

Driers

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Abstract: Paints and other coating systems form a solid layer during the film-forming process where different physical and chemical processes are important.

Oxidative drying is a process in which the evaporation of solvents is followed by an oxidation process of the unsaturated binder under influence of oxygen in the air. This oxidative drying process is accelerated by the addition of catalysts, referred to as driers.

Keywords: Catalysts · Cobalt · Driers · Metal soaps · Paint additives

1. Introduction

Air-drying alkyd paints contain, besides the main constituents, alkyd resins (binders), pigment and solvents, small amounts of driers (e.g. cobalt-ethylhexanoate). These compounds speed up the oxidative crosslinking of unsaturated fatty acids, which are present as constituents of alkyd resins (Table 1).

Driers, also referred to as siccatives when in solution, are organometallic compounds soluble in organic solvents and binders [1].

Chemically, driers belong to the class of metal soaps and they are added to air-drying coating systems to accelerate or promote after application the transformation from the liquid film to the solid stage within an appropriate time. The transformation occurs by oxidative cross-linking of the binder system, a process which is

catalyzed by the metallic cation of the drier. The anionic part of the drier molecule serves as the carrier, to solubilize the drier in the binder system.

Driers are commonly classified in three different ways:

- according to the carrier; the acid
- according to the metal and
- according to the applied acid/base ratio.

The carriers are usually synthetic acids, typically aliphatic C6 up to C18 mono carboxylic acids. First liquid driers were offered to the industry in the 1930s; these driers were based on naphthenic acid, a crude oil fraction. Nowadays predominantly synthetic acids are used, like 2-ethyl hexoic acid and Versatic™ acid.

In practice a common way to classify driers is according to the acids used: naphthenates or synthetic driers

A main pre-condition in order to reach optimal catalytic efficiency is good compatibility and solubility of the drier in the polymerizing binder system. New developments in binder technology, such as the introduction of waterborne alkyds and high-solids alkyds, have led to the development of new driers. This article presents an overview of the working mechanism, composition and special fea-

tures of classical driers as well as recently introduced driers for use in low VOC air-drying paints.

2. The Drying Process and the Effect of Driers

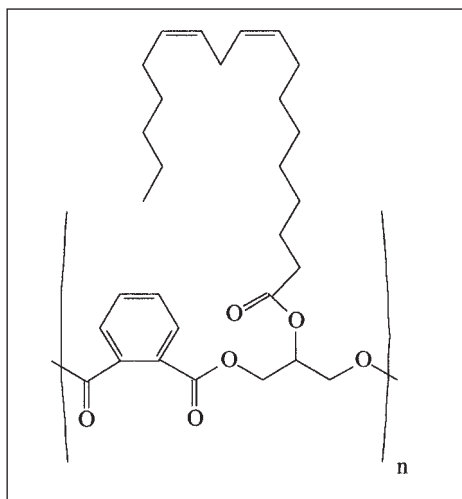
The drying process of a paint refers to the transformation of the liquid paint layer to a solid film layer. Binders are the main organic materials responsible for the film formation. For our purpose the only binders considered in this paper are organic polymers; alkyd resins [2].

The term alkyd is derived from the term *alcohols* and *acids*, from which the binders are made. An alkyd resin is polyester in which a fatty acid chain is included. They can be considered as synthetic drying oils. They are polyesters of one or more polyols, one or more dibasic acids, and fatty acids from one or more drying or semidrying oils. The most common polyol in use is glycerol and the most common dibasic acid is phthalic acid anhydride (PAA). A source of fatty acids in common use is soybean oil (linoleic acid for instance). The idealized structure of the alkyd made from PA, glycerol and linoleic acid is presented in Fig. 1.

Table 1. Typical solvent-borne alkyd paint composition

Component	Weight [%]
Binder: alkyd resin	30
Volatile components, mainly mineral spirits	41
Pigments, like TiO ₂	25
Additives: driers (e.g. Co-Zr-Ca)	2
Additives, other (incl. anti-skinning agent)	2

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Due to their high viscosity, alkyd resins are handled in solution to aid their application. Common solvents are mineral spirits. More recently alkyd resins emulsified in water have been made available and are successfully used now in waterborne alkyd paints.

After application of the paint layer onto the substrate the solvent is released into the air. However, in order to obtain a hard paint layer, further polymerization of the binder is necessary. This polymerization process involves the reaction between the binder and oxygen (from the air) and is known as the 'autoxidation process' (Scheme 1).

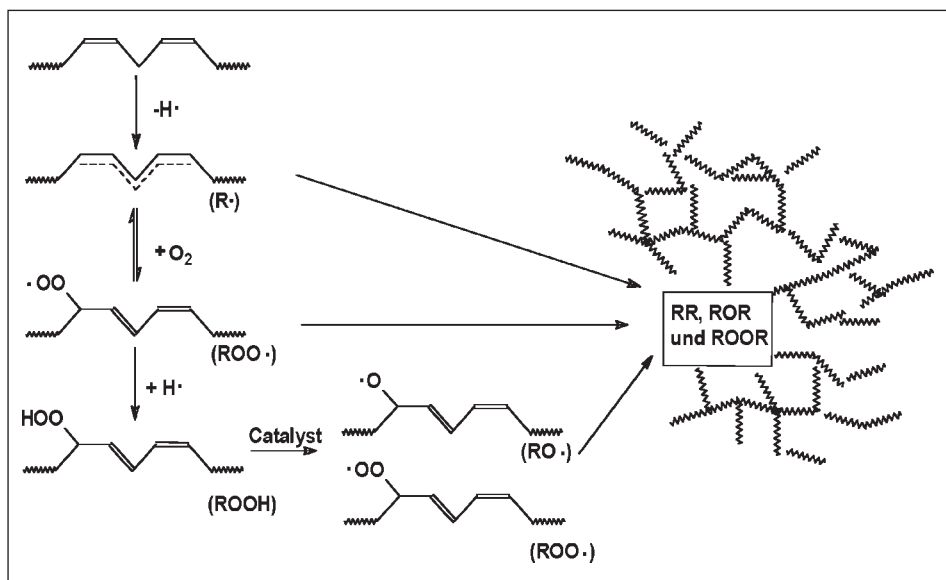
The chemical reactions result in oxidative crosslinking and polymerization which significantly effect film formation. Driers strongly speed up this process. Without these drying catalysts the paint layer may dry only after some months; with driers this is accomplished within a few hours.

The most important catalysts known and in use as driers for the drying of paint are transition metal-based driers, such as cobalt octoate. In conventional solvent-based alkyd paints, cobalt octoate shows the highest activity at room temperature. The general reaction catalyzed by the cobalt catalyst is reported in Scheme 2.

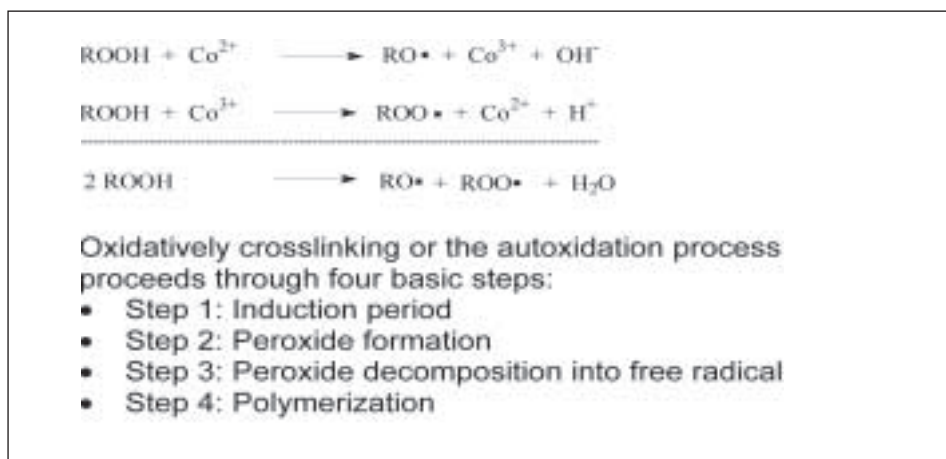
The induction step is measured from the time the coating is applied until the film begins to absorb oxygen from the air. The absorbed oxygen forms peroxides across the conjugated double bonds in the binder (step 2). When the peroxides begin to decompose, active crosslinking sites are formed. As crosslinking proceeds during the polymerization, the viscosity increases rapidly.

Step 2 and 4 proceed most effectively with resins containing conjugated double bonds; however, non-conjugated but poly-unsaturated resins also show some reactivity.

Fig. 1. Structure of an alkyd made from 1 mol of PA, 1 mol of glycerol, and 1 mol of linoleic acid.



Scheme 1. Schematic presentation of the autoxidation process of alkyd resins.



Scheme 2. General reaction catalysis by the cobalt catalyst (ROOH = hydroperoxide form of fatty acid).

In such a case the multiple double bonds may cause the activation of the various methylene groups, to rearrange the position of the non-conjugated double bonds, depending on the original position of the double bonds.

The steps 1 and 2 (induction and peroxide formation) are accelerated dramatically by the presence of driers.

The multivalent metals in the drier system act as oxygen carriers because of their susceptibility to redox reactions.

Driers also activate the formation of peroxides; it is assumed that the multivalent metal is associated to the double bonds, increasing the oxidation susceptibility. The addition of cobalt drier reduces the energy that is necessary for the activation of the oxygen absorption by an unsaturated resin by a factor 10 [1]. The penetration of activated oxygen into the film favors the peroxide formation. As soon as peroxides are formed their dissociation into free radicals takes place (Fig. 2).

3. Composition and Typical Properties of Driers

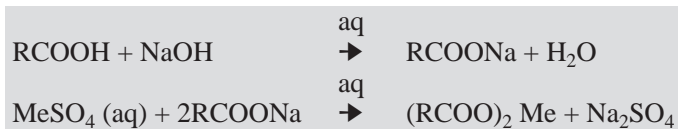
The following three manufacturing processes are best known for the manufacture of driers [3][4]:

- the precipitation process, also known as the double decomposition process,
- the fusion process and
- the direct metal reaction process (DMR).

The choice of the process and variation depends upon the metal used, the desired form of the product, the required purity, the raw material availability and costs as well as on the metal content. The fusion process offers the widest possibilities for selection of raw materials, notably the type of acid and is the most popular production process for driers.

The precipitation process is the oldest manufacturing process for driers and was used already for the first naphthenate driers. During the precipitation or double decomposition process the sodium salt of the acid is reacted with the appropriate metal salt in an aqueous medium. The metallic soap precipitates and is filtered, washed, dried and ground. A modification of the process is to use a combination of water and the hydrocarbon solvent as the solvent medium for the drier. In this case the metal drier soap will dissolve in the white spirit and separate from the water layer. After washing the drier is filtered and adjusted to the right concentration. The precipitation process is used for the production of aluminum, calcium,

magnesium, zinc, cadmium, strontium, and barium soaps as well as for cobalt soaps.



In the fusion process, metal oxides, hydroxides or carbonates and other salts react directly with the selected organic acids at 150–200 °C. The reaction is carried to completion by removal of the reaction water. The molten soap is treated with filter aids and filtered while still hot. It is packaged directly or dissolved in suitable solvents.



In the direct metal reaction (DMR) process the finely divided metal powder is added to the reactor vessel in a melted state or dissolved in hydrocarbons. The oxidation of the metal is carried out over a catalyst with air and in the presence of the organic acids. The metal reacts directly with the acids producing the metal soap as well as hydrogen.



Metal Ions

Main drier metals in common use are cobalt, zirconium, calcium, and manganese. In addition to these strontium, zinc, barium, cerium, lithium, bismuth and vanadium are also used. Lead driers, in the

past a major drier next to cobalt, have been replaced in most paints by less toxic alternatives (see section 6).

Acids

To a large extent the quantity and quality of the anion used to prepare the metal soap determines whether the drier will meet the following basic requirements:

- good solubility and high stability in various kinds of binders; this excludes the use of acids with short aliphatic chain lengths,
- good storage stability of the drier,
- the capability for high metal concentration,
- low viscosity to make the handling of the drier easier,
- the drier should have an optimal catalytic effect and
- the best price/performance relation.

Most driers are based on synthetic acids, like 2-ethyl hexanoic acid and neodecanoic acid (Fig. 3). Naphthenic acid, originally the main acid used for driers, is rarely used nowadays.

Very often mixtures of various synthetic acids are used to optimize cost/performance attributes. To improve stor-

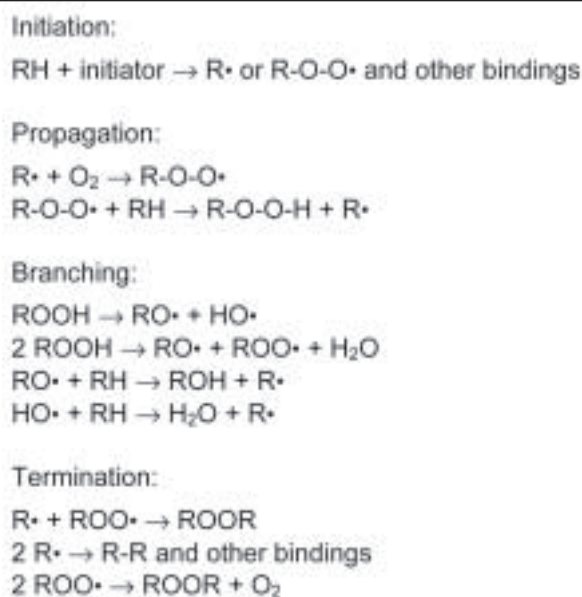


Fig. 2. Reactions during the autoxydation and polymerization process

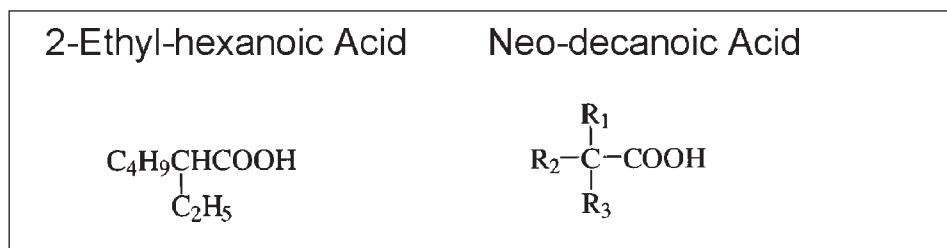


Fig. 3. Synthetic acids used for drier production.

age stability and compatibility with binders and reactive pigments most driers contain additional specific stabilizers, like polyols or phosphate acid derivatives.

4. Drier Metals

Essentially, the metals can be divided into two groups: active driers and auxiliary driers. This difference should be considered arbitrary as a considerable amount of overlap exists between them. Active driers promote at ambient temperatures oxygen uptake, peroxide formation and peroxide decomposition. At elevated temperatures several other metals, such as bismuth, display this catalytic activity but are ineffective at ambient temperature. Auxiliary driers do not show catalytic activity themselves at ambient temperatures, but enhance the activity of the active drier metals (Table 2).

Table 2. Active and auxiliary driers

Active driers	Auxiliary driers
Cobalt	Barium
Manganese	Zirconium
Iron	Calcium
Cerium	Bismuth
Vanadium	Zinc
Lead	Potassium
	Strontium
	Lithium

4.1. Active Driers

The following active driers are used commercially:

Cobalt

Cobalt is the most important and most widely used drier metal. No other metals are known which can show a similar effectiveness at room temperature. Cobalt is primarily an oxidation catalyst and as such acts as a surface drier.

Used alone, cobalt may have a tendency to cause surface wrinkling and poor through drying. To provide a uniform drying cobalt is used in combination with other metals such as manganese, zirconium, lead, calcium and in combination driers based on these metals.

Cobalt has a strong red-violet color, which may effect the color of the liquid paint if used at higher concentrations. However, the color of the dried paint layer is hardly effected.

Manganese

Manganese is also an active drier, although less effective than cobalt.

As an accelerator of polymerization in baking finishes manganese is normally more effective than cobalt. Manganese is not preferred for use in white paints as it affects the color. Manganese is seldom used alone; cobalt is the primary drier with manganese as a useful modifier.

Vanadium

Vanadium is only rarely used in alkyd paint. A considerable disadvantage is the tendency to stain the film.

Cerium/Rare Earths

Cerium- and rare earth driers promote the polymerization and through drying processes and are used mainly in over-print varnishes, where color retention is vital.

Lead

Lead functions as a drier by promoting polymerization. However, the activity as sole drier is very low; this is why lead is often ranked as an auxiliary drier instead of primary drier. In contrast to cobalt and other surface driers, lead causes the film to dry through its entire thickness and is therefore known as a through drier. Lead also improves flexibility and durability of the film. A strong limitation to the use of lead driers is the toxicity: lead is cumulative poison. Because of raised environmental awareness the current application possibilities of lead driers in coating materials are limited.

4.2. Auxiliary Driers

Barium

This drier is used as a substitute for lead in lead-free coating materials. Barium improves the through drying of a coating and has good pigment wetting characteristics.

Unlike lead barium is not considered as a cumulative poison but it has quite a high acute toxicity which limits its use.

Calcium

Calcium is very effective used in conjunction with cobalt and zirconium and promotes drying under adverse weather conditions such as low temperature and high humidity. Loss-of-dry problems during long storage times of paints can be reduced by using calcium as an auxiliary drier. Calcium drier helps to improve hardness and gloss as well as to reduce skin formation and silking. Moreover, calcium drier is also useful as a pigment wetting and dispersing agent. In-volume calcium is one of the most successfully used driers.

Bismuth

Bismuth is used to a limited extent as a substitute for lead. It strongly activates cobalt and improves through drying properties and drying under adverse weather conditions (like calcium does). Bismuth is used in baking finishes to improve the hardness.

Zinc

The primary function of zinc is to keep the film 'open', thus permitting hardening throughout and preventing surface wrinkling, particularly in very reactive binder systems and cobalt-containing coatings. It inhibits wrinkling.

Potassium

Potassium functions best in conjunction with cobalt. Potassium activates cobalt in aqueous coatings and in high-solids coatings.

Strontium

Strontium is another candidate to substitute lead in lead-free systems. It functions well under adverse weather conditions and promotes through drying. Compared to other candidates to replace lead, such as zirconium, strontium has the advantage resulting in best storage stability and lowest gelling tendency of the paints.

Lithium

Lithium shows the best results in combination with cobalt. It is sometimes

used as substitute for lead as well as in high-solids coatings, based on a low-molecular binder.

Zirconium

Zirconium driers are the most widely accepted replacements for lead. Zirconium improves through drying mainly by the formation of co-ordination bonds with hydroxyl- and carboxylic groups, available from the resin or formed during the drying process. Apart from co-ordination, it is assumed that zirconium also forms complexes with cobalt, which influences the catalytic effect of the primary drier. Zirconium is usually applied in combination with cobalt and calcium. The results reached with this combination are nearly the same as with cobalt/lead/calcium-combinations. In comparison with other auxiliary driers, zirconium shows best color, lowest yellowing tendency and best durability.

5. Application of Driers in Alkyd Paints

5.1. Singular Driers

Drier systems for ambient-cured decorative paints based on long oil alkyd resins are usually siccated using a cobalt/ zirconium/ calcium combination drier. Cobalt is the active drier. However, in order to improve through-drying, hardness and stability, auxiliary driers, like zirconium and calcium, are being used in conjunction with cobalt. The exact dosage and ratio depends on the composition of the paint and desired properties and application conditions. The following table shows example for typical and maximal additional quantities in middle- and long-oil alkyd resin varnishes (Table 3).

5.2. Combination Driers

Because of the synergistic effects previously described, it has become common practice in the coating industry to use ready-made combinations of metals. These combinations involve one or more active driers with at least one or more auxiliary driers. Ready-to-use mixed driers offer the advantage of constant quality, optimal ratio and metal composition, and low solvent-content, enabling a more rationalized production process.

In addition to these advantages so-called 'pre-complexed driers' (the complex of various metal types is formed during the manufacturing process of the drier) generally show better drying performance. These advantages are of interest when using the driers in high-solids

Table 3. Typical application concentration of the drier metals (metal referred on binder solid content).

Drier metal	Typical concentration	Normal max. concentration
Co	0.06	0.2
Mn	0.02	0.1
Pb	0.5	1.0
Ce	0.2	0.6
Zr	0.3	0.4
Ca	0.2	0.4
Ba	0.2	0.4
Va	0.03	0.05
Bi	0.3	0.5
Zn	0.2	0.4
Sr	0.4	0.6
K	0.03	0.08
Li	0.03	0.05

systems, in waterborne air-drying coatings or in paints applied under adverse weather conditions.

Table 4 presents recommended starting formulations for different binder systems.

5.3. Loss-of-dry

The drying time of air-drying paints tends to increase on storage, because the drier is inactivated. This phenomenon is known as 'loss-of-dry' and may be caused by unwanted interactions between the drier and other paint ingredients.

In order to function as a polymerization catalyst, the drier should be in contact with the binder and should be mobile in order to compensate for the relatively low amount of drier *versus* the large number of double bonds in the binder. In a paint formulation the mobility of the drier molecule will affect the speed of drying.

Most common causes for loss-of-dry are:

- Chemisorption of the drier onto the pigment surface: as opposed to physical adsorption, which is a reversible

process, chemisorption leads to a permanent immobilization of the drier. Chemisorption occurs onto pigments having acidic groups on the surface and occurs most strongly on pigments with a large surface area such as most oxidized carbon blacks and various organic pigments.

- Salt formation: the reaction product of the drier ion and the long-chain aliphatic acids – formed by hydrolysis of the binder or other ingredients – is usually not soluble in the coating material and deposits after crystallization.
- Formation of insoluble complexes: this phenomenon is typically noticed in low-odor paints, diluted with pure aliphatic solvents. Complexes of different types of driers and made with aliphatic acids of relatively short chain length like octoates only show a limited solubility in these systems and have the tendency to crystallization. Overbased driers are more sensitive to this effect than neutral driers.
- Hydrolysis of the drier: this is the main reason for loss-of-dry in water-

Table 4. Recommended formulations for combination driers by using different types of binders. % metal on vehicle solids.

Resin type	Active drier	Auxiliary drier
Drying oils	0.03 Co or Mn	0.2 Zr, 0.1 Ca
Medium-oil alkyd resins	0.04 Co	0.2 Zr, 0.1 Ca
Long-oil alkyd resins	0.05 Co	0.3 Zr, 0.2 Ca
Epoxide ester	0.03 Co	0.1 Ce
Polyurethanes	0.02 Co or Mn	0.1 Zr, 0.05 Ca
Oleoresin systems	0.03 Co or Mn	0.2 Zr, 0.1 Ca
Polyester	0.01 Co	

borne coating systems. In presence of water the drier is rapidly hydrated. Moreover, water is a good ligand for cobalt and complexes cobalt easily. The hydrates formed are unstable and lead to hydrolysis of the metal soap and subsequently to insolubility of the basic metal soap.

Loss-of-dry may be avoided using one of following options:

- The first approach is to choose a drier system that is totally compatible with the coating system. The drier should be soluble in the binder and not result in any haze formation upon storage or during the drying stage. For pigmented systems it is recommended to carry out a compatibility test in the medium without the addition of pigment or extenders.
- The second approach is to include a 'sacrificial (auxiliary) drier' in the grinding paste during the coating manufacturing process. Calcium drier may be used for this purpose.
- The third approach is to use a 'feeder drier' like cobalt-hydroxy-naphthenate. This feeder drier is offered as a paste and is insoluble in mineral spirits. It functions by reacting with the acid, as formed during storage by hydrolyses of the binder, and becomes more soluble in the binder and thus compensates for lost cobalt drier.

6. Lead-free Drier Systems

For decades lead drier has been the main auxiliary drier. However lead is a cumulative poison, which makes the application in coating materials nowadays less attractive. In many countries strict labeling prescriptions for coatings containing lead have to be followed. Nowa-

days the application of lead drier in coating materials is limited. Replacing lead drier means that the complete drier composition has to be adjusted; this has been confirmed experimentally, both in the laboratory as well as in practice. Lead is typically used as a drier in combination with cobalt and calcium.

A characteristic composition for a lead-based drier combination is (percentages indicated as metal on total resin solids of the coating formula) 0.05% cobalt, 0.5% lead and 0.1% calcium.

The main contribution of the lead drier in this combination is to promote the through drying of the coating layer.

Various replacements for lead-based drier combinations have been proposed. However, in practice the combination of cobalt, zirconium and calcium has found wide acceptance. This combination gives at ambient temperature and humidity condition quite similar drying properties to the lead-based combination drier. However it is not just a replacement of the lead with zirconium: also the ratios of cobalt and calcium have to be adjusted. Low-toxic lead-free systems, showing similar application properties, are being used instead of lead-based drier combinations (Table 5).

7. Driers for Water-borne (WB) Coatings

Water-borne, oxidative drying coatings like water-borne alkyd paints, meet the requirements for environmentally friendlier paints, with lower solvent emissions and are used as alternatives for solvent-borne alkyd paints. The binder in water-borne, oxidative drying alkyd paints is in most cases an alkyd emulsion or a colloidal dispersed alkyd resin. Drying takes place physically by evaporation

of the water, solvents and neutralizing agents and a subsequent oxidative polymerization of the resin.

Essentially same drying mechanism applies for water-borne and solvent-borne alkyd paints.

However, considerable differences exist in disadvantages of the water-borne paints regarding initial drying speed, drier incompatibility, surface defects, poor hardness and through drying and poor drying stability during storage.

Water is a strong ligand for metal ions like cobalt. The complex formed, $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$, has a lower oxidation potential compared to the free Co ion. This results in a lower effectiveness of Co as a redox catalyst. Moreover, the complex is quite instable and tends to hydrolyze, followed by precipitation of the Co hydroxide.

A practical solution to compensate for loss of drier through these reactions is to use higher concentrations of the primary driers cobalt and manganese in water-borne compared to solvent-borne coatings.

The different composition of water-soluble and solvent-soluble oxidative drying coating materials makes accurate adjustment of the drier system essential.

The traditional driers, used in solvent-borne paints, are dissolved in mineral spirits or xylene and are not soluble or emulsifiable in water.

Best drying properties can be reached using water-emulsifiable (WEB) metal complexes in which cobalt is the primary drier (Scheme 3), indicated as 'WEB' drier [5].

The improved drying properties using WEB driers instead of traditional octoates is explained by a number of properties. In the first place there is a more homogeneous dispersion throughout the liquid paint; as a consequence the appearance and gloss of the dried paint is positively effected (Table 6). Secondly, WEB driers exhibit improved stability against hydrolysis.

Drier composition	Metal content [%]	Dosage ^a	Exterior varnish	Interior varnish	Remarks
Co-Zr-Ca	10.2	3...7	limited suitability	suitable	Universal-drier, basic lead- and barium-free
Co-Zr-Ca-N	8.8	6...9	suitable	suitable	Optimal low temperature drying; also for high-solids
Co-Zr	15	0.8...1.2	unsuitable		economical in use
Co-Ba-Zn	11.6	3...6	suitable	suitable	Barium-containing, toxic
Co-Li	3.0	3...5	suitable	suitable	For high-solids, not for white coatings

^a Weight combination drier, based on resin solids

Table 5. Lead-free combination-drier recommendations



Me = Metal ion

Lig. = Ligand

n = number of Ligands

m = valency metal ion

Scheme 3. Pre-complexed drier for waterborne paints: 'WEB drier'

Table 6. Performance of WEB drier in a semi-gloss WB alkyd-acrylic paint

Drier	Total dry time	Gloss 60°	Appearance
Co Octoate 10%	8.30 h.	22	coagulated
WEB Co 8%	5.30 h.	45	O.K.

8. Driers for High-solids Coatings

High-solids (H.S.) coatings meet the requirements for environmentally friendlier coatings, with lower emissions of organic solvents in comparison to conventional alkyd paints.

However, the drying characteristics are quite different. Next to the higher solids content, the molecular mass of the H.S. binder is lower and the reactivity to autoxidation polymerization much higher. Moreover, as a result of the high-solids content, the applied film thickness is much higher and as a consequence, the

through drying properties more critical compared to lower solids systems.

A typical composition of a high-solids alkyd paint formulation is presented in Table 7.

Per definition high-solids alkyd coatings contain lower amounts of organic solids, compared to the traditional low-solid alkyd paints. This explains a shorter flash-off time after paint application (Table 8). The open time is nevertheless much longer.

Poor through drying and hardness are main shortcomings of high-solids alkyd systems. Surface-wrinkling of the dried

paint layer is another problem associated with H.S. paints. Because of the higher polymerization reactivity of the binder, high-solids coatings are more sensitive to this phenomenon than low solids alkyds. The right balance between the drier effectiveness regarding surface drying (cobalt) and through drying (auxiliary drier) is of prime importance. Reducing the primary drier cobalt too much means slow formation of peroxides, consequently a low supply of radicals, slow polymerization resulting in soft film and slow total drying performance. The surface drying properties of primary driers, notably cobalt, can be influenced *via* complexation with organic ligands [6]. This retards the surface-drying properties, avoiding wrinkling and enabling the formulator to increase the concentration of the primary drier. Pre-complexed driers of cobalt and alkali metals are typically used in high-solids, as are cobalt/zirconium/calcium-combination-driers or cobalt/strontium/calcium drier combinations.

9. Trade Names

Nuodex (Sasol Servo BV)
 Octa-Soligen (Borchers)
 Valirex (van Loocke)
 Manosec (Rhone Poulenc)

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Table 7. High-solids alkyd paint, 88% solids, based on a long-oil alkyd resin

Titanium dioxide	39.0 weight-%
High-solids resin (100% solids)	48.0
Dispersing agent	0.4
Drier	3.2
Aliphatic mineral solvent	8.8
Odor-less anti-skinning agent	0.6
	100.0

Table 8. Typical drying properties of a high solids paint versus a traditional alkyd paint

	'High-solid' alkyd	Traditional alkyd paint
Flash-off time	0.75 h	1 h
Open time ^a	2.50 h	1 h
Dust-dry time ^a	3 h	2.5 h
Tack-free time ^a	5.5 h	4 h
Through-dry time ^a	7 h	6 h
Koenig Hardness, 100 µm layer, wet	22 s	50 s

^aBK-drying recorder ratings

- [1] J.H. Bieleman, Ed. in 'Additives for Coatings', Wiley-VCH, Weinheim, New York, 2000, chap. 7.1.
- [2] M. Fabrizio, Internal report ATO B.V., P.O. Box 17, 6700 AA Wageningen, Neth., January 2001.
- [3] D.J. Love, *Pol. Paint Col. J.* **1985**, 175, No 4146, 438.
- [4] M. Feldman, F. Bueno, 'Kirk-Othmer Encyclopedia', Wiley, New York, 1979.
- [5] J.H. Bieleman, *Fatipac Brussel 1996*, Congress proceedings, A, p. 112.
- [6] Company brochure, 'Driers/ Drymax', Sasol Servo BV, Delden, Netherlands, 2000.