

6 INDUSTRIAL AND MARINE PROTECTIVE COATINGS AND COATING SYSTEMS

Introduction

As we described in Module 1, one of the primary means of corrosion protection is the use of industrial protective coatings. These coatings primarily protect the underlying substrate by barrier, galvanic and/or inhibitive protection. While proper surface preparation and installation of protective coatings is critical to long-term corrosion protection, proper *selection* of a coating system, based on the prevailing or projected service environment is equally important. That is, despite how well a surface is prepared and how well a coating system is applied and cured, the substrate may be unprotected if the coating cannot withstand the environment.

It is acknowledged that the coatings inspector typically would not be responsible for identifying service environments or selecting coating systems for a project. In fact, these activities would typically take place long before a coatings inspector becomes involved in a project. However, it is important that a coatings inspector have a working knowledge of protective coatings and coating systems, and background information on why certain coating systems are used in some environments and not in others. Also, by understanding how a coating cures, an inspector can anticipate potential problems (based on prevailing ambient conditions) and work with the contractor to ensure proper curing of the applied film.

This module begins with an introduction to the basic, primary ingredients in industrial and marine coatings, and reviews the three primary methods that coatings employ to protect the underlying substrate (these were already described in Module 1). The module continues with an explanation of the various methods that industrial and marine coatings employ to convert from a liquid to a solid state, once applied to a surface. These are called “curing mechanisms.” Five curing mechanisms will be described, and examples of coatings that cure using the various mechanisms are provided.

One of the key ingredients in most industrial and marine coatings is solvent. Many solvents used in coatings react with solar radiation (sunlight) as they evaporate from the coating and contribute to air pollution. As a result, the type and amount of solvent that can be used in a coating formulation and/or added to a coating in the field is oftentimes regulated, based on the location where the work will take place. These solvents are regulated as volatile organic compounds or “VOC’s.” The inspector’s responsibilities relating to verifying conformance to VOC regulations are described in this module.

A common challenge experienced by most coating specifiers is the identification of the prevailing service environment (for existing structures/facilities) or the anticipated service environment (for new structures or facilities). This module provides guidance on methods used to properly identify service environments, and provides examples of ten common environments.

A chart listing twenty one (21) common coating types and their inherent properties and characteristics is provided, along with examples of how the chart can be used to select a coating material based on the desired performance characteristics. For each of these coating types, there are key inspection concerns that the quality assurance/control inspector must consider. A chart listing generic coating types and the key inspection concerns associated with each is provided in this module.

There are a wide variety of coating systems that a specifier can select from. These systems are typically “assembled” by the coating manufacturer and oftentimes have a “track record” of successful performance in a given service environment. This module contains a series of eight (8) charts listing common generic coating systems used

by ten industries. Examples of how these charts can be used to select a coating system are also provided.

Finally, independent verification of coating system performance based on laboratory testing and/or field exposure is a critical component to coating system selection. That is, all manufacturers of a single coating system are not necessarily equal. Evaluations of coating system performance prior to full-scale field application can be facility-specific, industry specific and/or coating type specific. Each of these methods and their inherent advantages and limitations will be described.

Industrial and Marine Protective Coatings Versus Paint

A house paint and an industrial/marine protective coating can look very much the same from the outside of the can. Therefore, it is what is inside the can that makes the difference. When asked, “What is the difference between house paint and an industrial/marine coating?” some will respond, “About \$30.00 a gallon!” While the per-gallon cost of an industrial/marine protective coating is typically higher than house paint, this is not the only difference. The main reason for the added cost is related to the ingredients that are used to formulate a coating, versus the ingredients used to formulate a house paint. Think about the performance requirements of house paint versus that of a coating. A house paint is used primarily to improve aesthetics, but must have, say color and gloss retention properties (exterior paints) and scrub resistance (interior paints). Conversely, an industrial/marine protective coating may have to be resistant to immersion in water, chemical exposure, impact and abrasion, as well as be able to retain color and gloss.

Industrial/Marine Coatings: Components

There are many ingredients or raw materials that are used to formulate an industrial/marine coating. They can be categorized as non-volatile components and volatile components. Non-volatile components remain in the coating and on the surface once applied. Conversely, the volatile components evaporate from the coating into the air once the coating is applied to the surface. The non-volatile components typically include the resin or binder, the pigmentation and any additives that may be

incorporated into the formulation. The volatile component is the solvent system used in the formulation that is a component to the wet film, but not the dry film of the coating.

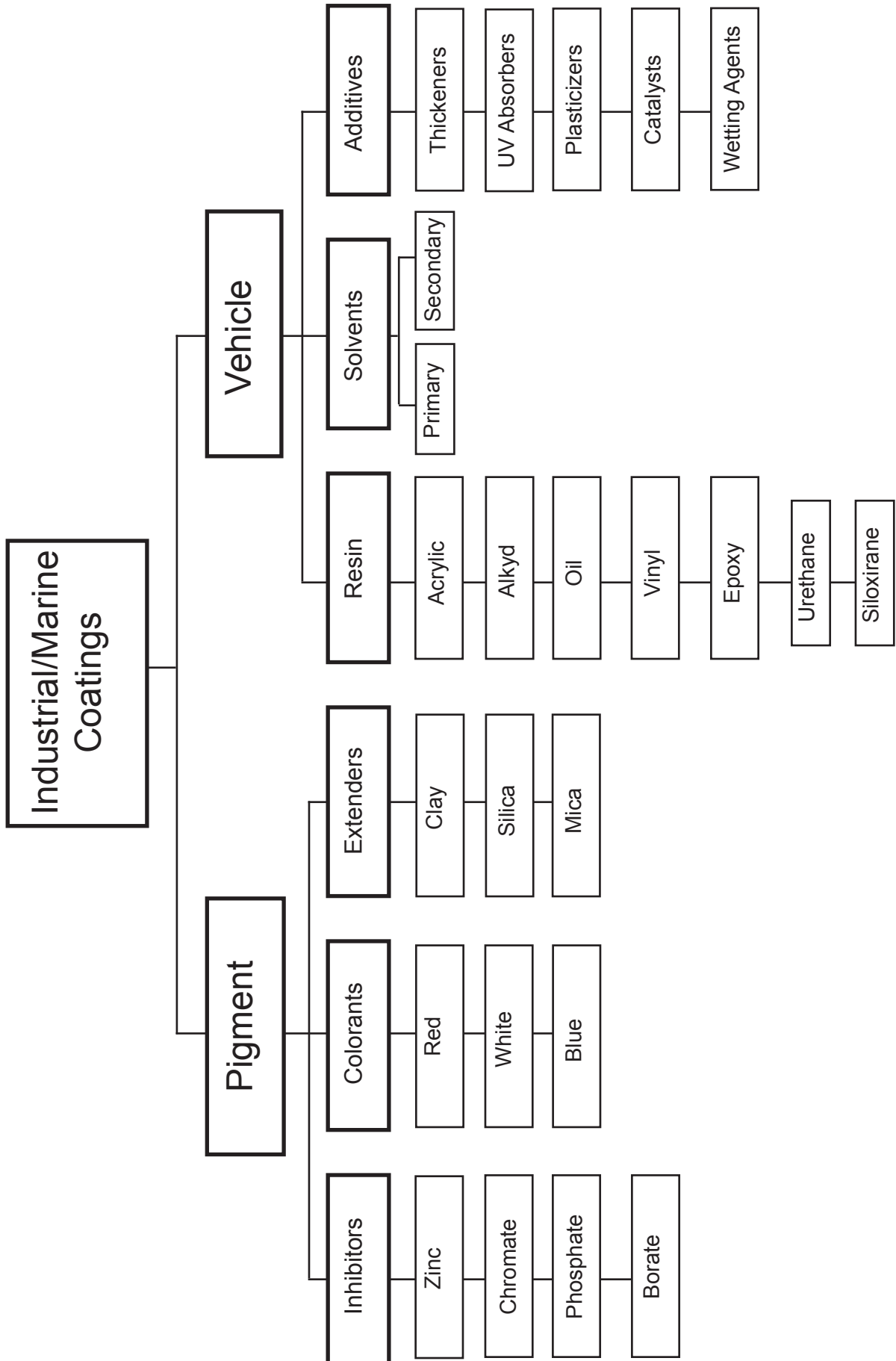
The diagram on the next page illustrates the basic components of an industrial/marine protective coating. It divides a coating into two major components: pigment and vehicle. The pigment (solid component) typically consists of corrosion inhibitors, colorants and extenders, although other raw materials may also be included. The vehicle (liquid component) “carries” the pigment to the surface and binds it into the coating film. The vehicle typically consists of the resin or binder, solvents and any additives that may be included in the formulation. The vehicle may also contain other raw materials to provide additional or different performance characteristics.

Resin (Binder)

The resin or binder is a non-volatile component. That is, it is both part of the wet film and the dry film. Oftentimes (but not always), a coating is identified generically by the type of resin used in the formulation. For example, a commonly specified coating system for the interior of a potable water storage tank is a two or three-coat epoxy. In this case, “epoxy” is used to describe both the coating type and the raw material resin system used to formulate the coating. The resin system is the film-forming component of a coating. It cohesively bonds the pigmentation together and adhesively bonds the coating to the underlying substrate or coating layer. It is essentially the “glue” of the coating. In many cases, the resin system dictates the performance properties of a coating.

Pigment

The pigment is also a non-volatile component of the coating formulation. The pigment is essentially an insoluble raw material. That is, it does not dissolve in the resin and solvent, but rather is suspended in the vehicle. Many of us think that the pigment merely gives the coating its color. While color is certainly a function of the pigment, it is only one of several potential functions. The pigment gives the coating its ability to “hide” the underlying surface. This is called hiding power. A coating formulated with pigment that demonstrates poor “hiding” may require the application of multiple coats, in order to



cover over the previous coating layer. For example, if a white coating is to be applied over a black coating, the coating must be formulated with good hiding pigments. Otherwise the black will show through, requiring multiple applications of the white overcoat. The level of pigment, and to a lesser extent, the shape and size (e.g., fineness of grind) of the pigment also determines the gloss level of a coating. For example, a “flat” sheen level is created by formulating the coating with more pigment than say a semi-gloss or gloss sheen level, which is generated by using less pigment in the formulation.

The pigment in a coating may also provide corrosion protection. If used, the pigment must be formulated into the primer layer (the layer adjacent to the carbon steel substrate). Inhibitors like iron oxide and barium, phosphorous and other compounds formulated into a primer “inhibit” the corrosion process. And zinc powder added to a primer in sufficient quantities galvanically protects the underlying carbon steel. Certain pigments even provide barrier protection. That is, their inherent shape and the way in which they orient themselves in the dry film create a barrier to moisture penetration through the coating. Examples include micaceous iron oxide and leafing aluminum pigments. These raw materials are “lamellar,” which means they are plate-like, lay flat in the coating film and cause any moisture that penetrates the coating film to take a considerably longer pathway to the substrate. Finally, extenders such as silica, mica and clay may be incorporated into the formulation to improve film build, increase the solids content of the coating and/or provide added barrier protection.

Additives

Finally any additives formulated into the coating also become part of the dry film. Various quantities of additives are used by the formulator to adjust the consistency, flow-out, surface wetting, color, ultraviolet (UV) light (or solar radiation from sunlight) resistance and flexibility, or to prevent settling in the can (suspending agents). For example, polyurethane coatings are formulated with hindered amine light stabilizers (HALS) to help preserve gloss and color upon exposure to sunlight, and plasticizers formulated into a coating provide film flexibility. There are many additives that a formulator can employ. These are only examples.

Solvents

The solvent system in a coating is the volatile component. While the solvent system is part of the wet film during application, it is not intended to be part of the dry film once the coating dries or cures. The reason we refer to this component as a “solvent system” is that it is very uncommon for a coating to be formulated with only one type of solvent. Typically, a blend of solvents is used, and each type of solvent in the blend may perform a different function. The flow chart we looked at earlier divided solvents into two basic categories: primary and secondary. As a general rule, primary solvents are formulated into the coating to reduce the viscosity of the resin, pigment and additives, so that the coating can be properly atomized through a spray gun, or applied by brush and roller. Secondary solvents typically stay in the wet coating film a little longer than the primary solvents (they are slower evaporating solvents) and help the coating to flow-out and knit together to form a uniform, continuous film. Solvents used to formulate a coating should not be confused with thinner that may be added to the coating by the applicator.

Many solvents systems in a coating (and thinners added to a coating by the applicator) are categorized as “volatile organic compounds” (VOC’s). Therefore, the type and amount of solvent(s) used in an industrial coating may be regulated, because as these solvents evaporate from the coating film into the air, they photochemically react with sunlight and become a precursor to ozone (a component of smog).

Coatings are tested for VOC content according to ASTM D3960. Water content is determined according to ASTM D4017 (Karl Fischer Titration) and exempt solvents are detected according to ASTM D6133. Exempt solvents and water are not considered detrimental VOC’s, so their concentrations are deducted from the VOC content of a coating formulation.

The VOC content of a coating is expressed in pounds per gallon or grams per liter, and is reported on the manufacturer’s product data sheet (PDS). Many manufacturers also recalculate the VOC content of a coating after the addition of thinner. This information is also commonly referenced on the PDS. As we learned in Module 4, to convert from pounds/gallon to grams/liter, multiply pounds per gallon by 119.8. To convert from grams/liter to pounds/gallon, divide grams/liter by 119.8.

When painting a structure in the field, the VOC limit is typically dictated by the specification or the local air pollution agency for that project. Conversely, fixed facilities like painting shops are sometimes required to log the number of gallons of paint used over a specific period (say 90 days) and the VOC content of each type. In this manner, the total VOC emission can be calculated (e.g., 500 gallons of coating “X” with a VOC content of 2.8 pounds/gallon = 1400 pounds of solvent emission in 90 days). The local environmental agency regulates the maximum quantity of VOC’s produced by the fixed facility.

Coating manufacturers can formulate coatings to comply with governing VOC regulations by using non-regulated solvents (like water and acetone), or by increasing the non-volatile content of the coating. Note, however, that the addition of thinner in the field contributes to the VOC content of a coating. A coating that was formulated and selected based on the VOC content “as manufactured” may not be compliant once thinner added. In some cases, field thinning is prohibited. If thinning is permitted, the amount of thinner added must be carefully monitored, in order to avoid exceeding the allowable VOC content threshold.

Curing Mechanisms

The method in which a coating converts from a liquid to a solid state is known as the curing mechanism. Many liquid-applied coatings “dry” by solvent evaporation, but cure by employing a separate chemical reaction. In this introductory course five basic curing mechanisms are discussed: solvent evaporation, coalescence, oxidation, polymerization and moisture cure. Special curing mechanisms (heat and UV) are briefly described.

Solvent Evaporation

Coatings that “cure” by solvent evaporation really only dry. That is, the resin, pigment and additives are suspended in a solvent system. When the solvent evaporates from the applied film into the air, the resin, pigment and additives remain on the surface. Because there is no subsequent curing reaction (i.e., no chemical change), the resin can be redissolved by the solvent system that evaporated from the coating

film. That is why a coating that cures by solvent evaporation should not be overcoated with a coating containing strong solvents, since they will dissolve the underling coating film. A vinyl lacquer is an example of a coating that cures by solvent evaporation.

Coalescence

Waterborne acrylic coatings cure by solvent evaporation and form a coating film by a process known as coalescence. Water (the primary solvent in these coatings) first evaporates from the coating film. As the water evaporates, a special coalescing solvent (e.g., propylene glycol) aids in fusing the acrylic molecules together to form a solid film. The coalescing solvent then evaporates from the coating film. Without this coalescing solvent, the acrylic particles will not impinge and fuse together, and can result in a poor performing coating film. Note that the coalescing process typically requires a minimum 50°F air temperature. Should the air temperature fall below 50°F before the coalescing process is complete, curing may stop and may not start again once the temperature recovers. This is a major concern with industrial waterborne acrylic coatings, and should be carefully considered by the specifier.

Oxidation

Drying oils in coatings that cure by oxidation actually react with oxygen (air) to form a film. This oxidation process never stops, as long as the coating is exposed to oxygen. For example, alkyd coatings (which typically contain unsaturated oils, pigments and driers) cure by oxidation. Many aged alkyd systems (those that have been in service for many years) become very brittle, as the resin continues to oxidize long after the coating is fully cured. Coatings that cure by oxidation are also sensitive to excess film build and may wrinkle or crack.

Polymerization

Polymers and co-polymers are formulated into resin components and the components are packaged by the coating manufacturer separately. It is only when these components are blended together (in the correct proportions) that a chemical reaction occurs, generating a very resilient, coating layer. The chemical reaction that occurs is known as polymerization. Coatings that cure by polymerization

are multi-component (typically two or three containers). Prior to application, these components are blended together in the correct ratio (or complete kits are blended). Once blended, the chemical reaction begins. Coatings that cure by polymerization have a pot life. The blended components must be used before that pot life expires. The pot life will vary from a few minutes to several hours, depending on the formulation and temperature of the coating. Many coatings cure by polymerization; epoxy coatings and aliphatic acrylic or polyester polyurethane coatings are a few of the more common.

Moisture Cure

The reaction of a coating with moisture (in order to cure) is known as hydrolysis. Only a few industrial coatings “hydrolize” in the curing process. These include moisture-cure urethanes and ethyl silicate-type inorganic zinc-rich primers. These coatings require a minimum amount of moisture to cure. In this process, moisture-cure urethanes release carbon dioxide (CO₂), and inorganic zinc-rich primers release ethyl alcohol. The result is a very resilient coating layer, similar to that achieved by polymerization.

Heat and UV Cure

Some coatings require exposure to heat or ultraviolet light to attain a complete cure after application. The heat or UV light reacts with the resin causing a chemical reaction and subsequent cure of the coating film.

Identifying the Service Environment

One of the most difficult tasks for a coating specifier is properly identifying the prevailing service environment (for existing structures/facilities) or the projected service environment (for new structures or facilities). Stated more simply, once the coating system is installed, what will it be subjected to? For a new structure (and even for an existing structure) this can be a little like gazing into a crystal ball to see the future. Service environments can be both predictable and unpredictable (a 1000°F spike on an exhaust stack designed to operate at 500°F). When attempting to identify or predict the service environment, there are several conditions to consider, including these ten (10) examples.

1. Interior verses exterior.
2. Atmospheric verses immersion, verses gaseous. If immersion, constant or intermittent (i.e., splash), or condensation. If gaseous, the type and pressure.
3. If immersion, the medium (potable water, waste water, salt water, solvent, acids, caustics, fuels, etc.) and the pH.
4. Vapor phase of a partial immersion environment
5. Temperature (normal operating and upset conditions).
6. Likelihood and type of physical damage (i.e., impact damage from river debris on a set of dam gates).
7. Surrounding operations (i.e., adjacent chemical plant).
8. Prevailing environment (coastal airborne sea salt water mist).
9. Biological life.
10. The type and concentration of product that will be stored/transported in tank cars or vessels.

The specifier should consider these and other potential environments before selecting a coating system. The coating manufacturer will almost certainly request this type of information before recommending a coating system. Note also that there may be multiple service environments for a given structure, as is commonly the case with chemical plants. Interviewing facility owners and plant maintenance personnel may provide added insight into the actual service environment that may not be obvious.

Characteristics by Coating/Lining Type

A chart listing twenty-one (21) common coating/lining types and their inherent properties and characteristics is shown on the next page. An explanation of the chart design and an example of how the chart can be used to select a coating material (based on the desired performance characteristics) follows.

The left column of the chart contains twenty-one (21) industrial coating types. Note that within a coating type category, there can be subcategories that are not shown. For example, the category of organic zinc-rich primer includes an epoxy-zinc, urethane-zinc, vinyl-zinc, etc. This list is not exhaustive, but rather contains some of the more common coating and lining types. The top row on the chart contains seventeen (17) common characteristics. Like the coating type column, it too is not exhaustive.

Using the Chart

Once the service environment (described earlier) is identified and the intended use of the coating is determined, the specifier can review which generic categories of coatings are available. For example, if the specifier is considering overcoating, there are six coatings that can be considered for his application (alkyd, acrylic, calcium sulfonate alkyd, epoxy mastic, moisture cure urethane and coal tar). However, if the overcoat material must also demonstrate abrasion resistance, then only two candidates remain (epoxy mastic and moisture cure urethane), as the other three do not possess abrasion resistant properties. If single pack is desirable, then the specifier can select a moisture cure urethane from these two, as the epoxy mastic is multi-component.

Coating and Lining Characteristics Chart

Coating Type	Color & Gloss Retention	Surface Tolerant	Flexible	Easy to Apply	Low Cost	Can be Modified	Acid Resistant	Caustic Resistant	Abrasion Resistant	Solvent Resistant	Fast Dry	Single Pack	Low VOC Available	Overcoat Material	Chemical Resistance	Immersion	Typical Max. Service Temp.*
Alkyd		•	I	•	•	•				A	F	•	•	•			250° F
Silicone Alkyd	•	•	I	•							F	•	•				250° F
CSA	•	•	•	•								•	•	•			250° F
Epoxy						•	•	•	•	•			•		•	•	250° F
Epoxy Mastic		•				•	•	•	•	•			•	•	•	•	250° F
Coal Tar Epoxy							•	•	•	•			•		•	•	250° F
Vinyl	•		•		•	•	•	•	•		•	•			•	•	250° F
Urethane (aliphatic)	•		I			•	•	•	•	•			•		•		250° F
MCU	•	•	I	•			•	•	•	•		•	•	•	•		250° F
Inorganic Zinc-Rich									•	•	•		•			•	750° F
Organic Zinc-Rich									•	•		mcuz	•			•	Binder Dependent
Waterborne Acrylic	•		I	•	•	•						•	•	•			250° F
Polyurea (aliphatic)	•		I				•	•	•	•	•		•		•	•	350° F
Polysiloxane	•		I				•	•	•	•			•		•	•	200-1400°F
Polyester	•		I				•	•	•	•			•		•	•	220° F
Vinyl Ester						•	•	•	•	•			•		•	•	350° F
Baked Phenolic						•	•	•	•	•		•			•	•	250° F
Epoxy-Modified Phenolic							•	•	•	•		•			•	•	250° F
Coal Tar		•	I	•	•		•	•				•		•	•	•	150° F
Anti-foulings			I	•		•						•				•	NA
TSC			•						•	•	•	•	•		WD	•	Wire Dependent

*Consult PDS

MCU: Moisture Cure Urethane

CSA: Calcium Sulfonate Alkyd

TSC: Thermal Spray Coating

mcuz: Moisture Cured Urethane Zinc

WD: Wire Dependent

I: Initially

F: Formulas Available

A: Aged

Key Inspection Concerns by Coating/Lining Type

A chart, similar to the one just discussed lists twenty-one (21) common coating/lining types and their corresponding key inspection concerns. An explanation of the chart design and an example of how the chart can be used by quality control/assurance personnel follows.

The left column of the chart contains the same twenty-one (21) industrial coating types described earlier. Some of the sub-categories of coatings are shown as well. The top row on the chart contains 18 key inspection concerns. Based on the types of coatings specified for a given project, quality control/assurance personnel can quickly reference the chart and become aware of the key inspection points to consider after final surface preparation and during mixing and application of the coating(s).

Using the Chart

The project involves the application of an epoxy mastic primer and an acrylic polyurethane topcoat. Based on these two generic product categories, there are eight (8) key inspection points for the epoxy mastic and for the polyurethane, as shown in the table below:

Key Inspection Point	Epoxy Mastic Primer	Acrylic Polyurethane Topcoat
Thickness	•	•
Recoat Interval	•	•
Intercoat Cleanliness	•	•
Ambient Conditions	•	•
Mixing	•	•
Potlife	•	•
Amine Blush	•	
Curing Conditions	•	•
Outgassing		•

Key Inspection Concerns Chart

Coating Type	Thickness	Recoat Interval	Intercoat Cleanliness	Soft Film	Ambient Conditions	Mixing Multiple Components	Pot Life	Amine Blush	Surface Cleanliness	Surface Profile	Package Stability	Out Gassing (from curing or porosity)	Pot Agitation	Dry Spray	WFT Difficult	Curing Conditions
Alkyd	•		•		•				•	•						•
Silicone Alkyd	•		•		•				•	•						•
CSA	•		•	•	•				•	•						•
Epoxy	•	•	•		•	•	•	•	•	•						•
Epoxy Mastic	•	•	•		•	•	•	•	•	•						•
Coal Tar Epoxy	•	•	•		•	•	•	•	•	•						•
Vinyl	•		•		•				•	•				•		•
Urethane (aliphatic)	•	•	•		•	•	•		•	•		•				•
MCU	•	•	•		•				•	•	•	•				•
Inorganic Zinc-Rich	•		•		•	•	•		•	•		•	•	•	•	•
Organic Zinc-Rich	•	•	•		•	•	•		•	•			• (not mcuz)		•	•
Waterborne Acrylic	•		•		•				•	•						•
Polyurea (aliphatic)	•	•	•		•	•	•		•	•						•
Polysiloxane	•	•	•		•	•	•		•	•						•
Polyester	•	•	•		•	•	•		•	•						•
Vinyl Ester	•	•	•		•	•	•		•	•						•
Baked Phenolic	•	•	•		•				•	•						•
Epoxy-Modified Phenolic	•	•	•		•	•	•		•	•						•
Coal Tar	•		•		•				•	•						•
Anti-foulings	•		•		•	•	•		•	•						•
TSC	•	•	•						•	•					•	

MCU: Moisture Cure Urethane

CSA: Calcium Sulfonate Alkyd

TSC: Thermal Spray Coating. Special inspections described in SSPC CS 23.00.

mcuz: Moisture Cured Urethane Zinc

Coating Systems Defined

The coatings listed in the Coating and Lining Characteristics Chart described earlier can, in some cases be combined to create a coating system. A coating system is defined as the surface preparation and the application of one or more coats. If multiple coats of the same product are specified, contrasting colors are sometimes employed to assist the applicator in assuring coverage.

The level of surface preparation to be performed is an integral component to the coating system. For example, there is little point in applying a zinc-rich primer to a marginally-prepared surface, since the zinc must maintain intimate contact with clean steel to provide galvanic protection. Conversely, applying a surface tolerant coating to a surface prepared to SSPC-SP5/NACE 1, “White Metal Blast” is also of little use. While the coating will perform well, equivalent performance could be achieved over a much lesser degree of cleaning (at a much lower cost).

A coating system oftentimes consists of a primer and topcoat. In many instances, an intermediate coat may be specified. However, there are single coat systems, and four and five coat systems that are employed to protect industrial structures. When multiple coatings are used to create a system, they must be compatible with one another. Also, each coating layer has a function that is performed at a given thickness. Accordingly, one cannot make up for an inadequate zinc primer thickness by adding an extra few mils of an epoxy intermediate coat. Each layer should be applied at the optimum thickness (not too thick or too thin), and verified for proper thickness prior to the application of subsequent layers.

Primer Function

The function of the primer is to bond the coating system to the substrate. The primer also provides corrosion protection of the steel substrate using barrier, inhibitive, or galvanic protection, or a combination of them. The primer must also be tolerant of the level of surface preparation performed and must be compatible with the next layer applied, when applicable. If the primer is the only layer (as with a single coat system), it must be resistant to the service environment.

Intermediate Coat Function

An intermediate coat is typically incorporated into a coating system for the purpose of adding barrier protection. The intermediate coat must be compatible with both the primer and the topcoat.

Topcoat Function

The topcoat or finish coat is the first line of defense in a corrosion protection system. It must also be aesthetically pleasing, and should be able to maintain color and gloss levels for long periods of time. Naturally, the topcoat must be resistant to the service environment, and must be compatible with the underlying layer (primer or intermediate coat, as appropriate).

Coating System Selection

There are a wide variety of coating systems that a specifier can select from. Several of these systems are recognized by the coatings industry as having a track record of successful performance in a given service environment. These systems are “assembled” (according to product) by the coating manufacturer. Note that in many cases, a given system can be used in a multitude of industries and service environments. For example, a zinc-rich primer/epoxy intermediate coat/acrylic polyurethane topcoat can be used to protect bridge steel, the exterior of a storage tank, and structural steel in chemical and power generating plants.

A coating system is selected based on the prevailing service environment, the intended life of the structure, the level or degree of surface preparation possible, the intended service life of the coating, access, and any economical restraints. Once selected, several coating manufacturers of the coating system can be solicited to submit bids, based on the estimated quantities required for the project (described earlier in this module).

A series of eight (8) charts listing common generic coating systems used by thirteen (13) industries follows. When applicable, each chart includes common service environments within a given facility/structure and candidate coating systems for each. It should be noted that these charts represent a cross-section of industries and

coating systems, and are not meant to be exhaustive. The *Journal of Protective Coatings and Linings (JPCL)* publishes an annual coating systems buying guide that lists many coating systems and suppliers for a variety of service environments. The guide is a more comprehensive source for this information. Charts were developed for the purpose of this training course for the following industries:

- Chart CS-1: Coating Systems for Highway Bridges
(new construction and maintenance)
- Chart CS-2: Coating Systems for Water Storage (interior/exterior)
and Tank Lining
- Chart CS-3: Coating Systems for Waste Water Treatment Facilities
- Chart CS-4: Coating Systems for Power Generating Facilities
(coal-fired plants)
- Chart CS-5: Coating Systems for Power Generating Facilities
(nuclear power)
- Chart CS-6: Coating Systems used in Pulp & Paper Facilities, Lock
& Dam Structures, Chemical Plants and Buried Pipeline
- Chart CS-7: Coating Systems for Marine and Offshore
- Chart CS-8: Coating Systems used in Food and Beverage
Manufacturing Facilities

Using the Charts

Following are two examples of how the charts can be used to help select candidate systems. Note that system selection is dependent on proper identification of the service environment, and may be influenced by the degree of surface preparation possible, the intended service life of the coating, access, and other conditions or economical restraints.

Example 1:

Replace interior lining and exterior coating system on existing ground potable water storage tank in southern Nevada

Reference Chart:	CS-2
Reference Columns:	Water Storage (interior) and Water Storage (exterior)
Possible Lining Systems:	1. Polyamide Epoxy (2- or 3-coat) 2. Organic (epoxy) Zinc-Rich Primer and Two Coats Polyamide Epoxy
Possible Coating Systems:	1. Organic (epoxy) Zinc-Rich Primer/Polyamide Epoxy/ Polysiloxane Topcoat 2. Organic (epoxy) Zinc-Rich Primer/Polyamide Epoxy/ Acrylic Polyurethane Topcoat 3. Alkyd Primer/Silicone Alkyd Topcoat 4. Organic (epoxy) Zinc-Rich Primer/Waterborne Acrylic Topcoat

Note: Moisture cure coatings were not considered candidates due to traditionally low humidity in southern Nevada.

Example 2:

Replace coating system on structural steel in pulp & paper plant.
Service environment pH is > 4.

Reference Chart:	CS-6
Reference Column:	Pulp & Paper; pH >4
Possible Lining Systems:	Epoxy Mastic Primer/Polyamide Epoxy/Acrylic Polyurethane Topcoat

CS-1: Coating Systems Used in the Bridge/Highway Industry

Coating System	Highway Bridges (New)	Highway Bridges (Maintenance-1)	Highway Bridges (Maintenance-2)
Inorganic Zinc-Rich Primer/Polyamide Epoxy/Acrylic Polyurethane	✓		
Organic Zinc-Rich Primer/Polyamide Epoxy/ Acrylic Polyurethane	✓	✓	
Organic Zinc-Rich Primer/ Polyamide Epoxy/Polysiloxane	✓		
Organic Zinc-Rich Primer/ Polyamide Epoxy/Fluoropolymer	✓	✓	
Organic Zinc-Rich Primer/ Polyurea	✓	✓	
Moisture Cure Urethane Zinc-Rich Primer/Moisture Cure Urethane/ Moisture Cure Urethane	✓	✓	
Moisture Cure Urethane Zinc-Rich Primer/Moisture Cure Urethane/ Acrylic Polyurethane	✓	✓	
Inorganic Zinc-Rich Primer/ Waterborne Acrylic	✓		
Organic Zinc-Rich Primer/ Waterborne Acrylic		✓	
Thermal Spray Coating/Sealer	✓	✓	
Epoxy Sealer/Epoxy Mastic/Acrylic Polyurethane			✓
Epoxy Mastic /Acrylic Polyurethane			✓
Epoxy Mastic/Waterborne Acrylic			✓
Moisture Cure Urethane Sealer/ Moisture Cure Urethane/ Moisture Cure Urethane			✓
Moisture Cure Urethane/Moisture Cure Urethane/Acrylic Polyurethane			✓
Alkyd/Silicone Alkyd			✓
Calcium Sulfonate Alkyd (2 coats)			✓

Maintenance 1: Total removal and replacement of existing system

Maintenance 2: Spot repair and overcoat

CS-2: Coating Systems Used in the Water Storage Industry Tank/Vessel Linings

Coating System	Water Storage (interior) ¹	Water Storage (exterior)	Tank/Vessel Linings ²
Organic Zinc-Rich Primer/Polymide Epoxy/Polysiloxane		✓	
Moisture Cure Urethane Zinc-Rich Primer/Moisture Cure Urethane/ Moisture Cure Urethane		✓	
Organic Zinc-Rich Primer/ Waterborne Acrylic		✓	
Thermal Spray Coating			✓
Moisture Cure Urethane/Moisture Cure Urethane.Acrylic Polyurethane		✓	
Alkyd/Silicone Alkyd		✓	
Polyamide Epoxy (2-3 cts)	✓		
Organic Zinc-Rich Primer/ Polyamide Epoxy/Polyamide Epoxy	✓		
Baked Phenolic			✓
Baked Phenolic/Polyamide Epoxy			✓
Polyester			✓
Vinyl Ester			✓
Inorganic Zinc-Rich Primer			✓

¹NSF 61 approval required for potable water storage

²Railcar, food processing, chemical, etc.

CS-3: Coating Systems Used in the Waste Water Treatment Industry

Coating System	Submerged	Severe Damp Atmospheric	Mild Exterior	Mild Interior	Elevated Temperature
Epoxy Mastic/Acrylic Polyurethane			✓		
Alkyd (3 cts.)				✓	
Alkyd/Silicone Alkyd			✓		
Polyamide Epoxy (2-3 cts.)	✓			✓	
Organic Zinc-Rich Primer/ Polyamide Epoxy/Polyamide Epoxy		✓			
Coal Tar Epoxy	✓				
Waterborne Acrylic (3 coats)			✓	✓	
Moisture Cure Urethane (3 coats)			✓		
Inorganic Zinc-Rich Primer/Silicone					✓

CS-4: Coating Systems Used in Power Generation (Coal)

<i>Coating System</i>	<i>Coal Handling</i>	<i>Structural Steel</i>	<i>Hydraulic Structures</i>	<i>High Temperature Surfaces</i>	<i>Mechanical Equipment</i>	<i>Flue Gas Desulfurization (exterior)</i>	<i>Flue Gas Desulfurization (interior)</i>	<i>Water Treatment (exterior)</i>	<i>Water Storage (interior)</i>
Inorganic Zinc-Rich Primer/ Polyamide Epoxy/Acrylic Polyurethane		✓						✓	
Inorganic Zinc-Rich Primer/ Polyamide Epoxy					✓		✓		
Organic Zinc-Rich Primer/ Polyamide Epoxy/Acrylic Polyurethane		✓							
Inorganic Zinc-Rich Primer/ Waterborne Acrylic		✓							
Organic Zinc-Rich Primer/ Waterborne Acrylic		✓							
Alkyd (3 cts.)					✓				
Alkyd/Silicone Alkyd		✓							
Polyamide Epoxy (2-3 cts.)	✓	✓				✓			✓
Organic Zinc-Rich Primer/ Polyamide Epoxy/Polyamide Epoxy	✓	✓							✓
Polyester			✓						
Vinyl Ester						✓			
Inorganic Zinc-Rich Primer				✓					
Coal Tar Epoxy			✓						
Inorganic Zinc-Rich Primer/ Silicone				✓					
Phenolic Epoxy			✓						
Silicone				✓					

CS-5: Coating Systems Used in Power Generation (Nuclear)

<i>Coating System</i>	<i>Suppression Chamber</i>	<i>Structural Steel (inside containment)</i>	<i>Concrete Wall/Floors</i>	<i>Structural Steel (outside containment)</i>	<i>Hydraulic Structures</i>	<i>Mechanical Equipment</i>	<i>Water Treatment (exterior)</i>	<i>Water Storage (interior)</i>
Inorganic Zinc-Rich Primer/ Polyamide Epoxy/Acrylic Polyurethane				✓			✓	
Inorganic Zinc-Rich Primer/ Polyamide Epoxy		✓					✓	
Organic Zinc-Rich Primer/ Polyamide Epoxy/Acrylic Polyurethane			✓					
Inorganic Zinc-Rich Primer/ Waterborne Acrylic				✓				
Organic Zinc-Rich Primer/ Waterborne Acrylic				✓				
Alkyd (3 cts.)						✓		
Alkyd/Silicone Alkyd				✓				
Polyamide Epoxy (2-3 cts.)	✓	✓		✓				✓
Organic Zinc-Rich Primer/ Polyamide Epoxy/Polyamide Epoxy				✓				✓
Polyester					✓			
Inorganic Zinc-Rich Primer	✓	✓						
Coal Tar Epoxy					✓			
Phenolic Epoxy	✓	✓			✓			
Thermal Spray Coating/Polyamide Epoxy	✓							
Thermal Spray Coating/Phenolic Epoxy	✓							
Epoxy Sufacer/Polyamide Epoxy			✓					

CS-6: Coating Systems Used in Pulp and Paper, Petrochemical, Lock and Dam, Buried Pipeline, and Chemical Plants

Coating System	Pulp & Paper (pH<5)	Pulp & Paper (pH>4)	Lock & Dam Structures	Buried Pipeline	Chemical Plants (see Note)
Epoxy Mastic/Amine Adduct Epoxy/Polyester Polyurethane	✓				
Epoxy Mastic/Polyamide Epoxy/Acrylic Polyurethane		✓			
Moisture Cure Urethane Zinc-Rich Primer/ Moisture Cure Urethane/Moisture Cure Urethane			✓		
Thermal Spray Coating/Sealer			✓		
Polyamide Epoxy (2-3 cts.)			✓		
Coal Tar Epoxy			✓		
Polyamide Epoxy/Acrylic Polyurethane			✓		
Organic Zinc-Rich Primer/Vinyl			✓		
Coal Tar				✓	
Fusion Bonded Epoxy				✓	
Polyethylene				✓	
Polypropylene				✓	
Tapes				✓	
Heat Sleeves				✓	

Note: Service environments are highly variable (e.g., mineral acids, organic acids, caustics, high temperature, corrosive salts, solvents, gases, weather extremes). No panacea coating system. Common generic coating types include zinc-rich primers, epoxies, polyurethanes and aluminum filled silicones (for high temperature resistance).

CS-7: Marine and Offshore (Oil Platforms)

Coating System	Ballast Tanks	Interior Accommodations	Engine Room Decks	Engine Room Bulkheads	Engine Room High Temperatures	Engine Room Steel Piping	Topside	Hull
Inorganic Zinc-Rich Primer/Polyamide Epoxy/Acrylic Polyurethane							√	
Alkyd (3 cts.)		√		√			√	
Polyamide Epoxy (2-3 cts.)	√		√	√		√	√	
Inorganic Zinc-Rich Primer						√		
Coal Tar Epoxy	√							
Waterborne Acrylic (3 cts.)		√						
Inorganic Zinc-Rich Primer/Silicone					√			
Phenolic Epoxy						√		
Epoxy Mastic	√	√	√	√			√	
Antifouling								√

CS-8: Food Manufacturing Facilities

Coating System	Ceilings, Structural Steel, and Handrails	Equipment	Equipment Motors	Steel Tank Linings	Exposed Exterior Metal Surfaces	Freezer Areas	Refrigerated Boxcars and Tank Car Exteriors	Coatings for Boilers and Various Piping	Highly Acidic Conditions
Solvent Epoxies	√	√							
Epoxy-Polyester			√						
High Solid Epoxies				√					
Phenolic Epoxies				√					
Novolac Epoxies				√					
Urethane					√		√		
Alkyd	√	√			√				
Polyurea						√	√		
Acrylic	√	√			√				
Zinc	√	√	√	√					
Silicone								√	
Vinyl Ester									√

Performance Evaluation of Protective Coating Systems

Independent verification of coating system performance based on laboratory testing and/or field exposure is a critical component to coating system selection. For a given coating system, there may be ten or more manufacturers. It is not safe to assume that all coating systems within a given generic category are created equal. Therefore, careful evaluation of coating system performance prior to full-scale field application can be employed to determine which of the candidate systems will perform the best. These performance evaluations can be facility-specific, industry specific or coating type specific. Each of these evaluation methods and their inherent advantages and limitations are described below.

Facility-Specific Performance Evaluations

Many facility owners (particularly chemical plants) cannot rely 100% on industry-generated performance data, since it may be too generalized and not address specific service environments or upset conditions unique to a given plant. And few, if any, rely on coating manufacturer-generated data because of perceived bias. Therefore, many facilities establish their own coating/lining system performance testing program, which often includes actual plant site exposure of candidate systems applied to test panels.

The advantage of this type of performance evaluation is that, if designed properly, it can closely approximate the actual service conditions of the facility. However, if the testing is not based on existing ASTM test procedures and custom testing facilities or equipment is required, the testing may be expensive and it may be difficult to locate laboratories that can generate the data.

Industry-Specific Performance Evaluations

An industry-specific coating performance evaluation program generates performance data based on testing that represents (as close as possible) the service environment of that industry. Once the data is generated, it can be uploaded into a central database so that all member agencies in that industry can access the information and establish their own qualified products list.

Coating System-Specific Performance Evaluations

The final method to evaluate the performance of a protective coating/lining system is employing an industry standard testing procedure designed specifically for a type of coating. An example of this type of performance evaluation is SSPC's Paint Specification No. 36, "Two-Component Weatherable Aliphatic Polyurethane Topcoat, Performance-Based." These types of specifications give the coating manufacturer wide latitude in the selection of raw materials used in the manufacturing process, and focus on the performance of the formulated product rather than dictate the ingredients. In fact, the only raw material requirement referenced in "SSPC Paint 36" is that the curing agent be an aliphatic polyisocyanate and that the minimum polyisocyanate content be 17% by weight. Instead, the specification gives requirements for package stability, application properties and weathering requirements (gloss and color retention properties). The focus is on the performance of the formulated product.

The advantage to this type of performance testing is that it establishes minimum performance requirements for a given type of coating that can be readily adopted by many industries. There are no significant limitations to this type of performance evaluation.

Employing Multiple Performance Evaluation Methods

Some facility owners and agencies may choose to employ a combination of the performance evaluation methods listed above. For example, a bridge owner may subscribe to the AASHTO NTPEP SSC *Datamine* (industry-specific performance evaluation) and may also suspend or mount racks of test panels containing candidate coating systems from a bridge structure (facility-specific performance evaluation) and rate them every 6 months for corrosion and/or aesthetics.

Summary

Despite how well a coating system is applied and cured, the substrate will be protected only for a short period of time if the coating cannot withstand the environment. Therefore, selection of a coating system must give primary consideration to both the type of substrate and the service environment. One of the most difficult tasks for a coating specifier is to properly identify the prevailing service environment (for existing structures) and the projected service environment (for new structures). Module Six has provided guidance on methods used to identify different service environments and examples of ten common environments.

Module Six begins by describing the differences between ordinary household paints and industrial/marine protective coatings. One notable difference is the increased cost of protective coatings, another is the reason behind the higher costs. The performance requirements of industrial/marine coatings are much higher than those of house paints, which are used primarily to improve aesthetics. Protective coatings, on the other hand, may have to withstand immersion in water, chemical exposure, impact and abrasion, as well as provide aesthetics.

There are many different ingredients or raw materials that are used to formulate an industrial/marine coating. This curriculum divides them into two categories: 1. volatiles and non-volatiles, and 2. pigment and vehicle. In the first category, volatiles are part of the wet film, but evaporate into the air once the coating is applied to the surface, while non-volatiles are part of the wet and dry film and remain on the surface once the coating is applied.

In the second category for coating components, pigment and vehicle, the vehicle “carries” the pigment to the surface and binds it into the coating film. The vehicle typically consists of the resin or binder, solvents, and any additives that may be included in the formulation. While part of the vehicle evaporates (the solvents) once the coating

is applied, other components, like the resin, remain behind as part of the dry film. The resin system cohesively bonds the pigmentation together and adhesively bonds the coating to the underlying substrate or coating layer. In fact, the resin is so significant that the type of resin in the formulation is often used to generically identify the coating. In many cases, the resin system dictates the performance properties of a coating.

Additives are also a part of the vehicle that remains on the surface. Additives are added to coating formulations to improve flow-out, surface wetting, and flexibility. Additives can also be used to adjust the consistency of a coating, to resist ultraviolet light, and to prevent settling in the can.

In the category of pigment and vehicle, the pigment gives the coating the ability to hide the underlying surface. Pigments also give coatings their color and gloss, but pigments may also provide corrosion protection. Pigments like iron oxide or barium can be formulated into a primer to inhibit the corrosion process. Pigments like zinc powder can be added to the primer in sufficient quantities to galvanically protect the underlying carbon steel. Still other pigments, like micaceous iron oxide and leafing aluminum pigments provide barrier protection. These pigments are plate-like, and the way they position themselves in the coating film forces any moisture that penetrates the coating film to take a longer path to reach the substrate.

Extenders are pigments like clay, silica, and mica, which can be incorporated into the formulation to improve film build. Extenders also increase the solids content of a coating and provide added barrier protection. Remember that all pigments, regardless of their individual functions in the coating, remain on the surface and become part of the dry film.

When coating components are divided into volatiles and non-volatiles, the solvent system is the volatile component. While it is part of the wet film during application, it is not intended to be part of the dry film once the coating dries or cures. Typically, a blend of solvents is used in the formulation of a coating and each type of solvent in the blend performs a different function. As a general rule, primary solvents reduce the viscosity of the resin, pigments and additives, so the coating can be properly atomized through a spray gun or applied by brush or roller. Primary solvents evaporate from the coating film first, while

secondary or coalescing solvents typically remain in the wet film a little longer to help the coating flow-out and knit together to form a uniform, continuous film.

Many solvent systems (and thinners) are categorized as “volatile organic compounds” or VOC’s. The amount of VOC’s that can be legally emitted into the atmosphere varies from location to location. Some densely populated areas have very strict regulations, while less populated areas typically are less restrictive. In the field, the VOC limit is usually dictated by the specification or the local air pollution agency for that project. Fixed facilities like paint shops, however, are sometimes required to log the number of gallons of paint used over a specific period, as well as the VOC content of each type. The local environmental agency regulates the maximum quantity of VOC’s produced by fixed facilities.

Coating manufacturers can formulate coatings to comply with VOC regulations by using non-regulated solvents, like water and acetone, or by increasing the non-volatile content of the coating. Since adding thinner in the field may increase VOC levels, the amount of thinner added must be carefully monitored.

The method in which a coating converts from a liquid to a solid state is known as the curing mechanism. In this module, five basic curing mechanisms were discussed: solvent evaporation, coalescence, oxidation, polymerization and moisture cure. Two others (heat and UV) were briefly described.

Solvent evaporation is perhaps the most commonly understood coating cure. In this process, the solvent in the coating evaporates into the air after application, while the resin, pigment, and additives remain on the surface to form the dry film. There is no second step or subsequent curing reaction, so the resin can be redissolved by the same solvent system that was used in the blended coating. Coatings that cure by solvent evaporation should not be overcoated with a coating that contains strong solvents.

Coalescence also involves evaporation of solvents from the coating film, but in this case there are primary solvents which evaporate first and coalescing solvents (secondary solvents) which remain in the film a little longer (to help fuse the molecules together to form a solid film). After the film has been formed, the secondary solvents also evaporate

from the film. This type of cure typically requires a minimum air temperature of 50°F.

Oxidation is a third method of coating cure. Components in the coating (drying oils) react with oxygen (from the surrounding air) to form a film. One problem with this method of cure is that the process of oxidation never really stops as long as the coating is exposed to oxygen. Alkyds, which cure by this method, can become very brittle after many years of service, since the resin continues to oxidize long after the coating is fully cured.

A fourth method of cure or polymerization is more complex than the first three. Different resin components are carefully measured by the manufacturer and packaged separately, so that when these components are properly blended a chemical reaction occurs, generating a new, resilient coating. The components must be blended in the correct ratios (complete kits) for the chemical reaction (or polymerization) to produce the correct blend. Coatings that cure by this method are multi-component, and once they are blended together, the pot life begins. The pot life may vary from a few minutes to several hours. A few of the more common coatings that cure by polymerization are epoxies, aliphatic acrylics, and polyester polyurethanes.

Moisture cure is the fifth method of coating cure discussed. The coating components react with moisture and require a minimum amount of moisture to cure. Moisture-cure urethanes cure this way and release carbon dioxide (CO₂) during the process, while inorganic zinc-rich primers also cure by moisture cure, but release ethyl alcohol during the process. The result is a very resilient coating layer, similar to that produced by polymerization.

Some coatings require post-application curing using an external source of heat or ultra-violet (UV) light.

Properly identifying the service environment is another challenge to the specifier. As the curriculum has pointed out, even when the substrate is prepared according to the specification and the coating is applied properly, the substrate will not be protected if the coating cannot stand up to the service environment. Therefore understanding what the coating system will be subjected to, once applied, is critical. The problem is that service environments aren't always predictable.

For example, when an exhaust stack that was designed to operate at 500°F, undergoes a 1000°F spike, will the coating system fail?

There are a number of questions to answer about a service environment before a coating system is selected. Will the coating be subjected to immersion service? If so, will the immersion be constant or intermittent (i.e., splash)? Will the immersion be in potable water, waste water, salt water, solvent, acids, etc.? What is the likelihood and type of physical damage that the coated substrate might sustain (i.e., the impact damage from river debris on a set of dam gates)?

Questions on service environments must be answered prior to selecting a coating system. And it should be noted that there may be multiple service environments for a given structure, for example the interior of a chemical plant.

Once all the background questions are asked and answered, specifiers can look at the history and performance records of coating systems that have been commonly used in specific industries and service environments.

Module Six includes a series of charts to guide participants through a multitude of questions on commonly specified coatings:

The Coating and Lining Characteristics Chart can answer:

1. Which coatings are easy to apply?
2. Which coatings are flexible?
3. Which coatings are lower in cost (by comparison to others)?
4. Which coatings have good chemical resistance?
5. Which coatings have good color and gloss?
6. Which coatings are surface tolerant?
7. Which coatings are not surface tolerant?
8. Which coatings can be used in immersion service?
9. Which coatings can be modified?
10. Which coatings are available in low VOC formulations?
11. Which coatings can withstand high temperatures?

The Key Inspection Concerns Chart can answer:

1. Which coatings are highly dependent on surface profile.
2. Which coatings may dry spray.
3. Which coatings are sensitive to variations in thickness.
4. Which coatings may out gas.
5. Which coatings require pot agitation.

6. Which coatings are sensitive to package stability.

The information provided in the referenced charts on individual coatings is very useful. However, coatings are typically specified in “systems,” which consists of the specified surface preparation and the application of one or more coats. Specifiers may recommend multiple layers of the same product, or specify one coating to be used as the primer, another to be used as the midcoat and still another to be used as the topcoat. If the coatings applied are different formulations, they must be compatible with each other.

In addition, each layer must be able to perform the function intended for that layer. For example, the function of the primer is to bond the coating system to the substrate. The primer may also be selected to provide corrosion protection to the substrate. The primer must be equally compatible with the level of surface preparation beneath it and the coating directly above it.

The intermediate coat is typically part of the coating system for the purpose of adding barrier protection. It must also be compatible with the primer and the topcoat.

The topcoat is the first line of defense against corrosion and must be resistant to the service environment. Typically, the topcoat must also be aesthetically pleasing (good color and gloss) and be compatible with the underlying coating layer.

Selecting a coating system is based on the prevailing service environment, the intended service life of the structure, the level of surface preparation possible, the intended service life of the coating, access to the structure to be coated, and economical restraints and considerations. Once a coating system is selected, coating manufacturers can be solicited to submit bids. Module Six provided charts on coating systems that are commonly used in eight different industrial categories:

- Chart CS-1: Coating Systems for Highway Bridges
- Chart CS-2: Coating Systems for Water Storage and Tank Linings
- Chart CS-3: Coating Systems for Waste Water Treatment Facilities
- Chart CS-4: Coating Systems for Power Generating Facilities
- Chart CS-5: Coating Systems for Power Generating Facilities

- Chart CS-6: Coating Systems Used in Pulp & Paper Facilities,
Petrochemical Plants, Lock and Dam Structures,
Chemical Plants and Buried Pipeline
- Chart CS-7: Coating Systems for Marine and Offshore Facilities
- Chart CS-8: Coating Systems Used in Food Manufacturing
Facilities

Another consideration for the specifier when selecting a coating system for an industry is past performance and testing. There are industry specific coating performance evaluations that generate data based on testing that represents the service environment. Once this data is generated, coating manufacturers can access the information and establish their own qualified products lists. The advantage of this type of performance evaluation is that many agencies within a given industry can access performance data with little or no associated costs.

An additional method to evaluate the performance of a protective coating or lining system is to employ an industry standard testing procedure designed specifically for a type of coating. The focus of this type of testing is on the performance of the formulated product, not the individual ingredients of the coating. Therefore, the specification/ testing includes functions like package stability, application properties, weathering properties, and color and gloss retention.

And a final method to evaluate a coating system prior to specifying that system is to employ a combination of the performance evaluations described above. A bridge owner, for example, may refer to industry specific coating performance evaluations, while they simultaneously conduct their own testing for a variety of coating systems on panels of the substrate at the actual site of a future project.

	Module Six
	Industrial and Marine Protective Coatings and Coating Systems

	Module Six Learning Outcomes
	Comprehension of Module Six will enable the participant to: ■ Identify basic differences between house paint and industrial/marine protective coatings ■ List volatile and non-volatile components of a coating ■ Describe the functions of the resin, additives, pigments and solvents in a coating ■ Describe the methods by which coatings cure

	Module Six Learning Outcomes (con't.)
	■ Describe the procedures used to identify service environments ■ List advantages and limitations of various generic types industrial/marine coatings ■ Describe functions of the primer, mid-coat and finish coat ■ Identify common coating systems used by various industries ■ Describe methods used to evaluate coating performance prior to full scale installation

	Introduction
	■ Proper surface preparation and installation of the coating system is critical, but ■ Proper <u>selection</u> of a coating system is equally important

	Importance of Coating System Selection
	■ Despite how well a surface is prepared and how well a coating system is applied, it will not protect the substrate if it cannot withstand the environment ■ Coating inspectors typically do not identify service environments or select coating systems ■ Inspector's knowledge of coatings, coating systems and curing mechanisms is important

	Module Content
	■ This module includes: ➢ Information of coating ingredients ➢ Primary methods of protection afforded by industrial/marine coatings ➢ Description of coating curing methods ➢ Description of VOC and the inspector's role ➢ Methods used to identify service environments ➢ Examples of common service environments

	Module Content (con't.)
	■ This module includes: ➢ Common coating types, their properties and characteristics ➢ Inspection concerns for each coating type ➢ Common generic coating systems used by ten industries

	Industrial/Marine Protective Coatings vs. Paint
	■ Cost ■ Ingredients ■ Performance characteristics

	Categorizing Coating Components
	■ Non-volatile ➢ Remain on the surface ■ Volatiles ➢ Evaporate from the coating

	Non-volatiles and Volatiles
	■ Non-volatiles include: ➢ Resin (binder) ➢ Pigment ➢ Additives ■ Volatiles ➢ Solvents (part of the wet film, but not part of the dry film)

	Pigment and Vehicle
	■ Pigment (solid component) ➢ Corrosion inhibitors ➢ Colorants ➢ Extenders ■ Vehicle (liquid component; carries the pigment to the surface - binds it into the coating film) ➢ Resin ➢ Solvents ➢ Additives

	Vehicle: The Resin
	■ The resin can be categorized as both "vehicle" and "non-volatile" ➢ The resin is part of the wet film and the dry film ➢ Oftentimes a coating is identified by the type of resin

	Vehicle: The Resin (con't.)
	■ The resin: ➢ Is the film forming component of a coating ➢ "cohesively" bonds the pigments together ➢ "adhesively" bonds the coating to the substrate or the underlying coating layer ➢ often dictates the performance properties of a coating

	Components of an Industrial/Marine Coating
	<i>See Page 6-3 in the Student Manual</i>

	Pigment
	■ Non-volatile ■ Insoluble raw material ➢ Does not dissolve in the resin and solvent ➢ Remains suspended in the vehicle

	Functions of the Pigment
	■ Provides hiding ■ Determines gloss level ➢ Flat sheen: more pigment ➢ Semi-gloss or gloss sheen: less pigment ➢ Shape & size (grind) affects gloss

	Functions of the Pigment
	■ When formulated into the primer the pigment may provide corrosion protection: ➢ Iron oxide & barium, phosphorous, others "inhibit" the corrosion process ➢ Zinc (in sufficient quantities) provides galvanic protection ➢ Micaceous iron oxide and leafing aluminum provide barrier protection

	Functions of the Pigment
	■ Extenders (silica, mica and clay) may be incorporated to: ➢ improve film build ➢ increase the solids content ➢ provide added barrier protection

Additives

- Additives are categorized as “vehicle” and are used to adjust or provide:
 - Consistency
 - Flow-out
 - Surface wetting
 - Color
 - Solar radiation (sunlight) resistance
 - Flexibility

Solvents

- Volatile (part of the wet film, but not the dry film)
- Solvent blends perform different functions

Solvents

- Primary solvents
 - Reduce the viscosity of the resin, pigment and additives to aid application
- Secondary solvents
 - Slower evaporating
 - Aid in flow-out to form a uniform, continuous film

Volatile Organic Compounds

- Many solvents and thinners are volatile organic compounds
- Solvents evaporate into the air, become a component of smog (a precursor to ozone)

VOC Content of a Coating

- Expressed in grams per liter (g/L) or pounds per gallon (lbs./gal.)
- Reported on the Product Data Sheet (PDS)
- Most manufacturers recalculate the VOC content after thinner addition

Effect of VOC Regulations on Painting Operations

- Field Painting:
 - VOC limit dictated by specification or the local air pollution agency
- Shop Painting:
 - Number of liters (gallons) of paint used (over a specific period) and VOC content logged
 - Total emission calculated (i.e., per quarter)

	Curing Mechanisms
	■ The method employed to convert a coating from a liquid to a solid state ➢ Solvent Evaporation ➢ Coalescence ➢ Oxidation ➢ Polymerization ➢ Moisture ➢ Heat and UV

	Solvent Evaporation
	■ Resin, pigment and additives are suspended in a solvent system ■ Solvents evaporate from the applied film ■ Cannot be overcoated with a coating containing strong solvents

	Coalescence
	■ The primary solvent (typically water) evaporates from the coating film ■ Coalescing solvents fuse the molecules together to form a solid film, then evaporate ■ Typically requires minimum 10°C (50°F) air temperature

	Oxidation
	■ Drying oils in coatings react with oxygen (air) ■ Oxidation process never stops ■ Coatings can become brittle, since oxidation process is continual ■ Oxidation-cured coatings sensitive to excess film builds

	Polymerization
	■ Separate components containing polymers & co-polymers blended together ■ A chemical reaction occurs ■ Form a resilient coating layer

	Moisture Cure
	■ The coating reacts with moisture (also called hydrolysis) ■ Require a minimum amount of moisture to cure ➢ Moisture-cure urethanes (release carbon dioxide) ➢ Inorganic zinc-rich primers (release ethyl alcohol)

Heat and UV Curable Coatings

- Exposure to high temperature or ultraviolet light after application
- Resin system reacts with heat or UV and chemical reaction occurs, causing coating to cure

Identifying the Service Environment

- Once the coating system is installed, what conditions will it be subjected to?
 - Predictable – e.g., deicing salt exposure on a bridge in Northeast US
 - Unpredictable – e.g., a 538°C (1000°F) spike in an exhaust stack designed to operate at 260°C (500°F)

Predicting the Service Environment

Consider the following conditions:

1. Interior verses exterior
2. Atmospheric verses immersion, verses gaseous
 - If immersion, constant or intermittent (i.e., splash), or condensation
 - If gaseous, the type and pressure

Predicting the Service Environment (con't.)

3. If immersion, the medium (potable water, waste water, salt water, solvent, acids, caustics, fuels, etc.) and the pH
4. Vapor phase of a partial immersion environment
5. Temperature (normal operating and upset conditions)

Predicting the Service Environment (cont'd.)

6. Likelihood and type of physical damage (i.e., impact damage from river debris on dam gates)
7. Surrounding operations (i.e., adjacent chemical plant)
8. Prevailing environment (coastal, airborne, sea salt, water mist)

Predicting the Service Environment (cont'd.)

9. Biological life
10. The type and concentration of product that will be stored/transported in tank cars or vessels
11. Consider multiple service environments

Coating manufacturer needs service environment information before recommending a coating system

	Coating System Selection and Key Inspection Concerns
	■ Properties and characteristics of 21 coating/lining types (<i>see Coating and Lining Characteristics Chart on page 6-13</i>) ■ Key inspection concerns for 21 coating/lining types (<i>see Key Inspection Concerns Chart on page 6-15</i>)

	Coating Systems Defined
	■ Coating System: ➢ Degree of surface preparation and the application of one or more coats ■ Functions of Primer ➢ Bond layers to the substrate ➢ Provide barrier, inhibitive and/or galvanic protection to the substrate ➢ Compatible with surface conditions and next coat (intermediate or finish coat) ➢ Compatible with service environment (if untopcoated)

	Coating Systems Defined
	■ Functions of Intermediate Coat ➢ Adds barrier protection ➢ Compatible with primer and topcoat layers ■ Functions of Topcoat ➢ First line of defense ➢ Aesthetics ➢ Resistant to service environment ➢ Compatible with underlying layer

	Coating System Selection
	■ Several coating "systems" are recognized by the coatings industry as having a track record of successful performance in a given service environment ■ Coating "systems" are typically assembled by coating manufacturers

	Multiple Industry Use
	■ Coating systems may be used across industries and service environments (<i>e.g., zinc-rich primer/epoxy intermediate coat/acrylic polyurethane topcoat for</i>): ➢ Bridge steel ➢ Storage tank exteriors ➢ Structural steel in chemical, petrochemical and power generating plants

	Coating System Selection
	■ System selection based on: ➢ The prevailing service environment ➢ The intended life of the structure ➢ The level or degree of surface preparation possible ➢ The intended service life of the coating ➢ Access ➢ Economic restraints

Common Coating Systems for Various Industries

CS-1: Highway Bridges
 CS-2: Water Storage Tank Lining
 CS-3: Waste Water Treatment Facilities
 CS-4: Power Generating Facilities (coal)
 CS-5: Power Generating Facilities (nuclear)
 CS-6: Pulp and Paper, Lock and Dam, etc.
 CS-7: Marine and Offshore
 CS-8: Food and Beverage Manufacturing
 See CS charts on pages 6-20 through 6-27

Using the Coating System Selection Charts

- Example 1:
 - Replace interior lining and exterior coating system on existing ground potable water storage tank in southern Nevada
 - Reference Chart CS-2 on page 6-21
 - Interior: Two options
 - Exterior: Four options (*no MCU systems, since lack of moisture may retard cure*)

Using the Coating System Selection Charts

- Example 2:
 - Replace coating system on structural steel in pulp and paper plant. Service environment pH is >4
 - Reference Chart CS-6 on page 6-25
 - One coating system listed (*epoxy mastic/epoxy/polyurethane*)

Performance Evaluation of Protective Coatings

- All coating systems within the same generic category are not created equal
- There are methods to evaluate coating system performance prior to full-scale application
 - Facility owners/agencies may choose to employ a combination of performance evaluation methods

Facility - Specific Performance Evaluations

- Apply candidate systems to test panels and expose them to actual site conditions
 - Advantage: testing can closely approximate the actual service conditions of the facility
 - Limitation: Can take many months or years to generate performance data

Industry Specific Performance Evaluations

- Performance data based on testing that represents (as close as possible) the service environment common to the industry
 - Data can be uploaded into a controlled database
 - Agencies can access the information and establish their own qualified products list

	System Specific Performance Evaluations
	■ Employ a standard testing procedure designed specifically for a type of coating ➢ Example: SSPC Paint Specification No. 36 (two-component acrylic polyurethanes)

	Summary
	■ Coating system selection is critical for performance ■ Identifying the prevailing service environment can be challenging ■ A coating contains volatile and non-volatile components ■ Non-volatile components include resin, pigment and additives (part of wet and dry film) ■ Volatile component is solvents (part of wet film only) ■ Resin, pigment, additives and solvent all have key functions in a coating

	Summary (con't.)
	■ VOC's in coatings include solvent and any thinners/reducers ■ Reduced VOC formulations employ non-regulated solvents or are higher in solids content ■ Coatings cure by any of five basic mechanisms (solvent evaporation, coalescence, oxidation, polymerization, moisture) ■ Coatings may also "post-cure" using heat or UV light ■ Coating system selection based on service environment and desired performance characteristics

	Summary (con't.)
	■ There are key inspection concerns associated with all coating types ■ A coating system is comprised of the surface preparation and the application of one or more coats ■ Each applied coating layer has a function ■ Coating system selection is based on: ➢ The service environment ➢ The degree of surface preparation possible ➢ The intended service life of the coating system & structure ➢ Access ➢ Economic restraints/considerations