,50	5,30	4,34	1,55	0,73	0,57	0	19,56	100,0
WT-L	Mix 1	0	1,72	2,32	68,62	1,23	2,25	4,07	2,28	0	0	0	17,50	100,0
OH - L	H	51,00	10,27	9,80	0	2,50	4,20	3,00	1,24	0,08	0,07	0	17,85	100,0
OH-S		0,47	1,59	1,99	0	1,04	19,66	11,38	32,31	7,88	2,68	0	21,02	100,0
OH-A1		0	0,83	1,44	0	2,40	19,00	11,85	36,79	8,32	1,93	0	17,53	100,1
OH-A2		0	0,80	0,85	0	2,50	18,73	10,83	37,00	8,18	2,12	0	19,44	100,5
WHT-L	J	23,91	36,65	10,95	0	1,44	8,00	3,13	0	0,19	0,25	0	15,47	100,0
WHT-S		0,79	1,47	2,21	0	1,15	23,06	18,62	17,42	7,79	2,68	0,97	23,86	100,0
WHT-A1		0	0,69	1,30	0	2,54	17,53	14,17	35,56	9,43	2,00	1,78	15,10	100,1
WHT-A2		0	0,30	0,80	0	1,30	19,00	15,76	36,00	9,70	1,63	1,00	14,60	100,1
WS-L	N	21,00	32,16	12,29	0	2,50	5,30	4,34	1,55	0,73	0,57	0	19,56	100,0
WS-S		0	0,85	6,05	0	4,65	23,3	19,93	14,07	6,26	2,25	1,24	21,6	100,2
WS-A1		0	1,90	1,90	0	3,27	21,69	18,25	15,12	7,67	2,73	1,93	25,5	100,0
WS-A2		0	1,05	9,88	0	3,38	22,51	19,04	12,16	5,37	2,02	1,54	23,1	100,1
WT-L		0	1,72	2,32	68,62	1,23	2,25	4,07	2,28	0	0	0	17,50	100,0
WT-S		0	0,67	1,34	0	1,75	16,11	14,01	29,32	10,74	2,3	1,9	21,9	100,0
WT-A1		0	0,68	1,30	0	3,27	19,00	15,00	29,95	9,94	3,00	0,83	17,70	100,7
WT-A2		0	0,90	1,05	0	5,68	19,00	15,00	30,00	9,18	1,19	2,68	15,50	100,2

Mix 1: Boiled A and 20 wt% tung oil A

Mix 2: sum of α-eleostearic and linolenic FA

SUPPLEMENT 3: Assessments of Surfaces Drying Stages

Painter´s Vocabulary

A workshop was held in Mariestad in May 2019 with ten professional painters and paint-makers. The sensory verbalisations of selected oil, varnishes and varnish paints which had been applied onto steel sheets, were assessed in different drying stages. A comprehension of the type and number of reported attributes was compiled afterwards and are comprehended in **Table S3:1**. Attributes 1–7 are placed in chronological order, compared to the drying process.

Table S3:1: Attributes for describing drying stages and perception of oil varnishes and paint films.

English attribute	Swedish main attribute	Swedish co-attribute	Description
1. Wet	*Våt*	Blöt, fuktig. Ej torr, "otorr"	The oil/varnish/paint is still liquid.
2. Daubing, sticky	*Kletig*	Kladdig/färgar, plastisk	Material is transferred from the surface, by a light touch. Clear remaining fingerprints can be seen.
3. Tacky	*Klibbig*	Limmig, klistrig, häftande	Material is not transferred by a light touch, but may give weak remaining fingerprints. The touch feels similar to the backside of an adhering tape.
4.T ack-free	*Klibbtorr*	Torr	No liquid or semi-liquid material is left on the solid surface. The surface does not stick to the skin. A screaming sound may arise when a finger is pulled over the surface. A touch may result in a elastic deformation.
5. Dust-free	*Dammtorr*	Halvtorr, torr, kärv	Dust does not stick on the solid surface. A touch is tack-free. Through-dry and dry-through are used as synonyms.
6. Through-dry or dry-through	*Genomtorr*	Genomhärdad	Everything of the liquid has solidified, also beneath the surface. When a finger is pulled over the surface, the friction is very low, and a weak sound can be heard.
7. Over-paintable	*Övermålnings-bar*	Mogen, klar	The surface is dry enough for being over-painted.
Other characteristics that may be assessed			
The harshness	*Kärv*	Sträv, fästande, med fäste/friktion, sug, motst-ånd, bet, hugg	The surface feels like warm rubber. A touch could also feel slightly gritty.
The sound	*Ljudlig*	Olika hög ljud-intensitet	When a finger is pulled over the surface in a hard, resolute manner, the surface is "quiet" or squeak, creak, whine, talk, scream. "Gold-scream´", in analogy to when guilders check if a substrate is ready, could be heard.
The smell/ odour	*Doftande*	-	The odour is described in non-hedonic attributes.

Cont. Table S3:1

The temperature	Temperatur	*Kall/varm*	A rapid or slow temperature gradient is perceived when a finger or hand is put over the surface. Glossy surfaces may (falsely) be associated with wetness or cold, not dried surfaces.
The gloss	Glans	*Matt, halvblank, blank*	Matte, semi-glossy, or glossy surfaces. High gloss tends to be associated with a higher drying stage.
The surface structure	Ytstruktur	*Jämn, glatt, hal, len.*	
Kritig, randig, fibrig. Dammig/kornig, fet, oljig	Surface structure may be described as, for instance, smooth, soapy, fatty, oily, grainy, fibrous, dusty.		
The hardness	Hårdhet	*Mjuk, hård, repkänslig, sviktande, gnuggkänslig*	Tested by scratching with a fingernail, a finger, or a tool of any kind. The film may be soft, hard, yielding, or sensitive to rubbing or rolling, or ripping.
The film quality	Filmkvalitet	*Jämn film, pärlande film, skinntork, rynkbildning*	
	The film may be described as uniform, crawling, skin- drying, striped, wrinkled.		
Expressed as symbols	-	*Symbolisk* *Gummi; torr/våt, typ Suddgummi. Eltejp över/ undersida* *Is, lack, glas*	The film may be described as similar to wet or dry rubber, insulation tape, ice, glass.

Standards

Some known standards are ISO 150:2006, ISO 9117–1:2009, and ISO 9117–3:2010. In these standards terms such as “surface-drying state” or “surface-drying time” are used. Different drying stages are described in **Table S3:2**. (Silva, 2012, p. 528–529).

Table S3:2: Drying stages for drying films and for testing driers (Silva, 2012, 9. 528–529, Schnall, 2012, p. 40–41).

Termination	**Description**
Set-To-Touch Time	The film is gently touched with a fingertip. The fingertip is immediately afterward put on another clean glass in order to assess if any material-transfer could be observed.
Dust-Free Time	Dust or cotton fibers are placed on the film and gently blown away. If the fibers do not adhere, the film is dust-free.
Tack-Free Time	No stickiness could be detected under moderate pressure. An aluminium foil will not adhere to the film when it is pushed on.
Dry-To-Touch Time	The film is firmly touched by a finger, and if no marks could be seen, the film is dry-to-touch. For drying oils, it is checked whether the film could be gently rubbed by a finger, without remaining deformation.
Dry-Hard Time	A maximum thumb-pressure indentation does not leave any marks (after being lightly polished with a soft cloth).
Dry-Through (Dry-To-Handle) Time	The film is tested in a horizontal position by holding a thumb on the surface with a straight arm under moderate pressure, then pressed with a 90-degree twist. No remaining deformation should be allowed on the film surface.
Dry-To-Recoat Time	The surface may be recoated without causing any defect (such as material-lifting or adhesion-loss).

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SUPPLEMENT 4: Experiences of the Sensory Profiling, Part 3

Methodology

This is a summary of the results of the research in Part 3, Paper IV. The investigation is conducted two months after the profiling sessions were finished. The participants reported their experiences according to the questions below, to the database Eyequestion at Örebro University (through an internet link). This was performed by answering the questions in a fixed questionnaire sequence. The respondents were identified by their names, and the answers were interpreted by the answering frequency. Some follow-up calls were made when there was uncertainty about the answers. My comments are added to the summary.

PART ONE/OLFACTORY PROFILING OF LINSEED OILS.

1. How did you experience the verbalization odours? Use a scale of 1–10: where 1 is easy, and 10 is difficult.
2. Was the verbalization getting easier or more difficult, as the profiling was progressing?
3. How would you like to describe your mindset before, during, and after the profiling?
4. How would you like to describe your present odor memory of linseed oils?
5. How, or has, the odour profiling affected you in your work? For instance, are you more aware of odours (of linseed oils)? Do you communicate differently, than before the profiling?
6. Anything else that you want to comment on, regarding the odour profiling?
7.

PART TWO/VISUAL AND HAPTIC PROFILING OF LINSEED OILS.

8. How did you your experience the verbalization of colour, turbidity, and haptic touch? Use a scale of 1–10: where 1 is easy, and 10 is difficult.
9. How, or has, the haptic and visual testing affected you in your work? For instance, are you more aware of sensorial judgments or differences between linseed oils? Do you communicate differently, than before the profiling?
10. Could you distinguish between characteristics of different oils?
11. Anything else that you would like to comment on, on regarding the profiling in part two?

Summary of Part one

Verbalisation difficulties: The olfactory profiling was experienced as much more difficult, compared to visual and haptic profiling, by the panellists (as stated by 93%). Only three persons (all women) stated that the olfactory profiling was easy. The rest stated that the odour profiling was difficult, and no differences in gender could be detected. No connection was found between the panellists′ proficiency and verbalization capacity. The women stated more frequently that despite initial difficulties, they felt able to find odour associations and descriptive words. Since women usually show a larger verbal ability, this could explain their larger capacity in labelling the odours (Zucco, Herz & Schaal, 2012, p. 48). Feredenzi et al., (2013), found no difference between gender in the capacity to detect odors but women are more sensitive to odour sensitisation and intolerance, and do report odours as more intensive than men do. They found that it is easier for women to recall odor-evoked emotional memories and they are better than men in identifying and remembering odors of origins such as food or body odours.

Stronger disgust reactions were observed for women to human or animal odours and, food (especially sulphur containing products). Video recordings from this study from the sessions reveal, for instance, that unpleasant odours were fast and spontaneously illustrated by intense mimicry (by women).

The mindset: Almost all participants state that their mindset was positive, concentrated, and present before, during, and, after the profiling. Some panellists report that they experienced some frustration, uncertainty, or "performance anxiety" before they became able to find words for odour associations. The panellists described themselves as focused, and most of them were very quiet, introverted during the sessions (with closed eyes, some with earmuffs and laboratory gloves in order to exclude disturbing influences).

The odour memories, sensitivities: A majority stated (85%) that it gradually went easier to verbalise the odour attributes with time during the profiling session. Some panellists stated that they needed several "sniffing", or 10–15 minutes, to get started. Some describe how they "saw" mental images connected to the odours, and that they needed to penetrate and return to the images several times, in order to grasp the association. These observations support that odour remembering is based on imagery and associative learning, as described in Paper V. Some panellists stated that they experienced a clear, lingering odour post-note a short while after the sniffing, in analogy to some post-taste sensations. The women stated more frequently that they are sensitive to, and conscious about odours, after the profiling session. However, as already mentioned, the genders stated the odour profiling difficulty-scale in similar ways. About 66% of the panellists, mainly women, stated that their odour memories of linseed oil from the sessions are diverse, strong, and may be recalled. The men expressed themselves more laconic, during and after the profiling. Experiences from this study indicate that the ability to associate, recognise and label odours could be trained with the RGM method, also in a short time period. The first two triads were tough and frustrating, but after approximately 3–6 "sniffing" of each oil, it gradually got easier. After a day, the panellists (both men and women) were capable of ranking the oils after intensity and odour qualities, without the need of neutralising the smelling sense in between the oils. It appears as when the panellists became more able to identify and label the odours, they also discriminated odours easier. This supports observations that verbalisation of odours enhances the long-term mental imagery of the odours (Palmiero, Di Matte & Belardinelli, 2014, p. 144). About 33% of the panellists stated that they were mentally exhausted, tired, and felt slightly unwell after the profiling session. Some sensitive persons reacted physically on the stand oils, with skin redness and headache. Citations below (my translations) describe how the odours, or the memories of the odours, followed the panellist after the profiling session.

> *"It was a new experience that the odour of the linseed oils could be so strong and feel so real. It was with me in the car on my way back home, and then later in evening, when I was sitting in my armchair watching TV. "*
> *"I had the odours of linseed oils inside my brain, for two days".*

Any effects on work? The panellists described that they have not noticed any difference, yet (after two months). They stated that they use the odours of paint materials, as they usually do for quality assessments. The employees at a paint-maker company that use a stand oil (with a significant, strong odour) reacted on it during the profiling (they found it unpleasant, but did not recognise it).

Other comments? At the end of the sessions, when we were summarising and smelling the oils from the wine glasses, many panellists commented that they experienced the odours with a higher intensity, compared to the smelling from the bottles. The higher intensities could be connected to the larger gaseous volume emitted from the glasses due to the larger contact area to the air, but possibly also because the senses got more trained with time. The similarities to colour perception were also commented, for instance, that the perception is affected by the neighboring odor/colours (by a phenomenon that is called induction). After each session, and also afterwards when the created olfactory vocabulary was used in new profiling sessions, new associations and words came up. For instance, tung oil was described as un-baked wheat dough, or raw and heated linseed oils as ensilage, raw potatoes, rotting cucumber, or orange. It appears that the panellists are getting more sensitive to the odours at each time, and also that discussions favours the odour associations.

Summary of part two

The colour was experienced as the easiest to verbalise, and the most difficult was the haptic touch profiling. The panellists stated that they would have needed some sort of references during the profiling sessions. Ten women stated that the visual and haptic profiling was *easy*, and four men did. Mainly women found part two as *difficult*. The difficulty of verbalising haptic perception, due to poor-existing language is similar to the results of Dagman et. al 2010. About 50% of the panelists (no connection to gender) state that they have become more sensitive to haptic and visual assessments, after the profiling. No connection was found to proficiency levels. It appears olfactory and haptic profiling needs to pass a "hump" before it starts to get easier.

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SUPPLEMENT 5: Suggestions of Makers´ Maxims.

A suggestion of vital characteristics of binders, pigments, anticorrosive paints, and painting treatments, to be considered as hypotheses (based on chapters 5–8 and **Paper I** to **V**).

A. The anticorrosive paint oil varnish *binder* should	
1	Have linseed oil as a major ingredient and be of stand oil character, preferably with the addition of heat-bodied and refined stand oil or tung oil; *– because linseed varnish is the original binder for authentic-like varnishes utilised for painting treatments of ferrous heritage; and this is an effect of long traditions.* *– because stand oils and tung oil additions are made as active ingredients in anticorrosive paints since the early twentieth century; effects of their ability to through-dry/polymerise and beneficial properties (such as high elasticity and hydrophobicity).*
2	Be produced from mild-smelling cold-pressed linseed oils that are absolutely clear (i.e., non-turbid), free from all impurities, and without showing any sediments when stored; *– because pure oils improve the drying power and the quality of the formed solid film; effects of improved gel formation kinetics (such as shorter induction period).*
3	Stand a breaking test (heating temperature ≥ 175-250°C), without getting lumpy; *– because the breaking test shows that the oil varnish is purified, see 2A.*
4	Be prepared by high-temperature heating and addition of driers (such as metal oxides or other beneficial compounds, for instance, litharge or manganese borate) and heat-bodied to viscosity greater than for raw linseed oil and modern heated linseed oil varnishes (this probably involves viscosities ≥ 20 dPa·s); *– because this type of refinements results in the formation of a film with high waterproofness, and characteristics similar to Mulders Linoxyn´: effects of improved drying kinetics, the ability to withstand shear stresses due to improved cohesive strength (high proportion of crosslinking with C=C bonds). It also enables the application of thicker paint applications due to a higher body (if the paint formulation is correctly designed).*
5	Contain no VOCs; *– because the presence of VOCs results in more porous films: effect of the vapourisation of the solvent (and changed gel formation kinetics?).*
6	Show a *stand oil character* with a clear body, feel "long" (stringy), feel fat, do not smell as rancid or empyreumatic (burnt), do not have a dark brownish-black colour; *– because stand oil characteristics are sensory quality attributes; effects of high-quality refinements (see also 4A).*
7	Not gelate, when the liquid varnish is mixed with alkaline pigments (but form a dense film due to saponification); *– because gelation indicates rancidity and too high acid values (effects of inappropriate varnish quality), while controlled saponification is an effect of reaction with unsaturated fatty acids and conscious use catalysing metal compounds/driers, or catalysing pigments, in order to form dense and elastic films.*
8	Spread without crawling, when the varnish is applied onto cleaned metal or glass plates, *– because non-crawling favours uniform film quality; effects of surface-colloid effects and autophilicity.*
9	Dry into elastic, rubberlike, firm, and stable film within 24 hours at 20°C when the liquid is spread on glass-plates, and it should dry-through (and not only on the surface); *– because these quality attributes are often stated as indicators of high varnish quality, effects of high-quality refinement process such as purification, use of appropriate heat/energy exposure, and potent driers (see also 4A, 6A).*
10	Form a solid film (when applied onto glass-plates) which stands a water immersion test for at least 24 hours, with low imbibition tendency but without forming milkiness; *– because these quality attributes are similar to Mulder´s Linoxyn (formation of insoluble metal carboxylic acid), and desired qualities of the film; effects of colloidal phase differentiation and high-quality refinement processes (and especially dependent on the type of drier and the presence of high molecular weight and cyclic compounds)(see 9A).*

11	Show low solubility (of the solid film), in solvents such as alcohol, ether, chloroform; *- causes and effects, see 10A.*
12	Not discolour the pigments (or paint); *– because discolouration may jeopardise the function of the paint: effects of probable chemical non-equilibrium, or insufficient material qualities, or inappropriate combinations of raw ingredients.*
B. The used paint *pigments* should	
1	Preferably, be similar to the authentic ones; *– because authentic pigments indicate the evidence of long traditions and appropriate function (effects of accessibility, ideals, and chemical stability). When possible, substitute toxic pigment with less toxic.*
2	Be well-ground (if the morphology is not lamellar, since grinding usually ruins the lamellar form); *– because well-ground pigments result in paint of high quality (such as appropriate body, applicability, hiding power, and so on); effects of efficient paste making, due to the intimate and efficient contact between the binder and the pigments.*
3	Contain no sulphur or water-soluble salts; *– because these compounds reduce the lifetime of the paint system; effects of the presence of water-soluble ions may increase the diffusion and osmosis through the paint film that will start to function as a permeable membrane, and this will lead to increased corrosion rates of the ferrous substrate (unless the water-soluble pigment has inhibitive electrochemical action, such as is the case for red-lead or phosphates in primer paints).*
4	If possible, be neutral or alkaline rather than acidic; *– causes and effects, see 3B.*
5	Have high chemical stability: such as high light-proofness, be mixable with other pigments, resist alkaline and acidic conditions, resist humidity, have low solubility in oil and water; *– because these characteristics improve the lifetime of the paint system and have aesthetical benefits; effects chemical equilibrium, or sufficient material qualities, or appropriate combinations of raw ingredients.*
6	Preferably, be inhibitive or anodic in the primer paint; *– because inhibitive pigments retard the corrosion rate of the substrate; effects of the suppression of the redox reactions.*
7	If possible, contain a small proportion of catalysing pigments in the primer paint; *– because catalysing pigments may increase the drying power of the over-painting and reduce the need for additional driers; effects of chemical interactions that favours the free radical reactions in the curing process of the binder.*
8	Preferably, have a lamellar grain morphology in the location paints; *– because lamellar pigments and fillers prolong the lifetime of the paint system; effects of resulting longer moisture pathways due to a higher proportion of close-packing of the paint layer, compared to rounded pigments.*
9	Preferably, utilise the leafing effect of aluminium pigments; *– because "leafing" keeps the subsurface binder "immature", unreactive with oxygen for a longer time, and protects the binder from deterioration; effects of the surface tension of the fatty acid lubricants (during gel-formation) and resulting high close-packaging of the surface layer, restricted oxygen access that would accelerate the ageing of the binder.*
10	Preferably, have a high reflectivity; *– because high light reflectivity reduces the UV-dosage exposure of the surfaces, and hence reduces the deterioration rate of the organic binder; effects of reduced energy input to the chemical reactions which accelerate the ageing of the binder (such as photo-oxidation, thermal oxidation, and hydrolysis).*
C. The anticorrosive *paint* should	
1	Contain binders of heat-bodied fat oil varnishes; *– because fat varnishes result in well adhering, improved paint cohesion, long-lasting elasticity, UV-radiation resistance and waterproofness, and (possibly) low imbibition; effects of the refinement processes with a high degree of polymerisation (high proportion of C=C bonds, cyclic compound formation, etc.). See also 1A.*

2	Consist of ingredients of the highest quality; *– because high-quality ingredients result in improved durability of the paint system; effects of high chemical stability, and intended function.*
3	Be fully/satisfyingly declared concerning the type of ingredients; *– because declaration enables quality assessments of the paint formulation, assessment of authenticity and intended use, and the producer dialogue with the users; effects of increased transparency and goodwill. Most probable, no other paint-maker will be able to produce the same product anyway.*
4	Be well-mixed, with intimate wetting and blending of the ingredients; *– because mixing and wetting enable beneficial applications characteristics, appropriate paint body, and the possibility to follow the lean-to-fatter principle; effects of rheological suspension and shear factors.*
5	Have a can-stability of at least 1-2 years; *see 2C.*
6	Be a part of a paint system including lean, firm, inhibitive primer paint and bodied location paints with increasing fattiness for each layer; *– because this has been a successful concept, which improves the lifetime of the paint system; effects of retarded diffusion (and deterioration) rates, high elasticity and high hydrophobicity, effective barrier properties.*
7	Not break or sag on vertical surfaces; *– because paint instability makes uniform applications impossible, which, in return deteriorates the entire paint system effects of how acting shear stresses exceed the cohesive strength of the paint and this indicates inappropriate paint body effects of low PVC, binder viscosity, and thixotropy. (Or: in order to form stable paint systems).*
8	Have beneficial application characteristics and high hiding power, without the addition of VOCs; *– because well-functioning paint application features enable the formation of dense, defect-free paint layers; effects of appropriate paint formulations.*
9	Have a primer paint that adheres well to the substrate, and is firm and lean after curing; *– because these characteristics are crucial for the stability of the paint system; effects of chemical bonding and mechanical anchoring between the primer paint and the substrate. It also enables the absorption of binder from the over-painting in order to follow the leaner-to-fatter principle.*
10	Not require too intense muscle power at application (unless it is a primer paint); *– because this may increase the risk of thickness variations (especially at brush “starts” and “stops”); effects of inappropriate paint formulations and/or unsatisfactory affordances at the intervention.*
11	Reach a drying state (set-to-touch) within a short time (approximately within 12 hours after application) *– because short set-to-touch state will increase the robustness of the paint system since the negative impact of rain decreases; effects of the paint´s colloidal state, and thixotropy.*
12	Enable the application 40–60 µm dry film thickness with maintained high density; *– because the durability of the paint system is proportional to individual and total layer thicknesses; effects of longer pathways for moisture, hence improved barrier efficiency.*
13	Form adhesive and cohesive paint layers, with long-term elasticity; *– because this increases the durability of the paint system; effects of surface colloidal effects, and intermolecular binding forces.*
14	High capacity to penetrate crevices, and to prevent the formation of water traps; *– because this retard the risk of crevice corrosion and under-film corrosion of the substrate connected to the water traps; effects of preventing capillary transport of moisture and the formation of corrosion cells due to blocking paint masses.*
15	Have a reasonable curing time outdoors at summertime, and become through-dry within 24 hours at 20°C, be over-paintable within 2–7 days; *– because high drying power is needed in order to conduct the painting treatments in a smooth flow, to reduce the risk of rain exposure and formation of defects; effects of paint formulations.*
16	High reflection of UV-radiation: *– causes and effects, see 10B.*

17	Act as an efficient barrier for a long time; *– because the durability of the paint system increases; effects of paint formulation, the way painting treatments are conducted, and the impact of the atmospheric exposure.*
18	Have such a colour, that rust spots could be easily detected; *– because rust spots are early indicators that painting maintenance is needed; effects of the human eyes´ sensitivity to colour contrasts.*
19	Preferably be a part of a paint system, where the intermediate paint layers slightly differ in colour; *– because differing paint colours increase the possibility of reaching uniform coverage and barrier thicknesses at the paint application, which improves the durability of the paint system; effects of the human eyes´ sensitivity to colour contrasts.*
20	Be easily repainted and touched-up, after cleaning; *– because easy touch-up features favour continuous care; effects of paint system ageing characterised by chalking (and not cracking and disintegration).*
21	Be free of compounds that are highly toxic and may harm the environment; *– because run-off due to ageing of the paint system, may harm the eco-system; effects of the compounds´ solubility in water, and the durability of the paint system. Of course, the spreading of respirable particles should be avoided due to health concerns.*
D. Painting treatments	
1	Keep up the hygiene standards, in every step of the work; *– because high hygiene standards reduce the risk of defect materials and insufficient quality of the painting treatment, risk of damages to property; effects of entropy (risk of disorder).*
2	Assess a clean, firm, rust-free, and adhering substrate; *– because this is crucial for ensuring the anchoring of the primer paint layer, thus the stability of the entire paint system, and also retards under-film corrosion; effects of chemical and physical interactions between the paint and metal.*
3	Use very short sensitivity time (between wash/cleaning of the metallic substrate and the first paint application), and consider the weather conditions; *– because by this the risk of initiated corrosion is thus reduced, which improves the paint system integrity; effects of well adhering primer paint.*
4	Use tools that are appropriate for the paint and the object; *– because suited tools will reduce the defect level in the paint barrier and improve the surface finish; effects of the paint-to-painter correspondence, and paint thixotropy.*
5	Use the leaner-to-fatter principle; *– because the principle results in an appropriate firm to elastic gradient from the bottom to the top of the barrier, and also provides for a water repellent surface finish and hence efficient barrier; effects of paint formulation and PVC gradients.*

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Painting Treatments of Weather-Exposed Ferrous Heritage

Exploration of Oil Varnish Paints and Painting Skills

This thesis is about protecting ferrous heritage by using anticorrosive, authentic-like, fat oil varnish paints. The purpose of this thesis in Kulturvård and craft research is to provide guidelines, tools, concepts, and models that may be used in anticorrosive oil varnish painting maintenance of ferrous heritage to improve maintenance interventions and working descriptions which have historical relevance. The methodology is a holistic, mixed-methods approach; involving methods that collect quantitative and qualitative data to enlighten the phenomena from different views and exemplify different types of quality assessment of substrates, paint, craft skills, and final results. The research is characterised by an insider perspective of the craft and paint materials. Different types of methods are used for material characterisations. The maintenance could be improved by systematic anamnesis, diagnosis, therapy, control, and monitoring. Tools for assessing existing paint layers status, a matrix for the the specification and documentation of working procedures, suggestions of critical quality control checkpoints and tools are provided. An example is given on a working procedure that encounters some of the quality assessments that traditional architectural painters do while conducting the painting treatments – taking into account the continuous correspondence between the materials and the painter. The paint types in focus are fat oil varnish paints, especially so-called armour paint, used from the 1920s until the 1960s. The armour paints have shown long durability, and the concept of the paint system is explained, in terms of origin, formulation, use, and characteristics. Armour paints produced with the guidance of historical recipes are aged naturally in Southern Sweden and in profiling of oils and varnishes methods standard in sensory studies in the food and beverage field has been used by many professional traditional architectural painters to put attentive focus and articulate quality assessments, reflection on characteristics, for craft interactions, discussion, and in educations.

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