NACE®
INTERNATIONAL

THE CORROSION SOCIETY

PCS 1
Basic Principles

Version 1.01.01

IMPORTANT NOTICE

Acknowledgments

The time and expertise of a number of NACE International members have gone into the revision of this course, PCS 1 Basic Principles. Their dedication and efforts are greatly appreciated by NACE, the author, and those who have assisted in making this course possible.

The scope, desired learning outcomes and performance criteria were developed by the Protective Coatings and Linings Task Group under the auspices of the NACE Education Administrative Committee in cooperation with the NACE Certification Administrative Committee.

NACE would like to particularly thank the task group for its work. Their efforts were extraordinary and their goal was in the best tradition of public service — to help improve corrosion control efforts industry-wide. This outstanding task group has *also* revised the NACE PCS 2 Advanced course *and* developed a valuable addition to the NACE Protective Coatings and Linings program, the new NACE PCS 3 Management course.

We also wish to thank their employers for being generously supportive of the substantial work and personal time that the members dedicated to this program.

This group of NACE members also worked closely with the contracted course developer from Elzly Technology Corporation, J. Peter Ault.

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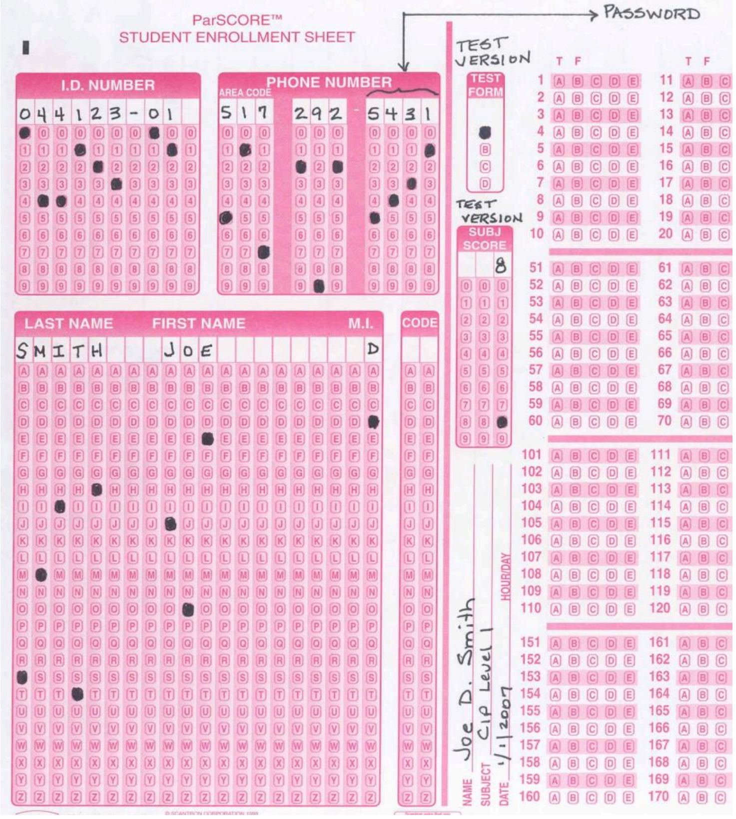

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I.D. NUMBER
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AREA CODE
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PASSWORD

TEST VERSION
TEST FORM

TEST VERSION
SUBJ SCORE
8

LAST NAME
SMITH

FIRST NAME
JOE

M.I.
D

CODE

NAME
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SUBJECT
CIP Level 1

DATE
1/1/2007

INSTRUCTIONS FOR ACCESSING SCORES ON-LINE

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Welcome to

PCS 1 Basic Principles

Introduction

PCS 1 Basic Principles will introduce you to the theoretical and practical aspects of the use of coatings to control corrosion as well as the economic benefits. This course defines and examines common corrosion control coatings and addresses when, how, and where they should be used. The course was designed to be applicable for specifiers, maintenance and project engineers in all industries, marketing representatives of coating materials or equipment, and unit managers involved in corrosion.

Course Design

PCS 1 Basic Principles is presented in a concentrated format spanning three days with a final examination on the afternoon of the third day. There is a variety of supplemental information in the manual appendices. Make certain you review the specific information in *all* of these references so you will be familiar with important concepts and be better prepared for class discussions and activities. These materials will prove useful both in the course and as you deal with protective coatings in your career.

During the course, you will participate in discussions and activities, ask questions, exchange ideas, and gather information. Several class activities will occur in small groups or teams. An individual from each team will be asked to present the results of the team's project. Each of you will have the opportunity to make one of your team's presentations during the course. Case studies will be used to give you an opportunity to apply some of the concepts and skills presented.

Prior to, and in preparation for the final exam on the last afternoon of the course, there will be several practice quizzes. Quiz and exam questions are drawn both from material presented during the class and the student manual. The practice quizzes are designed to help you check your understanding of the material, prepare for the final exam, and help the instructor check your progress. The final, *open-book* exam determines whether you have the required grasp of the material. The exam is graded *pass-fail*, with a score of 70% or above required to pass.

Reference Books

Corrosion Prevention by Protective Coatings, 2nd Edition

Outline of Schedule and Course Topics

Please Note: ***The Instructors may cover more or fewer topics in the morning according to the needs of the class.***

Day 1 Morning

Chapter 1 — Introduction

Chapter 2 — Corrosion

Chapter 3 — Coatings

Day 1 Afternoon

Chapter 4 — Coating System Selection

Summary and Assignment (Case Study A)

Day 2 Morning

Practice Quiz 1

Review Case Study A

Chapter 5 — Surface Preparation

Chapter 6 — Application (Part 1)

Day 2 Afternoon

Chapter 6— Application (Part 2)

Chapter 7 — Safety

Chapter 8 — The Specification and Pre-job Conference

Summary and Assignment (Case Study B)

Day 3 Morning

Practice Quiz 2

Review Case Study B

Chapter 9 — Inspection

Chapter 10 — Reporting

Practice Quiz 3

Day 3 Afternoon

Review Quiz 3

Review for Final Examination

Final Examination

Code of Conduct

While on site at a NACE course, appropriate behavior towards instructors, NACE/class location staff, and fellow students is required. If appropriate behavior is not maintained, NACE has the authority to take proper action against the student(s) in violation, which could result in revocation of one or more of the following: NACE Certification, Membership, and current/future classroom attendance.

PCS 1 BASIC PRINCIPLES

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Chapter 1: Introduction

Objectives

Upon completion of this chapter, you will be able to:

- Discuss the evolution of the coatings industry.
- Discuss the various reasons that modern day “protective” coatings are used.
- Discuss the various industries that are the predominate users of protective coatings

1.1 Evolution of Coating Industry

1.1.1 Early History

Colored paint has been in use at least 30,000 years. The first record of paint manufacture is by the Chinese tens of thousands of years ago. An early experiment by Plato showed that mixing two colors produces a third color.

Throughout history paint has been made with the same three basic components: a pigment to color it, a binder to hold it together, and appropriate thinners to make it easy to apply.

1.1.2 1ndustrial Age

Around 1600, Sir Isaac Newton showed that the component colors of white were: red, orange, yellow, green, blue, and violet and that mixing them together could create all other colors.

In the 1860s manufacturers developed metal paint cans with tight-fitting lids. This meant a manufacturer could make paint in quantity, package it in the cans, and ship it to dealers elsewhere.

Also during the 1800s some railway bridges and ships made of iron required protection from the elements. Oil-based paints, linseed and fish oil were predominant, with lead pigments used as protective coatings. When Henry Bessemer developed the “Bessemer Process” to mass-produce steel in 1855, the use of paint as a protective coating grew in demand.

1.1.3 20th Century

Most paints and coatings used animal-based glue, milk, or natural oils as the binder until the early 1900s. Industrial and marine coatings were all made with an oil binder. In 1913 a process to produce *vinyl chloride* was patented, followed by the development of vinyl paints. This was perhaps the first new binder in over 1,000 years. Industrial customers now had a choice in coating types, and with choice came the need for an informed decision about the properties and characteristics of the different coatings.

One of the issues with most oil-based paints is drying time; some oil-based paints take days or longer to dry unless cobalt and Japan driers are added to speed up the process. Vinyl paints dry within minutes, which gives them a distinct advantage. However, vinyl paints tend to fade faster (chalk) than oil-based materials. So with this new choice, buyers had to decide which features were most important.

Vinyl paints have excellent resistance to water, far better than oil-based materials. Unlike oil-based materials that have very poor wet adhesion and tend to break down if submerged in water for very long, vinyl paint has excellent wet adhesion. Vinyl paints are easy-to-apply and can be used as a lining. Before vinyl paints, only hot melt bitumen coatings were used as linings and these were very difficult to apply.

Vinyl paint, which can be tinted to any color, was widely used in the marine industry. However, it was not resistant to most solvents. Another product developed around the same time was chlorinated rubber-based material (based on technology similar to vinyl). Chlorinated rubber, like vinyl, was widely used in the marine industry. Both of these materials need large amounts of solvent to dissolve the binder and allow it to be applied. For this reason, paint manufacturers phased out both of them in the 1990s because they were required to follow government regulations limiting the amount of volatile organic compounds used in paints.

The use of vinyl and chlorinated rubber paints gave birth to today’s industrial coating manufacturing processes. A few existing commercial paint companies started separate divisions to research and sell what were then “new” types of protective coatings. The word ***coatings*** came to mean “heavy duty materials” to differentiate them from the typical commercial paints.

During the period between World War I and World War II, several companies worked on polymer-based technology. Polymers in a coating allow greater opportunities for protective applications. The first epoxy coating based on bisphenol-A, an organic compound, was developed and patented as early as 1936.

It was found that epoxy resin made into a coating material solved many of the issues that other materials could not. Epoxies are hard dense materials that can take some physical abuse, are very resistant to the passage of water vapor through the film, have excellent wet adhesion, and are even resistant to many of the common chemicals that were also starting to appear during this time. Epoxies have excellent adhesion to steel as well as most other building materials. Epoxies were, and still are, used as adhesives. Epoxies also are non-conductive. This feature fit very well with another corrosion control methods developing during this same time, like cathodic protection, a means of protecting a structure by using electrical current. For cathodic protection to work efficiently, there must be a way to insulate steel from electrical current and epoxy was the right material.

The use of epoxy as a coating changed the way the industry worked. It was the first coating that had to be packaged in two containers. One container held the epoxy resin and pigment, and the second container held the curing agent. The applicator had to mix both parts together, in correct proportion, just prior to use. As soon as the two components were mixed, a chemical reaction began. During a short period of time, referred to as **Pot Life**, the molecules from each component linked together to form larger molecules, thus creating a more solid form of the material.

Since the curing of epoxy is a chemical reaction, temperature is a major concern. At temperatures below 50°F (10°C), the reaction dramatically slows down, and generally stops at about the freezing point of water. Applicators must consider temperatures when applying coatings. Unlike epoxies that are negatively affected by cold temperatures, the curing of most oil-based coatings slows down at low temperatures but does not seem to affect the eventual use of the paint.

In 1937 the German, Otto Bayer, developed the first polyurethane resin. This material had many potential uses but was not readily available as a coating until the 1950s. The first experimental use was as an exterior coating on airplanes during the World War II. One of the major features of polyurethane coatings is its resistance to UV light. Epoxies and many oil-based coatings tend to break down from exposure to UV light for any period of time.

In the mid-1940s inorganic zinc coatings were invented in Australia using powdered zinc with a sodium silicate liquid binder. Initially, this new type of inorganic zinc coating had to be force cured in an oven and became known as **stoving grade** zinc. The second generation version required a spray of a mild acid after application as soon as the water evaporated to cure the coating. The new coating bonded to steel, came in only one or two colors, was very porous and resistant to most solvents, and provided galvanic protection to the steel.

1.1.4 Major Changes

The development of these new coating resins changed the entire industrial and marine coating industries. The resins required organic chemistry knowledge to develop new products. Because making paint had become a science rather than an art, paint and coating manufacturers began hiring chemists and setting up laboratories.

Although the major components were the same as those made for thousands of years — binder, pigment, and solvent — adjusting the formulas using **additives** required chemistry. Additives are small quantities of chemicals that add features to coatings, such as a higher level of UV resistance. Manufacturers found they needed additives for many things: to keep the material from foaming; to lengthen possible storage time; or to improve the application characteristics of the material. One additive commonly used is a thixatrope[1], which enables a thicker coating film.

The new products required new application equipment along with new application expertise. Applicators had to acquire new knowledge such as proper mixing, timing the pot life, and waiting

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[1] Thixotropy is the property of certain gels or fluids that are thick (viscous) under normal conditions, but flow (become thin, less viscous) over time when shaken, sheared, agitated, or otherwise stressed.

after mixing for the proper induction time (discussed in a later chapter). The applicators had to become very knowledgeable about the requirements and limitations of the materials they were working with.

1.1.5 Industry Support and Standards

These early 20th century changes created the need for two new segments of the industry: industrial coating contractors and coating inspection firms. Several new organizations were founded to handle the need for industry-wide standards and to assist in research about coatings and their use.

Little was known about the science of corrosion control early in the century, but by the 1930s, significant advances were in place and cathodic protection (CP) was in widespread use to control corrosion on underground and sub-sea pipelines. These advances generated well-founded concern about potential damage to adjacent structures from stray current. It soon became apparent that a dedicated organization was needed to serve as a clearinghouse for information about underground operations and to establish standard procedures for installing and maintaining CP systems. This led to the formation of the Houston, Texas based Mid-Continent Cathodic Protection Association in 1938. In 1940, the Petroleum Industry Electrical Association (PIEA) offered to sponsor the work of this group, which then became the PIEA Cathodic Section. Members of this section soon determined the value of forming a separate association dedicated specifically to corrosion and its control. On October 9, 1943, eleven corrosion engineers formed the National Association of Corrosion Engineers (NACE).

Over the years, NACE broadened its scope beyond CP and pipelines to oil and gas production and its chemical processes, the refining industry, and to other methods of corrosion control including protective coatings and linings, chemical treatment, and materials selection and design. Now, NACE International is involved in every industry and area of corrosion prevention and control, from chemical processing and water systems to transportation and infrastructure protection. Its mission is to protect people, assets, and the environment from the effects of corrosion.

Another USA based organization, SSPC, was founded in 1950 as the Steel Structures Painting Council, a non-profit professional society concerned with the use of coatings to protect industrial steel structures. SSPC's focus was entirely on industrial coatings and their application to carbon steel. In 1997, the name of the association was changed to The Society for Protective Coatings to better reflect the changing nature of coatings technology and the ever-expanding types of construction materials. While they concentrate on the selection and application of high performance coatings, they no longer focus solely on carbon steel and now include other metals as well as concrete. Some of the first steel cleaning standards came from SSPC as well as standards that cover the testing of coatings for particular uses.

During the same time, organizations in India, Japan, Sweden, Britain, Germany, and other countries began developing standards for marine and industrial coatings.

The most commonly used are:

- Indian Standard-IS: 1477 (part 1&II) 1963
- British Standards Code of Practice BS 5493
- DIN 55928 for Protective Coating of Iron and Steel structures against Corrosion
- Shipbuilding Research Association of Japan – Standard for the preparation of Steel Surfaces Prior to Painting ("SPSS" Standard)
- Japanese Shipbuilders Research Association (JSRA)

Eventually, many of the European coating and corrosion control related standards merged into the International Organization for Standardization (ISO) standards. In the U.S., NACE and SSPC produced the Joint NACE/SSPC set of cleaning standards that are currently in use. This course covers specific NACE, SSPC, and ISO coating standards in later chapters.

1.2 Current Protective Coatings Use

Today, high performance coatings are used for many different reasons. Table 1.1 details many of the most prevalent reasons.

Table 1.1: Reasons to Use Protective Coatings

Reason	Function
Acoustic Insulation	Foam, rubber and other special coatings absorb or reflect sound
Aesthetics	Company branding; make workplace pleasant
Biocide need	Resist attack by fungus, insects, rot and mildew on wood and cementitious surfaces
Chemical Resistance	Protect against chemical attack
Color Code	Indicate use, process paths, security or safety zones, infrastructure system segments, and process paths, etc.
Control Corrosion (primary use of industrial and marine protective coatings)	Provide a barrier to separate surfaces from electrolytes; to provide galvanic protection; to retard corrosion
Decontamination (Cleanability)	Provide easier decontamination of porous substrates, such as concrete, wood, and plaster as well as non-porous surfaces; required in nuclear facilities
Ensure Safety	Make hazard warnings more visible; provide non-skid/non-slip surfaces; fulfill safety marking and law-mandated color coding requirements
Environmental Protection	Line cargo tanks (land based, railcar, ships) to prevent leaks; control corrosion on ships and off shore platforms to avoid structural collapse
Fire Protection	Resist and retard spread of fire; some coatings do not burn; others slow the spread of flames; a specific class of fire retardants, intumescent coatings, swell when exposed to heat to create a protective barrier
Flow-properties	Reduce friction and increase liquid flow in pipelines, etc.
Heat Absorption	Help heat equipment or interior spaces
Heat Reflection	Help cool equipment or interior spaces
Insulation	Protect against electrical shock; and unwanted transfer of electricity in facilities; referred to as **conformal coatings**
Luminescence	Allow signs to be seen in the dark or in areas that could lose lighting
Prevent Product Contamination	Protect products in containers from other substances; used for chemicals or food products
Reduce Friction	Enables substances that need to flow or slide to do so more freely
Resist Wear	Reduce substrate wear in high-traffic areas; including wear on flooring or cavitation-erosion of surfaces like pump impellers
Retard Marine Bio Fouling	Antifouling or foul release coatings help keep marine surface smooth and reduce drag

Slip and Skid Resistance	Used on floors and decks for safety; used on aircraft carrier decks to keep jets from sliding off
Sound Protection	Absorbs radar waves; used by the world's militaries for obvious reasons
Transfer heat	Increase or reduce heat transfer
UV Degradation	Protects epoxy and other surfaces from UV breakdown
Water Resistance	Prevent or reduce transmission of moisture
Weather Resistance	Protect against degradation from the environment; wind-driven debris and water, temperature fluctuations, ultraviolet sunlight, etc.

1.3 Markets

High performance coatings are used in many markets, from arboretums to zoos and everything in between. This course focuses on the industrial, transportation, marine, and infrastructure markets, primarily:

- Bridge and Highway
- Petrochemical (oil and gas) both offshore and land-based
- Chemical industry (and other industries with heavy use of chemicals)
- Marine Transportation
- Power Generation
- Water and Waste-water Treatment

1.3.1 Bridge and Highway

The fact that only a few bridges have collapsed due to corrosion speaks well of the bridge industry's diligent inspection procedures. When inspectors find corrosion, transportation departments replace or repair what is needed and put corrosion control measures in place. Coatings are the most common method used to protect steel and concrete bridge structures. Coatings help protect the reinforcing bar that gives concrete better tensile strength.

1.3.2 Petrochemical — Oil and Gas

This is one of the largest markets for protective coatings worldwide. Offshore oil rig legs are commonly used as examples of the most difficult structures to protect from corrosion. Land-based refineries and related chemical plants also use protective coatings. Coatings in these facilities have to resist high temperatures, a wide range of chemicals, physical damage, salt-water immersion and spray, and high humidity.

1.3.3 Industrial Plants

Many industries require the protection of their structures and equipment. They also must protect the chemicals they use in their manufacturing processes and keep them free from contamination. Industries that use chemicals in high quantities include:

- Pulp and Paper
- Electronics
- Circuit Board
- Aerospace
- Mining
- Steel Mills

1.3.4 Marine

One of the most severe environments on earth is the ocean. Salt water, temperature extremes, moving water, physical abuse, and chemical attack are common problems faced by owners and operators of ships and offshore structures. Almost all of these structures have areas that are difficult, if not impossible, to see while in service. Premature failure of coating systems and the inevitable subsequent corrosion has caused numerous ships to sink with loss of life and major environmental damage.

1.3.5 Power Generation

Hydroelectric, fossil, and nuclear power generation and distribution require protective coatings. Power generation worldwide requires protective coatings for numerous reasons. Nuclear power plants require protection from corrosion and the coatings must stand up to decontamination and cannot fail by peeling or flaking. Flaking in containment structures could clog pumps, interfering with critical cooling of fuel rods. The need for protective coatings and linings is distributed throughout all power-generation facilities and distribution networks, and even into individual homes.

1.3.6 Water and Waste-water Treatment

Providing clean drinking water for everyone, and removing and treating waste products, demands a huge infrastructure of pipe networks and plants. All of this infrastructure must be coated — from the facilities and pipelines that ensure water is fresh and clean for drinking to the waste-water system that contends with the chemicals used to purify the wastes from the water. Both ends of the system use chemicals that attack steel and/or concrete.

Chapter 2: Corrosion

Objectives

Upon completion of this training material, you will be able to:

- Identity the principles of corrosion control.
- Describe the effects of corrosion.
- Recognize the cost reduction potential of protective coatings.
- Identify the forms of corrosion.

2.1 What is Corrosion?

NACE defines corrosion as ***“the deterioration of a material and its properties from a chemical or electrochemical reaction with its environment.”*** Another way to say it is: the corrosion process is the return of a metal or alloy to its natural state through an electrochemical reaction.

To make carbon steel and other metals, producers use energy to change the basic structure of the raw ore. This energy disburses unevenly through the metal in very small amounts. The fact that the energy disburses unevenly is important. Some areas of the steel have more energy, while other areas have less energy. Because nature does not like imbalances, the areas of differing energy try to equalize that energy throughout the steel by passing electrons between them. The areas with excess energy are called anodes; the areas with less energy are called the cathodes.

If it can, an electron flows from an anode to a cathode. What it needs is a **pathway** or **conductor** to carry it to the cathode. In a metallic structure, the metal itself is the pathway or conductor, since it is itself an excellent conductor of electrons.

However, and this is very important in the science of corrosion, a full circuit needs to be created. An ion, a very small particle of matter, needs to move between the cathode and anode *at the same time the electron moves*. This ion has to move through an electrolyte, commonly water. *The more conductive the electrolyte, the faster the rate of corrosion is.* This means the anode deteriorates and eventually disappears. The evidence of the process is in corrosion’s product — rust— that builds up around the cathode.

The full process, the movement of the electron from the anode to the cathode and the passage of ions back and forth *is the electrochemical reaction called corrosion*.

2.1.1 Principles of Corrosion Control

The principle of corrosion control is built around the fact four things must be present for corrosion to take place:

- Anode
- Cathode
- Electrolyte
- Metallic Pathway

To control corrosion, you can remove any one of these. A good illustration of the corrosion process is an ordinary dry-cell battery which depends on the corrosion process to generate electric power. The four elements present in Figure 2.1 are:

- An electrolyte (moist ammonium chloride and zinc chloride).
- A negative electrode (zinc case) — the anode in a corrosion cell.
- A positive electrode (carbon [graphite]) — the cathode in a corrosion cell.
- A conductive wire — the metallic pathway in a corrosion cell.

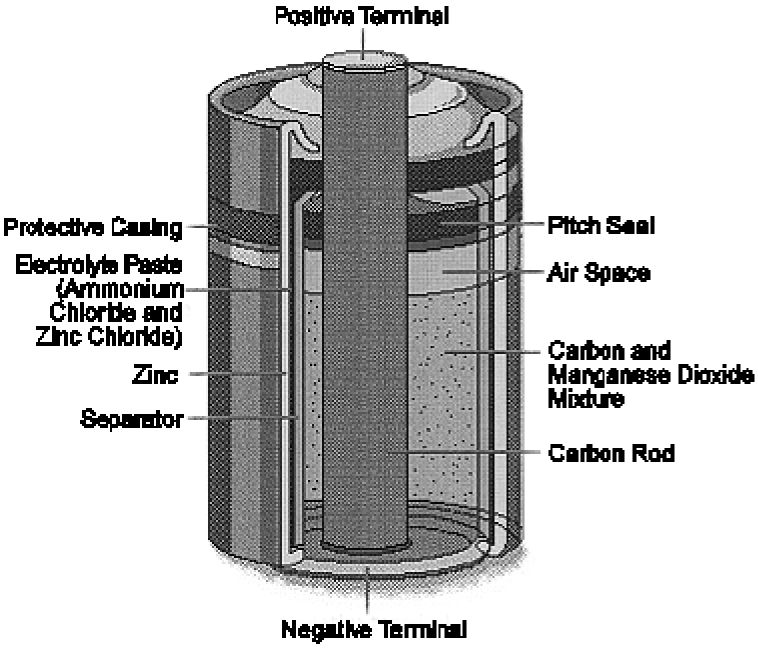

Figure 2.1 Dry Cell Battery – Example of Electrochemical Corrosion

2.1.1.1 Electrolyte

The electrolyte is a liquid or corrosive medium that conducts electricity. The majority of electrolytes are based on water. Electrolytes contain ions, which are particles of matter such as water soluble salts that carry a positive or negative charge.

2.1.1.2 Anode

The anode is the part of the metal that corrodes, i.e., dissolves in the electrolyte. Particles of the anode that dissolve become positively charged ions. The electrons left behind in the metal cause the immediate area to be negatively charged.

2.1.1.3 Metallic Pathway

Generally speaking, if there is no metallic pathway, the anode corrodes very slowly; the battery holds most of its charge while discharging very slowly.

2.1.1.4 Cathode

The cathode is the less-active area on the electrode (the metal surface) where the electrons are consumed. The area around the cathode is positively charged, thus attracting the negatively charged electrons.

2.1.2 Effects of Corrosion

Corrosion is harmful to the safety, cost, and appearance of a structure. It can also be a significant component of maintenance costs and planning.

Stakeholders in industry, such as plant owners, refinery operators, ship owners, mechanical engineers, chemical engineers, etc., are affected by corrosion and, as a result, look for ways to prevent it. The desire to protect all types of materials from corrosion — wood, concrete, steel, cast iron, stainless alloys, aluminum, plastics, ceramics, and so on — drives the need for a basic understanding of corrosion, and the means to both prevent it and mitigate its effects.

2.1.2.1 Safety

Corroded structures may be unsafe; they can endanger the life and health of users. Ships and buildings that support extreme weights provide two examples of how corrosion renders structures unsafe. Another example is the contaminating presence of metal corrosion products in the food and beverage industry.

2.1.2.2 Cost

The cost of repainting and repairing rusted steel usually far outweighs the initial cost to properly protect a surface against corrosion, or to design structures and equipment specifically to make corrosion control easier. In September 2001, the U.S. Department of Transportation issued a study, “Cost of Corrosion.” The study estimates that the total annual cost of corrosion in the oil and gas exploration and production industry in the United States is $1.4 billion. That does not account for the cost of corrosion in other industries.

2.1.2.3 Appearance

Peeling coatings and rusting steel are eyesores in any setting. For many engineers and facility owners, appearance is a major reason to coat their structures.

2.2 Program Maintenance

Controlling corrosion is an ongoing and expensive process in any type of industrial or marine structure. Maintenance-painting program costs generally account for almost 25% of a maintenance budget. In addition to costs for materials and labor, there are downtime costs as well. The losses that accrue while a refinery, process plant, or large transport ship is out of service can be many times the cost of the work being performed.

2.2.1 Cost Reduction Potential of Protective Coatings

Protective coatings are by far the most significant of the technologies used to control corrosion. Approximately 90% of corrosion control expenditures are related to protective coatings. A properly selected and applied coating system not only reduces the rate of corrosion but also reduces **future** costs of corrosion control and mitigation.

Example:

A natural gas pipeline is left to corrode and develops leaks. Consider the number of leaks, plus the number of years the leaks exist — this adds up to a significant monetary loss. Look at these figures:

- **Leak 1:** A $\frac{1}{16}$ in (0.16 cm) diameter leak in a 15 psig (103 kPa) gas line would leak roughly 1,100 Mcf (1,100,000,000 Btu) per year.
- **Leak 2:** A $\frac{1}{4}$ in. (0.6 cm) diameter leak in a 230 psig (6 kPa) line would leak roughly 24,000 Mcf (24,000,000,000 Btu) per year.

If you assume a price for gas of $3.00 USD per Mcf:

- **Leak 1** costs $3,300 per year

- **Leak 2** costs $72,000 per year

Multiply this by the number of leaks in a pipeline, then by the number of years the leaks exist, and it is clear that the costs of leaks are enormous. ***However, these costs are miniscule compared to costs from an explosion.*** An explosion creates a quantum leap in costs: replacing equipment or an entire unit, costs of injury and worse, and loss of life. Remember, containment is everything in the petrochemical industry.

Coating systems, in addition to other corrosion prevention measures, are used on natural gas pipelines to reduce the rate of corrosion, and as a result, the number of leaks or explosions that may occur. Even a fairly expensive coating system quickly pays for itself.

2.3 Forms of Corrosion

More forms of corrosion exist than can be covered in this course. NACE International has several corrosion courses, including basic, intermediate, and advanced that address corrosion in more detail. This course focuses on the following major categories (defined by Mars Fontana):

- Uniform Corrosion
- Localized Corrosion
- Metallurgically-influenced Corrosion
- Mechanically-assisted Degradation
- Environmentally-induced Cracking
- Microbiologically-influenced Corrosion

2.3.1 Uniform Corrosion

Uniform corrosion has many sub-forms; most have to do with either aqueous or gaseous corrosion. Uniform corrosion forms include:

- Aqueous Corrosion.
- Atmospheric Corrosion.
- Galvanic Corrosion.

- Stray-current Corrosion.
- Molten Salt Corrosion.
- Liquid Metal Corrosion.
- High Temperature Gaseous Corrosion.

2.3.2 Localized Corrosion

Localized corrosion occurs at discrete locations on a material. Localized corrosion forms include:

- Pitting Corrosion.
- Crevice Corrosion.
- Filiform Corrosion.

2.3.3 Metallurgically Influenced Corrosion

When metal is made, elements from ore are recovered and by a variety of processes it is changed into a form usable by humans. These processes influence the structure, composition, stresses, and impurities in metals and alloys as well as their corrosion behavior. When the metal is formed and welded those processes also change the structure of the material and affect corrosion. Forms of metallurgically influenced corrosion include:

- Exfoliation.
- Intergranular corrosion.
- Dealloying corrosion.

2.3.4 Mechanically Assisted Degradation

Mechanically Assisted degradation is the process where external interactions influence the corrosion rate. Mechanically assisted degradation forms include:

- Erosion.
- Fretting.
- Cavitation.
- Corrosion Fatigue.

- Impact.

2.3.5 Environmentally Induced Cracking

Environmentally Induced Cracking is a form of corrosion in which stress is the external influence on the corrosion process. Environmentally Induced cracking forms include:

- Stress Corrosion Cracking.
- Hydrogen Damage.
- Liquid Metal-induced Embrittlement.
- Solid Metal-induced Embrittlement.

2.3.6 Microbiologically Influenced Corrosion

Bio films form on most metals and alloys immersed in water-based environments. The interaction of these films with the metal leads to other types of corrosion such as uniform and localized corrosion, particularly localized pitting.

Chapter 3: Coatings

Objectives

Upon completion of this training material, you will be able to:

- Define coating terms including paint, protective coating, exterior protective coating, and interior protective lining.
- Describe the composition and corrosion prevention mechanisms of barrier, inhibitive, and sacrificial coatings.
- Discuss the desirable properties of a coating.
- Discuss types of organic and inorganic coatings.
- Describe components of liquid/liquefiable coatings.
- Describe manufacturing mechanisms for liquid/liquefiable coatings.
- Describe principal types of protective coating curing mechanisms.
- Identify types of coatings according to their curing mechanisms.

Terms

The terms paint and coating are sometimes used interchangeably. However, when considering coatings in relation to corrosion, you have to specifically define the two terms. NACE uses specific terms to clarify the meanings most commonly used in the coating industry. Other definitions exist, so always define the terms you are using when talking or writing about coating technology.

Coating: A liquid, liquefiable, or mastic composition that, after application, converts into a solid protective, decorative, or functional adherent film

Lining: A coating, a layer of sheet material, or a solid substance (brick or tile) that adheres to, or is in close contact with, the interior surface of a container. A lining protects the interior against corrosion stemming from the contents, and/or protects the contents from contamination by the container material.

Paint: A pigmented liquid or resin applied to a substrate as a thin layer that converts to an opaque solid film after application. It is commonly used as a decorative or protective coating.

Protective Coating: A coating applied to a surface to protect it from corrosion.

Coating vs. Paint

The word coating generally describes a material, thicker than paint, which has a more functional purpose. Some materials can be correctly described as both coatings and paints depending on their purpose, e.g., alkyds; others clearly fall into one category or the other, e.g., mastics, acrylic latex house paint.

Coating vs. Lining

Linings are used to separate a structure from its contents. A lining can protect the structure, e.g., sulfuric acid tanks, or the contents, e.g., food holds on ships. Coatings are used as linings in many applications.

3.1 Basic Mechanisms of Protection

A coating can provide corrosion protection by one or a combination of three basic mechanisms:

- Barrier
- Inhibitive
- Sacrificial

3.1.1 Barrier Coating

Barrier coatings act as a physical barrier between the substrate and its environment by keeping moisture, oxygen, and other chemicals away from the substrate. They can be used in immersion or exterior weathering environments. Examples of barrier coatings are epoxies, polyurethanes, and many alkyds.

Barrier coatings need to:

- Be highly resistant to the passage of air, water, oxygen, and carbon dioxide through the film.

- Impede the passage of ions.
- Form an inert barrier over the surface.
- Be resistant to chemicals when in immersion service or on containers holding them.
- Resist passage of electrical currents, i.e., have good high-dielectric strength.
- Have good adhesion to the underlying surface.
- Be able to wet the surface well enough to prevent voids at the coating/substrate interface.
- Resist the absorption of water or other liquids.

3.1.2 Inhibitive Coating

Inhibitive coatings contain pigments that react with absorbed moisture in the coating itself, and then react with the steel surface, passivating the metal by spontaneously forming a hard non-reactive surface film that interferes with the corrosion process. Inhibitive coatings are used primarily for structures exposed to atmospheric conditions; they are not used in immersion conditions because many pigments draw water into the coating causing blistering. Inhibitive pigments include:

- Zinc chromate.
- Strontium chromate*.
- Zinc oxide.
- Zinc phosphate.
- Red lead*.

These pigments are commonly incorporated into epoxy, alkyd, and urethane coatings.

*Although chromates and lead are still used in some parts of the world, the U.S. prohibits their use.

3.1.3 Sacrificial Coatings

Sacrificial coatings use a metal, usually zinc, to provide galvanic protection for steel. In the presence of an electrolyte, the zinc will corrode instead of the steel. In most instances, the zinc reaction products fill in a scratched or damaged area to protect it even further from atmospheric conditions. There are several types of sacrificial coatings including:

- Zinc-rich.
- Hot-dip galvanized.
- Spray-metallized.

Table D.1, "Sacrificial Coatings." (SEE BACK OF MANUAL TAB D)

3.2 Desirable Coating Properties

No one coating possesses all of the desirable properties of a coating. Choosing a coating requires compromises between differing properties. One coating may have high performance in one property, but its chemical formulation forces the sacrifice of another desired property. Thus, it is vital to prioritize your needs before selecting a coating system. There are many test methods to measure coating properties. Some tests need relatively simple equipment while others require sophisticated instruments. ASTM International is a good source for information about coating test methods.

3.2.1 Chemical Resistance

Chemical resistance is the ability of a coating to resist deterioration of its properties by chemicals present in its intended service environment.

3.2.2 Water Resistance

Water resistance is a crucial coating property since almost all substrates come into contact with water in one form or another. It is a very complex problem to which no one coating material will provide a universal solution. A coating with excellent water resistance must withstand continuous or near-continuous immersion in water without loss of adhesion, blistering, cracking, softening, or swelling. It must also withstand the normal wet-to-dry cycling (dew condensation on coatings during the evening and night, and evaporation during the day), that is inherent in atmospheric service. Three major factors in water resistance are:

- Resistance to moisture absorption.
- Resistance to moisture vapor transmission.
- Temperature impact on water transport through coating film.

Water molecules are extremely small and have the ability to penetrate into and through most organic compounds. They do this by passing through the intermolecular spaces of the organic material. Water molecules either *remain* in the organic material in an absorbed state, or *pass through* the material. Another important factor in water resistance is the type of water involved..

Types of Water

Swamp Water	Usually acidic and may corrode both steel and concrete
Sulfide Water:	Relevant in many areas, reacts readily with most metals such as iron, steel, brass, copper, etc.
High Conductivity Water or Seawater	Conductivity can lead to rapid formation of anodic-cathodic areas on steel, causing severe pitting
Pure Water (Deionized and Distilled)	Different levels of water purity occur naturally or are produced for use in various processes. In general, high purity water tends to dissolve more solids. As water purity increases, so does the likelihood that the water can permeate a coating system, resulting in blistering and/or pigment attack. Pure water, including snowmelt, can dissolve calcium out of concrete at a rapid rate, leaving the aggregate exposed.
Water with High Oxygen Content	High oxygen levels may facilitate or increase corrosion; hot water accelerates oxygen activity, thereby increasing corrosion.

3.2.3 Resistance to Moisture Absorption

A corrosion-resistant coating should have low water absorption, i.e., low amounts of water picked up and retained in the coating's molecular spaces. After a coating forms and is in use, the moisture content moves to a state of equilibrium with the atmosphere by:

- Desorbing or evaporating water in the dry stage.

or

- Adsorbing more water when there is high humidity or immersion.

Moisture vapor contributes to corrosion when it combines with other elements such as very small molecules of hydrochloric acid, ammonia, or similar materials. *As a general rule of thumb, coatings with less water absorption provide better corrosion protection*.

3.2.4 Resistance to Moisture Vapor Transmission

Moisture vapor transmission is the rate at which moisture vapor transfers through a coating. When there is a difference in the quantity of moisture vapor from one side of a coating to the other, moisture vapor generally transfers through the coating.

Each individual coating has its own moisture vapor transfer rate. Generally, *a lower moisture vapor transfer rate results in a coating with better corrosion protection.*

Moisture adsorption and moisture vapor transmission are entirely different processes:

- *Moisture absorption* is the amount of water held within a coating.
- *Moisture vapor transfer rate* is the rate at which moisture passes through a coating.

Imagine the difference between a sponge and a metal screen mesh. The sponge is highly moisture absorbent, but transmits moisture fairly slowly. That is, it tends to retain moisture. A metal screen mesh generally allows a fairly rapid rate of moisture transmission, but absorbs relatively little.

If a coating has poor adhesion, it is either inherent in its formulation or it is because of application over a contaminated surface. When a coating is applied over contamination, an extremely small void is created between the coating and the substrate, a prime candidate for moisture vapor transfer. The result: the moisture vapor in the void expands and creates a blister.

3.2.5 Ease of Application

A coating must be easy to apply to a substrate, and the required surface preparation and application methods must not affect the properties of the substrate. An easy-to-apply coating is particularly important where areas of the structure are intricate, with many corners, edges, recesses, etc.

Intricate structural components need easy-to-apply coatings since these areas are more likely to corrode first in a corrosive atmosphere. Most industrial structures are fairly difficult to coat because of the intricate nature of their design.

Even under the best conditions, there are usually many welds, corners, and edges that are focal points for corrosion. If the coating is not easy to apply, it is more likely to be done improperly, negatively affecting the corrosion resistance of the coating.

3.2.6 Adhesion to Substrate

Adhesion results when the physical and chemical characteristics of the coating and substrate react as they come into contact. Good surface preparation and proper coating application are essential to good adhesion. A crucial coating characteristic for coating adhesion is the coating’s ability to wet-out, or flow in a thin film, on the surface. Organic coatings vary in adhesive value from approximately 100 psi (689.5 kPa) to over 1,000 psi (6,900 kPa). Metallized coatings can have adhesive values of over 2,000 psi (13,800 kPa). Coating adhesion values vary greatly depending of the type of test used.

3.2.7 Cohesive Strength

This is a coating’s ability to resist internal stress caused by the processes of curing, thermal expansion or contraction, cold working (forming), etc. Cohesive strength is a measure of the internal strength of a coating and is usually a good indicator of toughness.

3.2.8 Tensile Strength

Tensile strength is the ability of a coating to resist breaking and cracking under linear stress.

3.2.9 Flexibility/Elongation

Many coatings are applied to structures that undergo thermal expansion, vibration, bending, or other mechanical deformation. A coating must be able to withstand deformation of the substrate.

3.2.10 Impact Resistance

Impact resistance refers to the ability of a coating to withstand sudden mechanical shock. It may be shown as direct impact, when something strikes the surface of the coating directly, or reverse impact, when something strikes the uncoated side of the substrate but is significant enough to impact the coating on the opposite side. Some coatings, such as glass filled epoxies or polyesters, can have excellent resistance to direct impact, but will fail rapidly when subjected to reverse impact.

3.2.11 Abrasion Resistance

Coatings applied to the decks or hulls of ships, barges, offshore platforms, vehicle ramps, warehouse floors, and walkways in many plants and working areas **must** be abrasion-resistant. Abrasion-resistant coatings must withstand constant wear from heavy equipment, foot traffic, wheel traffic, or damage by tools and equipment. To withstand this type of service, the coating must be tough, extremely adhesive, and resistant to shock. If it does not meet these criteria, it soon loses its ability to protect against corrosion.

Abrasion resistance is also required on internal surfaces in which a solution containing particles is agitated; where there are areas of direct impingement of a solution at high velocity; or on hoppers where dry abrasive particles may erode the surface. Some standards include:

- ISO 7784-2: 1997 Paints and varnishes—Determination of resistance to abrasion-Part 2: Rotating abrasive rubber wheel method
- ASTM D4060-07 Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser
- ASTM F609-05 Standard Test Method for Using a Horizontal Pull Slipmeter (HPS)

3.2.12 Temperature Resistance

Temperature resistance is a coating's ability to resist deterioration of its properties from exposure to extreme temperatures within its environment.

It is important to note: **coating properties can vary with temperature**. For example, a coating's abrasion resistance may be lessened by high temperatures, even if temperatures are within its recommended range. Similarly, impact resistance may decrease at lower temperatures. Coatings subjected to hot-cold cycles experience thermal stresses that can cause cracking or delamination.

3.2.13 Resistance to Cold Flow

Resistance to creep, or cold flow, is an important property in high-build thermoplastic coatings. For example, glass can be considered a thermoplastic material that cold flows with age. That is, it tends to flow down (or slump) with age, though not all experts agree with this.

Thermoplastic coatings, materials that soften when heated, have what is called a **glass transition temperature** (**Tg**) which is the temperature at which cold flow begins. If a coating with an 85ºF (29°C) Tg is exposed to temperatures above 85ºF (29°C), cold flow will occur. It is particularly vital to consider this property when coal-tar enamels and pitch compositions are used.

3.2.14 Dielectric Strength

Dielectric strength is a coating property that breaks the electrical circuit created during a corrosion reaction. The coating resists the passage of electrons and prevents the metal from going into solution at the anode. If electrons cannot travel to the cathode, the corrosion process is arrested.

Dielectric strength is also crucial when coatings are used with cathodic protection, since there are abundant electrons on the metal surface. When the coating is sufficiently dielectric, it breaks the electrical circuit and prevents the cathodic current from flowing in coated areas, thus reducing the cathodic protection current required to protect the substrate. A coating’s dielectric strength can be affected by moisture absorption. Lower moisture absorption results in more favorable dielectric strength.

High dielectric strength un-pigmented coatings, commonly referred to as *conformal coatings,* are used as insulating varnishes in motors, circuit boards, and generators. Typically, films of 1 mil (25.4 µm) must withstand 4,000 volts.

3.2.15 Other Properties

The properties for corrosion-resistant coatings described so far are general, and most corrosion-resistant coatings have a majority of the properties described. However, other general coating properties include:

- Weather Resistance.
- Resistance to Bacteria and Fungus.
- Age Resistance.
- Ability to Retain Appearance.

Some coatings are designed for specific purposes that demand even more specialized properties. These are part of the very specific ***coating-use-category*** which includes resistance to:

- High or low temperature.
- Marine biological growth (antifouling and foul release).
- Radioactivity.
- Soil stress.
- Cathodic disbondment.
- Atmospheric exposure.

- Immersion exposure.
- Underground exposure.

3.3 Coating Classification

Coatings are so varied in their characteristics and so numerous that the industry classifies them in many ways. This course focuses on classifying coatings by:

- Type of coating (**Organic** or **Inorganic**).
- Film formation and cure (**Convertible** or **Non-Convertible**).
- State: Liquid or Non-Liquid (**Liquid/Liquefiable Coatings** or **Non-Liquid Coatings**).

3.3.1 Type of Coating

3.3.1.1 Organic (Carbon-containing)

Most coatings are organic. These high-performance coating formulations give long-term corrosion protection to industrial, marine, chemical, and petrochemical structures. Organic coatings have carbon-to-carbon bonding. They are generally made from living, or once-living things, such as vegetable oil, animal fats and waxes, petroleum, coal, etc. Alkyds, epoxies, oils, and tars are examples of organic coatings.

3.3.1.2 Inorganic (Non-Carbon-containing)

Inorganic coatings are generally made of salts, lithium, potassium, and silica. Inorganic coatings have very specific properties and are primarily used for specialized purposes. Inorganic coatings do not have carbon-to-carbon bonding. Examples include phosphate, metallic, silicate, cement, and glass coatings.

3.3.2 Film Formation and Cure

The curing mechanism is the way a coating changes from a liquid to a solid state. It is the most important reaction that takes place to form a coating film. There are two types of coatings and each has several curing mechanisms. This course focuses on:

- Non-convertible coatings.

  - Solvent-evaporation cure
  - Coalescence cure
  - Fusion cure

- Convertible coatings.

  - Oxygen-induced
  - Chemically induced
  - Heat-induced
  - Moisture-induced

3.3.2.1 Non-convertible Coatings (Thermoplastic)

Non-convertible coatings do not go through a chemical change when they dry. They can be re-dissolved by their original solvent, or softened with heat and re-hardened by cooling. No chemical reaction or molecular change takes place during curing, only a change in form from liquid to solid. Non-convertible coatings are also referred to as **thermoplastic**, or formed by solvent or water evaporation or by a phase change such as melting and solidifying.

Non-convertible coatings cure primarily by the three curing mechanisms discussed in the next sections. Table D.2 lists some examples of non-convertible coatings and their cure. The curing mechanisms are:

- Solvent Evaporation
- Coalescence
- Fusion

Table D.2, "Examples of Non-convertible Coatings and their Cure Mechanisms." (SEE BACK of MANUAL TAB D)

3.3.2.2 Solvent-Evaporation Cure

Solvent-evaporation cure coatings are made by dissolving a resin, such as a vinyl or chlorinated rubber, in a suitable solvent, such as xylene or toluene. When these coatings are applied, they form a film by simple evaporation of the solvent. The resin remains unchanged and can be re-dissolved by its original hydrocarbon solvent, no matter how old the film.

Do not top-coat evaporation-cure coatings with a coating that contains a strong solvent. The solvent can attack the base coating and cause it to re-dissolve. Solvent-evaporation cure coatings are less resistant to chemical exposure and should not be applied where chemical contact is likely to degrade the coating film.

Solvent evaporation-cure coatings may be applied over a base coat with a different cure mechanism. For example, apply a vinyl coating over an epoxy basecoat but ensure the epoxy coating surface is not hard and slick, i.e., fully cured, otherwise poor inter-coat adhesion occurs.

Since all the solvent must evaporate for these coatings to cure properly, do not apply them too thickly. A thick application traps solvent within the film. The pockets of trapped solvent become voids as the solvent escapes. The voids create areas of weakness in the coating’s integrity. Sometimes trapped solvents that do not evaporate become solvent-filled blisters in the film.

Solvent evaporation-cure coatings have been in use as industrial coatings for many years and were among the first of the new generation of industrial and marine coatings. Because they contain a large amount of organic solvent, their current use is severely redistricted. Vinyl or chlorinated rubber coatings are not readily available in countries with clean air regulations including the U.S., Canada, most of Europe, and many other areas.

3.3.2.3 Solvent Evaporation Cure Coatings

Chlorinated Rubber

Chlorinated rubber is the result of a natural rubber or a polyolefin that reacts in solution with chlorine. The reaction forms an elastomeric material. These coatings are sometimes low in solids (though high-build formulations are available) and are generally applied in thin coats of 1 to 3 mils (25 to 75 µm) DFT. Do not use chlorinated rubber coatings in environments where temperatures are higher than 140°F (60°C).

Vinyl

Vinyl is made by dissolving polyvinyl chloride copolymers in a suitable solvent such as Methyl Ethyl Ketone (MEK). Toluene and xylene are used as diluents with the MEK. Vinyls are also low in solids and must be applied in thin coats of 1 to 3 mils (25 to 75 µm) DFT.

Acrylics

Acrylics are thermoplastic copolymers of acrylic acid and methacrylic acid, esters of these acids, or acrylonitrile. These materials combine with many other resins to improve color retention and exterior weatherability.

Bitumen

Bitumen is a hydrocarbon product that occurs in a natural state as gilsonite, or as a residue from petroleum distillation. Asphalts are probably the best-known bituminous products. Coal tar (coal-tar pitch) is a by-product of the destructive distillation of coal. Asphalts and coal tars used as coatings are generally heavy-bodied materials that are often described as bituminous. Asphalt coatings are made by dissolving the base material in an aliphatic hydrocarbon solvent, such as mineral spirits. Coal-tar coatings are made by dissolving coal-tar pitch in an aromatic hydrocarbon solvent, such as xylene or toluene. Both asphalt and coal-tar coatings apply successfully in thicker films, often 16 to 25 mils (400 to 625 µm) wet per coat.

When used in a multiple-coat system, solvent evaporation coatings fuse together, forming a single solid film rather than a layered film. Ease of maintenance painting is considered to be a major advantage of these coatings.

3.3.2.4 Coalescence/Evaporation-cure

These cures result from coalescence/evaporation. Coalescence is a special type of evaporation. Coalescence/evaporation-cure coatings encapsulate tiny particles of resin in a soap-like material which then disperses in water. The water acts as a carrier rather than a true solvent. This type of coating blend is known as an **emulsion**.

When the water evaporates, the resin particles fuse together (**coalesce**), forming a stable coating film. After these coatings cure, they will not re-disperse in water, though they *may* dissolve in strong solvent.

3.3.2.5 Coalescence/Evaporation-cure Coatings

Waterborne coatings, such as emulsions, are important because they allow formulation of VOC-compliant coatings using high-performance, chemically resistant resins. Resin blends used for emulsion coatings are generally high in molecular weight. In epoxy emulsions the resin forms cross-links during curing which results in higher molecular weight. The high-molecular-weight resins also do not easily re-dissolve.

When using water-based emulsion coatings:

- Do not expose the coating to moisture (dew, rain, or spray) before it is fully cured. Such exposure may cause streaking, wash-off, running, and inadequate protection of the substrate.
- Do not expose liquid components to freezing temperatures during shipment, storage, or application. Freezing disrupts the emulsion and causes coating components to separate.

3.3.2.6 Fusion Coatings

Some coatings are actually solid materials that are “cured” when heat is applied; the heat allows them to liquefy, flow, and bond to the surface. These are called fusion coatings.

Do not confuse fusion coatings with heat-cured coatings. Since fusion coatings can be reheated and cooled into a coating with similar properties, this makes them easy to repair. Of course, fusion coatings have upper limits to their operating temperatures.

Examples of fusion coatings include thermal sprayed metals, thermoplastic powder coatings, and hot applied waxes.

3.3.2.7 Convertible Coatings (Thermoset)

Convertible coatings go through a **chemical change** as they dry. Therefore they cannot be re-dissolved by their original solvent, or softened with heat and re-hardened by cooling. Convertible coatings are also referred to as **thermoset. Theroset coatings** are formed as a result of a chemical crosslinking reaction (oxidation, polymerization, chemical additive reaction, heat, or a combination of these).

Convertible coatings cure primarily by the four coating mechanisms described in Table and the following sections. Other forms of convertible coating curing mechanisms, such as UV light-cured are not covered in this course. The curing mechanisms discussed here are:

- Oxygen-induced.
- Co-reaction.
- Heat-induced.
- Water-induced.

Table D.3, "Examples of Convertible Coatings and their Cure Mechanisms." (SEE BACK of MANUAL TAB D)

Polymerization occurs when two or more resin molecules combine to form a single, more complex molecule. This is a chemical reaction that forms a new compound when many similar chemical groups called monomers join. Polymerization is the most common curing mechanism of today's high performance coatings. The primary characteristics of the monomers in polymerization are that:

- They are inherently stable.
- They are capable of linking together chemically.

Polymerization can form long chain molecules (one-dimensional linking) or a more complex three-dimensional molecule (cross-linking). The term *polymerization* can mean the reaction used to produce synthetic resins, or it can mean the cure process of a coating after mixing and application. Cross-linking is a rigid, three-dimensional molecular structure formed as a coating film on the substrate. The cross-linking polymerization process generally results in a stronger and more chemically-resistant cured resin.

A good example of polymerization is when the monomer ethylene (C2H4) joins into the polymer polyethylene; up to 1,400 ethylene monomer groups may be joined in this formulation. Polyethylene is a thermoplastic that can be used for coating buried pipes, as an extended sheath, as a sintered (heated) powder, or as a tape wrap.

Many resins used in coatings are partially developed polymers, sometimes called *adducts*, which cure by completing the polymerization. An important characteristic of the polymerization process is the *Glass Transition Temperature (Tg)* of the completed (formed) polymer. Tg is related to the flow and brittle properties of the cured.

With age, some additional polymerization continues and the coating film becomes more glass like, harder, and less resilient. This effect can be said to increase the Tg.

3.3.2.8 Oxygen-induced Polymerization Coatings

By using atmospheric oxygen these coatings form a solid film by a process called oxidative cross-linking. There is some evaporation because solvents are added for easier application. Types of coatings that cure by oxidation include:

- Alkyds.
- Drying oils.
- Epoxy ester.
- Oil-modified urethane.
- Oil-modified phenolic.

The main ingredients in many oxidation coatings, such as alkyd coatings, are:

- Vegetable oils.
- Linseed oil.
- Tung oil.
- Soybean oil.
- Dehydrated castor oil.
- Fish oils (Menhaden and others).

Film formation results when the oil reacts with oxygen to form a cross-linked structure. To speed up the reaction between the oil and oxygen, small amounts of metallic catalysts, called driers, are added during manufacturing. The usual driers are cobalt, lead, and manganese compounds.

Because film formation depends on oxygen in the air entering the wet film and reacting with the oil, curing can take a considerable amount of time. The time taken to form a solid film varies from one to several days.

Since the oxygen in the air enters the film only at the surface, there is a limit to the appropriate wet-film thickness (WFT) during application. The maximum WFT achievable is around 5 mils (125 µm), equivalent to 2 to 3 mils (50 to 75 µm) DFT. If the wet-film thickness is greater than this, the oxygen may not completely penetrate to the bottom of the wet film, resulting in liquid at the bottom with a solid top. This generally causes the film to pucker and wrinkle at the top and take a **very** long time to turn into a solid at the bottom.

Like most chemical reactions, the speed of the reaction increases with an increase in temperature. Thus, the coating dries faster in warmer temperatures. Air flow over the surface also speeds up the reaction.

On the other hand, if a thin film of moisture forms on the surface because of humidity or other factors, the oxygen uptake slows, extending the drying time. Wax and oil contaminants have a similar but more pronounced effect.

Manufacturers of oxidation coatings usually add a small amount of a material to prevent the oxygen reaction while the coating is stored in the can. This is usually effective but *only* while the can is full and *only* for a stated shelf life. If some of the coating is removed and the can is resealed, the coating reacts with oxygen in the can to form a solid film skin on top of the remaining coating. Remove the skin entirely and strain the coating before use. The oils used in oxidation coatings may react with alkali to form soap, a process known as saponification.

Since they may saponify and detach from the substrate, oxidation coatings are generally not suitable for:

- Conditions where severe corrosion may be encountered.
- Application on alkaline surfaces, such as new concrete.
- Over zinc coatings such as inorganic zinc or hot-dip galvanizing.

Another characteristic of oxidation coatings is their vulnerability to attack by strong solvents, such as acetone, MEK, ethyl acetate, etc. These solvents cause the film to swell and wrinkle. It is not a good practice to coat over the dry film of an oxidation coating with a coating containing strong solvents, such as vinyls and epoxies, etc.

3.3.2.9 Chemically Induced (Co-Reaction) Polymerization Coatings

Chemically induced (co-reaction) polymerization coatings form when a resin reacts with a curing agent, activator, converter, or catalyst. A catalyst is used to *start* a chemical reaction, to *accelerate* it, or *both*, but **a catalyst does not become part of the reaction mechanism**. Coatings that cure by chemically induced polymerization include:

- Epoxies.
- Polyurethanes.
- Vinyl wash primers (polyvinyl butyrate – PVB).
- Heat-induced polymerization.

3.3.2.10 Heat-Induced Polymerization Coatings

Coatings that cure by heat-induced polymerization include:

- Phenolics.
- Silicones.
- Fusion-bonded epoxy powder coatings.

Baked phenolic and most silicone coating films are formed when the resins cross-link when subjected to high temperatures 203–473°F (95–245°C). This cross-linking process, known as the condensation reaction, is characterized by the release of water during the resin polymerization.

3.3.2.11 Hydrolysis

Coatings are cured by hydrolysis when the reactive resins combine with moisture in the air to form hardened (chemically resistant) films. This process forms some urethanes and inorganic zinc coatings.

Table D.5, "Film-Forming Mechanisms." (SEE BACK of MANUAL TAB D)

3.3.3 Liquid/Liquefiable Coatings

Conventional coatings are either liquid or liquefiable. They are made with two major components:

- Pigment (a part of the solids portion of what is in the can).
- Vehicle (the liquid portion of what is in the can). The Vehicle also contains:

  - Resin (aka binder).
  - Liquid additives.
  - Solvent.

Miscellaneous additional components are also included to meet specified conditions.

3.3.3.1 Pigment

A pigment is a discrete particulate solid used to give specific protective, mechanical, or decorative qualities to a coating. Pigments do not dissolve; instead, they remain solid individual particles in both the liquid coating and the solid film. Interestingly, the shape of a pigment can influence the physical properties of the coating. Inert fillers such as chalk, talc, or mica (used to add bulk to the film) are also called pigments.

Pigments are added to coatings to:

- Inhibit rust.
- Decrease film permeability.
- Hide the surface.
- Provide color.
- Protect film from UV and weather.
- Decrease or increase film flexibility.
- Provide non-slip properties.
- Provide antifouling, anti-microbial, or mold resistant properties.

- Provide strength.

Pigment also meets other needs, such as:

- Self-cleaning.
- Controlling chalking.
- Increasing abrasion resistance.
- Controlling gloss; decreasing gloss and increasing adhesion (bond) of subsequent coats.
- Assisting in the drying of coating binder.
- Providing desired finishes, e.g., metallic luster or special glosses.
- Aiding in storage properties of paint.
- Increasing body consistency so thicker films can be applied.

Hundreds of pigments are available; the properties vary with manufacturer, type of manufacture method, etc. In the U.S., commercially available pigments are classified and listed by the National Paint, Varnish, and Lacquer Manufacturers Association in its Pigment Index.

While some pigments are more dangerous than others, you should consider all of them as hazardous. Always take appropriate safety precautions to avoid ingestion or inhalation. For example, those who blend zinc dust into the vehicle of a zinc-rich coating should always wear the correct respirator.

Pigments are primarily classified by shape:

- **Nodular (lump-shaped):** Nodular pigments are the most commonly used pigments. Generally they add color (titanium dioxide) or are sacrificial (metallic zinc).
- **Acicular (needle-shaped):** These pigments reinforce and strengthen the coating film as well as provide color. Zinc oxide and glass fibers are examples. In the past, asbestos fibers were added to coatings to provide reinforcement (cohesion) and are

still found when old coatings are removed during maintenance painting. The removal of coatings containing asbestos requires special precautions.

- **Lamellar (plate-like):** Lamellar pigments overlap when the coating dries and increase the pigment's impermeability to moisture. Some examples include Mica, aluminum flake, glass flake, and micaceous iron oxide.

3.3.4 Vehicle

The vehicle is the liquid portion of the coating and consists of:

- Resin (aka binder).
- Liquid additives.
- Solvent.

3.3.4.1 Resin

Also known as the binder, this *non-volatile* portion of the vehicle is the primary film-forming constituent of the coating. To create a protective coating film, the resins must convert from the pliant liquid form, which allows application, to a cohesive solid form that adheres to and protects the surface. *Only resins with the ability to change from one form to the other are suitable to use in coatings.*

Generally, the name given to a coating is that of its principal resin. Resins may be natural organic materials or synthetic materials. Common resins include:

- Acrylic.
- Alkyd.
- Asphalt.
- Chlorinated rubber.
- Coal tar.
- Drying oil.
- Epoxy.
- Phenolic.

- Polyvinyl chloride.
- Silicone.
- Urethane.
- Vinyl.
- Siloxirane.

3.3.4.2 Liquid Additives

Any number of special components (additives) can be added to a coating. They are usually less than 5% of the total coating formula by weight. These additives differentiate similar generic coatings made by different manufacturers. Additives can be used as:

- Driers.
- Suspension agents (increase shelf life).
- Anti-sag agents (thixitropes).
- Flow-control agents.
- Gloss-control agents.
- De-foaming agents.
- Friction modifiers (e.g., sand, aluminum oxide, Teflon, fluorocarbons).
- Miscellaneous functions.

3.3.4.3 Solvent

The solvent is the *volatile* portion of the vehicle. Most coatings contain solvents that are added to coatings to:

- Dissolve the base resin into a solution so it can be used as a coating vehicle; many synthetic resins are solids, e.g., alkyd and vinyl resins.
- Make the coating easier to apply; when used for this the solvent is usually called a thinner.
- Control the evaporation rate and improve the quality of the final film.

3.3.4.3.1 Principal Solvent Groups

Principle solvent groups include:

- Aliphatic hydrocarbons
- Aromatic hydrocarbons
- Ketones
- Esters
- Alcohol
- Glycol ethers
- Water

3.3.4.3.2 Aliphatic Hydrocarbon Solvents

Solvents in this group are also called paraffins. Chemically, they are open chain (also called straight chain) compounds. Common examples are mineral spirits, and V.M. and P. (Varnish Makers and Painters) naphtha.

Mineral spirits is known as painter's naphtha. It is a high-boiling petroleum product used to dissolve oils, asphalts, and alkyds. Table 3.1 lists some common aliphatic hydrocarbons and a few of their properties.

Table 3.1: Aliphatic Hydrocarbon Solvents

Solvent	Evaporation Rate (n-Butyl acetate = 1)	Flash Rate °F (°C) Closed Cup
Lacquer Diluent	4.0	43°F (6°C)
V.M. & P.	1.5	55°F (13°C)
Mineral Spirits	0.10	131°F (55°C)

3.3.4.3.3 Aromatic Hydrocarbon Solvents

Aromatic hydrocarbon solvents have a closed-chain, six-carbon group (often called the benzene-ring structure) that is the principal part of the molecule. The simplest chemical of this family is benzene. Other examples are toluene (toluol) and xylene (xylol). Aromatic hydrocarbon solvents are active for chlorinated rubber, coal tar, and certain alkyds. They are also used as diluents in combination with other solvents for epoxies, vinyls, and polyurethane materials. Table 3.2 lists some aromatic hydro-carbon solvents and their properties.

Table 3.2: Aromatic Hydrocarbon Solvents

Solvent	Evaporation Rate (n-Butyl acetate = 1)	Flash Rate °F (°C) Closed Cup
Benzene	5.0	10°F (-12°C)
Toluene	2.0	41°F (5°C)
Xylene	0.6	82° (28°C)
High-flash-point Naptha	—	100°F (38°C)

3.3.4.3.4 Ketone Solvents

Ketone solvents are oxygenated hydrocarbons of the acetone family and include methyl ethyl ketone. They are the most effective solvents for vinyls and are often used in epoxies and other resin formulations. Table 3.3 lists some ketone solvents and their properties.

Table 3.3: Ketone Solvents

Solvent	Evaporation Rate (n-Butyl acetate = 1)	Flash Rate °F (°C) Closed Cup
Acetone	9	14°F (-10°C)
Methyl ethyl ketone (MEK)	4	25°F (-4°C)
Methyl iso-butyl ketone (MIBK)	1.6	72°F (22°C)
Methyl iso-amyl ketone (MIAK)	0.5	104°F (40°C)
Cyclohexanone	0.2	129°F (54°C)
Diacetone alcohol	0.2	59°F (15°C)

3.3.4.3.5 Ester Solvents

These are oxygenated hydrocarbons like ketone solvents, but they have a distinctive, pleasant, banana-like odor. Acetate esters are excellent solvents for synthetic resins, including cellulose esters, acrylics, polyvinyl acetate, and polyvinyl butyrate. Ethylene glycol monoethyl ether acetate is used in large quantities in thermoplastic acrylic finishes and is noted as the best slowly-evaporating solvent for those acrylics based on methacrylate resins.

The esters are also used as latent solvents for vinyls and are commonly found in epoxy and polyurethane formulations. Table 3.4 lists some ester solvents and their properties.

Table 3.4: Ester Solvents

Solvent	Evaporation Rate (n-Butyl acetate = 1)	Flash Rate °F (°C) Closed Cup
Ethyl acetate (95%)	4.1	55°F (13°C)
n-Propyl acetate	2.	64°F (18°C)
n-Butyl acetate	1.0	100°F (38°C)
Amyl acetate	0.4	106°F (41°C)
Ethylene glycol monoethyl ether acetate (Cellosolve™ acetate)	0.2	134°F (57°C)

3.3.4.3.6 Alcohol Solvents

Alcohols are oxygenated hydrocarbons and are good solvents for highly polar binders, such as phenolics. Some alcohols are used with epoxies. Table 3.5 lists various alcohol-type solvents and some of their properties.

Table 3.5: Alcohol Solvents

Solvent	Evaporation Rate (n-Butyl acetate = 1)	Flash Rate °F (°C) Closed Cup
Methyl alcohol	6.0	61°F (16°C)
Ethyl alcohol	2.3	75° F (24°C)
Propyl alcohol	1.0	88° F (31°C)
Isopropyl alcohol (91%)	1.6	67° F (19°C)
Butyl alcohol	0.5	115 F° (46°C)
Cyclo-hexanol	< 0.1	154° F (68°C)

3.3.4.3.7 Glycol Ethers

The usual ether used in protective coatings is glycol ether (alcohol ether), e.g., ethylene glycol monethyl ether, commonly known as Cellosolve™. A number of glycol ethers are sold under this designation.

Cellosolve™ is a good solvent for many oils, gums, natural resins, and synthetic resins, such as alkyds, ethyl cellulose, nitro-cellulose, polyvinyl acetate (PVA), polyvinyl butyral, and phenolics. It is a slow solvent and is used in many lacquers to improve flow-out and gloss. These materials are combined with other solvents to help achieve formulations which have higher flash points. Table 3.6 lists some glycol ethers and their properties.

Table 3.6: Glycol Ethers

Solvent	Evaporation Rate (n-Butyl acetate = 1)	Flash Rate °F (°C) Closed Cup
Ethylene glycol monomethyl ether (Cellosolve™)	0.5	115°F (46°C)
Ethylene glycol monobutyl ether (Butyl Cellosolve™)	0.06	165°F (74°C)
Ethylene glycol monethyl ether (Cellosolve™)	0.3	130°F (54°C)
Ethylene glycol	0.06	165°F (74°C)

3.3.4.3.8 Solvent Types and Functions

Three basic types of solvents used in coatings are:

- Active Solvents
- Latent Solvents
- Diluents

3.3.4.3.9 Active Solvents

A binder’s **primary** solvents are called **active solvents**. Active solvents completely dissolve the resin and form a true solution.

3.3.4.3.10 Latent Solvents

Latent solvents generally are not good solvents for binders and, may only swell a binder at room temperature. At somewhat elevated temperatures, however, they may become active enough to form a solution; but on cooling, the solution is likely to become a gel.

Latent solvents are used in coatings that have active solvents; the latent solvents act to regulate solvent evaporation and, in some cases, improve film properties.

3.3.4.3.11 Diluents

Diluents are not true solvents for a resin, but can, when combined with active solvents, dilute the solution. Diluents are used for a variety of purposes, such as to improve film properties such as epoxy flexibility. The combination of an active solvent with a diluent may provide a smoother, stronger film than an active solvent alone. Diluents are often used to reduce costs.

Both **non-reactive** and **reactive** diluents commonly are used to meet VOC requirements that would otherwise be impossible, such as with resin systems using only active or latent solvents. Examples of reactive diluents are mono- and di-functional glycidyl ethers (for epoxy systems) and certain oxazolidine-based materials for urethanes.

3.3.4.3.12 Amount of Solvent

The amount of solvent used in a coating varies with the type of resin and the application procedure. The quantity varies from several percent-by-weight of vehicle (some high-solids epoxy coatings) to roughly 75%-by-weight of vehicle (vinyl or chlorinated rubber).

The volatile content is expressed in terms of either weight or volume percent of the vehicle. When calculated as a percentage of the total coating volume, the volatile content may be as high as 50-90% (vinyl-type coatings) or can be as low as 2% (some ultra-high-solids epoxy coatings).

The high percentage of solvents in vinyls, like high VOCs (volatile organic compounds) that reduced their use in the U.S., Europe, and many other parts of the world.

Adding solvents to a coating at the application stage decreases viscosity and the wet-film thickness (WFT) that can be obtained by ordinary application methods. In turn, the dry-film thickness (DFT) is reduced because the thinning creates a lower volume-solids percentage. This is the primary objection to excessive thinning of coatings (whether it is done in cold weather to make application possible or done falsely thinking it is an “economy”). Adding thinner may also increase the risk of solvent entrapment and may interfere with film formation as the extra solvent evaporates out of the coating.

Many coatings have a significant reduction in viscosity when heated. Often it is better to heat the material rather than thin it. Coatings referred to as “100% Solids” or “Solvent Free” typically must be heated prior to application. Special application equipment is required for these materials. Most of the coatings advertised as solvent free or 100% solids actually do have some solvent, up to 5%. Using these products does not eliminate the need for any of the safety requirements used with traditional solvent-containing coatings. Follow good safety practices and the coating manufacturer's instructions when heating these materials.

3.3.4.3.13 Solvent Safety

The two primary safety concerns in use of solvents are fire hazards and health hazards.

3.3.4.3.14 Fire Hazards

A solvent's flash point is the lowest temperature at which enough vapor has gathered above the liquid to be ignited. Ignition sources include an open flame, static electric sparks, sparks from nails in shoes, sparks from grinding operations, lit cigarettes, and many others.

The lower the flash point, the greater the amount of vapor released from the liquid and the greater the risk of vapor ignition. In other words, the lower the flash point of a solvent, the more highly flammable the solvent, and the more cautious you must be.

3.3.4.3.15 Health Hazards

All solvents are health hazards and should be handled accordingly. In the U.S., **use** National Institute of Occupational Safety and Health (NIOSH)-approved breathing apparatus and protective clothing **at all times**, particularly when handling solvents or when working in enclosed areas. Handle all solvents with care; store them in accordance with local and federal regulations.

3.3.4.3.16 Key Solvent Safety Terms

TLV: Threshold Limit Value — The concentration of airborne material that can be inhaled for a period of time by workers; the TLV is established by pertinent safety regulations (OSHA in the US)

TWA-TLV: Threshold Limit Value (Time-Weighted Average) — Time-weighted average allowable TLV for a stated working period such as an 8-hour day or 40-hour week

STEL-TLV: Threshold Limit Value (Short-Term Exposure Limit) — Maximum concentration to which workers can be exposed for a specific period of time

VOC: Volatile Organic Compound — Referenced in EPA, European, and other regulations that limit the amount of organic solvent allowed in a coating formulation

UEL: Upper Explosion Limit — Maximum concentration in air that will support combustion in air without being too rich

LEL: Lower Explosion Limit — Minimum concentration in air that will support combustion in air without being too lean

PEL: Personal Exposure Limit — Varies according to the material

3.4 Manufacture of Liquid/Liquefiable Coatings

The primary coating manufacturing process involves dispersing the component materials of a formulation to a homogeneous state. As noted in the preceding section, component materials generally are a combination of pigments, resins, and solvents. The specific equipment used to disperse the components is very important since a single type of equipment does not work equally well for all formulations. The equipment used depends on the type of product, batch size, and capacity. Types of dispersion equipment generally used in industry today include:

- Ball/pebble mills.
- Sand mills.
- High-speed dispersers.

The dispersion process is critical to the ultimate performance of the coating. The dispersion process involves multiple stages:

- **Pre-mix stage:** Pigments, resins, and/or solvents are combined in proportions to result in the most efficient dispersion. The proportions depend on the equipment, the specific components, and the batch size.
- **Dispersion stage:** The pigment particles are broken apart and wetted by the liquid binder.
- **Post-dispersion stage:** The remaining resin, solvent, and additives are added. Both the speed and order of addition in this stage

of the process are carefully controlled to maintain homogeneity of the coating.

3.4.1 Ball/Pebble Mills

Ball/pebble mills are hollow, cylindrical shells that contain grinding media. They may be lined with a burrstone or porcelain block, and use natural flint pebbles or porcelain balls as the grinding media. Dispersion is accomplished by the tumbling or cascading action of the grinding media as the mill rotates (from 16 to 60 hours depending on the formulation). The shear and impact forces produce a very fine grind. After initial grinding, the remaining vehicle and solvents are added, dispersed, and then discharged from the mill.

3.4.2 Sand Mills

A sand mill is a continuous-process disperser that uses sand and other aggregates as the grinding media. Shear force generated by the movement of one sand grain against another achieves dispersion. Rotating disks continuously move the sand/liquid mixture and so disperses the premixed material. The dispersed material passes through retainer screens that hold back the sand.

3.4.3 High-Speed Dispersers

High-speed dispersers generally blend materials that do not need a fine grind, or pre-mix high-viscosity materials, which then are processed in a roller mill. High-speed dispersers consist of two counter-rotating blades. Dispersion is accomplished by shear force.

The high-speed disperser has a disk impeller. The configuration of the impeller varies with manufacturer, but is equipped with a variable motor. Dispersion results from a combination of shear force and attrition. The particle size is reduced by attrition as the particles contact each other and the serrated disk.

3.4.4 Quality Control in Manufacturing

Quality control is essential during coating manufacture to ensure proper dispersion of the pigments used. This is done with a draw-down of the mixed material, with an evaluation to determine the fineness of grind. Other tests are conducted to ensure quality of viscosity, weight-per-liter (-gallon), spray-ability, solids, cure, color, and gloss.

3.5 More on Coatings

While it is common to refer to coating materials by their curing mechanism, neither this classification system nor many others account for the **broad range of properties possessed by generically similar coatings**. There are numerous ways to get good information, including:

- **The manufacturer**: Get the **most current** and **specific information** about the properties and performance of coatings straight from the manufacturer.
- **The Internet:** Other than information directly from the manufacturer, this is the best place to look for accurate information.
- ***The Protective Coating User's Handbook:*** by Lou D. Vincent, PhD
- ***Corrosion Prevention by Protective Coatings (Second Edition)***: by C.G. Munger

Chapter 4: Coating System Selection

Objectives

Upon completion of this training material, you will be able to:

- Describe single-coat systems.
- Describe multi-coat systems.
- Determine factors to consider when selecting a coating system.

Introduction

The three main types of coating systems presented in this chapter are:

- Single-coat systems.
- Multi-coat systems of the same generic type.
- Multi-coat systems of different generic types.

4.1 Single-Coat Systems

A single-coat system consists of only one layer of coating and is **most** commonly used when:

- Only a short life is required, such as when structural steel is coated at the mill to protect it until it is properly blast cleaned and coated at the construction site.
- It is applied for purely decorative reasons, such as in the interior of a house or office.
- The coating is specifically formulated for one-coat application, i.e., solvent-free high-build urethanes and epoxies, or certain types of zinc-rich coatings.

Some problems frequently encountered with single–coat systems are:

- Solvent entrapment in thick films.
- Holidays, or other exposed areas of the substrate, and misses

- Difficulty in maintaining specified coating thickness and uniformity

Adding a stripe coat to welds, edges, and corners can significantly improve single-coat systems.

4.2 Multiple-coat Systems

There are two categories of multiple-coat systems:

- The same coating applied in a number of layers.
- Different coatings applied in a number of layers.

4.2.1 Multiple-coat Systems with the Same Coating

These systems are generally applied in contrasting colors and are often formulated so the coating can be used as both a primer and a topcoat. Many systems, including epoxies, are used this way. The use of multiple barrier coats is the result of the *impermeable coating concept* since any *single* organic coating is permeable to some degree.

4.2.2 Multiple-coat Systems with Different Coatings

These systems are made up of multiple applications of different generic types of coatings. They are most frequently found on structures with exposed exterior structural steel like offshore platforms and highway bridges. Because these structures are usually subjected to extreme environmental conditions, the systems generally use two or three types of coatings. Examples are: a zinc-rich primer with an epoxy topcoat; or a zinc-rich primer, an epoxy intermediate coat, with a urethane topcoat.

4.2.2.1 Components of Multiple-coat Systems

Primers

Primers are a class of coating used within a multi-coat system. It is the first coating applied to the work piece and it must:

- Adhere to the substrate.
- Provide a base for subsequent applications of coatings.
- Protect the substrate against corrosion by acting as a corrosion inhibitor, a barrier coating, or a sacrificial coating.

Primers are often named according to their pigment. There are three types of primers: galvanic (or sacrificial), inhibitive, and barrier.

Galvanic/Sacrificial Primers: Galvanic primers have high concentrations of metallic zinc and actively protect the steel substrate, much like zinc galvanizing. Zinc in electrical contact with steel protects the steel by sacrificing itself, acting as an anode.

Galvanic primers also provide electrochemical protection to steel even if the steel is exposed at small discontinuities such as breaks, scratches, etc. This protection is localized and does not extend for more than a fraction of an inch from the source of the zinc coating.

Inhibitive Primers: To create a rust-inhibitive primer, inhibitive pigments are added to the coating during manufacture. Inhibitive pigments interact with corrosion-promoting influences (e.g., water vapor passing through a coating) to modify the chemical conditions at the substrate and thus slow down or prevent (inhibit) corrosion.

Commonly used inhibitive pigments are:

- Red lead.
- Zinc phosphate.
- Barium metaborate.
- Strontium chromate.
- Zinc chromate.

Health and safety issues are particularly important with inhibitive primers, since many of the traditional inhibitors are based on heavy metals.

Barrier (Non-Inhibitive) Primers: These primers, like most coatings, form a protective barrier. Barrier primers range from highly cross-linked phenolic or epoxy types to a lacquer type of coating. The only difference between these primers and their topcoats is the modification of the formulation to improve surface wetting characteristics and, therefore, adhesion properties.

Intermediate Coats (Mid-Coats): The mid-coats in a multi-coat system are typically added to the system to improve the barrier characteristics of the system.

All organic coatings are permeable to some extent and will allow some passage of water vapor, oxygen, and other vapors through the cured coating film. Some resins are more effective than others.

Most coating systems become more permeable as the amount of pigmentation is increased. Materials used for mid-coats are frequently modified by adding certain pigments (e.g., lamellar pigments) to reduce water permeability. Their DFT may also increase by adding inert fillers and thickening agents to give high-build properties.

High-build ***does not equal*** *low permeability*; some pigment shapes and quantities may actually encourage water vapor transfer via wicking.

Finish Coats: Finish coats are often chosen for their appearance, i.e., good color retention, low levels of chalking, and good gloss. But their function generally goes far beyond that. A smooth finish helps discourage retention of surface contamination and allows rain to wash away deposits, both of which benefit appearance and corrosion resistance. Specific resins require small quantities of nodular shaped pigments to achieve a smooth finish. Some exposures need increased chemical or solvent resistance; the correct finish coat can supply that. Finally, a finish coat with good UV resistance can help minimize degradation of the resin binder.

4.3 Factors to Consider

When selecting a coating system, there are numerous factors to consider:

- Type of exposure
- Operating conditions/upset conditions
- Substrate (type and condition)
- Atmospheric conditions during application

- Environmental regulations and constraints
- Budget
- Application during facility operation or shutdown
- Application Labor
- Time constraints
- New construction/maintenance
- Shop/field application
- Design/fabrication considerations
- Government and Industry Regulations

4.3.1 Type of Exposure

Always select coating systems according to exposure zone conditions, which define the type of environment where the coating will serve. Table 4.1 provides one classification of exposure zones.

Table 4.1: Common Exposure Zones

Type of Exposure		
Level of Severity	Zone	Zone Conditions
Least Severe	0	Dry interiors where structural steel is imbedded in concrete, encased in masonry, or protected by membrane or non-corrosive contact-type fireproofing
	1A	Interior, normally dry (or temporary protection)Very mild (oil-based paints now last ten years or more)
	1B	Exteriors, normally dry (includes most areas where oil-based paints now last six years or more)
	2A	Frequently wet by fresh water. Involves condensation, splash, spray, or frequent immersion (oil-based paints now last five years or less)
	2B	Frequently wet by salt water. Involves condensation, splash, spray, or frequent immersion (oil-based paints now last three years or less)
	2C	Fresh water immersion
	2D	Salt water immersion
	3A	Chemical exposure, acidic (pH 2.0 to 5.0)
	3B	Chemical exposure, neutral (pH 5.0 to 10.0)

	3C	Chemical exposure, alkaline (pH 10.0 to 12.0)
	3D	Chemical exposure, presence of mild solvents. Intermittent contact with aliphatic hydrocarbons (mineral spirits, lower alcohols, glycols, etc.)
Most Severe	3E	Chemical exposure, severe. Includes oxidizing chemicals, strong solvents, extreme pHs, or combinations of these with high temperatures

4.3.1.1 Atmospheric Environments

Table 4.2 compares atmospheric environment standards ISO 12944-2: 1998 and U.S. Corrosion Professionals

Table 4.2: ISO 12944-2:1998 Atmospheric Corrosivity Category vs. U.S. Corrosion Professionals

ISO 12944-2: 1998	U.S. Corrosion Professionals
C1 - Very Low	Rural
C2 - Low	Rural/Low Humidity
C3 - Medium	Chemical/Low Humidity
C4 - High	Marine High Humidity
C5-I - Very High (Industrial)	Chemical/High Humidity
C5-M - Very High (Marine)	Chemical/Marine

4.3.1.2 Operating Conditions vs. Upset Conditions

The operating conditions of a particular structure are usually the major factor in coating selection. If a structure or facility operates at high temperatures and is exposed to acid fumes, the selected coating must withstand both conditions to be effective. Specific exposure zones on the structure or within a facility also need to be considered.

Upset conditions *are a change in equipment operations* that could damage or destroy a coating. For example; a vat is properly coated on its interior to hold an acid, and the exterior coating is only mildly resistant. But, if the vat overflows, the exterior coating fails. So the upset condition indicates the need to apply a highly acid-resistant coating to the exterior.

4.3.2 Substrate

Substrate type and condition affect the chemical compatibility, thermal compatibility, flexing, and adhesion of the coating. A wide variety of coatings works well on a ferrous metal substrate that is abrasive-blast cleaned. However, if the surface is mechanically cleaned, a good coating choice is one which also has good wetting properties.

4.3.3 Atmospheric Conditions During Application

Ambient temperature, relative humidity, dew point, and surface temperature can affect coating selection.

4.3.3.1 Ambient Temperature

Manufacturers' data sheets usually detail the recommended ambient temperature range for application. Some coatings do not adhere to the surface correctly or have a shorter pot life at higher ambient temperatures.

4.3.3.2 Relative Humidity

Some coatings, such as certain types of inorganic zinc coatings, require high humidity to cure. However, most coatings are negatively affected by high humidity. The upper relative humidity limit at which a coating can be effectively applied is usually included in the manufacturer's data sheet.

4.3.3.3 Dew Point

Dew point is a function of temperature and relative humidity. It is the temperature at which water condenses at a given relative humidity. If the substrate is below this temperature, water condenses on the surface. Because thermometers are not always accurate and structures have areas of temperature difference, always factor in a margin of safety by requiring the surface temperature to be higher than the dew point. It is common to require a substrate temperature about 5°F (3°C) higher than the dew point during surface preparation and coating application. Also, if weather forecasts indicate the ambient temperature will reach the dew point before the coating cures, delay application.

4.3.3.4 Surface Temperature

A high or low surface temperature can affect the application and curing of a coating. If the temperature is too low, invisible ice can form on the substrate or a convertible coating reaction may slow too much for a proper cure. A temperature that is too high may boil off parts of the liquid coating before it has time to cure.

4.3.4 Environmental Regulations

In some areas, government environmental regulations may restrict the use of certain coating materials or application techniques, such as:

If dry abrasive blast cleaning is restricted and the steel surface is cleaned by hand or mechanically, select a coating that wets the surface well. Coatings designed for application over these surfaces are more effective than a coating that needs a high level of surface preparation.

If solvent emissions are regulated, use water-borne coatings, coatings with high solids (low VOCs), or coatings that are formulated with approved solvents.

4.3.5 Budget

Some projects may require the most expensive system available. However, in **mos**t cases, budget considerations influence coating system selection. Costs range from low-cost alkyds to expensive zinc/epoxy/urethane coatings and reinforced linings. It is important to recognize that material cost is typically a small portion of the overall installed cost. Budgets should consider all tangible and intangible costs. Intangible costs may include lost production, equipment downtime, and inconveniences.

4.3.6 Operation or Shutdown Conditions

Consider conditions during operation or shutdown when selecting a coating.

Metal temperature: If a metal with a high temperature needs coating, select a coating that can be applied to a hot surface and perform at the required temperature. Conversely, when coating low-temperature metal or when moisture is present, select a coating that can handle low temperatures and damp surfaces.

Application methods: Spray application may not be an option if a unit is operating. Select coatings that flow well and can be applied by brush or roller.

Recoat time: A coating with a shorter recoat time may be better for prevailing conditions than a better performing coating with a longer recoat time.

Personnel: When operating personnel must be in or near the coating area, select a coating with a low level of solvent fumes.

Safety: When applying coatings near spark or fire hazards, choose a coating that is not affected by those hazards.

Time pressure: During a shutdown, the pressure to complete the job as quickly as possible may determine the coating selection.

4.3.7 Application: Labor

The complexity of a coating system may determine whether a company uses contract labor or in-house labor for coating application.

4.3.8 Time Constraints

The time allowed to complete a coating project may affect coating selection. A coating may be needed that has a reasonable film build and short recoat time. When a commercial ocean-going ship is dry-docked for bottom inspection and maintenance, the normal time frame to clean and paint the entire underwater hull is only ten days.

4.3.9 New Construction/Maintenance

New construction projects usually require a complete coating system. Surface preparation and exposure considerations may dictate the coating choices. With maintenance work, new coatings must be compatible with in-place coatings as well as with limited surface preparation.

4.3.10 Shop/Field Application

If coating is done entirely in a shop or entirely in the field, the selection of coatings may be unlimited. However, if the coating is done in a combination of shop and field, the coating choices are limited. If cleaning and priming are done in the shop, the primer must be able to withstand exposure to the atmosphere until the topcoat is applied in the field. Drying time can also be a requirement in certain shop applications.

4.3.11 Design/Fabrication Considerations

Structures that are designed to be coated are often easier to keep corrosion-free. These structures should be as simple as possible with as little exposed surface area as possible. Common design issues that make coating difficult:

- **Inaccessible areas** accumulate dirt and moisture and can be difficult to reach with either a brush or spray. Coatings applied to gouges may bridge over the gouge creating a void where corrosion can occur.
- **Rivets** and **bolts** increase the chances for crevices and other surface discontinuities around their edges. Air, chemicals, and moisture can easily penetrate these areas, increasing the opportunity for corrosion.
- **Gaps** between adjacent structural components can accumulate sand, dirt, and moisture, as well as abrasive material; they also create areas that are difficult to coat effectively.
- **Angles** present the most problems since coatings have a tendency to become thinner at edges and exterior corners.
- **Threaded areas** are difficult to coat evenly. When possible replace threaded outlets with more accessible pad-type outlets.
- **Dissimilar metal**s can become connected by an electrolyte and cause galvanic corrosion. To avoid this, coat the entire alloy, as well as the steel.

4.3.12 Fabrication Defects

The following fabrication defects also influence coating selection:

Imperfect welds with irregular or rough areas can present coating problems and lead to corrosion failure.

Weld spatter (the small balls of metal which fly away during welding and stick to the surface) can cause the coating to flow away from them and become thin. Crevices can also form at the base of the metal balls, creating areas that coatings cannot penetrate well.

Skip welds are areas with five to eight centimeters of welding, several centimeters of non-welded area, then another welded area of five to eight centimeters. The lack of a continuous seam creates a crevice, which is impossible to fill with a coating.

Rough welds can leave jagged ridges or spikes that are difficult to coat. Rough welds should be ground smooth to eliminate sharp edges and other surface irregularities.

Laminations, scabs, rollovers, and defects of this type can interfere with proper coating application; holidays often result.

Gouges are sharp indentations that can be difficult to coat completely. Voids may form since the coating cannot be applied uniformly on the surface.

Sharp corners and **edges** frequently cause the coating to thin thus allowing corrosion to build up along the edge. Sharp **bends** and **angles** can create voids under a coating, which trap moisture and air, promoting corrosion.

4.3.13 Government and/or Industry Regulations

Certain markets have specific coating requirements to meet governmental regulations. The International Maritime Organization (a committee of the U.N.) requires coating systems to have been tested in accordance with the “Performance Standard for Protective Coatings” (PSPC) before they can be used in the ballast tanks of certain ship types. The U.S. Nuclear Regulatory Committee regulates the coating systems used inside of nuclear power plants. Other organizations regulate coatings for offshore oil platforms, food handling, and petroleum pipelines. A protective coating specialist has to be fully aware of the regulations covering the industry.

4.4 Candidate Coating Systems

After the requirements for the coating system are identified, examine the candidates in more detail. A well-conducted selection and evaluation process includes:

- **Referrals** and/or **recommendations**, i.e., reports issued by professional associations such as NACE, the advice of knowledgeable professionals (certified protective coating specialists, vendors, peers, contractors, and consultants, etc.).
- Actual **performance tests** of candidate systems.
- **Experience** and **informed judgment**.
- A **comprehensive survey** of available products, examining major variables.

4.4.1 Variables to Consider

4.4.1.1 Cost

Examine candidate coating systems' past performance data. If two coating systems are similarly effective and offer the same protection in the same service conditions, but one system costs twice as much, all other things being equal, the less expensive system is the better choice.

4.4.1.2 Cost-Benefit

Candidate coating systems generally offer a *range* of performance for a *range* of costs. Conduct tests to obtain information specific to the expected coating service conditions. Weighing a coating's performance against various service conditions helps determine a more cost-effective coating.

4.4.1.3 Service Life

Always consider how long the coating system needs to function. A longer service life isn't always warranted. Two good examples: equipment with a 5-year design life doesn't need a 20-year coating system, nor do structures that require periodic coating removal to perform testing.

4.4.1.4 Accessibility

The cost of accessing a structure, e.g., critical process equipment, unmanned structures in remote locations, excessively high structures, offshore wind turbines, is often the cost driver in coating applications. The costs of access may dictate selection of a costlier, longer-lasting system.

4.4.1.5 Surface Preparation Requirements

Some surface preparation methods are not feasible in certain situations. These coating systems are easy to eliminate from the pool of candidates, because they simply are not feasible.

4.4.1.6 Performance in Specific Tests

Most manufacturers publish data for their coatings in a variety of standardized tests. Compiling the data for a range of candidate systems can help identify equivalent systems suitable for a specific application.

A few of the most common tests are:

- Salt Fog.
- Adhesion.
- Abrasion.
- Hardness.

4.4.1.7 Qualification of Specific Vendors

Assess products on the manufacturers' credentials. To compare coating manufacturers it is a good idea to consider:

- Technical competence.
- Quality of raw materials.
- Manufacturing quality control.
- Manufacturing record keeping.
- Field technical service.
- Operations aspects (supply, support, etc.).

Chapter 5: Surface Preparation

Objectives

Upon completion of this training material, you will be able to:

- Understand the purpose of surface preparation.
- Identify surface preparation errors/omissions.
- Describe commonly used surface preparation standards and the techniques, material, and equipment used with each.
- Describe surface preparation methods for concrete
- Describe surface preparation quality control tests

5.1 Purpose of Surface Preparation

Premature coating failures are commonly caused by inadequate or improper surface preparation. There are many tools, techniques, and methods to prepare surfaces for coating, as well as a large number of very specific standards for various types and degrees of surface preparation, as well as governmental safety and environmental regulations. All of these factors contribute to a properly prepared substrate ready for a coating to be applied.

A properly prepared surface ensures that the coating, chosen for its specific purpose and its specific service environment, will succeed and successfully protect the substrate against the damaging incursions of corrosion for the full length of its expected service life. Without a properly prepared surface — there are *no* guarantees.

A successfully prepared surface is the result of knowledge, experience, training, and keen attention to detail by many coatings professionals.

This chapter covers the standards that govern surface preparation methods, the various methods themselves, and their techniques and tools. Not all of the surface preparation methods are easily categorized or fit into the two large categories of blast cleaning methods (abrasive and non-abrasive), but all methods are presented.

5.2 Surface Preparation Errors and/or Omissions

Many surface preparation errors and/or omissions adversely affect the life of a coating:

- **Residues of oil, grease, and soil**: can prevent adhesion (or mechanical bonding) of the coating to the surface
- **Residues of various chemical salts**: can induce corrosion
- **Rust on the surface**: interferes with coating adhesion to the surface
- **Loose or broken mill scale**: can cause early coating failure
- **Tight mill scale**: can cause later failure
- **Rust scale**: cannot be protected by any coating, and prevents coatings from maintaining adhesion to steel
- **Improper anchor pattern**: may be *so deep* that peaks cannot be adequately protected with coating, or *too shallow*, causing coating failure from loss of adhesion
- **Sharp ridges, burrs, edges, or cuts** from mechanical cleaning equipment: can prevent adequate coating thickness over the irregularities
- **Surface condensation**: if coated over can result in blistering and delamination failure
- **Old coatings**: may have poor adhesion, may be incompatible with new coatings, or may be too deteriorated to recoat

5.3 Surface Preparation Standards

This section contains names and descriptions of various surface-cleaning standards. These are **not** the complete standards. Always obtain a copy of the most recent edition of any standard that relates to an upcoming coatings project and study it thoroughly prior to beginning the project.

Several organizations publish standards for the preparation of surfaces to be coated. The more notable ones are:

- NACE International
- SSPC — The Society for Protective Coatings
- ISO — International Organization for Standardization

In 1994 NACE and SSPC united to publish the first in a series of joint standards on surface preparation. The NACE and SSPC versions of these abrasive and waterjetting standards, listed below, are identical in wording to one another.

5.3.1 NACE/SSPC Joint Surface Preparation Standards

NACE No. 1/SSPC-SP 5	White Metal Blast Cleaning
NACE No. 2/SSPC-SP 10	Near-White Metal Blast Cleaning
NACE No. 3/SSPC-SP 6	Commercial Blast Cleaning
NACE No. 4/SSPC-SP 7	Brush-Off Blast Cleaning
NACE No. 6/SSPC-SP 13	Surface Preparation of Concrete
NACE No. 8/SSPC-SP 14	Industrial Blast Cleaning
NACE WJ-1/SSPC-SP WJ-1	Waterjet Cleaning of Metals-Clean to Bare Substrate (WJ-1)
NACE WJ-2/SSPC-SP WJ-2	Waterjet Cleaning of Metals-Very Thorough Cleaning (WJ-2)
NACE WJ-3/SSPC-SP WJ-3	Waterjet Cleaning of Metals-Thorough Cleaning (WJ-3)
NACE WJ-4/SSPC-SP WJ-4	Waterjet Cleaning of Metals-Light Cleaning (WJ-4)

Copies of some of the NACE standards mentioned are included in the appendix of this course.

5.3.2 SSPC Surface Preparation Standards

SSPC-SP 1	Solvent Cleaning
SSPC-SP 2	Hand Tool Cleaning
SSPC-SP 3	Power Tool Cleaning
SSPC-SP 8	Acid Pickling
SSPC-SP 11	Power Tool Cleaning to Bare Metal
SSPC-SP 15	Commercial-Grade Power Tool Cleaning

5.3.3 International Organization for Standardization (ISO)

ISO 8501-1 contains descriptions of grades of cleaning for new steel or steel that has had all of a previous coating removed:

Sa 3	Blast Cleaning to Visually Clean Steel
Sa 2-½	Very Thorough Blast Cleaning
Sa 2	Thorough Blast Cleaning
Sa 1	Light Blast Cleaning
St 3	Highly Extensive Manual and Electromechanical Cleaning
St 2	Extensive Manual and Electromechanical Cleaning

ISO 8501-2 contains descriptions of grades of cleaning for previously coated steel that has had localized removal of the coating. These use the prefix "P" in their description:

P Sa 3	Localized Blast Cleaning To Visually Clean Steel
P Sa 2½	Very Thorough Localized Blast Cleaning
P Sa 2	Thorough Localized Blast Cleaning
P St 2	Thorough Localized Hand And Power Tool Cleaning
P St 3	Very Thorough Localized Hand And Power Tool Cleaning

5.3.4 Initial Conditions

All of the surface preparation standards (NACE, SSPC, or ISO) are based on a **visual assessment** of the cleaned surface. The visual appearance of a steel surface after cleaning depends in part on the condition of the surface prior to cleaning. All of the standards agree that the following initial conditions of new steel are the most common and they agree on the essential definitions of each although they are not identical. The following definitions are from ISO 8501-1:

Grade A: New Steel	**Adherent Mill Scale** – Steel surface largely covered with adhering mill scale but little, if any, rust
Grade B: New Steel	**Rusting Mill Scale** – Steel surface that has begun to rust and from which the mill scale has begun to flake
Grade C: New Steel	**Rusted** – Steel surface on which the mill scale has rusted away or from which it can be scraped, but with slight pitting visible under normal vision
Grade D: New Steel	**Rusted and Pitted** – Steel surface on which the mill scale has rusted away and on which general pitting is visible under normal vision

5.3.5 Visual Guides for Surface Preparation

Both SSPC and ISO have booklets that contain very clear color photographs of surfaces in their initial condition and after cleaning to various degrees of cleanliness.

These guides assist those viewing the surface to determine if it meets the requirements of a particular standard. Do not confuse these visual guides with the verbal standard called for in a project contract or specification.

Table D.7, "Surface Preparation." (SEE BACK OF MANUAL TAB D)

5.4 Solvent Cleaning, SSPC-SP 1

Solvent cleaning removes all visible oil, grease, soil, drawing and cutting compounds, and other soluble contaminants from steel surfaces. Use solvent cleaning just prior to coating application, and in conjunction with surface preparation methods specified for the removal of rust, mill scale, or paint.

Solvent cleaning materials include:

- Organic solvents .
- Alkaline cleaners.
- Acidic cleaners.
- Detergents.
- Emulsion cleaners.
- Water/steam.

5.4.1 Organic Solvents

Organic solvents include kerosene, turpentine, naphtha, mineral spirits, toluene, and xylene. They clean metal by dissolving and diluting the oil and grease contamination on the surface. Inorganic materials, such as chlorides, sulfates, weld flux, and mill scale, cannot be removed by organic solvents. Some solvents, especially coal tar solvents (e.g., xylene and toluene) also dissolve some coating vehicles. In general, cost considerations and regulations restricting the use of organic solvents are so stringent that organic solvents are primarily used only in highly controlled special situations.

Use clean solvent for the last wash or rinse, or a slight film of oil or grease may be left on the surface when the solvent of the last washing evaporates. That remaining film could interfere with coating adhesion.

Use petroleum-based mineral spirits with a minimum flash point of 100°F (38°C) as a general-purpose solvent under normal conditions. In 80 to 90°F (28 to 32°C) weather, use high-flash-point mineral spirits with a minimum flash point of 50°C (120°F).

All solvents are potentially hazardous, so always use in accordance with current federal, state, and local regulations for threshold limit values. Use appropriate fresh-air masks in confined spaces and when the safe concentration may be exceeded. Ensure the fresh air is free of carbon monoxide (CO) or other contaminants from sources such as combustion engines. Make sure the concentration in air does not exceed 10% of the lower limit of flammability, or a fire or explosion could occur.

5.4.2 Alkaline Cleaners

Alkaline cleaners include trisodium phosphate (TSP) and sodium hydroxide. They saponify certain oils and greases, and their surface-active components wash away other contaminants such as oils. The soaps formed by these cleaners can be washed away with water.

These cleaners often are combined with surfactants (wetting agents), inhibitors, and detergents to form proprietary products. These products are often used at elevated temperatures. Always follow the manufacturer's use recommendations.

During cleaning, a slightly soapy film may remain on the surface. Use a high-pressure, hot-water rinse to remove this film. Otherwise, the residue can compromise the coating's adhesion to the metal. Use a pH paper test to determine the effectiveness of the wash. In general, the pH of the washed surface should not exceed the pH of the wash water.

In some cases, owners may elect to use an acidic wash, such as 0.1%-by-weight chromic acid, sodium dichromate, or potassium dichromate, to neutralize traces of the alkali on the surface.

Strictly follow safety precautions when using alkaline cleaners. The alkaline materials can cause burns. Ensure workers follow all requirements detailed on the product data sheets and MSDS. At a minimum, wear rubber gloves and safety goggles or eyeglasses. Use respirators when these materials are spray applied.

5.4.3 Acidic Cleaners

Acidic cleaners are usually composed of fairly strong acids, such as phosphoric acid, with small quantities of surfactants, water-miscible solvents, and organic wetting and emulsifying agents.

Acidic cleaners remove soil by chemical attack and by dissolving the reaction products. They can also be used to remove corrosion products or for other special purposes. Acidic cleaners can pose health and safety hazards. As with all materials, consult the product MSDS for safety requirements.

5.4.4 Detergents

Strict regulations about the use of organic solvents and the safety hazards from use of alkaline or acidic cleaners have led to the increasing use of detergents, especially the biodegradable types, to remove oil, grease, and other similar contaminants from surfaces.

These cleaners are generally composed of buffering salts, dispersants, soaps, and inhibitors. They wet, emulsify, disperse, and dissolve the contaminants, which are then washed away with hot water or steam. They are frequently used at temperatures ranging from 150° to 212°F (65° to 100°C).

5.4.5 Emulsion Cleaners

Emulsion cleaners are proprietary products, so use them in accordance with the manufacturers' instructions. Emulsion cleaners contain oil-soluble soaps or emulsifying agents, buffering salts, dispersants, and inhibitors, along with kerosene or some type of mineral spirits. They are formulated to spray onto the surface where they, like detergents, wet, emulsify, disperse, and dissolve the contaminants.

Generally, emulsion cleaners leave a film of oil on the surface. Wash this away with hot water, steam, solvents, detergents, or some type of alkaline cleaning agent.

5.4.6 Water and/or Steam

Water and/or steam are very powerful solvents and are effective surface cleaners. Water blast cleaning and waterjetting are surface preparation methods presented in subsequent sections of this chapter.

5.5 Hand Tool Cleaning, SSPC-SP 2

The hand tool cleaning method to prepare steel surfaces uses non-power hand tools. This method removes all loose rust, mill scale, paint, and other detrimental foreign matter. Hand tool cleaning is **not** intended to remove adherent mill scale, rust, and paint. *Mill scale, rust, and paint are considered adherent if they cannot be removed by lifting with a dull putty knife*.

Hand cleaning is one of the oldest methods of non-abrasive blast cleaning. It is generally used:

- When power-operated equipment is not available.
- Where work is inaccessible to power tools.
- Where the job is too small to warrant the use of power tools.

Hand cleaning tools include:

- Wire brushes.
- Scrapers.
- Chisels.
- Knives.
- Chipping hammers.

Hand tool cleaning procedures include:

- Inspecting the surface to determine the presence of rust, oil, grease, dirt, or other visible contaminants.
- Pre-cleaning with solvent/emulsion cleaners to remove the oil, grease, or dirt (rust should be chipped away) per SSPC-SP 1.
- Cleaning the surface with hand tools.
- Inspecting the surface before coating.
- Applying the coating within the time required by the specification.

5.6 Power Tool Cleaning, SSPC-SP 3

Power tool cleaning uses power-assisted hand tools to prepare steel surfaces for coating. This method removes all loose rust, mill scale, paint, and other detrimental foreign matter, but is **not** intended to remove adherent mill scale, rust, and paint. As in SSPC-SP 2, mill scale, rust, and paint are considered adherent if they cannot be removed by lifting with a dull putty knife.

Maintenance operations frequently use power tool cleaning. In addition to removing loose mill scale, rust, and paint, power tool cleaning removes weld flux, weld spatter, and laminations. It also smooths out rough welds and rounds out gouges before abrasive blast cleaning.

Power-tool cleaning tools include:

- Rotary wire brushes.
- Impact tools.
- Chipping/Scaling hammers.
- Needle scalers.
- Air-operated needle scalers.
- Piston scalers.
- Rotary scalers.
- Grinders and sanders.
- Air-operated right-angle grinders.

Rotary Wire Brushes

There are two general types of rotary wire brushes:

- Straight or in-line
- Vertical or right-angle

Before using rotary wire brushes, solvent clean the surface. This is essential since the tools easily spread oil and grease. Be very careful not to overwork the surface with the rotary wire brush; excessive burnishing can develop a polished surface, which is a poor anchor for most coatings.

Impact Tools

Scrapers and special chisels are mounted into pneumatically- or electrically-powered impact tools. Rotary impact tools operate on the same basic principle as the other impact tools, i.e., through a cutting or chipping action. However, rotary tools use centrifugal force rotating the cutters or hammers at high speed and throwing them against the surface to be cleaned. Use these types of tools to remove heavy deposits of rust scale, mill scale, old coatings, weld flux, slag, and other brittle products from a metal surface.

Chipping/Scaling Hammer

Chipping or scaling hammers are the most widely used type of impact tool in coating surface preparation. Insert a chisel into a power tool; the impact (from an air-operated or electrically-operated piston) is transmitted to the chisel and, in turn, to the surface. Chisels are different shapes and materials and should be kept sharp; otherwise, they can drive rust and scale into the surface. Scaling or chipping hammers are generally a slow, costly method to clean surfaces, but in some cases (such as when considerable rust scale or heavy paint formation must be removed), they prove to be economical.

Needle Scalers

A needle scaler uses a head fitted with a bundle of spring-mounted needles positioned forward of the striking piston rather than a chisel. The piston strikes the needles simultaneously, propelling them against the surface which removes rust and scale from the surface on impact. The needle scaler is effective on welds, corners, and irregular surfaces.

Air-Operated Needle Scalers

Some needle scalers fitted with vacuum devices are used to remove lead-based coatings in a manner compliant with federal regulations for lead abatement.

Piston Scalers

Piston scalers are similar to scaling hammers, but the piston also acts as the impact tool. A hammer piston takes the place of the chisel. It is a circular shaft with a cross shaped cutting end, somewhat like a star chisel. These scalers can have one, two, or three pistons operating in one tool. Also, some scalers have large assemblies with as many as 15 pistons. These are designed to work on flat, horizontal surfaces, such as steel decks.

Small, lightweight, pneumatic chippers are particularly well adapted to clean welds. Clearly, a wide variety of chisels are available for different types of work.

Use great care with these tools; there is a tendency to cut into the surface excessively, removing sound metal while leaving sharp burrs where the coating can fail prematurely. However, a skilled operator uses the cutting action of the sharp chisels to not only clean the surface, but to shape sharp edges into rounded or less-sharp areas

These tools can remove some tight mill scale and surface rusting, but in general practice, this is not the most practical or economical method. There is a high possibility of gouging the metal, which must then be smoothed to do a thorough job.

Rotary Scalers

Rotary scalers work well to remove rust and scale on large areas. Use care to avoid cutting the metal to the extent that metallic points extend far above the surface. A surface profile with high points can cause early coating failure due to insufficient coverage.

Using these tools to remove mill scale and rust is very likely to leave a very rough surface. Take care to ensure that all peaks of the anchor pattern are covered by the coating.

Grinders and Sanders

Grinders and sanders are also used to prepare surfaces for coating. Use the same power tools as those used to power wire brush clean; just substitute the suitable sanding discs or grinding wheels for the wire brushes.

Air-Operated, Right-Angle Grinder

Select the proper abrasive size to use with this type of cleaning equipment. Too coarse an abrasive creates a deep anchor that can be unsuitable for good coating performance, whereas an abrasive that is too fine can clog the grinding wheel or sanding disc, causing wasted time and inefficiency.

Grinders work well to remove weld spatter, smooth weld seams, or to round off sharp edges or corners. They are frequently used to repair minor fabrication defects. They can produce an extremely good anchor profile and completely remove rust and mill scale. However, such cleaning methods are very expensive for large areas.

Sanders

Pneumatic- and electrically-operated sanders have a flat pad or abrasive surface to clean the metal. Some of the motor-driven sanders have an orbital motion.

5.7 Power Tool Cleaning to Bare Metal, SSPC-SP 11

In 1989, SSPC adopted a new standard, SP 11, *Power Tool Cleaning to Bare Metal*. This standard details power tool cleaning to produce a bare metal surface which retains or produces a profile for circumstances where a clean, roughened, bare-metal surface is desired but where abrasive blast cleaning is not feasible or is not allowed.

Metallic surfaces prepared according to SSPC-SP 11, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, mill scale, rust, paint, oxide, corrosion products, and other foreign matter. Slight residues of rust and paint may be left in the lower portion of pits, if the original surface is pitted.

Power tool cleaning in accordance with this standard produces a greater degree of cleaning than SSPC-SP 3 or SSPC-SP 15; however, surfaces prepared according to SP 11 should not be compared to surfaces prepared by abrasive blast cleaning.

Although this method produces surfaces that *look* like near-white or commercial blast, they are **not** equivalent to those surfaces produced by abrasive blast cleaning as called for in NACE No. 2/ SSPC-SP 10 and NACE No. 3/SSPC-SP 6.

5.8 Power Tool Cleaning to Commercial Grade, SSPC-SP 15

A commercial grade of power tool cleaning falls between an SSPC-SP 3 and SP11. Like SP11 it also requires a minimum of a 1 mil (25 micron) profile. As with most of the cleaning standards, this one requires that when viewed without magnification, the surface shall be free of all visible oil, grease, dirt, rust, coating, oxides, mill scale, corrosion products, and other foreign matter.

The major difference between SP15 and SP11 is that SP15 allows staining of less than 33% to remain on the cleaned surface.

The peaks and valleys of the profile on the surface shall form a continuous pattern with no smooth, un-profiled spots in between. The appearance of a profile created by power tool cleaning is different from the appearance of a profile created by abrasive blast cleaning. Do **not** confuse power tool cleaning to a commercial grade with abrasive blasting to a commercial grade such as SP6 — **they are not equal.**

5.9 Acid Etching (Pickling), SSPC-SP 8

Pickling prepares steel surfaces by chemical reaction, electrolysis, or both. The surfaces, when viewed without magnification, shall be free of all visible mill scale and rust.

The uniformity of color may be affected by the grade, original surface condition, and configuration of the material being cleaned, as well as by discoloration from mill or fabrication marks and the shadowing from etching patterns.

5.9.1 Safety

Workers must wear protective clothing, eye wear, and breathing apparatus, and should stay as far as possible from the acid as it is introduced into the water in the pickle bath. Even when properly adding the sulfuric acid to water, the exothermic reaction of the two generates enough heat to boil and blow the acid around. Since some acid fumes invariably escape, provide ample ventilation.

5.9.2 Types of Acids

Acids are used in the pickling process to attack and remove the mill scale, without attacking the steel. Various acids used in commercial pickling are sulfuric, muriatic (hydrochloric), phosphoric, and mixtures of these. Because of its low cost, high boiling point, availability, and general suitability, sulfuric acid is used quite extensively throughout the U.S. to pickle simple low-carbon steel, although some hydrochloric acid is used.

Some users add inhibitors to prevent the acids from attacking (dissolving) the bare metal and to help passivate the steel surface, making it more corrosion resistant. Both muriatic and sulfuric acid can be inhibited in this way.

5.9.3 Process

The pickling process is divided into three steps:

- Cleaning and preparation of the metal
- Acid Etching (also called pickling)
- Treating the pickled metal

5.9.3.1 Cleaning and Preparing the Metal

Before acid etching (pickling), first clean any heavy deposits of rust, paint, and scale off the metal. These contaminants must be removed so the acid can fully contact the metal. Oil is very frequently found on the metal surface; remove it with solvents or high-temperature baking. The most common method to remove oil is using a hot alkaline solution.

5.9.3.2 Pickling

The acid etching (pickling) process usually immerses metal (configured or not) into tanks of hot or cold acid solutions. The same principle works whether the pickle solution is sprayed on, poured over the metal, or if the work is pulled through the acid.

Promptly rinse the acid off the metal with hot water (above 140°F [60°C]). Do not allow the film of acid etching (pickling) acids and salts, a by-product of the reaction of the acid with the metal, to dry on the metal. If it dries, it becomes very difficult to rinse away, and can cause trouble in many of the operations that follow.

5.9.3.3 Treating Acid Etching (Pickled) Metal

Treating the acid etching (pickled) metal prevents steel from rusting and prepares it for coating. Treatment methods include:

- Application of an alkali solution (unless work piece is stored)
- Application of a chromate/phosphate solution

The pH balance of the surface should be between 6 and 8 to prepare the metal for painting.

5.9.4 Limitations

Acid etching (pickling) does not always accomplish what it should; it sometime leaves mill scale that later pops off the surface causing premature coating failure; however, similar comments are made about other methods of surface preparation.

5.10 Waterjetting

5.10.1 Waterjetting: NACE WJ-1/SSPC-SP WJ-1, NACE WJ-2/SSPC-SP WJ-2, NACE WJ-3/SSPC-SP WJ-3, NACE WJ-4/SSPC-SP WJ-4

NACE WJ-1/SSPC-SP WJ-1, NACE WJ-2/SSPC-SP WJ-2, NACE WJ-3/SSPC-SP WJ-3, NACE WJ-4/SSPC-SP WJ-4 describe the use of a high-energy water stream to strip off existing coatings and remove contaminants on a substrate being prepared prior to coatings application. When compared to abrasive blasting, this method has certain advantages particularly for safety and environmental control. Respiratory protection requirements are less stringent and waste (abrasive) disposal is not an issue because water is the medium.

The term **waterjetting** denotes the use of “water only,” without the addition of solid particles such as sand or garnet in the water stream. Modern waterjetting equipment produces pressures of up to 60,000 psig. However, as technology improves, equipment with higher operating pressures may be developed.

This cleaning method is particularly well suited to the marine, process and utility (power plants) industries, where high-performance coatings require extensive surface preparation and/or surface decontamination with minimal effect on surrounding equipment and the environment. In the marine industry, waterjetting is widely used to remove marine growth, depleted antifouling coatings, and surface preparation of tank/ hold interiors. Data also proves it is effective in removing marine growth on offshore structure’s jackets (submerged sections).

It is very important to remember that while waterjetting will remove contaminants and millscale at varying pressures, it will **not** create an anchor profile, which plays a critical role in coatings adhesion. In maintenance and repair operations, waterjetting exposes the existing anchor profile (if there is one).

Waterjetting NACE WJ-1/SSPC-SP WJ-1, NACE WJ-2/SSPC-SP WJ-2, NACE WJ-3/SSPC-SP WJ-3, NACE WJ-4/SSPC-SP WJ-4 also addresses **water cleaning** which is basically the same process at lower pressures. It is important for inspectors to understand these terms and the working pressures associated with them.

In comparing water cleaning with waterjetting, these definitions apply:

Low-Pressure Water Cleaning (LP WC)

Cleaning performed at pressures below 34 MPa (5,000 psig). This is also called "*power washing*" or "*pressure washing*."

High-Pressure Water Cleaning (HP WC)

Cleaning performed at pressures from 34 to 70 MPa (5,000 to 10,000 psig).

High-Pressure Waterjetting (HP WJ)

Waterjetting performed at pressures from 70 to 210 MPa (10,000 to 30,000 psig).

Ultrahigh-Pressure Waterjetting (UHP WJ)

Waterjetting performed at pressures above 210 MPa (30,000 psig).

5.10.2 Standards

The joint NACE/SSPC standards for abrasive blast cleaning are complete and clearly define the surface conditions to be achieved. However, when and if specifications are being written for surface preparation utilizing waterjetting, the 4 standards (WJ-1, WJ-2, WJ-3, WJ-4) which replaced NACE 5/SSPC-SP-12 should be referenced. WJ-1 through WJ-4 defines different degrees of cleanliness. The non-visual contaminants are still addressed in the standards but have been moved to Appendix A. Keep in mind that in case of any dispute, the written standards take precedence over visual reference photographs or visual standards such as NACE VIS 7/SSPC-VIS 4.

An example of a specification statement is:

"All surfaces to be recoated shall be cleaned in accordance with NACE WJ-1/SSPC-WJ-1 Joint Standard The method of HP WJ or UHP WJ ultimately selected by the contractor will be based on his confidence in the capabilities of the equipment and its components."

If non-visible contaminants are to be addressed the specifier, inspector, and contractor must agree on the test methods to determine the amount of non-visible contaminants that can be left on the prepared substrate. Consult the manufacturer of the specified coatings to determine the coating’s tolerance to the surface conditions after waterjetting, commensurate with the in-service conditions.

The definition of visible and non-visible contamination is as follows:

Non-visible contamination (NV) is the presence of organic matter, such as very thin films of oil and grease, and/or soluble ion materials such as chlorides, ferrous salts, and sulfates that remain on the substrate after cleaning that cannot be seen with the naked eye.

Visible surface cleanliness (VC) is the visible condition of the substrate when viewed without magnification and after cleaning.

The degrees of cleanliness defined in WJ-1 through WJ-4 are defined as follows:

5.10.2.1 Visual Surface Preparation Definitions

WJ-1, Clean to Bare Substrate: A metal surface after Clean to Bare Substrate, when viewed without magnification, shall have a matte (dull mottled) finish and shall be free of all visible oil, grease, dirt, rust and other corrosion products, previous coatings, mill scale, and foreign matter.

WJ-2, Very Thorough Cleaning: A metal surface after Very Thorough Cleaning, when viewed without magnification, shall have a matte (dull mottled) finish and shall be free of all visible oil, grease, dirt, rust, and other corrosion products except for randomly dispersed stains of rust and other corrosion products, tightly adherent thin coatings, and other tightly adherent foreign matter. The staining or tightly adherent matter shall be limited to more than 5% of each unit area of surface and may consist of randomly dispersed stains of rust and other corrosion products or previously applied coating, tightly adherent thin coatings, and other tightly adherent foreign matter.

WJ-3, Thorough Cleaning: A metal surface after Thorough Cleaning, when viewed without magnification, shall have a matte (dull mottled) finish and shall be free of all visible oil, grease, dirt, rust, and other corrosion products except for randomly dispersed stains of rust and other corrosion products, tightly adherent thin coatings, and other tightly adherent foreign matter. The staining or tightly adherent foreign matter shall be limited to no more than 33% of each unit area of surface and may consist of randomly dispersed stains of rust and other corrosion products or previously applied coating, tightly adherent thin coatings, and other tightly adherent foreign matter.

WJ-4, Light Cleaning: A metal surface after Light Cleaning, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, loose mill scale, loose rust and other corrosion products, and loose coating. Any residual material shall be tightly adherent to the metal substrate and may consist of randomly dispersed stains of rust and other corrosion products or previously applied coating, tightly adherent thin coatings, and other tightly adherent foreign matter.

It goes on to explain that coatings, mill scale, and foreign matter are considered tightly adherent if they cannot be removed when lifting with a dull putty knife.

A unit area of surface is an area approximately 5,800 mm2 [9.0 inches2] (i.e., a square 76 mm by 76mm) [3.0 inches x 3.0 inches].

The inspector and contractor should know that surfaces prepared by LP WC, HP WC, HP WJ, or UHP WJ do not exhibit the hue of a dry abrasive-blasted steel surface. After waterjetting, the matte finish color of clean steel surface immediately turns to a golden hue unless an inhibitor is used or environmental controls are employed. However, the use of any inhibitor outside of the specification requirement is never encouraged. The use of any such inhibitor without the written approval of the coatings manufacturer can result in the voiding of all performance warranties from the manufacturer. On older steel surfaces that have areas of coating and areas that are coating free, the matte finish color varies even though all visible surface material has been removed. Color variations in steel can range from light gray to dark brown/black.

Prepared steel surfaces show variations in texture, shade, color, tone, pitting, flaking, and mill scale that should be considered during the cleaning process. Acceptable variations in appearance that do not affect surface cleanliness include variations caused by type of steel or other metals, original surface condition, thickness of the steel, weld metal, mill fabrication marks, heat treating, heat-affected zones, and differences in the initial abrasive-blast cleaning or in the waterjet cleaning pattern.

The gray or brown-to-black discoloration seen on corroded and pitted steel after water-jetting cannot be removed by further water-jetting. A brown-black discoloration of ferric oxide may remain as a tightly adherent thin film on corroded and pitted steel and is not considered part of the percentage staining.

Waterjetting at pressures in excess of 240 MPa (35,000 psig) is capable of removing tightly adherent mill scale, but production rates are not always cost effective.

5.10.2.2 Flash Rust

Flash rust is an additional technical consideration when a carbon steel substrate is subjected to waterjet cleaning. Gray or brown/black discoloration remaining in the pits of water jet cleaned carbon steel is not the same as flash rust. Metals other than carbon steel can manifest discoloration as well. Degrees of flash rust may be qualitatively described as follows:

No Flash Rust - A carbon steel surface that, when viewed without magnification, exhibits no visible flash rust.

Light (L) flash rusted surface: A carbon steel surface that, when viewed without magnification, exhibits small quantities of a rust layer through which the carbon steel substrate may be observed. The rust or discoloration may be evenly distributed or present in patches, but it is tightly adherent and not easily removed by lightly wiping with a cloth.

Moderate (M) flash rusted surface: A carbon steel surface that, when viewed without magnification, exhibits a layer of rust that obscures the original carbon steel surface. The rust layer may be evenly distributed or present in patches, but it is reasonably well adherent and leaves light marks on a cloth that is lightly wiped over the surface.

Heavy (H) flash rusted surface: A carbon steel surface that, when viewed without magnification, exhibits a layer of heavy rust that hides original carbon steel surface completely. The rust may be evenly distributed or present in patches, but it is loosely adherent, easily comes off, and leaves significant marks on a cloth that is lightly wiped over the surface.

Appendix B of WJ-1 provides additional information on methods of assessing the degree of flash rust.

5.10.2.3 Description of Non-Visible Surface Cleanliness Definitions

None of the standards (WJ-1 through WJ-4) specifies the amount of non-visible contaminants (soluble salts) that are allowed to be left on the surface. This is left up to the specifier.

5.10.3 Waterjetting Equipment and Systems

This section introduces basic waterjetting systems and the basic equipment required to successfully accomplish the work. (Figure 5.1)

Figure 5.1 Typical UHP Pump

A commercial waterjet unit can be skid, trailer, or truck-mounted and usually consists of pumps, hoses, a prime mover (diesel, electric, etc.), along with various tools such as guns, nozzles, lances, etc. (Figure 5.2)

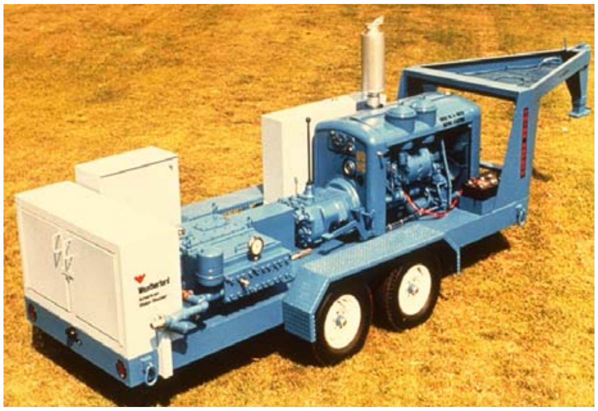

Figure 5.2 Trailer Mounted UHP Pump/Unit

The high-pressure hose, hose connections, and all other equipment, including the nozzle control valve, lance, and nozzle, should have minimum burst strength of 2½ times the capability of its maximum-rated operating strength. (Figure 5.3)

High-pressure hoses are fitted with a safety device known as a **whip-lock** or **whip check**. This is a short length of cable or wire looped over each end of two hoses connected by a coupling. The whip-lock or whip check prevents the ends of the hoses from whipping around if the coupling breaks.

The section of hose next to the gun is fitted with a **hose shroud**, which usually is a short length of heavy-duty hose placed over the high-pressure hose to provide instantaneous protection if the hose bursts. A hose shroud also can be used over other hose connections. The shroud, however, does not form a permanent barrier to the flow of water from a damaged hose or broken connection.

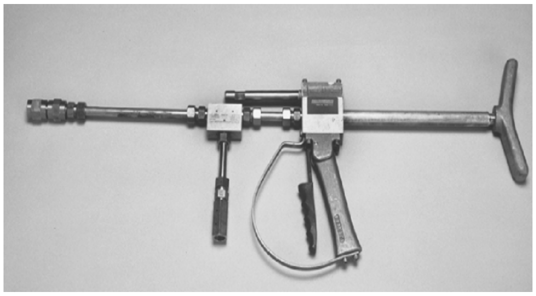

Figure 5.3 Typical Shoulder Gun w/Nozzle

5.10.3.1 Equipment Types

Waterjeting equipment types generally fall into one of two basic categories:

- Manual
- Robotic

5.10.3.1.1 Manual Waterjetting

The majority of waterjetting falls under the manual category and is the topic of most of this chapter. A human operator using a hand-held wand performs the surface cleaning effort.

5.10.3.1.2 Robotic Waterjetting

Technology is quickly improving and a new kind of equipment recently developed is a robotic water jetting unit. It is a cleaning vehicle that attaches itself, using vacuum, cables, or magnets to a vertical, horizontal or overhead surface. It is controlled by a single operator.

A unique feature is that it collects in excess of 95% of the water, removed coatings and rust (waste generated). The coatings and water are transported to a filtration bag, where the waste is contained for future disposal. The water drains out at a clarity level generally acceptable for treated sewers. However, check with area authorities before disposing untreated waste in the sewage system.

A standard 40,000-psi direct-drive pump powers the unit. A vacuum system process that provides suction, attaches the Hydro-Cat® to the work surface where it conveys removed coatings and water to the filtration bag mentioned earlier.

This unit is used on vertical surfaces such as ship hulls and tanks on horizontal surfaces such as flat decks and on overhead surfaces such as the bottom of ship hulls. It also works well over weld seams, doubler plates, lap joints and riveted seams, and moves easily in and around keel blocks and other common obstructions. For straight-line work, it uses an “auto path” control feature. (Figure 5.4)

Figure 5.4 Robotic Waterjetting Unit

5.11 High-Pressure Water Blast Cleaning with Abrasive Injection

High-pressure water blast cleaning with abrasive injection uses high-pressure water to remove most contaminants, such as dirt and chemical salts. The abrasive is then added into the water stream to increase production rates and produce a profile on the surface.

The force of the water through the gun and gun lance draws the abrasive into the water stream by suction. Refer to NACE Report TG 323 for more information.

Slurry blast cleaning mixes the abrasive and water together at or near the blast pot with constant agitation to form slurry. The slurry is then pumped through a single hose to the blast nozzle.

5.12 Abrasive Blast Cleaning

Abrasive blast cleaning abrades the surface by the high-velocity impact of abrasive particles against the surface. This process prepares steel surfaces for coating by removing rust, mill scale, and old coatings along with some of the base metal.

5.12.1 Pre-Preparation

A certain amount of pre-preparation is needed to remove:

- Grease
- Dirt
- Soluble chemical salts

For the best results, abrasive blast cleaning should be performed on a clean, dry surface. The NACE/SSPC Abrasive Blasting Standards requires the surface to be free of all visible oil, grease and dirt in accordance with SSPC-SP1 before blasting. If it is probable that the surface has been contaminated with a soluble ion, such as salt, test the surface and remove contaminates prior to blasting. However, neither the NACE/SSPC nor the ISO abrasive blasting standards *require* a soluble salt test.

5.12.2 Standards

The abrasive blast cleaning standards for new and previously painted steel most commonly used in non-automatic abrasive blast applications are the NACE, SSPC, or ISO standards. Remember**,** *these standards are **not** equivalent, only similar.* The joint NACE and SSPC abrasive blast cleaning surface preparation standards are listed and defined here again for quick reference in this part of the chapter.

5.12.3 NACE Standards

NACE No. 1/SSPC-SP 5 — White Metal Blast Cleaning

A white metal blast cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dust, dirt, mill scale, rust, coating, oxides, corrosion products, and other foreign matter.

NACE No. 2/SSPC-SP 10 — Near-White Metal Blast Cleaning

A near-white metal blast cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dust, dirt, mill scale, rust, coating, oxides, corrosion products, and other foreign matter. Random staining shall be limited to no more than 5 percent of each unit area of surface (approximately 9 in^2 [5,800 mm2], i.e., a square 3.0 in x 3.0 in [76 mm x 76 mm]) and may consist of light shadows, slight streaks, or minor discolorations caused by stains of rust, stains of mill, or stains of previously applied coating.

NACE No. 3/SSPC-SP 6 — Commercial Blast Cleaning

A commercial blast cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dust, dirt, mill scale, rust, coating, oxides, corrosion products, and other foreign matter. Random staining shall be limited to no more than 33 percent of each unit area of surface (approximately 9 in^2 [5,800 mm^2], i.e., a square 3 in x 3 in [76 mm x 76 mm]) and may consist of light shadows, slight streaks, or minor discolorations caused by stains of rust, stains of mill scale, or stains of previously applied coating.

NACE No. 4/SSPC-SP 7 — Brush-Off Blast Cleaning

A brush-off blast cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, loose mill scale, loose rust, and loose coating. Tightly adherent mill scale, rust, and coating may remain on the surface. Mill scale, rust, and coating are considered tightly adherent if they cannot be removed by lifting with a dull putty knife after abrasive blast cleaning has been performed.

NACE No. 8/SSPC-SP 14 — Industrial Blast Cleaning

An industrial blast cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dust, and dirt. Traces of tightly adherent mill scale, rust, and coating residues are permitted to remain on 10 percent of each unit area of the surface (approximately 9.0 in^2 [5,800 mm2], i.e., a square 3.0 in x 3.0 in [76 mm x 76 mm]) if they are evenly distributed. The traces of mill scale, rust, and coating are considered to be tightly adherent if they cannot be lifted with a dull putty knife. Shadows, streaks, and discolorations caused by stains of rust, stains of mill scale, and stains of previously applied coating may be present on the remainder of the surface.

5.12.3.1 ISO Surface Cleaning Standards

A common requirement for all types of surface preparation described in the ISO standards is removal of any heavy layers of rust by chipping. Visible oil, grease, and dirt must also be removed prior to cleaning. After blast cleaning, loose dust and debris must be cleaned from the surface.

ISO 8501

ISO 8501 is the standard that contains the surface preparation requirements for preparation of steel substrates before application of coatings and related products and for the visual assessment of surface cleanliness.

These standards are very similar to the NACE and SSPC surface preparation standards; however, the coating professional has to understand and work with the standard stipulated by the owner of the item being coated. **The standards are not interchangeable** as they do have differences.

ISO 8501 consists of four parts:

Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings

Part 2: Preparation grades of previously coated steel substrates after localized removal of previous coatings

Part 3: Preparation grades of welds, edges, and other areas with surface imperfections

Part 4: Initial surface conditions, preparation grades, and flash rust grades in connection with high-pressure water jetting

ISO 8501-1 – Preparation grades of uncoated steel and of steel with overall removal of previous coatings

The letters "Sa" designate surface preparation by blast cleaning

The letters "St" designate surface preparation by hand and power tool cleaning

Sa 1 – Light Blast Cleaning

When viewed without magnification, the surface shall be free from visible oil, grease, and dirt, and from poorly adhering mill scale, rust, paint coatings, and foreign matter.

Sa 2 – Thorough Blast Cleaning

When viewed without magnification, the surface shall be free from visible oil, grease, and dirt, and from most of the mill scale, rust, paint coatings, and foreign matter. Any residual contamination shall be firmly adhering.

Sa 2½ – Very Thorough Blast Cleaning

When viewed without magnification, the surface shall be free from visible oil, grease, and dirt, and from mill scale, rust, paint coatings, and foreign matter. Any remaining traces of contamination shall show only as slight stains in the form of spots or stripes.

Sa 3 – Blast Cleaning to Visually Clean Steel

When viewed without magnification, the surface shall be free from visible oil, grease, and dirt, and shall be free from mill scale, rust, paint coatings, and foreign matter. It shall have a uniform metallic color.

St 2 – Thorough Hand and Power Tool Cleaning

When viewed without magnification, the surface shall be free from visible oil, grease, and dirt, and from poorly adhering mill scale, rust, paint coatings, and foreign matter.

St 3 – Very Thorough Hand and Power Tool Cleaning

As for St 2, but for the surfaces to be cleaned shall be treated much more thoroughly to give a metallic sheen arising from the metallic substrate.

ISO 8501-2 – For previously Painted Steel Surfaces with localized removal of coatings

The letters "P Sa" designate surface preparation by blast cleaning

The letters "P St" designate surface preparation by hand and power tool cleaning

P Sa 2 Thorough Localized Blast Cleaning

Firmly adhering paint coatings shall be intact. The surface of the other parts, when viewed without magnification, shall be free from visible oil, grease and dirt, from loose paint coatings and from most of the mill scale, rust and foreign matter. Any residual contamination shall be firmly adhering.

P Sa – 2½ Very Thorough Localized Blast Cleaning

Firmly adhering paint coatings shall be intact. The surface of the other parts, when viewed without magnification, shall be free from visible oil, grease, and dirt, from loose paint coatings, and from mill scale, rust, and foreign matter. Any remaining traces of contamination shall show only as slight stains in the form of spots or stripes.

P Sa 3 – Localized Blast Cleaning to Visually Clean Steel

Firmly adhering paint coatings shall be intact. The surface of the other parts, when viewed without magnification, shall be free from visible oil, grease, and dirt, from loose paint coatings, and from mill scale, rust, and foreign matter. It shall have a uniform metallic color.

P St 2 – Thorough localized hand and power tool cleaning

Firmly adhering paint coatings shall be intact. The surface of the other parts, when viewed without magnification, shall be free from visible oil, grease, and dirt, and from poorly adhering mill scale, rust, paint coatings, and foreign matter.

P St 3 – Very thorough localized hand and power tool cleaning

As for P St 2, but the surfaces to be cleaned shall be treated much more thoroughly to give a metallic sheen arising from the metallic substrate.

5.12.4 Types of Abrasives

Abrasives are the materials that do the actual work in abrasive blast cleaning. Types of abrasives include:

- Metallic.
- Hard nonmetallic (oxides).
- Free-silica-containing.
- Agricultural.
- Slag.
- Specialty abrasives.

Table lists the five major classifications of abrasives and some types of abrasives found in each category. The specification generally determines which abrasive to use. Always follow the recommendations of the manufacturer and the technical data sheets, if the specification does not detail use instructions. Table shows some abrasives that may be used to attain a given anchor pattern.

Table D.4, "General Types of Abrasives." (SEE BACK OF MANUAL TAB D)

Table D.6, "General Abrasives and Anchor Patterns." (SEE BACK OF MANUAL TAB D)

5.12.4.1 Metallic Abrasives

Types of metallic abrasives include:

- Cast steel.
- Steel grit.
- Steel shot.
- Cast iron.
- Malleable iron.

Metallic abrasives are often heat-treated to different hardness levels to increase their life and cleaning rate. Use hard abrasives, 62 to 65 HRC (Rockwell-C hardness), for etching, but remember they break down rapidly. Use softer abrasives, 35 to 40 HRC, for easier cleaning jobs. The softer abrasives may round off after use. The average hardness of metal abrasives is 45 to 50 HRC, which works well as an air blast abrasive.

Cast Steel

Cast steel is a hard metallic abrasive used to remove scale and other hard surface deposits.

Steel Grit

Grit has irregular shapes. This effectively cuts away surface deposits or imperfections. Steel grit is expensive and is generally used only in recycling systems, or when less expensive abrasives are unavailable.

Steel Shot

Shot is spherical in shape. It can be produced accidentally as a by-product, or produced intentionally for blast cleaning. Steel shot removes heavy brittle deposits well. Because of its spherical shape, it ricochets in enclosed areas and causes multiple impacts. Be aware that shot *may* stretch *light materials*, which drives mill scale and other impurities into the surface. Shot leaves a profile that is less angular than grit leaves. Because many coating manufacturers require an angular profile to achieve good coating adhesion, some users mix shot with steel grit to achieve the benefits of each medium.

Cast Iron

Cast iron is the hardest metallic abrasive. It removes scale and other hard surface deposits. Do not confuse hardness with toughness. Some hard abrasives have high breakdown rates because of their brittleness. Use cast iron abrasives in non-corrosive environments. It has a high initial cost, but can be recycled.

Malleable Iron

Malleable iron is a relatively hard metallic abrasive that removes scale and other hard deposits.

5.12.5 Hard Non-Metallic Abrasives (Oxides, natural, or synthetic)

These abrasives are useable indoors and outdoors, under various atmospheric conditions. They have a low initial cost, but have a higher breakdown rate than any of the metallic abrasives, which means they have a high loss rate. Reclaim (re-cycle) silicon carbide and aluminum oxide abrasives to make them economical to use. The hard nonmetallic abrasives are free of the silica hazard present with siliceous abrasives. The types of hard nonmetallic abrasives follow.

Garnet

Garnet (oxide) is a fast-cutting abrasive with a long life. Garnet is good for blasting cabinets and blasting rooms. It is diamond-shaped.

Silicon Carbide

Silicon carbide is an expensive and fast cutting oxide. Silicon carbide is also used for grinding wheels.

Aluminum Oxide

Aluminum oxide comes from the mineral corundum, a natural aluminum oxide. Emery, ruby, and sapphire are impure crystalline varieties of corundum. Aluminum oxide is also manufactured from bauxite. It is fast cutting, durable, uniform, and expensive.

Free-Silica-Containing Abrasives

Siliceous abrasives, like the synthetics, can be used indoors and out, and under various atmospheric conditions. However, the potential for release of free silica is a limiting factor because of the health hazards caused by breathing dust containing free silica.

Because of their greater breakdown into dust, free-silica-containing abrasives should not be used anywhere dust can present a hazard to workers or machinery. In the US, all persons working near such an operation, including coating inspectors, are required by OSHA to wear protective clothing, goggles, and breathing equipment. The types of free-silica-containing abrasives are:

Sand

Sand was once the most commonly used abrasive in heavy-duty situations such as cleaning old rusty surfaces. Sand is available in many sizes. Sands differ in breakdown rate, but generally become significantly finer after the first use. Many operators do not allow reuse of sand abrasives.

Sand is still used in the US because it is inexpensive. But, the high breakdown rate tends to counter its original low cost, and generally no attempt is made to reclaim it. Despite its problems, it is often considered (particularly in the US) to be the most economical abrasive in industrial field applications. Sandblasted surfaces may require a final cleaning with air to remove dust remaining on the surface.

Flint/Chert

Flint (sometimes called chert) is a crystalline form of native silica or quartz. The color varies from smoky gray to brownish-black to dull yellow. Flint is a by-product of hard-rock mining and breaks to very sharp edges, so it is a sharp, fast-cutting, and expensive abrasive.

5.12.5.1 Agricultural Abrasives

Agricultural abrasives are common in situations where abrasive dust may harm sensitive equipment. When stainless steel or other high-purity alloys are blasted, it is important that the abrasive does not embed metallic particles in the surface. Crushed walnut shells were the choice, for example, to clean components of the space shuttle while preserving the integrity of the special alloy materials.

5.12.5.2 Slag Abrasives

Slag use is delineated in SSPC-AB 1, *Mineral and Slag Abrasives*. This specification defines the requirements to select and evaluate mineral and slag abrasives to blast clean steel and other surfaces for coating. SSPC-AB 1 primarily covers abrasives intended for one time use without recycling. Recycled materials must be retested before reuse.Refractory slag is manufactured from by-products of burning coal, refining copper, and nickel. It is fast cutting with medium durability.

5.12.5.3 Specialty Abrasives

Dry Ice

Dry ice is frozen carbon dioxide. It can be produced onsite by cooling liquid carbon dioxide and compressing the resulting flakes into pellets, or by grinding and screening blocks of dry ice. Dry ice has been used successfully to remove certain types of surface contaminants and existing organic coatings. It does not change the surface profile of metal surfaces, produces little or no dust, and usually leaves the substrate dry and cold. Dry ice is a single-use abrasive. *Caution: Dry ice is very cold, -110.2° F (-79°C), and can cause immediate frostbite on contact with exposed skin.*

Ice

Freezing water, either on- or off-site, of course, produces ice. The ice is crushed and sieved to produce a blast abrasive. Ice is used to remove certain types of surface contaminants and existing organic coatings. It does not change the surface profile and does not produce dust, but it leaves the substrate wet. Ice is a single-use abrasive.

Plastic Beads

Plastic beads are small, about the size of the holes in a plastic button. They remove coatings when minimum change of surface profile is desired. Plastic beads are almost always used in recycling systems and are used extensively to strip coatings from aircraft. Since the dust they produce can be combustible, take appropriate care during use. Operators need more extensive training to use plastic beads because the abrasive flow, work-to-nozzle distance, and blast air pressure vary for different coating types. With this abrasive, the blast operator usually determines these variables.

Sodium Bicarbonate

Sodium bicarbonate is often used in a water-slurry delivered by compressed air. It removes surface contamination and existing coatings with minimum substrate change. Although it produces little or no dust, rinse the substrate with fresh water as a final step. The operator requires special training. This abrasive cannot be recycled.

Sponge

Use synthetic sponge abrasives to remove surface contaminants. Compressed air propels the particles into making multiple impacts on the surface; the sponge cleans by absorbing contaminants. Users may discard the particles after one use, or clean and reuse them. Sponge is not advertised to remove existing protective coatings other than grease-type coatings.

Sponge with Abrasives

Sponge abrasives that encase different types of abrasive particles are available. This material both removes coatings and creates a surface profile. While it works at a slower rate than regular abrasive, it significantly reduces dust levels and collateral damage in the work area. It is often specified when maintenance work is performed in machinery spaces.

5.12.6 Abrasive Selection

Always use the type of abrasive specified. These are some of the considerations when a blasting abrasive is selected:

- Kind of surface to be cleaned

- Size and shape of object to be cleaned
- Type of cleaning facility: outdoor, indoor with cabinet, or blast room
- Existing surface conditions
- Conditions desired after cleaning
- Types of coating to be applied
- Desired surface profile
- Desire to recycle the abrasive

where it falls into a chute. This is less precise than the screen method.

5.12.7 Methods of Abrasive Blast Cleaning

Some of the common methods of abrasive blast cleaning include:

Manual

- Dry abrasive blast
- Wet abrasive blast
- Slurry blast
- High-pressure water blast with sand injection
- High-pressure water blast

Automatic (Centrifugal Blast)

- Wheelblast abrasive cleaning
- Mobile (Portable) blast equipment

5.12.7.1 Dry Abrasive Blast Cleaning

Dry abrasive nozzle blasting prepares steel surfaces for coating. This type of cleaning generally uses all of the following pieces of equipment:

- Compressor
- Blast pot

- Hoses
- Nozzle
- Abrasives
- Safety equipment

Compressor

The effectiveness of the blasting process depends in part on the volume and pressure of the compressed air that passes through the nozzle or nozzles. Adequate pressure is critical to an effective blast process. If the abrasive is not transported with sufficient pressure, achieving the specified finish takes much more time.

Set the compressor pressure control to compensate for pressure lost while the air and abrasive move through the blast hose. Measure the pressure at the nozzle with a hypodermic needle gauge (discussed later).

Always select a compressor with the **capacity to supply more air than is required** to allow for reserve capacity when there are peak loads or if more equipment is added. Each additional 3/8 in (9.5 mm) nozzle drops the pressure an estimated 5 lb (35-KPa) for each 50 ft (15 m) of hose. This pressure drop compounds as the number of operating nozzles, the nozzle sizes, and the lengths of hose increase.

Another consideration is the size of the compressor manifold valve. The compressor should be equipped with outlets of 1.5 to 2 in (38 to 50 cm) to match the air supply hose.

An undersized compressor is a bad investment because it:

- Wastes time waiting for it to reach the required pressure.
- Experiences undue pressure during peak loads.
- Operates inefficiently and wastes time.
- Is unable to add new tools to the system.
- Has a greater possibility of breakdowns or shutdowns.
- Runs excessively to supply the quantity of air needed
- Experiences excessive heat and condensation.

Another consideration is the size of the compressor manifold valve. The compressor should be equipped with outlets of 38 to 50 cm (1.5 to 2 in) to match the air supply hose.

Compressors may have these accessories:

Water and Oil Separators: They remove oil, water, and other contaminants from the compressed air stream.

Filters: They contain charcoal and supply purified air to the blast hood. They also have monitors to detect the presence of carbon monoxide (CO).

Driers: They have absorbent filters that remove water from the compressed air (preventing the abrasive from becoming wet), and prevent condensation on the work piece.

Blast Pot

The blast pot is the unit where the compressed air and the abrasive mix in the air stream are delivered via the blast hose to the surface being cleaned. Blast pot accessories include:

- **Abrasive metering valve**: meters the proper balance of abrasive to the nozzle size
- **Deadman valve or handle**: when an operator releases the valve (handle), the blast equipment shuts down. If the operator becomes ill or loses consciousness and drops the hose, no one is endangered by a still-operating blast nozzle and hose propelling abrasives at high pressure. An approved deadman control is required in the US by OSHA regulations.

Hoses

The **air hose** supplies air from the compressor to the blast machine. The **blast hose** carries air and abrasive from the pressure vessel to the nozzle.

Air Hose: Generally, the larger the air line, the better. Air hoses should have an inside diameter no smaller than 1.25 in (3.18 cm). The recommended size is three to four times the nozzle orifice. On hoses longer than 100 ft (30.5 m), the hose diameter should be four times the nozzle orifice. The larger sizes eliminate loss of air pressure through the air hose from friction.

Abrasive Blast Hose: There are two types of abrasive blast hoses:

- **Four-ply**. Use when the hose is subject to heavy-duty external wear, or if there is danger of the operator pulling it at right angles.
- **Two-ply.** Some blasters prefer this lighter hose because of its greater flexibility.

Ensure all hoses have capped ends to allow coupling and to prevent moisture or compressed air from working its way through the braid or ply of the hose. Air inside the braid or ply of the hose can cause the hose cover to bubble, whereas water can cause the hose wrapping to rot.

Nozzles

Important aspects of nozzles include:

- Nozzle lining materials
- Nozzle orifice size (opening)
- Interior design of the nozzle

Nozzle Lining Materials

The nozzle lining is where the abrasive is in active contact with the nozzle.

- **Tungsten carbide**: Nozzles lined with tungsten carbide have a 300-hour life, but life expectancy shortens when aluminum oxide or silicon abrasives are used.
- **Silicon carbide:** A silicon carbide nozzle weighs 42% less than a tungsten carbide nozzle, making it easier to hold for a long period. With a dependable abrasive, the silicon carbide nozzle lasts up to 500 hours, which is 50 to 60% longer than tungsten carbide nozzles.
- **Norbide (boron carbide):** Norbide is the most durable nozzle lining, with a 750- to 1,000-hour life. It can be used with all abrasives. Although boron carbide nozzles are two to three times more expensive than silicone and tungsten, their long life makes them cost effective.

Nozzle Orifice Size

Nozzle size is determined by the:

- Type of work.
- Volume and pressure of compressed air available.
- Type of blast unit.

Longer nozzles are preferable on tough cleaning jobs because they result in more velocity and a more concentrated blast pattern. However, using a nozzle too large for the work can result in wasting power with undue blasting. Larger nozzles also require a greater volume of air (hence a larger air compressor) to work properly. Table 5.1 shows the volume of air required to operate different nozzles at various pressures. Use **a blast nozzle orifice gauge** to check the internal diameter (ID) of blast nozzles. Nozzles are valuable pieces of equipment; do not use them as hammers or drop them on the ground.

Table 5.1: Air Requirements for Various Nozzle Sizes

Blast Nozzle Orifice Size	Volume of air required (ft3/min)					
	60 psi	70 psi	80 psi	90 psi	100 psi	120 psi
¼ inch	#4	67	76	85	94	103
⅜ inch	#6	151	171	191	211	232
½ inch	#8	268	304	340	376	413
Blast Nozzle Orifice Size	Volume of air required (L/min)					
	4.1 bar	4.8 bar	5.5 bar	6.2 bar	6.9 bar	8.3 bar
6.3 mm	#4	1900	2150	2400	2660	2920
9.45 mm	#6	4280	4840	5410	5980	6570
12.6 mm	#8	7590	8610	9630	10650	11700

Nozzle Designs: Venturi vs. Straight Bore

For many years, all nozzles had a straight internal bore with a small throat opening. The straight nozzles have an outlet abrasive velocity of about 217 mph or 315 ft/s (349 km/h) and tend to spread the abrasive in a large blast pattern, with more concentration in the center and less at the edges.

In 1954, the Venturi shape was adapted to abrasive blast nozzles. The new shape has a large entrance throat that tapers gradually into a short straight section in the middle, and then flares at the outlet end. The Venturi shape allows abrasive velocity to go up to 450 mph, 660 ft/s (724 km/h) with an almost equal impact over the entire surface. The Venturi is the most effective nozzle shape for tough cleaning jobs.

5.12.8 Wet Abrasive Blast Cleaning

In one method of wet abrasive blast cleaning the blast nozzles is fitted with an adapter that injects water into the abrasive stream to deliver wet abrasive to the surface.

Another method uses a water-ring attachment on the end of the blast nozzle. The water-ring attachment connects to a low-pressure water source; a small valve controls the flow of water.

In use, the water stream wets the abrasive stream outside and in front of the nozzle discharge, which helps keep dust to a minimum. Use this process when dust is objectionable.

5.12.9 Centrifugal Blast Cleaning

Centrifugal blast cleaning works by means of centrifugal force. In this process abrasive enters the equipment through the hub of the blast wheel, slides onto the vanes (paddle-like spokes) and then to the edges, where it moves at high velocity.

Wheel blast advantages include:

- Dust containment
- Recycling
- In-line operation
- Very high productivity compared to nozzle blasting
- High volume compressed air not needed for actual blast operation

Wheel blast disadvantages include:

- Initial cost

- High wear
- Complex shapes may require nozzle blasting to finish

5.12.9.1 Components

- Several basic components are found in all centrifugal blast systems.
- **Blast enclosure or cabinet**. Contains the abrasive as it is thrown from the wheel and prevents dust from escaping.
- **Separator.** Removes contaminant particles and abrasives too small to be effective.
- **Work conveyor.** Brings the work piece into the wheel's blast stream.
- **Dust collector.** Withdraws dust from the abrasive and ventilates and removes dust from the blast enclosure.
- **Wheel.** The size and number is set to meet the needs of the specific job.

5.12.9.2 Systems

- **Tumbling Mill.** Use to batch-load parts for cleaning. The wheel units are mounted on the roof of the cabinet to blast clean the parts as they tumble in the mill.
- **Multi-Table.** This has a series of independently revolving worktables mounted on a rotating platform or spider. The individual tables rotate as they move beneath the blast stream from the abrasive throwing wheel.
- **Plain Table.** This has generally been replaced by multi-table and swing table machines.
- **Swing Table.** These provide a high degree of work handling flexibility and can accommodate large and heavy work pieces. The worktables rotate under the blast of one or more abrasive throwing wheels.
- **Custom-Designed Systems.** A variety of semi-standard and special machines are available.

5.12.9.3 Portable Wheel Blast Cleaning Systems

Portable wheel blast cleaning systems make it possible to do on-site wheel blast cleaning during new construction and maintenance work. Steel, concrete, and wood surfaces can be cleaned. The portable systems recycle the abrasive, and collect for disposal both the surface material removed by blast cleaning and the dust generated by the process.

5.12.9.4 Wheel Blast Abrasives

Abrasive manufacturers' shot and grit are screened to meet SAE (Society of Automotive Engineers) International screening specifications. As an abrasive is repeatedly blasted against work pieces, the pellets eventually fracture into smaller particles. As a result, an operating mix develops within the machine. This operating mix consists of varying amounts of new and fractured abrasive particles. The operating mix is automatically maintained by the machine as long as required quantities of new abrasive are added regularly to the machine.

The commonly used, SSPC-AB 2, *Cleanliness of Recycled Ferrous Metallic Abrasives,* covers **testing the cleanliness of abrasives in a wheel blast system**.

5.13 Vacuum Blasting

Vacuum blasting offers safe removal of contaminated material from steel and concrete surfaces without containment. The removed contaminant, coating, corrosion products, as well as the used abrasive, are vacuumed into a closed, negative-pressure waste compartment.

Vacuum blasting machines are compact and portable, which lead to on-site utilization and in tight locations. In addition, they virtually eliminate all dust and do not interfere with other work, such as welding, painting, and equipment maintenance, going on in the same area.

In vacuum blasting, after the abrasive is blasted onto the surface, the abrasive and debris return to the machine, where the dust is separated and stored. The cleaned abrasive is deposited in another area of the machine and is available for continuous blasting.

5.14 Surface Preparation of Concrete

To prepare concrete for coating, a number of operations are needed to:

- Remove form-release agents.
- Level and fill irregularities.
- Remove residues.

5.14.1 Initial Surface Inspection

Inspect concrete prior to surface preparation to determine both the condition of the concrete and the appropriate method to prepare the surface. Inspect the concrete for:

- Laitance, a weak surface layer of a cement-water-rich mixture
- Pits
- Voids
- Efflorescence, a fluffy, white crystalline deposit on the concrete surface caused by soluble salts carried to the surface by moisture reacting with carbon dioxide in the air
- Projections
- Porosity
- Moisture content
- Form-release oils
- Expansion joints
- Visible residues of dirt, salts, or other substances
- Ice or liquid water

5.14.2 Techniques for Surface Preparation

Several surface cleaning methods as well as mechanical and chemical surface preparation techniques are suitable to prepare concrete surfaces for coating, including:

- Mortar application

- Abrasive blasting
- Hand or power tool cleaning
- Low-pressure water cleaning, 3,000 to 4,500 psi (20,000 to 30,000 KPa)
- Acid etching (usually hydrochloric acid, etc.)

5.14.2.1 Mortar Application

Mortar can be applied by two techniques:

Sacking

Apply the cement mortar by rubbing it over the surface with a sack (cement sack, gunny sack, or sponge-rubber float). Ensure the mortar is correctly mixed and remove any fins or projections before sacking.

The steps are:

- Wet the substrate with water
- Apply the mortar
- Rub the mortar over surface in a circular manner

When the concrete surface is almost dry, re-work it to remove as much of the sacking material from the surface as possible.

Stoning

Stoning is similar to sacking, except applicators use an abrasive block to rub the mortar onto the surface instead of a sack. The block grinds down surface imperfections, opens up surface cavities, and works the mortar into the cavities. Sometimes applicators rub the surface with a sack after stoning to smooth it.

Trowels are also used to smooth concrete surfaces; however, excessive troweling can create a surface that is too smooth.

5.14.2.2 Abrasive Blasting

Abrasive blasting provides a roughened surface, removes laitance, and opens holes and voids so they can more easily be sealed. The surface attained is different than abrasive blast cleaned steel. When using abrasive blast cleaning methods on concrete surfaces, it is good practice to:

- Hold the blast nozzle farther from the work than when blast cleaning steel
- Use lower pressures at the nozzle than for steel surfaces
- Move the blast nozzle as rapidly as needed to avoid gouging the surface
- Use a finer size of abrasive than on steel to avoid removing too much concrete

5.14.2.3 Hand and Power Tool Cleaning

The effectiveness of using hand and power tools to clean concrete surfaces varies on the tool and/or the technique used. Using hand and power tools can be a fairly slow and costly process. These tools remove loose and powdery (weak) concrete at the surface, but they do not open air pockets as effectively as abrasive blasting does.

5.14.2.4 Low-Pressure Water Cleaning

Low-pressure water cleaning at 3,000 to 4,500 psi (20,000 to 30,000 KPa) is sometimes used on concrete surfaces. This method generally does not roughen the surface as well as other techniques. Also, it may also cut into or through the concrete if too much pressure is used. Allow adequate time for the water to evaporate out of the concrete prior to applying the coating. Various tests are available to determine the moisture content of concrete prior to coating.

5.14.2.5 Acid Etching

Acid etching uses dilute acid (usually hydrochloric acid) to remove laitance and roughen the concrete surface. The acid etching procedure includes:

- Inspecting and removing grease and other residues
- Applying acid
- Allowing sufficient time period for acid to react
- Washing surface thoroughly

- Ensuring pH of the concrete is between -1.0 to + 2.0 pH units of the rinse water

There are several hazards with acid etching; hydrochloric acid is a volatile material and the fumes are toxic. It can attack other metal surfaces in the area. Most acids should never come into contact with skin or clothing. Always wear goggles, rubber gloves, and rubber boots. ***Never** acid etch on vertical or overhead substrates*.

5.14.2.6 Surface Preparation Inspection

During and after surface preparation, inspect the concrete to determine if:

- Surface preparation operations were performed as specified.
- Voids were filled, if required.
- The surface was smoothed, if required.
- Acid etch by-products were removed.
- Surface pH was recorded.
- Abrasive blast by-products were removed

5.14.3 Testing For Degraded Concrete

Methods to test for concrete surface soundness include:

- With a screwdriver, file, or pocketknife, lightly scratch across the concrete surface. If the concrete is sound, the metal object will not loosen any particles and will only make a shiny mark on the surface.
- Lightly striking the concrete surface with the edge of a hammerhead. If the hammer rebounds sharply with just a small fracture at the impact area, the surface is sound; if the hammer lands with a dull thud and leaves powdered dust in the impact area, the surface is not sound.
- Drag a chain across horizontal concrete surfaces. The differences in sound indicate holes or pockets within the concrete.

5.15 Effects of Environment on Abrasive Blasting

Ambient conditions, such as those listed below, all have **a serious effect** on abrasive blast operations, as well as on the blast cleaned surface before coating.

5.15.1 Temperature (air and substrate)

It is always unwise to abrasive blast if the steel surface is much colder than the surrounding air. Moisture may condense on the blasted surface, causing it to flash rust. Check the substrate temperature with a steel-surface thermometer. The substrate temperature must be at least 5º F (3º C) above the dew point prior to abrasive blasting.

5.15.2 Relative Humidity

When blast cleaning, high humidity usually results in rapid rust formation. For that reason, do not commence final dry abrasive blasting when the relative humidity exceeds 85%.

5.15.3 Dew point

Dew point is the temperature at which water vapor condenses and forms a liquid. It is commonly measured and calculated with a sling psychrometer and psychrometric charts. If abrasive blast cleaning is done when environmental conditions are close to the dew point, flash rusting may occur.

5.15.4 Atmosphere (Environmental Exposure)

In marine and industrial environments where the air contains particles of chemical salts, the possibility exists that these salts may deposit on the work piece. If this occurs after blast cleaning but before coating, it may be necessary to wash and re-blast the surface. Test for the presence of certain chemical salt deposits, such as ferrous sulfate, or ferrous hydroxides using pH or litmus paper tests. Special indicators will not reveal the presence of neutral salts, such as sodium chloride.

5.16 Surface Preparation Quality Control Tests

Surface preparation quality control tests are normally performed on surface preparation equipment and materials as well as on the surface itself.

5.16.1 Equipment and Material Tests

5.16.1.1 Nozzle Throat Test

The nozzle throat test calls for a nozzle gauge marked with a grease pencil to be inserted in the back of the nozzle and twisted slightly. The gauge is withdrawn and the black mark examined. The internal diameter of the nozzle is indicated by where the grease pencil is rubbed off.

5.16.1.2 Blotter Test ASTM D4285

The blotter test checks for oil or water contamination of the blasting system. The tester sprays compressed air (no abrasives) onto a blotter to check for cleanliness.

5.16.1.3 Needle Gauge Test

The needle gauge test measures the air pressure at the blast nozzle. The tester inserts a hypodermic needle into the blast hose just behind the nozzle with both abrasive and air flowing. Low pressure means the compressor, airlines, piping line, coupling, and/or blast hose lining may not be functioning correctly, or the nozzle size may be incorrect, or the blast pot may be clogged in some way.

5.16.2 Abrasive Tests

5.16.2.1 Size

Abrasives are tested for size (determined by sieve test) and cleanliness. ASTM C 136 is the test method for sieve analysis of fine and coarse aggregates. Typically the tester puts a 1kg (2 lb) representative sample of abrasive through a series of screens (such as 12/40 or 16/40), and records the percentage retained on each screen size. This test allows the tester to compare the particle size and distribution of the abrasive with the data furnished by the abrasive supplier.

5.16.2.2 Cleanliness

Test abrasives for cleanliness by dropping some abrasive into a small vial of water of known pH (preferably pH 7) then shake. Inspect the top of the water for a film of grease or oil. Also check the water for cloudiness due to sediment, which is usually a sign of excess dirt, dust, or clay in the abrasive.

5.16.3 Surface Cleanliness Tests

5.16.3.1 Visual Tests

When abrasive dust, grease, and other contaminants are found on the surface, they need to be removed. A small mirror, mounted on a telescoping handle, is ideal to check around corners and in other hard-to-reach places to ensure these areas have been adequately blasted and that all blast materials were removed.

5.16.3.2 Water Mist

Spray a small amount of clean (preferably de-ionized water) on the surface. If oil is present the water will bead up. Remove the water ***immediately*** after the test to avoid flash rust.

5.16.3.3 Ultraviolet (UV) light

Use an ultraviolet light to illuminate a surface to reveal traces of certain hydrocarbon oils, grease, and fingerprints, etc. UV light also may reveal other things, which may or may not be detrimental to the coating. UV light does not normally fluoresce synthetic oils. SSPC Technology Guide 11 covers the use of UV light for coating inspection. It includes many of the safety concerns regarding the use of UV lights.

5.16.4 Surface Profile (Anchor Pattern)

Anchor pattern is important because it can increase the surface area or tooth to which the coating can adhere. A too shallow surface profile can result in premature coating failures, such as peeling, delamination, and lack of adhesion. A too high surface profile can have peaks that project through the coating, resulting in rust spots. There are several ways to evaluate anchor patterns, including:

5.16.4.1 Profilometer/Digital Dial Depth Gauge Micrometer

This is a handheld gauge to measure the peak to valley height of the surface profile using a cone shaped tip. Because the gauge measures the peak to valley height and the surface measured is not uniform, it is important to obtain *multiple readings* in a *given area* **and** to take multiple reading in *a number of areas* over the entire prepared surface. ASTM D 4417, Method B fully describes the method.

5.16.4.2 Comparators and Coupons

This method of testing surface profile consists of a reference disc and a 5X-illuminated magnifier. The disc has five separate leaves, each of which has a specific surface profile with an assigned a number representative of the profile depth of the leaf.

Coupons also allow testers to determine surface profile through comparison. Refer to ASTM D 4417, Method A for a fully description this method.

5.16.4.3 Replica Tape (Testex® Tape)

The test uses a piece of tape with a small square of compressible foam plastic attached to a non-compressible plastic film. Apply the test tape to the blast cleaned surface, dull side down. Use a hard, round object (a burnishing tool) such as a swizzle stick to crush the foam to the blast-cleaned surface. This compression causes the foam to form an exact reverse impression of the actual surface profile. Remove the tape from the surface and use an anvil micrometer to check the thickness of the foam and the plastic. The thickness of the polyester film is subtracted from the micrometer reading, and the result is the depth of the surface profile. Replica tape is addressed in NACE Standard RP0287 and ASTM D 4417, Method C.

5.16.4.4 Magnification

There are numerous types of magnifiers to check surfaces for:

- Contamination
- Embedded abrasives

- Blisters
- Rust
- Mill scale
- Pinholes

NACE/SSPC/ISO surface preparation standards state that viewing a surface to determine if it meets the standard must be done "without magnification."

5.16.5 Tests for Soluble Salts

The presence of soluble chemical salts such as ferrous sulfate (FeSO4) and sodium chloride (NaCl) can also be detected by a variety of tests. The tests can be qualitative (indicates the presence of a soluble salt on the surface) or semi-quantitative (roughly indicates the quantity of a soluble salt).

5.16.5.1 Qualitative Test for Soluble Ferrous Salts

This is a very sensitive test. The tester can use a ready-made indicator paper, or prepare a test paper by saturating filter paper in a 5% solution of potassium ferricyanide.

- Spray the surface to be tested with a fine mist of distilled water
- Press small piece of prepared test paper to the surface
- Soluble ferrous salts on the surface produce blue dots on the test paper (if potassium ferricyanide paper is used)

5.16.5.2 Semi-Quantitative Tests for Soluble Chemical Salts

There are a number of methods to semi-quantitatively determine the level of soluble salts on a surface. SSPC Technology Guide 15, *Field Methods for Retrieval and Analysis of Soluble Salts on Steel and Other Nonporous Substrates*, describes many of these methods.

Each of the methods involves three fundamental steps:

- Extraction of salts from surface
- Analysis of extract

- Calculation of the result

To extract salts, keep liquid in contact with surface. Depending on the method, some level of mechanical action enhances extraction. The five most common methods to extract salts include:

- Apply a patch (latex w/adhesive) to the surface and inject and withdraw water with a syringe
- Attach a sleeve containing water to the surface (flexible latex sock w/adhesive)
- Swab/wash the surface (cotton swabs)
- Extract with filter paper
- Boil water to extract salts (lab method)

ISO 8502-6, *Extraction of Soluble Contaminants for Analysis — The Bresle Method*, describes the use of the latex patch.

After retrieving the extract, analyze it using one of several methods. Measuring the conductivity of the extract can indicate total soluble salt content. Alternatively, make ion-specific measurements for chloride, sulfate or nitrate ions. The ion specific measurements may require titration, colorimetric comparison, or turbidity measurement. Calculation of the final result may include converting the results to soluble species per unit area.

5.16.6 Testing for Moisture

A moisture detector determines moisture in wood, plaster, concrete, foam, and other porous surfaces. Press the two contact pins of the electrode to the substrate, and read the moisture content directly from the meter. The moisture detector operates according to the principle of electrical resistance. The greater the moisture level of the substrate, the lower the resistance of the substrate between the two contact points.

Chapter 6: Application

Objectives

Upon completion of this chapter, you will be able to:

- Identify the various methods of application.
- Differentiate between conventional air-spray and airless spray methods.
- Describe spray application equipment.
- Describe hot-dip galvanizing application method.

This chapter addresses several methods used to apply industrial coatings/linings:

- Brush/roller/mitt
- Spray application
- Hot-dip galvanizing
- Thick barrier lining operations

6.1 Brush/Roller/Mitt Application

Brushes may be used for:

- **Stripe coating:** To coat difficult areas, such as edges, around rivets, crevices, rough welds
- **Touch-up coating:** To coat over holidays or small, scattered areas
- **Special situations:** To coat critical areas where spray application, if used, may cause damage because of overspray on surrounding surfaces, such as sensitive machinery, motors, instruments, and gauge glass

Rollers are used for:

- **Large, flat surfaces:** These areas include tank shells or roofs, floors, concrete pits, ship hulls

- **Special situations:** When spray equipment is not available, not allowed, or not practical. Rollers hold much more coating than the typical brush, and application is two to three times faster.

Mitts are used for:

- **Small projects:** Use to coat handrails, piping in racks, etc., where roller and spray applications are not feasible
- **Odd-shaped objects:** Use where other application methods would not be practical such as fences, and transmission or microwave towers

6.2 Spray Application

Generally, spray application is the best method to rapidly apply coatings to a large surface area to achieve highly uniform application of most coatings in nearly all situations. There are three types of spray application equipment:

- Conventional Air Spray
- Airless Spray
- Spray Application Variations

6.2.1 Conventional Air-Spray

This method atomizes the coating with a stream of compressed air and semi-floats it to the surface on that current of air. The air and coating enter the gun through separate passages (channels), where they mix and are driven through the air cap in a controlled spray pattern.

6.2.1.1 Air Control Equipment

Air control equipment is any piece of equipment installed between the air compressor and the point of use that modifies the nature of the air stream. Air control equipment can modify the:

- Air volume.
- Air pressure.
- Cleanliness of air to the spray gun.

- Distribution of air to multiple pieces of equipment.
- Some combination of the above.

The main types of air control equipment are:

- **Filter regulator:** Also called an *air transformer.* Removes oil, dirt, and moisture from compressed air; regulates air pressure; shows pressure on a gauge; provides multiple air outlets for spray guns and other air-operated tools
- **Condenser:** A filter installed in the air line between the compressor and the point of use; separates particles, such as oil, water, and dirt; cools compressed air; not capable of regulating air pressure
- **Regulator:** reduces air pressure in the main line as it comes from the compressor; automatically maintains desired air pressure with minimum fluctuations; use in lines already equipped with an air condenser or other filtration device.

6.2.1.2 Hoses

Conventional air-spray equipment has two kinds of hoses, air, and fluid. The **air hoses** are typically red (in small, low-pressure systems they may be covered with an orange and black fabric) and transfer the compressed air from the air regulator to the spray gun. Never use air hoses for coatings. The fluid hoses that carry coatings are lined with special solvent-resistant materials that are imperious to the common coating solvents. These hoses are also electrically conductive to ground the system.

6.2.1.3 Material Supply

Any system must have a way to provide an adequate supply of coating material to the spray gun; generally the material supply is either by suction feed or pressure feed. Suction feed systems rarely are encountered in industrial coating operations. Pressure feed equipment delivers material to the spray gun by a pressure pump or pressure pot. A pressure pump may be powered by electricity, hydraulics, or compressed air. It draws material from an unpressurized container and delivers it to the spray gun under pressure.

6.2.1.4 Spray Pots (Pressurized Tank Containers)

Pressure-feed tanks are closed containers that range in size from about 2 to 120 gal (8 to 454 L). They provide a constant flow of coating material at a uniform pressure to the spray gun. The tanks are pressurized with compressed air and force the fluid out of the tank through the fluid hose to the gun. The tanks also can be equipped with agitators to keep the material mixed and in suspension.

To control the rate of fluid flow, either increase or decrease the air pressure in the tank. Pressure-feed tanks are a practical, economical method to feed material to the gun over extended periods of time. Pressure-feed tanks are usually used when it is necessary to maintain continuous production since they provide a positive and uniform flow of material.

6.2.1.5 Pressure-Feed Tank Regulators

Almost all pressure-feed tanks are equipped with regulators for three primary reasons. Regulators:

1. Ensure constant, accurately regulated material flow.
2. Make it possible to adjust material flow across a wide range of material viscosities, and to increase pressure as needed for increased hose length.
3. Make it possible to more precisely adjust the balance between material flow and the atomization air pressure.

There are two types of regulated pressure-feed tanks:

- Single regulator
- Double regulator

Always use double regulator tanks in industrial spray applications. They are equipped with two air regulators. One regulator controls the air pressure of the material in the tank, thereby controlling fluid flow; the other controls the atomization air pressure to the spray gun.

6.2.1.6 Guns

The equipment piece that actually puts the coating on the surface is the spray gun. There are two broad classes of spray guns:

- **Manual spray guns** are held by an operator who triggers the flow of air and material.
  - The operator controls the spray pattern and density by adjusting various valves and gun components.
  - The material is applied when the operator aims the gun and pulls the trigger.
  - Operator technique is important to producing a fine finish.
- **Automatic spray guns** are identical in operation and specification to manual spray guns.
  - They are mounted on a fixed or moving apparatus to coat objects, which are usually carried past them on a conveyor.
  - Automatic guns are triggered by remote control through an attached air cylinder and are pre-adjusted to spray the correct mixture for a good finish.

The principal components of a typical manual air-spray gun are:

- **Air flow**, which includes:
  - Air control valve
  - Air adjusting valve
  - Pattern adjusting valve
  - Air cap. The air cap determines whether an industrial air-spray gun is *internal* mix or *external* mix; both types are used in manual and automatic set ups
- **Fluid flow**, which includes:
  - *Fluid adjusting valve and fluid needle:* These are made of a screw, a spring, and a housing. A collar on the shank of the needle adjoins the trigger assembly. Pulling the trigger unseats the needle, allowing material to pass the tip.
  - *Fluid tip:* This meters and directs the material into the air stream. Fluid tip materials include hardened steel, nitralloy, stainless steel, and carboloy inserts.
- **Gun body**, which includes:
  - *Nozzle combination.* This affects the quality of the spray pattern and finish. The following parts work as a single unit and form the nozzle combination:
  - Air cap

- Fluid tip
- Fluid needle

6.2.1.7 Techniques

After the equipment is balanced and ready to spray, good spray technique is required to produce an acceptable coating application. Improper technique can cause defects, such as runs and sags, in the coating.

Always check the spray gun before using it to ensure it delivers a normal spray pattern.

- Adjust the gun to produce the optimum fan —neither too wide nor too narrow.
- Hold the gun so the spray pattern is perpendicular to the surface at all times.
- Keep the gun a uniform distance of about 10 to 12 in (25 to 30 cm) from the surface.

Lap each stroke about 50% over the preceding one. Less than a 50% overlap results in streaks on the finished surface. Move the gun at constant speed while pulling the trigger, since the material flows at a constant rate. A 50% overlap not only eliminates streaks, but also provides uniform coverage.

6.2.1.8 Coating Corners and Edges

Large, flat areas are easier to coat than corners, edges, bolts, nuts, rivets, etc. Before spraying difficult areas, such as corners and edges **stripe coat them**, if required, or allowed by the specifications.

Pay special attention while spraying bolts, nuts, threads, and rivets. These are critical areas where the coating must deposit uniformly. Also pay special attention when coating curved surfaces. Always keep the spray gun perpendicular to the surface.

6.2.2 Airless Spray

Airless spray, unlike conventional air-spray, does not use compressed air to atomize the coating. Instead, the airless spray gun itself atomizes the coating; *it forces the material through a small orifice under high pressure where it atomizes as it is discharged* *from the gun*. The liquid coating is pumped from a container (either the manufacturer's original cans or 55 gal (208 L) drums) through a supply hose to the airless spray gun. This process is similar to the ordinary garden hose that atomizes water merely by forcing it through a nozzle under pressure.

In airless spray equipment, the coating material is under pressure between the pump and the gun, but is not under pressure in the material container. Thus, the material is sucked directly from the original container by the pump. Refer to Table 6.1 for the advantages and disadvantages of using this equipment and method to apply coatings.

6.2.2.1 Safety

The safety precautions for airless spray are essentially the same as for air-spray equipment, with one very important addition.

Airless spray forces materials at very high pressure through a very small opening. *The atomization is so effective that liquids can pass through human skin without breaking it.* Thus, the possibility of accidentally injecting coating materials into someone is a very real and always-present hazard. Accidental injection can cause someone to lose a limb or die. Always treat an airless spray gun as if it is a loaded firearm.

In the U.S., OSHA recognizes the danger and requires that airless spray guns:

- Carry a safety warning.
- Have a safety spacer at the exit end.

The spacer reduces the possibility of injecting paints or solvents through the skin without breaking the surface. All airless spray equipment must conform to OSHA (U.S.), Health and Safety at Work Act (U.K.), or other required standards.

Accidental injection is highly unlikely ***if*** all safety precautions are observed. However, if someone is accidentally injected, get medical attention for the person ***immediately***, even if the injury seems minor. Delaying a few minutes could cost the person an arm, leg, or life.

Additional safety rules for airless spray include:

- Never leave a pressurized unit unattended — anytime an operator moves away from the equipment:
    1. Engage the spray gun’s trigger safety.
    2. Shut off the unit.
    3. Relieve the pressure.
    4. Shut off the power.
- Ensure the fluid connections are high-pressure rated.
- Ensure the fluid hose is grounded.
- Follow coating and solvent manufacturers’ safety precautions.
- Report unsafe conditions/practices immediately to a safety supervisor.

6.2.2.2 Equipment

The most commonly used airless spray system is the **direct supply type**. In this system, the pump operates only during spraying. It starts when the spray gun is triggered, and stalls out against pressure and stops when the trigger is released.

A typical direct airless spray system contains:

- Paint supply
- Pressure pump
- Filter
- Hose
- Spray gun

6.2.2.3 Pumps

An airless spray pump draws the coating from the coating container and supplies it under pressure to the rest of the airless spray system. Most pumps are reciprocating, positive-displacement types that deliver coating under pressure on both the up stroke and the down stroke.

Although the pumps are driven by compressed air, the air does not come into contact with the coating and is not used to atomize the paint; hence, the principle remains that of airless spray. Electricity or hydraulics can be used to power the pumps.

6.2.2.4 Hose and Fittings

Fluid hoses (depending on size and fittings) are designed to safely withstand the high pressures, up to 7,500 psi (52 MPa), produced by these systems. They are also resistant to the materials and solvents they carry. The most common materials used to produce airless fluid hoses are nylon, Teflon®, and polyurethane.

Properly care for airless spray hoses by always:

- Checking before each use.
- Tightening connections securely.
- Using only properly grounded hoses.
- Checking hose pressure ratings.

Ensure the gun is grounded through hose connections. Never abuse the hose; improper use or handling can result in hose failure and possible personal injury. Always handle hoses carefully and route (lay out) to avoid kinking, abrasion, cutting, or exposure to temperatures above 180°F (82°C) or below -40°F (-38°C).

Check the entire hose for cuts, leaks, abrasions, cover bulges, or damage or movement of couplings before each use. If any of these conditions exist, replace the hose immediately. Do not use tape or any temporary measure in an attempt to mend the hose.

Never use chemicals or agents that are not compatible with the hose material in airless hoses. Always tighten fluid connections securely before each use. Never try to recouple hoses when the system is under pressure. Do not use the hose to pull the airless unit or other equipment. For airless applications, use only those fluid and air hoses that are both conductive and grounded. Make sure the gun is grounded through hose connections. Overall, the combined hose length should not exceed 500 ft (150 m).

6.2.2.5 Guns

As stated earlier, the airless spray gun forces the coating through a small orifice at high pressure, atomizing and shaping the coating spray into an oval pattern for application. The two basic types of airless guns are:

- **Internally ported:** The pressurized coating passes through the gun body before being forced through the orifice.
- **Externally ported:** The coating is carried to the orifice through a tube on the outside of the gun.

The major components of an airless spray gun include:

- ***Inlet*:** Usually 1/4 in (6-mm) NPSM (American National straight pipe thread for mechanical joints) nipple to which the grounded fluid-hose is attached.
- ***Material port*:** Carries the pressurized coating from the inlet to the diffuser.
- ***Tip guard safety tip*** (required by OSHA in the U.S.): The safety tip is colored bright OSHA Safety Orange. The safety tip is designed to prevent anyone from getting part of his or her body close enough to the orifice to receive an injection of coating.
- ***Orifice (tip):*** Airless spray tips are available in a wide variety of sizes. They generally are constructed of a tungsten carbide alloy. Since an airless spray gun acts as an on/off switch and does not have the air and fluid controls found on air-spray guns, the airless spray fan width and spray pattern are adjusted solely by the tip chosen. Tip configurations include:
  - **Standard tip:** Single fan width and single orifice size
  - **Dual-width tip:** A ball with two orifices. This tip can spray two different size spray patterns — narrow or wide
  - **Reversible ball tip:** If the tip plugs, turning a lever can reverse it
  - **Cylinder tip:** If the tip plugs, the cylinder can be reversed, the gun triggered, and the obstruction blown out
- **Gasket:** Ensures a tight seal between the fluid tip and the diffuser, thus preventing high-pressure leaks.
- **Diffuser:** Helps the efficiency of atomization. The diffuser has a 0.09 in (2.3 mm) orifice with a bar inside which splits the high-pressure stream of material. The diffuser is also a built-in safety device, designed to break up the high-pressure coating stream

should the gun be triggered without a spray tip in position to atomize it.

- **Trigger safety:** This is a safety device required by OSHA in the U.S. When in the **ON** position, the trigger safety prevents the gun from being triggered, just as a safety on a firearm prevents accidental discharge. When in the **OFF** position, the gun may be triggered and used.

Table D.8, "Comparison of Conventional Air-Spray and Airless Spray Coating Methods." (SEE BACK OF MANUALTAB D)

shows advantages and disadvantages of conventional air-spray and airless spray coating application.

6.2.3 Spray Application Variations

Conventional air-spray and airless spray equipment are sometimes modified for special-use systems including:

- Plural-component spray equipment.
- Electrostatic systems.
- Centrifugal spray systems.
- Powder coating application.
- Spray metallizing.
- Hot spray systems.

6.2.3.1 Plural-component Spray Equipment

Plural-component spraying automatically meters, mixes, and applies plural-component coatings such as polyesters, epoxies, and catalyzed urethanes with:

- Special spray guns that mix the components at the gun itself.
- Manifold mixing systems which draw the component coating elements from separate containers, combine them, then deliver the mixed coating to the spray gun

The principal advantage of plural component systems is that the coating materials are not mixed until immediately before application. This means coatings with pot lives as brief as five seconds can be applied.

Plural-Component Spray Guns

Plural-component spray guns are available for either conventional air-spray or airless spray application situations.

Coating materials are mixed internally (inside the spray gun itself), or externally (components are carried separately outside the gun, and mixed in the spray pattern).

External mix spray guns are sometimes used when chopped glass fibers are added to the sprayed coating materials. A chopper attachment is used in these cases. The chopper unit is usually air-powered and attached to the top of the gun. Its function is to chop roving, a glass-fiber rope, into appropriate lengths, called shreds. The chopper propels the chopped glass fibers into the coating material spray pattern.

Manifold Mixing Systems

In this type of system, the pump draws the individual coating components from their containers, brings them together in a manifold, mixes them, and then delivers the mixture to the spray gun or spray head for spraying.

Both conventional air-spray and airless spray equipment use manifold mixing systems. Some mixing devices are designed to vary the proportions in which the separate coating components are mixed. The range of proportions possible can be as great as from 1:1 to 18:1 or greater. Most manifold mixing systems are in use in shop situations but sometimes are used in field structural steel coating applications.

6.2.3.2 Electrostatic Spray Equipment

Both conventional air-spray and airless spray equipment (manual or automatic) can use electrostatic spray equipment.

In electrostatic spray operations the coating particles are given an electrical charge and the work piece is grounded. This equipment applies an electrical charge (up to 75 kV for hand-held guns and up to 180 kV for some automated equipment) to the coating particles as they exit the spray gun. As the coating particles move through the spray gun and into the air, the opposite charges attract each other and the finely divided coating is attracted to all sides, edges, corners, and some recesses of the grounded work piece.

The electrostatic spray coats all sides of an object.Generally, almost all of the coating gets to the surface with very little loss. This application method cannot be used in some circumstances, but is highly useful where it is appropriate. It is widely used for in-plant production finishing, but is not used as frequently in maintenance coatings or high-performance coatings for complex structures. ***Table D.9, “Electrostatic Spray Advantages and Disadvantages.” (SEE BACK OF MANUAL TAB D)***

details its advantages and disadvantages.

6.2.3.3 Centrifugal Spray

Centrifugal spray equipment uses a rapidly spinning disc to atomize the coating. Centrifugal spray equipment may be used with or without electrostatic charge. This type of equipment is used to internally line pipe and in specialized shop applications.

6.2.3.4 Powder Coating

Typical methods of powder coating include:

- Dipping (or fluidized bed).
- Spraying (electrostatic).
- Cloud chamber.

Dipping

When a finely divided stream of air passes through a powder, a solid-in-gas dispersion forms and behaves like a liquid. A fluidized bed is a tank with a false bottom made of porous material. The equipment forces air through the false bottom so the powder in the above tank lifts and stays in suspension. The volume of the powder nearly doubles and, in this fluidized condition, the powder-air mixture behaves like a liquid. When the operator dips a heated article into the fluidized powder, the powder closest to the heated article melts and adheres to the surface.

The temperature of the article during dipping and its heat capacity control the amount of powder that adheres, and hence, the thickness of the coating.

The higher the temperature and the heat capacity of the article (proportional to the mass of the article), the greater the amount of powder that adheres to the article, creating a thicker coating. After removal from the fluidized bed, the coated article receives more heating in an oven to effect complete fusion of the coating to form a smooth coherent film. When the coating is a thermoset material, the heating cycle must be adequate to completely cure the coating.

Spraying

Another method to apply powder coatings is electrostatic spray. As noted in the previous section on electrostatic spraying, the hand-gun applies a charge to the fluidized powder as it moves through the gun. The electrostatic spray gun can apply coating thicknesses from 50 µm to over 500 µm.

Cloud Chamber

This is essentially a large box with openings for the work piece to enter and exit the chamber. A cloud of fluidized powder is introduced by one or more distribution heads.

6.2.3.5 Spray Metallizing

This process confers corrosion protection by spraying a variety of molten metals as a coating. Aluminum and zinc are the principal metals used for corrosion protection, although lead is sometimes used for the interior of vessels that will contain strong chemicals. Spray metallized coatings are appropriate for a wide range of uses including:

- Fresh water tanks (American Water Works Association [AWWA] Standard D102).
- Industrial service atmospheres.
- Bridges.
- Salt environments.
- Ship hulls.

- Tanker interiors.
- Hot surfaces (where aluminum is applied by spray metallizing to stacks, mufflers, steam and process piping, etc.).

Surface Preparation

Any abrasive blast method may be called for by the job specification. Remember, the abrasive blast step is very critical. Generally, a thicker coating demands a greater anchor pattern, even up to 8 mils (203 µm) or more.

Surface preparation is extremely important, because any foreign materials, and even trace surface moisture, can cause a defect or premature failure of the coating. If necessary, perform double abrasive blasting.

Application

After surface preparation, apply the metallized coating as quickly as possible, and always within the time required by the specification.

The spraying metallizing gun draws a wire of the chosen metal through the gun by the wire drive rolls and guides. Some operations use powdered metal rather than wire. A combustible gas mixture enters the gun where it is ignited at the tip of the gun, forming a hot flame which melts the wire as it passes through. The melted wire is atomized and propelled onto the surface of the work piece.

A gas control unit regulates the flow of combustible gas, usually a mixture of oxygen and either acetylene or propane. The wire control unit ensures that the wire is kept free of kinks and is continuously supplied to the metallizing gun.

Relatively speaking, spray metallizing application is fairly slow; application rates of 10 ft^2 (1 m^2) per hour are not uncommon. Because of the slow application rate, it is an expensive process.

Always operate the metallizing gun in strict accordance with the specification and the manufacturer’s recommendations. The speed of the gun at it passes across the surface greatly influences the thickness of the coating, as does the speed at which the wire is fed through the gun.

Additional factors to help ensure a successful metallized coating:

- Use a fan spray air cap; this spreads the coating more evenly than the standard metallizing air caps used for machine shop metallizing operations.
- When successive metallized coats are required by the specification, spray each coat at a different angle to help to eliminate holidays.
- Handle the metallizing wire carefully to avoid kinks and bends that can hamper passage through the gun.
- Store metallizing wire in a dry place until required.

Common flaws in spray metallized coatings include:

- Dry spray.
- Porosity.
- Low adhesion.
- Delamination due to poor surface preparation.

Some *safety considerations* of particular importance during metallizing operations include:

- Use of air-supplied breathing equipment
- Adequate ventilation
- Safe handling and storage of combustible gases

Seal Coating

A seal coating may be applied to:

- Reduce electrolytic action.
- Increase coating life.
- Improve cleanliness.
- Improve appearance.

NACE No. 12/AWS C2.23M/SSPC-CS 23.00, *Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel* covers metallizing in more detail.

6.2.3.6 High-Volume/Low-Pressure (HVLP) Equipment

High-volume/low-pressure (HVLP) equipment uses a low-velocity air stream to deliver a controlled spray pattern. This equipment improves transfer efficiency, creates less overspray, and generates less bounce-back. HVLP equipment provides a cleaner environment with greater visibility for operators. Additionally, fewer passes are needed because more coating is applied on each pass compared to high-pressure equipment.

HVLP atomizes the coating material when a high volume of air is delivered at 10 psi (69 kPa) of pressure or less. Conventional spray methods normally deliver 40 to 70 psi (276 to 483 kPa) of pressure.

Use HVLP spray with a variety of coatings including two-component coatings, urethanes, acrylics, epoxies, enamels, lacquers, stains, and primers.

Both HVLP and conventional air spray techniques use compressed air for atomization; however, HVLP is limited to 10 psi (69 kPa) while conventional air spray uses 60 psi (414 kPa) or greater. Higher pressures result in greater overspray and bounce-back.

System Components

An HVLP system consists of:

- **High-volume air source:** Can be centralized, serving multiple guns, or used for a single gun.
- **Material supply system:** May be supplied through any conventional supply system.
- **Special HVLP guns:** Special caps and tips are needed to give correct atomization.

Air Supply Designs

There are three basic HVLP air supply designs:

- **Turbine-generated air flow.** Air flow is produced by a turbine generator. This method makes it easy to move equipment and provide the requisite air volume when shop air lines are not available. Drawbacks are: air temperature cannot always be controlled, pressure may be insufficient to properly atomize the material, and turbines may require a high level of maintenance.

- **Diversion of shop air through an air conversion unit.** This air supply method reduces atomization air pressure to 10 psi (69 kPa) or less before the air reaches the spray gun. Air heaters can deliver a constant temperature. This design can also deliver constant pressure. Although more reliable than turbine generated air flow, air conversion units need a larger internal diameter (ID) hose and a separate air conversion unit.
- **Shop-supplied air**. The gun reduces shop air pressure from 50 to 100 psi (345 to 690 kPa) to 10 psi (69 kPa) or less. There is no need for a separate air conversion unit and the air pressure is easily regulated. This design allows connection to a standard airline fitting, 1/4 in (6.4 mm), and a 5/16 or 3/8 in (7.9 or 9.5 mm) air hose.

System Operation

Operators can lower the fluid flow rate since HVLP spray equipment reduces overspray and bounce-back. They can also hold the gun 6 to 8 in (15 to 20 cm) from the surface compared to the 10 to 12 in (25 to 30 cm) required by other air spray equipment. HVLP equipment makes less noise than conventional air spray guns because of the lower pressure required.

6.2.3.7 Hot Spray Systems

Both air-spray and airless spray methods can heat the coating liquid prior to application. To heat the coating use either an *in-line heater* or a *hot box* which heats the coating before it passes through the spray gun.

Increasing the temperature of the liquid coating generally reduces viscosity, making application easier and somewhat faster. It also means as the coating travels through the air, it cools rapidly, increasing viscosity immediately after it reaches the surface. This helps the coating remain in place and reduces the chance of sags and curtains, which makes a smoother, more uniform film.

The fast-evaporating solvents in a coating liquid tend to evaporate readily between the gun and the surface. This leaves a higher quantity of the slowly evaporating solvents in the material which in turn helps level the coating.

Heating the coating makes it possible to spray higher-solids and higher-viscosity materials, which enables more material to be deposited per coat without the danger of runs or sags.

Ensure the coating is not heated hotter than allowed by the specification or manufacturer's recommendation. Heating normally shortens pot life of two-component materials.

In-Line Coating Heaters

There are many coating heater suppliers and the heaters come numerous sizes, shapes, and forms. They generally pre-heat coatings from 120°F (50°C) to as high as 180 to 200°F (82 to 93°C).

Some heaters are portable to attach to the spray applicator's belt. They are heated with electricity and require an electric cord to the heater. This, along with the weight of the heater itself, makes the equipment somewhat more cumbersome for the applicator.

Some heaters are stationary and located between the pump and the gun so the coating must pass through them. This method can lose considerable heat depending on the length of the hose, although insulated and heat traced hoses are available.

Many shop-finish application units use airless spray with in-line heaters as a standard procedure. Coating heaters are not used as often on large structural steel units, offshore rigs, or large storage tanks.

Some of the advantages of heated spray include:

- Coating with a more uniform viscosity
- Even coverage with fewer runs and sags
- Decreased drying time
- Faster application
- Coatings spray more readily at lower ambient temperatures
- Fewer solvent fumes because no added solvents
- Finer atomization with lower application pressures are possible

- Reduced viscosity improves coating adhesion
- Longer lengths of hose as needed

6.3 Hot-Dip Galvanizing

Hot-dip galvanizing cleans steel of all mill scale or other impurities and then dips the steel into molten zinc. It is the most commonly-used process to coat steel with zinc.

Hot-dip galvanizing can be used with extremely small steel objects, such as nuts and bolts, as well as large fabricated work pieces, such as tanks, transmission towers, and containers. The thickness of the galvanizing determines the service life of the coating. Thicker zinc coatings prevent corrosion longer than thinner zinc coatings.

6.3.1 Other Types of Zinc Coatings

Organic zinc-rich coatings (Type 2) are made with many organic vehicles. Type-2 zinc coatings are used as a repair primer for both inorganic zinc primers and galvanized surfaces that have been top-coated and then damaged. Organic zinc-rich coatings are subject to weathering, and adhesion can lessen as a result of water absorption, etc.

Inorganic zinc coatings (Type 1-A, -B, -C) were first developed to replace galvanizing. When applied to clean steel, even as a single coat, they offer long-term corrosion protection in arctic and tropic regions as well as all moderate climates; they are used on industrial and marine structures as well. In addition to good corrosion resistance, Type-1 zinc coatings offer:

- Cathodic protection (forms barrier protection as a secondary means of protection)
- Weather resistance
- Undercutting prevention
- No shrinkage upon drying or curing
- Temperature resistance
- Solvent resistance
- Radiation resistance

- Excellent friction characteristics
- Abrasion resistance
- Fire resistance
- Welding effectiveness

Inorganic zinc coatings and galvanizing are not competitive processes, but rather, are complementary processes. When applied correctly they both provide excellent corrosion resistance. However, in general, when compared in the same type of exposure service, over a period of time, inorganic zinc coatings do have a longer life span than galvanized steel of the same thickness. ***Table D.10, "Comparison of Inorganic Zinc Coating with Galvanized Coating." (SEE BACK OF MANUAL TAB D)***

compares inorganic zinc coatings with galvanized coatings.

6.4 Thick-barrier Lining Operations

An interior protective lining is a material applied to an interior surface subject to direct contact and immersion in liquids, chemicals, or other products. In addition to mitigating corrosion of the surface to which it is applied, it must be able to mitigate contamination of the product contained.

Linings protect the:

- Interior of equipment from corrosion.
- Contents of a vessel from being contaminated by a substrate.
- Interior of equipment from abrasion and the corrosion that can accompany abrasion.

6.4.1 Safety

Observe safe practices during all stages of producing a lining. Safety considerations include:

- Appropriate ventilation
- Proper safety equipment including fresh-air breathing equipment

- Spark-proof tools

The NACE publication, TPC 2, *Coatings and Linings for Immersion Service*, Chapter 1: Safety, provides an in-depth review of many important safety issues.

6.4.2 Surface Preparation, Application, and Inspection

The job specification indicates the surface preparation techniques to use, which application and inspection standards to follow, and the materials to use; all are generally similar to exterior coating operations. Because most linings are located in a severe service environment, surface preparation, application, and inspection must be done precisely and correctly. There are two primary types of linings — unbonded and bonded.

6.4.3 Unbonded Linings

Unbonded linings are either shop- or field-fabricated to fit the service vessel. They attach either mechanically or by adhesion to nozzles, manholes, and other vessel penetrations. The primary steps in unbonded lining installation are:

- Surface preparation
- Surface preparation inspection
- Pre-installation inspection
- Installation
- Post-installation inspection

6.4.4 Bonded Linings

Bonded linings are the application of any organic or inorganic material in liquid or spray form to attain a desired thickness for protection. Bonded linings are also sheet materials (rubber, fiberglass), membranes, or brick constructions. Sheet materials include:

- Rubber
- Polyvinyl Chloride (PVC)

- Polyethylene
- Proprietary materials generally known by brand names, such as Kinar®, Halar®, Penton®, etc.

Chapter 7: Safety

Objectives

Upon completion of this training material, you will be able to:

- Recognize safety considerations associated with the application of protective coating systems.

7.1 Regulatory Agencies

Always verify that you are complying with the safety rules and regulations of the country in which the work is being performed.

In the U.S., the primary regulatory agencies that influence the coatings industry include:

- **OSHA** — Occupational Safety and Health Administration (US); Federal agency that sets job safety regulations.
- **NIOSH** — National Institute of Occupational Safety and Health (US); non- governmental standard-setting and testing organization.

Safety is the responsibility of every workers at the job site. Safety aspects this chapter addresses include:

- Safety checklists.
- Material Safety Data Sheets.
- Personal protective equipment.

7.2 Safety Checklists

The following safety checklists not only highlight and emphasize critical safety issues, but paying close attention to them can help prevent serious injury to yourself or others and save your life or others' lives.

7.2.1 General Work Site Safety

- Locate nearest telephone
- Identify restricted areas

- Locate fire alarm
- Locate fire extinguisher and fire blankets
- Locate moving objects, cranes, and traffic
- Identify and observe safety warning tags and signs

7.2.2 Ladder Safety

- Periodically inspect for loose, worn, or damaged rungs
- Wear shoes with heels
- Do not carry tools in hand while climbing
- Face ladder while climbing; never jump from a ladder
- Prevent metal ladder from contacting electric power lines
- Tie off ladder

7.2.3 Scaffold Safety

- Ensure that scaffolding has been inspected and tagged by an appropriate competent/certified/licensed person
- Prior to each use inspect for damage/deterioration
- Ensure scaffolding is plumb and level
- Check for hand rails on all scaffolding
- Do not ride scaffolding when it is being moved on rollers

7.2.4 Abrasive Blast Safety

Make sure the following are installed and in working order:

- Deadman valve
- Pressure control valves
- Adequate moisture and oil separators
- Protective clothing (hoods and gloves)
- Filtered and regulated air-supplied respirators
- Ensure:

  - Entire system is grounded, including hoses, operator, and work piece
  - Hose couplings are wired shut
  - Abrasive hose is stored in dry place
  - Abrasive hose is curved around; not bent at 90° angle
  - Nozzle is never pointed at human body or breakable object
  - Abrasive hose is inspected for damage and wear

7.2.5 Spray Application Safety

Coating materials and solvents are fire hazards, so:

- Ensure no ignition sources are present around flammable materials.
- Minimize the use of low-flash-point materials.
- Ensure there is adequate ventilation.
- Make sure spray booth is clear of exhaust fumes from previous spraying.
- Do not leave rags soaked with flammable liquids in spray area.

7.2.6 Personal Protection Safety

- Ensure operator is upwind of object being sprayed
- Use:
  - Regulated air respirator
  - Appropriate protective solvent-resistant skin cream

- Wear:
  - Goggles and safety glasses
  - Hard hat
  - High-top shoes with steel toe caps
  - Ear protection
  - Body covering
  - Clothing closed at wrist and neck

7.2.7 Hose and Gun Safety

- Inspect hose periodically for weak or worn spots
- Ensure hose connections are correct and tight
- Never disconnect or recouple hose while under pressure
- Never leave a pressurized unit unattended
- Ground the gun through hose connections
- Never point the gun at a human body
- Use the required trigger guard
- Always use electrically conductive hose in airless applications

7.2.8 Solvent and Coating Material Safety

While everyone must handle all solvents and coating materials carefully and according to the manufacturer's specifications, *remember that some are* ***extremely*** *dangerous* and require very particular caution. These include, but are not limited to:

- Acetone, MEK (methyl ethyl ketone) solvents
- Vinyl solvent-solution coatings
- Epoxy coatings and compounds
- Neoprene-Hypalon (synthetic rubber) coatings
- Any allowable coating containing lead or mercury
- Aromatics (xylene, toluol)
- Cellosolve
- Cellosolve acetate
- Urethanes

7.2.9 Test Equipment Safety

- Ground holiday detectors
- Do not use high-voltage holiday detectors when volatile substances are present

- Equip ultraviolet detectors with appropriate safety filters

7.3 Material Safety Data Sheets

In most countries, Material Safety Data Sheets (MSDS) are required to be available onsite whether in a facility or in the field. Coating manufacturers supply MSDS specific to the country of origin to inform coating users of the safety requirements for a particular product. The **main topics** in an MSDS are:

- Distributor.
- Section 1: Product Identification.
- Section 2: Hazardous Ingredients.
- Section 3: Physical Data.
- Section 4: Fire and Explosion Data.
- Section 5: Health Hazards.
- Section 6: Reactivity Data.
- Section 7: Spill or Leak Procedure.
- Section 8: Special Protection Information.
- Section 9: Special Precautions.

Legislation in various states and countries outlines requirements for workers' Right-to-Know about safety and health hazards of products and equipment.

Distributor

Section 1: Product Identification includes:

- Company name and address.
- Emergency telephone information.
- Specific product name.
- Product class (shipping information).
- Hazardous Materials Information System (HMIS) codes.
- Personal Protective Equipment (PPE) requirements class.

Section 2: <u>Hazardous Ingredients</u> includes:

- Name of each hazardous ingredient.
- Amount of each hazardous ingredient.
- Chemical Abstract Service (CAS) number of each hazardous ingredient.

> ***Note:*** *In the U.S., the Environmental Protection Agency (EPA) and the chemical industry use the CAS number for computer tracking and identification of each chemical product (over 100,000 of them).*

- Lower explosive limit (LEL) (if applicable).
- Vapor pressure (if applicable).

Section 3: <u>Physical Data</u> includes:

- Boiling point.
- Weight per gallon relative to the weight of one gallon of water (known as the specific gravity).
- Evaporation rate of the solvents.
- Freezing point of the paint (if applicable).
- Vapor density, relative to air, of the solvent vapors; the higher the number, the heavier the solvent vapor.
- Percent solids by volume (indicates the amount of solvent per gallon).
- Relative water solubility.
- Appearance and color.

Section 4: <u>Fire and Explosion Data</u> includes:

- Flash point.
- Explosion limits (upper and lower).
- Media suitable to use to fight fire.
- Special fire-fighting procedures.

- Unusual fire and explosion hazards.

Section 5: Health Hazards includes:

- Effects of overexposure.
- Danger symptoms.
- Emergency aid procedures.

Section 6: Reactivity Data includes:

- Required storage conditions.
- Items with which the product will react.
- What expected reaction products will be.

Section 7: Spill or Leak Procedure includes emergency clean-up procedures for spills and leaks.

Section 8: Special Protection Information includes personal protective equipment requirements for:

- Eye protection.
- Breathing protection.
- Gloves, coveralls, boots, etc.

Section 9: Special Precautions includes:

- Precautions unique to this product.
- Other special information.

7.4 Personal Protective Equipment

7.4.1 Breathing Apparatus

Operators performing coating application procedures must use a respirator or breathing apparatus since many application procedures create overspray, hazardous vapors, and toxic fumes.

A respirator is a mask worn over the mouth and nose to prevent operators from inhaling overspray fumes and vapor. Before work begins, each individual operator must:

- Receive proper training in the use and care of respirators.

- Have a medical exam to determine his or her pulmonary function.
- Have the respirator properly fitted, then tested while the operator wears it.

Respirators are necessary for two reasons:

- Respiratory protection is dictated by the applicable regulation body.
- Even without regulations, common sense indicates that inhaling solvent vapors is not healthy.

There are two primary types of respirators:

- Negative pressure respirators
    - Full face (hood)
    - Mouth and nose
    - Organic vapor
    - Dust and other particles
- Positive pressure respirators
    - Full face (hood)
    - Mouth and nose
    - Organic vapor
    - Dust and other particles

7.4.1.1 Hood Respirators

Hood respirators cover the head and neck and supply the wearer with clean, dry air through a low-pressure connection to a filtered air supply. They protect the wearer from heavy concentrations of vapor, fumes, dust, and dirt that can harm respiratory organs, eyes, ears, and exposed skin. Use these where other types of respirators are impractical and/or do not provide sufficient protection. Hood respirators are generally regarded as the best means of protection, because they offer complete eye protection and generally do not fog.

There are Federal material standards that cover personal protective equipment, including respirators. Some states in the U.S. have slightly different regulations than the Federal government. If the state requirements differ from the federal requirements, the more stringent requirements always take precedence.

7.4.1.2 Mouth and Nose Air-Supplied Respirators

Air-supplied respirators also operate from an external air supply. They cover the nose and mouth only and do not provide the degree of protection against splashes that the hood respirators do. The operator must wear eye protection such as goggles with this type of respirator. It is very safety-critical to maintain an effective seal between the mask and the face.

When air-supplied respirators are used, it is essential that the air is fresh and pure. The common practice of using plant air — air taken off of the plant's compressors — can be very dangerous if that air is contaminated by operations elsewhere in the plant.

7.4.1.3 Organic-Vapor Respirators

Organic-vapor respirators cover the nose and mouth and have replacement filter cartridges to remove organic vapors by chemical absorption. Some of these respirators also first remove solid particles from the air before it passes through the filter cartridge. These are commonly used in finishing operations with standard materials and are not recommended for commercial coating operations. Use the correct cartridge to match the operating environment. These respirators also require a complete seal between the mask and the face. Wear separate safety goggles or other eye protection. Do not use this type of respirator in oxygen-deficient areas.

7.4.1.4 Dust and Particulate Respirators

Dust and particulate respirators are sometimes used in spray finishing, but they are unsatisfactory in most other applications. These respirators are equipped only with cartridges to remove solid particles (like those from the sanding, grinding, or buffing of surface preparation) the air; they do not remove vapors. Operators must wear separate safety goggles or other eye protection. Do not use this type of respirator in oxygen-deficient areas.

7.4.2 Protective Clothing

Operators should always wear protective clothing in hazardous or potentially hazardous conditions. Protective clothing includes:

- Coveralls, including fireproof clothing.
- Safety helmets.
- Steel-toed safety shoes.
- Non-skid soles when working in enclosed areas with flammable vapors.
- Acid-proof clothing when handling acid material.
- Rubber gloves or plastic protection.

Never store clothing that has become saturated with chemicals. Either launder immediately or dispose of properly.

Chapter 8: Specification and Pre-Job Conference

Objectives

Upon completion of this training material, you will be able to:

- Recognize the main sections of a coating specification
- Understand the importance coating specifications play in ensuring desired results in a protective coating project
- Identify the purpose of the pre-job conference
- List the typical pre-job conference attendees.

8.1 Coating Specification

The coating specification is a guideline is an official document that tells contractors what to do and where to do it, but generally doesn't tell them how to do it.

Coating specifications are written to meet the requirements for a particular job. Often, specifications are copied from specifications used on other jobs, without regard for the unique aspects of the new job. Many times, the specification doesn't address technological advances in coating products. Some coating specifications are so vague that no one can interpret their meaning.

Before each coating job, the coating specification author (the specifier) should:

- Carefully review and correct whatever is inaccurate, impractical, or ambiguous.
- Get a second opinion from someone to spot what may have been overlooked.
- Distribute copies of the specification to everyone involved with the project.
- Review the specification requirements with everyone involved with the project.

- Define the procedure for work-in-progress changes or deviance from the specification.

8.2 Coating Specification Sections

A good coating specification should contain information and criteria in each of the following sections:

1. General
2. Terms and Definitions
3. Reference Standards and Codes
4. Environmental Regulations
5. Scope (includes the coating schedule)
6. Safety
7. Pre-Job Conference
8. Surface Preparation
9. Coating Materials
10. Sampling Coatings
11. Coating Schedule
12. Workmanship
13. Application
14. Work Schedule (sequence of work to be done)
15. Repairs and Remedial Coating Work
16. Inspection
17. Documentation

The following portion of the chapter briefly examines each section of a specification.

8.3 General

The general section of a specification may only show the owner's name and address, the owner's job number, and the designated representative, if any. It may also contain additional details about the responsibilities of the contract parties, procedures to resolve conflicting information, and other items of general interest.

8.3.1 Terms and Definitions

A good specification defines specific words or terms to clarify their meaning. For example, words such as *shall, will, shall not, will not, should*, and *may* need specific statements about what they mean in the context of the specification; there should be no ambiguity. Additionally, terms such as *owner, company, contractor, foreman, inspector, specifying engineer, specifier,* and *coating supplier* must be defined.

8.3.2 Reference Standards and Codes

The specification generally lists a set of published standards that are referred to, i.e., referenced, in other sections of the document. Any part of a referenced standard can be as binding on all contracted parties as the entire standard, *unless* an exception is noted.

8.3.3 Environmental Regulations

The specification includes all applicable air, land, and sea environmental regulations. It also provides a list of all regulatory requirements, including national and local requirements.

8.3.4 Scope

The scope section describes the work to be done, when and where it will be done, and what the contractor will supply. It specifies if the project is a time-and-materials contract or a fixed-price contract. The scope may also define the purpose of the coating job. This section usually includes a list of each item to be coated and all areas that are to be protected and not coated.

8.3.5 Safety

Many specifications begin the *safety section* with a general phrase, such as:

> *Work shall be done in a safe manner in accordance with all applicable federal, state, and local safety codes.*

Specific safety requirements may also be cited:

- Wear hard hats
- Use breathing apparatus (owner may require respirator fitting for all contract personnel)
- Use of protective clothing, with contrasting, identifying colors specified, such as:

  - Refinery personnel — blue
  - Paint contractor personnel — orange
  - Other contractor personnel — yellow, etc.
- Requirements for special permits for certain plant areas, such as confined spaces
- Other plant requirements, such as identification of safe havens in the event of emergencies

8.3.6 Pre-Job Conference

A good specification calls for a pre-job conference so all parties (owner, contractor, coating supplier, inspector, etc.) can meet to review standards, work procedures, clarify roles and responsibilities, review reporting hierarchy, and dispute resolution, etc., for the project. The pre-job conference also provides the opportunity to resolve errors or ambiguities in the specification. Topics generally include:

- Scope
- Safety procedures
- Coating materials and handling practices
- Cleaning operations
- Application procedures
- Materials and material handling procedures
- Inspection procedures (tools, methods, sequence)
- Authority of the inspector
- Submittals
- Change orders, if any

8.3.7 Surface Preparation

This section covers surface preparation methods and standards. Requirements vary with the project, but surface preparation should describe all parts of the cleaning process, including:

- Pre-inspection: procedure to inspect for, mark, and correct all fabrication defects.
- Pre-cleaning: removal of contaminants, such as oil, grease, dirt, etc., by solvent cleaning to a known standard, e.g., SSPC-SP 1, Solvent Cleaning.
- Cleaning operations to referenced standards: NACE, SSPC, ISO.
- Containment requirements during surface preparation.

Additional information included in this section describes the abrasives, equipment, techniques, and restrictions to use in surface preparation. Restrictions may include work hours, areas with limited physical access, areas to be protected during surface preparation, location of available equipment, etc.

In maintenance work the contractor is sometimes required to prepare a test section, sometimes known as a “reference area.” This is an area representative of the actual structure (several square feet) that is prepared in accordance with the precise specification requirements. The owner, inspector, and project personnel should all participate in this effort. When all concur the test section represents the quality of work expected on the entire project, it is then the official “reference area.” The test section preparation should be well-documented and maintained for reference throughout the project.

8.3.8 Coating Materials

This section identifies the exact coatings to use by manufacturer and type. The specification author (the specifier) may state the selection in terms of:

- ***Generic formula,*** such as SSPC Paint #20, AWWA C-204 Interior System #8, etc.
- ***Performance criteria***, such as percent solids by weight and volume, viscosity, weight per gallon, gloss, dielectric strength, per-

meability, abrasion resistance, pencil hardness, etc., all according to test methods listed in such publications as those issued by ASTM.

- ***Multiple sources***, in which the specification identifies more than one specific acceptable alternative material. This also includes instances where a published "Qualified Products List" is referenced by the specification.
- ***A single source,*** which is the adoption of a specific coating or coating system, usually based on known field performance, generally supplied by a single manufacturer.
- An ***"or approved equal,"*** which means the specifier has determined that coating materials from one manufacturer are acceptable, but is willing to consider other products. Note that "or approved equal" can be subject to interpretation and misunderstanding. If this statement is included, the specifier should know what constitutes "equal" coating materials. This may be based on test data, performance statements, or coating chemistry, each of which has important implications.

Other issues addressed in this section may include material storage, shelf life, mixing, thinning, and agitation.

8.3.9 Sampling Coatings

This section of the specification spells out a sampling procedure if samples of the project coatings are required. It details the number of samples to be taken, the labeling procedures, and the storage requirements.

8.3.10 Coating Schedule

The coating schedule is a specific list of exactly what items are to be coated. It also identifies each area to be protected, covered, and not coated. In complex jobs involving multiple coating systems, the coating schedule includes an easy-to-reference summary of the surface preparation, coatings, and any special notes associated with each item.

8.3.11 Workmanship

Coating specifications often include a general phrase, such as:

> *All work shall be performed in strict accordance with these specifications and the coating manufacturer's current printed instructions for materials to be used on this project. Work shall be performed by skilled workmen in a safe and workmanlike manner.*

This statement is ripe for misinterpretation, ambiguity, and misunderstanding. Specifications should ***define*** good workmanship with terms that can be objectively measured and enforced (e.g., no runs and sags).

8.3.12 Application

The application section of the specification defines the approved application methods to be used on the project from among the many possible alternatives:

- Brush
- Roller
- Air spray
- Airless spray
- Plural-component spray
- Air-assisted airless spray, etc.

This section states the required wet-film thickness (WTF) and/or dry-film thickness (DFT), expressed either as a range, or simply a minimum requirement. The specified thickness should never be a single number.

If the specification calls for stripe coating, it also identifies the areas to be striped and the procedure to follow. Minimum and maximum cure times between coats are also stated in this section, as well as the cure schedule (especially for tank linings) before service can restart. This section also usually contains a statement that the applied coating should be free of film defects such as runs, sags, pinholes, etc.

8.3.13 Work Schedule

The contractor usually establishes his crew's work schedule and submits it to the engineer for approval **before** starting the job. The work schedule lists the specific order in which the coating job is to be done, including:

- Pre-inspection of surfaces to be coated
- Pre-cleaning
- Repair of fabrication defects
- Surface preparation
- Application
- Inspection intervals
- Repair and remedial coating work
- Records and reports

This section also clearly identifies access points to the plant and/or job site, and the allowable working hours for the contractor. Other known restrictions and limitations regarding the work schedule are included in this section, such as identification of possible coordination issues between the contractor, other trades working in the area, and the inspector. It also states requirements for the contractor to make the work available for inspection and provide access for the inspector and other owner's representatives.

8.3.14 Repair and Remedial Work

This portion of the specification states procedures for repair work. It requires the contractor to repair damage to the coating and describes the procedure to use. Repair procedures commonly depend on the size and nature of the defect. For example, it may not make sense to require abrasive blasting to repair small (a few square inches) non-compliant areas. Instead, it may specify power tool cleaning.

8.3.15 Inspection

The specifics of the inspection section vary according to the particular requirements of the coating job. Some owners want inspections to be performed by their own staff; others prefer independent inspectors hired specifically for the project, and some want the contractor to provide his or her own inspection and quality control crew. Inspection specifications can include:

- Qualifications of an inspector.
- Required measurement of ambient conditions (dew point, relative humidity, air and steel temperatures, etc.) at the actual work site throughout the job.
- Pre-inspection for fabrication defects.
- Pre-cleaning oil, grease, dirt, etc., from substrates.
- Surface preparation details (equipment, abrasives, cleanliness, profile, etc.).
- Coating materials (storage, identification, mixing and thinning, etc.).
- Application (equipment, thinners, WFT, recoat times, etc.).
- Inspection of the cured coating (DFT, visual, holiday detection, degree of cure, etc.).
- Documentation (record keeping, reports, etc.).

Specifications often contain an outline of inspection procedures which define the inspector’s tasks:

- When, where, and how many measurements to take, as well as *hold points*
- Pass/fail criteria for all measurements
- The specific inspection tools to use
- Guidelines for completion and submission of inspector’s reports
- A comprehensive statement of the inspector’s responsibilities and authority
- An organizational chart showing the chain of command and the inspector’s position

Finally, the coating inspector may be asked to record project-related information that is of a non-technical nature such as:

- Workers on site

- Equipment on site
- Working/operating hours.
- Energy consumption.
- Paint/thinner consumption.
- Impact on other operations (machinery downtime, road closures, etc.).
- Visitors to the job site.

8.3.16 Documentation/Submittals

This section covers all record keeping and reporting from the inspection process. It is also common to require coating contractors to submit documentation at various project stages. For example, prior to beginning work, they must submit Product Data Sheets, Material Safety Data Sheets (MSDS), and a project plan. It is also common to request Work Safety Plans, Contractor Points of Contact, Certifications (for the company and workers), Containment of Scaffolding Design, Quality Control Plans, Product Batch Certifications, and other documents.

See appendix "Documentation" for more information

8.4 Pre-Job Conference

The purpose of the pre-job conference is to:

- Ensure clear, common understanding of the job.
- Minimize the chance of undesirable results.
- Cover all contingencies.
- Ensure common understanding of roles.

The pre-job conference, as its name indicates, takes place prior to starting work. It gives everyone involved in the project the opportunity to understand everyone's responsibilities and authority, and the chain of authority. The meeting also ensures participants understand what is required by the owner’s specification and what restrictions, if any, apply. It also clarifies the procedures, processes, and methods to be used. The meeting offers the opportunity to answer questions and resolve and agree on issues such as:

- The conduct of the job.
- Requests to modify job conditions.
- Proposed changes to the specification.
- Submittals.
- Change orders.

Make sure minutes of the meeting include answers to the questions, along with other practical information. The meeting leaders should distribute the minutes to all of the parties involved before any work begins.

The following individuals usually attend the pre-job conference:

- Owner
- Engineering and construction personnel
- Primary contractor
- Erector
- Coating material supplier
- Coating applicator contractor or subcontractor
- Safety engineer (owner)
- Inspector (owner or independent)
- Consultant/others (as required)
- Providers of special services, such as dehumidification or special surface preparation equipment

Case Study B: Megamark Industries

George Phillips, Manager — Coating Department, considered the most recent request he had received for a coating specification.

Phillips had very little time to develop an initial recommendation, in fact he was due to present it at a construction committee meeting the following day. His task was complicated by having only the information received via a phone call that morning.

Megamark was in the process of expanding their Seaview facility and as a last minute item, heartily endorsed by the local fire marshall and Megamark's insurance carrier, a large fire-water storage tank had been added to the project.

Phillips mulled over the situation. The Seaview facility was located in the industrial section of a large seaport city. In addition to the fallout from Megamark's own facility, there were many other factories, process plants, even a major refinery within several miles. There also was the pollution from the thousands of vehicles which each day drove the expressway adjacent to the Megamark plant.

The tank would contain water that was "clean, not potable," which to Phillips meant that while it would be clear and without sediment, it could and probably would contain traces of unidentified chemicals, solvents, and/or other materials.

Service life requirements are:

Exterior: Five years' initial service life with touch-up maintenance thereafter for an additional 20 years.

Interior: Ten years' initial service life, maintenance as required, then an additional ten years' service.

The dimensions of the cylindrically shaped tank: height – 20 ft, radius – 50 ft. It would be fabricated of steel sections welded together, with a steel bottom on a concrete slab.

Phillips calculated the following areas to be coated (in square feet):

	Interior	**Exterior**
Wall	6,280	6,280
Roof	7,850	7,850
Floor	7,850	------
Rafters, ladders, columns, etc.	2,230	------
	24,210	14,130

Team Assignment

Based on the information presented in this case:

1. Select from the Data Sheets (as reviewed in Case Study A), the coating system which will, in your team's collective technical judgement, best provide appropriate protection for the interior and exterior of the tank.
2. Develop a list of any additional information you feel Phillips needs to have for this job.
3. Identify the following key elements of the coating specification:

Table 1: Interior Lining System

	Recommendation	Reason for Recommendation
Coating system		
Quantities of coating material required		
Surface Preparation Method (including abrasive material if recommended)		
Prepared surface condition (profile, cleanliness, etc.)		
Number of coats required and specified dry film thickness per coat		
QA checkpoints to be required		
Environmental conditions to be maintained during the work		

Table 2: Exterior Coating System

	Recommendation	Reason for Recommendation
Coating system		
Quantities of coating material required		
Surface Preparation Method (including abrasive material if recommended)		
Prepared surface condition (profile, cleanliness, etc.)		
Number of coats required and specified dry film thickness per coat		
QA checkpoints to be required		
Environmental conditions to be maintained during the work		

4. How would your recommendation change if management decided they wanted to use the tank for potable water rather than fire water?

Chapter 9: Inspection and Quality Control

Upon completion of this training material, you will be able to:

- Identify various instruments and tests used during inspection and quality control

Introduction

Inspection ensures that a coating application meets the requirements of its specification. Proper inspection is the key to effective coating performance; good specifications require inspection at the appropriate stages of a coating job. Good owner/operators also include inspection as an integral part of coating maintenance over the lifetime of the coating. Effective inspection and maintenance extend that life, particularly when coating maintenance and repair begin before major coating failures occur.

Since many critical coating operations are quite expensive and labor intensive, quality assurance (QA) is extremely important. Even an improperly selected coating or poor quality material can provide good service if applied properly, while high-performance coatings may be completely ineffective if poorly and carelessly applied. This is why the inspection is such a crucial part of a coating program.

The quality of coating application depends on three very important items:

- Coating specification
- Proper surface preparation and application
- Proper inspection

Inspections ensure that both the intent of a specification and its details are carried out. The coating application is often the last operation in any construction or maintenance job. Many coating defects and failures occur because of pressure to complete the coating either during operation or prior to the start-up of new construction. Without good specifications and strong inspection requirements, serious and costly errors can occur when pressures to complete a job are extremely strong.

Inspection and quality control are the responsibility of the coating inspector but the protective coating specialist should be familiar with the instruments and processes.

9.1 Inspection Instruments and Tests

9.1.1 Wet-film Thickness Gauges

Specifications state what the wet-film thickness (WFT) of the coating should be during different points in the application process. The wet-film gauge is a simple device that makes those measurements. WFT gauges have two end points on the same plane, with progressively deeper notched steps in between. Each step has a number that shows the distance in mils between the step and the plane created by the two end points. To use, simply press the gauge firmly into the wet film, down to the surface, and withdraw. The two end points will be wetted by the coating material and possibly some of the steps in between. Never drag the gauge across the surface.

The WFT is the last **coating-wet step**. If no steps are wet, turn the gauge to a different side with different step measurement. Metric-calibrated WFT gauges are also available which measure coating thickness in µm.

Take WFT readings as soon as possible after coating application. As soon as coatings leave the container, they begin to evaporate which slightly changes the solids by volume. This is especially true of spray application, where the coating travels through the air.

The WFT of some coatings cannot be accurately measured. This is true of coatings which cure very quickly (i.e., polyureas and inorganic zincs) and coatings which contain pigments that interfere with measurement (i.e., inorganic zinc and non-skid coatings).

Do not place the gauge on surface irregularities that distort measurements. On curved surfaces, take readings along the length of the curve, rather than across its width, to prevent irregular wetting of the steps.

The WFT gauge leaves marks. In some applications, these can adversely affect the integrity of the coating. Immediately over-coat the measurement marks with fresh coating to avoid pinholes.

9.1.2 Dry-Film Thickness Magnetic Gauges

Magnetic gauges measure the dry-film thickness (DFT) of cured coatings. **ASTM D 7091** and **SSPC-PA 2** are two methods to verify calibration of magnetic DFT gauges and take DFT measurements of nonmagnetic coatings over ferrous magnetic metal surfaces. There are two types of magnetic gauges according to SSPC-PA-2:

- ***Type 1, pull-off gauges***, measure the force required to pull a permanent magnet from a coated ferrous metal surface. These gauges can be either dial or pencil gauges.
- ***Type 2, fixed probe gauges***, are electronic and use measuring probes which work based on magnetic induction, the Hall-effect. A variety of Type-2 gauges are manufactured with various electronic data collection features.

DFT gauges have limitations to consider during their use:

- Different magnetic gauges have different calibration standards
- Dirty magnets alter results
- Soft coatings cause thin readings
- Vibrations can cause high readings
- Some Type-1 gauge dials continue to turn even when the magnet lifts off the surface causing incorrect readings
- Type-2 gauges require special probes to measure curved surfaces, inside angles, or in the presence of stray magnetic fields

9.1.3 Eddy Current Instruments

Eddy current instruments test the DFT of non-conductive coatings applied to nonferrous metal substrates. Magnetic and conductive properties of the substrate, substrate thickness, edges, curves, and the conductivity of the coating all can influence the instrument’s readings.

9.1.4 Ultrasonic Thickness Gauges

The ultrasonic pulse-echo technique of ultrasonic gauges is used to measure the thickness of coatings on nonmetal substrates (plastic, wood, etc.) without damaging the coating.

9.1.5 Holiday Detectors

A variety of holiday detectors– low-voltage, wet-sponge, DC high-voltage, and AC high-voltage – find nicks, pinholes, and discontinuities in coatings. Holiday detectors can cause shock and are spark hazards; they also may damage the coating if the voltage is set too high. NACE SP0188, "*Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates*" covers their use.

9.1.6 Tooke Gauges (paint inspection gauge)

Tooke gauges are destructive instruments that test coating thickness. If a coating has visually distinguishable layers (e.g., by different colors), the Tooke gauge identifies the thickness of individual layers. The test microscopically observes a precise angular cut in a coating film. Tooke gauges are the most commonly used of the three methods covered in ASTM D4138-07a, "S*tandard Practices for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive, Cross-Sectioning Means.*"

9.1.7 Knife Adhesion Test

Use a pocket-knife, or a highly sharpened putty knife, to determine the adhesion of a coating. Ensure the knife is very sharp because its sharpness affects test accuracy. The process is fully described in ASTM D6677-07, *"Standard Test Method for Evaluating Adhesion by Knife."*

9.1.8 Tape Adhesion Test

This method to test adhesion is described in ASTM D3359-08, *"Standard Test Methods for Measuring Adhesion by Tape Test."* The tester cuts through the coating in either a cross-hatch or "X" pattern, then applies pressure-sensitive tape to the cut surface. When the tape is pulled from the coating, the amount of coating pulled off indicates the coating’s adhesion. Tape test effectiveness is somewhat limited with increasing coating thickness.

9.1.9 Pull-off Adhesion Testers

Perform pull-off adhesion tests according to ASTM D4541, *“Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers.”* This test uses a metal test dolly firmly adhered to a coating surface. After the adhesive cures, a testing device applies a load to the fixture until the adhesion fails. The load at failure is the pull-off strength of the coating. It is important to record where the failure occurs (e.g., adhesive or cohesive failure within the coating). Disadvantages to this type of test:

- The coating may not adhere fully to the dolly
- Incorrect calibration of the instrument influences accuracy
- Different types of testers provide different results with no way to compare values

9.1.10 Pencil Hardness Test

This test uses a selection of pencils of varying degrees of hardness. The pencils are pressed firmly into the coating and pushed across the surface. Factors that affect test accuracy include lead grade hardness, the amount of pressure applied, and interpretation of the indentation. This test is fully described in ASTM D3363-05, *“Standard Test Method for Film Hardness by Pencil Test.”*

9.1.11 Hardness Testers

Several hand-held hardness testers are available for use in the field. These primarily make indentations in the coating, and the tester observes either the force required to penetrate the film or the degree of indentation under prescribed conditions. Material type, degree of cure, ambient temperature, material thickness, and size of the test piece all influence coating hardness readings. The use of a popular hardness tester is described in ASTM D2583-07, “*Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor.”*