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## ***Abstract***

Water-borne coatings accounts for less than 3% of the total heavy duty (HD) protective coating market in Europe. There is however an increasing use of water-borne coatings in typical HD protective coating market segments such as infrastructure, oil & gas, power, tankage, marine and chemical industry. The average growth rate (AGR) for water-borne coating technology is surpassing the AGR for conventional solvent-borne coatings, mainly due to an increased focus on health and environmental issues and implementation of environmental legislation in EU and NAFTA. An increasing number of successful case histories are proving that you can use water-borne coatings to protect steel from corroding even under extreme conditions. The HSE aspects is just an extra bonus for using water-borne coatings the real benefits are high performance and cost savings by higher throughput due to shorter drying time/shorter recoating times, lower insurance premium, no expenses for thinners and shorter down time due to fewer coats or odor problems from solvents.

This presentation will put focus on three water-borne technologies that are suitable for HD corrosion protection i.e. acrylics, epoxies and inorganic zinc silicates. Both results from severe accelerated testing and real life field experiences will be used to illustrate the technologies suitability. In particular new developments in water-borne epoxy primer technology will be highlighted. This new technology will open up possibilities for use of water-borne coatings in HD areas where only solvent-borne coatings have been used so far, like for instance protecting offshore installations from corrosion.

Nobody should ignore the fact that there is a limitation for use of water-borne coatings in the HD area, with regard to climatic conditions on site. Fully understanding "the rules of the game" with regards to temperature, relative humidity and ventilation requirements will enable the user to have as few limitations as possible and avoiding early failure of the coating system. The author will present and discuss new findings that will answer such questions such as when will a hydrophilic water-borne coating become water-resistant enough to support extreme weather conditions, how long time depending on climatic conditions does it take for all the water to evaporate from a water-borne coating, what are the limits for film thicknesses of water-borne coatings before there is a risk of entrapment of water in the coating film etc. There is a big need to educate the users of water-borne coatings in the HD corrosion protection area to reduce the skepticism and assure that the coating job is always done correctly the first time.

## ***Keywords***

Corrosion protection, water-borne, epoxy, acrylic, zinc alkali silicates, advantages, limitations, testing, field experience, case-histories, legislation.

## ***Introduction***

There is an increasing use of water-borne coatings for heavy duty (HD) corrosion protection in areas such as infrastructure, oil & gas, power, tankage, marine and chemical industry, but it still accounts for just a few percent of the total HD-market. This presentation will put focus on three water-borne technologies that are suitable for HD corrosion protection area i.e. acrylics, epoxies and inorganic zinc (IOZ) alkali silicates. The author will highlight pros & cons, field experiences, new developments, "working rules" and the future for these three technologies. The first generations of water-borne acrylics were introduced in the 1960'ties, epoxies in 1968 and IOZ alkali silicates already in the 1940'ties so these three technologies have existed for many years and are well proven.

The evident reasons for the introduction of water-borne protective coatings for metal are health, safety and environment (HSE), since the coatings contain no flammable or health hazardous solvents and the low content of volatile organic compounds (VOC) leads to a significantly reduced environmental impact (see table 1). Other not so evident reasons for converting to water-borne coatings are performance, speed, smell and cost. An increasing number of real life case histories and results from severe accelerated testing confirm that water-borne coatings match solvent-borne equivalents in corrosion protection and even surpass solvent-borne coatings in performance. Water-borne acrylics, epoxies and IOZ alkali silicates are in general faster drying and have shorter recoating times than their solvent-borne equivalents. They also have no or little solvent smell and since water is the main solvent, water are used for cleaning and thinning of water-borne coatings. Converting to water-borne coatings are also giving the user reduced cost by saving time through faster drying coatings, lower insurance cost by reduced flammability, lower overall energy consumption for indoor ventilation, no expenses for thinners/cleaners and the possibility of one coat systems with thick film IOZ alkali silicates that saves both downtime and scaffolding expenses.

Combining the water-borne coating types in table 1 in 1-4 coat systems or in 2-3 coat hybrid combinations with solvent-borne primers or topcoats gives excellent corrosion protection. The coating systems can be used for HD areas such as new building and maintenance for ships, offshore installations, storage tanks, steel structures in power stations, containers, gas & oil pipelines, oil refineries, bridges, windmills, railway, communication towers, steel structures for buildings etc. Some case histories on this will be shown later in this chapter.

The obvious limitations for water-borne coatings in HD corrosion protection are extreme climatic conditions such as relative humidity (RH) above 85%, temperatures (T) below 5°C and not being coatings for under water use. However even solvent-borne coatings do not work too well under extreme weather conditions and the latest water-borne epoxy technology might allow for under water use, when the paint is properly formulated. To sum up the benefits of water-borne compared to solvent-borne coatings by far outweighs the disadvantages and they are better for health, safety and environment and have no compromise on corrosion protection. Many users

only focus on price/liter paint and then in most cases solvent-borne coatings are cheaper, but if you look at price compared to performance, price/m<sup>2</sup> or even lifecycle cost the picture is different. If you add the benefits of saving time, human health and reduced amount of harmful ground level ozone, the calculation will definitely fall in favor of converting to water-borne coatings.

### ***Water-borne technologies for HD corrosion protection***

The author will in this chapter describe advantages, disadvantages and some of our company's experiences with the three main water-borne technologies we offer for corrosion protection.

#### **Water-borne acrylics**

With acrylic copolymer dispersions in water you can obtain much higher molecular weight ( $MW_w > 200\ 000$ ) for the polymer than for acrylics in solvents. A polymer dispersion has a solids content (approx. 50%) which enables fast air drying by evaporation of water, while high molecular weight removes the need for any post-curing or oxidative drying to obtain a tough integrated film which retains its flexibility over time and is durable against degradation. A polymer dispersion will also keep the same viscosity up to 50-60% solid content, independent of the degree of polymerization. The polymers properties can be tailor-made for different applications for instance by copolymerization of two or more monomers such as methylmethacrylate, methylacrylate, butylacrylate, styrene, butadiene, etc. in different proportions. The polymerization-process and selection of additives is decisive for the binder's properties and therefore the same generic type of binder can have widely differing properties. Since acrylics are thermoplastic, one usually uses hard polymers (with high glass transition temperature) of acrylics or styrene - acrylics to obtain a hard and resistant paint for industrial corrosion protection. Water-borne styrene-acrylics are used for metal topcoats and primers and have been used with success for this purpose since the 1970'ties. Water-borne vinyl-acrylics are especially suitable for metal primers due to their excellent adhesion to many different types of metals and their very good water-resistance.

The advantages with water as the solvent/thinner in polymer dispersions is self-evident, water is not poisonous, has no odor, is not health hazardous or flammable (no risk of explosions). Emissions of organic solvents to the atmosphere are minimal and waterborne products are therefore environmental friendly with low hazards for the user/applicator. In addition acrylics have good UV-resistance; they dry quickly, do not yellow or undergo saponification. Water-borne acrylics are 1-component paint ready to use and easy to spray apply.

The disadvantages with water in polymer dispersions are slow evaporation at low temperatures and high relative humidity in the air. Water has very high surface tension and therefore certain specialized additives (surfactants) are added in the formulations to, amongst others, make the paint wet the pigments and substrate better. Some of these additives can have a negative influence on the paints water-resistance and water permeability and in addition good film formation is more critical for the paint properties than for solvent-borne paints and of cause the paint will freeze below 0°C.

Below the author has listed the most important advantages and disadvantages with water-borne acrylics;

## Advantages

- good corrosion protection
- excellent gloss/UV resistance
- fast drying and recoating time
- good hardness development
- good chemical resistance (ISO 12944)
- good adhesion to coatings and metals
- low dirt pick up (topcoats)
- high degree of flexibility
- non-chalking & non-yellowing
- very good water-resistance
- competitive on price
- suitable for forced drying

## Disadvantages

- complex film formation process
- some limitations with regard to climatic conditions
- needs 6–24 hours to become water-resistant enough
- does not support high alkalinity before complete drying
- high flash point

## **Water-borne epoxies**

To be able to replace organic solvents with water and make epoxies waterborne, one has to make the epoxy resin and amine curing agent hydrophilic (“water loving”) either by chemical modification or by adding/using an external nonionic surfactant (emulsifier). In most cases the amine curative is water-soluble, while the epoxy resin is not soluble but emulsifiable in water. One can classify waterborne epoxy products after the type of epoxy resin used. Type I is low molecular standard or modified liquid epoxy, typically 190 in EEW (Epoxy Equivalent Weight). Type II is preformed dispersions of higher molecular weight solid epoxy, typically 500 in EEW, though there are also dispersions of solid epoxy with about 650 in EEW. Type III is epoxy resin emulsions where standard Bis-phenol A liquid epoxy is emulsified in water with the help of nonionic emulsifiers.

Curing agents for waterborne epoxies are made by using surfactants to emulsify or disperse polyamidoamines (PAA) and polyamines (AA) in water or use water-soluble polyamides (PA). In addition carboxylic-functional acrylic latexes are available to crosslink with epoxy emulsions. Polyamine curatives are very good pigment wetting agents and therefore one usually grinds the pigments in the curing agent A-component of the paint. The first viable generation of water-borne epoxies was introduced in 1973 by Anchor, based on liquid Bis A/F epoxy cured with a modified fatty polyamidoamine (Casamid 360). It took 10 years before solid epoxy dispersion (Epi-Rez 3520) was introduced in the market in 1983 and another 15 years later in 1998 a polyamine adduct dispersion was introduced in the market.

Waterborne epoxies are as the name indicates water-thinnable, they can be applied on moist/damp substrates, have low odor, not flammable and type I epoxies are also possible to formulate without solvents. A big advantage when one wants to formulate a water-borne epoxy paint is the possibility to grind the pigments in either the curing agent or the epoxy resin or both. Type II epoxy dispersions, where an epoxy functional emulsifier has been reacted/incorporated into the epoxy resin backbone, are cured with an aliphatic AA can obtain just as good anticorrosive properties as an equivalent solvent-borne epoxy. Waterborne epoxies will usually have excellent

adhesion to most substrates and especially type I epoxies exhibits good water resistance.

When we come to the disadvantages with waterborne epoxies the first thing worth mentioning is the fact that the film formation process is more critical than for solvent-borne epoxy, since there are two additional steps in the film formation process, the evaporation of water and that the film has to flow together (coalescence) before solvents will evaporate and cross linking will take place. This makes it more important to have a better control on temperature, relative humidity and ventilation during application than with solvent-borne epoxy. Assuming that these precautions are taken and that the paint is correctly applied one would in most cases be able to match the properties of solvent-borne epoxy paints with the exception of chemical resistance which is a bit weaker. Another weakness with waterborne epoxy is the fact that you can not thin the paint unlimited with water since there is a risk of destabilizing/breaking the epoxy/amine emulsion. One can however easily thin with up to 20% water on total formulation without any problems, however this is not recommended since this would lead to a huge drop in paint viscosity. When formulating waterborne epoxy primers an inhibitor has to be added to prevent flash rust formation on steel and the inhibitors available in the marketplace today will usually to a certain extent diminish the paints anticorrosive properties. Pot life for waterborne epoxies is shorter than the one for equivalent solvent-borne epoxies. Type I epoxies have pot lives in the range of 1½-3 hours and for type II epoxies 2-6 hours, which should be enough in most cases.

Waterborne epoxy has much of the same health hazards as the equivalent solvent-borne ones, i.e. danger for sensibilizing and development of allergic contact-eczema after long term exposure. The epoxy resin can irritate eyes, throat and skin after long time and repeated exposure. For solvent-borne epoxy you need to use low molecular weight liquid epoxy to formulate high solid or solvent free epoxy primers. The advantage with solid epoxy dispersions is the high molecular weight and low viscosity of the resin, which makes it easy to formulate very low VOC anticorrosive primers without the need to use liquid epoxies. Polyamines are allergy sensibilizers, can give serious eye damage by direct contact and when they contain more than 10% free amine they are also classified as corrosive. Polyamine adducts (i.e. polyamines pre-reacted with small amounts of epoxy) have very low amounts of free amines and have therefore a more lenient health hazard labeling, i.e. the labeling can be reduced from health hazardous to irritating and there also exists polyamine adducts that are free of any labeling. From a SHE point of view polyamidoamines are preferred since they usually do not have any health hazard labeling.

Below the author has listed the most important advantages and disadvantages with water-borne epoxy;

## Advantages

- excellent corrosion protection
- low SHE risk
- fast drying and short re-coating time
- very low VOC
- excellent adhesion
- high flash point
- overcoat able with most coatings

## Disadvantages

- some types have not visible end of pot life
- slow curing drying at low T and high RH
- needs 6–24 hours to become water-resistant enough
- complex film formation process

- good flexibility
- low aerosol formation when spraying
- good spray ability
- very good water-resistance
- zinc epoxy with high performance

### **Water-borne IOZ alkali silicates**

Silicate film formers have been known for over a century and metallic zinc as an anticorrosive pigment for about 150 years. Alkali water-borne silicates have been known and used since the 1850'ties, but not for coating purposes. They are based on alkali metals (Me) sodium, potassium and lithium or blends of these, usually in the form of solutions of alkali metal-polysilicate in water and general formula  $\text{Me}_2 \text{SiO}_2$ . The molar ratio  $\text{SiO}_2 : \text{Me}_2\text{O}$  is important and can vary from 2.5 : 1 to 5.5 : 1. Combining zinc dust pigments with alkali water-borne silicates to make water-borne IOZ alkali silicate paints were first developed in Australia in the 1930'ties. At that time they used an alkali silicate binder with a low  $\text{SiO}_2$  content and heat curing or post curing was needed to make the paint film hard and water insoluble. Already in the 1940'ties water-borne inorganic zinc alkali silicate paint for corrosion protection was developed. Later on there has been a development towards self curing alkali zinc silicate by higher  $\text{SiO}_2 : \text{Me}_2\text{O}$  ratios (3.2 : 1 or greater) using either potassium or lithium silicates. The latest development is a silicate with an even higher ratio (up to 5: 1) of silica to alkali. The increased number of reactive OH-groups gave a faster water insolubility, faster curing, quicker hardening and stronger adhesion. Curing of a water-borne IOZ alkali silicate is done by evaporation of water that leads to concentration of zinc and silicate binder and the zinc ions will crosslink with the binder by reacting with the SiOH-groups to form an insoluble three dimensional zinc silicate matrix.

IOZ silicates have become the first choice for HD corrosion protection of prepared steel. There is an increasing use of a single coat of inorganic zinc silicate in environments that are not chemically aggressive, i.e. not being outside of the pH range of 6 to 12.5 where zinc is dissolved. In extreme acid or alkali environment IOZ silicates are used as primers, but over coated with a high performance chemical resistant topcoat. The corrosion protective properties of water-borne zinc alkali silicates are at the same level as solvent-borne zinc ethyl silicates that should be well known for offshore corrosion protection. The solvent-borne zinc ethyl silicates have been more popular than the zinc alkali silicates due to easier application and drying properties. The main drawback with the zinc alkali silicates is their reliance on good weather conditions, such as low humidity and high ambient temperature, to enable water to evaporate fast from the paint film. In adverse weather conditions curing is prolonged and the water insolubility can range from 1 to 24 hours. If the paint film is exposed to rain before it is cured, water can leach out unpolymerized silicates and damage the film. In marine environment contact with a salty atmosphere will accelerate the curing of a zinc alkali silicate coating. The zinc alkali silicates are known to be more difficult to overcoat than the zinc ethyl silicates, due to the higher alkalinity at the surface that could lead to osmotic blistering of the topcoat. However un-topcoated well applied zinc alkali silicate primers gives extreme corrosion protection and there exists many examples of coatings lasting more than 40 years without signs of corrosion. A comparison of properties of water-borne and solvent-borne zinc silicate paints is given in table 2.

The main advantages with water-borne IOZ silicates are of course that they have zero VOC and therefore contain no health hazardous or flammable solvents. The Si-OH groups in the silicate backbone forms chemical primary valance bonding with a metal substrate giving excellent adhesion. Other advantages both for zinc ethyl silicates and zinc alkali silicates are cathodic protection with no under rusting, excellent abrasion-, UV-, chemical- and heat resistance (400°C). Traditionally there have been strict demands posed to the steel surface preparation when painting with zinc silicates. The steel has to be grit blasted to Sa 2½ with a surface profile of 30-50 µm. Zinc alkali silicates are very sensitive to impurities like oil and fat on the surface, since they do not contain any solvents for secondary cleaning of residual oils and contaminants.

Water-borne high ratio zinc alkali silicates have been used with success in North America and Australia for many years for protection of steel tanks, bridges, barges, oil platforms, steel structures and internal tank linings. There is an extensive use of this technology for in-shop temporary protection of steel in North America. For one coat long term corrosion protection a dft of 100-150 µm is recommended. There are successful application and use of water-borne IOZ silicates with more than 10 years protection on oil rigs in the Gulf of Mexico and in the Bass Strait of the coast of Australia, up to 40 years of protection to date on structural steelwork, railway bridges and road bridges in Australia, more than 20 years protection on oil refinery in Japan and even the statue of Liberty in New York is internally coated. The most famous application of water-borne IOZ alkali silicates is the coating of the 250 –mile Morgan – Wyalla pipeline in South Australia. This pipeline is still in excellent condition after more than 50 years exposure, however the big limitation back then was the heat curing (baking for 30 min. at 150-200°C) the coating need to cure completely.

Below the author has listed the most important advantages and disadvantages with water-borne inorganic zinc alkali silicates;

### Advantages

- ultimate corrosion protection
- environmental efficient
- fast drying and short recoating time
- no VOC
- long pot life
- excellent adhesion and water-resistance
- excellent abrasion and chemical resistance
- high solids
- good hardness development
- no mud cracking problems < 200 µm dft
- very good water-resistance
- can be used at 1-coat HB paint system
- zinc content in dry film complies with SSPC 20
- dry heat resistance up to 400°C

### Disadvantages

- requires blast cleaning to Sa 2½ with profile
- some limitations on spraying equipment
- high zinc salt formation without top coating
- needs epoxy intermediate coat before top coating
- not to be used at T < 5°C and RH > 85%

## Field experiences with water-borne coatings for HD corrosion protection

Today there are in general two principles for protecting metal against corrosion with liquid coatings. We have paints that form a barrier between air and moisture on one side and the metal on the other side and for many years solvent-borne coatings like epoxy, epoxy ester, glass flake polyester, vinyl ester, vinyl, alkyd, acrylic, polyurethane etc. have been used for this purpose. The second principle consists of using active rust inhibiting zinc-rich paints like zinc epoxy or zinc silicates. The zinc in these paints works as an anode in the electrochemical corrosion process. This technology has worked very well and three coat systems with a zinc coating as the first coat to give cathodic protection of the steel, combined with a thick epoxy intermediate coat and polyurethane topcoat has proved to give long life time durability with maintenance intervals of 12-15 years. ISO 12944-1 defines durability and maintenance intervals for anti corrosive paint systems and the durability is given in three intervals; low(L) 2 to 5 years, medium(M) 5 to 15 years and high(H) > 15 years. A typical film thickness for a solvent-borne coating system for the most aggressive and corrosive environments, with high humidity or high salt content (corrosivity category C5-I or C5-M), is 300-500  $\mu\text{m}$  dft with 2-4 coats of an organic/inorganic coating. A solvent-borne epoxy mastic primer for HD metal protection is typically spray applied in 2 coats of 200  $\mu\text{m}$  dft and is over coated with 50  $\mu\text{m}$  dft of a high performance solvent-borne polyurethane topcoat. When using solvent-borne epoxy mastic as a high build intermediate coating on top of a solvent-borne zinc rich primer and over coating with a solvent-borne 2K-topcoat, typically a total dft of 340-360  $\mu\text{m}$  is applied for HD corrosion protection. If we compare these two solvent-borne coating systems with a water-borne coating system, we will see that the average dft is around 250  $\mu\text{m}$ , so you need lower total film thickness to obtain similar or better performance 1-4.

There are basically two ways to go when using water-borne coatings for HD corrosion protection, you can either use pure water-borne 1-4 coat systems or combine water-borne coatings with solvent-borne coatings in 2-3 coat hybrid systems. The hybrid systems are usually solvent-borne primers over coated with water-borne intermediate and topcoats, but it is also possible to use water-borne primers and overcoat them with solvent-borne topcoats.

### Pure water-borne coating systems for HD corrosion protection:

1. 2 x 100  $\mu\text{m}$  WB solid epoxy primer + 1 x 50  $\mu\text{m}$  WB acrylic topcoat
2. 1 x 120  $\mu\text{m}$  WB solid epoxy primer + 1 x 80  $\mu\text{m}$  WB acrylic topcoat
3. 1 x 50  $\mu\text{m}$  WB zinc epoxy primer + 1 x 120  $\mu\text{m}$  WB epoxy intermediate + 1 x 80  $\mu\text{m}$  WB acrylic topcoat
4. 1 x 40  $\mu\text{m}$  WB IOZ silicate primer + 2 x 80  $\mu\text{m}$  WB liquid epoxy intermediate + 1 x 50  $\mu\text{m}$  WB acrylic topcoat
5. 1 x 50  $\mu\text{m}$  WB IOZ silicate primer + 1 x 200  $\mu\text{m}$  WB HB solid epoxy intermediate + 1 x 50  $\mu\text{m}$  WB acrylic topcoat
6. 2 x 125  $\mu\text{m}$  WB HB solid epoxy primer + 1 x 50  $\mu\text{m}$  WB acrylic topcoat
7. 1 x 125 - 150  $\mu\text{m}$  WB IOZ silicate primer
8. 3 x 100  $\mu\text{m}$  WB acrylic primer + 1 x 50  $\mu\text{m}$  WB acrylic topcoat

### Solvent-borne/water-borne hybrid coating systems for HD corrosion protection:

9. 1 x 50  $\mu\text{m}$  SB zinc epoxy primer + 1 x 120  $\mu\text{m}$  WB epoxy intermediate + 1 x 80  $\mu\text{m}$  WB acrylic topcoat
10. 1 x 75  $\mu\text{m}$  SB zinc silicate primer + 1 x 75  $\mu\text{m}$  WB epoxy intermediate + 1 x 75  $\mu\text{m}$  WB acrylic topcoat
11. 2 x 125  $\mu\text{m}$  WB HB solid epoxy primer + 1 x 75  $\mu\text{m}$  SB polysiloxane topcoat
12. 1 x 200  $\mu\text{m}$  WB HB solid epoxy primer + 1 x 110  $\mu\text{m}$  SB polysiloxane topcoat
13. 1 x 200  $\mu\text{m}$  SB epoxy mastic primer + 1 x 80  $\mu\text{m}$  WB epoxy intermediate + 1 x 50  $\mu\text{m}$  WB acrylic topcoat
14. 2 x 200  $\mu\text{m}$  Solvent free epoxy primer + 1 x 50  $\mu\text{m}$  WB acrylic topcoat  
(WB = water-borne, SB = solvent-borne, HB = high build)

Demands from the oil companies for prequalification tests of coating systems according to Norsok M-501 put strong demands to the quality of the different coatings and systems. The test requirements for approval of coating systems according to Norsok M-501 and other accelerated test methods have been described by the author in detail in other publications<sup>1-3</sup>. Paint systems no. 1-3, 5, 9, 10 have all been pre-qualified for HD corrosion protection of offshore installations (Norsok M-501 approvals for protection of carbon steel in atmospheric exposure) for either blast cleaned steel Sa 2½ or for water jetted steel or both surface preparation grades. Table 3 shows the rust creep from the artificial scribe after 4200 hours cyclic salt spray/QUV for the tested paint systems (Norsok M-501 allows for maximum 3 mm rust creep from scribe for approval. NT = not tested);

The general conclusion from this severe test is that the three coat hybrid and pure water-borne coating systems are best and are matching, in corrosion protection performance, known solvent-borne coating systems with up to 20 years track record from the North-Sea<sup>1-3</sup>. The Norwegian state owned oil company Statoil have stated that they only accept three coat systems with less than 1 mm rust creep at scribe from the Norsok testing and we see that water-borne and hybrid system 3, 5, 9 & 10 fulfills this requirement while several pure solvent-borne coating systems used on North Sea installations the last 15 years do not fulfill this requirement.

## **Offshore field experiences with water-borne coatings**

The largest independent research institute in Norway, SINTEF performed from year 1995 – 2000 a five years field test of several organic coating systems for HD corrosion protection on the Snorre platform in the North Sea. The conclusions from this test is rather remarkable since it ranked the pure water-borne coating system no. 4 as second best in the test, only surpassed by a duplex system (200 µm thermally sprayed aluminum + epoxy tie coat). The performance of the different coating systems were ranked after rust creep at scribe, adhesion, chalking, cracking and flaking and the duplex system was ranked at 100 points. See figure 1.

In 1990 a water-borne high-build high ratio IOZ silicate primer was approved for maintenance on offshore and gas platforms for ESSO in the Bass Strait between South Australia and Tasmania. See figure 2. A single coat of 150-200 µm dft of the ambient curing water-borne primer was applied as the sole protective coating on areas on the platforms above the immediate splash zone. Several platforms have been protected with excellent results under the adverse and rapid changing weather conditions found in the Bass Strait. Similar good results with long term corrosion protection have been obtained with water-borne IOZ silicate primers on oil installations in the Gulf of Mexico.

Some years ago several oil companies in the North Sea decided to start field testing of water-borne coatings on oil platforms in the North Sea. The oil company Norsk Hydro started three years ago to test out two-coat water-borne and three-coat water-borne/solvent-borne hybrid coating systems for use on onshore and offshore installations. They tested out the coatings at three sites in Norway, a) onshore chemical industrial, b) coastal marine industrial and c) offshore on the legs of an oil platform Troll B. As a reference they used a typical solvent-borne coating system used for maintenance offshore consisting of a zinc rich polyamide adduct cured epoxy primer plus a polyamide adduct cured epoxy MIO intermediate and a 2-component acrylic topcoat. Test panels blast cleaned to Sa 2½ with weld on brackets were painted

indoors and placed for exposure in environment a) and b), while sections of a 20” pipeline was high pressure water jetted (UHPWJ) to moderate flash rust (C-VIS WJ-2M) and painted outdoors on site. The paint is inspected for disbonding, blistering, rusting, cracking, flaking, chalking and after 2½ years exposure the main conclusion is that the three coat hybrid paint system no. 9 performs similar or better than the thicker three coat solvent-borne coating system, see table 4 and figure 3. The oil company has therefore started to use the water-borne/solvent-borne hybrid system for maintenance and new construction onshore and one work package will be coated offshore this summer.

### **Other field experiences with water-borne coatings for corrosion protection**

The author has presented a number of case histories with water-borne and hybrid coating systems in previous publications<sup>1-3</sup>. The author would however like to show that you do not necessary need a solvent-borne or water-borne zinc rich primer in a coating system to have good corrosion protection in a marine environment. Some years ago the load-bearing steel structures for a motor-way bridge on the coast of Denmark (Fiskebæk) was painted with a thick water-borne acrylic coating system (according to Danish bridge standards), consisting of 3 x 100 µm dft of a vinyl acrylic primer plus 50 µm dft of a hard styrene-acrylic topcoat. The coating system is giving excellent corrosion protection due to the high total dft. See figure 4. Thick film acrylic coating systems have for many years been used with success for corrosion protection on steel bridges in North America and in some European countries.

A typical use for water-borne acrylic topcoats is for maintenance of solvent-borne coating systems on steel tanks oil or chemical tanks and in particular recoating the existing topcoat to get back a fresh and glossy appearance of the tank. One of the big advantages with a water-borne acrylic topcoat is the excellent gloss and color retention and this is fund both in accelerated QUV-tests and in real life exposure. In the long run we see that even a solvent-borne polyurethane topcoat is surpassed in UV-resistance, see figures 5-7. Similar experiences with water-borne acrylic topcoats on crude oil storage tanks is found in many countries around the world like Saudi Arabia, Oman, Malaysia, Thailand, Greece etc.

### ***Working rules for Water-borne Coatings for HD corrosion protection***

Coatings for protection of concrete, wood, plastic, metal etc. are only semi-finished products and are highly dependant on the correct surface preparation and application. In fact 90% of all early failure of coatings is due to either inadequate surface preparation or improper application of the coating to the substrate. In HD corrosion protection incorrect surface preparation of the steel or failing to apply the coating in a correct manner will severely shorten the service life of the coating. Another aspect to take into consideration is selecting the correct coating system, meaning a coating system that is designed for the service conditions it will be exposed to. For instance specifying a coating system designed for use above the waterline for continuous water immersion or specifying a heat resistant coating for continuous service conditions above the coatings dry heat resistance limit, would be the same as asking for trouble. There are a set of rules and standards made to safeguard that a coating job is done correctly, no matter what type of coating is used either solvent-borne, solvent-free or water-borne. For water-borne coatings there are some extra rules with regard to the climatic conditions (temperature and relative humidity) during application and they are limited to use above water-line and above 0°C. Following the paint producers

guidelines given in technical datasheets or working manuals<sup>5</sup>, will assure that the coating job with a water-borne coating is always done correct the first time. As more and more users of coatings are converting to new environmental friendly coatings there is an increasing need for technical training and some paint producers even have special paint schools<sup>6</sup> to coach the users in understanding and using water-borne coatings in a correct manner.

Below the author will highlight a few findings regarding water evaporation evolution, risks with over application and early over coating and finally indicating accurate time for a water-borne coating to build up enough water-resistance to support all weather conditions.

### **Water-evaporation evolution from a water-borne coating**

There are three parameters that are decisive for the evaporation of water from a paint film i.e. temperature, relative humidity and presence of ventilation. Gravimetric measurement of water remaining in an anticorrosive waterborne acrylic topcoat and epoxy primer as a function of time is performed by applying paint on glass-panels and drying under controlled temperature and relative humidity (RH) in a Termaks climate cabinet. The Termaks cabinet has no air exchange/ventilation, but the air volume of the total cabinet compared to the 50 cm<sup>2</sup> area of the paint drawdown on glass is large enough to simulate an open air situation with no ventilation.

In figure 8 we see that 50% of water in the acrylic paint film is evaporated within 5-20 minutes from the most extreme conditions i.e. 5°C and 85% RH to the best conditions at 40°C and 50% RH. The remaining 50% of water left in the paint film is evaporated within 25-200 minutes. By reducing the % RH at 5°C from 85% RH to 20% RH, the time for water to evaporate from the paint film is reduced with more than 250%. As can be seen from figure 8, there is one or several breaks in the water evaporation curve, which is probably due to a collapse in the stability of the paint film as water evaporation leads to concentration and dense packing of the polymer particles and deformation under the action of surface and capillary forces.

In figure 9 we see that 50% of water in the epoxy paint film is evaporated within 10-50 minutes from the most extreme conditions i.e. 5°C and 85% RH to the best conditions at 40°C and 50% RH. The remaining 50% of water in the epoxy paintfilm is evaporated within 25-300 minutes down to 10°C and 70% RH. For the lowest temperature 5°C and 85% RH we see that 90% of the water is evaporated after 225 minutes, while the evaporation of the remaining 10% of water takes 5 times longer, approximately 24 hours. At the lowest temperature 5°C, we see a huge impact on water evaporation time by reducing relative humidity from 85% RH to 20%. Please note that the time scale on the x-axis in figure 9 is three times longer than for figure 8.

In general we see a huge impact on water evaporation time for a water-borne coating by variation of relative humidity in the air and this impact is increasing with several magnitudes as the drying temperature is decreased. Water is evaporating much faster from a water-borne acrylic topcoat than from a water-borne epoxy primer, even if the volume solids (see tabel1) is higher for the epoxy primer. This means for instance that to early over coating a water-borne epoxy primer at low temperature and high relative humidity, with a fast drying water-borne acrylic topcoat, can lead to water entrapment in the epoxy film resulting in cracking, blistering and ultimately loss of adhesion. This illustrates the importance of having good control on temperature and relative humidity

when painting with water-borne coatings under extreme weather conditions. Finishing a paint job to late in the afternoon in the cold/wet season can in the worst case lead to adhesion failure, since the dew point and relative humidity in the air is changing rapidly as the sun sets. When painting indoors at low temperatures, you have a good possibility to reduce the drying time of a water-borne coating by using dehumidifiers or other ways to reduce the relative humidity in the air.

### **Risks with over-application or thick films of water-borne coatings**

The main reasons for not using thick coats of water-borne paint for corrosion protection is the risk for getting water entrapment in the film. We have therefore looked at applying dry film thicknesses (dft) of 150  $\mu\text{m}$  and 200  $\mu\text{m}$  of a water-borne vinyl-acrylic primer and for the same water-borne epoxy primer as studied in section 3.1. The typical dft for both these primers are 60  $\mu\text{m}$ . We have measured drying time of the primers applied on glass panels(surface dry, ISO 9117 & through dry time, ASTM D-1640), adhesion on 3 mm steel panels(pull-off, ISO 4624 or x-cut, ISO 2409) for coatings dried in a Termaks climate cabinet with constant 70% RH and with 4 different temperatures, 5, 10, 23 and 40°C.

The main conclusions for drying of a thick coat of a water-borne vinyl-acrylic primer is that for 200  $\mu\text{m}$  dft the coating will be surface dry after 60 minutes and through dry after 5 hours at 40°C and at 5°C the coating will be surface dry after 4.5 hours and through dry after 12 hours. For a water-borne epoxy primer at 200  $\mu\text{m}$  dft the coating will be surface dry after 2 hours and through dry after 48 hours at 4°C and for both 10 and 5°C the coating will be surface dry after 3.5-4 hours, while the coating will take between 7-17 days to become through dry. This means that the physical drying properties of the epoxy primer will make the coating dry fast in the surface and water further down in the coating will not get out before the film closes at the top.

When looking at adhesion to steel for over-application (150 & 200  $\mu\text{m}$  dft) of the two primers, we see the following. The fast drying vinyl-acrylic primer has good adhesion to steel for both film thicknesses for all drying temperatures (5, 10, 23, 40°C and 70% RH) both when checking adhesion after 24 hours and 7 days of drying/curing. Adhesion (pull-off values) is slightly better after 7 days of drying/curing compared to 24 hours drying/curing. For the slower drying/curing epoxy primer we see that it has good adhesion to steel for both film thicknesses for all drying temperatures (5, 10, 23, 40°C and 70% RH) when checking adhesion after 7 days of drying/curing. The adhesion for the water-borne epoxy primer is not good enough after 24 hours drying/curing at the lowest drying temperatures 5 and 10°C, since there is still water left in the paint film.

The last test we did was to look at over coating 150 & 200  $\mu\text{m}$  dft of the two primers, after 4, 8, 16 and 24 hours drying, with 60  $\mu\text{m}$  dft of a water-borne styrene-acrylic topcoat and 75  $\mu\text{m}$  dft of a solvent-borne high solids oxiran-ester topcoat. The drying conditions and relative humidity conditions were the same as above i.e. 5, 10, 23, 40°C and 70% RH. The primers were both airless spray applied on 3 mm steel panels blast cleaned to Sa 2½ and then immediately after placed in a Termaks climate cabinet for drying. Topcoats were applied by applicator on the primed steel after 4, 8, 16 and 24 hours drying. Adhesion was measured by pull-off (ISO 4624) after 24 hours and 7 days of drying/curing.

For the vinyl-acrylic primer at 150 and 200  $\mu\text{m}$  dft, over coated with the water-borne topcoat, we see that adhesion is good for all recoating times and drying temperatures after 7 days of drying/curing (for 5 and 10°C over coating with topcoat was done after 6, 16 and 24 hours). As previously observed the pull-off adhesion values are slightly lower after 24 hours drying/curing compared to 7 days drying/curing. At the lowest drying temperatures 5 and 10°C we see that adhesion is good after 24 hours drying/curing with 6 hours over coating interval with water-borne topcoat, while for the solvent-borne topcoat adhesion is good after 48 hours drying/curing with 16 hours over coating interval for 10°C and after 48 hours drying/curing and 24 hours over coating interval at 5°C.

For the epoxy primer at 150 and 200  $\mu\text{m}$  dft, over coated with both topcoats, we see that adhesion is good for all recoating times and drying temperatures 23°C/40°C after 7 days of drying/curing. At 10°C with 6 hours over coating interval with both topcoats and after 48 hours or 7 days drying/curing, we see that adhesion is not good enough. At 5°C we observe that the adhesion build up in the coating system is slow, due to water and solvent entrapment after over coating. The pull-off adhesion values are low with 6 hours over coating with both topcoats and drying/curing for both 48 hours and 7 days. When over coating with both topcoats after 16 hours or 24 hours, the pull-off adhesion values are good after 7 days drying/curing.

These simple tests therefore concludes that over application of a water-borne epoxy primer at 150 or 200  $\mu\text{m}$  dft and early over coating with topcoats is not recommended below 23°C. While for a water-borne vinyl-acrylic primer both drying time and adhesion of the coating at all temperatures and early over coating with topcoats is found to be acceptable and it is therefore possible to apply dry film thicknesses up to 200  $\mu\text{m}$  with such a primer. This makes thick film water-borne acrylic coating systems for HD corrosion protection a possible option.

### **The time a water-borne coating system needs to build up water-resistance**

To be able to safely recommend and use water-borne coating systems for HD corrosion protection during all weather conditions, it is of outmost importance to accurately measure when such a hydrophilic coating system has build up good enough early water-resistance. In other words when painting with water-borne coatings in all seasons, we need to know how soon the coating will support heavy rain weather, condensation, snow and freezing conditions, after the paint job is done.

We have therefore painted a typical water-borne paint system consisting of 120  $\mu\text{m}$  dft water-borne epoxy primer and 80  $\mu\text{m}$  dft water-borne styrene-acrylic topcoat and dried indoors at 23°C or 30°C and 30, 50, 70% RH in a Termaks climate cabinet. Primer was dried for 2 or 4 hours and then taken out and over coated with topcoat and again dried for 2 or 4 hours and then dried under the following three conditions;

- a. drying in a Termaks climate cabinet at 10°C and 30, 50 and 70% RH
- b. drying outdoors under half-roof in January in East-Norway (-2°C - 4°C and 90-100% RH measured at noon every day)
- c. drying indoors in unheated room in January in East-Norway (3-8°C, 52-76% RH)

Adhesion on steel, blast cleaned to Sa 2½, checked by x-cut (ISO 2409) and knife after 24 and 7 days drying of the whole coating system.

For drying condition a) we see that drying at 23°C or 30°C for 2 + 2 hours, the adhesion is somewhat low after 24 hours drying/curing, while adhesion is good after 7 days drying/curing. With 4 + 4 hours drying at 23°C or 30°C with condition a) adhesion is good already after 24 hours drying/curing. For drying condition b) we see that adhesion is only good after 7 days drying/curing with initial drying at 23°C or 30°C for 4 + 4 hours. All other drying conditions give bad adhesion. For drying condition c) we see that drying at 23°C or 30°C C for 2 + 2 hours, the adhesion is good after 7 days drying/curing. With 4 + 4 hours drying at 23°C or 30°C with condition c) adhesion is good after 24 hours drying/curing.

The conclusions from this indicates that it is possible to paint with such a water-borne coating system all seasons and obtain good adhesion with short over coating intervals even under extreme drying conditions outdoors. To have short over coating intervals for such a coating system wintertime it is recommended to force dry at 23°C or 30°C for 4-8 hours before the coated object can be exposed to freezing or condensation conditions. Please note that for drying condition b) the temperature during nighttime was below - 4°C. As long as the water has evaporated from the paint film and coalescence is underway, early adhesion indicates that the coating will be able to support extreme weather conditions. A curing epoxy product would therefore not be fully cured after 24 hours, but sufficient to give good enough adhesion. For the record please note that when comparing surface dry time and recoating times for solvent-borne acrylic topcoat and epoxy primer equivalents with the above mentioned water-borne coatings, we see that the drying times are very comparable for all temperatures 5, 10, 23 and 40°C, see table 5 below. Please note that the drying times for the water-borne products are measured for a slightly higher dft and relative humidity than for the solvent-borne coatings.

A similar test as done above has been done for a water-borne acrylic coating system used for painting waste containers, consisting of 100 µm dft water-borne vinyl-acrylic primer + 50 µm dft water-borne styrene-acrylic topcoat. The idea was to give recommendations for how fast after painting a container indoors, with a water-borne acrylic coating system, can it be placed outdoors for different weather conditions. The four weather conditions were warm & wet, warm & dry, cold & wet and cold & dry, which was supposed to simulate the 4 seasons spring, summer, autumn and winter in South-Scandinavia. As table 6 below indicates we found that the water-borne coating system (primer + topcoat) needed maximum 7 hours forced drying before it could be placed outdoors for any season. For an equivalent solvent-borne acrylic system (primer + topcoat) the recoating/drying times for the system is 6.5-12 hours, which means that converting to a water-borne system would save the applicator time and money.

In the analysis of the evaporation process of water from the three water-borne coatings described above the author has chosen to simplify the matter somewhat mainly since we are assuming that the high boiling co solvents used remain in the paint film much longer than water. Otherwise the film formation of a water-borne coating is a complex process and there is a wide selection of cosolvents<sup>7, 8</sup> to choose between to help melting hard polymer particles together. Some co solvents like isopropanol can form an azeotrope with water to lower the mixtures total boiling point temperature and therefore evaporation of water is aided. Other co solvents like propylene glycol mono-methyl ether, acetone or methyl ethyl ketone is evaporating

too fast to help in the film formation of a water-borne coating in particular at low temperatures and high relative humidity. Under such conditions these co solvents will have left the paint film long before all the water has evaporated, leaving a paint film with incomplete film formation that can be open for water & solvent penetration. The most typical way to approach the use of co solvents in particular hard thermoplastic acrylic coatings is to use a blend of partly water miscible and completely water immiscible co solvents in the coating. Table 7 below lists some typical solvents used in water-borne industrial coatings (marked in green) and some typical solvents used in solvent-borne industrial coatings (marked in blue) and as one can see from the list it is possible to select co solvents that are matching solvents in evaporation rates.

Note the high surface tension of water compared to the solvents used. The high surface tension of water is the reason for the need of adding surface active material to the coating to lower the surface tension of the coating, but at the same time the water-resistance of the coating is reduced, creating problems with blistering of the coating exposed to early rain, condensation, snow etc. For an industrial water-borne styrene-acrylic topcoat for HD corrosion protection, we have found that tinting such a product with pigment pastes will reduce the water-resistance of the coating severely due to the large amount of surfactants in the pigment pastes. We have therefore designed a special coloring system to maintain an excellent water-resistance for the colored topcoat.

### ***Legislation and technology is pushing water-borne coatings for corrosion protection forward***

There is no doubt that water-borne coating for protection of steel is the future in corrosion protection. The ever increasing pressure on health and environmental issues in general and in the coating industry in particular will leave us with fewer technological options. Low solids coatings will die out in EU and NAFTA to be replaced by solvent-free, high solid and water-borne coatings due to the high focus on VOC-content in architectural and industrial coatings. The health hazards with human exposure to strong solvents like xylene, containing 20% of the carcinogenic ethyl benzene, might lead to a ban on xylene and other health hazardous solvents with a high ozone creation potential. Xylene is an important tool for making high solid epoxy and epoxy mastic coatings for corrosion protection. Solvent-free epoxy technology is for most HD corrosion protection purposes impractical due to long drying and over coating times below 15°C and inferior corrosion protection compared to solvent-borne high solid epoxy and water-borne epoxy. In addition both high solid epoxy and solvent-free epoxy is dependant on using low molecular weight epoxy that can give epoxy allergy for the user. In fact in some countries skin contact allergies from epoxies and health problems from high exposure to strong solvents for industrial painters is threatening recruitment to that profession. In EU and the Scandinavian countries the substitution principle is by law a regulation that demands that a user shall evaluate if there are alternative products or chemical compounds that leads to a reduction in HSE risk for the company and user. If such an alternative exist the company or user shall use such an alternative if it can be done without an unreasonable increase in cost or inconvenience. The substitution principle became a part of the product control law in Norway in January 2000. If the law is put in to practice in Scandinavia and EU, the company or user of solvent-borne coatings for HD corrosion protection will have to document towards the authorities that for instance water-borne alternatives are substantially more expensive or inconvenient to use. This will be very difficult for a company or user to document.

The author believes that implementation of environmental legislation and technological developments within coatings for corrosion protection, goes hand in hand. Water-borne coatings for corrosion protection did not get a good start since in the early days since the products were simply not good enough and the users did not understand how to use the products in a correct manner. Technologically we have gone a long step forward since then and I hope that this paper has given a small glimpse of what is possible and not possible with water-borne coatings for corrosion protection. The implementation of environmental legislation in EU and NAFTA and the CEPE proposed product group VOC limits in grams/liter for protective coatings in EU, will change the situation for use of solvent-borne coatings for corrosion protection of steel. As can be seen from figure 5 below, there are several levels of regulations to reduce VOC emissions from organic coatings to the atmosphere.

National emission ceiling (NEC) on VOC's and other health and environmental harmful compounds will be put in act in year 2010 giving an upper limit in tons of emissions allowed for each EU-country. The EU solvent emission directive (SED) has as a target to reduce solvent emissions from industrial processes (including painting) with 67% by year 2007 compared to the emission levels in 1990. Several countries in EU and states in NAFTA have implemented national VOC-limits (UK, Austria), VOC-tax (Switzerland) or national VOC-regulation (France, Portugal, Germany, Italy, and Holland). In the US the federal AIM coatings VOC-regulation has been in act since 1998 and further restrictions will be implemented by 2005. In the US there are several states that have stricter VOC-regulations/limits than the federal regulation; these are California, Delaware, Maryland and Pennsylvania. In EU, working groups for protective coatings within CEPE are just these days finalizing a proposal for product group VOC limits in g/l, similar to limits already proposed for vehicle refinishing (VR) and decorative coatings in EU. It is reasonable to assume that the working group for marine coatings will follow the protective coatings approach from CEPE.

### ***Conclusions***

The suitability of water-borne acrylic, epoxy and IOZ silicate coatings for HD corrosion protection has been discussed with emphasis on advantages and limitations. Both results from accelerated testing and numerous case histories are shown to illustrate the technology suitability. All in all we see that the use of water-borne coatings for corrosion protection will grow substantially in the years to come. The author believes that there is a big need to educate the users of water-borne coatings in the HD corrosion protection area to reduce the skepticism and assure that the coating job is always done correctly the first time. There is a different set of working rules when using water-borne coatings compared to using solvent-borne coatings and this is something the users will have to adapt to. Water-borne coatings for corrosion protection can give the user cost savings due to shorter coating time or possibility to use one coat systems. Results from accelerated corrosion testing and a growing number of successful case histories is confirming good performance and that water-borne coatings can be used in HD corrosion protection. There is no doubt that the advantages with water-borne coatings by far outweigh the disadvantages or limitations, so there should not be any viable reason not to use them.

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## FIGURES

Type	Function	VS,%	Max. d.f.t., $\mu\text{m}$	VOC, g/l
IOZ alkali silicate	1 coat primer/topcoat	75	200	0
IOZ alkali silicate	Primer	57	50	0
Hard styrene-acrylic	Topcoat	36	80	106
Vinyl acrylic	Primer	46	120	66
High $M_w$ epoxy	Primer/intermediate	46	125	60
High $M_w$ zinc epoxy	Primer	56	90	92

**Table 1:** Types and features of water-borne technologies for corrosion protection

Properties	WB IOZ alkali silicate	SB IOZ ethyl silicate
Surface preparation	-/+	+
Ease of application	-	+
Mud cracking	++	-/+
Overcoating	+	-/+
Hardness	++	+
Solvent content	+++	-
Popping when overcoating	-	-
Volume solids	+++	+
Drying	+	++
Chemical resistance	+++	+++
Corrosion protection	+++	+++

**Table 2:** Comparison of properties of water-borne and solvent-borne zinc silicate paints  
(+++ = excellent, ++ = very good, + = good, +/- = not so good, - = bad)

Paint system no.	Creep at scribe, mm <i>Water jetted steel</i>	Creep at scribe, mm <i>Sandblasted steel</i>
1	NT	2.6
2	2.5	2.3
3	0.5	0.5
5	NT	0.8
6	3.4	NT
9	0.6	0.3
10	1.4	0.7
11	NT	4.0
12	3.9	NT
14	6.4	NT

**Table 3:** Average rust creep from scribe after 25 cycles in the cyclic test of NORSOK M-501 rev.4 for the complete water-borne and hybrid paint systems given above, except system no. 4, 7, 8 & 13

Paint system	DFT, $\mu\text{m}$	Creep at scribe Site a)	Creep at scribe Site b)	Creep at scribe Site c)
Hybrid no. 9	250	0.4 mm	0 mm	0 mm
Solvent-borne Reference	390	0 mm	0 mm	20 mm many blisters

**Table 4:** Rust creep and blistering at artificial scribe after 2 ½ years exposure at a) onshore chemical industrial, b) Coastal marine industrial and c) offshore on the legs of an oil platform Troll B

Drying time	Temperature, °C	WB acrylic TC VOC: 106 g/l*	SB acrylic TC VOC: 580 g/l**	WB epoxy Pr. VOC: 60 g/l*	SB epoxy Pr. VOC: 460 g/l**
Surface dry:	40	20 min.	15 min.	40 min.	30 min.
	23	25 min.	30 min.	45 min.	60 min.
	10	30 min.	45 min.	60 min.	2 hours
	5	90 min.	60 min.	60 min.	5 hours+
Dry to recoat:	40	60 min.	90 min.	90 min.	3 hours
	23	90 min.	2 hours	90 min.	4 hours
	10	2.5 hours	4 hours	8 hours	8 hours
	5	8 hours	5 hours	24 hours	12 hours+

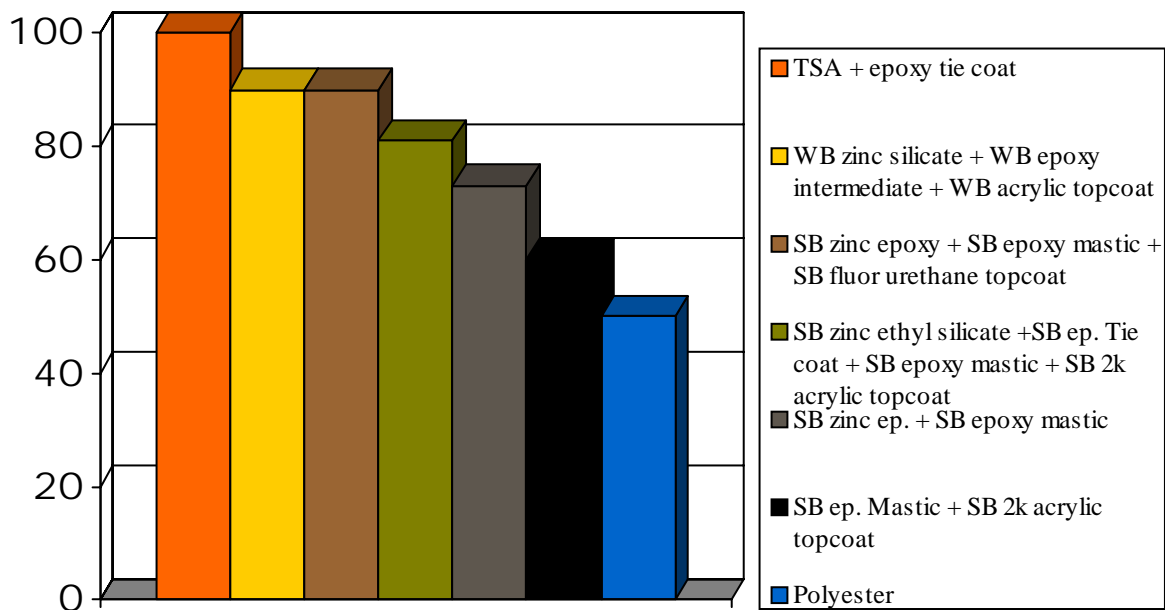
**Table 5:** Comparison of drying and recoating times for water-borne and solvent-borne industrial topcoats and primers for HD corrosion protection. (\* 60  $\mu\text{m}$  dft, 70% RH, \*\* 50  $\mu\text{m}$  dft, 50% RH, + the solvent-borne epoxy primer needs a low temperature additive to be able to cure at 5°C)

Weather condition outdoors	Warm & wet > 15°C, > 80% RH	Warm & dry > 15°C, > 50% RH	Cold & wet > 5°C, > 80% RH	Cold & dry > 5°C, > 50% RH
Drying 23°C & 50% RH	Primer 2.5 hours Topcoat 2.5 hours	Primer 2 hours Topcoat 2 hours	Primer 4 hours Topcoat 3 hours	Primer 3 hours Topcoat 2.5 hours
Drying 23°C & 30% RH	Primer 2 hours Topcoat 2 hours	Primer 1.5 hours Topcoat 1.5 hours	Primer 3 hours Topcoat 2 hours	Primer 2.5 hours Topcoat 2 hours
Drying 30°C & 50% RH	Primer 1.5 hours Topcoat 1.5 hours	Primer 1.0 hours Topcoat 1.0 hours	Primer 2.5 hours Topcoat 1.5 hours	Primer 2 hours Topcoat 1.5 hours
Drying 30°C & 30% RH	Primer 75 min. Topcoat 1 hour	Primer 50 min. Topcoat 40 min.	Primer 2 hours Topcoat 75 min.	Primer 1.5 hours Topcoat 1.5 hours

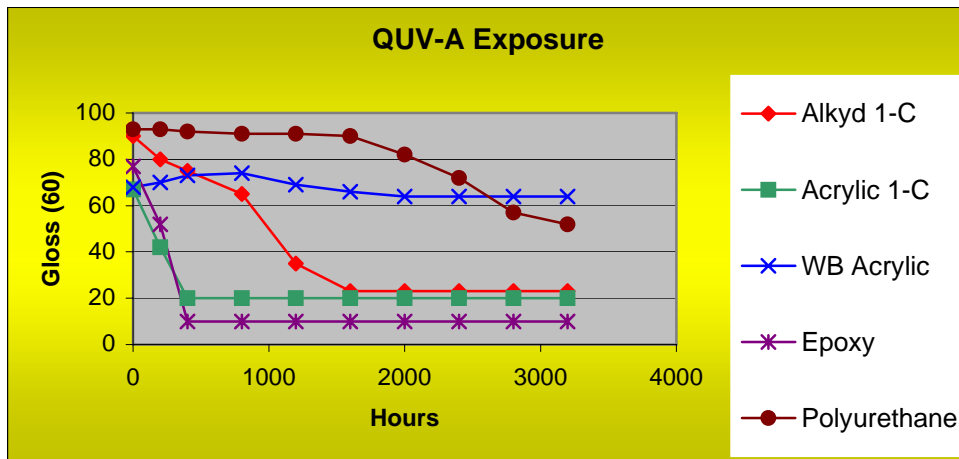
**Table 6:** Drying time for water-borne acrylic coating system for corrosion protection.

Paint solvents	Evaporation rate (ether = 1)	Boiling point Temperature, °C	Surface tension MN/m
Acetone	2	56	22
Isopropanol	7	82*	21
Xylene	17	106	28
Propylene Glycol Methyl Ether	17	121	28
n-Butanol	33	118	23
White Sprite	55	155	25
Propylene Glycol Propyl Ether	60	150	27
Water	80	100*	73
Benzyl Alcohol	1750	205	40
Butyldiglycol	4034	232	30
Texanol	6551	245	29

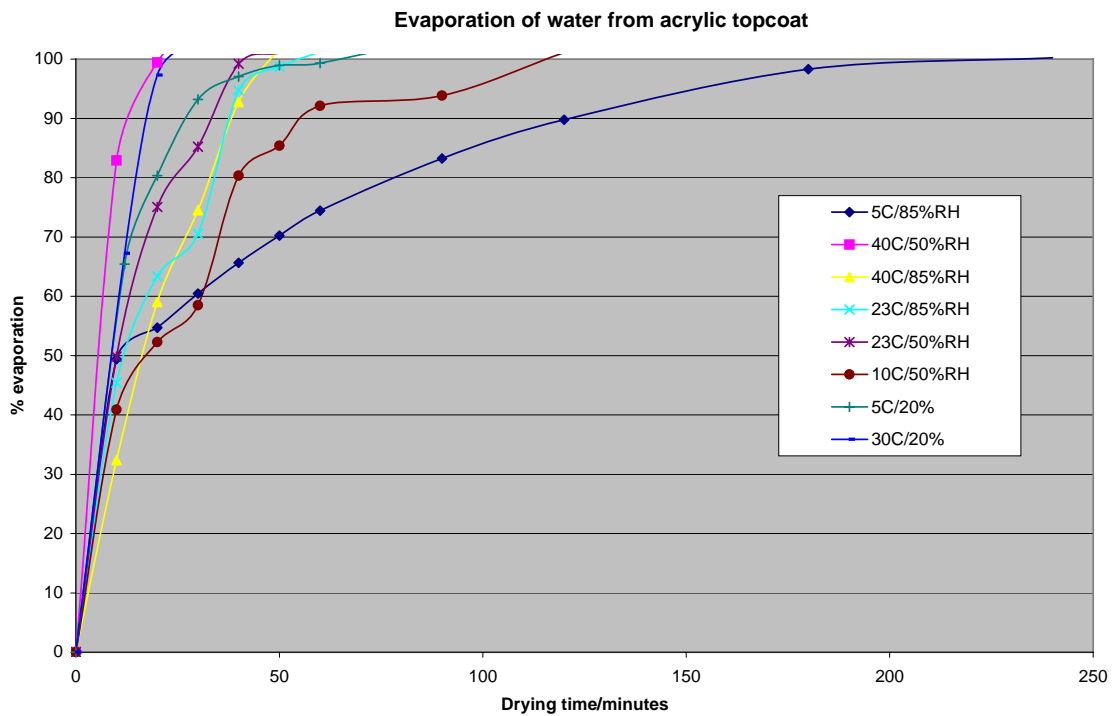
**Table 7:** Evaporation rates, boiling point temperatures and surface tension for some typical paint solvents.  
 (\* an azeotrop is formed with water + iso-propanol ⇒ boiling point temperature of 80°C)



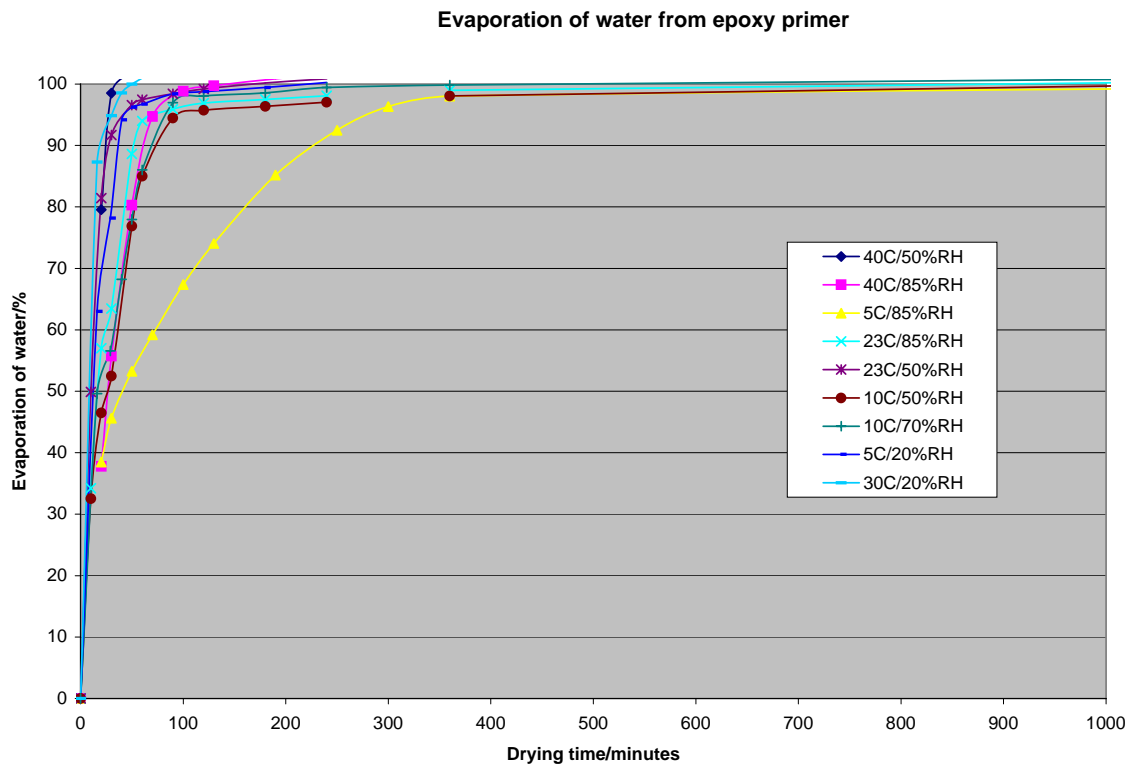
**Figure 1:** Five year North Sea offshore field test of organic coatings for HD corrosion protection



**Figure 2:** Gloss retention of different topcoats used for corrosion protection after accelerated testing in QUV-condensation chamber, ASTM G53. The increase in gloss before 1000 hours QUV-exposure for the water-borne acrylic is due to melting of polymer particles by UV-light at 60°C.



**Figure 3:** Evaporation of water from a water-borne acrylic topcoat as a function of time, temperature and % relative humidity.



**Figure 4:** Evaporation of water from a water-borne epoxy primer as a function of time, temperature and % relative humidity

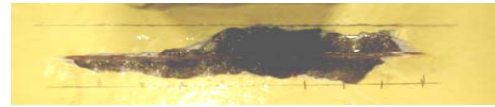


**Picture 1:** Offshore oil platform in the Bass Strait between South-Australia and Tasmania painted with a water-borne high-build high-ratio IOZ silicate primer in 1990

Hybrid system



Reference system



**Picture 2:** Rust creep at artificial scribe for water-borne/solvent-borne hybrid system no. 9 and solvent-borne reference system after 2½ years exposure offshore on the Troll B oil platform



**Picture 3:** Thick water-borne coating system used for HD corrosion protection of load-bearing steel structures on a motor-way bridge



**Picture 4:** Crude oil storage tank at Esso Slagentangen in Norway coated in 1995 with a solvent-borne PU-topcoat. Light blue square at bottom of tank is a water-borne acrylic topcoat, coated at the same time as the PU-topcoat that has maintained its original color and gloss, while the solvent-borne PU-topcoat has faded.



**Picture 5:** Crude oil storage tank, west coast of Norway, painted in 1995 with a hybrid paint system and with a water-borne styrene acrylic topcoat. The coating system is in excellent condition after 8 years service and the topcoat has maintained its colour and gloss.