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Update Handbook for Surface Preparation and Coatings in Tanks and Confined Areas

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

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Update Handbook for Surface Preparation and Coatings in Tanks and Confined Areas

NSRP Project N3-98-1

Prepared by

Society for Protective Coatings

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UNIT 1 INTRODUCTION

1.1 Background

The advent of large complex ocean-going vessels represents millions of dollars in capital investments. Corrosion prevention through surface preparation and coating application is essential to protect the value of these ships as capital assets and for prolonging their productive life. Panel SP-3 of the National Shipbuilding Research Program (NSRP) has conducted numerous studies which have benefited shipyards and contributed to improved efficiency and productivity of coating operations. Nevertheless, there is still a great need for the shipyards to implement the latest technology; many yards are still not fully utilizing the latest advances that could result in improved efficiency (see Figure 1). For example, it is estimated that optimizing abrasive blasting could result in 30% savings in abrasive consumption and corresponding increases in production rates. In 1981 NSRP Panel SP-3 developed a handbook to establish an organized approach to the surface preparation and coating work in tanks. The present handbook represents a major overhaul of the original version. The current edition reflects the numerous technological advances over the last two decades. In addition the current handbook is organized and formatted to increase its value to shipyard personnel.

1.2 Purpose

The handbook is developed as a tool for shipyard personnel for planning and conducting surface preparation and coating work in ship tanks and other confined spaces.

1.3 Scope

This handbook covers the various stages in preparing and coating interiors of steel tanks on ships. The emphasis is on the work done while the tank is partially or completely constructed. These are conditions that define the structure as a confined space (see Figure 2). Much of the discussion, however, is also applicable to blasting and coating done during the pre-construction stage.

This scope addresses both new ships and ships being repaired. The surfaces encountered and the type of cleaning required, as well as the coatings, may differ substantially for these two situations. For new ship work, the work may be performed in blocks or after the tank has been built onto the ship. It must be integrated with the work of other trades. For repair work, a major distinction is whether the ships are re-coated in the drydock or while the ship is afloat. The latter case, for example, would significantly impact the conditions for dehumidification. Another major difference is access to materials, equipment, and utilities.

1.4 Organization of Topics

The handbook is divided into 12 units. The initial units emphasize blasting operations and equipment (Unit 2) and abrasives (Unit 3). Alternate methods of surface preparation are described in Unit 4. The next several units cover environmental controls for the blasting and coating operations. These include dehumidification (Unit 5), ventilation (Unit 6), and dust control (Unit 7). Discussions follow on application of the coating (Unit 8) and other support equipment, such as scaffolding and utilities (Unit 9).

Additional units include waste handling and disposal (Unit 10); and safety in confined spaces, pressure testing, and microbiologically induced corrosion (Unit 11). Finally, the handbook contains a list of reference and resource materials (Unit 12). Separately bound documents prepared under this project include an annotated bibliography, an assessment of shipyard and coating technology, and a list of equipment and vendors.

1.5 Format and Use of Handbook

1.5.1 *Desk handbook*

The full handbook is designed as a reference tool for shipyard personnel. It includes more detailed descriptions of the technology and the equipment, as well as step-by-step procedures and exercises.

1.5.2 *Field handbook*

A condensed version of several key units of the handbook has also been prepared with greatly reduced descriptive material. The condensed handbook emphasizes field procedures, such as assessing dew point. This version is expected to be more useful for field personnel in monitoring on-going activities rather than in planning the work.

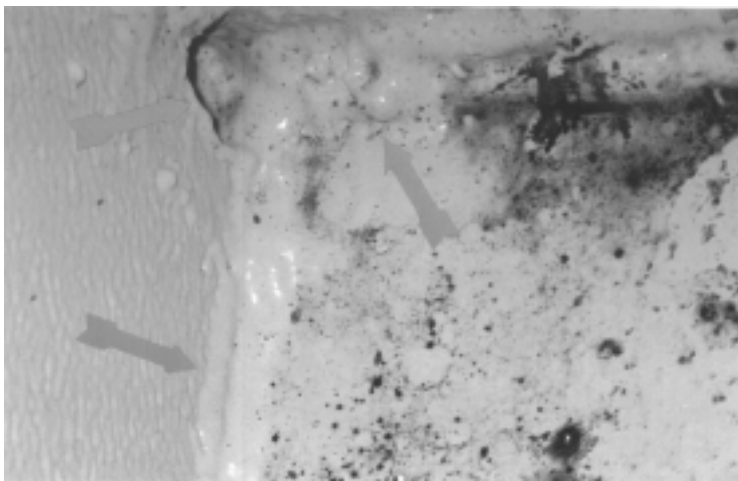


Figure 1-1: Corrosion of Ballast Tank
(Courtesy of Sherwin-Williams Co.)

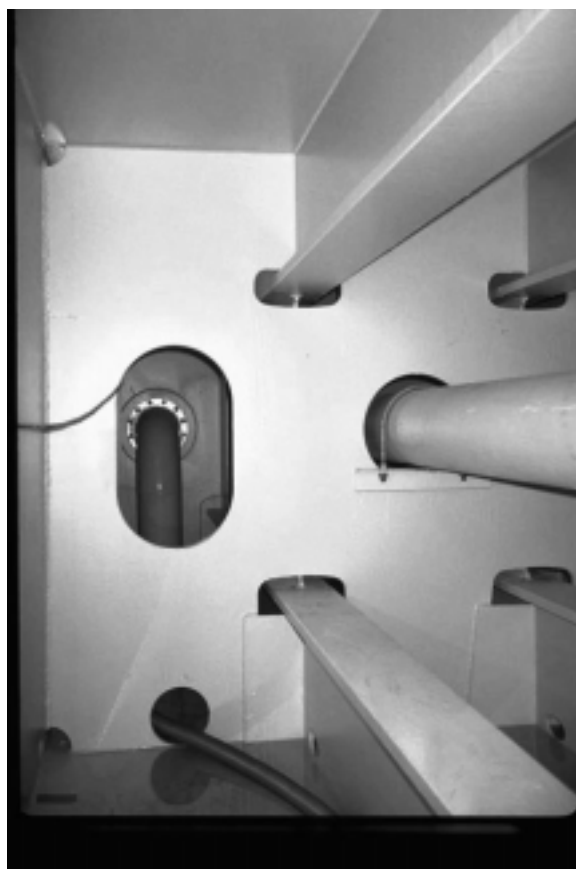


Figure 1-2: Painted Multiple Bay Ballast Tank
(Courtesy of Hempel Coatings)

UNIT 2 DRY ABRASIVE BLASTING

Various methods are used for surface preparation of ship tanks. Manually operated air abrasive blasting (discussed below) is by far the most widely used method and is generally considered the most productive method. Alternate methods include vacuum blasting (manual or robotic), water jetting, power and hand tool cleaning, wet abrasive blasting, and solvent and chemical cleaning. These alternate methods are discussed in Unit 4.

2.1 Introduction

Manual abrasive air blasting is a process used to clean substrates in preparation for coating and lining applications. Dry compressed air is used to accelerate and propel the abrasive blast media against the substrate. This process creates large volumes of dust consisting of spent abrasive and removed surface contamination. This dust and debris must be controlled and dealt with in the planning process.

Several types of equipment are needed to optimize dry blast cleaning operations. These include:

- Abrasive Blasting Equipment (properly sized and adjusted) (discussed in Section 2.2)
- Blast nozzles (discussed in Section 2.3)
- Air Delivery (high volume, clean, dry air) (discussed in Section 2.4)
- Valves and Gauges (Section 2.5)
- Blast hoses, fitting and couplings (discussed in Section 2.6)
- Filters (Section 2.7)
- Safety and Communication Equipment (discussed in Sections 2.8 and 2.9)

In addition, an example is given for determining requirements for a blasting project (Section 2.10). Selection and use of abrasives, and environmental controls will be discussed in other units.

The full system for abrasive blasting is illustrated in Figure 2-1.

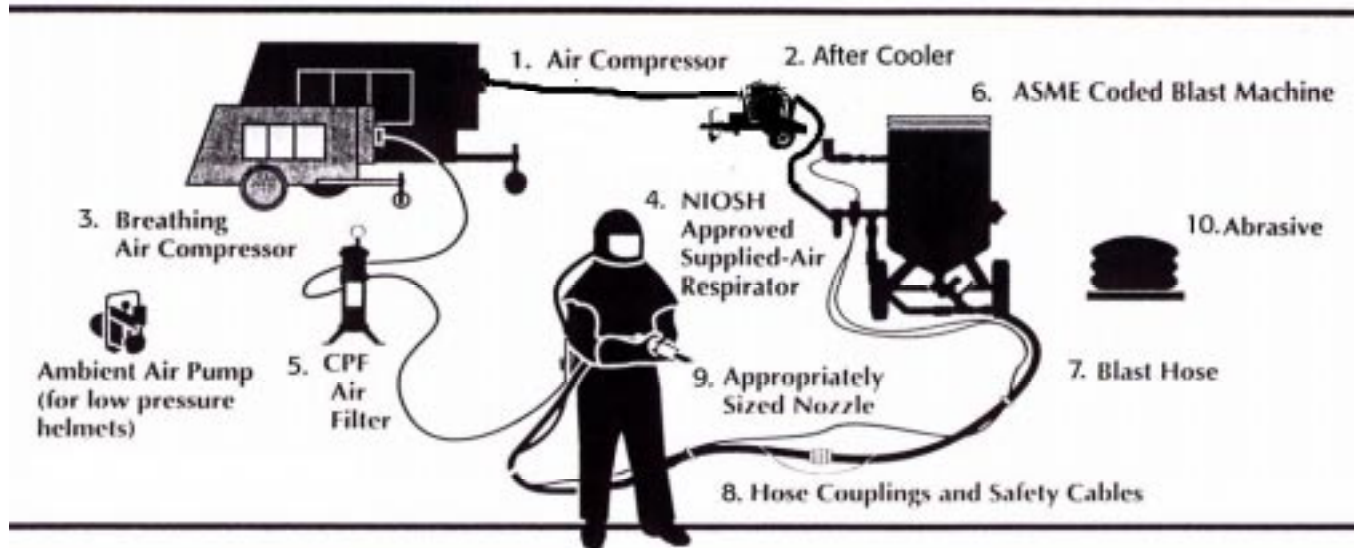


Figure 2-1: Full System for Abrasive Blasting
(Courtesy of Clemco Industries)

2.2 Abrasive Blast Machine (Properly Sized and Adjusted)

The abrasive blast machine is the heart of the system. Figure 2-2 is a schematic of a pressurized blast machine. Blast machines can be classified into light duty, medium duty, heavy duty and bulk units.

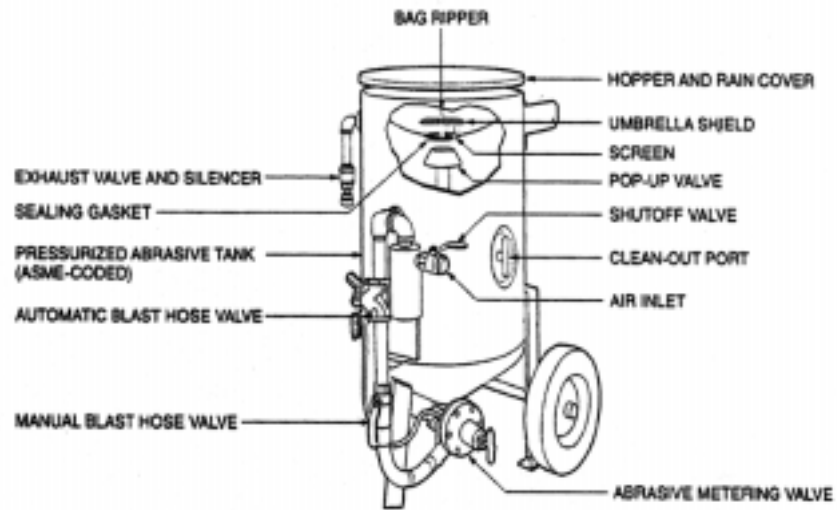
2.2.1 *Light and Heavy Duty Blast Machines*

- **Light duty blast machines**
Light-duty machines have a capacity of 1/2 to 1 cubic feet (15 to 30 liters) of abrasive, small piping, and a short blast hose; light machines can have any type of small bore nozzles. Their light weight and portability make them suitable for spot cleaning on rusted or contaminated surfaces. They are not commonly used at shipyards.
- **Medium duty blast machines**
Medium-duty machines offer portability and high efficiency in capacities from 1.5 to 6.5 cubic feet (40 to 185 liters). They usually have 1-inch (25 mm) piping and blast hose, suitable for use with 3/16-inch, 1/4-inch, and 5/16-inch (5, 6.5, and 8 mm) venturi nozzles. Medium-duty machines are ideal for jobs that take an hour to two to complete.

In the past, small capacity blast machines were used much of the time. These units usually held between 600 and 1,000 pounds (272 and 454 kg) of abrasives with a maximum operating time of about 30 minutes. Small abrasive storage hoppers of 3 to 5 ton (2.7 to 4.5 tonne) capacity were placed overhead by crane or forklift. If a crane or forklift were not available to lift the hoppers, the machines would run out of abrasives, and the result was wasted manpower and lost production due to standby time. On jobs that required large amounts of blasting, the use of these machines resulted in reduced productivity and increased abrasive consumption because of spillage. Equipment of this size should only be used for jobs requiring minimum blasting.

2.2.2 *Heavy Duty Blast Machines*

High-production machines are the most versatile and popular, with capacities from 8 to 40 cubic feet (226 to 1140 liters), standard 1.25 inch or 1.5 inch (32 mm or 38 mm) piping and blast hose feeding venturi



nozzles.

High-production machines provide ample abrasive capacity for extended blasting.

Figure 2-2: Schematic of Pressurized Blast Machine
(Courtesy of Clemco Industries)



Figure 2-3: Small Blast Pot
(SSPC File Photo)

2.2.3 Bulk Blast Machines

Bulk blast units offer the same results as the high-production machines, but with greater abrasive capacity. Bulk units range from 60 to 800 cubic feet capacity (1700 to 23,000 liters). Bulk units usually have outlets for multiple operators. The 120 to 160 cubic feet (3400 to 4500 liters) portable units fitted with 2 to 4 outlets are most popular. The air inlet piping and air supply hoses for bulk blast machines must be large enough to serve all the outlets.

These units allow bulk pneumatic refilling from delivery trailers that provide weather protection for abrasives and unattended machine operation. They also have greater abrasive capacity. Bulk abrasive costs less than bagged abrasive; also the time spent loading bagged abrasive is non-productive.

There are, however, drawbacks associated with bulk units. Bulk blast machines with multiple outlets require a very large volume of air to supply multiple nozzles. These bulk machines demand high-efficiency air dryers and after-coolers to remove moisture from such large volumes of air.

A four-operator bulk unit equipped with 3/8-inch (9.5 mm) nozzles uses 800 CFM at 100 psi (22 m³/min at 7 bar [700 kPa]). The piping and coupling on the bulk machine must be large enough to provide this 800 CFM (22 m³/min), plus



to accommodate normal nozzle wear, which significantly increases demand. If all four nozzle orifices wear to 7/16 inch (11.0 mm), consumption increases to 1040 CFM (28.4 m³/min).

Bulk machines are usually stationed in one centralized location, while the multiple blast hoses are strung out to blasting sites (see Figure 2-4). Extremely long blast hoses suffer pressure loss due to friction. Pressure losses of 25 psi (1.7 bar/170 kPa) or more are common in long, twisted hose.

Figure 2-4: Heavy Duty Blast Machine
(Courtesy of Todd Shipyard)

2.2.4 *Double Chamber Blast Machines*

The basic machines described above have a single chamber that operates one to eight outlets. An alternative is the double chamber blast machine. This machine allows continuous operation without having to stop blasting to fill the pot with abrasive. The double-chamber system fills automatically from overhead storage hoppers. While maintaining the bottom chamber under constant pressure, the top chamber can be depressurized and filled with abrasive. The abrasive will then be automatically transferred to the lower chamber when the top chamber is closed. Using this principle, a relatively small 8 cubic-foot (226 liter) capacity blast pot can support two abrasive blasters in continuous operation. Less area (i.e., smaller “footprint”) is required to set up the pot because it is

lighter than the 20 cubic-foot (570 liter) pot, and can be lifted into position using a smaller crane (see Figure 2-5).



Figure 2-5: Two-Chamber Blast Machine
(Courtesy of Todd Shipyard)

Some commonly available abrasive blast equipment sizes and capacity are shown in Table 2-1.

Table 2-1
Sizes and Capacities of Blast Machines

Volume Capacity in Cubic Feet (Liters)	Weight Capacity *	Number of Outlets	Configuration
<u>Light Duty</u>			
0.5 (14)	50 lbs (22.7 kg)	1	Wheels
<u>Medium Duty</u>			
1.5 (42)	150 lbs (68.0 kg)	1	Skid or Wheels
3.5 (100)	350 lbs (159 kg)	1	Skid or Wheels
6.5 (185)	650 lbs (295 kg)	1	Skid or Wheels
<u>Heavy Duty</u>			
8 (226)	800 lbs (363 kg)	1	Skid or Wheels
20 (570)	2000 lbs (907 kg)	1	Skid or Wheels
40 (1140)	2 tons (1810 kg)	1	Skid or Wheels
<u>Bulk</u>			
60 (1,700)	3 tons (2.72 Mg**)	1-2	Skid or Wheels
120 (3,400)	6 tons (5.44 Mg)	2	Skid or Wheels
160 (4,500)	8 tons (7.26 Mg)	2	Skid or Wheels
500 (14,250)	25 tons (22.7 Mg)	4	Free Standing
650 (18,500)	32.5 tons (29.5 Mg)	4	Free Standing
800 (22,770)	40 tons (36.3 Mg)	6	Free Standing

* This weight capacity is based on the average bulking value of silica sand, which is approximately 100 pounds per cubic foot (1600 kg/liter); the weight capacity could increase

** 1 Mg (tonne) = 10⁶ gram = 1.10 ton

2.2.5 Portability and Placement

Each machine is designed for a specific application. Both portable and stationary models are available with capacities from 0.5 cubic feet (50 pounds) to 800 cubic feet (60 tons).

The 9 to 12 ton (8.2 to 10.9 tonne) units can be mounted on wheels or skid. A 20-30 ton (18-27 tonne) machine is supported by legs and is basically portable. The 20-30 ton (18-27 tonne) units are primarily used for blasting jobs that require several operators working in a central area. Thirty-five to 40 ton (32-36 tonne) units are usually used for stationary blasting projects in which the work pieces are transported to the blast area. These units provide sufficient storage capacity for several operators and are often used when high production rates are required. For large tank blasting jobs, or for external hull work, the 40 ton (36 tonne) units can be mounted at the head of a drydock or aboard ship.

Portable bulk blast units come fitted with wheels only, for movement within a work site. Also, they can be ordered with brakes, lights, fenders, and other equipment that allow them to be relocated within a shipyard. Most bulk

machines can be towed while filled with abrasive that weighs approximately 100 pounds per cubic foot (1.5 kg/liter). Filling such a machine with steel grit may exceed its gross vehicle weight (GVW) rating.

In most cases, the blast machine should be located as close to the work area as possible to avoid an air pressure drop through the blast hose. It is important to note that properly sized blast hose and nozzles are essential to the operation.

2.2.6 *Blast machine construction*

In the United States, blast machines and other pressurized containers must meet American Society of Mechanical Engineers (ASME) standards. ASME specifies the type of steel and welding methods, and an ASME-authorized inspector supervises the hydrostatic testing of each pressure vessel. A metal plate bearing the board approval number is permanently affixed to the blast machine.

In the U.S., most existing blast machines are rated for a working pressure of 125 psi (8.8 bar/880 kPa). However, most new equipment is rated at 150 psi (1030 kPa) or greater to allow blasting at higher pressure. ASME requires a safety margin 50 percent greater than the working pressure; thus, machines rated at 150 psi are tested at 225 psi (1550 kPa) or higher.

2.3 **Blast Nozzles**

Abrasive blast nozzles are available in many different sizes, shapes and configurations. There are essentially three variables: nozzle size, nozzle shape, and nozzle length. A blast nozzle must allow the compressed air stream to increase the velocity of the abrasive particle.

2.3.1 *Nozzle Sizes*

Table 2-2 below lists some of the available blast nozzles and associated air consumption requirements:

Table 2-2
Air Consumption (CFM)* per Blast Nozzle

Nozzle Size Inch (mm)	70 psi (480 kPa)	80 psi (550 kPa)	90 psi (620 kPa)	100 psi (690 kPa)	120 psi (827 kPa)
No. 4 - 1/4 (6.3)	65 *	72	80	90	105

No. 5 - 5/16 (7.9)	101	113	125	150	160
No. 6 - 3/8 (9.5)	145	163	182	200	235
No. 7 - 7/16 (11.1)	193	215	240	270	315
No. 8 - 1/2 (12.7)	260	290	320	350	410
No. 10 - 5/8 (15.9)	406	454	500	550	640
No. 12 - 3/4 (19.1)	585	652	720	790	925

* 1 CFM = 0.0283 m³/minute

Nozzle size is also related to the cleaning rate. Table 2-3 below lists some typical comparative cleaning rates of several Venturi nozzle sizes using silica sand abrasives. This data is empirical and is taken from more than one source. Each facility should develop cleaning rate and abrasive consumption data based on actual blast pressures, nozzles and abrasives used.

Table 2-3
Cleaning Rates* at 100 psi (690 kPa) for Different Nozzle Sizes and
Initial and Final Conditions

Degree of Cleaning Surface Condition	Nozzle Size in Inches (mm)				
White Metal	1/2 (12.7)	7/16 (11.1)	3/8 (9.5)	5/16 (7.9)	1/4 (6.3)
Loose mill scale	250	200	145	102	61
Tight mill scale	211	164	121	84	50
Pitted paint	125	100	71	50	32
Multicoats	100	80	58	40	25
Near White	1/2	7/16	3/8	5/16	1/4
Loose mill scale	265	210	150	106	65
Tight mill scale	220	172	125	90	55
Pitted paint	132	104	75	55	34
Multicoats	106	84	60	44	25
Commercial	1/2	7/16	3/8	5/16	1/4
Loose mill scale	632	495	360	255	155
Tight mill scale	420	320	240	170	102
Pitted paint	316	246	181	128	76
Multicoats	210	165	120	85	50
Brush-Off	1/2	7/16	3/8	5/16	1/4
Loose mill scale	1264	990	720	508	310
Tight mill scale	1264	990	720	508	310
Pitted paint	1264	990	720	508	310
Multicoats	1264	990	720	508	310

* Square feet cleaned per hour. 1 ft²/hr = 0.0929 m²/hr.

2.3.2 *Nozzle Shapes and Types*

There are two basic nozzle shapes: venturi and straight bore. The venturi nozzle is flared at the end so that it functions in a manner similar to a rocket engine. The compressed air and abrasive mixture is accelerated as the mixture travels through the restricted venturi orifice of the nozzle (Figure 2-6). This acceleration increases the inertia (speed) of the abrasive. Nozzle length can also affect the efficiency of the nozzle. Within limits, the longer the nozzle, the more efficient the nozzle. For example, a long venturi nozzle can increase production rates up to 40 percent over straight bore nozzles.

The big advantage with straight bore nozzles is the larger blast pattern. Reduction in operator fatigue is another reported advantage. For sweep or brush-off blast cleaning and commercial blast cleaning, the straight bore nozzle may be the best selection to increase production rates. Some “bazooka” nozzles with flared ends can increase the blast pattern by up to 60 percent.

Both short and long nozzles are available in the venturi and straight bore designs. In confined and restricted spaces, only short nozzles can be maneuvered into position. Special 45 and 90 degree nozzles are also available for use in confined areas.

Another nozzle type is the double venturi nozzle. The double venturi nozzle is less fatiguing to the blaster at elevated nozzle pressures compared to conventional venturi nozzles.

Newer nozzle designs can reduce abrasive consumption by improving abrasive productivity. The results of a Pennsylvania State University study have demonstrated a 35% increase in abrasive particle exit velocity compared to conventional venturi nozzles.

A review of properties of nozzle types is as follows:

- Short nozzles give wide blast patterns at close range while longer nozzles give larger, denser blast patterns at greater distances.
- Longer venturi nozzles clean faster with less abrasive consumption than shorter or straight bore nozzles.
- Straight bore nozzles are best suited for close, limited blasting such as spot blast, hand
- Venturi nozzles are best suited for large area, open blasting.



Figure 2-6: Tungsten Carbide Venturi Nozzle
(Courtesy of Boride Products)

2.3.3 Nozzle Construction and Wear

Nozzle bores are generally constructed of either tungsten carbide, silicon carbide, or boron carbide. In rare cases, alloy steel may also be available. The tungsten carbide nozzles are the most commonly used type. Silicon carbide provides better wear resistance than tungsten carbide, but is more brittle and subject to increased breakage. Boron carbide nozzles have the longest wear life. These nozzles are reported to have a useful production life up to seven times that of the tungsten carbide or silicon carbide nozzles.

It is commonly thought by blasters that as a nozzle wears,



it becomes more productive. This statement may have been true with the old, straight bore nozzles; as the straight bore gradually eroded, it wore into a rough venturi configuration. However, for the modern venturi nozzles this is not the case. As the diverging end of the nozzle wears, the abrasive flares out more, losing velocity and reducing productivity.

Figure 2-7: Gauge to Measure Nozzle Wear
(Courtesy of Clemco Industries)

Nozzle wear can significantly increase the volume of air required at a given pressure. A worn nozzle could result in decreased pressure and productivity if the CFM is not adequate for the increased orifice diameter (see Table 2-4). Thus, a nozzle is usually replaced when it is worn to the next larger size. Nozzle wear is measured with an orifice gauge (see Figure 2-7).

Table 2-4
The Effect of Nozzle Wear on Air Consumption

Nozzle No.	Orifice Size	Increase in Air Consumption
No. 4	1/4" (6.3 mm)	-----
No. 5	5/16" (7.9 mm)	60% more than No. 4
No. 6	3/8" (9.5 mm)	38% more than No. 5
No. 7	7/16" (11.1 mm)	36% more than No. 6
No. 8	1/2" (12.7 mm)	33% more than No. 7

Materials for the exteriors of nozzles include steel, brass, polyurethane, and aluminum. These latter materials are selected because of their impact resistance. This property reduces the likelihood of damaging the hardened interior bore material when dropped. Once the interior bore liner has cracked, the useful life of the nozzle has been significantly reduced.

In summary, many different sizes and types of blasting nozzles are available to increase the efficiency of the abrasive blasting operation and meet specific needs. The important point is to configure and size the nozzle both to the job and the available air supply.

2.4 Air Delivery (High Volume Clean Dry Air) to Blast Machine

High volume, clean dry air is probably the most neglected attribute of abrasive blasting. This section describes the relationships between pressure, air volume and flow rates, and reviews the methods used for drying air.

2.4.1 Air Delivery Parameters

Blasting requirements are often given in terms of pressure (e.g., 90-100 psi [620-1030 kPa]). The volume of air flow is also a critical parameter for success of blasting work.

Air volume, air flow and pressure are interrelated. Assuming an adequate source of high pressure air, air volume delivered to the blast chamber and the blast nozzle is directly related to the size of the pipe or hose. Strange as it may seem, pressure can be achieved in any size line in a closed system; however, as soon as the system is opened to a pipe or hose, the pressure drops proportionally to the size of the line. The air volume and the pressure will be reduced by frictional and other losses described below.

Pipe or hose diameter is a major consideration. It must be sized to accommodate the required volume of air. The pipe cross sectional area determines the volume of air that can flow through the pipe at a given pressure. A one inch (25.4 mm) internal diameter (ID) pipe will carry four times as much air as a 0.5 inch (12.7 mm) pipe. This is because the cross sectional area is four times as great (0.8 square inch [520 mm²] vs 0.2 square inch [130 mm²].) Listed below (Table 2-5) are some pipe and valve internal dimensions with associated cross sectional areas.

**Table 2-5
Cross Sectional Areas of Pipes**

Pipe or Valve ID Inches (mm)	Cross Sectional Area sq. Inches (mm ²)
0.5 (12.7)	0.20 (130)
0.75 (19.0)	0.45 (290)
1.0 (25.4)	0.8 (520)
1.25 (31.8)	1.2 (774)
1.5 (38.1)	1.8 (1160)
2.0 (50.8)	3.2 (2060)
2.5 (63.5)	4.9 (3160)
3.0 (76.2)	7.2 (4650)

2.4.2 Frictional Loss

2.4.2.1 Causes of Pressure Drop

Pressure losses and thus reduced volume flow occur in pipe sections at fittings and bends. They also occur at restrictions in pipe diameter such as valves or crimps in the line. These pressure losses are caused by friction between the moving air and the pipe or hose wall. The length of the pipe also affects pressure drop due to frictional resistance. Table 2-6 below shows the pressure loss for different pipe lengths and diameters.

Table 2-6
Pressure Loss in psi per 100 Feet (0.30 m) of Length of Pipe *,**

Air Flow Rate CFM (m ³ /min)	Nominal Pipe Size (Inches [mm]) - Schedule 40 Pipe							
	1 (25)	1.5 (38)	2 (51)	2.5 (64)	3 (76)	4 (102)	6 (152)	
40 (1.1)	1.24	0.37	--	--	--	*	*	*
70 (2.0)	3.77	1.05	0.12	*	*	*	*	*
90 (2.5)	6.00	1.69	0.19	*	*	*	*	*
100 (2.8)	7.53	2.09	0.24	*	*	*	*	*
400 (11)	--	32.2	3.59	0.98	0.41	0.13	*	*
700 (20)	--	--	10.8	2.92	1.19	0.38	0.10	*
900 (25)	--	--	17.9	4.78	1.97	0.62	0.15	*
1,000 (28)	**	**	22.0	5.90	2.43	0.76	0.19	*
4,000 (110)	**	**	**	**	**	11.9	2.90	0.35
7,000 (200)	**	**	**	**	**	**	8.77	1.06
9,000 (250)	**	**	**	**	**	**	14.6	1.75
10,000 (280)	**	**	**	**	**	**	18.0	2.13
40,000 (1100)	**	**	**	**	**	**	**	33.8

* Based on 100 psi (690 kPa) at the compressor

** 1.0 psi/100 ft = 0.226 kPa/m

Table 2-7 shows approximate pressure losses due to fittings in one-inch diameter pipe operating at 100 psi (690 kPa).

Table 2-7
Approximate Pressure Losses from Fittings

Fitting	Pressure Loss * psi (kPa)
90 degree pipe elbow	3 (21)
45 degree pipe elbow	1.5 (10)
pipe tee	5 (34)
swing check valve	18 (120)

* Based on 100 psi (690 kPa) pressure at the nozzle and 1 inch (25 mm) pipe

2.4.2.2 Computing Pressure Drop

Assume that a 650 cubic feet (18,500 liter) portable blast pot has been selected to perform an abrasive blast cleaning job. This pot has 4 blast outlets. The standard blast nozzle for this example is a No. 6, 3/8 inch (9.5 mm) ID Venturi nozzle. This nozzle requires 200 CFM (5.6 m³/min) at 100 psi (690 kPa) (see Table 2-2). The inlet air fitting is 2 inch (51 mm) ID. The closest that the pot can be positioned to the blast operation is 200 feet (61 mm). The total CFM required is computed as follows:

- 4 nozzles X 200 CFM/Nozzle = 800 CFM (23 m³/min) required

The next step is to determine the pressure drop through the 2 inch ID air hose. From Table 2-6, it can be seen that the nearest value that approaches our example is 900 CFM (25 m³/min) at 100 psi (690 kPa) (the requirement should always be rounded up to the next highest value). The table shows that the pressure drop in a 2 inch (51 mm) line is 4.78 psi per linear 100 feet (1.08 kPa/m) (use 5 psi/100 ft [1.13 kPa/m]). The blasting pressure drop for 200 feet (61 mm) is computed as follows:

- (5 psi drop/100 feet) x 200 feet = 10 psi (69 kPa) pressure drop
- 100 psi - 10 psi = 90 psig pressure at the nozzle (690 kPa - 69 kPa = 621 kPa)

If the inlet air line is reduced to 1.5 inch (38 mm) ID, the pressure drop would be 17.9 psi/100 ft (4.05 kPa/m); the pressure drop is computed as:

- 18 psi/100 feet X 200 feet = 36 psi pressure drop (4.05 kPa/m x 61.0 m = 247 kPa)

- $100 \text{ psi} - 36 \text{ psi} = 64 \text{ psi}$ ($690 \text{ kPa} - 247 \text{ kPa} = 441 \text{ kPa}$)

At this nozzle pressure, the efficiency of the operation would decrease significantly. To solve the problem, either the number of blasters could be reduced or the size of the nozzle could be reduced. For example, assume that only two blasters were assigned to the job because of the reduction in inlet air line size to 1.5 inch (38 mm). The air consumption requirement would reduce to:

- $2 \text{ nozzles} \times 200 \text{ CFM} = 400 \text{ CFM}$ ($2 \times 5.6 \text{ m}^3/\text{min} = 11.2 \text{ m}^3/\text{min}$)

From Table 2-6 above, at 400 CFM ($11.2 \text{ m}^3/\text{min}$), the pressure drop in the 1.5 inch (38 mm) ID line is 3.59 psi/100 ft (0.81 kPa/m) (use 3.5 psi/100 ft [79 kPa/m]). This results in a pressure drop of:

- $3.5 \text{ psi/100 feet} \times 200 \text{ feet} = 7 \text{ psi pressure drop}$ ($0.79 \text{ kPa/m} \times 61 \text{ m} = 48.2 \text{ kPa}$)
- $100 \text{ psi} - 7 \text{ psi} = 93 \text{ psi at the nozzles}$ ($690 \text{ kPa} - 48 \text{ kPa} = 642 \text{ kPa}$)

This is sufficient blast nozzle pressure. By trial and error, the correct combination can be found; however, as can be seen, the best solution is to increase the air supply hose diameter.

2.4.3 *Methods and Equipment for Drying Air for Blasting*

2.4.3.1 *Sources of Moisture in Air Systems*

Clean, dry air is achieved through filtration and moisture removal. When ambient air is compressed, it is first heated due to compression and then cooled as it expands while traveling through the line. As the air cools in the line, the moisture condenses as water in the line. Except possibly in the desert, this occurs with all compressed air to some degree. To further complicate moisture problems in abrasive blasting is the refrigeration effect resulting from the expanding compressed air at the nozzle. As the air exits the restricted orifice of the nozzle, expansion and cooling take place, which also promotes the formation of water mixed with abrasive at the nozzle. Moisture-containing compressed air also adds to the quantity of water in enclosed spaces.

2.4.3.2 *Equipment for Drying Air*

There are several types of equipment for drying air.

- Oil and water separator (knock out drum)
 - Coalescing filter
 - Desiccant driers
- Air-cooled heat exchangers
 - Water-cooled heat exchangers
 - Refrigerant air driers

Oil and water separator

The most common and possibly the least effective is the knock out drum (oil and water separator). The drum removes water and oil that has already condensed in the line. This unit consists of a receiver tank, which is installed at the blast machine air inlet (Figure 2-8). As the compressed air enters and exits the receiver, a pressure differential in the receiver tank condenses water out of the air. These units must be continuously bled to both promote moisture condensation and removal. Many times the air receiver on the compressor is used for this purpose. This is not good practice. It is actually a surge tank to assist in maintaining constant delivered pressure from the compressor.



Figure 2-8: Moisture/Oil Separator on Blast Machine
(SSPC File Photo)

Coalescing filter

Coalescing filters are often installed at the compressor outlet, but can be located at the compressor inlet. They collect some of the water vapors that can form small droplets.

Desiccant driers

Desiccant (or deliquescent) compressed air dryers provide dry, clean air at dew points as low as 20°F (-7°C) or less. In these units, air is filtered through a

moisture-absorbing chemical (see Figure 2-9). As the amount of available desiccant decreases, the used chemical is either replaced or regenerated. Regenerative units allow reuse of the chemicals, but require pre-filtration of the air to remove oil and other contamination plus an energy source to power the regeneration cycle. Chemical replacement type units require no energy. They are described more fully in 5.2.2.

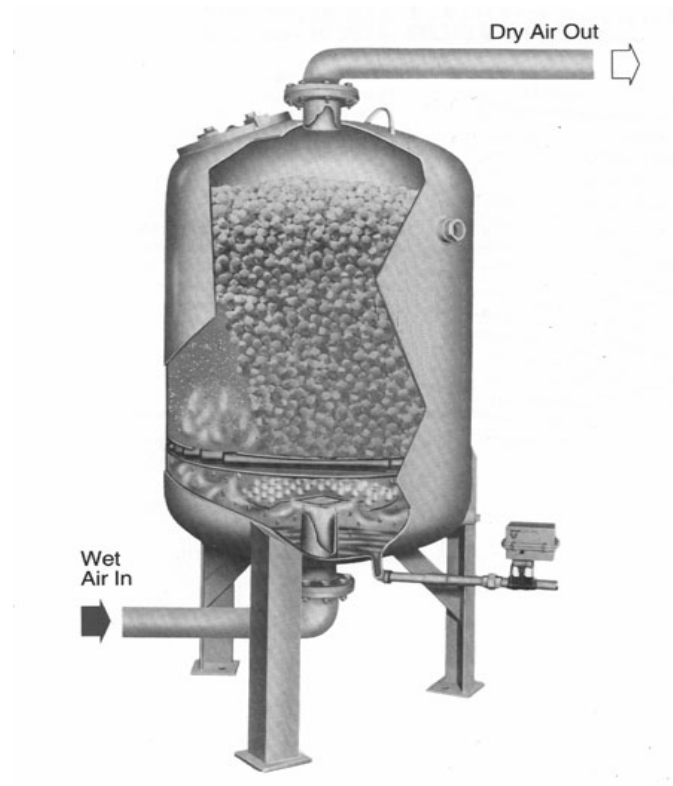


Figure 2-9: Desiccant Compressed Air Drier
(Courtesy of Van Air Systems)

Air-cooled heat exchangers

Air-cooled heat exchangers are also effective at removing moisture. The hot compressed air travels through finned tubes that are cooled by ambient air flow across the tubes. Air cooled units require motors to drive the cooling fans. These drivers can be either electric or pneumatic. These and the water cooled heat exchangers are often referred to as after-coolers.

Water-cooled heat exchangers

The water-cooled unit operates the same way as the air-cooled heat exchangers except that ambient temperature water is the heat exchange medium. Water-cooled units require a cooling water source and electric or pneumatic energy to drive the pump.

Refrigerant air driers

This unit operates in the same manner as a home air conditioning unit. The compressed air is transferred over the cooling coils of a compressor. These units must be protected from the dust generated during blasting operations. Refrigeration units require an electrical power source, generally 220 or 440 3-phase.

2.4.4 *Placement of Air Drying Equipment*

Air drying equipment may be placed at various locations between the compressor and the blast machine. Typical placements of the units are shown in Table 2-8.

Table 2-8
Placement of Air Drying Equipment

Drier type	Placement
Oil and water separator	Blast machine air inlet
Coalescing filter	Compressor inlet or after moisture separator
Desiccant drier (chemical)	Between compressor and blast machine

Air-cooled or water-cooled heat exchanger (after cooler)	Compressor outlet
Refrigerant air driers	Between compressor and blast machine

The location of the dryer depends on whether the compressed air distributing system is portable or stationary. Since all air will be used outdoors, the dryer must also be located outdoors. The unit should be placed in the coolest area possible to avoid radical changes of temperature between the drying point and use point. This arrangement will prevent condensation in pipes downstream of the dryer.

For portable applications, it is best to locate the dryer away from (e.g., as far as 50 feet [15 m]) the blast machine. This gives the air an opportunity to cool in the air lines before entering the dryer. In addition, some types of driers will catch any contaminants which might have entered into the system. A typical layout is shown in Figure 2-10.

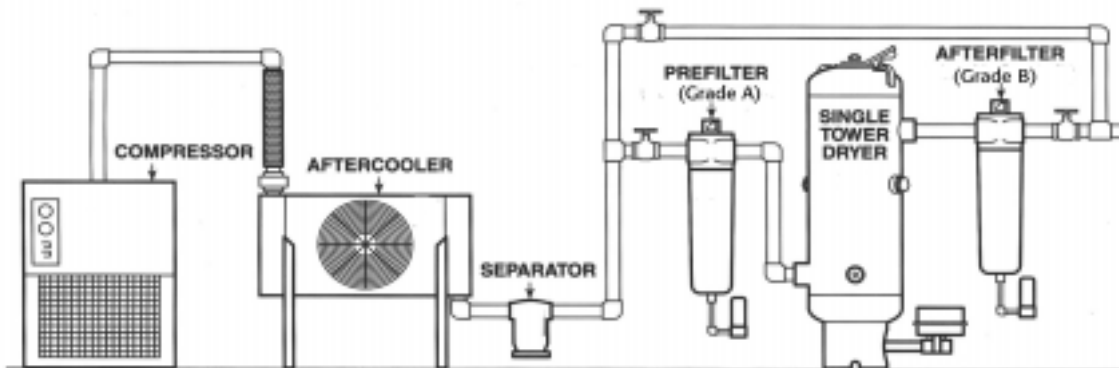


Figure 2-10: Typical Air Drying Installation
(Courtesy of Van Air Systems)

2.4.5 *Selecting Air Drying Equipment*

The unit selected for a given job depends on the following:

- Moisture content of ambient air
- Volume of the required compressed air
- Available energy and water source
- Disposal of desiccant

2.4.5.1 *Impact of Moisture Content of Ambient Air*

Dry ambient air

If the ambient air is dry and the compressor is operating efficiently, a moisture separator alone, installed at the blast machine inlet, should remove any small amounts of oil and water from the compressed air. Select moisture separators that allow more than the expected flow. Small units may restrict the air flow to the blast equipment.

Slight humidity

If the ambient air is only slightly humid, install a coalescing filter in the air line just after the moisture separator.

Moderate humidity

Install an after-cooler near the compressor outlet and a moisture separator near the blast machine.

High humidity

Install a refrigerant or desiccant air dryer. The refrigerant dryer cools the compressed air, then sends it through a series of coalescing, absorbent, and desiccant filters. These filters trap the moisture, oil, dust, and other contaminants. A moisture separator, installed at the blast machine inlet, removes any remaining water and oil.

2.4.5.2 *Volume of the Required Compressed Air*

Selection of appropriately sized equipment is based on the total equipment CFM requirement. A practical guide is to assume a service factor of 300 CFM (8.5 m³/min) delivered at 100 psi (690 kPa) per blaster. At 120 psi (827 kPa), the air flow is increased to 375 CFM 10.6 m³/min). If a central compressor is used to

distribute air, the CFM delivered to any given point will not exceed the amount that is passed through the orifices in the blast nozzles. The CFM per nozzle can thus be used to estimate the total CFM of required compressed air.

Optimum utilization of the desiccant dryer requires large volumes of air to be processed at high pressures. Therefore, it is important to measure air pressure available at the points where the dryers might be installed prior to ordering a system. As an example, a unit which is capable of processing 2,300 CFM (65.1 m³/min) at 125 psi (862 kPa) may only process 1,550 CFM (43.9 m³/min) at 80 psi (552 m³/min).

2.4.5.3 *Maintenance and Disposal Considerations*

Desiccant air drier

For abrasive blasting operations, the desiccant system provides a relatively trouble-free solution to cleaning and drying the air. In addition, it has a relatively low maintenance and initial cost. High-volume units are available which are constructed with lifting eyes to permit easy relocation.

The regenerative system may require qualified service personnel for maintenance. These units require pre- and after-filters. It is also necessary to properly dispose of the spent chemical cartridges.

Refrigerant air driers

Refrigerated units may require qualified service personnel to assure dependable year-round operation. The filter housing and condenser fins should be protected from dirt and dust and cleaned periodically.

2.4.5.4 *Other Factors*

Refrigerant or desiccant air dryers are also required, regardless of the humidity in the ambient air, for applications where moisture-control is critical. This includes use of plastics or agricultural media and blasting surfaces where no contamination is allowed.

Climatic conditions at the blast site dictate the type of filtering system necessary. Even in a desert, moisture, oil, and other contaminants are present. Some efficient method of filtering compressed air must be installed to ensure only clean, dry air reaches the blasting system.

It is also important to determine energy requirements for air drying equipment. Units range from 20 to 100 amps with 220 to 240 or 440 to 480 volts.

2.5 **Valves and Gauges**

2.5.1 *Air Control Valves*

Most air control valves used in abrasive blast operations are simple “on and off” valves of two basic types: ball and gate. These valves should not be used for metering or regulating air pressure. Pressure regulators, discussed below, should be used for this purpose. Three important points that must be considered when selecting and using air control valves are:

- Valve is rated for the pressure of the system in which installed.
- Actual internal unrestricted diameter is critical.
- Operate only in the full open or closed position.

For safety reasons, the valve must be rated for the service. Under-rated valves in pneumatic systems can fail catastrophically. (Note: Air valves should never be used in hydraulic systems.) The second point is to select a valve with minimum restriction in internal diameter. This can be accomplished by reviewing the valve data sheet or by visual inspection. The intent is to reduce pressure drop across the valve. As noted, airflow is controlled by the smallest restriction in the airline. Partially closed valves in effect reduce internal diameter and therefore airflow.

2.5.2 *Pressure Regulators and Gauges*

All blasting machines should have pressure regulators and gauges installed on the blasting machine. Maintaining correct pressure assures both safe and efficient blast cleaning operations. Most blasting machines made in the United States are limited to 125 psi (862 kPa). Newer blasting machines and those used in Europe may be rated to 150 psi (1030 kPa) or 175 psi (1210 kPa). The gauge should be read during static conditions and during operation.

The pressure gauge at the blast machine inlet allows for a quick determination of pressure loss and the possible cause of the pressure drop. When no blast cleaning operation is in progress, the gauge helps to assure that the compressor is set to the correct outlet pressure. During operation, the blast machine pressure gauge should be compared to the actual pressure at the nozzle during abrasive blasting. If the gauge pressure at the blast machine is reading between 120 and 125 psi (827 and 862 kPa), and the system is correctly installed, the pressure at the nozzle should be between 90 to 100 psi (620 to 690 kPa). If nozzle pressure is low, the system should be evaluated to assure that the correct size lines have been used, that the pressure regulator is correctly set, and that there are no restrictions in the blast hose. Examples are undersized hoses or valves. If the pressure at the compressor is correct and the pressure at the blast machine is low, then the problem is probably because of a line restriction between the compressor and the blast machine (i.e., too small a hose, too long a hose, partially clogged line, etc.) (see Figure 2-11).

A pressure regulator will allow control of any excess pressure, which may result from a compressor that may be set at too high a pressure. Always read the

ASME label plate to assure that the rated pressure of the blast machine is not exceeded.



Figure 2-11: Pressure Gauge
(SSPC File Photo)

2.5.3 Abrasive Control (Metering) Valves

There are two types of abrasive valves: metering valves and shut-off valves. Abrasive metering valves are classified as either a gate or knife (or pinch ["on or off"]) valve (Figure 2-12).

Abrasive metering valves use gravity to feed abrasive into a flowing stream of compressed air. Too little abrasive results in an uneven blast cleaning pattern that reduces production rate. Too much abrasive results in both wasted abrasive and a lower production rate. Metering valves should be designed to feed the abrasive into the compressed air stream accurately with minimum turbulence. This reduces machine wear and results in a consistent blast pattern.



Figure 2-12: Cut-Off Valve for Abrasive Flow Control
(SSPC File Photo)

To properly adjust the metering valve, start with the metering valve in the off or “no abrasive flow” position. Activate the blast hose and continue until there is no residual abrasive flow. Slowly open the valve and observe the air and abrasive mixture exiting the blast nozzle. A proper setting will result in a slight discoloration with a steady sound. Too much abrasive will choke the line resulting in a pulsating sound. Too little will result in a high pitched sound. This procedure should be followed each time the machine is started up and whenever the type or size of abrasive is changed. Each abrasive and machine setup has an optimum adjustment.

Increasing the flow beyond the optimum results in a major reduction in productivity even though the amount of abrasive used increases. Changes as small as a half turn on the metering valve can increase abrasive consumption by 50% with little or no improvement in productivity.

Metering valves are subject to plugging which requires tearing down the valve and cleaning out the obstruction. This generally requires shutting down the system, getting out pipe wrenches and opening up the line to remove the plugged valve (see Figure 2-13)



Figure 2-13: Manual Metering Valve
(Courtesy of Clemco Industries)

2.6 Blast Hoses, Fittings and Couplings

When properly installed and utilized, blast hoses, fittings, and couplings can provide many operating hours of service. Improperly installed and utilized setups can result in rapid wear and create safety hazards. Failure of a blast hose coupling can result in accidental spraying of high-pressure air and abrasive onto the operator or other personnel in the area.

2.6.1 Blast Hose

Acceptable abrasive blast hose is constructed of a thick, fabric-supported gum rubber tube, protected by a durable outer cover. Gum rubber blasting hoses have been found to provide better wear resistance than styrene butadiene rubber (SBR) and most other types of synthetic rubber materials. The inner rubber tube is normally 0.05 inches (1.3 mm) thick. The outer layer can be four ply, two braid, or a super flexible hose with an increased inner tube thickness (see Figure 2-14). This latter type of hose is generally used as the last (10 to 15 feet [3 to 5 m]) section of the blast hose, attached directly to the blast nozzle to allow for easier maneuverability and reduced operator fatigue (see NSRP 0499, Reduced Volume of Spent Abrasive in Open Air Blasting for further discussion).

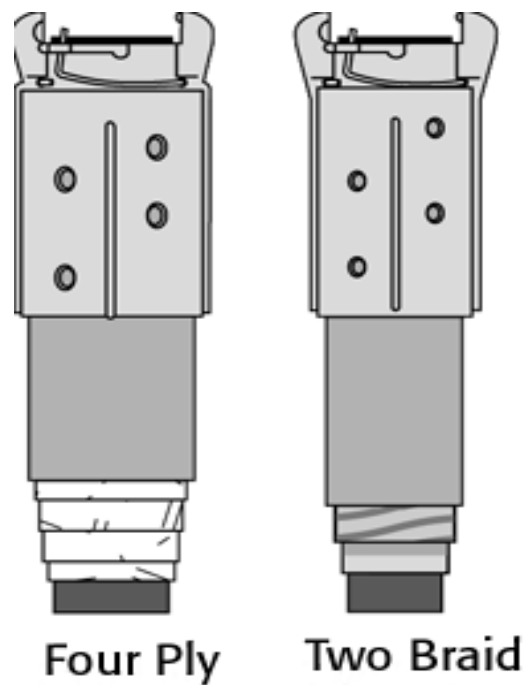


Figure 2-14: Cutaways of Blast Hose
(Courtesy of Clemco Industries)

2.6.1.1 Selection Criteria

Hoses must be constructed to dissipate the static electricity that is generated from the flow of dry air and abrasive through the hose. Static electricity can result in an electric shock to the operator or static discharge spark that can ignite flammable components normally used in blasting and painting operations.

Just as with compressed air lines, the blast hose must be rated to the working pressure of the abrasive blasting operation. This is extremely critical when combining European and US equipment types.

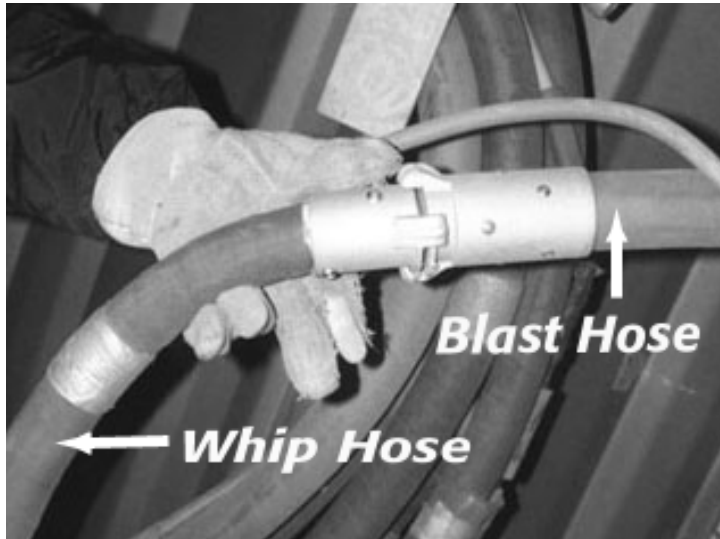
Cheap blast hoses made from recycled materials should be avoided. Under no circumstances should compressed air hoses or hoses designed for other purposes be substituted for blast hose designed for abrasive blasting. Abrasive blast hoses should be inspected on a regular basis for wear and damage. Worn and damaged hoses should be replaced immediately.

2.6.1.2 Sizing of Blast Hoses

The proper sizing of blast hoses is as critical as the sizing of compressed air hoses. In general, the blast hose inner diameter should be three to four times the size of the nozzle orifice.

Using a blast hose with an inner diameter that is smaller than the blast machine outlet diameter greatly reduces the amount of air-abrasive mixture flowing to the nozzle. For example, a blast machine with a standard 1.5 inch (38.1 mm) pipe outlet feeding into a 1 inch (25.4 mm) inner diameter blast hose must overcome a 64% reduction in capacity. This restriction in flow can be overcome by switching to a smaller nozzle but this reduces production rates and under-utilizes the capabilities of high production equipment.

Steel abrasives are 2.5 times as dense as coal slag or copper slag abrasives. When blast hoses exceed 50 feet (15 m), smaller hoses are used to increase abrasive velocity and keep the abrasive moving through the hose at a steady flow rate. Generally, higher volume air sources are required to make this effective.



Flexible hose whips should only be used where required to accomplish the work (see Figure 2-15). When used, the length of the hose whip should be kept as short as possible, generally 10 to 15 feet (3 to 5 m) maximum. Table 2-9 demonstrates the internal area loss due to using whip hoses. The reduced cross-section area results in pressure drops and lower production rates.

Figure 2-15: Flexible (Whip) Hose Attachment
(SSPC File Photo)

When using whip hoses, always install the whip hose closest to the nozzle. If various size hoses are the only hoses available to complete a job, always install the largest hose closest to the blast pot and work down in size to the nozzle so that the smallest hoses are closest to the nozzle.

Table 2-9
Internal Area Loss Due to Hose Size Reduction

Main Hose Size Inches (mm)	Whip Hose Size Inches (mm)	Percent Reduction in Area
2 (51)	1.5 (38)	44%
2 (51)	1.25 (32)	61%
1.5 (38)	1.25 (32)	31%
1.5 (38)	1.0 (25)	56%
1.25 (32)	1.0 (25)	36%
1.25 (32)	0.75 (19)	64%
1.0 (25)	0.75 (19)	44%

Most US hoses are manufactured in 50 feet (15 m) lengths. Metric hoses are generally supplied in either 20 or 40 meter lengths; however, many shipyards purchase bulk reel hoses and fabricate them into lengths suitable for shipyard operations. Care must be exercised when purchasing bulk hose to assure proper fit of hardware.

Smaller diameter blast hoses are also more prone to wear. Changes in direction such as bends and kinks increase wear. They also result in increased pressure drop through the hose. Where turns are required, the radius of the turn should be kept as large as feasible. Coiled hoses are subject to tremendous wear.

2.6.1.3 Inspection of Blast Hoses

Blast hoses should be inspected daily for wear. One technique is to squeeze the hose along 6-inch (150 mm) intervals. If the hose can be squeezed such that the inner walls touch, this is a good indication that the hose is worn and

should be replaced. If pinholes or cuts are discovered in blast hose, blasting operations should be suspended at once until the hose can be repaired or replaced. At the end of the shift, all abrasive should be removed from the hose. Removal of the abrasive will preclude stopped hoses at the beginning of the next shift.

2.6.2 *Fittings and Couplings for Blast Hoses*

2.6.2.1 *Couplings*

Blast hose couplings and nozzle holders are available in brass, aluminum alloy, and reinforced nylon. Each type has distinct advantages and disadvantages. Brass will take a lot of abuse but will bend easily. Aluminum is lightweight but is brittle. Reinforced nylon overcomes many of these disadvantages but its use should be verified to be compatible with shipyard practices.

There are many different configurations from quick disconnect types to hard piped types. Some but not all of these coupling are interchangeable. However, do not attempt to connect together couplings from different manufacturers; each manufacturer's mold may be different resulting in cables that are too tight or too loose.

2.6.2.2 *Hose Safety Cables*

Always use safety lanyards or blast hose safety cables when performing blast cleaning operations. These safety devices should be attached in such a manner that the hose will be restrained should the coupling or fitting fail. See Figure 2-16 below.

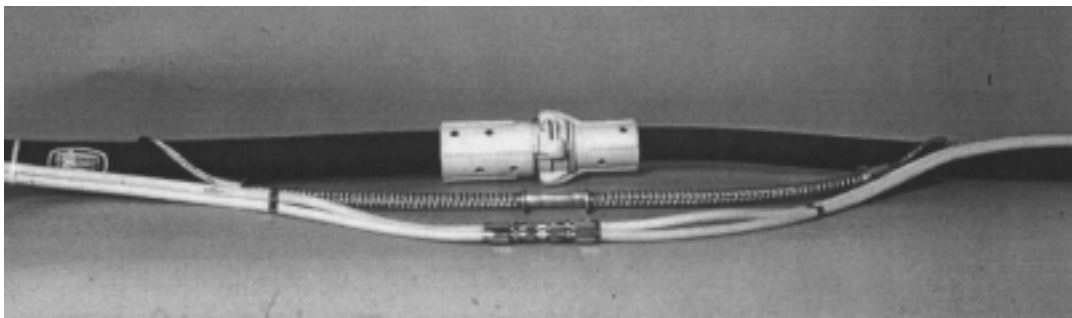


Figure 2-16: Safety Cables
(Courtesy of Clemco Industries)

2.6.3 Blast Hose Safety Tips

Listed below are several safety tips, which will assist in assuring a safe blast cleaning operation.

- Inspect hose and couplings for wear prior to each use.
- Check coupling fit. Avoid mixing different brands.
- Only use retaining screws supplied by the coupling manufacturer.
- Check nozzle and coupling gaskets before each use. Replace frequently.
 - **Never** operate without a gasket.
- Always cut hose ends square and smooth.
- Ensure that hose end fits uniformly flush with coupling shoulder.
- Never use loose fittings, blast nozzle holders or couplings.
- Daily test entire hose length for softness and compressibility.
- Replace hose with damaged outer cover.
- **Never** use hose and couplings not specifically designed and manufactured for abrasive blasting.
 - Use only static-dissipating hose.
- Always ground abrasive blasting equipment.
- **Never** exceed the blast hose's rated working pressure.
- Install safety pins in all couplings.
- Install safety cables at all coupling connections.
- **Never** substitute compressed air hoses for NIOSH-approved breathable air hoses used for air fed helmets. Never use NIOSH-approved hoses for carrying contaminated air.
- **Never** attach a breathing air hose to any source without verification of the air quality, pressure, and volume.

2.7 Filters

Filters are important in extending the useful life of air dryer equipment. Oil, dust, and water attack any compressed air system, plugging orifices, wearing out seals, eroding hoses and other system components, and reducing the efficiency of surface preparation. The effect is increased at higher temperatures. See Table 2-10.

Table 2-10

Variation of Oil Vapor Concentration with Temperature for Typical Compressor Lubricant (100 psi [690 kPa] pressure)	
Temperature F (C)	Vapor Concentration (ppm)

35 (2)	0.004
50 (10)	0.019
100 (38)	0.62
150 (66)	5.8
200 (93)	26.8
300 (149)	206
400 (204)	22,700

Filters remove contamination by interception, impingement, and adsorption. Interception occurs as a particle is trapped when the particle encounters an orifice smaller than the particle. The particle is then retained on the filter. Impingement occurs when the air stream changes direction. The inertia of the particle results in impingement on the filter media. Adsorption is the actual adhering of the contained molecule (i.e., the particle) to the absorber chemical.

Filter efficiency is defined as the ability of the filter to remove contaminant. Efficiency is rated as the minimum size particle that the filter removes and the amount of oil which the filter can adsorb. The important point is that filters are restrictions in the compressed air line. As the filter becomes contaminated, the effectiveness of the filter is decreased and the pressure drop across the filter is increased.

2.8 Safety Equipment

The United States Occupational Safety and Health Administration (OSHA) enforces regulations pertaining to the safe operation of abrasive blast equipment. OSHA regulations must be read, understood and followed when performing blast cleaning operations. The OSHA blast cleaning regulations will not be presented in this Handbook.

There are many potential hazards associated with blast cleaning operations. Large volumes of compressed air in conjunction with abrasive blast media propelled with the force of a shotgun blast are just some of the common dangers. Abrasive blasting can be a safe activity provided the rules of safety are followed.

2.8.1 Air-Fed Helmets

OSHA defines an air-fed helmet for abrasive blasting as a continuous-flow, supplied-air respirator (Type CE). These helmets are designed to provide protection to the worker from concentrations of toxic dust and rebounding abrasive. These helmets are usually fitted with approved hard hat head protection. Any air-fed helmet used must be NIOSH approved. The helmet manufacturer's instructions should be followed to assure proper fit and wear of the helmet.

2.8.2 *Air Supply Hose*

The most important aspect of using air-fed blast helmets is the supply of clean, non-toxic breathable air. The air supply to the helmet must be through tight, non-leaking fittings. The breathing air hose carries breathable air from the air filter to the air control valve. It must meet NIOSH specifications for size, strength, composition, and manufacturing techniques. These hoses must carry a NIOSH-approval stamp.

Several types of optional air control valves are available to warm or cool incoming breathable air. These are primarily comfort items but have been shown to reduce operator fatigue and increase productivity. These devices increase air consumption demand, which should be taken into account when calculating compressed air demand.

2.8.3 *Breathable Air Supply*

Breathable air furnished to helmets must be clean, dry, and contamination-free and at NIOSH prescribed pressure and volume. Air source, filtration, and composition must all be considered. Air filters must comply with OSHA 29 CFR 1910.134 for Grade D breathing air. OSHA regulations also require that air be frequently tested for carbon monoxide. The safest approach is to install continuous air monitors with an alarm to assure carbon monoxide levels are not exceeded.

2.8.4 *Protective Clothing*

OSHA safety regulations (29 CFR 1910.94 and 1910.134) require that blast cleaning operators wear canvas or leather gloves and aprons to protect them from high velocity, rebounding abrasive blast particles. Lightweight clothing does not provide adequate protection to blast cleaning operators. Heavy duty, long sleeve clothing should be worn. Each shipyard's safety department generally has specific rules and regulations to satisfy the requirements of worker safety.

2.8.5 *Deadman Controls*

All abrasive blast systems must be fitted with remote control systems, generally known as "deadman" controls; these controls allow for activation of the abrasive blast system at the blast nozzle by the abrasive blast operator. In the early days, blast systems were operated using hand signals between the blast pot operator and the blast operator. This is an extremely dangerous practice and has been prohibited by OSHA regulations.

There are two types of remote control systems: pneumatic and electric. In both cases, the fail condition of both the compressed air and the abrasive valves is the off condition. This means that the control valves at the blast

pot are normally closed to preclude air and abrasive flow. By activating the control valve at the nozzle, the blast operator opens the compressed air and abrasive valve and allows the compressed air abrasive mixture to flow to the nozzle. See Figure 2-17.

Pneumatic valves have a short dwell time (2 to 5 seconds depending on the length of the control line) between the time the operator activates the control from the nozzle and the valves at the pot activate. This dwell time results because compressed air must flow and reach the valve activation pressure before the valves open. This same response time occurs when the operator releases the nozzle control. Because of this response time, pneumatic control systems are generally limited to 100 feet (30 m) in length (i.e., the maximum distance between the blast pot and the blast operator cannot exceed 100 feet [30 m]). One advantage of the pneumatic system is that no auxiliary electric power is required at the blast site; however, the compressed air volume requirement must be considered when calculating the total compressed air requirements for the job.

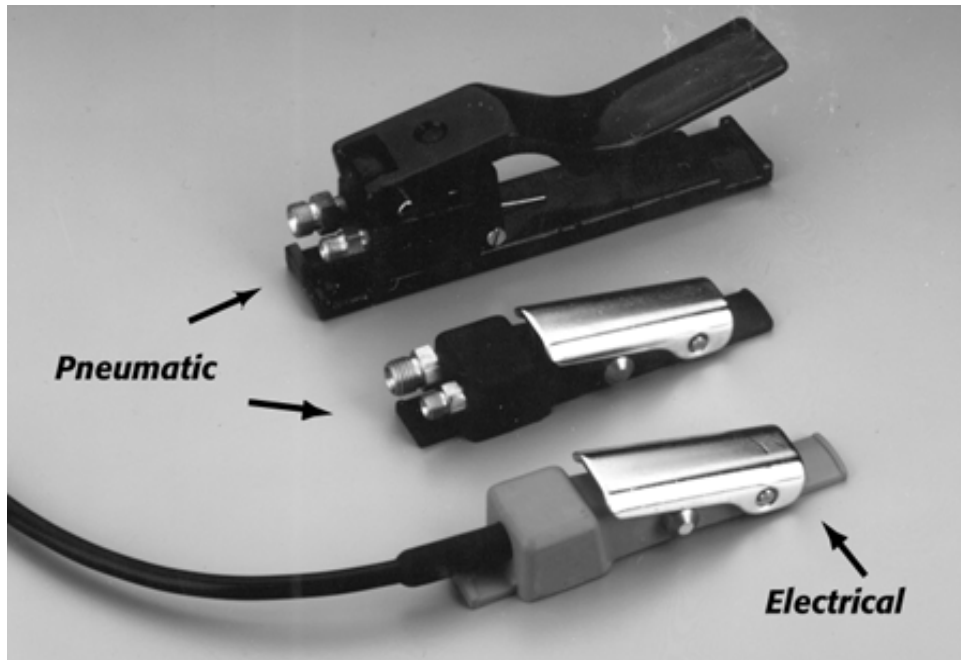


Figure 2-17: Examples of Deadman Switches
(Courtesy of Clemco Industries)

Electric control systems activate almost instantaneously, even though there is some reaction time to allow for pressurizing the blast hose. This is also true when the blast operator releases the pneumatic control. Residual pressure must dissipate from the hose, i.e., the abrasive blast hose must depressurize. Some equipment suppliers have relief systems that depressurize the hose

from both ends. The response times for electric control systems are not dependent on control line length; therefore, these systems can be used for distances over 100 feet (30 m). The distance limitation between the blast pot and operator becomes dependent on frictional losses in the hose as discussed in previous sections.

Electrical control systems are powered by 12 volt DC for safety reasons. This prevents electric shock to the operator. This feature is especially important because of the high potential for operator exposure to conductive surfaces such as steel substrates. The 12 volt system also allows for the operation off the battery of the diesel compressor.

2.9 Communication Equipment

Abrasive blasting is a very noisy operation, making it extremely difficult to communicate with the blaster. However, communication can be very important for blasting efficiency, productivity, and safety. The blaster needs to be able to modify the pressure or flow rate and indicate starting and stopping times. The traditional method of signaling by tapping the nozzle is not very effective. Based on new technology, two way communication systems are available that can be installed directly into the blasting helmet.

The two-way FM radio lets operators communicate with supervisors and each other without shutting down blasting or removing helmets. Training time for new operators is substantially reduced and productivity of experienced operators is enhanced. A compact headset and microphone mount inside the helmet and an impact-resistant polycarbonate transceiver mounts on the operator. A touch of the elbow activates the large, belt-mounted “push-to-talk” switch. Operator’s hands stay safely on the blast nozzle controls. Also, supervisors and observers can talk to the operator while remaining outside the blast environment. One limitation is that it is still very difficult to hear while the blast nozzle is operating. Another is that the radio units do not fit into all types of blasting helmets.

2.10 Example of Blast Project Set Up

This section provides a step-by-step procedure to determine the equipment and manpower requirements for a blast cleaning project. This example is for cleaning a tank on a new ship.

The job conditions and requirements are as follows:

Table 2-11
Project Description

Tank Location	Installed On Ship
Size of Tank	24,000 ft ² (2200 m ²) of surface
Configuration	Double bay ballast tank
Existing surface condition	Rusty steel
Cleanliness	Near White Blast (SSPC-SP 10/NACE No. 2)
Surface profile	1 to 3 mils (25 to 75 micrometers)
Schedule	Complete in 12 working days (8 hour shifts)

The project will be planned using an eight step procedure as follows:

Table 2-12
Eight Step Procedure

Step Number	Activity	What you will determine
1	Estimate man-hours to complete work	• Number of man-hours • Number of blasters
2	Determine compressed air requirements	• Nozzle size (orifice diameter) • CFM of compressed air • Number and size of compressor
3	Determine number & size of blast hoses	• Number of nozzles • Total number of hose sections • Diameters of blast & whip hoses
4	Determine size of blast pot	• Number and size of blast pots
5	Determine the number of portable storage hoppers	• Number of hoppers
6	Estimate quantity of abrasive needed	• Abrasive used per hour or per ft² (m²) • Number of tons (tonnes) of abrasive used
7	Determine the number & size of air driers	• Number of air driers • CFM of air driers
8	Design of air supply	• Piping size to and from air manifold • Size and number of flexible bull hoses

STEP 1 - Estimate Man Hours to Complete Work

Objective: Determine the number of man hours and the number of blasters

a) Number of man-hours and man-days

First determine the rough number of man-hours necessary to abrasive blast clean the tank. Fifty (50) ft² (4.6 m²) of surface blast cleaned per man-hour worked is a good rough cleaning rate.

Note: This rate is not the industrial engineering standard unit rate, as the latter includes days off and other administrative factors.

- Divide no. of sq ft by rate (sq ft per man-hr)

$$\begin{aligned} 24,000 \text{ ft}^2 / 50 \text{ ft}^2 \text{ per man-hr} &= 480 \text{ man-hours} && (2200 \\ \text{m}^2 / 4.6 \text{ m}^2/\text{hr} &= 478) \end{aligned}$$

- Divide number of man-hours by 8 to get the number of man-days

$$480 \text{ man-hours} / 8 = 60 \text{ man-days}$$

b) Number of Blasters

Assuming that one day is required for set-up and three days for abrasive removal and clean-up. Therefore, the blasting must be completed in eight working days. $(12 - [1 + 3] = 8)$.

- To determine the number of blasters needed, divide number of man-days required by number of days available to complete the work.

$$60 \text{ man-days} / 8 \text{ days} = 7.5 \text{ men or } 8 \text{ men (blasters)}$$

Therefore, the job should be set up with sufficient abrasive blasting equipment to support eight blasters.

STEP 2 - Determine Compressed Air Requirements

Objective: Nozzle size (orifice diameter), CFM of compressed air and number and size of compressor.

a) Nozzle size

Nozzle size may be dictated by yard availability, but for a job of this size, the largest size available should be used. Assume a one-half inch (12.7 mm) (no. 8) venturi nozzle is selected. Also assume that the blasting will be done at 100 psi (690 kPa) pressure at the nozzle.

b) CFM

The compressed air requirements can be determined based on nozzle size (see Table 2-13 below). A one-half inch (12.7 mm) venturi nozzle requires 350 CFM (9.9 m³/min) at 100 psi (690 kPa).

- To compute total CFM, multiply CFM per nozzle by number of nozzles needed

$$\begin{aligned} 350 \text{ CFM/Blaster} \times 8 \text{ Blasters} &= 2800 \text{ CFM} \\ (9.9 \text{ m}^3/\text{min} \times 8 &= 79.2 \text{ m}^3/\text{min}) \end{aligned}$$

Table 2-13
Nozzle Sizes and Air Consumption Rate

NOZZLE SIZE Inch (mm)	1/2 (12.7)	7/16 (11.1)	3/8 (9.5)	5/16 (7.9)	1/4 (6.3)
CFM (m³/min) @100 psi (690 kPa)	350 (9.9)	260 (7.4)	200 (5.7)	150 (4.2)	90 (2.6)
Air Hose - ID inches (mm)	2.0 (51)	1.5 (38)	1.5 (38)	1.25 (32)	1.25 (32)
Blast Hose - ID inches (mm)	1.5 (38)	1.5 (38)	1.25 (32)	1.25 (32)	1.0 (25)
Material lb/hr (kg/hr)	2250 (1020)	1750 (795)	1260 (570)	900 (410)	54 (245)

c) Compressor capacity

If plant air is used, the capacity must be verified. If portable compressors are used, the number required will be based on capacity of the individual compressor.

- To compute number of compressors divide total CFM by CFM of available compressors.

. * for 650 CFM (18.4 m³/min) compressors

2,800 CFM/ 650 CFM per compressor = 4.3 or 5 compressors
(79.3/18.4 = 4.3)

* for 1200 CFM (34.0 m³/min) compressors

2,800 CFM/ 1200 CFM per compressor = 2.3 or 3 compressors
(79.3/34.0 = 2.3)

For this example, assume that 1200 CFM (34.0 m³/min) compressors are available.

STEP 3 - Determine the Number and Size of Blast Hoses

Objectives: Number of hoses per blaster; total number of hose sections; diameters of blast and whip hoses.

To efficiently convey air driven abrasives from the blast pot to the nozzle, the blast hose should have sufficient inner diameter and be kept as short as possible. The largest available blast hose should be selected to carry the abrasives from the blast pot to the worker.

a) Blast hose diameter

The blast hose inner diameter should be a minimum of three times the nozzle size. In our case using a 0.5 inch (12.7 mm) nozzle, the blast hose diameter should have a minimum of 1.5 inch (38.1 mm) inner diameter.

The outlet piping of the blast machine must be at least 1.5 inch (38.1 mm) inner diameter. If the blast pot outlet is smaller than 1.5 inch (38.1 mm), the blast nozzle should be resized to a smaller size to match the blast pot outlet pipe size. This will assure efficient abrasive flow at the correct pressure.

b) Number of hose sections for blasting:

Hoses typically are sized in 50 foot (15.2 m) sections. To determine the number of hose lengths, one needs the following distances:

- * from the pot to the tank access
- * from the tank access to the furthestmost point in the tank

For this example, assume these are each 75 feet (22.9 m).

To compute the number of hose lengths per blaster (for blasting):

- Divide the sum of the two distances by 50 ft (15.2 m) per hose length
 $(75 \text{ ft} + 75 \text{ ft}) / 50 \text{ ft} = 3 \text{ hose lengths per blaster}$
 $(22.9 + 22.9) / 15.2 = 3$
- Multiply by number of blasters
 $3 \text{ hose lengths per blaster} \times 8 \text{ blasters} = 24 \text{ hose lengths}$

c) Whip hoses

Many times whip hoses are used to reduce blaster fatigue and facilitate blasting in tight areas. The length and size (inner diameter) of the whip should be balanced between reduced production and blaster requirements. Table 2-9 shows the reduction in area (loss of production) for various combinations of main hose and whip hose sizes. For this example, assume a whip hose diameter of 1.25 inches (31.8 mm). This will reduce the production by about 30%. The whip hose should be as short as practical, and no longer than 25 feet (7.6 m).

Summary for Step 3:

- Twenty-four (24) fifty-foot (15.2 m) 1.5 inch (38.1 mm) diameter blast hoses
- Eight (8) twenty five-foot (7.6 m) 1.25 inch (31.8 mm) diameter whip hoses

Note: Dead-man controls and valve activation hoses or cable must match blast hose lengths.

STEP 4 - Determine Number and Size of Blast Pots

Objective: Number and size of blast pots.

Now that the blast nozzles and hose sizes and quantities have been determined, the next step is to size the blast pot. For a job of this size and schedule, the bigger the better, within crane lift capacity and ship deck space limitations.

a) Size and outlets of blast pots:

Assume that the yard standard blast pot is six ton capacity and that each pot is fitted with two each 1.5 inch (38.1 mm) ID outlets.

b) Number of blast pots

To determine the number of blast pots required:

- Divide the number of blasters by the number of outlets per blast pot

$$8 \text{ blasters} / 2 \text{ outlets per pot} = 4 \text{ blast pots}$$

STEP 5 - Determine the Number of Portable Storage Hoppers

Objective: Number of hoppers and capacity.

The number of blast pots and the quantity of abrasive required will help determine the number of portable storage hoppers required. There should be at least one hopper per blast pot plus one extra as a standby. For example, if we have four each 6-ton (5.4 tonne) blast pots, we should have at least five storage hoppers. Each hopper is assumed to have 30 tons (27 tonne) storage capacity (700 cubic feet [19.8 m³]).

The bulk density of boiler coal slag or copper slag is 85 lb/ft³ (1.36 Mg/m³).

$$85 \text{ lb/ft}^3 \times 700 \text{ ft}^3 = 59,500 \text{ lb} \quad 2000 \text{ lb/ton} = 29.8 \text{ ton}$$

$$(1.36 \text{ Mg/m}^3 \times 19.8 \text{ m}^3 = 26.9 \text{ Mg [tonne]})$$

STEP 6 - Estimate Quantity of Abrasive Needed

Objectives: Selection of abrasive; abrasive used per hour; number of tons of abrasive used.

a) Selection of abrasive

Assume a locally available 16/40 mesh coal slag meets the hardness, particle size distribution and other attributes discussed in Unit 3.

b) Abrasive consumption

From Step 1 we determined that 480 man-hours of blasting time would be required.

From Table 2-13, the approximate consumption rate of abrasive for 1.5 inch (38.1 mm) blast hose and 0.5 inch (12.7 mm) nozzle at 100 psi (690 kPa) is 2250 lb/hr (1020 kg/hr).

To determine the quantity of abrasive used:

- Multiply the lbs. of abrasive per hour by the number of man-hours of blasting

$$2,250 \text{ lbs of abrasive per hour} \times 480 \text{ hrs} = 1,080,000 \text{ lbs.} = 540 \text{ tons}$$

$$(1020 \text{ kg/hr} \times 480 \text{ hr} = 489,600 \text{ kg} = 490 \text{ tonne})$$

STEP 7 - Determine the Number and Size of Air Driers

Objective: Number of air driers and CFM of air driers.

a) CFM of air driers

Assume that sufficient electrical capacity is available to power 350 CFM (9.9 m³/min) air-cooled after-coolers.

b) Number of air driers

To determine the number of air driers:

- Divide the total CFM by the CFM per air drier

$$2,800 \text{ CFM} / 350 \text{ CFM per unit} = 8 \text{ air driers} \\ (79.3/9.9 = 8)$$

Note: All the air used for blasting must be dried, so the quantity of air to be dried (CFM) is the same as the CFM for blasting. Eight such units would be required.

STEP 8 - Design of Air Supply

Objectives: Piping sizes for compression to air manifold and air manifold to air cooler, and the number and size of flexible bull hoses to connect air coolers to blast pot.

a) Piping from compressors to air manifold

Once the compressed air source has been determined, either hard piping or large hoses are required between the air source through the air coolers to the blast pots. One of the best configurations is to pipe all the compressors to a large air manifold, i.e., 6 to 8 inch (150 to 200 mm) inner diameter pipe.

Note: Remember, this is a pressure vessel and must be constructed to the appropriate code.

b) Piping from air manifold to air coolers

From the manifold, the air lines should be hard piped to the air coolers using pipe sizes to match the inlet on the air coolers. For 350 CFM (9.9 m³/min) air driers, assume air inlets of 2.0 inch (50.8 mm). Pipe length of 2.0 inch (50.8 mm) ID is required to connect to 8 air driers.

c) Bull hoses from air coolers to blast pots

From the air coolers to the blast pot, flexible bull hoses should be used. These should be sized to match the inlet air connections on the blast pots. Remember, the smallest inner diameter line, valve fitting, coupling, and elbow will determine maximum allowable air flow. For 6 ton (5.4 tonne) blasting pots, assume 1.5 inch (38.1 mm) inlet air connection. Eight flexible bull hoses at 2.0 inch (50.8 mm) ID are required.

Summary

A review of the eight step procedure is given in Table 2-14:

Table 2-14
Results of Eight Step Procedure

Step Number	Activity	What you determined
1	Estimate Man-hours to complete work	• 480 man-hours • 8 blasters
2	Determine compressed air requirements	• 8 @ 0.5 inch (12.7 mm) (#8) venturi nozzles • 350 CFM (9.9 m³/min) per blaster • 2800 total CFM (79.3 m³/min) air • 3 Compressors @ 1200 CFM (34.0 m³/min)
3	Determine number & size of blast hoses	• 24 @ 50 ft (15.2 m) air hose section (3 per blaster) • 8 25 ft (7.6 m) whip hoses (1 per blaster) • 1 inch (25.4 mm) diameter for blast & whip hoses
4	Determine size of blast pot	• 4 @ six-ton (5.4 tonne) blast pots (2 blasters per pot)
5	Determine the number of portable storage hoppers	• 5 @ thirty-ton (27 tonne) hoppers (1 per blast pot plus 1 extra)
6	Estimate quantity of abrasive needed	• 2250 lbs (1020 kg) of abrasive per hr • 540 tons (490 tonne) of abrasive
7	Determine the number & size of air driers	• 8 @ 350 CFM (9.4 m³/min) air driers
8	Design of air supply	• 6 @ 8 inch (200 mm) diameter piping to manifold • 2.0 inch (50.8 mm) hard piping to driers • 8 @ 1.5 inch (38.1 mm) flexible bull hoses

Equipment Summary for Example

- Three (3) 1200 CFM (34.0 m³/min) air compressors
- Four (4) inch (100 mm) piping from compressors to manifold
- Eight (8) inch (200 mm) air manifold
- Two (2) inch (50.8 mm) ID piping for driers
- Eight (8) each 350 CFM (9.9 m³/min) air-cooled after coolers
 - Eight (8) each 1.5 inch (38.1 mm) flexible bull hoses
 - Four (4) each 6-ton (5.4 tonne) blast pots
- Twenty-four (24) fifty-foot (15.2 m) sections of 1.5 inch (38.1 mm) ID blast hoses
- Eight (8) 25-foot (7.6 m) sections of 1.25 inch (31.8 mm) ID whip hose
- Eight (8) 0.5 inch (12.7 mm) venturi blast nozzles
- Five (5) each 30-ton (27 tonne) storage hoppers
 - Five hundred forty (540) tons (490 tonne) of 16/40 slag abrasive

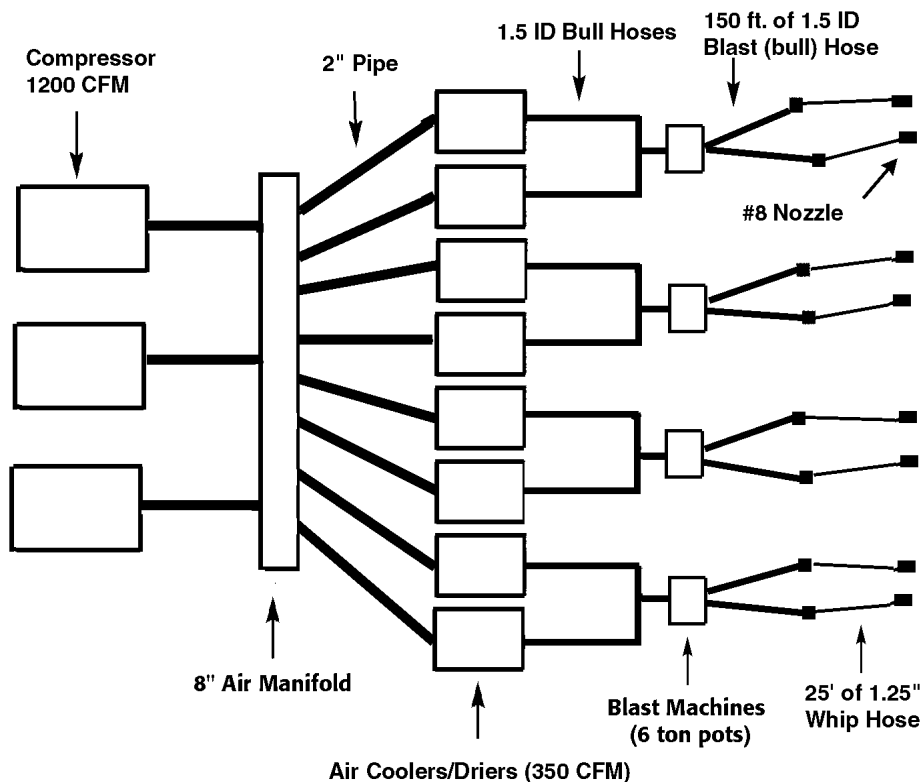


Figure 2-18: Schematic of Front End of Setup for Blast Project

A typical setup is shown in Figure 2-19.



**Figure 2-19: 40-Ton (36 tonne) Blast Pot, 24-Ton (22 tonne) Hopper with 6-Ton (5.4 tonne) Pot
and 1400 CFM (40 m³/min) Compressor**
(Courtesy of Long Painting Company)

UNIT 3 ABRASIVE SELECTION AND USE

3.1 Types and Properties of Abrasives

Proper selection and use of abrasives are essential for a productive, effective and safe blast cleaning operation. Selecting the wrong abrasive can reduce coating performance, significantly increase dust and debris, delay project completion and greatly increase operating costs.

This unit discusses the following topics:

- Types and properties of abrasives
- Selecting abrasives
- Removing spent abrasives
- Recycling and reuse of abrasives

3.1.1 *Types of Abrasives*

Abrasive blast media are generally divided into manufactured, naturally occurring, and by-product. Commonly used manufactured abrasive types include steel shot and grit, aluminum oxide, and silicon carbide. Other more specialized manufactured abrasives are glass beads, sodium bicarbonate (water slurry), plastic beads, sponge encapsulated abrasives, and frozen carbon dioxide pellets. Naturally occurring abrasives include silica sand, garnet, flint, zirconium, staurolite, and crushed granite. By-product abrasives include copper, coal, and nickel slag from smelting and power generation. Also included in this group are organics such as crushed walnut shells and corncobs.

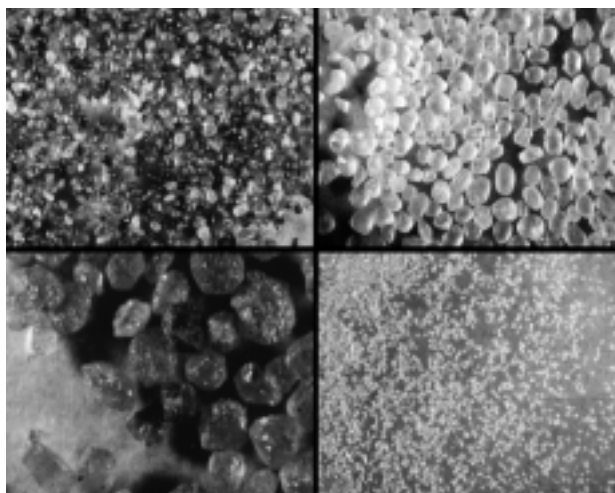


Figure 3-1: Mineral Abrasives (magnified): heavy staurolite mineral abrasive (top left), silica sand (top right), garnet (bottom left), zircon (bottom right)
(Courtesy of Chesapeake Specialty Products)

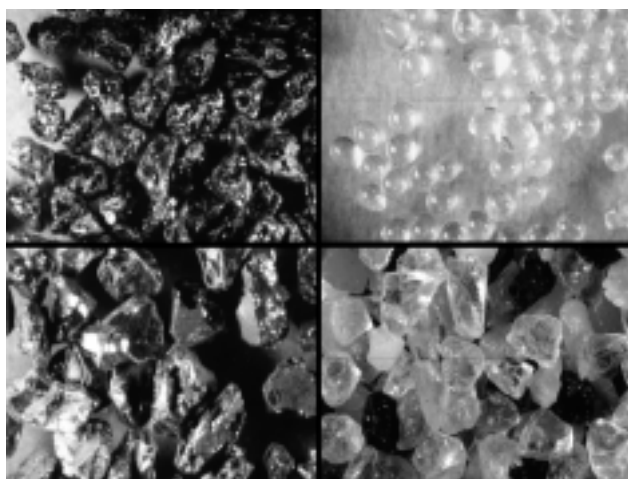


Figure 3-2: Manufactured Abrasives (magnified): aluminum oxide (top left), glass beads (top right), silicon carbide (bottom left), plastic pellets (bottom right)
(Courtesy of Chesapeake Specialty Products)

3.1.2 Properties of Abrasives

Before selecting an abrasive, it is important to be familiar with several key properties of abrasives, which directly affect cleaning rate. These include hardness, friability, density, particle size distribution, and cleanliness.

- a) **Hardness and Friability:** Hardness is the ability to resist scratching and is rated on the Mohs and Rockwell scales. Friability is a measure of the tendency of an abrasive to break down and produce dust.

Hardness and friability are generally, but not always, related. (That is, hard abrasive will tend to be more friable than soft abrasives.) Garnet and staurolite abrasives are generally harder, denser, and less friable than slag. Harder materials transfer more energy to the substrate. At higher pressure, the extent of abrasive breakdown increases, particularly for coal and copper slag.

- b) **Density:** Density is the weight per unit volume in lbs/ft³ (g/cm³). (It is also referred to as specific gravity compared to water with specific gravity of 1.0.) Bulk density is defined as the mass per volume of loose, dry abrasive. It is less than the absolute density as it includes the air voids between the particles.

Denser materials (e.g., steel grit) have greater impact energy. The higher the impact value, the greater the cleaning potential. Denser abrasives deliver more energy to the surface and can increase productivity.

- c) **Particle size distribution:** Abrasive sizes are classified based on the smallest diameter mesh sieve they will be retained on; e.g., 40 mesh abrasive will be retained on #40 sieve, but will pass through a larger sieve (#30 mesh). Abrasives for blasting are typically supplied in a range of particle sizes. For example “20/40 mesh” indicates that approximately 50% to 80% of the abrasive falls within the 20 to 40 mesh range (i.e., will pass through a #20 mesh, but not through a #40 mesh).

Table 3-1
Abrasive Screen Sizes

Screen Number	Screen Size (inches)	Screen Size (micrometers)
10	0.0787	2.00
16	0.0469	1.18
20	0.0331	0.850
30	0.0234	0.600
40	0.0165	0.425
50	0.0117	0.300
80	0.007	0.180

Abrasives used for blast cleaning should normally contain both large and small particles. Larger particles crack mill scale and existing hard coatings, whereas the smaller particles result in increased cleaning rate. The particle size distribution of slag abrasives varies significantly depending on the source and processing. Particle size distributions of garnet and staurolite are more uniform. Since neither slag nor naturally occurring abrasives are manufactured to a specification, each abrasive should be tested and qualified for each specific work process.

- d) **Cleanliness of abrasive:** Abrasives may become contaminated during the manufacturing process or from the environment. Potentially detrimental contaminants include soluble chlorides and carbonates, and unreacted metal in copper and nickel slags. Abrasives may also contain trace amounts of heavy metals such as arsenic, cadmium or lead. These heavy metals may

not impact the coating performance, but could affect the health of the blasters. Properties of commonly used abrasives are shown below in Table 3-2.

Abrasive cleanliness includes both visible and non-visible contaminants. The visible contaminants such as dirt and dust increase the weight but add no cleaning value. Non-visible contaminants include soluble salts which can be deposited on the surface and detract from coating and lining performance. One good method to help assure that the abrasive is of good quality is to always require that the abrasive be certified to meet SSPC-AB 1 or SSPC-AB 3. These specifications establish hardness, friability, particle size, distribution and cleanliness. Certification should be supplemented with routine receipt inspection and verification of abrasive delivered to the job. Use SSPC-AB 2 to determine the cleanliness of used steel abrasives.

Table 3-2
Typical Properties of Abrasives Commonly Used in Shipyards

Abrasive	Reusability	Dust Level	Hardness Mohs (Rockwell C)	Bulk Density lb/ft³ (g/cm³)	Mesh Sizes	Shape *
Aluminum oxide	High	Low-Medium	8.0-9.0	120 (1.92)	12-325	A
Coal slag	Low	High	7.0	85 (1.36)	12-50	A
Copper slag	Low	High	7.0-7.5	112 (1.79)	12-100	A
Corn cobs	Low-Medium	Low	4.5	35-45 (0.560-0.730)	8-40	A
Garnet	Low-Medium	Medium-High	7.0-8.0	147 (2.35)	20-100	A
Glass beads	Medium	Low-High	5.0-6.0	100 (1.60)	30-440	S
Plastic media	Medium	Medium	3.0-4.0	50-60 (0.80-0.96)	12-80	S
Silica sand	Low	High	5.0-7.5	100 (1.60)	12-100	A
Silicon carbide	High	Medium-High	9.0	106 (1.70)	36-220	A
Sodium bicarbonate	Medium	High	3.0	62 (0.99)	54-150	A
Steel grit	Very High	Low	6.0-7.5 (40-66)	270 (4.32)	10-325	A
Steel shot	Very High	Low	6.0-7.5 (20-66)	280 (4.49)	8-200	S
Walnut shells	Low	Medium-High	3.0-3.5	45 (0.72)	Many	A

* A = Angular, S = Spherical

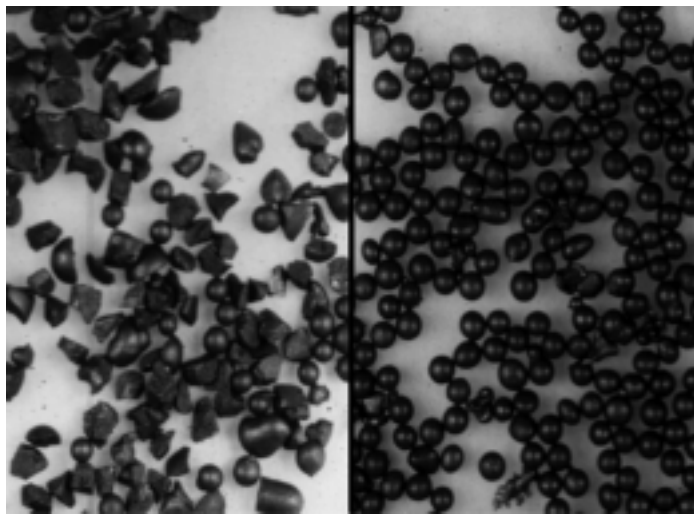


Figure 3-3: Metallic Abrasives (magnified): steel grit (left), steel shot (right)
(Courtesy of Chesapeake Specialty Products)

3.2 Procedure for Selecting Abrasives

The selection of abrasives depends on the following factors:

- Availability
- Cost
- Surface to be cleaned
- Cleaning rate (productivity)
- Surface cleanliness requirements
- Surface profile (or surface roughness) requirements
- Health and safety concerns

The following paragraphs describe a five-step procedure for selecting abrasives for a particular shipyard project. The procedure is summarized in Table 3-3 below.

Table 3-3
Procedure for Selecting Abrasives

Step	Activity	What you will determine
1	Identify candidate abrasives	• standard yard abrasives • regional availability • costs
2	Evaluate surface to be cleaned	• type & condition of surface
3	Assess abrasives vs. surfaces to be cleaned	• ranking of abrasives • tentative selection
4	Match abrasive size against profile requirement	• profile requirement of coating • profile achieved by abrasive selected
5	Verify other properties of abrasives	• cleanliness of abrasive • availability of MSDS

3.2.1 *STEP 1 - Identify Candidate Abrasives*

As noted above shipyards have a wide choice of abrasives. The first step is to determine which abrasives will be considered for the project. The initial factors to examine are the yard standard or preference, availability of the abrasive and the approximate cost.

a) Shipyard standard or preferences for abrasives

Prepare a list of the abrasives that have been used by the shipyard for blasting new steel, pre-construction primer (PCP) surfaces or repair work. Also include the names of suppliers, the product names, and the sieve sizes. (See Table 3-3 for format.)

b) Other abrasives available within the region

Each shipyard or tank lining contractor should survey product availability prior to beginning the job. Slags are regionally available and are one of the materials most commonly used abrasives for shipbuilding. The type of slag varies from location to location but coal and copper are most commonly used. Silica sands are not commonly used in shipyards because of worker safety concerns. Garnet and staurolite materials are beginning to find favor but are somewhat limited because of relative higher cost when compared to the slags. Steel shot and grit are used in areas where these materials can be recycled.

Bulk deliveries as well as packaged quantities are important. Steel products are generally provided in packaged weights of 100 pound (45 kg) and one ton (0.9 tonne) containers. Slags are delivered in bags or bulk, transported by pneumatic truck and trailer. Garnets and staurolite are also available in bags and bulk.

Add to the list in a) any abrasives that are produced or stocked within 500 miles (800 km) or so of the shipyard. Sources include: catalogs from abrasive suppliers in the area; the yellow pages phone directory; the JPCL

Product Directory (annual June issue) or industry web sites. Also list any other abrasives which the yard may want to consider.

c) Costs of abrasives

For each abrasive listed, estimate the cost per 100 lb (45 kg) bag or ton (0.9 tonne) delivered. This information is available from suppliers or from bids or completed projects. (See Table 3-4.)

Table 3-4
Candidate Abrasives (Example)

Abrasive type	Supplier	Product Name	Size distribution *	Cost per 100 lb (100 kg) and per ton (tonne) delivered *
Coal slag	Reed Minerals	Black Beauty	30/60	\$60/100 lb (\$130/100 kg) \$800/ton (\$880/tonne)
Garnet	Barton Mines	Fast Cut	20/40	\$190/100 lb (\$420/100 kg) \$3,000/ton (\$3300 tonne)
Staurolite	DuPont	Starblast	10/20	\$90/100 lb (\$200/100 kg) \$1,400/ton (\$1540 tonne)
Steel Grit	Chesapeake	Metgrain	50% G-30 50% G-50	\$300/100 lb (\$660/100 kg) \$4,400/ton (\$4850 tonne)

*Note: Sizes and costs not verified (examples only)

3.2.2 STEP 2 - Evaluate surface to be cleaned

Once availability and cost have been determined, the next step is to evaluate the surface to be cleaned. The surface to be cleaned can consist of any one of the following:

Surfaces on New ships

- Steel with intact or slightly rusting mill scale (Rust Grades A or B)
- Rusted and pitted steel (Rust Grades C or D)
- Steel primed with a pre-construction primer (to be retained)
- Steel primed with a pre-construction primer (to be removed)

Most new-build ship and other marine tanks are blasted and primed prior to fabrication. One factor is the condition of the original steel before blasting. Another is whether the pre-construction primer (PCP) will be completely removed or only the welds and damaged areas cleaned by blasting.

Surfaces on ships being repaired

- Soft coatings (e.g., waxes, paraffins)
- Hard coatings (e.g., epoxy or alkyd)
- Rusted and pitted steel (Rust Grades C or D)

Tanks and other confined spaces in operating ships and structures present different challenges. In these cases, abrasive selection must be based on the

condition of the existing coating, and the degree of corrosion of the steel surfaces.

List the type or types of surfaces expected for the project.

3.2.3 *STEP 3 - Assess abrasives versus surfaces to be cleaned*

In this step, determine how well each candidate abrasive works on surfaces encountered, based on the following discussion of abrasive cleaning capabilities.

- **Steel with intact or slightly rusting mill scale**
Steel shot and grit mixtures are used extensively as the abrasive of choice for automatic blasting and shop priming of steel plates and shapes prior to fabrication. This surface requires high energy to crack and remove the mill scale. Being a very dense material with high energy of inertia, steel shot and grit are very effective in removing mill scale. Equipment to clean and recycle the abrasive is required. Hard slag at higher pressures (e.g., 120 psi [830 kPa]) will also remove mill scale, as will garnet.
- **Rusted and pitted steel (Rust Grades C or D)**
The performance of steel abrasives on rusted and pitted steel is similar to that of steel with intact mill scale. However the cleaning rate will be lower (especially for pitted steel) and more dust will be produced because of the fracturing of the rust scale.

Note: In some yards the steel plate and shapes are de-scaled but not primed prior to fabrication. This initial blast and priming operation is sometimes referred to as primary surface preparation.

- **Steel primed with a pre-construction primer to be retained**
This option consists of removing damaged areas of the PCP and weld areas. Abrasive with finer particle sizes such as garnet or staurolite may be better than slag abrasive. Steel grit is also available in fine particle sizes. These materials have more uniform particle distribution, are harder, and less friable. Cleaning rates are higher per pound of abrasive used and less dust is generated. Garnet, staurolite, and especially steel abrasives can offer added advantages where recycling is available.
- **Steel primed with a pre-construction primer to be removed**
This option consists of total removal of the pre-construction primer (PCP), and cleaning of welds and other damaged areas. An abrasive having an operating mix with large and small particles is preferred. Copper or coal slag are most commonly used. Steel grit can also be used if recycling is feasible.
- **Soft coatings (e.g., waxes, paraffins)**

Soft coatings present unique problems as does the presence of muck. These materials cannot be effectively removed through abrasive blasting. Either chemical cleaning, high-pressure water, or hand scraping are required. Once these materials are removed, abrasive selection follows the same general rules as discussed earlier. Large particles are often necessary to crack and remove existing coatings. Small particles increase cleaning rates and provide better cleaning of pits. If the scope of work is to retain sound, intact coatings, the quantity of larger particle sizes should be reduced.

- **Hard coatings**
An abrasive having an operating mix with large and small particles is preferred. Copper or coal slag are most commonly used.

For each surface expected to be countered, identify the abrasive available from Table 3-5 below and list the first and second preferences based on cleaning ability.

Table 3-5
Summary of Abrasives for Each Surface Encountered

Surface encountered	Typical abrasives
Intact mill scale	Copper, coal slag *, garnet, steel grit
Rusted mill scale	Hard copper/coal *, garnet, steel grit
PCP to be retained	Garnet, staurolite, fine copper slag, fine steel grit
PCP to be removed	Copper/coal slag (mixed sizes), steel grit
Hard coatings	Copper/coal slag (mixed sizes), garnet, steel grit
Soft coatings	Water jetting, chemical cleaning

* 120 psi (830 kPa) pressure preferred

3.2.4 *STEP 4 - Match abrasive size against profile requirement*

All else being equal, smaller particles provide more impacts per pound (kg) of abrasive and are, therefore, preferred. The more impacts per unit area, the faster the cleaning rate. Smaller particles, however, produce smaller surface profiles. As most coating and lining manufacturers require a minimum and maximum profile to guarantee coating performance, profile must be balanced against cleaning rates.

- Determine the profile required or sought (minimum and maximum) for the project.

This can be accomplished in one of two ways:

- First check the project specification.
- Contact the manufacturer of the primer.
Alternatively, the manufacturer should be asked to recommend a profile requirement based on the system specified.

- b) Determine the profile expected from the abrasives tentatively selected in Step 3. Typical profiles for different types and sizes of abrasives are shown in Table 3-6 below.

Table 3-6
Typical Profiles of Various Abrasives

Abrasive Type	Size Distribution	Profile Range mils (micrometers)
Copper slag	12/40	2-4 (50-100)
Copper slag	30/60	1-3 (25-75)
Coal slag	30/60	1-3 (25-75)
Garnet	18/50	1-3 (25-75)
Staurolite	Coarse 40/140	0.5-2 (13-50)
Steel Grit	G-40	2-4 (50-100)
Steel shot	S-280	2-4 (50-100)

The above table is based on a blasting pressure of 90 to 100 psi (620 to 690 kPa) at the nozzle. A higher pressure will result in a higher surface profile.

- c) Compare the desired profile with the profile achieved by the abrasives selected. If these do not match, review the available abrasives and select a particle size range for the desired abrasive or alternate abrasive that matches the required profile.

3.2.5 STEP 5 - Verify other properties of abrasives

a) Cleanliness

It is important to assure that the abrasive used does not introduce additional contamination. Abrasive contamination should be ascertained by requiring manufacturers to meet an abrasive specification (e.g., SSPC-AB 1, SSPC-AB 2, SSPC-AB 3, MIL-A-22262). See Table 3-7 below. See also the discussion in Section 3.1.2 regarding cleanliness of recycled abrasives. Alternately, the yard can require specific tests for oil and soluble salt contamination as described in those standards.

b) Health and safety hazards from abrasives

The abrasive supplier is required to supply a Material Safety Data Sheet for each abrasive. The industrial hygienist or responsible safety department person must review all materials prior to use.

Table 3-7
Abrasive Property Tests From Standard Specification SSPC-AB 1 *

Property	Method	Requirement
Water Soluble Contaminant	Conductivity (ASTM D4940)	1000 microsiemen max
Oil Content	Observe Surface of Extract	No oil
Moisture Content	ASTM C566	0.5% max
Weight Change or Ignition	Heat to 75° C (24° F)	1.0% loss to 5.0% gain
Hardness	Mohs scale	6 min

* Specification for Mineral and Slag Abrasive

3.3 Spent Abrasive Removal Systems

There are essentially three types of spent abrasive removal systems. Manual, pneumatic, and vacuum.

3.3.1 Manual

Manual techniques can be cost-effective and expedient in large confined spaces if a large access opening can be cut. Workers with brooms, shovels, wheelbarrows, and skids can move large volumes of spent abrasive in a relatively short period of time. If large accesses cannot be cut, this technique becomes very unproductive and time consuming.

3.3.2 Pneumatic

Most pneumatic systems operate on a principle similar to an abrasive blast pot. These units consist of a pressure chamber with hopper and abrasive hose. The spent abrasive is manually collected using brooms and shovels and placed into the hopper on top of the pressure chamber. The pot is pressurized using plant or compressor air. The spent abrasive is transferred through the hose and discharged into a container that can be transported using crane lifts. The main

disadvantage of this technique is that the access opening into the tank must be large enough to accommodate placing the unit into the tank.

3.3.3 *Vacuum Removal of Abrasive*

3.3.3.1 *Vacuum Operation*

The most effective technique for abrasive collection is vacuuming. Electricity, compressed air, and diesel engines can power vacuum producers. The rate of spent abrasive removal is directly related to the horsepower and CFM of the vacuum. Vacuum units can range from simple inductors working off compressed air and CFM that mount on 55-gallon (208 liter) drums to large diesel powered truck mounted units. When selecting a unit both horsepower rating and vacuum rating in inches of mercury are important considerations. The vacuum rating is meaningless without knowing horsepower. A home vacuum unit may have a vacuum rating of 18-20 inches of mercury (61-67 kPa) but a low horsepower rating. Horsepower provides the ability to do work; whereas vacuum is necessary to move the spent abrasive through the discharge hose.

The spent abrasive density, size, and shape all have an effect on the removal of spent abrasive. Dust control is another important consideration. The vacuum unit must be fitted with a device to keep discharge dust levels below allowable limits. Vacuum nozzle clogging is yet another problem with vacuum units. Some nozzles are designed to reduce clogging. Proper use of the nozzle is also important. Many times the nozzle will clog if inserted directly into the spent abrasive. Some air passage along with the pickup of the abrasive is required.

The compressed air units can be extremely noisy. The smaller units are fitted with sound mufflers; some of the larger "eductor" units require operator noise protection. Compressed air units are limited as to the distance spent abrasive can be moved vertically. The manufacturer should be contacted for specific service air requirements, vertical lift restrictions, and volume of abrasive that can be moved per hour. Liquid ring vacuum producers or P-D blowers are more efficient and produce better vacuum than Venturi type inductors using compressed air. Electric and diesel power units come in many sizes and horsepower ratings.



Figure 3-4: Abrasive Recovery Unit
(Titan Abrasive Systems, Inc.)

3.3.3.2 *Selecting A Vacuum Recovery Unit*

Abrasive density, sizes, and shape are important considerations in selecting the appropriate unit. Table 3-8 lists some examples of the capacities of a sample unit.

Table 3-8
Capacities of a Sample Vacuum Recovery Unit *

Horsepower (kilowatts)	20 (15)	25 (19)	30 (22)	40 (30)	50 (37)
Capacity in Tons/Hour ** (tonne/hr)	3-5 (2.7-4.5)	5-7 (4.5-6.4)	6-10 (6.4-9.1)	9-14 (8.2-12.7)	10-16 (9.1-14.5)

Hose Diameter inches (mm)	2.0 (51)	2.5 (66)	2.5 (66)	3.0 (76)	3.0 (76)	3.5 (89)	3.0 (76)	3.5 (89)	3.5 (89)	3.5 (89)
Conveying Distances feet (m)	75 (23)	100 (30)	100 (30)	125 (38)	125 (38)	150 (46)	125 (38)	150 (46)	150 (46)	150 (46)

* Based on 3/4 inch (19.1 mm) line at 80 psi (552 kPa)

** Based on 50 foot (15 m) hose length

3.3.4 *Types of Vacuum Recovery Units*

There are three different types of vacuum recovery machines available:

- Portable unit with single-chamber collection tank
- Portable unit with automated discharge tank
- Mobile truck unit with single-chamber collection tank

In selecting a vacuum recovery system for shipboard tank blast-cleaning, the following criteria should be considered:

- Equipment operation with reduced labor
- Support services requirements
- Equipment size in relation to available space in the work area
- Hose size needed to operate at maximum efficiency
- Initial and maintenance costs

3.3.4.1 *Portable Unit with Single-Chamber Collection Tank*

The portable single-chamber vacuum recovery tank is designed to operate unattended and can be located close to the worksite. This unit is equipped with an easy to handle, flexible hose. These characteristics allow for ease in setting up the vacuum system. If the unit is to be positioned on deck, a crane is usually required for placement.

Suction is created by a high-performance liquid ring-type vacuum pump. A typical abrasive removal rate of the unit is ten tons (9 tonnes) of abrasive debris per hour. This type of vacuum pump can handle large amounts of dust particles which carry over from the secondary dust cyclone tank (larger particles settle out). The unit is powered by a 50 to 70 HP (37 to 52 kilowatts) motor and requires water and electrical service hook-up. Both equipment maintenance and initial cost are relatively low.

Portable single-chamber units can be hooked up to a pneumatic discharge device if the material is to be disposed directly from the area without using a tank. The collection tank of the portable single-chamber unit can be placed on an elevated platform so that a dump truck can pick up the abrasive for disposal or recovery. If abrasive recycling is desired, the collection tank insures that the recovered abrasives are protected for reuse.



Figure 3-5: Vacuum Recovery Unit
(Courtesy of Clemco Industries Corp.)

3.3.4.2 *Portable Unit with Double-Chamber, Automatic Discharge Tank*

This unit can be moved to an area where needed for abrasive recovery. No attendant is necessary and each component can be separated. It is designed to operate with a 4 to 6 inch (100 to 150 mm) ID hose. The typical production rate is ten tons (9 tonnes) per hour. Like the portable single-chamber units, the initial cost is relatively low.

Suction is produced by a positive-displacement, rotary vacuum pump. The portable unit with double-chamber automatic discharge tank is not suited for most tank vacuuming. Debris removed along with the abrasive cannot pass through the discharge valves and may lodge between the valve and seat, resulting in a vacuum leak.

3.3.4.3 *Mobile Unit with Single-Chamber Collection Tank*

This unit is permanently truck-mounted for mobility. The unit has a typical production rate of ten tons (9.1 tonnes) per hour. Performance is increased by moving the unit closer to the job site which is sometimes difficult in shipyard operations. Some units are capable of removing water and other fluids. This system is designed to operate with a 6 to 8 inch (150 to 200 mm) diameter hose and is equipped with a positive displacement vacuum pump.

Being mobile, this unit requires an attendant. The truck system is normally operated for short periods at a time before being shut down and driven away for disposal. The initial cost of the mobile unit is high. Although the mobile unit is suited for some shipyard applications, maintenance requirements and short-cycle performance make it impractical for most internal tank-cleaning jobs. See Figure 3-6 below.



Figure 3-6: Mobile Vacuum Recovery Truck with Single-Chamber Collection Tank

3.4 **Recycling of Abrasives**

Recycling systems generally consist of the standard blasting pots, air delivery system, dust collectors, and dehumidification equipment. The added equipment includes abrasive handling equipment and abrasive air wash classifying equipment. When recycling steel abrasive, dehumidification is extremely important to control rusting.

3.4.1 *Description of recycling*

Recycling entails collecting, processing, and reusing abrasives for blast cleaning. If abrasives are recycled they are not classified as waste (see Unit 10, Section 2). However, the recycled abrasives still need to conform to

requirements identified previously for productive blast cleaning. These include proper size distribution to ensure adequate cleaning and profiling and absence of contaminants. The physical properties (e.g., hardness and friability) are not expected to change after abrasives are used.

The most commonly used recyclable abrasive for shipyard blasting is steel grit. This abrasive can be reused 50 or more times because the particles degrade only very slightly during the blasting process. Other recyclable abrasives used in shipyards include aluminum oxide and garnet. Aluminum oxide can be recycled about 10 to 20 times and garnet about 3 to 5 times. One shipyard established a procedure for recycling coal slag, but the material could only be reused once. In this instance, the process was economical because of the large volumes involved.

Most shipyards recycle abrasives for shop blast cleaning. This can be air abrasive blasting or centrifugal blast steel machines (e.g., Wheelabrator). Recycling abrasives in ship tank blasting presents more of a challenge. This difficulty is due to the tight and irregular configuration and the difficulty of keeping the space dry. However, the process can also reduce disposal cost.

3.4.2 *Equipment for recycling*

Blast cleaning with recyclable abrasives such as steel grit or aluminum oxide requires specialized equipment for:

- Vacuuming or otherwise collecting the abrasive for reuse
- Separating the dust and fines from the reusable abrasive
- Maintaining clean, dry air to avoid rusting of the steel grit abrasive

Significant advances in abrasive recycling have been made in recent years. Examples are: metering the debris into the unit; modifications to and better control of the air-wash system; incorporating magnetic separation; and adding impinger plates to dislodge particles.

Maintaining abrasive cleanliness is the key to successful abrasive recycling. Periodic sampling and checking of the recycled abrasive for contaminants such as salt, oil or heavy metals should be incorporated into the production schedule. SSPC has issued a specification (SSPC-AB 2) for recycled steel abrasives. This specification outlines the specific physical and chemical tests that should be run to assure abrasive cleanliness. Table 3-9 below summarizes the requirements.

Table 3-9
Requirements for Recycled Abrasive Cleanliness from SSPC-AB 2 *

Property	Measurement	Requirement
Non-abrasive residue	Separate metal from	1.0 % maximum

	non-metal	
Lead content	ASTM D3335	0.1% maximum
Water-soluble contaminants	ASTM D 4940 (conductivity)	1000 microsiemen maximum
Oil content	Add to water (vial test)	None present

* SSPC-AB 2 - Specification for Cleanliness of Recycled Ferrous Metallic Abrasives.

The equipment used has three basic functions: abrasive blasting, recovery and classification (cleaning spent abrasive). These functions can be combined in a single unit or as separate integrated units. When adapting these units to shipyard applications, it is important to consider an individual yard's needs and existing equipment. In many cases portions of a yard's existing equipment can be used as part of the abrasive blast, recovery and classification system.



Figure 3-7: Set-up for Steel Grit Recycling
(Courtesy of Long Painting Company)

3.4.3 Advantages and limitations

The major advantage of using recyclable steel grit are:

- Reduction in the amount of abrasives to be purchased and handled. Theoretically, steel can be recycled over 50 or more times. Practically, there are losses of abrasive due to incomplete recovery from containment or loss of good abrasive in the recycling step. New steel must be added periodically to keep the mix constant.

- Reduction in the amount of waste.
- Reduction in dust: recyclable abrasives do not pulverize as much as expendable abrasives.
- Allows blasting at higher pressure for greater productivity.

Limitations are:

- Abrasives need to be recovered. This may be difficult in some areas of the tank. Vacuuming is the most common method for recovering abrasives. See Section 3.3.
- Abrasives must be kept thoroughly dry throughout the process. Otherwise abrasives will rust and form clumps that will clog the system.
- Recycled abrasives must be thoroughly cleaned. Otherwise, they can contaminate the work environment and the steel being blasted with residues from previous surface preparation.
- The initial investment in equipment is more expensive than that used for blasting with expendable abrasives.

3.4.4 *Shipyard experience and economics*

Steel recycling has been investigated by two shipyards under the NSRP program. In each case the technique was considered feasible for use on tanks. However, the shipyards have been slow to adopt this technology, which is widely used on bridges and other structures.

The decision on whether to use steel grit should be based on a comprehensive economic analysis for the individual shipyard. A complete recycling unit may cost upward of \$100,000. The return on investment would depend on reductions in cost for purchase and disposal of abrasives and for improved production. The latter may be achieved by using higher pressures or from improved vision (less dust) inside a close area.

NSRP 0387 proposed the following procedure for using recyclable abrasives on a ship's tank. For tank blasting, abrasive blasting and recovery cannot generally occur simultaneously if the tanks are small and confined. Therefore, a holding tank or tanks should be set up to hold sufficient steel abrasive to support a full complement of blasters for a single shift. Air dryers, dehumidification and dust collectors should be integrated into the system to eliminate moisture in the blast pots, rust-back of the blast cleaned surface and excessive dust during blasting. A typical set-up is shown schematically in Figure 3.8 below. To take full advantage of steel abrasive's productivity, high pressure compressors capable of up to 150 psi (1000 kPa) nozzle pressures should also be utilized. After blast cleaning, abrasive recovery is best accomplished using a vacuum pick up system and collection tank. If the tanks being blasted are of sufficient size,

however, it may be advantageous to incorporate some mechanical recovery system while blast cleaning, such as conveyors and augers.

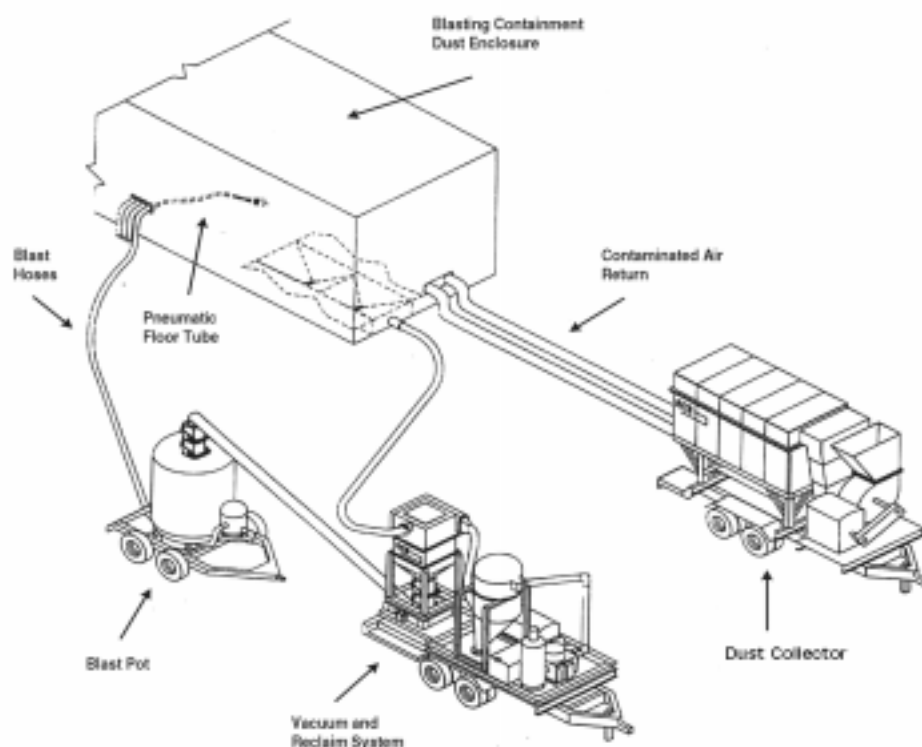


Figure 3-8: Layout of a steel abrasive blast and recovery system with dust collector

3.4.5 Recycling of Slag Abrasives

A recent NSRP Report (0529) reviewed recycling options for coal and copper slag in a shipyard. The researchers analyzed two physical separation methods and an on-site thermal processing method for separating the abrasives at 1400 to 1600°F (760 to 870°C). The thermal processing was the only method which brought the abrasive into conformance with SSPC AB-1. The results also indicated that the coal and copper slags could be effectively recycled only one time. The approximate efficiencies of recovering the abrasive under these conditions of the experiment were 65% (coal slag) and 80% (copper slag). The estimated payback periods for the equipment ranged from about 1 to 7 years depending on the volume of abrasive recycled per year.

3.5 Abrasive Delivery and Storage

In the past, abrasives were delivered to the shipyard and distributed to the blast machine hoppers in a variety of ways, from 100 pound (45 kg) bags to railcars.

Today, the most efficient method for distributing abrasives to blasting locations is by pneumatic delivery trucks. These units are operated at low pressure, and transfer the abrasive pneumatically through discharge hoses to the blast machine or storage hopper.

The main advantage of such a trailer unit is mobility and the direct transfer of the abrasives for use in blasting. If a local supply of abrasives is available, and if the blasting equipment is accessible to the trailer, materials can be picked up and transferred directly to blast machines.

If the supply source is distant, installation of a large-capacity bulk storage hopper should be considered. The storage hopper can be loaded directly from a railcar or truck. Depending on the quantity of materials used and the time needed for replacement materials to arrive, this storage hopper should have a capacity of 500 to 1000 tons (450 to 900 tonnes).



Figure 3-9: Abrasive Hopper
(SSPC File Photo)

Large sealed portable hoppers should also be made available for installation in areas where frequent blasting takes place, or where the pneumatic trailer cannot reach blast units. These units should be sized as large as possible without exceeding the lifting capacity of available cranes. The hoppers can be filled by the pneumatic trailer and then lifted by crane and positioned over the blast units. By decreasing the number of lifts required, these large hoppers can reduce the number of times cranes are required.

Distributing and storing abrasives in completely enclosed pneumatic delivery trailers and storage hoppers also reduces the possibilities of spillage and moisture contamination. If delivery and storage in large bulk is feasible, purchase of a yard-owned pneumatic trailer will reduce the overall cost of the operation. Materials can be bought in bulk and the labor required for handling and distribution will be reduced.

UNIT 4 OTHER SURFACE PREPARATION METHODS

4.1 Introduction

Although compressed air dry abrasive blast cleaning is the most commonly used method of surface preparation of ships for coating, other methods are sometimes more efficient or practical to use. The practical aspects of alternative surface preparation methods are summarized in this unit. Alternate methods discussed are:

- Portable centrifugal and vacuum blast cleaning
- Power and Hand Tool Cleaning
- Water Jetting
- Wet Abrasive Blasting
- Solvent and Chemical Cleaning

4.2 Portable Centrifugal and Vacuum Blast Cleaning

4.2.1 *Portable Centrifugal Blast Cleaning*

Centrifugal blasting systems commonly used in shop facilities (e.g., Wheelabrator) are also available as portable field units. Portable centrifugal units have containment and vacuum recovery systems. These features control particulate dust and permit recycling of abrasive. Portable centrifugal blast equipment is most practical for large flat areas, like ship decks and hulls. Steel grit abrasive is generally used, and abrasive recovery can be as much as 90%. Recovery greatly reduces the time for abrasive clean up and the quantity of waste abrasive. Robotic blast cleaning/recycling equipment is also available, but it is much less portable and only practical for large, flat vertical or horizontal surfaces. (See Figure 4-1.)

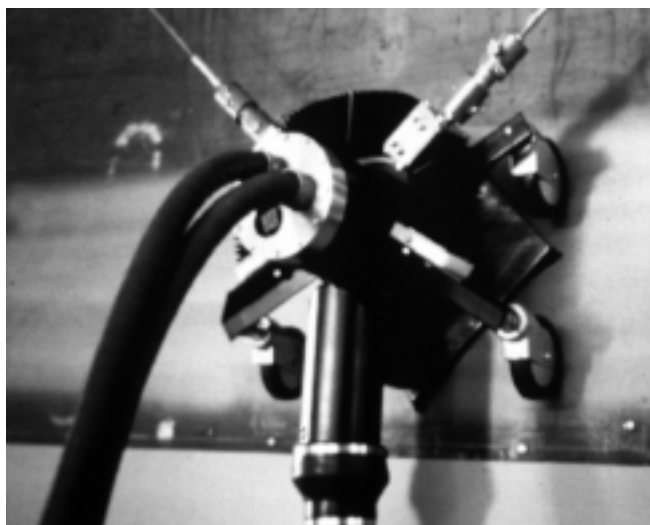


Figure 4-1: Robotic Blast Cleaning Machine on Tank
(SSPC File Photo)

4.2.2 Vacuum Blast Cleaning

Vacuum blasting is capable of producing the highest degree of surface preparation on large open surfaces, but does not have the same capability in areas of difficult accessibility. With present technology, the blast nozzle vacuum recovery tool is too bulky to fit into restricted areas such as behind stiffeners. Another limitation of this method is the requirement to maintain a tight seal around the area being blasted. This is needed to eliminate dust and to recycle all the abrasive. It is not normally possible to hold the mask or brush surrounding the blast nozzle tightly to the surface at all times on all irregular surfaces (see Figure 4-2). Under most production operations, vacuum blasting is too slow and requires too many specialized tools to be used on a large scale. Even on flat surfaces, productivity is limited by a small blast pattern. The need to maintain a seal between the head and the surface also limits productivity. This requirement also adds to operator fatigue.



Figure 4-2: Vacuum Blasting Demonstrating Poor Seal
(SSPC File Photo)

4.2.3 Specialized Uses for Vacuum Blasting

Vacuum blasting can be, however, useful for specialized applications. These include weld areas, damaged areas and other areas requiring repair.

- Weld areas: Vacuum blasting is well-suited to clean weld areas. This technique is an alternative to power tool cleaning
- Post-construction on-board blast cleaning: After ship construction and prior to delivery there are many areas requiring final spot blast and

painting. Open blasting of these areas can cause major problems with other crafts. Open blasting could also seriously damage neighboring coatings, machinery and other shipboard equipment. To overcome these difficulties, Avondale Shipyard developed mini, portable containments for use in blast cleaning two specific areas: deck tie-down fittings and small area paint damage. An inverted funnel is placed over the tie-down and blasting commences along with the vacuum recovery. When using the tie-down blaster system there is no abrasive debris to clean up. Other crafts, including painting and welding, can continue unhampered.

- Small damaged areas: Similarly, vacuum blasting can be used for blasting small areas of damaged paint. A unit was developed by Avondale as follows. A 16 x 26 x 12-inch (406 x 660 x 30 mm) box is constructed of aluminum, making it lightweight and portable. The box is fitted with the following:
 - * Blast hose and vacuum line. (Magnets hold the box in place until the vacuum line is activated.)
 - * 2 long sleeve gloves for manipulating the blast hose
 - * Plexiglas window for viewing the work area
 As with the tie-down blaster, the small area paint damage blaster allows other crafts to work adjacent to the unit unhampered.

4.3 Power and Hand Tool Cleaning

Power and hand tool cleaning may be useful on ships where abrasive blasting is impractical. These situations include small coating and repair jobs or those in difficult to access areas. Power tools also can be used to round sharp edges and smooth welds. As power tool cleaning is much faster and more economical than hand tool cleaning, it is much more often used.

4.3.1 *Power Tools*

Power tools (pneumatic or electric) used for cleaning of steel surfaces fall into three basic categories:

- Impact tools
- Rotary tools
- Rotary impact tools

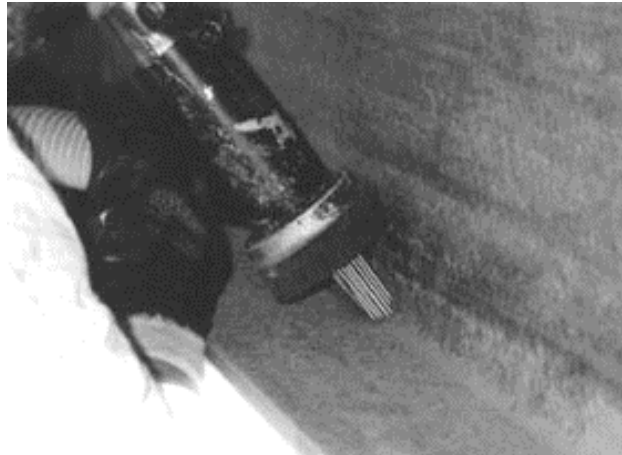
Tools in each of these classes have their unique characteristics that make them adaptable to different cleaning requirements.

4.3.1.1 *Impact Tools*

Impact cleaning tools include chipping and scaling hammers. These tools contain chisels that are struck by an internal piston to impact the steel.

The chisels have different sizes and shapes to meet specific needs. They are effective in removing heavy deposits of rust scale, mill scale, old thick paint, weld flux, slag, and other brittle deposits. However, their cleaning rates are very low. Care must be taken when using these tools to avoid cutting into the surface of the metal and leaving burrs.

A needle scaler is a scaling hammer with a bundle of steel needles with chiseled tips housed and positioned forward of the piston. The piston strikes all the needles simultaneously, propelling them against the steel surface. The needle scaler is most effective on brittle and loose



contaminants.

Figure 4-3: Needle Gun
(Courtesy of North Carolina Dept. of Transportation)

Piston scalers work like needle scalers except that the piston is also the chisel. This feature minimizes the size and permits use in tight spaces. They are available in single and multiple piston types and can be mounted in groups for cleaning larger areas.

4.3.1.2 Rotary Tools

Rotary tools can rapidly remove old paint, loose mill scale, rust, and other surface contaminants.

Media for Rotary Tools

Three types of abrasive media may be used with these tools: wire brushes, non-woven abrasives and coated abrasives. Non-woven abrasives and wire brushes work well to remove old paint, light mill scale, weld flux, slag, and dirt. Both are available in cup and radial (wheel) form. Wire brushes are available in different sizes and shapes and in crimped or knotted forms. Power wire brushes can remove loose mill scale by bearing down on the metal with the toe of a very stiff brush but cannot

remove tight mill scale. Too high a speed for too long a time may cause burnishing of the steel. Burnishing may result in reduced primer adhesion.

Non-woven abrasives are also available in disc form. They are recommended where base metal should not be removed but where wire brushes are not aggressive enough.

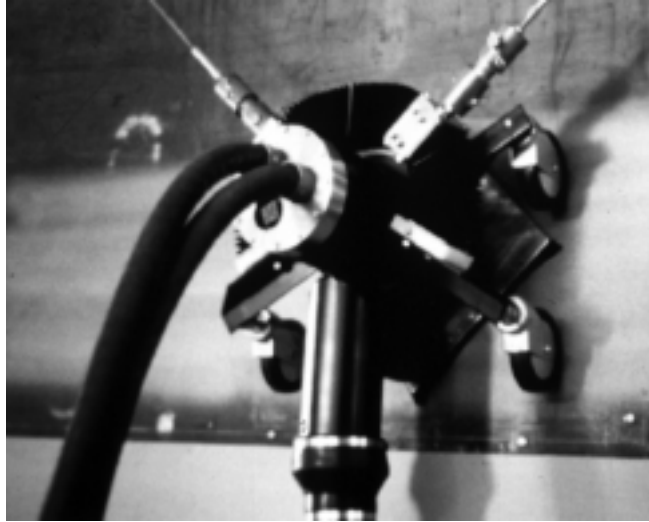


Figure 4-4: Non-Woven Abrasive Disk with Vacuum
(SSPC File Photo)

Coated abrasives are available in discs and flat wheels. They can remove loose rust and scale but not tight mill scale. They are more susceptible to clogging than are non-woven abrasives. They are particularly desirable for applications where metal removal is either desirable or acceptable, as in grinding of welds.

Types of Rotary Tools

There are two basic types of rotary tools for utilizing the abrasive media: straight (in-line) and vertical (right angle). The straight style tools are used with radial wire brushes, coated abrasive flap wheels, and non-woven abrasive wheels. Most air-powered tools contain governors to limit the free operating speed. Electrically driven tools operate at fixed speeds.

Care must be exercised in not overworking the tool but rather allowing the tool to do the work. Some studies have shown that if excessive pressure is exerted when using non-woven abrasive, the binder can melt and be deposited on the substrate.

4.3.1.3 Rotary Impact Tools

Rotary impact tools clean by cutting and chipping, as do other impact tools. However, the rotary action at high speeds results in much greater cleaning rates. The media used in these tools are of three major types: cutter bundles (stars), rotary hammers, and heavy-duty rotary flaps (Figure 4-5).



Figure 4-5: Examples of Rotary and Rotary Impact Tools
(Courtesy of 3M Company)

Cutter bundles consist of hardened steel star-shaped washers. The washers are free to rotate individually on spindles that orbit a powered axis. The resultant scraping action is suited for grinding concrete, surface preparation, coating removal, and generation of non-slip surfaces.

Rotary hammers consist of a series of free-swinging hammers. Through impact on a surface, these hammers can remove thermoplastics, heavy coatings, non-skid coatings, and heavy scale.

Heavy-duty rotary flaps utilize abrasive imbedded into the flaps to impact the steel. This fractures old coatings and scale. These flaps can also produce a profile and are frequently used when SSPC-SP 11 (described below) is specified. (Figure 4-6.)



Figure 4-6: Heavy Duty Rotary Peening Tool
(Courtesy of 3M Company)

4.3.2 Standards

Two levels of power tool cleaning and one level of hand tool cleaning of steel have been established by SSPC. In each case, the surfaces are first solvent cleaned (SSPC-SP 1) to remove grease, oil, and other contaminants that are not readily removed during the power tool cleaning.

SSPC-SP 3 (power tool cleaning) and SSPC-SP 2 (hand tool cleaning) remove only loosely bonded materials (e.g., loose mill scale, loose rust, and loose paint). The appearance of surfaces produced depends on the particular tool. SSPC-VIS 3 depicts the appearance of cleaned steel for three types of power tools (power wire brush, abrasive disc and needle gun) on different initial conditions. These conditions include different degrees of rusting and of coating degradation. Also SSPC-VIS 3 illustrates power tool cleaning of welds. Hand tool cleaning (SSPC-SP 2) is much slower and thus more costly than power tool cleaning.

SSPC-SP 11 differs from SSPC-SP 3 in that it produces a bare metal surface free of mill scale, rust, and paint. SSPC-SP 11 also requires retaining or producing a surface profile of 1 mil (25 micrometers) minimum. The surface may be produced using a needle gun, rotary flap or wheel, or many other tools. Although SSPC-SP 11 results in a much

cleaner steel surface for coating than does SSPC-SP 3, it is much more difficult and costly to achieve (Figure 4-7).

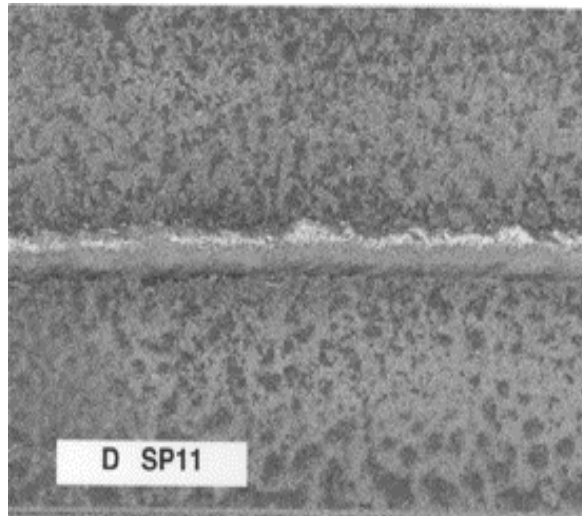


Figure 4-7: SSPC-SP 11 Over Rust Grade D
(SSPC File Photo)

4.4 Water-Jetting

4.4.1 *Descriptions and Definitions*

Pressurized water can be used to prepare steel surfaces for paint application. Water-jetting is defined in the standard SSPC-SP 12/NACE No. 5. High-pressure water-jetting operates at nozzle pressures between 10,000 and 25,000 psi (70-170 MPa). Ultra high pressures are those greater than 25,000 psi (170 MPa). High-pressure water-jetting is capable of removing all loose paint, rust and mill scale, most intact paint and chemical contamination (e.g., chlorides). Ultra high-pressure water-jetting is capable of removing all intact coatings. Neither of the techniques will remove tight rust and mill scale, or produce a surface profile in the metal substrate. However, they can restore an existing profile. The high-pressure water warms the steel but does not prevent flash rusting.

SSPC-SP 12/NACE No. 5 defines four water-jetting surface preparation conditions (WJ-1 to WJ-4) with WJ-1 the cleanest. The standard also defines three degrees of salt contamination (SC-1 to SC-3) with SC-1 the lowest level. WJ-2 and WJ-3 are commonly used for maintenance painting on ship hulls. Water jet cleaning has not been widely used on ballast tanks. Water jet cleaning is suitable only for primer materials recommended by their manufacturers for this type of surface preparation. While water pressure is high, only low volumes of water are used so that relatively small volumes of wastewater are produced. It may be necessary to collect the water by pumping and filtering before disposal.

4.4.2 *Water-jetting Equipment*

The basic equipment includes a portable high-pressure pump, a supply of water (preferably fresh), lances and nozzles. There are numerous suppliers of the equipment, which is becoming widely used in surface preparation, concrete restoration, and other cleaning activities. The field units use about 1 to 4 gallons (3.8 to 15 liters) of water per minute, so disposal or channeling of water may be of concern.

Because of the complexities of the water-jetting equipment, down-time due to equipment repair can be a concern. But is not as high for certain systems as was the case a decade ago. If a pump requires maintenance another pump must be available on-site to take its place. This is similar to the situation for an air compressor, which would need to be replaced if it were to break down during abrasive blasting operations.

Vacuum shrouded water-jetting is a relatively new technology. A high-pressure water jet is contained within a vacuum system to collect and recycle the water. The worker exposure is low because the water

encapsulates the dust. The environmental risk is also low as long as the water system is filtered and recirculated.

4.4.3 *Procedure for Waterjetting Tank*

Planning a waterjetting operation inside a tank entails consideration of:

- where best to place the units on deck;
- the best method of securing the units;
- the best method of supplying fuel;
- optimum hose runs;
- the capacity, number, and type of ventilation fans required;
- ventilation requirements;
- the ship's power supplies: location, voltage, amperage;
- fresh water requirements: the capability to supply sufficient fresh water for the work and the location of the supply points;
- entry and exit points for men and equipment;
- requirements for access equipment in the tank(s);
- accommodation arrangements for water jetting operations.



Figure 4-8: Water-jetting aboard ship
(Courtesy of Hempel Coatings)

4.4.4 *Water-Jetting Case Histories Inside Ballast Tanks*

A National Shipbuilding Research Program project evaluated water-jetting in two ballast tanks on ships (NSRP Report 0520). The procedure was as follows:

- Spot-blast corroded areas to bare metal, sweep blast all other surfaces to clean and remove staining, feather edges.

The units operated at pressures of 20,000 psi (140 MPa) and 36,000 psi (250 MPa). The cleaning rates ranged from 90 to 236 ft²/hr (8.4 to 21.9 m²/hr) at 20,000 psi (140 MPa) and 45-85 ft²/hr (4.2 to 7.9 m²/hr) at 36,000 psi (250 MPa). These rates included down times from manufacturer's tests and inspection. The rates are significantly reduced due to heat stress, worker dehydration and lack of visibility.

After final washing, the majority of paint chips and corrosion products were bucketed out from the bottom of the tank. The remainder was removed by rinsing debris through the outer hull sand holes. Water and paint waste was accumulated into a dry dock holding tank. From there the water was pumped through a series of two microseparator filters to remove paint debris. This filtered water was then transferred to a separate ballast tank within the dry dock where it was periodically analyzed and tested prior to disposal.

The researchers also observed the following:

- Due to limited access of the blasting nozzle to certain geometries, about 1% to 3% overall surface area must be hand and power tool cleaned prior to painting.
- In one tank, dehumidification was used to improve the visibility. However, the additional heat from the desiccant DH unit added to the discomfort factor (see Unit 5).
- The wood planking used in staging the tank retained moisture, and probably contributed to the high relative humidity.
- Adhesion tests indicated that the spot and sweep water-jetting did not adversely affect the integrity of the remaining coating.
- Flash rusting could be significantly reduced using ventilation.
- Chloride levels were measured before and after water-jetting on rusted areas and on intact paint. For both conditions, the water-jetting reduced the concentration of soluble salts measured by 80 to 90%.
- With the advancement of water-jetting pump technology from hydraulic intensifier pumps to positive displacement pumps, not only were higher pressures achieved but the pumps are more durable and well suited for the harsh shipyard environment.

4.4.5 *Water-Jetting Case Histories Work While at Sea*

Water-jetting has also been performed while a ship is at sea. The following assessment is derived from a recent trial application.

Advantages are:

- water-jetting can be done during the journey;

- no need to store large amounts of dry abrasives nor to dispose of contaminated abrasives;
- salts are removed from the steel surface;
- water can easily be pumped out of the ballast tanks together with the paint chips.

Disadvantages are:

- tools are more complicated;
- operation is more difficult;
- only trained personnel can carry out repair;
- no surface profile is created.

Recommended practices include:

- simple, lightweight, easy to handle jetting guns and self-propelled rotary tools;
- a rotary nozzle with a spray angle of about 30 degrees is most suitable; spray gun and 0.13 inch (5 mm) ID hose can be used and coupled to 0.20 inch (8 mm) ID hoses via rotary joint to avoid hose twisting;
- snap coupling is very helpful for easy change of tools.

4.5 Wet Abrasive Blasting

Wet abrasive blasting combines water with abrasive. Wet abrasive blasting reduces the particulate dust normally produced in dry abrasive blasting. This feature can reduce health hazards and improve visibility in the work area. SSPC-TR 2/NACE 6G198 describes various aspects of wet abrasive blasting. The two basic types of wet blast equipment are air abrasive blasting with water injection (see Figure 4.9) and pressurized water with abrasive injection. Inhibitors may be needed to prevent flash rusting. When wet blasting, the helmet shield or visor will become splattered with water and must be wiped frequently. This can be avoided by rigging a small water hose to the top of the helmet. Also, damp or wet abrasive will stick to the surface requiring a second cleaning with water by itself. Cleaning up the spent abrasive may require shoveling or use of a wet vacuum system. The water in wet blasting does not completely suppress dust so it is important for the operator to wear a NIOSH approved respirator.

A system for wet abrasive blasting with a reduced level of water has been developed and introduced to the industry. Because of the reduced water volume, the surface dries very rapidly. As a result this system does not

present the same problems of abrasive cleanup and flash rusting as conventional wet blasting systems. Also, it is claimed that the amount of abrasive used per square foot is reduced.

A wet blast system has been used to remove coatings from submarine hulls in dry docks. Its use has been limited to dry docks equipped to capture the water. However, one yard achieved considerable cost savings by eliminating the construction of containment. A full containment system is needed for dry open abrasive blast cleaning. The cleaning rate per nozzle hour was about 50% - 60% that of dry blasting. The abrasive consumption rate was only about 20% that of dry blast (2.6 vs. 12.5 lbs/ft² [12.7 vs 61.0 kg/m²]). Because of the added cost for an abrasive additive, however, the overall abrasive material costs for the two methods were approximately equal. Major advantages cited for wet blasting were reduced coating removal costs, reduction in waste, and the high quality of surface produced. Disadvantages included: noise hazard, operator fatigue, need for waste and water collection and disposal, and interference with other dry dock work.

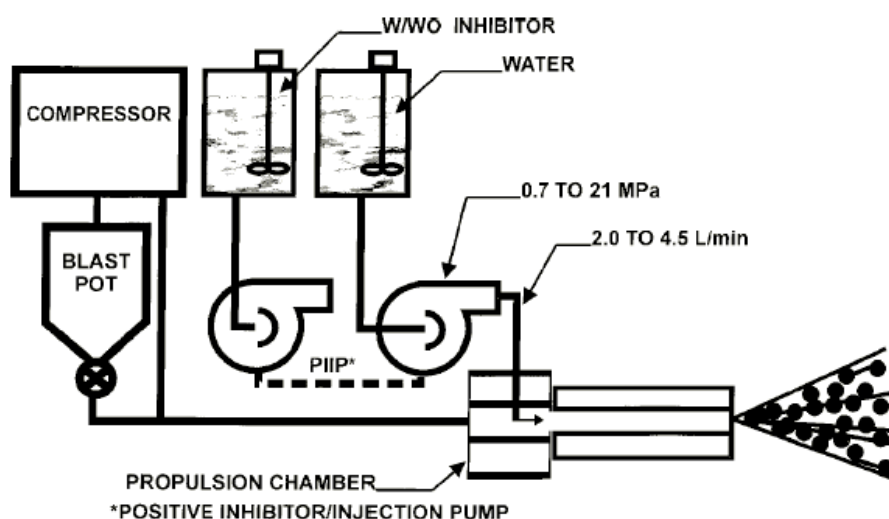


Figure 4-9: Schematic of Wet Abrasive Blasting Unit (Co-axial injection)
(SSPC File Photo)

4.6 Solvent and Chemical Cleaning

Organic solvents, detergents, emulsifiers and other chemicals are used to remove oil, grease and dirt from steel surfaces prior to painting.

4.6.1 Solvent Cleaning

Organic solvents clean by dissolving and diluting oil, grease, dirt, chemical paint stripper, and other soluble contaminants to permit removal by wiping or washing off. It is best to first remove soil and other dry contaminants by wire brushing. When applied by clean rags, or immersion, the solvent soon becomes contaminated. Thus, a final rinse is always necessary. Recommended solvents are mineral spirits and high-flash naphtha. In all cases, it is necessary to obtain permission for this cleaning method from local authorities. Solvent cleaning with organic solvents finds limited use aboard ships because of the health and safety hazard.

4.6.2 *Alkaline Cleaning*

Alkaline cleaners attack oils and greases converting them into soapy residues that can be washed away. Dirt and other contaminants can also be washed away. Alkaline strippers may similarly be used to remove alkyd coatings. Alkyd coatings occur on ships as exterior silicone alkyd topcoats for epoxies and flame-resistant chlorinated alkyds in habitability spaces. Chemical cleaning using alkaline cleaners is more efficient and less costly than solvent cleaners but is an inherently more difficult method.

The most commonly used alkaline cleaners are trisodium phosphate (TSP), caustic soda, and silicated alkalis. They are dissolved in water and used at a relatively high temperature (e.g., 150°C [66°F]). They can be applied by brushing, scrubbing, spraying, or by immersion of the surface in soak tanks. Cleaned surfaces must be thoroughly rinsed with hot water, preferably under pressure. The rinse is needed to remove the soapy residue and all traces of alkali. The cleaning solutions often contain 0.1 % potassium dichromate to prevent corrosion.

Metal surfaces of steel ships can be cleaned with alkaline solution before repainting, but never in submarines and surface ships with aluminum hulls. Details on alkaline cleaning of ships can be found in the Naval Ships' Technical Manual Chapter 631. This manual also describes the safety precautions that must be taken to protect workers from the alkalinity and the hydrogen gas that may be produced during the cleaning.

4.6.3 *Emulsion Hand Cleaning*

Emulsion cleaning uses a combination of solvent and alkaline cleaning. It is used primarily for bilge surfaces to be repainted. Work sections no larger than 200 to 300 sq ft (19 to 28 m²) are treated at one time. Each section should be fully cleaned and primed before going to the next one. Two chemical solutions are used in the hand tool cleaning method: an emulsifiable solvent and an alkaline water-borne cleaner.

The emulsifiable solvent is used first to penetrate and loosen oil-saturated soils. The process emulsifies these contaminants so they can be rinsed

away with a high velocity stream of fresh water. Any remaining residues of rust, paint, or oily incrustation are removed by brushing and scraping.

Emulsion and solvent cleaning always leave an oily film on surfaces that will inhibit good primer adhesion. This film must be removed with the alkaline solution. Again, details of the hand cleaning method are described in Naval Ships' Technical Manual Chapter 631.

4.6.4 *Citric Acid Cleaning*

The citric acid cleaning system is intended to remove oil, old coatings, and rust from bilge areas and tanks prior to recoating. It is described fully in the Uniform Industrial Process Instruction (UIPI) No. 6311.455. This instruction entails the preparation of the bilge and equipment, identification of the existing coating system, acquisition of necessary chemicals and tools, degreasing/cleaning, paint/stripping/removal, citric acid rust removal, passivation of bare steel, and drying and preparation for coating application. Because of the specialized equipment required, the chemicals, and disposal requirements, it is usually done in controlled areas of shipyards.

4.6.5 *Electrolytic Descaling*

Heavy scale can be removed by an electrochemical reaction between the scale and a metal strip. The process is known as electrolytic descaling. Descaling is recommended for use in ballast tanks having more than 70% coating breakdown. Magnesium strips with iron cores are welded or clamped to the ballast tank surface to provide electrical contact with the tank. When the tank fills with seawater, an electrochemical reaction occurs, which produces a calcareous layer. This causes rust scale and old coatings material to loosen and drop to the bottom of the tank. This layer can be removed with water jetting at 15,000 psi (100 MPa) and the tank dried and prepared for recoating. The electrochemical reaction also generates hydrogen gas at the steel surface. This reaction makes it necessary to ventilate the tank. The descaling process takes about 8-14 days.

According to one source, 1 to 2 ft. (0.3 to 0.6 m) of magnesium strip is needed for 10 sq. ft (0.9 m²). of steel to be descaled. The cost for the magnesium strip is about \$0.56 per ft² (\$6.00/m²).

UNIT 5 DEHUMIDIFICATION

5.1 Principles of Dehumidification

5.1.1 *Introduction*

Dehumidification (DH) is the process of removing moisture from air. This prevents condensation (“sweat”) on internal tank surfaces during blasting and painting. Moisture in the air also affects the curing of coatings such as inorganic zinc-rich coatings, moisture curing polyurethanes and waterborne coatings.

5.1.2 *Properties of Air and Moisture*

Condensation occurs when warm, moisture-laden air contacts a cooler surface. As the air next to the surface is cooled, the moisture carrying capability is reduced, and some of the water vapor is deposited as droplets on the cooler surface.

The temperature at which the ambient air becomes saturated with water vapor is called the dewpoint temperature. Any reduction in the air temperature below the dewpoint (for example when warm air contacts a cooler surface) causes moisture condensation. Reducing moisture content in the air will lower the dewpoint temperature of that air. The amount of water vapor the air can hold depends on temperature; warm air can hold more vapor than cold air.

Increasing the temperature of the air by heating does not decrease its moisture contents (its weight of vapor) but does increase its ability to hold moisture. Heating therefore decreases relative humidity although no vapor has been removed. Heating the air in an enclosed tank also does not change the dewpoint temperature. For example, air at 40°F (4°C) at 70% relative humidity has a dewpoint temperature of 31°F (-1°C). Heating the air to 80°F will decrease relative humidity to 17%, but the tank has an identical dewpoint of 31°F (-1°C).

Condensation will not occur if the surface temperature of the tank is kept higher than the dewpoint temperature of the air. Therefore, the general rule for condensation prevention is to maintain the surface temperature at least 5°F (3°C) above the dewpoint temperature. Some shipyards prefer a spread of 10°F (6°C) or 15°F (8°C) as a safety factor.

Dehumidification involves removing moisture from the air. One must also consider the moisture introduced into the work area by the compressed air used for abrasive blast cleaning. Unless this wet air is cooled and dried this moisture will be deposited directly into the work area by the blasting operation.

When air is compressed, the water content is also compressed. For example, air at 100 psi (690 kPa) is about seven times the pressure of the atmosphere. So each cubic foot of air contains seven times as much air and water vapor as a cubic foot of uncompressed air. If the blast nozzle consumes 200 CFM (5.7 m³/min) at 100 psi (690 kPa), it will add about the equivalent of 1,400 CFM (40 m³/min) of air (7 x 200) at atmospheric pressure along with moisture contained in that air.

5.1.3 *Units and Conversions*

It is useful to review the units and methods for measuring moisture and related properties. Units of interest include air pressure and air flow; weight, volume and density of air; water vapor pressure, weight and density of water vapor in the air; and relative and absolute humidity and dewpoint.

- **Air pressure:** Air pressure is the force exerted by air on adjacent surfaces in all directions. It is measured in psi (pounds per square inch) or pascals. More correctly, the pressure is given as psia or psig. (See below.)
- **psia (psi absolute):** Absolute pressure is the total pressure exerted by the air; it is the sum of atmospheric pressure and a gauge pressure; it is the pressure measured from an absolute zero pressure as a base. Example: 100 psig + 1 atmosphere (14.7 psi at sea level) = 114.7 psi absolute. [690 kPa gauge + 1 atmosphere (101 kPa at sea level) = 791 kPa]
- **psig (psi gauge):** Gauge pressure is the pressure measured from atmospheric pressure as a base; it is the pressure indicated by a pressure measuring device (gauge) which has its scale calibrated so as to read zero under atmospheric pressure.

Alternate units for pressure are inches of mercury (abbreviated Hg) and inches of water. These are based on the pressure produced by a column of mercury or water at a given height. Comparisons are shown on Table 5-1. Pressure less than atmospheric (14.7 psig) is sometimes referred to as negative pressure. A vacuum is measured by the psi or inches of water or mercury that can be sustained (e.g., 8 inches of mercury vacuum is equivalent to -4 psig or 10.7 psia or 109 inches of water vacuum (Table 5-2).

Table 5-1
Comparing Units: Positive Pressure

Gauge psi kPa		psi Absolute	Inches Mercury	Inches Water
100	690	115	234	3186
10	69	25	50.9	693
1	7	15.7	32.0	435
0.2	1.4	14.9	30.3	413
0	0	14.7	29.9	407

1 atmosphere = 14.7 lb/in² = 101 kPa

Table 5-2
Comparing Units: Negative Pressure (Vacuum)

Psi (kPa) Gauge	Psi (kPa) Absolute	Inches Hg (Absolute)	Inches Hg (Vacuum)	Inches Water (Absolute)	Inches Water (Vacuum)
0 (0)	14.7 (101)	29.9	0	407	0
-0.1 (-0.69)	14.6 (100)	29.7	(0.2)	404	(3)
-1.0 (-6.9)	13.7 (94.5)	27.9	(2.0)	380	(27)
-4.0 (-28)	10.7 (73.8)	21.9	(8.0)	298	(109)

- **Air flow:** Air flow is measured in cubic feet per minute (CFM) (cubic meters per minute [CMM]). Sometimes the term SCFM (standard cubic feet per minute) is used. This represents the flow rate for air at “standard conditions” of 68°F (20°C) and 14.7 psi (101 kPa).
- **Weight of air:** Air has weight. Air pressure at the surface of the earth is due to the weight of the air above the earth. The weight of air is measured in pounds or grains, where one pound = 7000 grains = 0.45 kg.
- **Density of air:** Density is the weight divided by the volume. At normal atmospheric pressures one pound of air occupies about 14 cubic feet, so one cubic foot weighs 1/14 (0.071) pound or 500 grains (1 kg of air occupies 0.87 m³, so 1 cubic meter weighs 1.15 kg). Note: Knowing the density of air allows us to convert the air flow from CFM to weight of air per minute (for example, pounds of air per minute).
- **Water vapor:** The gaseous form of water. Like air it has a pressure (water vapor pressure).
- **Weight of water vapor:** Measured in pounds or grains (kg or grams).

- **Density of water vapor:** This density is the weight of water vapor in a given air volume (e.g., pounds per cubic feet or grains per cubic ft, [grams per cubic meter]).
- **Relative humidity (RH):** Relative humidity is a term used to express the amount of moisture in a given sample of air in comparison with the amount of moisture it would hold if totally saturated at the temperature of the sample. Relative humidity is stated in percentage such as 20 percent, 50 percent, 100 percent, etc. At any given temperature the amount of grains measured, divided by the grain saturation at the same temperature, represents the relative humidity.
- **Humidity Ratio (absolute humidity):** Humidity ratio is defined as grains of moisture per pound of dry air (grams of moisture per kg of dry air). This is a measure of the absolute moisture content of the air. It is also referred to as specific humidity or absolute humidity.
- **Dewpoint:** This is the atmospheric temperature at which moisture vapor begins to form into a liquid (e.g., dew starts to form as water vapor condenses). Also called saturation temperature.

5.1.4 *Tools and Techniques for Assessing Moisture*

5.1.4.1 *Psychrometers*

A psychrometer is a tool to measure dewpoint and relative humidity. The sling psychrometer is the most commonly used instrument for measuring temperature and humidity on the industrial coating job site. It measures dry bulb temperature and wet bulb temperature. The wick on the wet bulb thermometer must be kept clean and fully wetted with clean, preferably distilled, water (tap water or salt water will give erroneous readings). The psychrometer must be spun rapidly enough so that the speed of air across the wick is a minimum of 600 ft/min (33 m/s). The wick should be wetted and spun several times, using the lowest reading. Unless the wick is wetted with chilled water, the readings will be 4% to 7% above the actual humidity (e.g., 65% RH reading vs 60% actual RH).

Battery or electric powered psychrometers are also available. These are sometimes preferred, because they allow the operator to get closer to the surface. This tool is easier for entry level personnel to operate than a sling psychrometer. It has a battery operated fan that creates the air flow across the wet bulb and dry bulb thermometers. It also has a light, which illuminates the thermometers, making it easier to read the temperatures. An advantage in using this device is that the operator can observe the dropping temperature on the wet bulb thermometer while it is in operation. Battery-powered psychrometers typically require about two minutes for the thermometers to stabilize.

A capacitance-based instrument is a more accurate method of measuring relative humidity. The capacitance reduces as RH increases. A digital readout will display the signal in RH or dewpoint. Capacitance changes are small at very high and very low humidities (above 85% and below 10%). Therefore, accuracy is greatest in the middle of the scale. The repeatability of these devices is plus or minus 2%, when properly calibrated.

5.1.4.2 *Psychrometric Chart*

This is a chart, which provides information on the relationships among relative humidity, dry and wet bulb temperatures and other parameters. It can be used to determine relative humidity, dewpoint or the absolute amount of moisture in the air for any given set of conditions. Although the chart appears to be very complex, its use for deriving practical information is straightforward. A step by step procedure is given in Section 5.6.1.

5.2 **Types of Dehumidification**

There are essentially two ways of accomplishing dehumidification of atmospheric air. One approach (refrigerant DH) is to chill the air below the dewpoint causing moisture to condense on cool surfaces. The other method (desiccant DH) passes air over substances having a strong affinity for moisture. These substances are called desiccants and are capable of extracting moisture directly from the atmosphere.

5.2.1 *Refrigerant Dehumidification*

The cooling of air to below its dewpoint is an economical method of dehumidification. This method is most effective at high temperatures and high humidity. Ambient air is circulated over a system of refrigeration coils. The surface temperature of the coils is set at temperatures considerably lower than the temperature of the incoming ambient air. The air cools, reaches saturation, and condensation occurs. This condensation is collected and removed from the system. The air exits the cooling coil section of the dehumidifier at a reduced temperature, reduced dewpoint, and reduced absolute humidity. This refrigeration-based dehumidification system is illustrated below in Figure 5-1. The cooler air, which has a lower dewpoint, can then be reheated to lower the relative humidity.

Refrigeration is often used to pre-cool and dehumidify inbound air before it reaches a desiccant system. This process makes it possible to obtain lower dewpoints after desiccation. The air may be re-cooled, if necessary by refrigeration. This may be necessary because desiccant systems add heat to the air.

- Advantages

- * Provides cooling as well as dehumidification
- * Relatively low power requirements versus desiccant type units
- Limitations
 - * Does not work as well at low temperatures
(lower limit debated, somewhere between 65° and 40°F [18° and 4°C])
 - * At moderate and low temperatures, needs more airflow than desiccant for same level of protection

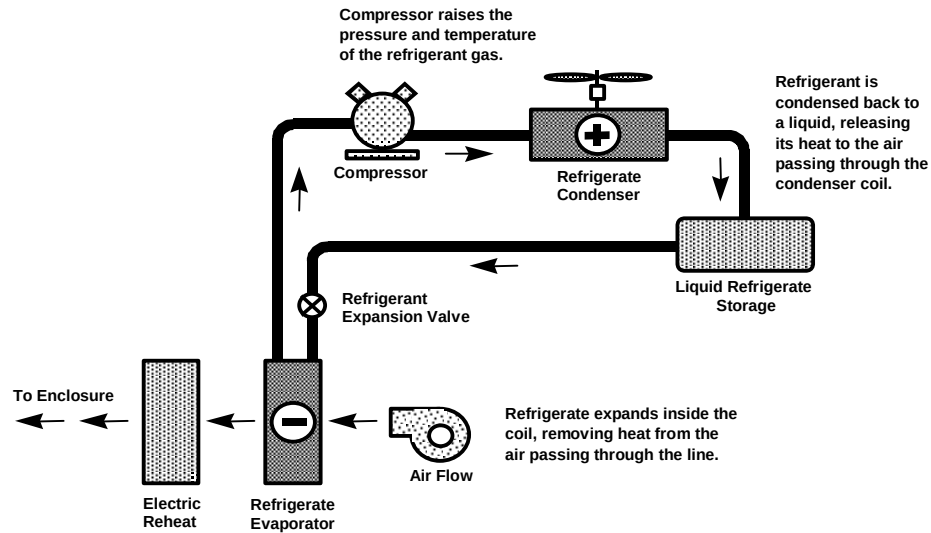


Figure 5-1: Refrigeration-Type Dehumidifier
 (Courtesy of Enviro-Air Control Corporation)

5.2.2 Desiccant Dehumidification

Desiccants are substances, which have a very high affinity for water. Because of these properties, they can draw moisture directly from the surrounding air. Desiccants may be solids or liquids.

One of the most important features of desiccant dehumidification is that the desiccant can be returned again (regenerated) to its dry state. In general, desiccant dehumidification involves exposing the desiccant to a flow of moist air. Moisture is extracted from the air and collected by the desiccant. Then the desiccant is heated, driving off the collected moisture into an exhaust air stream.

For liquid desiccants, the air is passed through a liquid sorbent that absorbs moisture from air. The sorbent must be continually regenerated by using heat to drive off water. The solid sorption (desiccant) method uses either granular beds or fixed desiccant structures that are used in automatic machines. The desiccant needs to be reactivated by heat to release moisture to an outdoor air stream.

The most commonly used desiccants are silica gel and lithium chloride. Air is passed through beds or layers of desiccant, which absorb moisture from the air stream, producing a hydrated salt. Regeneration of the hydrated salt is accomplished with heated air, which drives off the water of hydration, returning the sorbent to its dehydrated state. The hydration reaction typically raises the temperature of the exiting air stream by 10° to 15°F (6° to 8°C) or more. Therefore, in hot climates, refrigeration-type dehumidifiers are

frequently used in combination with this type of equipment to cool the air entering the space. A typical desiccant dehumidification system is illustrated below in Figure 5-2.

- Advantages
 - * Dehumidifies in any weather from + 95°F to -20°F (35°C to -29°C)
 - * Adds heat (reduces need for comfort heaters in cooler locales)
 - * Dries air very thoroughly
 - > Provides large safety margin for fast weather changes
 - > Allows untreated air to be blended with super-dry air, reducing equipment size
- Limitations
 - * Adds heat as it dries — requires supplemental cooling in hot weather
 - * Usually more expensive per CFM than refrigeration-type units (but less CFM may be required)

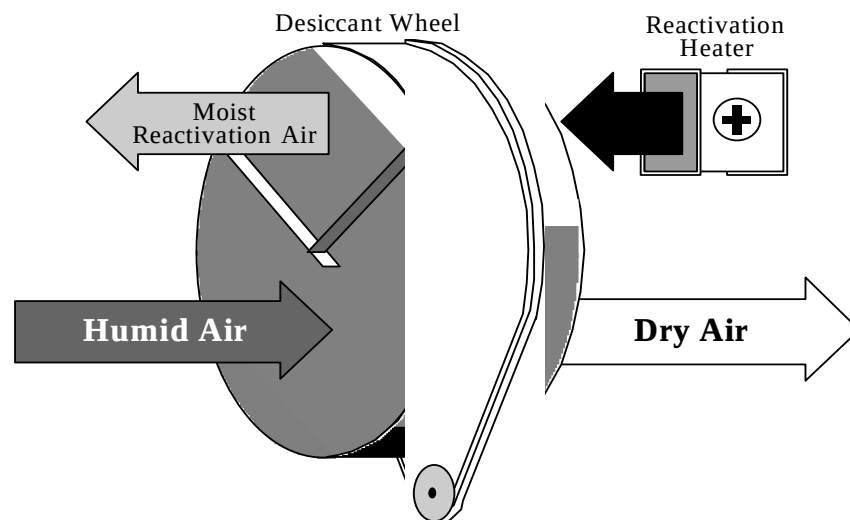


Figure 5-2: Solid-Sorption Desiccant System
(Courtesy of Munters Moisture Control Services)

5.2.3 Closed Loop System

A closed loop system is one that routes the air exiting an enclosure through an appropriate filter media. The air exiting the filter device is sent to the dehumidification equipment to be used as feed air. The dehumidifier further treats this air and sends it back into the enclosure (Figure 5-3).

During the blasting/surface preparation stage of the project, the air exiting the enclosure will be carrying all types of particulate matter (spent abrasive, paint

particles, rust particles, etc.). This air must be filtered through a dust collector before being exhausted or recirculated.

During paint application, it is important to avoid recycling potentially harmful solvent vapors back into the vessel. In addition, solvent fumes will damage desiccants.

There could be a significant difference in air handling requirements (i.e., increased CFM) between the dust collector, solvent removal, and dehumidification equipment. The dust collector is normally at a higher CFM. It may become necessary to introduce a diverter (a “Y”) into the air stream between the exit transition of the dust collector or solvent discharge and the inlet transition of the dehumidifier. This diverter can then be controlled, or set, to allow only enough air to the dehumidifier as its rated capacity. The remaining filtered air will then be released/exhausted to the environment.

This balance between the dehumidifier and the dust collector must be maintained. If not, there is a possibility that the “excess” capacity of the dust collector or ventilation equipment would pull untreated air into the work area and cause a problem as noted above.

Figure 5-3: Closed-Loop System for Dehumidification
(Courtesy of Enviro-Air Control Corp.)

5.3 Dehumidification Equipment

DH equipment can be characterized by a number of parameters. Several of these are briefly described, highlighting the importance for shipyard personnel. Much of this data isn't included in standard promotional literature of equipment suppliers, so comparing the different units is not always easy. However, each manufacturer will be able to furnish this information upon request. The parameters to be discussed are:

- Type of DH (desiccant or refrigerant)
- Volume of air flow (CFM)
- Air velocity through the dehumidifier
- Power requirements
- External static pressure
- Moisture removal capacity
- Initial & final temperatures
- Dimensions and weight
- Reactivation parameters (for desiccant type units)
- Maintenance and troubleshooting

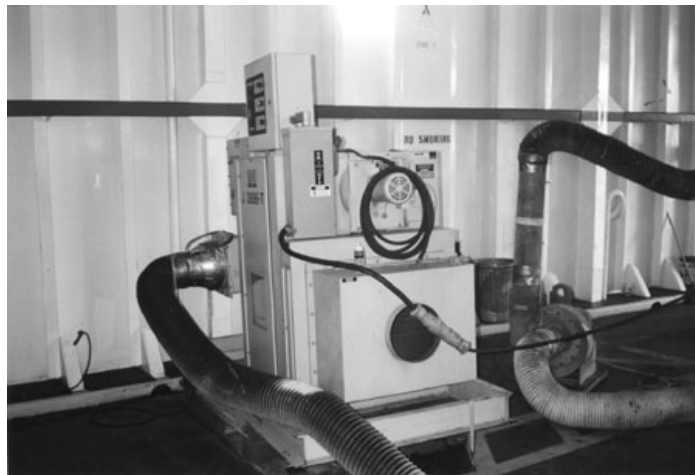


Figure 5-4: Dehumidification Unit:
2250 CFM (155 m³/min)
(SSPC File Photo)

5.3.1 *Type of DH* (desiccant or refrigerant)

Differences were discussed in Section 5-2.

5.3.2 *Volume of Air Flow* (CFM)

The most common designation for defining the capacity of the DH unit is the volume of conditioned air that can be delivered to a tank per unit time as

cubic feet per minute or CFM (m^3/min). However this information by itself is not necessarily adequate to define the end user needs.

5.3.3 *Air Velocity through the Dehumidifier*

It is often useful to know the velocity of the air exiting the DH unit and entering the work area. In general, velocity depends on the cross-sectional size opening of the plenum of the DH unit. Velocity affects how large a duct size can be used to convey the DH air.

The speed at which the air moves through a dehumidifier has a significant impact on the machine's ability to lower the dewpoint temperature of the air stream. The slower the air moves the more time it has in contact with the desiccant or the cooling coils, therefore allowing more moisture to be removed. Consequently, the temperature rise (or fall) will also be increased by slowing the air velocity. Performance for most dehumidifiers is stated at a particular air flow rate. Some units are dampered to allow the air flow to be adjusted. The performance of dehumidifiers at different air flows is available from the manufacturers.

5.3.4 *Power Requirements*

DH units are powered by electricity, gas or steam. In the USA, most use a 480-volt 3-phase electric power source. The current (number of amps) varies with the capacity and other factors. Smaller capacity DH units consume less current. For example, one yard prefers a desiccant unit with CFM of 2000-2500 (57-71 m³/min), because this unit draws about 50 amps. This amount of current is easier to provide than that required for a larger unit (e.g., 107 amps for a 4500 CFM [127 m³/min] unit or 236 amps for a 9000 CFM [255 m³/min] unit).

5.3.5 *External Static Pressure*

External static pressure is a measure of the change in pressure that can be maintained within the dehumidification unit, with typical values at 1 to 2 inches of water (0.25 to 0.50 kPa). During operation, the actual static pressure difference will be less than the rated static pressure. This is referred to as static pressure loss.

5.3.6 *Moisture Removal Capacity*

This parameter is a measure of how much moisture the unit can remove from the air stream per hour or day. It is important to select a DH unit that has adequate capacity to reduce and maintain the moisture level required for the project. This is more of a concern for hot humid conditions in a large tank. (See Section 5.6.2.)

5.3.7 *Initial and Final Temperatures*

DH units differ in how they operate under different temperature and humidity conditions. For example, refrigerant units are effective at very high temperatures. Also, DH units change the temperature as well as the

moisture content of the treated air. Recall that desiccant DH adds heat to the air. It is important to determine the final temperature of the air in the tank. If it is too hot or cold for the workers additional conditioning may be required. It may also be necessary to add heat to raise surface temperature for proper coating application and cure.

Performance charts supplied by manufacturers can be used to determine the initial and final temperature and moisture content based on the initial conditions and the DH unit parameters. (See Section 5.6.4.)

5.3.8 *Dimensions ("Footprint") and Weight*

This information is needed to determine if the unit will fit in available spaces. Check the footprint of the unit compared to the work space. If possible, the unit should be placed within about 100 feet (33 m) of the tank opening. Also, the weight is a consideration for moving the unit (e.g., by crane) and for supporting it on the structure being dehumidified.

5.3.9 *Reactivation Parameters* (for desiccant type units)

Most desiccant units are able to reactivate the desiccant. The parameters of interest are the CFM, power, and static pressure loss for the reactivation process.

5.3.10 *Maintenance and Troubleshooting*

As with any electromechanical equipment, the manufacturer must provide detailed maintenance instructions. One important parameter is the type of filter and the cost, frequency and difficulty of replacement.

Table 5-3 shows representative DH units with the data available from the manufacturers' literature.

Table 5-3
Data On Representative DH Units

Description/type /Mfcr.	CFM/Size	Power Requirements	Moisture Removal Capacity
Enviro-Air Series 1000 Refrigerant	1000/30x42x52	480V, 26A 3 phase	12.1 lbs/hr (85°F, 70% RH)
Enviro-Air Series 3000 Refrigerant	3000/44x52x100	480V, 85A 3 phase	69 lbs/hr (85°F, 70% RH)
Munters HC1125	1125 (100-400*)	480V, 28A	30 lbs/hr (75°F, 50% RH)
Munters HC2250	2250 (250-600*)	480V, 52A	60 lbs/hr (75°F, 50% RH)
Munters HC4500	4500 (500-1300*)	480V, 107A	118 lbs/hr (75°F, 50% RH)
Munters HC9000	9000 (1000-2800*)	Not obtained	230 lbs/hr (75°F, 50% RH)
Aggreko 180-Elec	1800 7x4x6 ft 1475 lbs	480V, 37A	60 lbs/hr **
Aggreko 330-Elec	3500 8x6x6 ft 3600 lbs	480V, 98A	115 lbs/hr **
Aggreko 940-Gas/Steam	10,000 1x8x7.5 ft 5900 lbs	480V, 35A	335 lbs/hr **
Aggreko Refrigerant DH Units	1000 to 13,000	Not obtained	Not obtained
VFB-9	900 (300*) 76x35x63 in. 550 lbs	64.8 reactivation energy (MBH)	30.2 lbs/hr (75°F, 100 gr/#)
VFB-24	2400 (800*) 8.2x4.25x6.25 ft 1025 lbs	172.8 reactivation energy	80.6 lbs/hr (75°F, 100 gr/#)
VFB-150	15,000 (5000*) 15.5x9.3x8 ft 1300 lbs	1080 reactivation energy	504 lbs/hr (75°F, 100 gr/#)
BRY-Air MVG-7.5A	4500 (1500*) 12.8x7x8.1 ft 5430 lbs	324 reactivation energy	25.2 lbs/hr (75°F 100 gr/#)
BRY-Air MVB-45-D	750 (250*) 8.2x3.8x5.9 ft 1300 lbs	54 reactivation energy	151 lbs/hr (75°F, 100 gr/#)
ATS 2000 DES-1500-55E Desiccant	1500 (500*) 105x52x68 in.	2.0 hp (1.5*) 460V/3, 43.4A	400 FPM face veloc. Chart given
ATS 2000 DES-9000-152G (gas) Desiccant	9000 (3000*) 185x84.5x97.5 in.	10.0 hp (5.0*) 460V/3 21.5A	600 FPM face veloc. Chart given

* Nominal reactivation CFM

** Estimated

NOTE: Information in Table 5-3 has not been verified and does not include all manufacturers of representative DH equipment.

5.4 Shipyard Responsibilities for Dehumidification

Implementing effective dehumidification entails several activities at a shipyard. Most of these are the responsibility of the paint department, but in some cases another shipyard department or an outside vendor or consultant is assigned responsibility. Table 5-4 lists the various activities, along with the information needed to determine what is required and which party is responsible.

Table 5-4
Responsibilities For Dehumidification Activities

Activity	Info Needed	Responsible Party
1. Define Tank Parameters	• Volume of tank • No. of Compartments • Configuration & Location • Design Drawings	Paint Dept.
2. Determine Expected Ambient Conditions During Coating Operations	• Substrate and Air Temperature Ranges • Dewpoint or RH Ranges • Seasonal Weather Conditions	Paint Dept.
3. Check Blasting & Coating Specifications	• Temperature & RH Max & Min Allowed • Dewpoint Spread	Paint Dept.
4. Is Dehumidification Needed?	• From 2 And 3 Above	Paint Dept.
5. Approximate Dehumidification Requirements	• No. and size of units • Amount of Dehumidification Needed (Moisture To Be Removed or CFM) • Is It Comparable To Other Projects?	Paint Dept. or HVAC Engineering
6. Designing DH System	• Who will design? A. Paint Department B. Other Dept at Yard • Consultant or Vendor • Complexity of tank • Routine or Minor Variation On Previous	HVAC Engineering
7. Setting up DH System	• Placement of DH unit • Sealing Tank • Inlets & Outlets	Paint Dept. or Manufacturer
8. Operating DH System	• Equipment setup • Monitoring equipment	Paint Dept.
9. Assessing Adequacy of DH	• RH, Temperature, Dewpoint (Psychrometric Chart) • Air flows • Cure of coatings	Paint Dept.
10. Quality Assurance	• Conformance to project specification	Paint Dept.



Figure 5-5: Dehumidification Unit: 9000 CFM (620 m³/min)
(Courtesy of Todd Shipyard)

5.5 Procedure for Dehumidification of Tanks or Other Voids

5.5.1 Planning for DH

5.5.1.1 Reasons for Dehumidifying Tank

Dehumidification may be required or desired for three reasons.

- Specification requires a minimum RH (e.g., 50%).
For example, US Navy specifications allow a maximum relative humidity of 50% during application and curing for solvent-free epoxies. For most shipyards in the US, the ambient humidity will normally be higher than 50%, so dehumidification is needed to meet the specification.
- Specification requires that temperature of the surface be at least 5°F (3°C) above the dewpoint to prevent condensation.
Condensation will occur when the dewpoint is at or above the surface temperature. Most coating specifications require the surface temperature to be at least 5°F (3°C) above the dewpoint temperature. If these conditions are not met, dehumidification can be used to lower the dewpoint. These conditions will then allow blasting and painting to proceed. Some shipyards prefer a spread of 10° or 15°F (6° or 8°C), especially for tanks. In many locations, the surface temperature is less than 5°F (3°C) above the dewpoint temperature, so without dehumidification, there would be a substantial risk of condensation.
- DH can create working conditions to improve productivity and reduce downtime.
Coating work on tanks under dehumidification can continue during periods of rain and high humidity. The ability to preserve the cleanliness of the

steel and prevent flash rusting allows the applicator to continue the dry abrasive blasting process over several days, without priming the steel daily. This can result in significant labor savings by eliminating the need to clean the surface, mix and apply primer and clean up spray equipment daily. Often, tanks are blasted completely, before cleaning and priming takes place. Dehumidification can also improve productivity by increasing worker comfort levels and reducing fatigue.

5.5.1.2 *Data Needed for DH Planning*

Basic data are needed for tank and ship factors, for expected weather conditions, and for end conditions.

- Tank and Ship Factors:
 - * Tank size(s)
 - * Tank configuration
 - * Location in the ship
 - * Space available (footprint)
 - * Proximity of tank to equipment location (to determine length of ducting)
- Weather Factors
 - * Temperature and humidity range expected during application and curing
 - * Dewpoint and moisture in air (relative or absolute humidity)
- End Conditions
 - * Required humidity or dewpoint
 - * Maximum and minimum surface and air temperatures

5.5.2 *Step-by-Step Procedure*

This section presents a multi-step procedure and flow chart for the dehumidification of a ship's tank or other space. These are summarized in Table 5-5.

Table 5-5
Steps for Dehumidification of Tank

Step	Description of Activity	Comments
A	Is DH specified?	Source: Specifications
B	Is dewpoint or RH specified?	Source: Shipyard tank procedures and manufacturer's Data Sheets
C	Is DH required for dewpoint or RH control?	Determine if dewpoint or RH conditions exceeded
D	Is DH required for production or scheduling?	Estimate impact of DH on down time and efficiency
E	Who normally designs DH?	Paint dept. or other group
F	Does DH require complex design?	Determine if paint dept. needs additional assistance
G	Determine CFM needed and type (e.g., desiccant or refrigerant)	Based on volume of tank and air changes per hr. and surface temperature expected and required.
H	Determine availability of equipment	Identify size and other parameters of in-house units
I	Are in-house units adequate?	Compare available DH units with CFM, moisture and other parameters needed
J	Acquire additional units	Rent or purchase
K	Determine layout of DH system	Includes placement, inlets, outlets and ducting
L	Design of DH outside paint shop	Identify source, contacts and procedures for review
M	Determine operating schedule	Starting and stopping times based on task and specific requirements
N	Determine adequacy of DH	3 methods: Check proper unit function; measure RH and temp.; air flows

A flow chart of this procedure is given in Figure 5-6.

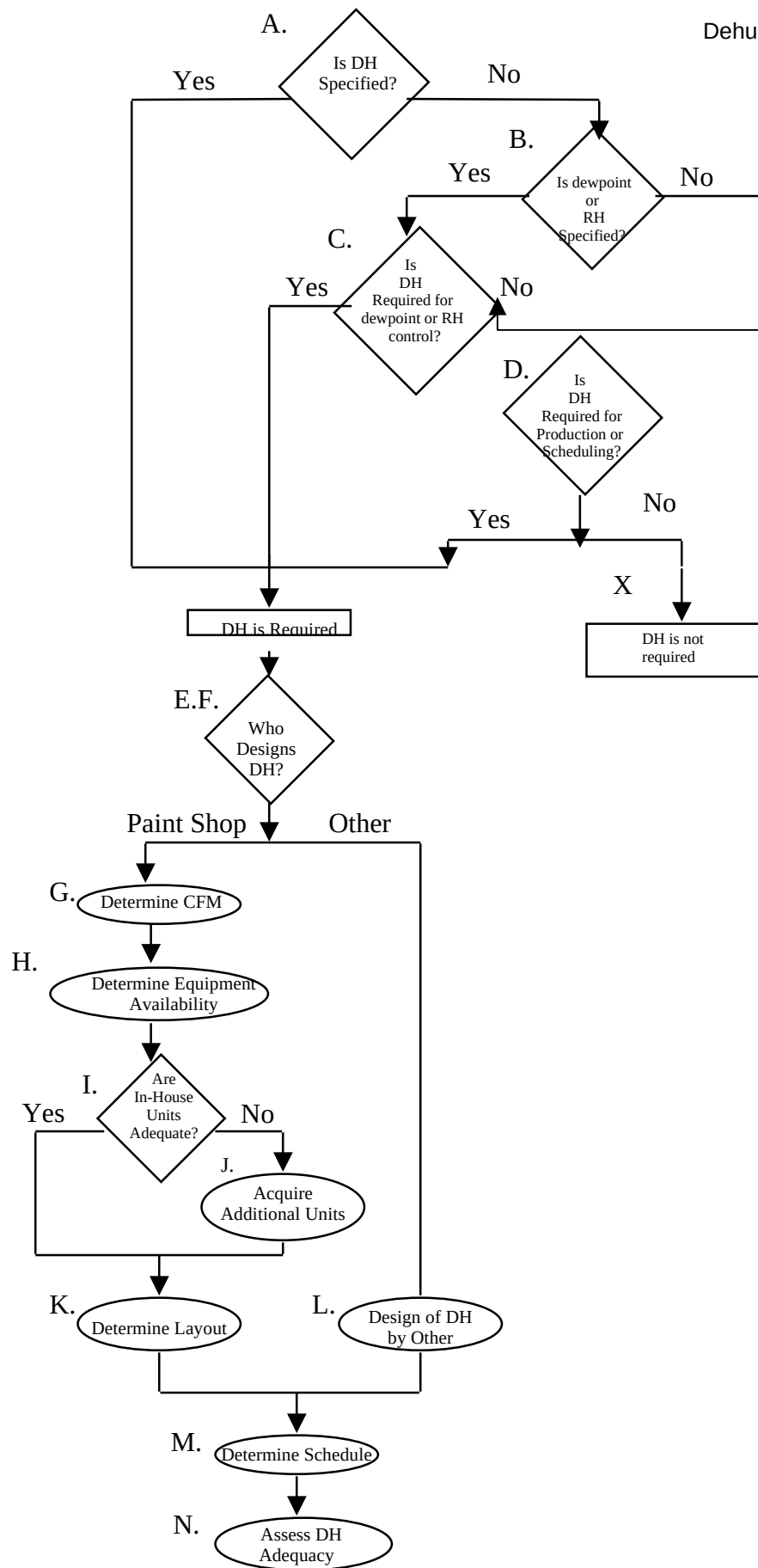


Fig.5-6: DH Selection Flow Chart

Step A: Determine if DH is specified

Review the project specification to determine if dehumidification is specifically required; if yes go to step E, if no go to step B. DH may still be needed to maintain dewpoint or to improve productivity.

Step B: Is relative humidity or dewpoint specified?**1. Tank Cleaning and Painting Procedure**

Review shipyard tank procedure to determine if there is any requirement for relative humidity or dewpoint (e.g., maximum relative humidity or surface temperature of 5°F or 10°F [3°C or 6°C] above dewpoint.)

2. Coating Manufacturer's Data Sheet

Also review the coating manufacturer's technical data sheet for any dewpoint or humidity requirements (be sure you have the latest edition). For the majority of ship coatings, the manufacturer specifies that the surface temperature be at least 5°F (3°C) above the dewpoint.

If dewpoint or RH is specified, record these requirements, along with requirements for maximum and minimum temperature in Table 5-6 and proceed to step C. If no requirements, go to step D.

Table 5-6
Written Requirements for Dewpoint, RH or Temperatures*

Item Specified	Tank Procedure (Minimum)	Tank Procedure (Maximum)	Product Data Sheet (Maximum)	Product Data Sheet (Maximum)
Dewpoint Spread		----- --		-----
Relative Humidity				
Surface Temperature				
Air Temperature				

* Separate chart for each different generic coating.

Step C: Determine likelihood of achieving 5°F (3°C) dewpoint criterion without DH.

The goal of this step is to review ambient conditions to determine if they are likely to exceed dewpoint and relative humidity requirements for blasting and painting (i.e., Is the surface temperature 5°F [3°C] above the dewpoint?)

First estimate typical and worst case ambient conditions for the tank to be painted. Consider 2 situations: A tank on a ship in the water and a tank on a ship in the drydock.

1. Tank on ship in water:
 - Surface temperature: Assume it is same as water temperature (e.g., 55 to 65°F (12° to 18°C)).
 - Air temperature:
 - * Select typical low, medium and high temperatures for the time period of the project (e.g., 50°F , 65°F and 85°F [10°C, 18°C and 29°C]).
 - * Select worst case high and low temperature (e.g., 45°F and 95°F [7°C and 35°C]).
 - Relative humidity: Estimate the typical RH (e.g., 60%) and a high RH (e.g., 90-95%).
2. Tank on ship in drydock
 - Surface temperature: Assume it is approximately the same as air temperature.
 - Air temperature: Same as for ship in water.
 - Relative humidity : Same as for ship in water.

Enter these approximate conditions in the table as shown below.

Determine the dewpoint from a psychrometric chart (see Section 5.6.2) and compute the difference between surface temperature and dewpoint as shown in the last column.

Table 5-7
Estimating Compliance With 5°F (3°C) Criterion for Dewpoint

Condition	Surface Temp.		Air Temp.		Relative Humidity	Dewpoint		Surface Temp. Dewpoint	
	F	(C)	F	(C)		F	(C)	F	(C)
SHIP IN WATER									
Typical (low T)	45°	(7°)	50°	(10°)	60%	43°	(6°)	2°	(1°)
Typical (medium T)	50°	(10°)	65°	(16°)	60%	57°	(14°)	-7°	(-4°)
Typical (high T)	55°	(13°)	85°	(29°)	60%	73°	(23°)	-18°	(-10°)
Worst Case (low T)	45°	(7°)	45°	(7°)	95%	44°	(7°)	1°	(1°)
Worst Case (high T)	55°	(13°)	95°	(35°)	90%	93°	(34°)	-38°	(-21°)
SHIP IN DRYDOCK									
Typical (low T)	50°	(10°)	50°	(10°)	60%	43°	(6°)	7°	(4°)
Typical (medium T)	65°	(18°)	65°	(18°)	60%	57°	(14°)	8°	(4°)
Typical (high T)	80°	(27°)	85°	(29°)	60%	73°	(23°)	7°	(4°)
Worst Case (low T)	45°	(7°)	45°	(7°)	95%	44°	(7°)	1°	(1°)
Worst Case (high T)	90°	(32°)	95°	(35°)	90%	93°	(34°)	-3°	(-2°)

For this example the ship in the water will always fail the 5°F (3°C) criterion. Therefore DH is definitely required.

For the ship in drydock, during the typical condition (e.g., at RH of 60%) the surface temperature exceeds the dewpoint by at least 5°F (3°C)(but less than

10°F [6°C]). However, under worst case conditions, the dewpoint criterion will not be met.

This situation requires additional analysis to determine the frequency of various combinations of surface and air temperatures and humidity. A conservative approach would be to use DH to eliminate the possibility of condensation on the surface and to increase the window for working.

If it is determined that DH is required to achieve the dewpoint spread, go to step E. If not, go to step D.

Step D: Is DH required based on productivity or scheduling factors?

Note: This step is intended for individuals with responsibility and authority for planning and implementing productivity.

1. Estimate reduction in down time from using dehumidification.
Based on previous analysis, estimate the number or percent of days or part days that surface preparation or coating application will be halted due to unexpected weather conditions.

Note: The above will pertain primarily to operations requiring surface temperature of 5°F (3°C) above dewpoint.

2. Determine the impact on scheduling.
Estimate the added cost of using dehumidification by comparing this project to other jobs.
3. Estimate improvements in worker efficiency from dehumidification.
This cannot readily be determined quantitatively. One approach is to compare production rates of jobs with and without dehumidification.
4. Based on above, determine if dehumidification is to be utilized during surface preparation or coating application.
If yes, go to step E; if not, no DH is required.

Step E: Who normally designs the dehumidification system?

The possibilities are:

- paint department
- other department at shipyard
- in house contractor
- vendor or consultant

If DH is normally designed by the paint department go to step F. If it is to be designed by another department, contractor, vendor or consultant, go to step L.

Step F: Determine the complexity of DH design required.

- Does the tank design allow for DH? If yes, go to Step G; if no, go to Step L.
- Is this a standard tank (e.g., one with no special features or restrictions requiring special design)? If yes, go to step G; if no, go to step L.

Step G: Determine air flow capacity needed (CFM).

The CFM is determined from the volume of the tank and number of air changes per hour.

- Determine the number of air changes per hour.

Note: Use four air changes per hour unless there is other information provided or the shipyard practice is otherwise.

- Compute CFM as follows

$$\text{CFM} = \text{Volume of tank} \times \text{number of air changes per hr} / 60 \text{ minutes per hr.}$$
(e.g., For a tank of 30,000 ft³, CFM = 30,000 X 4/60 = 2,000 CFM)
[m³/min = 850 m³ x 4/60 = 57 m³/min]
Go to Step H.

Step H: Determine availability of equipment.

- Identify dehumidification units available to shipyards.
- For each unit list the following (Table 5-8)
 - * description: model number and manufacturer
 - * capacity in CFM
 - * power requirements
 - * moisture removal capabilities (e.g., in lbs per hr [kg/hr])
 - * space needed (footprint)

Table 5-8
Data on DH Units Available

Description/type /Mfcr.	CFM/Size	Power Req'ts.	Moisture Removal Capacity	Footprint

Go to Step I.

Step I: Determine if existing units are adequate.

1. Compare the following DH requirements with the data on the dehumidification units identified in Step H.

- Compare CFM requirements (from Step G) with CFM available (Table 5-8).
 - Determine if treated air is suitable for the work environment (e.g., is additional heating or cooling for the workplace required?).
 - Determine adequacy of space for placement of DH unit.
 - Verify adequacy of power sources for DH units tentatively selected (Table 5-9).
 - Determine if DH unit selected meets tank needs for moisture removal. (See Section 5.6.2.)
 - Identify additional DH requirements.
 - Determine need for modifications (e.g. either pre-coolers, heaters or other equipment for the DH system).
2. If DH units and supplementary equipment are adequate, go to Step K; if not go to Step J.

Table 5-9
Checklist for Adequacy of Current DH Units

Factor	Requirements	Available	Adequate?
CFM			
Power			
Moisture Removal			
Space			
Condition of DH	Good working condition		

Step J: Determine additional DH or other equipment needed.

- Identify capacity (CFM and moisture removal rates) of additional DH units needed.
 - Determine if units are to be purchased or rented and the source.
 - Identify additional supplementary equipment needed (e.g., aftercoolers, driers, power supply) and source.
 - Add items to equipment list of project.
- Go to Step K.

Step K: Determine the layout of the DH system.

1. Determine where the DH unit is to be placed.
2. Determine how the tank is to be sealed.
3. Determine locations and dimensions of inlets and outlets of tanks.
4. Determine size, type, and length of ducting for inlet and outlet. Select a typical diameter (e.g., 10 inches to 20 inches [250 to 500 mm]).

Note: These are specific to the type of tank and the shipyard practices and will not be discussed in detail.
Go to Step M.

Step L: Design of DH system outside the paint shop.

1. Identify the party to design the DH system (e.g., another department or function within shipyard, in-house contractor, vendor, consultant).
2. Identify paint shop person responsible for working with outside designer.
3. Define requirements for DH (e.g., for RH or dewpoint).
4. Prepare contracts or authorizing documents for submission.
5. Review designs to ensure they meet specifications and are compatible with tank and other shipyard factors.

Note: the design should include the items in Steps G, H, I, J, and K.
Go to Step M.

Step M: Determine schedule for operating DH unit.

Based on the tank procedure, prepare a schedule for the starting and stopping times for DH including levels of DH to be applied if appropriate.

Note: The specific operating parameters are particular to the DH unit and are available from the manufacturer. A copy of these instructions should be kept with the DH unit along with a summary of the key operating parameters.
Go to Step N.

Step N: Procedure for assessing operation.

Three means are identified to determine if the level of DH is adequate.

1. Verify that unit is operating correctly.
The manufacturer should provide guidance to assure proper air flow and moisture removal. For example, it is possible to measure actual dewpoint of processed air prior to putting into tank.
2. Measure dewpoint and surface temperatures inside the tank.
To ensure conformance with the coatings specification, it is advisable to periodically measure dewpoint and surface temperature inside the tank. Use a sling or battery operated psychrometer as described in section 5.1.4.1. Readings should be taken at several locations including near the inlets, near the outlets, at the approximate center of each tank and in each separate bay or section. Readings should be taken at least twice a day (e.g., in morning and midday). Surface temperature should be recorded at the surface least exposed to sunlight (i.e., the coldest) and where dewpoint non-conformances are most likely to occur. Table 5-10 is derived from a form used by the US Navy.

Table 5-10
US Navy Ballast Tank QA Inspection Form – Environmental Readings

Date	Time	Measurement Location and Activity (Abrasive blasting,	Lowest Surface Temp.	Wet Bulb (°F) (°C)	Dry Bulb (°F) (°C)	% Rel. Hum.	Dewpoint (°F) (°C)
------	------	---	----------------------------	-----------------------	-----------------------	----------------	--------------------------

		applying prime strip, top, T/U coat, etc.)	(°F) (°C)				

3. Measure air flows inside tanks or ducts.

Air flow is necessary to ensure that dust and solvents evaporating from the coatings are removed. Proper air flow helps assure proper curing and also prevents buildup of solvent to the lower explosive level (LEL) (see Unit 6.3.1). Air flow can be measured by use of anemometers (in interior of tank) or pitot tubes (for ducts) (see Unit 6). Air flow should be compared with design of air flow or with air flows determined from previous projects which were successfully completed. Air flows are most difficult to achieve inside dead spaces or behind stiffeners or narrow sections in the ballast tanks. Air flow should be measured at several locations including those where air is entering and exhausting from the tank and at various locations in the tank.

5.5.3 Additional Comments

- From Shipyard

One shipyard's approach to ensure proper coating cure using DH is as follows: Determine the size of the tank/space, consider the shape/configuration, and set up supply tubing to obtain the "best uniform cure time". Tank/space configuration is of major importance, because a 2000-2500 CFM (57-71 m³/min) DH may only properly cure the coatings in the first and second bay of a 10 bay tank if not set up to force the air from the deepest part of the tank/space out. Generally, the supply needs to reach all areas to prevent the inconsistent cure problem. In addition, solvent entrapment can be a concern.

A shipyard paint specialist has noted a problem with the procedure for calculating the amount of DH based on the size or other features of the tank or space. It is rarely explained that baffled or remote portions of the same tank should be considered as separate tanks for the purposes of DH, air change, and ventilation. Areas of any tank that are allowed to cure too slowly may adversely affect the other areas that are curing on time. Solvent evaporation from below could affect or be absorbed by previously applied coating. The job at hand is to balance cure while staying below the lower explosive limit (LEL), and maintaining surface temperature above dewpoint to prevent condensation.

- From Proposed SSPC/NACE Technology Update

"Dehumidification and Temperature Control During Surface Preparation, Application, and Curing for Coatings/Linings of Steel Tanks, Vessels, and Other Enclosed Spaces"

The appropriate air-change rate for maintaining a prepared surface during blasting and between shifts while maintaining a large differential between dewpoint and surface temperature for an extended period of time is dependent on air-space volume, equipment, geographical location, climate, and season. The number of openings in the enclosure, the air tightness of the structure, the distance of equipment from the space, and the amount of air to be extracted or exhausted by means other than DH equipment also influence the DH capacity. Relatively airtight enclosures generally require less DH volume because little or no additional air or moisture is introduced into the space. Relatively large spaces usually require fewer air exchanges. Equipment contractors usually have guides that give volume data for their equipment.

5.6 Examples: Procedures for DH Requirements and Parameters

Note: A metric psychrometric chart was not available to provide metric equivalent to the examples for this section.

5.6.1 Using a Psychrometric Chart

The chart includes the following scales:

- Dry bulb temperature (the ambient air temperature)
- Wet bulb temperature (as measured with psychrometer). The wet bulb temperature is lower than dry bulb temperature because it is affected by the cooling effect of the evaporation of the water from the bulb.
- Relative humidity
- Humidity ratio (grains of moisture per pound of dry air). This is a measure of the absolute moisture content of the air.
- Dewpoint (saturation temperature)
- Vapor pressure (exerted by water vapor)
- Enthalpy (BTU per pound of dry air). This parameter will not be discussed in this handbook.
- Volume per mass (cubic ft per pound) of dry air. This parameter will not be discussed in this handbook.
- Sensible heat factor: The ratio of sensible heat (i.e., heat that results in change in temperature of a substance) to total heat load. This parameter will not be discussed.

The chart consists of a series of intersecting lines and curves on a two-dimensional plane (see schematic in Figure 5-7). Each point on the plane represents a unique set of the above properties. This point can be determined and plotted on the chart using two of the above parameters.

For example, from the dry bulb and wet bulb temperatures, one can determine the relative humidity ratio or dewpoint. Or from the dry bulb temperature and dewpoint one can determine the wet bulb temperature, relative humidity and humidity ratio.

Typical uses of psychrometric chart are as follows:

Table 5-11
Typical Uses of Psychrometric Chart

Parameter 1 *	Parameter 2 *	Parameter Derived	Usage of Data
Dry bulb T	Wet bulb T	Dewpoint temperature	Determine if surf. temp. is 5°F (3°C) above dewpoint
Dry bulb T	Wet bulb T	Relative humidity	Determine if RH conforms to spec.
Dry bulb T	RH	Humidity ratio	Determine moisture load for DH

* Measured or known

Example 1A: Determine dewpoint from wet and dry bulb temperature.

- Locate dry bulb temperature scales: these are vertical lines with readings at bottom of chart (Fig 5-8)
 - Locate wet bulb temperature scale lines: these are diagonal lines running from upper left to lower right with readings above the lines (Fig 5-8)
 - Locate the intersection of these two lines (Fig 5-8)
 - The dewpoint scale lines are horizontal lines which intersect this point. The number is read where this horizontal line intersects the curved line at the left of the chart. It is normally necessary to interpolate.
- * exercise: dry bulb = 80°F, wet bulb = 72°F , dewpoint = ?
(see below for answer)

Example 1B: Determine relative humidity from wet and dry bulb temperature.

- Locate the intersection of the dry and wet bulb lines as above.
 - The relative humidity scale lines are curved lines (from lower left to upper right) which intersect this point. The RH number is read to the left of the line. It is normally necessary to interpolate.
- * Exercise: dry bulb = 75°F, wet bulb = 70°F , relative humidity = ?
(see below for answer)

Example 1C: Determine humidity ratio from dry bulb temperature and relative humidity.

- Locate dry bulb temperature scales (vertical lines with readings at bottom of chart).
- Locate relative humidity scale line (curved lines from lower left to upper right; the RH number is read to the left of the line).
- Locate the intersection of these two curves.
- The humidity ratio scale lines are horizontal lines with the scale on the right side of the chart.

Note: horizontal lines are used for both dewpoint and humidity ratio.

- * Exercise: dry bulb= 85°F, RH = 60%, humidity ratio = ?
(see below for answer)

Answers to Exercises: 1B: 78%; 1C: 109 grains/pound; 1A: 68°F

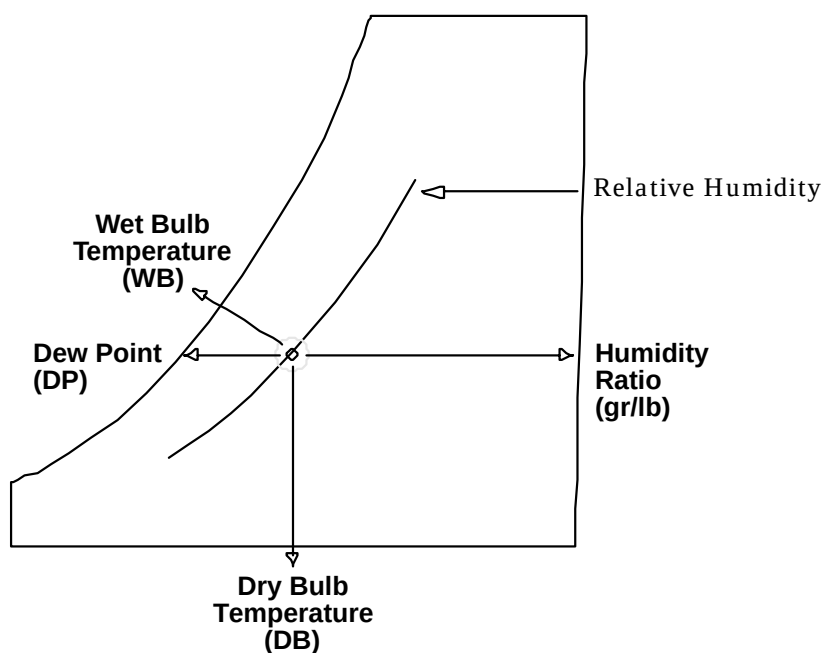


Figure 5-7: Dry Bulb and Wet Bulb Temperature
(Courtesy of Munters Moisture Control Services)

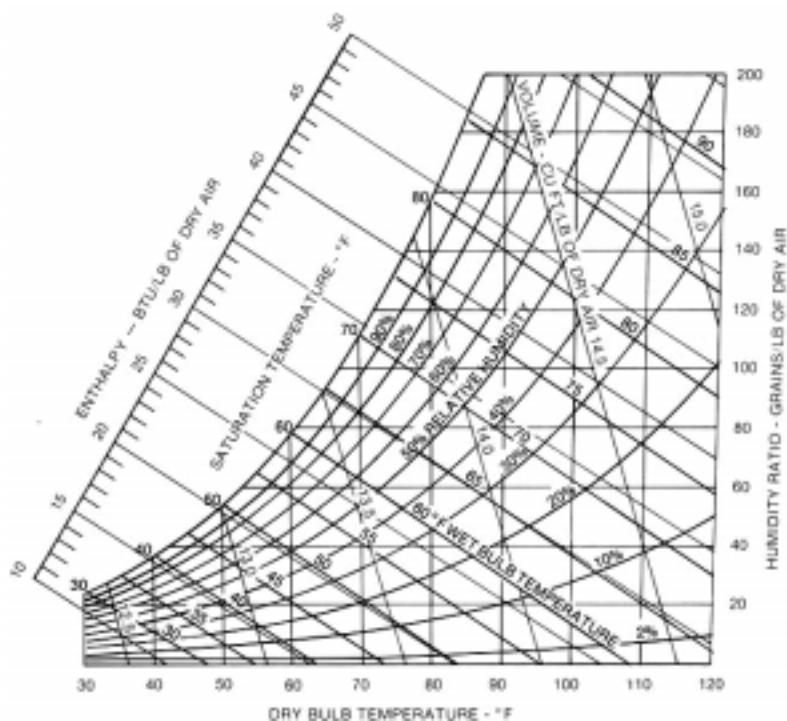


Figure 5-8: Simplified Psychrometric Chart
(Courtesy of Munters Moisture Control Services)

5.6.2 *Computing Moisture Loads and Removal Rate*

This Section shows how to estimate the moisture load (amount of moisture to be removed per hour) for dehumidifying a tank.

5.6.2.1 *Data needed*

- Input (ambient) air temp and relative humidity (from psychrometric chart)
- Required air temperature and moisture content (from specification or project document)
- Volume of air needed
 - * air changes per hour or
 - * rating of DH unit in CFM
- Size of tank

5.6.2.2. *Procedure*

The procedure includes 3 steps.

Step A – Determine quantity of moisture to remove

Step B – Determine volume of air flow (CFM)

Step C – Determine moisture removal rate required

Step A – Determine quantity of moisture to remove

- From psychrometric chart, determine moisture content of input (ambient) air and output air.
- Subtract output from input moisture content to get moisture to be removed.

Step B – Determine volume of air flow (CFM)

- If CFM is predetermined, use that number
- Alternate Procedure: multiply volume of tank by air changes per hr

Step C – Determine moisture removal rate required

- Multiply grains per ft³ (from Step A) by CFM (from Step B) to get grains per minute
- Multiply by 60 min/hr and divide by 7000 grains/ lb to get lbs of water per hour

5.6.2.3 *Example: Moisture removal rate*

- Input data
 - * Ambient air temperature: assume 85°F (30°C)
 - * Ambient relative humidity: assume 80%

Note: These are close to “worst case” conditions

- * Required air temperature: assume 70°F (21°C)
- * Required relative humidity: assume 50%
- * Air requirements: 4 changes per hour
- * Volume of tank: 30,000 ft³ (850 m³)

Step A – Determine moisture content of input and output air from psychrometric chart. The moisture contents are:

- Incoming air: 145 grains of water per pound of air or GPP (20.7 grams of water per kg of air)
- Outgoing air (air required in tank): 54 GPP (7.7 g water/kg air)
- Moisture to be removed is $145 - 54 = 91$ GPP ($20.7 - 7.7 = 13.0$ g water/kg air)
 divide by 14.2 ft³ of air per pound of air ($0.886 \text{ m}^3/\text{kg}$) to yield: $91/14.2 = 6.41$ grains/ ft³
 $(13.0/0.886 = 14.7 \text{ g/m}^3)$

Step B – Determine volume of air flow (CFM)

- $30,000 \text{ ft}^3 \times 4 \text{ changes per hr} / 60 \text{ min/hr} = 2000 \text{ CFM}$
 $(850 \text{ m}^3 \times 4/60 = 56.6 \text{ m}^3/\text{minute})$

Step C – Determine moisture removal rate

- $6.41 \text{ grains/ft}^3 \times 2000 \text{ CFM} = 12,800 \text{ grains per minute}$
 $(14.7 \text{ g/m}^3 \times 56.6 \text{ m}^3/\text{min.} = 830 \text{ g/minute})$
- $12,800 \text{ grains per minute} \times 60 \text{ min/hr} \text{ divided by } 7000 \text{ grains/lb} (49.8 \text{ kg/hr}) = 109.7 \text{ lbs per hr. Round to } 110 \text{ lb/hr} (150 \text{ kg/hr}).$

Note: These sections do not account for moisture loads from abrasive blasting or for equipment for pre-conditioning (drying or cooling) the input air from the DH unit.

5.6.3 *Determining moisture content and temperature of air from dehumidifier*

This section shows how to estimate the moisture content and temperature of the air exiting a specified dehumidification unit.

5.6.3.1 *Input Data Needed*

- Temperature of incoming (ambient) air
 - Moisture content of incoming air: assume 80 grains per lb (11.4 g/kg)
- Note: This can be read from a psychrometric chart if the wet bulb temperature is known.
- Face velocity of air exiting the DH unit

5.6.3.2 *Procedure for determining moisture content and temperature of exiting air*

The procedure includes six steps; steps A, B, and C are for moisture content and steps D, E, F are for temperature.

Step A – Using Figure 5-10, locate the point on the X axis (horizontal axis) representing the entering moisture content.

Step B – Find the curve most closely representing the entering air temperature (interpolate if necessary).

Step C – Locate the Y value for this intersection. This number will be the exiting air moisture content.

Step D – Using Figure 5-10, locate the point on the X axis representing the entering moisture content.

Step E – Find the curve most closely representing the entering air temperature (interpolate if necessary).

Step F – Locate the Y value for this intersection. This number will be the exiting air temperature.

5.6.3.3 *Example: Moisture content and temperature of exiting air.*

- Input data
 - * Temperature of incoming air: Assume 75°F (24°C) dry bulb temperature
 - * Moisture content of incoming air : Assume 80 grains per lb (11.4 g/kg).
Note: This condition corresponds to a wet bulb temperature of about 67.5°F (19.7°C) and relative humidity of 61%
 - * Face velocity: Assume 400 FPM (122 m/min)

Step A – Go to point 80 on X axis of Figure 5-9

Step B – Move up vertically to intersect 75°F curve

Step C – Move left horizontally to read approximately 27 grains per pound (338 g/kg)

Step D – Go to point 80 on X axis of Figure 5-10

Step E – Move up vertically to intersect 75°F curve

Step F – Move left horizontally to read approximately 128°F

5.6.3.4 *Notes*

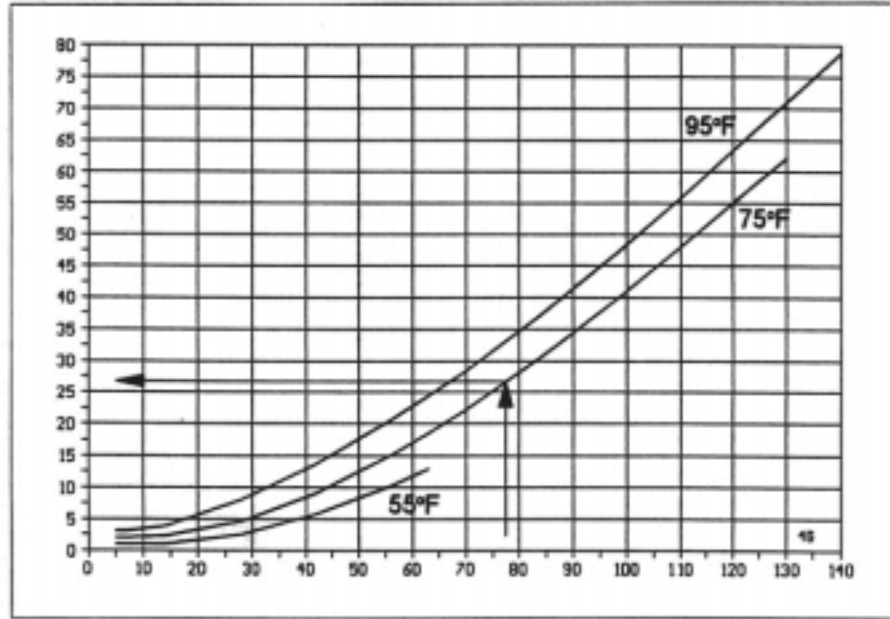
Process air leaving temperatures as shown are maximum values at standard full rated heater output. The actual process air leaving temperature will be lower whenever the heater output is below full rated output. This condition will occur during heater modulation cycles due to part loading of the dehumidifier.

A series of charts from Munters provide similar data with a few variations. The Munters charts show the data for different face velocities whereas ATS uses separate charts for different face velocities. The Munters charts also include the reactivation temperatures as a variable whereas the ATS charts assumed a constant (highest) reactivity temperature. Using the highest temperature

range of 250-300°F (121-149°C), the results are essentially equivalent for 400 FPM (122 m/min) face velocity.

The Munters chart also provides instructions to determine if the DH unit's size is adequate based on the maximum reactivation air capacity required.

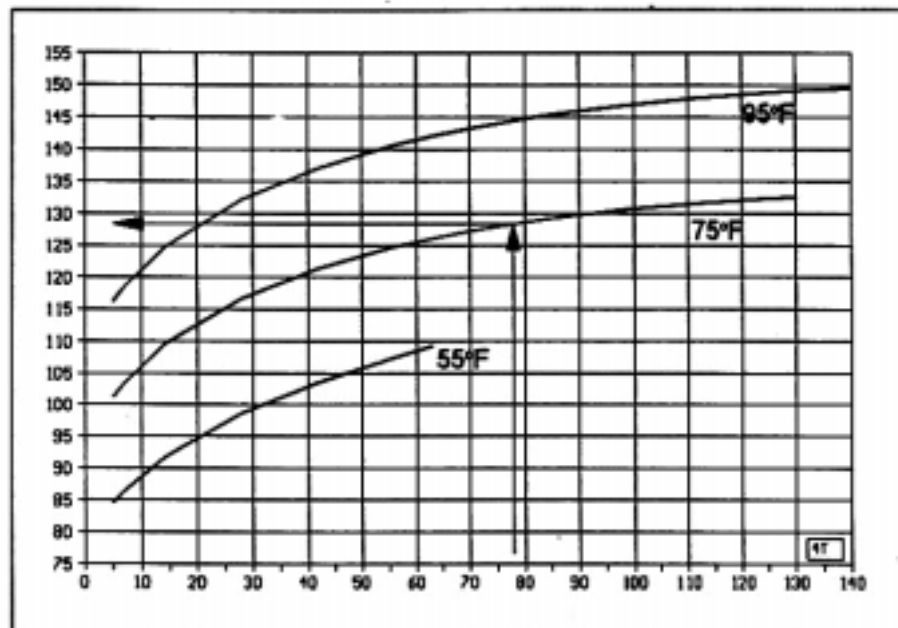
Leaving Process Air Moisture, GPP



Process Entering Moisture: GPP

Figure: 5-9: Moisture Removal Capacity 400 FPM (122 m/min) Process Air Velocity
(Courtesy of ATS)

Leaving Process Air Temperature F



Process Entering Moisture: GPP

Figure 5-10: Process Leaving Air Temperature 400 FPM (122 m/min) Process Air Velocity
(Courtesy of ATS)

UNIT 6 VENTILATION

6.1 Introduction

There are three primary purposes for ventilating tanks and enclosed areas during cleaning and coating operations:

- Operator health and safety
- Operator visibility
- Curing of coating

These purposes are accomplished by removal of contaminated air from the space and replacement of fresh air to the space. Where dehumidification or dust collection is indicated, ventilation is the basic component of a total air treatment system.

This Unit presents general guidelines for determining ventilation requirements during blast cleaning and coating application and curing. The Unit also discusses the design of the air-handling system to meet specific ventilation objectives. Additional detailed design information is contained in *Industrial Ventilation — A Manual of Recommended Practice*.

6.2 Ventilation During Blast Cleaning

The amount of ventilation (or the number of complete exchanges of incoming and outgoing air) required during blast cleaning depends primarily on the size (volume) of the tank. Other important factors are the number of blast operators, the amount of corrosion on the tank's surface, and the dusting or breakdown characteristics of abrasive and surface material being removed.

Ventilation is measured in terms of the volume of air movement over time, expressed as cubic feet per minute (CFM [m^3/min]). The more complete air changes there are, the better the visibility and the cleaner the air in the tank will be. There are no set rules for air changes required.

Some yards, however, have used a criterion of one (1) complete air change every three minutes during the blast cleaning operation in closed tanks. For example, a centerline or "jumbo" tank with a 100,000 cubic foot (2800 m^3) capacity would require approximately 33,000 CFM of ventilation ($100,000 \text{ ft}^3 \times 1/3 \text{ air changes per minute} = 33,000 \text{ ft}^3/\text{min}$ [CFM or $930 \text{ m}^3/\text{min}$]).

Ventilation requirements for one shipyard are as follows:

- Spaces 2000 ft^3 (57 m^3) and less shall have an air change every one (1) minute.
- Spaces from 2000 ft^3 to $30,000 \text{ ft}^3$ (57 to 850 m^3) shall have an air change every three (3) minutes.

- Spaces from 30,000 ft³ to 100,000 ft³ (850 to 2800 m³) shall have an air change every five (5) minutes.
- Spaces over 100,000 ft³ (2800 m³) shall have an air change every ten (10) minutes.

Any one of the listed variables can significantly affect conditions inside the tank. For example, the amount of dust being generated may increase due to an excessively corroded tank surface or high abrasive breakdown. In this case, the supervisor can compensate for these conditions by changing one or more of the other variables. He may choose to decrease the number of blast operators, stop blasting and mechanically descale the tank to improve surface conditions or increase the amount of ventilation in the tank.

Unlike ventilation for paint or welding fumes, dry airborne dust created by abrasive blasting consists of relatively large particles. As the particles can be seen, it is easy to monitor the success of the ventilation system in removing dust.

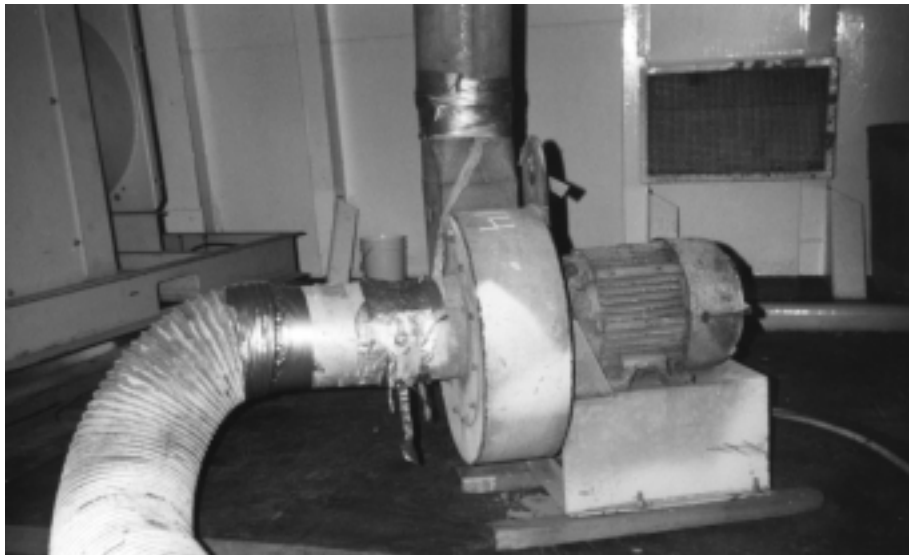


Figure 6-1: Blower and Hose in tank
(Courtesy of Todd Shipyard)

The balancing of incoming and outgoing air is an important aspect of a ventilating system. If a high volume of clean air is blown into the tank while a lower volume of dirty air is being extracted, the result is air turbulence. The dirty air will subsequently be blown out any crack or opening in the tank. Similarly, the extraction of too much air relative to treated incoming air will result in improper dehumidification for condensation control. Air circulation balance is achieved when the total amount of incoming air, treated or untreated, equals the total amount of air being exhausted. Conditions within the tank (i.e., visibility, temperature or humidity) are thus maintained within a predictable, controlled range of efficiency and in accordance with safety requirements.



Figure 6-2: Ventilation Duct into Tank
(Courtesy of Todd Shipyard)

6.3 Ventilation During Application and Curing

During painting operations in confined spaces, the air in these areas becomes laden with paint overspray and solvent vapor. The health and safety hazards presented by these conditions dictate that ventilation requirements be carefully calculated and subsequently monitored throughout the painting operation. To better understand the calculation of ventilation requirements, the following definitions are necessary: Threshold Limit, Lower Explosive Limit, and Vapor Volume.

6.3.1. Definitions

Threshold Limit (TL): TL is the maximum level of airborne toxic materials which workers may be exposed to safely. TL's are used as guides in the control of health hazards. TL is expressed as percent of the gas or vapor in air by volume. TL represents a time weighted average concentration. Nearly all workers may be exposed 8 hours per day over extended periods of time to those levels without adverse effects.

Lower Explosive Limit (LEL): LEL is the lower limit of flammability or explosiveness of a gas or vapor at ordinary ambient temperature. Below this concentration limit, the vapor from a solvent will not be flammable or explosive.

Vapor Volume (V_s): V_s is the volume of vapor in cubic feet per gallon (cubic meters per liter) of solvent at 70°F (21 C). It tends to be highest for highly volatile solvents such as acetone and ethyl alcohol.

The ventilation rates must be sufficient to dilute solvent vapor to 10 percent or less of the lower explosive limit of the specific solvent being sprayed. For example, for toluene, the LEL is 1.4% (i.e. lower explosive limit is reached when the volume of toluene is 1.4% of the air volume). To achieve the 10% design factor, the volume percent of toluene could not exceed 0.14% (10% of 1.4%).

In addition to safety factors, paint overspray can accumulate in enclosed tanks and reduce worker visibility with a dense particle fog. As in blasting, a relatively large rate of ventilation is necessary to maintain visibility and insure production efficiency.

6.3.2 Computing Ventilation Rate

Most paints used in marine applications contain solvents which rapidly evaporate during spraying. As stated above, sufficient air must be extracted from the tank during painting to limit the concentration of the flammable solvents to no more than 10% of their lower explosive limit (LEL). The following procedure can be used to calculate ventilation volumes for specific solvents. Toluene is selected as the representative solvent.

Recall that a typical ventilation objective for abrasive blasting is approximately one air-change every three minutes. This volume of air will, in most cases, maintain solvent vapor concentrations below the required percentage of the lower explosive limit. It will also maintain good visibility. The same ventilation system can, in most cases, be utilized for both blasting and painting operations. It must also be remembered that ventilation requirements extend through the paint curing process.

The next two sections contain information on how to calculate LEL and TL. Table 6-1 contains current information on the LEL and TL for some common

solvents. As these limits are subject to change, the latest Federal regulation should be used to calculate actual requirements.

Table 6-1
Properties of Common Solvents*

Solvent	a Vapor Volume (V_s) ft³/gallon (m³/liter)	b Lower Explosive Level (LEL) Percent by volume of air	c Threshold Limit (TL) Percent by volume of air at
Acetone	44.0 (0.329)	2.6	0.1
Butyl Acetate (n)	24.8 (0.186)	1.7	0.015
Butyl Alcohol (n)	35.2 (0.263)	1.4	0.01
Butyl Cellosolve	24.8 (0.186)	1.1	-
Cellosolve	33.6 (0.251)	1.8	-
Cellosolve Acetate	23.2 (0.174)	1.7	-
Ethyl Acetate	32.8 (0.245)	2.5	0.04
Ethyl Alcohol	55.2 (0.413)	4.3	0.1
Methyl Acetate	40.0 (0.299)	3.1	0.02
Methyl Cellosolve	40.8 (0.305)	2.5	-
Methyl Ethyl Ketone	36.0 (0.269)	1.8	0.02
Methyl n-Propyl Ketone	30.4 (0.227)	1.5	0.02
Naphtha (VM&P) (76 F [25 C] Naphtha)	22.4 (0.168)	0.9	0.01
Naphtha (100 F [38 C] flash) Safety Solvent-Stoddard Solvent	23.2 (0.174)	1.1	0.01
Propyl Acetate (n)	27.2 (0.203)	2.0	0.02
Toluene	30.4 (0.227)	1.4	0.02
Turpentine	20.8 (0.156)	0.8	0.01
Xylene (o)	26.4 (0.197)	1.0	0.01

* at 70 F (21 C)

Step One - Calculate Dilution Volume

The minimum amount of air required (dilution volume per gallon of solvent, in cubic feet) is obtained from the following equation, where v_s is the vapor volume in cubic feet of vapor per gallon of solvent (metric equivalents are given in parenthesis):

$$\text{Dilution Volume (ft}^3\text{)} = \frac{4 (100 - \text{LEL}) v_s}{\text{LEL}}$$

From Table 6-2 the LEL for toluene is 1.4% and the v_s is 30.4 ft³/gal (0.227 m³/L). The dilution volume required per gallon of toluene solvent is calculated as follows:

$$\begin{aligned}\text{Dilution Volume} &= \frac{4 \times (100/1.4) \times 30.4}{1.4} \\ &= 8,560 \text{ ft}^3 \text{ of air per gallon of toluene (64.0 m}^3\text{/L of air per}\end{aligned}$$

Step Two - Calculate Ventilation Rate

The required ventilation rate, in CFM, is found by multiplying the dilution volume per gallon of solvent by the number of gallons of solvent evaporated per minute.

Ventilation Rate (CFM) =

$$\frac{\text{Dilution Volume(ft}^3\text{)}}{\text{gal. of solvent}} \times \frac{\text{gal. of solv. evap.}}{\text{min.}}$$

In our example, several workers are painting in an enclosed tank. They are applying toluene thinned paint at a combined rate of one gallon per minute (gpm). The paint is 40% solvent by volume. The ventilation rate is calculated as follows:

Ventilation Rate =

$$\frac{8560 \text{ ft}^3}{\text{gal of solv.}} \times 1 \text{ gpm} \times \frac{0.4 \text{ gal solvent}}{1 \text{ gal paint}} \quad (64 \text{ m}^3/\text{L} \times 3.785 \text{ L} \times 0.4)$$

Ventilation Rate (for toluene) = 3430 CFM (97m³/min)

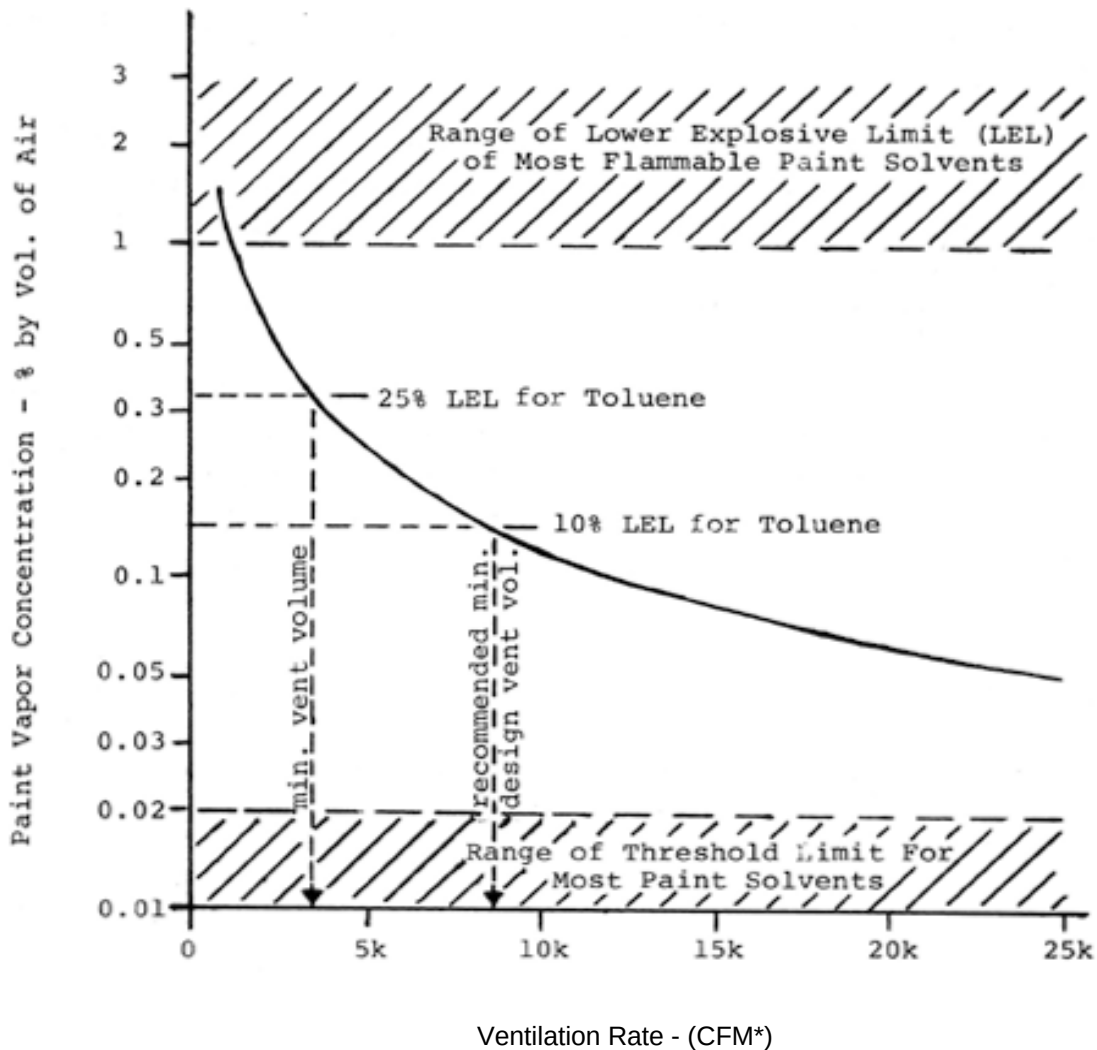
This ventilation volume is the minimum amount required to prevent the hazardous accumulation of flammable paint vapor (i.e., no more than 10% of the LEL).

For most commonly used solvents, this rate ranges from 3,000 - 15,000 CFM (85 - 425 m³/min). It depends on the size of the tank, the number of applicators, the solvent content of the paint and the particular solvent.

The most important factors to remember in determining the minimum ventilation volume to prevent explosions are:

- the rate at which the paint is being applied (gallons [liters] per minute),
- the amount of flammable solvent in the paint.

Tank size is not the controlling parameter. However, in larger tanks a greater amount of paint vapor would probably be generated due to the increased number of workers. Painting with water-borne paint requires almost no dilution volume to prevent explosion since these paints contain only 1% to 2% flammable solvents. Figure 6-3 shows graphically the resultant paint vapor concentration for various ventilation volumes. It is based on a paint application rate of 1 gpm (3.79L/min) and a solvent evaporation rate of 0.4 gpm (1.5L/min) and a solvent vapor volume of 30.4 ft³/gallon (0.227 m³/L)



* 1 CFM = 0.028 m³/min

Figure 6-3: Paint Vapor Concentration Versus Ventilation Rate

6.3.3 *Threshold Limit*

Limiting the flammable paint vapor concentration to 10% of the LEL is sufficient to prevent an explosion hazard. However, this concentration is normally too high for workers to breathe. Additional ventilation must be provided to reduce the paint solvent vapor concentration below the maximum levels allowed for workers on a routine basis. This concentration, the threshold limit (TL), varies with the individual solvents used. A listing of the values for various solvents is contained in Table 6-2. The dilution volume per gallon of solvent required to maintain a concentration below the threshold limit is given by:

$$\text{Dilution Volume} = \frac{(100 - \text{TL})}{\text{TL}} V_s$$

Where TL is expressed in percent by volume of air and V_s is cubic feet of vapor per gallon of solvent.

For toluene TL is 0.02 and V_s is 30.4 ft³/gal (0.227 m³/L). The dilution volume for the threshold limit of toluene solvent can be calculated as follows:

$$\begin{aligned} \text{Dilution Volume} &= \frac{(100 - 0.02)}{0.02} \times 30.4 \text{ ft}^3 \\ &= 152,000 \text{ ft}^3 (4300 \text{ m}^3/\text{min}) \end{aligned}$$

Using the same procedure as above, one can compute the minimum ventilation rate needed to maintain the vapor concentration below the threshold limits for the example shown; it is 60,790 CFM (1720 m³/min).

Maintaining the paint vapor concentration below the threshold limit requires extremely large volumes of fresh air, generally more than required for LEL maintenance or blasting operations. These volumes are difficult to provide due to air-handling equipment space limitations and cost, especially when dehumidification of the incoming air is necessary.

An alternative solution is to require workers to use respirators when applying solvent-borne paints in tanks. Air supplied respirators should be standard practice for these materials inside closed spaces.

Another alternative is to limit the paint application rate to coincide with the required blasting ventilation volume. The same ventilation equipment can then do an effective job for both operations.

As stated earlier, water-borne paints require only a small fraction (about 5%) of the ventilation volume required for solvent-based paints. This can be easily provided by the blasting ventilation air flow rate.

6.3.4 *Explosive Vapor Detection*

Two basic types of devices are used for explosive vapor detection, heated element detector and cold sensor.

- *Heated element detector:*
This type is extensively used in the petrochemical industry. It is equipped with a heated catalytic element which is a possible source of ignition. As a safety measure, the element is protected by a fine mesh screen that prevents flame propagation. The temperature of the heated element increases during exposure to a flammable atmosphere resulting in degradation of the sensing element. This device requires frequent recalibration. When located in an area where paint can deposit on the sensor, an additional problem is created. The fine screen is readily clogged by paint which requires frequent removal for cleaning.
- *Cold Sensor:*
The detection principle recommended for shipboard tank applications uses a "cold sensor". This sensor does not degrade with time or exposure to flammable vapors. No protective screen is used. The sensing element housing protects the instrument from physical damage. Sensitivity to paint solvents is good, and the electronic alarm circuitry is simple and rugged. Since the detection element is not heated, power consumption is much lower than with heated element types. Portable battery-operated units can operate for several days before requiring recharging. Simple construction and operation make this instrument suitable for fixed installations such as hood exhausts or duct work which are not accessible for service and maintenance. The use of these instruments and the determination of hazardous conditions should be restricted to an individual trained and certified as "Competent Person".

6.4 Ventilation Equipment

Proper ventilation consists of equipment for moving air, equipment for directing or channeling the air and the efficient setup of this equipment. The following paragraphs discuss the proper selection of equipment necessary for efficient operations.



Figure 6-4: Fan Ventilation in Tank
(SSPC File Photo)

6.4.1 Fans

Fans are used to ventilate tanks by exhausting dirty air or by blowing in fresh air. Fans can be selected from a wide variety of sizes and types for different applications. The most important factors involved in determining the fan requirements are:

- Type of fan required
- Amount of ventilation (fan capacity) required
- Static pressure required
- Available space

Generally speaking, the objective is to choose a fan which provides required air volumes at proper static pressures with minimum horsepower and space utilization.

6.4.1.1 Types of Fans

The two preferred types of fans for marine ventilation are duct-axial and centrifugal. See Figures 6-5 and 6-6. Compressed air driven fans are also commonly used by shipyards for general ventilation. However, air driven fans have low efficiency ratings relative to power requirements and are therefore not suitable for moving large volumes of air.

- Duct-Axial Fans:* The duct-axial fan is the best choice if the fan is to be used simply to ventilate the tank with ambient, untreated air. This fan is ideal for portable applications where large volumes of air are blown or exhausted through only 50 to 100 feet (15 to 30 m) of ducting at low static pressure. Having a simple heavy-duty design, the duct-axial fan can be successfully operated in abrasive and dirty conditions. These fans are available in ranges of 10,000 to 50,000 CFM (280 to 1400 m³/min) capacity. Due to their low static pressure ratings, they require minimum horsepower (3-10 HP). In addition, duct-axial fans can be mounted either vertically or horizontally. Fans used for blast or paint operations should always be ordered with explosion-proof electric motor and spark-resistant construction. See Figure 6-7.
- Centrifugal:* Centrifugal fans are capable of moving large volumes of air at high static pressure, and therefore are used in conjunction with dust collection and dehumidification systems. These fans can operate efficiently when connected to long runs of ductwork. The increased static pressure capability of centrifugal fans results in increased horsepower ratings. (25-250 HP). See Figure 6-8.

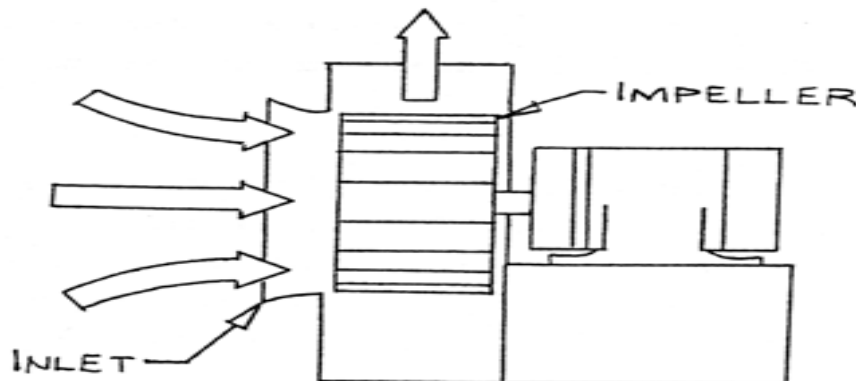
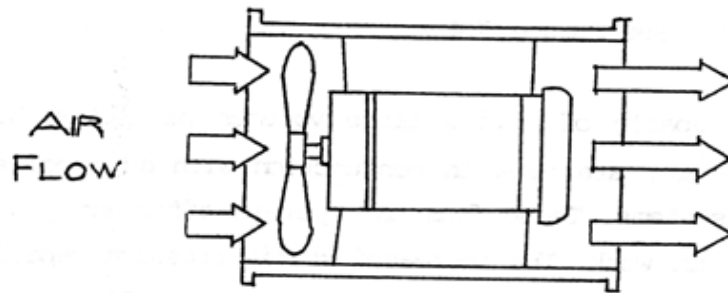


Figure 6-5: Centrifugal Fans - Air enters the center of the impellers in an axial



direction and is discharged by the impellers radially through the fan outlet. It is generally used when high static pressures are required, above 10 - 15 inches water column (2.5 - 3.7 kPa).

Figure 6-6: Axial Fans - Air enters and discharges in a straight line, parallel to the fan housing. It is generally used when a high volume of air is required, with the fan occupying the least amount of space.





Figure 6-7: Duct-Axial Fan

Figure 6-8: Centrifugal Fan

6.4.1.2 *Fan Capacity*

The required fan capacity (air flow rate) can be calculated based on the size of the tank and the frequency of air changes necessary for adequate visibility.

$$\begin{aligned} \text{ft}^3/\text{min (CFM)} &= \frac{\text{Tank volume (ft}^3\text{) x change / per hour}}{60 \text{ min / hr}} \\ &= \text{Volume (ft)/minutes per change} \end{aligned}$$

For example, an air change every three minutes in a typical 50,000 ft³ (3400 m³) wing tank would require a fan capacity of 16,500 CFM (470 m³/min) . A 100,000 ft³ (6900 m³) centerline tank would require a fan capacity of 33,000 CFM (930 m³/min) for the same air change frequency.

Fan capacity specifications are based on standard cubic feet per minute (SCFM) ratings. As discussed previously, a SCFM represents one cubic foot of air at 70°F (21 C) moving at a rate of one foot per minute. Air cooler than 70°F (21 C), and therefore denser, moves more slowly through a fan than warmer air. Also more horsepower is required to move a given volume of cold air at a given rate than the same volume of warm air at that rate.

6.4.1.3 *Static Pressure*

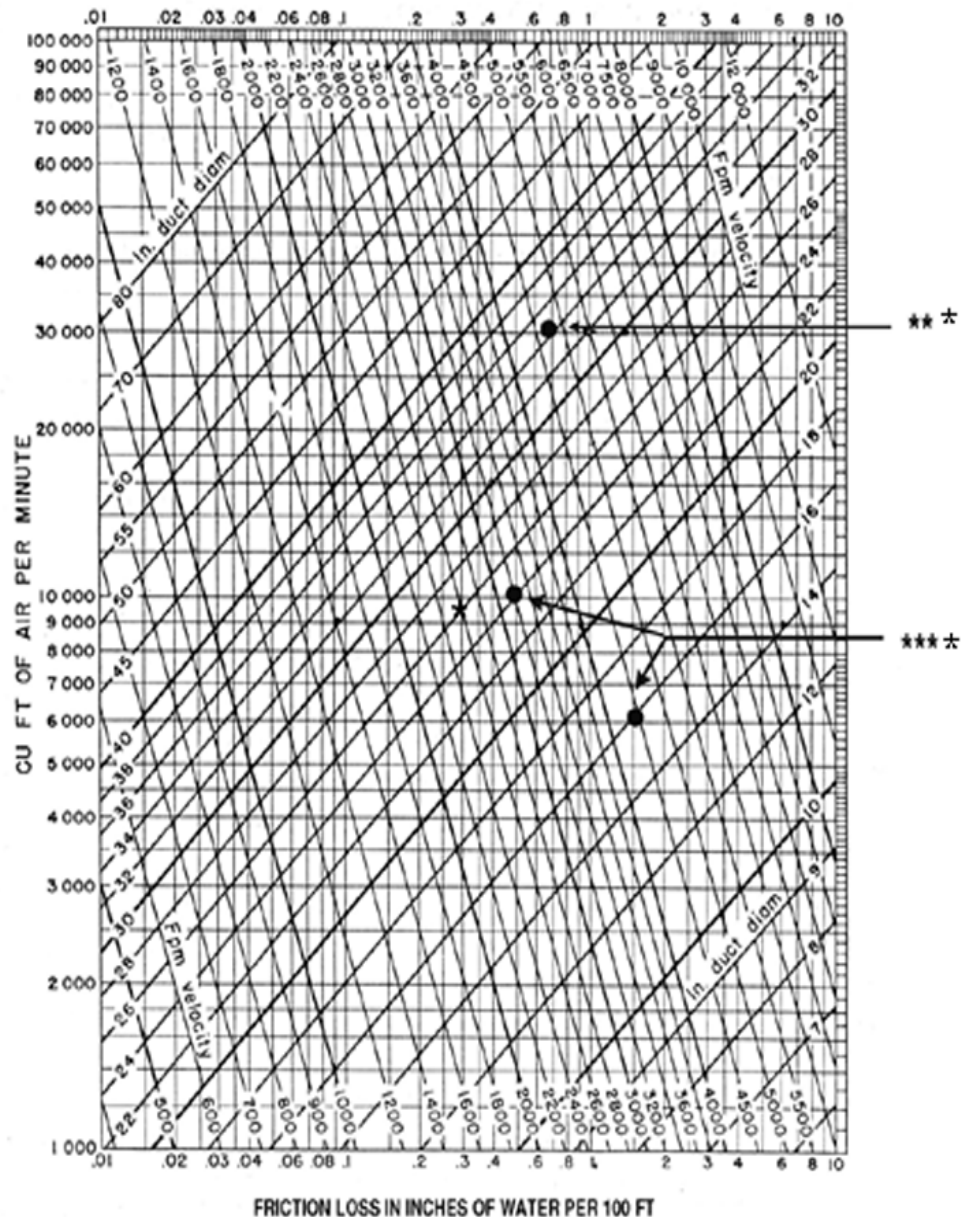
Static pressure potential is a measure of the fan's ability to maintain a pressure difference between the inlet and outlet of a fan. It is related to the fan's ability to overcome the resistance of air moving through ducting. It is measured using a water column, so the U.S. units are in inches of water. (One inch of water column is equivalent to 0.036 psi or 0.25 kPa.) Fans are designed for various maximum static pressure potentials.

Static pressure requirements are calculated based on the size, length, and number of bends of the ductwork. Size is the cross-sectional dimension of the duct. To demonstrate the effect of bends and elbows on static pressure loss, one foot of 18 inch (457 mm) duct with a 90 degree elbow has the equivalent resistance of approximately 28 feet (8.5 m) of straight duct. Static pressure requirements are also increased by air passing through air treatment equipment. The static pressure requirement for a fan should be determined after the ducting and equipment layout for the ventilation system has been designed.

As an example, assume a fan must blow 9,000 CFM (250 m³/min) of air through a dust collector unit and 200 feet (61 m) of 18 inch (457 mm) flexible ducting. The dust collector and the size and length of ducting each result in a 5 inches (1.2 kPa) loss of static pressure for a total pressure loss of 10 inches (2.5 kPa). Therefore, the fan must have at least 10 inches (2.5 kPa) of static pressure potential in order to maintain the 9,000 CFM required. See Table 6-2 for friction loss per 100 feet (30 m) of various sized ducting.

In many cases, the rated fan static pressure may not be sufficient to pull or push the air in the volume required. Generally, duct-axial fans used in single-purpose ventilation systems should have at least 1 inch (0.25 kPa) static pressure capability, and preferably 2 inches (0.50 kPa). Centrifugal fans used with dust collection equipment should be ordered with a minimum 12 inches (3.0 kPa) static pressure rating.

Table 6-2
Frictional Loss Per 100 Feet of Various Sized Ducting *, **



* (Based on Standard Air of 0.075 lbs/ft³ (1.2 kg/m³) density flowing through average, clean, round, galvanized metal ducts having approximately 1 joints per 2.5 ft. [0.76 m])

** Conversion: 1 cu. ft. = 0.028 m³ 1 inch of water/100 ft = 81.7 kilopascal/meter
 1 ft. = 0.305 M 1 inch = 25.4 mm

*** See Examples in 6.4.3

**** See Examples in 6.4.4

6.4.1.4 Placement of Fans

In a well-designed, permanently installed air handling system, fans can be located at practically any distance from the tank and still operate efficiently.

However, on jobs of short duration, portability and ease of installation are desired. In these jobs the fan should be placed as close to the tank as possible in order to reduce the amount of ductwork required.

Duct-axial fans can be ordered with spacial adapters enabling them to be mounted directly into “Butterworth” openings and cargo hatches. Ideally, the exhaust fan should be placed over the “Butterworth” opening and ducted to two sides of the tank bottom. Fresh air should be blown into the tank through the cargo hatch. This arrangement will distribute the clean air uniformly through the tank and through the same passage operators used to enter and exit. If deck space is severely limited, fans may be platform-mounted. If possible, fans should be isolated from communication areas because of high noise levels.

Installed fans should be checked periodically with a manometer. This device measures air flow. Measured reductions in air flow of an installed system can indicate worn parts such as impellers or obstructed ducts.

In summary, the most flexible type of fan for ventilating tanks with ambient air is the duct-axial type with a rated capacity of 30,000-40,000 CFM (850 - 1130 m³/min), 2 inches (51mm) of static pressure and a 42-48 inches (1.1 to 1.2 m) spark-proof case. Centrifugal fans with greater capacity for static pressures are primarily designed for use in air-treatment systems. Exact specifications will depend on the layout of the ductwork and/or treatment systems.

6.4.2 *Ducting*

6.4.2.1 *Ducting Design*

Well-designed and properly laid-out ductwork is essential to an efficient air handling system. Ducting design requires a thorough knowledge of requirements, accurate data on equipment, performance specifications, accessibility, duct length and weight and volume of material to be moved (i.e., abrasive dust, solvent fumes, etc.).

The two main areas of design criteria for ducting are sizing and layout. Sizing includes air flow rates, static pressure, velocity requirements, and fan specifications. Layout includes the type of job, ducting material, placement, and monitoring of the system.

The general objective for the ductwork design is a system of the smallest dimensions which combines the lowest practical static pressure requirements with sufficient velocity to transport the airborne materials.

6.4.2.2 *Duct Sizing*

Sizing is the most critical consideration in selecting ducting. Sizing determines whether the actual air flow rate, static pressure, and velocity of the air-flow in the finished ventilation system meet established design objectives.

Four factors must be considered when selecting duct size:

- Air flow rate in CFM
- Distance air is to be moved
- Static pressure limitation of available fans
- Air velocity requirements

With these four pieces of information, Table 6-2 can be used to select the proper duct size.

Air volume flow rate requirements are based on the size of the confined area and the characteristics of the material requiring venting. The distance the air is to be moved is simply the length of the ducting. Normally, a fan which best meets the air volume requirements is selected from the existing capital inventory. The static pressure rating of the selected fan then becomes a design parameter which must be considered in the final ducting size selection.

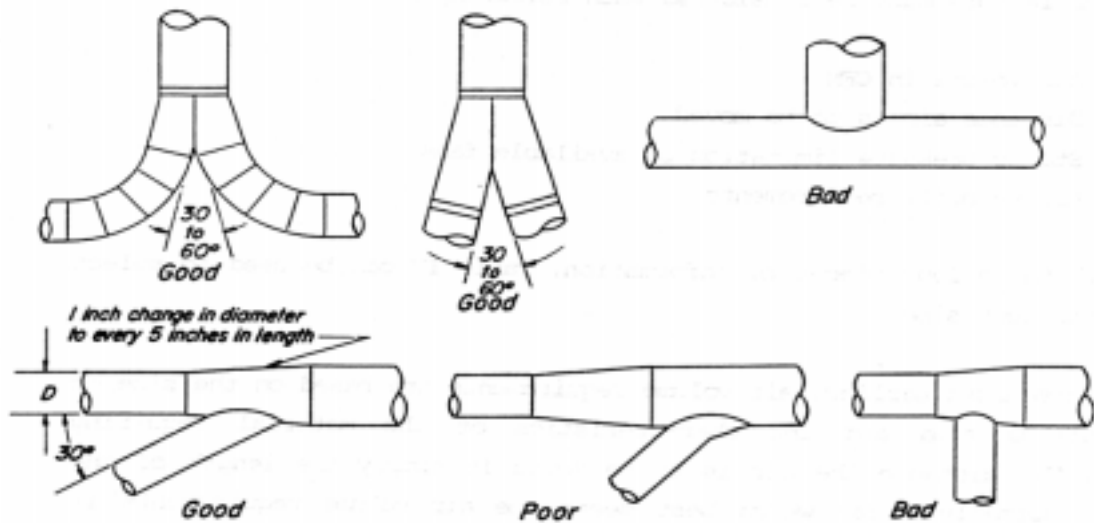
Static pressure loss along the length of the ducting is directly related to the size (internal cross-sectional area) of the duct. If the duct is too small, the static pressure required to offset frictional losses may overload the fan capacity. This would result in a reduction of air volume moving through the system. It must be remembered that as static pressure requirements increase, more energy (HP) is required to operate the system. Excessive energy requirements not only increase cost but may also restrict ventilation equipment usage at some locations within the yard.

Velocity calculations are based on the characteristics of each type of material to be vented. A duct which is too large results in a decrease in critical particle velocity along the length of the ducting. In this instance, the suspended material will fall out of the air-stream and build up in the bottom of the duct. As the duct fills, the ventilation capacity of the system is severely reduced. There is also the danger of the duct collapsing. As a rule, airborne dust resulting from abrasive blasting requires a minimum particle velocity of 3,500 FPM (1070 m/min).

6.4.3 Typical Static Pressure Losses

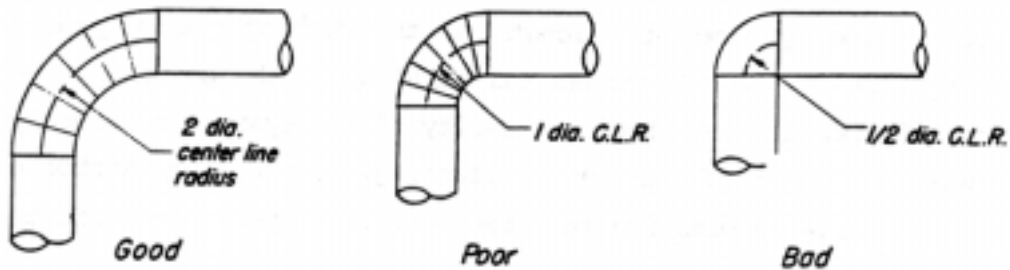
Some examples of static pressure loss for various types and sizes of duct are given as follows:

- *Smooth Ducting - Eighteen (18) inch [457 mm] Diameter* : Determine static pressure drop and velocity for 18 inch [457 mm] smooth ducting at 9,000 CFM (255 m³/min) as follows from Table 6-2. Find intersection of horizontal CFM line of 9,000 with diagonal line for duct diameter. These conditions result in 1.7 inch (0.42 kPa) of static pressure drop per 100 inch (2.54 m) of duct, and will provide a velocity of 5,000 FPM (1520 m/min).
- *Smooth Ducting - Twenty-four (24) inch Diameter*: With 10,000 CFM (283 m³/min), 24 inch (610 mm) smooth ducting has a static pressure drop of 0.5 inches (0.12 kPa) per 100 feet (30 m) (Table 6-3). However, velocity at the assumed CFM is 3,200 FPM (975 m/min), which would be marginal to transport abrasive dust. The air volume would have to be increased in order to move grit through this duct size. (Accurate static pressure figures for various CFM and duct sizes can be obtained from manufacturer's specifications.) Increasing to 12,000 CFM (340 m³/min) would increase velocity to 3,800 FPM (1160 m/min).
- *Flexible Ducting and Bends - Eighteen (18) inch (457 mm) flexible ducting*: This ducting has a static pressure drop of 2.8 inches (0.70 kPa) per 100 feet (30 m). Adding one 90 degree (81 mm) bend along 100 feet (30 m) will increase the static pressure drop to 3.2 inches (0.80 kPa). Two bends along 200 feet (61 m) increase the drop to 8.4 inches (2.1 kPa) and three bends along 300 (91 m) feet increase it to 12.6 inches (3.1 kPa). The smaller cross-sectional area inside the flexible ducting, due to surface irregularities, increases the velocity to 5,500 FPM (1680 m/min) as compared to the smooth ducting (see Figure 6-9 below for proper branch entry and elbow radius designs).



BRANCH ENTRY

Branches should enter at gradual expansions and at an angle of 30° or less (preferred) to 45° necessary.



ELBOW RADIUS

Elbows should be 2 or 2 1/2 diameters centerline radius except where space does not permit.

Figure 6-9: Branch Entry and Elbow Radius Design for Ducting Layout**6.4.4 Example: Determining Proper Duct Diameter**

Shipyard Example: A ship tank is scheduled for abrasive blasting. The size and configuration of the tank is such that 30,000 CFM (850 m³/min) of air and 300 feet (91 m) of duct are required for proper ventilation. The available fan is a 30,000 CFM (850 m³/min) duct-axial rated at 2 inch (0.5 kPa) of water static pressure.

Step One: Look at Table 6-2. Select the line on the y axis which represents 30,000 CFM (850 m³/min). As can be seen from the Table, duct sizes from 20 inches to 80 inches (0.51 to 2.0 m) in diameter will carry the required air volume.

Step Two: Calculate the maximum allowable static pressure drop for each 100 feet (30 m) of duct based on fan rating.

300 feet/100 feet = 3 lengths of 100 feet (30 m)

2.0 inch static pressure/3 lengths = 0.7 inches per 100 feet allowed (0.57 kPa/m)

Step Three: Again, look at Table 6-2. Follow the x axis to the point which corresponds to a frictional loss of 0.7. Trace up this line to the intersection of the line which corresponds to 30,000 CFM (850 m³/min). The diagonal line which intersects with x and y axis and represents “inch duct diameter” reads 34. Therefore, the appropriate size duct appears to be 34 inches (0.86 m).

Step Four: Verify that the duct size selected will maintain the proper velocity to keep abrasive dust suspended (3,500 FPM). The FPM velocity line is also a diagonal line. As can be seen, the velocity of the air ranges from 4,500 to 5,000 FPM (1370 to 1520 m/min) which is in excess of the minimum velocity required to transport abrasive dust (3,500 FPM) [1070 m/min].

Solution: In this example the 34 inches (0.86 m) ducting would be the correct choice.

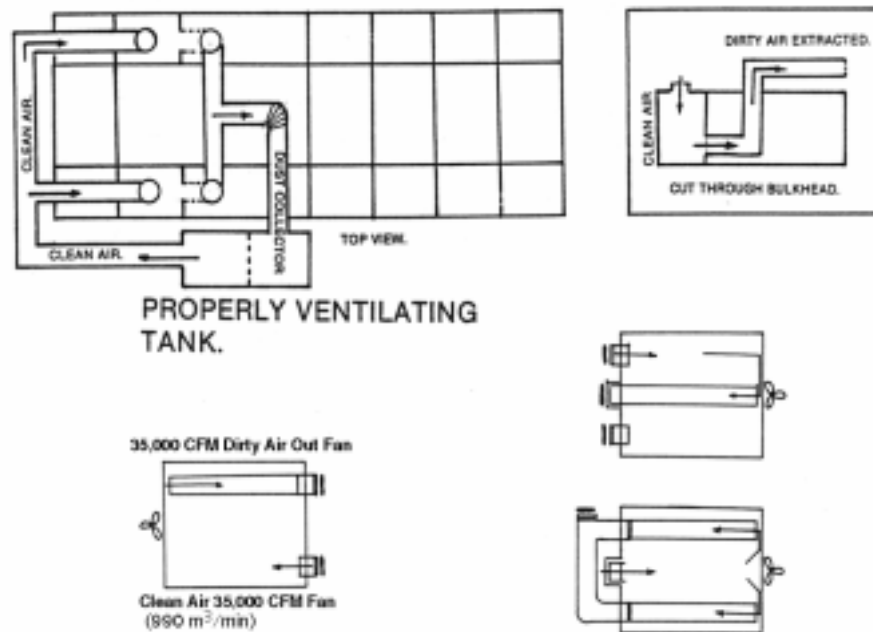
In conclusion, ducting which is not carefully and properly sized will greatly reduce the efficiency of the total ventilation system, and will result in problems related to equipment, visibility and worker safety.

6.5 Ventilation System Layout

When blasting marine tanks, the operator is faced with many different types of applications and tank configurations around which the ducting layout must be designed. The yard should stock ducting components in a variety of sizes and quantities. This practice allows for maximum portability and ease of set-up and breakdown. However, the shipyard should have some standard systems which are designed for the most frequent types of jobs.

In many cases, ventilation air is not distributed uniformly through the tank. As a result, only parts of the tank are properly ventilated, while other areas remain contaminated.

Clean air must be ducted into the tank in such a manner that the ductwork extends down no more than 6 inches (150 mm) below the tank top. Since the heavier airborne dust particles tend to settle to the bottom of the tank, the dirty air removal duct should be positioned in such a manner that the pick-up opening is near the tank bottom. This



arrangement permits the dust particles to naturally fall toward the bottom of the tank and be exhausted much faster than if the pick-up point were positioned higher in the tank. The duct openings should be separated as much as possible. See Figure 6-10 below.

Figure 6-10: Ventilation Diagrams of Enclosed Spaces, Small Tanks and Multiple Tanks

Some tank configurations and/or production requirements necessitate ventilation between tanks. This can be accomplished by cutting access holes through common bulkheads or through decks. These access holes are particularly advantageous when setting up a complete tanker job. The resulting cross-ventilation saves considerable time through standardization of duct sections. Blanks can be used to close off outlets or inlets when not in service. This practice also provides additional access entrances to each tank. It also avoids the constant problem of personnel and materials competing for too little space.

Metal ducting should be used for all straight runs. Flexible fabric-reinforced ducting is more expensive and is subject to high wear and tear. It should be used for making connections to machinery and to small, inaccessible tanks. Round duct is usually the best choice because it maintains a uniform air velocity and withstands higher static pressure. All ductwork for tank-blasting ventilation should be durable and light for optimum portability.



Figure 6-11: Ventilation System Component
(Courtesy of Todd Shipyard)

6.6 Inspection of Ventilation in Ducting

After the system has been installed, periodic inspection of the ductwork should be made to insure air-tightness. In addition, every new system should include access for measuring devices to monitor actual velocity, CFM and static pressure at various points along the ducting.

The Pitot tube is the standard air velocity meter (Figure 6-12). By multiplying the velocity reading in feet per minute (FPM) by the cross-sectional area of the duct in square feet, the actual CFM at that point can be calculated.

CFM (ft³/min) = air velocity (ft/min) x cross-sectional area of duct (ft²) or (m³/min = m/min x m²)



Figure 6-12: Pitot Tube
(SSPC File Photo)

For example, at a point on a straight run of 18 inch (457 mm) ducting, the air velocity is measured to be 3,200 FPM (975 m/min). The 18 inch (457 mm)

round duct has a cross-sectional area of 254 square inches, $([18]^2 \times \frac{\pi}{4})$ or 1.76 square feet (0.164 m²). The CFM at that point would be 3,200 x 1.76 square feet or 5,630 CFM (975 m/min x 0.164 m² = 160 m³/min). An anemometer is used to measure static pressure (Figure 6-13).



Figure 6-13: Rotating Vane Anemometer
(SSPC File Photo)

If measurements of CFM, static pressure, and velocity reveal that ventilation objectives are not being met, modification or repair of the ductwork or the fan may be necessary. A common problem with fans used for ventilation of blast cleaning is worn impellers caused by abrasive dust. If the fan does not have sufficient capacity, ducting must be straightened or shortened. The problem may also be caused by improperly sized ducting, constrictions or air leaks.

Ducting that has been used for ventilation during painting should be inspected for paint build-up on the interior surfaces before it is used for blasting ventilation. Friction created by the abrasive dust combined with flammable paint solvent particles can create a fire hazard. In addition, excessive paint build-up will reduce the efficiency of the ventilation system.

In this unit, basic procedures and guidelines have been given for general marine tank ventilation. Examples for the most part have been for ventilation of

ambient, untreated air. The next unit identifies the components of the dust collection system, which cleans the dust-laden air exhausted by ventilation.

UNIT 7 DUST COLLECTION AND FILTRATION

7.1 Introduction

Dust collection equipment is widely used to clean contaminated exhaust air resulting from manufacturing activities. If properly used by shipyards, dust collection and filtration will eliminate many of the problems associated with contaminated air from abrasive blast cleaning and coatings operations. It will also help to ensure compliance with EPA and OSHA regulations and substantially reduce job-site housekeeping.

7.2 Types of Dust Collectors

There are three types of dust collection equipment which are easily adaptable to shipyard blasting and painting operations.

- Dry Tube (Baghouse) Fabric
- Dry Cartridge
- Wet Scrubber

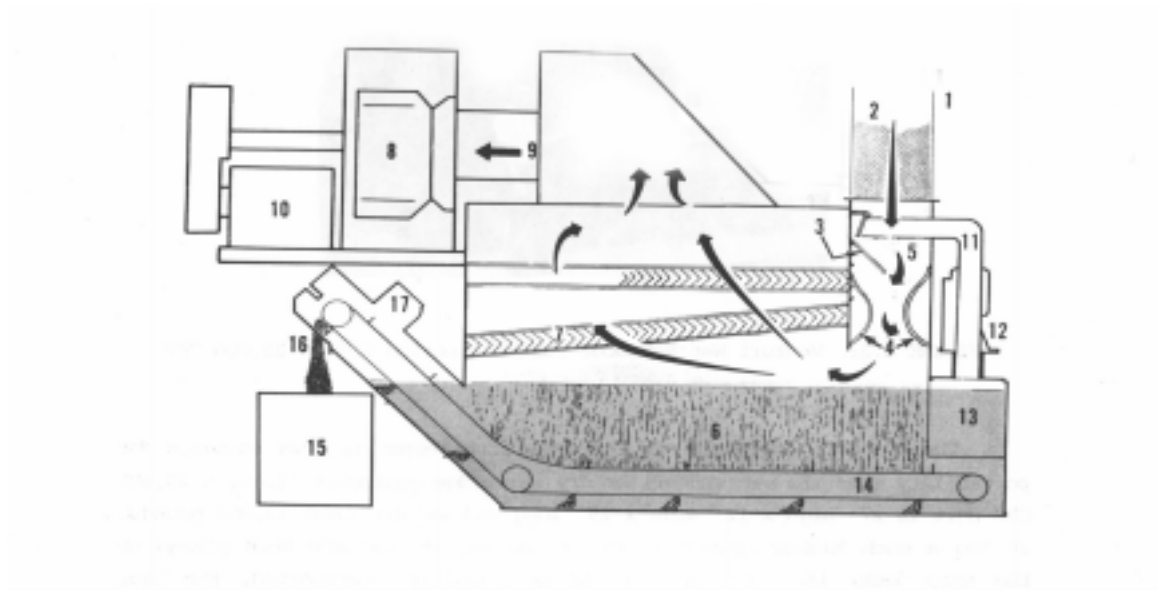
Dry fabric (baghouse) collectors use a series of fabric bags which filter dirty air drawn across or through the banks of filter elements (bags). The retained dust is then removed at regular intervals by blowing compressed air through the fabric bags, by shaker or by vibrating systems. The dislodged dry fabric dust collectors are suitable for high humidity conditions which occur frequently at shipyards. Dust collectors that rely on bags or filter tubes to trap dust are not recommended for hazardous dust applications. The cloth filter elements do not trap fine dust as well as cartridge filters do. Using such collectors may allow lead or other hazardous dust to escape with the exhaust air and fall onto the ground outside.

Dry cartridge systems collect and discharge dust in the same manner as the baghouse systems. They are frequently associated with very high filtration efficiencies. Most recycling systems use reverse pulse cartridge dust collectors. These units automatically clean their cartridges with a momentary pulse of compressed air. In operation, a powerful exhaust motor draws dust-laden air through pleated filter cartridges. The cartridges trap the dust particles down to as small as 0.5 micrometers. When dust builds up, it reduces the amount of air passing through the filter elements. To prevent the cartridges from becoming completely clogged, air jets, positioned just above each cartridge, send a blast of compressed air into the cartridges to momentarily reverse the flow of air. This knocks the caked-on dust off the cartridges, allowing it to fall into drums or storage hoppers below. Reverse pulse cartridge dust collectors virtually eliminate the need to handle toxic dust. Because the cartridge is rigid in the collector, the filter media does not require removal for transport. Cartridges are replaced as necessary. Figure 7.1 illustrates a drum filter ready to be replaced.



Figure 7-1: Dry Cartridge Filter Ready to be Replaced
(Courtesy of Todd Shipyard)

Wet scrubbers impinge the dust-laden air with moisture, wetting the dust and causing it to settle due to increased weight. The resulting sludge is drained of moisture and discharged by conveyor from the machine in a semi-dry condition. One suitable type of wet collector is Venturi design. (See Figure 7-2.) This design combines high constant efficiency and portability with low operating costs and low operating noise levels.



- | | |
|------------------------------------|--------------------------------|
| 1 — Inlet duct | 10 — Fan motor |
| 2 — Incoming dirty air | 11 — Pump discharge |
| 3 — Water distributor | 12 — Pump |
| 4 — Adjustable rectangular venturi | 13 — Pump inlet |
| 5 — Wash section | 14 — Sludge conveyor |
| 6 — Solution tank | 15 — Sludge container |
| 7 — Moisture eliminators | 16 — Sludge conveyor discharge |
| 8 — Fan | 17 — Sludge conveyor drive |
| 9 — Outgoing clean air | |

Figure 7-2: Venturi Wet Scrubber

7.3 Equipment Selection

The most important selection criteria for dust collection equipment in the shipyard are:

- Portability
- CFM and static pressure requirements
- Type of particles handled
- Efficiency and costs

7.3.1 Portability

Portability includes factors such as machine size, transportability, set-up time and ease of placement. If the shipyard frequently handles individual tank blasting jobs and/or multi-tank projects, a wet venturi system would be a good choice. A 25,000 CFM (708 m³/min) unit is compact (14 feet high x 8 feet wide x 18 feet long [4.3 x 2.4 x 5.5 m]), with a dry weight of approximately 12,000 lbs (5400 kg). The wet scrubber can be transported completely assembled. Because the fan is mounted on top of the machine, extra ducting is not required between the fan and scrubber. The unit can be disassembled or reassembled in about eight man-hours. The removal of the fan and transition piece make it a legal load for transporting outside the yard. The primary limitation of the wet venturi system is that it cannot be used with dehumidification equipment or when a high level of filtration efficiency is required.

When projects dictate dehumidified air (or when high levels of filtration efficiency are required), the dry tube or cartridge collector is the recommended choice of equipment. A reverse-jet continuous duty dry fabric collector (Figure 7-3) is most efficiently utilized in semipermanent, pierside, barge-mounted, or railcar-mounted arrangements. This system is also appropriate for large capacity permanent installations.

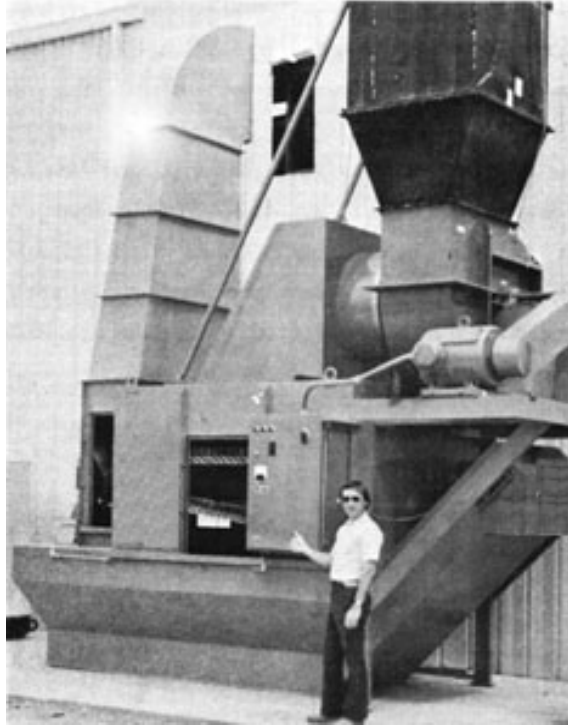


Figure 7-3: Reverse-Jet Continuous Duty Dry Fabric Collector Unit - 70,000 CFM (2000 m³/min)
(Courtesy of CAB)

For individual tank jobs requiring dehumidification, a combination of dry cartridge and dehumidification units provides high performance and portability. The dry cartridge dust collector system is also suitable for trailer-mounting because of its compact design. A system of up to 40,000 CFM (1100 m³/min) consisting of four 10,000 CFM (280 m³/min) units can be mounted complete with fan and motor on a single 40 foot (12m) trailer. As the cartridge unit can be moved without disassembly, this system can be transported on roads as well as within the shipyard.



Figure 7-4: Dust Collector at Shipyard: 18,000 CFM (510 m³/min)
(Courtesy of Long Painting Company)

7.3.2 CFM and Static Pressure

There is a pressure drop associated with moving air through filters. This pressure drop is usually a few inches of water column. The pressure drop increases as the filter cake builds up. Certain commercially available dust collectors have a manometric gauge to measure the pressure drop across the filters. Proper operation of the dust collector should include regular observation of this gauge to determine if the pressure drop is within the manufacturer's specified range.

The pressure drop associated with the dust collector must be considered in the overall design. A 1 inch (0.25 kPa) drop, a filter may be collapsed.

Each type of dust collection system can be assembled with high static pressure fans to accommodate flow rates up to 1400 m³/min).

7.3.3 *Types of Particles Handled*

Dust created by abrasive blast cleaning constitutes a moderate load of fine to medium sized particles. Both dry and wet systems are well suited to handle these dry particles. However, the overspray from coatings application is wet. The dry fabric collector cannot efficiently handle wet particles as they tend to clog the filter media. If air ventilated during painting is to be cleaned by a dry fabric collector, an expendable paint arrestor filter should be used to filter the air before it is exhausted to the collector. Wet paint will quickly clog the bags.

The wet collector can handle both dry and wet particles. Cleaning and disposing of the slightly damp sludge resulting from the wet scrubber system is relatively easy. The dry dust discharge can create a secondary air pollution problem during disposal. However, the residue can be discharged directly into drums.

7.3.4 *Filtration Efficiency*

Filtration efficiency is a measure of the ability of a filter to prevent emission of particulate of a specified size and type. Once the fabric has been in service any length of time, collected particulate, which is in contact with the fabric acts as a filter aid. This effect improves collection efficiency. In many instances the filtration is accomplished by the previously collected particulate or dust cake as opposed to the fabric itself. Even immediately after cleaning, a residual or redeposited dust cake provides additional filtration surface and higher collection efficiency than obtainable with new fabric. The collection efficiency of new, clean fabric is easily determined by laboratory tests and the information is often published. However, it is not representative of operating conditions, and so is of little importance when selecting the collector.

According to the ACGIH manual, the fabric filters (reverse jet) have greater efficiencies than the wet collectors for particles of 10 micrometers and less. These are the particles of greatest concern for worker respiration.

Fabric collectors are not 100% efficient. However, well-designed and carefully operated fabric collectors can be expected to operate at efficiencies in excess of 99% on a weight basis. The inefficiency, or penetration, that does occur is greatest during or immediately after reconditioning.

7.3.5 *Operating Efficiency and Costs*

In terms of efficiency, operating cost, and maintenance, the wet scrubber offers several advantages. It runs at a constant efficiency, has heavy-duty construction with few moving parts, requires less maintenance and has lower replacement costs. The unit is also easily accessible for repairs and external inspection. The wet unit can be installed for all-weather, year-round operation. The efficiency of the wet scrubber is not affected by the air moisture in humid areas. The use of water, however, may introduce corrosive conditions within the collector. When ordering scrubbers, a corrosion-resistant coating such as a coal-tar epoxy should be specified for all internal metal surfaces. The scrubber requires both electrical and water service hook-ups, although water used by the unit is recirculated.

In comparison, the dry system will operate efficiently only when air is dry enough to prevent condensation on the fabric. Under these conditions, the cartridge system offers the highest filtration efficiency. Under humid conditions, however, dust will cake on the bags, resulting in low efficiency and possible damage to the filter media. All openings and fittings on the suction side of the duct work should be sealed against moisture. The fans can overcome the static pressure caused by moisture, but can't handle wet paint that clogs the filters. The unit cartridge has a large number of parts and assemblies with limited accessibility which may result in increased maintenance costs.

An additional hazard of the dry tube system is the possibility of ignition of explosive dusts (i.e., finely divided titanium dioxide and aluminum oxide). Wet collectors a

According to the ACGIH manual, the costs per CFM are slightly higher for the continuous duty reverse pulse fabric filter than for the wet collector and the intermittent dust fabric collector (e.g., baghouse).

UNIT 8 APPLICATION OF COATINGS

8.1 Introduction

Proper application of coatings is critical for the economical, long-term protection of steel in ship tanks and other ship areas. To provide a high level of protection, protective coatings must be applied in a continuous film of relatively constant dry film thickness. Otherwise, early coating deterioration and rusting of steel may occur. This unit discusses common spray application methods and application practices.

New VOC requirements for low solvent content have resulted in more viscous coatings that are more difficult to apply successfully. Thus, special care must be taken to select the proper equipment and to closely follow the procedures recommended for its use.

8.2 Selection of Application Equipment

Successful coating application requires the selection of the most appropriate application equipment for the specific job. The basic criteria for equipment selection are described below.

Appropriateness for coating to be used. Present day ship coatings usually require special application equipment. The coatings are usually more difficult to apply because of high viscosities, suspended heavy particles (e.g., zinc dust), or short pot lives. Thus, matching the coating to the application equipment is critical.

Appropriateness for job. The application equipment must also match the specific job requirements. This includes size and portability of equipment for work in confined spaces, ability to coat difficult-to-reach areas successfully, and the ease and economics involved. For small jobs, smaller less efficient equipment may be more appropriate.

Rate of application/economics. Economics dictate that the application of coatings be quick and effective. Equipment must be readily available and efficient.

Transfer efficiency. A high transfer efficiency will consume less coating. It also reduces contamination of surfaces not scheduled for painting by overspray and bounce-back and provides a safer working environment.

Required operator skills. Newer coatings require greater applicator skills. Proportioning, mixing, and other special application techniques are critical in obtaining properly applied and cured protective films.

8.3 Spray Equipment

Spraying is the most commonly used method of coating application to ships; spraying has the greatest application rate, the greatest uniformity of application, and is, in most cases, the most economical. The two basic types of spray are air (conventional) and airless. In air spray, compressed air is used to atomize the liquid coating into a fine mist as it exits the spray gun. In airless spray, pumps are used to pressurize the liquid coating; the coating is forced through a small orifice and atomized hydraulically. These and other spray variations will be discussed briefly below

8.3.1 *Air (Conventional) Spray*

The components of a typical air spray system are shown in Figure 8-1. They consist of a compressor to supply a constant flow of air, hoses conducting the compressed air to the pressure tank (the pot that holds the coating) and to the gun, a fluid hose conducting the coating from the pressure tank to the gun, and the gun itself. Filters and regulators provide clean air at the desired pressures. A typical air spray gun and nozzles are shown in Figures 8-2 and 8-3 below. There are several design variations.

Advantages of air spray include:

- Finest atomization/finish
- Good operator control/versatility
- Low initial investment

Limitations of air spray include:

- Lower application rate than airless spray
- Lower transfer efficiency than other methods
- Production of overspray
- Limitation on thinning due to EPA restrictions on VOC emissions

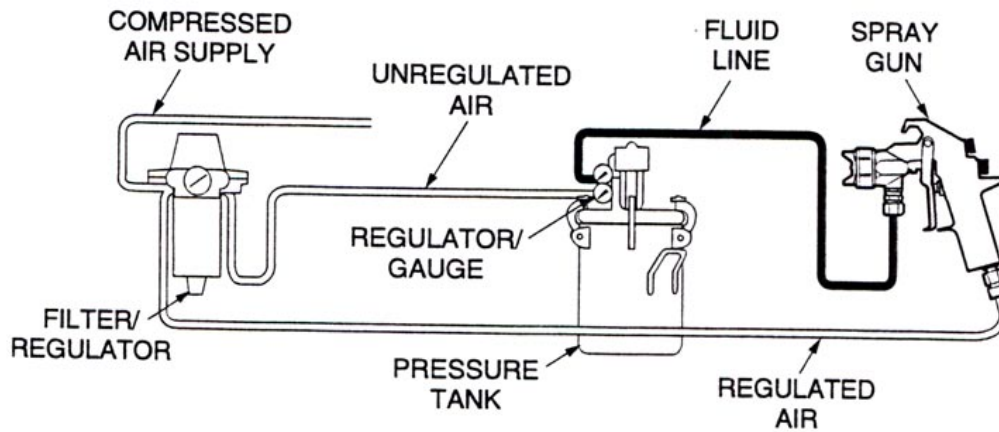


Figure 8-1: Components of a Typical Pressure-Feed Air Spray System
(Courtesy of Binks Manufacturing Company)

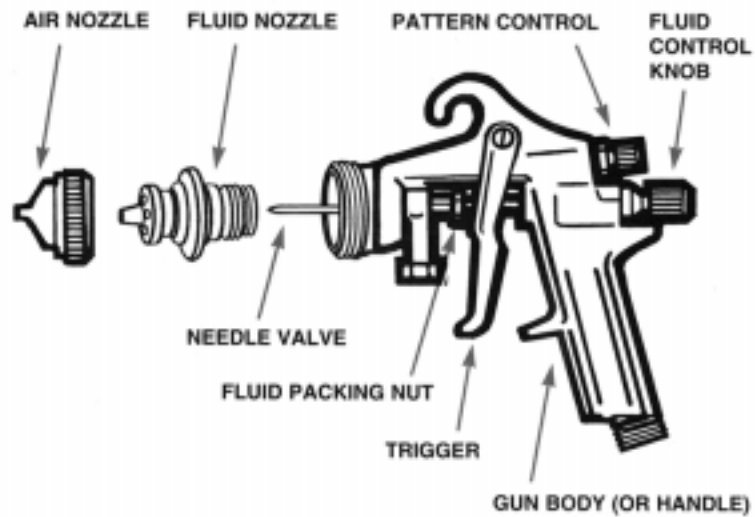


Figure 8-2: Parts of Typical Conventional Spray Gun
(Courtesy of Binks Manufacturing Company)

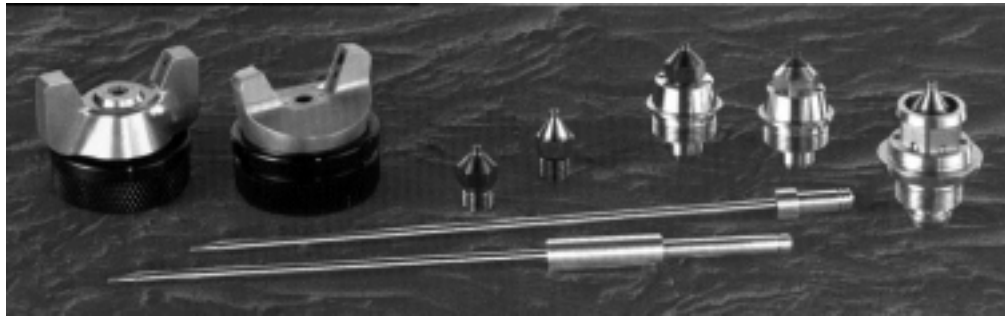


Figure 8-3: Spray Nozzles
(Courtesy of C.A. Technologies)

8.3.2 Airless Spray

The components of a typical airless spray system are shown in Figure 8-4. They consist of a pump for pressurizing the coating, a coating container, a high-pressure fluid hose, and a gun with a choice of tips. Pumps may be powered by compressed air, gasoline, or electricity. The pump is rated according to the ratio of the paint pressure produced to the pressure producing it. Thus, a pump that delivers a paint pressure of 30 psi (207 kPa) for each psi of pressure from the source has a 30:1 ratio. Typical airless spray pressures range from 2,000 to 3,500 psi (13.8 to 24.1 MPa), but they may go as high as 5,000 psi (34.5 MPa).

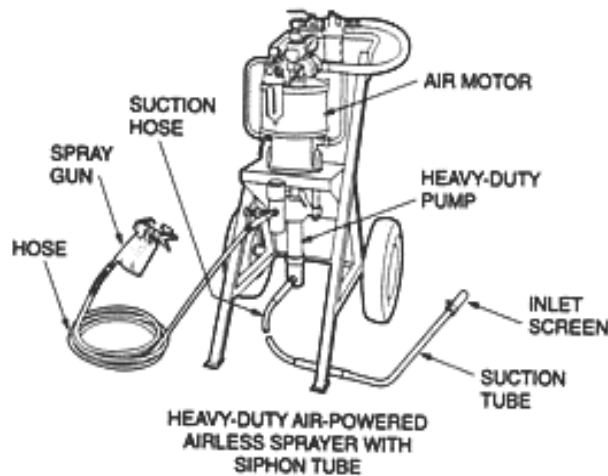


Figure 8-4: Components of a Typical Airless Spray System
(Courtesy of National Center for Construction Education and Research)

Because of the hazardous high pressures of airless spray, guns are equipped with tip guards (to keep fingers away) and trigger locks.

Advantages of airless spray, as compared to air spray, include:

- Higher application rate
- Higher transfer efficiency
- Reduced overspray fog
- Good application of high-viscosity materials

Limitations include:

- Hazardous spray pressures
- Reduced operator control
- Reduced quality finish
- More expensive to maintain

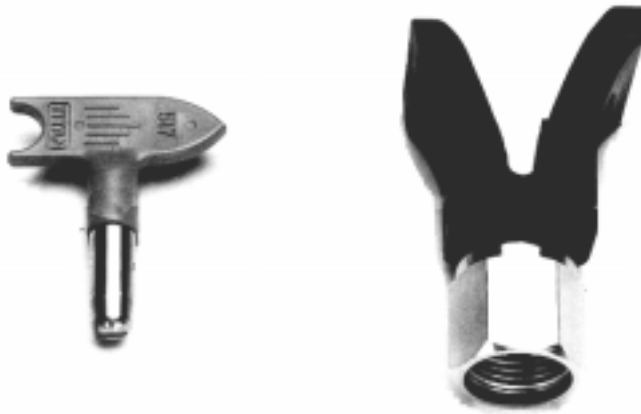


Figure 8-5: Airless Reverse Tips
(Courtesy of Titan Tool Inc.)

8.3.3 Air-Assisted Airless Spray Systems

Air-assisted airless spray atomizes liquid coatings by a combination of hydraulic and air pressures, typically 500 to 1,000 psi (3450 to 6900 kPa) and 10 to 15 psi (690 to 1000 kPa) respectively. It is designed to combine advantages of air and airless spray, i.e., a finer finish with higher application rates and transfer efficiencies.

Advantages of air-assisted airless spray include:

- Finer atomization/finish than airless
- Fewer runs and sags than airless
- Better transfer efficiency than conventional air
- Better operator control than airless

- Higher application rate than conventional air

Limitations of air-assisted airless spray include:

- Inability to produce as fine a finish as air spray
- Expensive to maintain

8.3.4 *High-Volume, Low-Pressure Spray (HVLP)*

High-volume, low-pressure spray atomizes coatings at low air pressures and then utilizes a high-volume air supply to propel the droplets at a low velocity. It is most often used where a high transfer efficiency is required. There are several design variations for the system.

Advantages of HVLP spray systems include:

- High transfer efficiency
- Reduced overspray and bounce-back
- Good gun control

Limitations of HVLP systems include:

- High initial/maintenance costs
- Reduced application rate
- May require special training
- Restrictions on thinning due to VOC regulations

8.3.5 *Plural-Component Spray Systems*

Plural-component spray systems automatically proportion and mix the two or more components of a coating. The mixing occurs either internally or externally near the spray gun as shown in Figure 8-6 below. Mixing immediately prior to spraying prevents the coating from curing too quickly. Immediately after spraying, the mixing chamber is purged with solvent to prevent the residual mixed coating from setting up in the mixing chamber. Both air and airless guns are available for plural-component use. Examples of coatings are chemically reacting epoxies and polyurethanes.

Precise proportioning of the two components (typically ranging from 1:1 to 1:4) is required for proper application and curing. Newer systems achieve this by use of electronic proportioners.

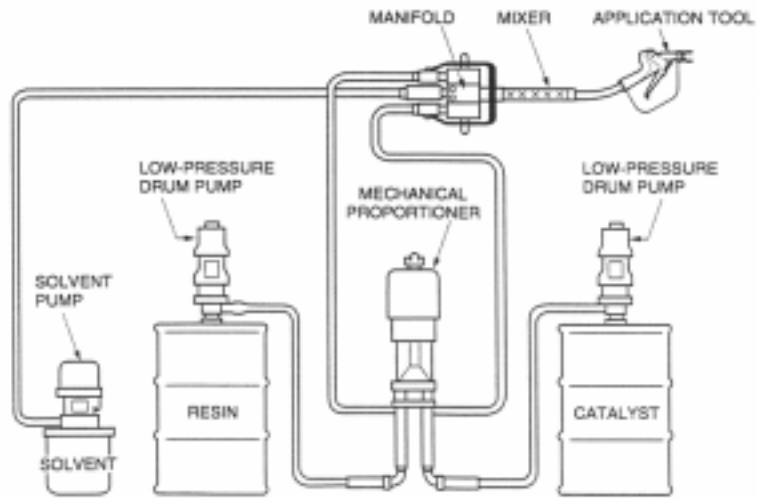


Figure 8-6: Mechanical Proportioning of Plural Component Spray
(Courtesy of Binks Manufacturing Company)

Plural component systems permit the use of coatings with very short pot lives and curing times. They are also capable of applying very high viscosity coatings; heating may be required for application of extremely viscous materials.

Advantages of plural-component spray systems include:

- No pot life problems
- Good for high-viscosity coatings
- Shorter curing times possible
- Conservation of materials
- Reduces use of solvent

Limitations of plural-component systems include:

- High initial/maintenance costs
- Proportioning/temperature controls required
- Skilled operator required
- Impractical for small jobs

8.4 Application by Brush, Roller, or Mitt

Application by brush, roller, or mitt may be used when spraying is impractical. This may occur on very small jobs or when no overspray can be tolerated. Mitts should be used as a last resort, because they seldom produce a continuous film of uniform thickness

8.5 Application Practices

8.5.1 *Storage of Coatings*

Proper storage of coating will minimize fire hazards and protect them from premature deterioration. Storage should be done according to OSHA requirements, indoors out of the weather. OSHA requirements for labeling and material safety data sheets (MSDS) must also be met. Coatings should be used well before the expiration of their shelf (storage) lives. No more coating should be taken to the work site than is actually required.

8.5.2 *Mixing, Proportioning, and Thinning*

Improperly proportioning, mixing, or thinning of a coating can lead to early coating failure, because a uniform product suitable for application is not received.

Mixing: Upon prolonged storage, the heavier pigments in coatings tend to settle to the bottom of containers. All coatings must be blended to ensure uniform composition and consistency prior to use. Mechanical mixing with electric or air-powered stirrers is faster and more efficient than hand mixing. Overmixing to cause foaming should be avoided. This most commonly occurs with water-borne and with some 100% solids coatings. Two-component systems should be mixed separately before combining and then again after combining.

After mixing, it may be necessary to strain the coating through a fine sieve to remove any lumps, skins, or other foreign material. Zinc-rich coatings should always be strained after mixing and before use.

Two-component mixed coatings may have a required induction time (also called sweat-in time). Induction times permit the two components to react chemically before application. Lower temperatures usually require longer induction times. Some coating manufacturers waive the induction period for epoxies applied by plural component airless spray.

Of course, all mixed two-component systems have limited pot lives. The pot life is the time period after mixing during which the coating can be

successfully applied. The higher the temperature and the greater the amount of mixed coating, the shorter will be the pot life. No more coating should be mixed than can be readily applied during the pot life.

Proportioning: If improper portions of two-component coatings are mixed, proper curing may not occur to produce a coating film with the desired properties. Indeed, complete curing may never occur. Automatic proportions must be precisely set. Proportioning by hand is best achieved by using full containers of each of the components rather than estimating volumes.

Thinning: Most coatings are manufactured for application as received. However, thinning may be required to reduce the coating viscosity for proper application, especially at lower temperatures. If this becomes necessary, it should be accomplished using the type and amount of thinner recommended by the coating manufacturer. Improper thinning may adversely affect both application and curing.

Thinners can be used effectively to clean application equipment. The equipment manufacturer usually provides information about the proper cleaning, lubrication, and maintenance of their equipment.

Disposal of thinners used in clean-up must be done using approved techniques. The preferred method is distillation for reuse (see Section 10.3 for information on solvent disposal).

8.5.3 *Application of Commonly Used Shipyard Coatings*

8.5.3.1 *Epoxies*

Two (2) component epoxy is the type of protective coating finding the greatest use on ships. These include specification paints, MIL-P-24441, MIL-P-23236, and proprietary commercial alternatives. More attention is now being placed on use of solvent-free, edge-retentive epoxy coatings, especially in tanks and other confined spaces. Solvent-free epoxy phenolic coatings can be used to provide greater durability on tank floors.

The higher viscosity materials described above can sometimes be applied successfully by high ratio airless systems, but plural component systems is sometime more economical. In all cases, the recommendations of the manufacturer should be followed carefully. The required surface preparation for use of epoxy coatings on ships is normally SSPC-SP 10/NACE No. 2 (near white blast cleaning).

The previous section discussed mixing, proportioning and thinning, as well as pot life and induction time. Another concern is the adhesion of multiple

coats of two component systems. When applying a chemically curing multiple coat system, the topcoat must be applied within the recoat window period of the previous coat specified by its manufacturer. Otherwise, good intercoat adhesion will not occur. If this window has been exceeded, other actions recommended by the coating manufacturer must be taken. This action is often a light sanding of the existing coating to provide a larger bonding surface. The U.S. Navy recommends use of a mist coat over cured MIL-P-24441 before application of a full topcoat, in order to achieve good bonding of the topcoat.

Care should be taken to avoid skin contact with epoxy coatings. Once the skin has been sensitized, the applicator is usually unable to use epoxy coatings again.

8.5.3.2 *Polyurethanes*

Two-component aliphatic polyurethanes are often used as a finish coat for exterior epoxy systems to provide resistance to the sun's ultraviolet light. The same precautions must be taken with their application as was described above for two-component epoxies.

One of the polyurethane components contains an isocyanate. Since free isocyanates are very toxic, respirators and other personal protective equipment should be used when applying polyurethanes.

8.5.3.3 *Inorganic Zinc-Rich Coatings*

Inorganic zinc-rich coatings are sometimes applied to ships, always by spray. For ship use, they usually require an SSPC-SP 10/NACE No. 2 (near white) or SSPC-SP 5/NACE No. 1 (white metal) blast cleaning, as recommended by the manufacturer.

Inorganic zinc-rich primers are commonly used as pre-construction primers (PCPs) in the construction of ships. Typically, they are applied at approximately 0.6 mils (15 micrometers) and have a reduced zinc content so that welding and torch cutting have minor adverse effects. The ethyl silicate type of inorganic zinc-rich coating has been used the most in the past.

It is best to mix a whole kit at one time. Low speed mixing (e.g., 20 rpm) is recommended to avoid air entrapment. As previously mentioned, the mixed product should always be strained before use. To minimize settling of the heavy suspended zinc particles, the container holding the coating should be continuously stirred; in addition, material hose lengths should be as short as practical.

Minimum spray pressures should be used to obtain a continuous wet film of uniform thickness. Care should be taken to avoid excess coating thickness (e.g., greater than 5 mils dry film thickness (125 micrometers) which may cause mud cracking during curing.

Ethyl silicate zinc-rich coatings require moisture for curing. On days of low humidity it may be necessary to spray a fine mist of water onto the coating to achieve its full cure. Curing of the coating can be determined using the solvent rub test (ASTM D4752) or by rubbing with a coin (a burnished surface indicates complete curing).

Topcoating of naturally porous inorganic zinc-rich coatings often results in the formation of small bubbles in the topcoat. This is caused by air in the pores attempting to escape through the wet topcoat. One approach to minimizing these bubbles is to apply a mist (thin) coat to the inorganic zinc-rich coating, allow it to partially dry, and then apply a full topcoat.

8.5.3.4 *Silicone and Chlorinated Alkyd Coatings*

Silicone alkyd coatings such as MIL-E-24635 are used on ships as an exterior finish for an epoxy or other system. These products are easily applied, but application must occur during the recoat window of curing of the epoxy. This problem was discussed above concerning application of multiple coats of epoxy.

Chlorinated alkyd coatings (DOD-E-24607) are still used in habitable areas but never in ship tanks or other confined spaces.

8.5.4 *General Application Techniques*

The recommendations of the coating manufacturer should be followed completely during all coating operations. This includes surface preparation, application equipment, permissible ambient weather conditions, coating preparation (mixing, proportioning, and thinning), and actual application details. Recommendations are normally available on application systems, hoses, tips, pressures, etc. The applicator should check the equipment, the spray pattern, and wet film thickness before starting the work.

8.5.5 *Film Thickness*

The amount of dry film thickness (DFT) after curing can be easily calculated from the wet film thickness (WFT) and the percent solids by volume of the coating:

$$\text{DFT} = \text{WFT} \times \frac{\% \text{Solids}}{100}$$

Thus, a coating with 80% solids by volume and a wet film thickness of 5 (125 micrometers) mils will have a dry film thickness of 4 mils (100 micrometers) ($5 \times 80/100 = 4$).

Conversely the WFT needed to achieve a specified DFT can be computed as follows: (These 2 equations do not take into account the effect of thinning.)

$$\text{WFT} = \text{DFT} \times \frac{100}{\% \text{Solids}}$$

For two component systems, the percent solids of the mixed components must be used to calculate dry film thickness from wet film thickness. Wet film thickness is easily measured using a simple gage pressed into the film.

8.5.6 *Spraying Technique*

The applicator must select a proper spray pattern and band width before beginning work.

Stroking during spraying should be done with the gun wrist, arm, and shoulder at right angles to the work and moving parallel to it. This prevents “arcing” or varying the distance of the gun to the work, which results in a variation in coating thickness. See Figure 8-7 below.

Figure 8-7: Right and Wrong Techniques for Conventional Air Spray
(Courtesy of Binks Manufacturing Company)

Triggering should also be used during conventional air spraying to obtain a uniformly thick coating. The stroke of the spray gun should begin before the gun is triggered and continued after the trigger is released.

Spraying directly into corners may also result in thicker films of coating. It is safer to spray each side of the corner separately. Outside corners may be sprayed directly, as shown in Figure 8-8.

An easy turn directional spray nozzle (swivel adapter), with or without an extension, may be used to spray at a variety of angles to coat behind structural members or other places that are difficult to reach.

Figure 8-8: Spraying Edges and Corners
(Courtesy of Binks Manufacturing Company)

8.5.7 *Other Application Considerations*

Striping (localized brush application) is often specified for edges and other configurations that are difficult to coat (e.g., corners, crevices, rivets, bolts, welds, etc.). See Figure 8-9.

Proper, safe lighting should be used in tanks and other confined spaces to permit good applicator vision (see Unit 9-4). Also, light colored coatings will help with vision.

Of course, the applicator should always wear appropriate personal protective equipment with all coatings. This usually includes a respirator, gloves, and eye protection.

Figure 8-9: Instructions for Striping Edges
(Courtesy of US Naval Sea Systems Command)

8.5.8 Curing

Curing of coatings may occur very slowly in tanks and other confined spaces with little natural ventilation (Figure 8-10). Thus, it may be necessary to use ventilation and/or heat to achieve complete curing (see Unit 6).

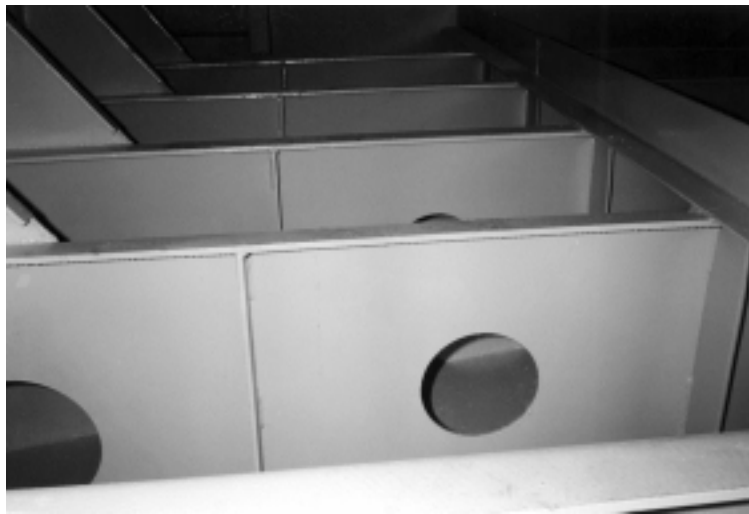


Figure 8-10: Newly Painted Tank Interior in Area of Limited Ventilation
(Courtesy of Todd Shipyard)

UNIT 9 SUPPORT EQUIPMENT

9.1 Introduction

Even with the finest materials and best trained work force, quality coating of ship interiors and exteriors cannot be achieved without vital support equipment. This section discusses ladders, scaffolding, lighting and utilities.

9.2 Ladders

Ladders are available in a variety of designs to meet specific worker needs to reach normally inaccessible places. Aluminum ladders have the advantage of being lighter in weight than other ladder materials. General requirements for ladders are found in OSHA 29CFR1926, Subpart X. These include:

- replace all loose, bent, split, or missing steps or rungs;
- place safety shoes on all straight and extension ladders;
- never use ladders as horizontal scaffold members;
- use ladders for worker transfer to a higher level only when top extends 3 feet (0.9 m) above point of support;
- rungs must be parallel and 10-14 inches (250-350 mm) apart;
- a minimum clearance of 7 inches (175 mm) behind and 30 inches (765 mm) on climbing side;
- ladders are required between working levels separated by 19 or more inches (483 mm);
- ladder safety training is required.

Both permanent and portable ladders are used aboard ships. Permanent (fixed) ladders must be capable of supporting 250 lbs (114 kg) and have a pitch of no more than 90 degrees. For ladders built after 1991, the rungs and steps must be corrugated, knurled, dimpled, coated with a slip-resistant material, or otherwise treated to minimize slipping. If multiple ladders sections are used, none shall exceed 50 feet (15m) in length.

The four most commonly used types of portable ladders aboard ships are step-ladders, single ladders, extension ladders, and trestle (including extension trestle) ladders.

Step-ladders are self-supporting, non-adjustable ladders ranging in height from 4 to 16 feet (1.2 to 4.9m). They usually have flat steps and a flat top or pail shelf on the back side. A hinged back frame and spreaders permit the ladder to be held and locked in place. Double step ladders have steps on both sides.

Single ladders (also called straight ladders) are not self-supporting but must lean against a fixed surface for support. They range in length from 6 to 20 feet (1.8 to 6.1m).

Extension ladders are formed from two simple (not single) ladders that slide within one another to extend to greater lengths (16 to 60 feet (4.9 to 18m). Most are equipped with a rope and pulley system for raising and lowering and have a latch to secure them in place (Figure 9-1).

Figure 9-1: Extension Ladder

(Courtesy of National Center for Construction Education and Research)

A simple trestle ladder is self-supported by two fixed sections of length with hinges and a spreader to secure it in a fixed position (Figure 9-2). Extension trestle ladders have a vertical section (e.g., a plank) extending between two trestle ladders to form a work platform. This section should overextend the two ladders by 3 to 6 feet (0.9 to 1.8 m).

Figure 9-2: Trestle Ladder

(Courtesy of National Center for Construction Education and Research)

9.3 Scaffolds

Workers conducting cleaning or coating application operations must be able to get close to their work if it is to be of high quality. Different equipment may be required for different situations. Most ship areas afford space for use of access equipment, but some confined spaces may limit the entry of larger pieces. General information on access equipment can be found in Industrial Painting Trainee Task Module 07402 “Ladders, Scaffolds, Lifts, and Fall Protection”.

A scaffold is a temporary framework built up from a solid surface or a suspended platform. It provides an upper structural member to support workers and necessary materials and equipment at a height not normally accessible. Most commonly used types aboard ships are built-up scaffolds, swing scaffolds and aerial lifts.

9.3.1 Built-Up Scaffold

Built-up scaffolds are assembled from a ground level at the work site to a maximum height of 125 feet (38 m). Most of the structural components are made of tubular steel designed to fit together as shown (Figure 9-3). General safety requirements for scaffolds includes:

- scaffolds securely in place;
- personnel must use fall-arrest equipment;
- rigid guard rails (never ropes) and toeboards or rails;
- keep platform clean and free of abrasive, mud, grease, and other debris;
- remove unnecessary equipment;
- keep platforms level at all times;
- regularly inspect and repair as necessary;
- never stand or sit on the top cap or paint shelf;

- never use an extension ladder upside down;
- never use a ladder on scaffolds to add extra height.

Figure 9-3: Parts of A Typical Built-Up Scaffold
(Courtesy of National Center for Construction Education and Research)

Pick boards are usually used on platforms during abrasive blasting to minimize the build-up of spent abrasive.

Rolling scaffolding which uses casters to permit easy movement to different locations has these additional requirements:

- Always set caster brakes when in a fixed position
- Never ride while moving
- Remove all materials from platform before moving

9.3.2 *Swing Scaffold*

A swing scaffold is often called a two-point suspension scaffold. It is suspended by ropes or cables that permits it to be raised and lowered. It provides a stable platform 20 to 36 inches (510 to 910 mm) in width (Figure 9-4). These platforms may be of wood or steel.

Figure 9-4: Swing Scaffold

(Courtesy of National Center for Construction Education and Research)

Additional requirements for swing (suspended) scaffolds include:

- Never permit them to swing freely
- Limit the number of personnel on them to two
- Always keep them level
- Follow OSHA requirements for suspension

Additional information on suspended scaffolds can be obtained from Scaffold Industry Association (SIA) documents “Suspended Scaffold Handbook” and “Safety Program for Suspended Scaffolds”.

9.3.3 Shipyard Experience

The type of scaffolding used by shipyards depends on the configuration and size of the tank, the availability of scaffold material and other uses of the scaffolding. At one yard visited, a contractor preferred swing staging to conventional wooden staging used by yard personnel. These consist of bed-spring type platforms that are secured to the support. Bed-spring platforms rest on eight-foot (2.4 m) sections of pipe, which are attached to a hanging wire rope. The ropes are supported at the top of the tank through rat holes via S-clips. This system has several advantages:

- Abrasives do not collect around the wooden slats
- The platform is secured to the pole supports and is therefore safer
- There is no need to weld or grind the supports inside the tank because they are supported from the top.

The bed-spring platform, however, may not be strong enough to support the weight of equipment used by other trades. Scaffolding is also required for welding and other installations (Figure 9-5).



Figure 9-5: Wooden Plank Scaffolding
(Courtesy of Todd Shipyard)

Swing staging is often used in Navy carrier tanks. Studs are frequently shot into the bulkhead to attach brackets for support of the staging. Some are kept in place for future use, while others are removed by grinding. Staging jacks (a type of arm) that hook over beams are sometimes used. Also used are portable anchorage clamps with a quick grab and lifeline secured to beams. Tank hatches are so small that tube and clamp staging is normally used.

9.3.4 Aerial Lifts

Aerial lifts are used to raise workers to high places normally inaccessible. The two main types are scissor lifts and boom lifts. Each type can be mounted on a vehicle or used without mounting. They can be used on both exterior and interior work, depending on design.

Scissor lifts raise a working platform vertically by means of crosslinked supports to reach a desired height. Some boom lift models permit

horizontal movements. Both types are usually powered electrically or hydraulically (Figure 9-6). Safety requirements for aerial lifts are found in OSHA 29CFR1962, subpart L. These include:

- Operate only with trained/authorized personnel
- Use only within operational limits (e.g., don't overload)
- Use only on a solid, stable surface (lock wheels on incline)
- Workers use appropriate personal fall arrest equipment
- Lower and lock in place before moving
- Keep platform clean
- Workers stand on floor/platform rather than leaning on guardrails

Figure 9-6: Aerial Lifts

(Courtesy of National Center for Construction Education and Research)

9.4 Lighting

Adequate lighting is essential for quality work and maximum productivity. It also increases worker motivation and reduces the risk of accidents. In the past, there was no accurate way to determine the amount of light at the surface, but today light meters are available to accurately measure the level of lighting.

The lighting standard of most concern for work in interior non-habitability ship spaces is the American National Standards Institute (ANSI) Z117.1,

“Safety Requirements for Working in Tanks and Other Confined Spaces”. It establishes minimum requirements for safe entry, continued work, and exit from tanks and other confined spaces.

After lighting levels have been established, portions of National Fire Protection Association (NFPA) 70 “National Electrical Code” and OSHA 29CFR1926.402-408 regulations on portable lamps and wiring must be addressed.

Lighting fixtures used in hazardous locations (i.e., where the potential for explosions and/or fires exists) must be explosion proof and approved by Underwriters Laboratory (UL) or Factory Mutual. Lighting fixtures in non-hazardous areas must be designed to UL Standard 298. Lighting fixtures in wet locations must be designed to ANSI/UL 1570, 1571, or 1572. Also, those having an electrical supply including service greater than 12 volts must be properly grounded, including ground fault circuit interrupter (GFCI) protection. An alternative is an integrated circuit breaker wired into the specific electrical line supplying the power to the light fixtures.

Areas requiring explosion-proof lighting, also called hazardous duty lighting, have been classified by OSHA (Figure 9-7). Classes I and II are most relevant for blasting and painting operations. Class I refers to the presence of combustible gases or vapors. Class II locations are considered hazardous because of the presence of combustible dust and fibers.

All lighting fixtures should be removed from any direct spray of paint, abrasives, or other materials. Paint overspray accumulation may reduce the amount of light emitted. Overspray may also reduce heat disbursement that might result in premature failure or overheating.

The GFCIs, plugs, integrated circuit breakers, and power cords and their connectors should be inspected periodically. Any worn or frayed cables should be repaired or replaced.

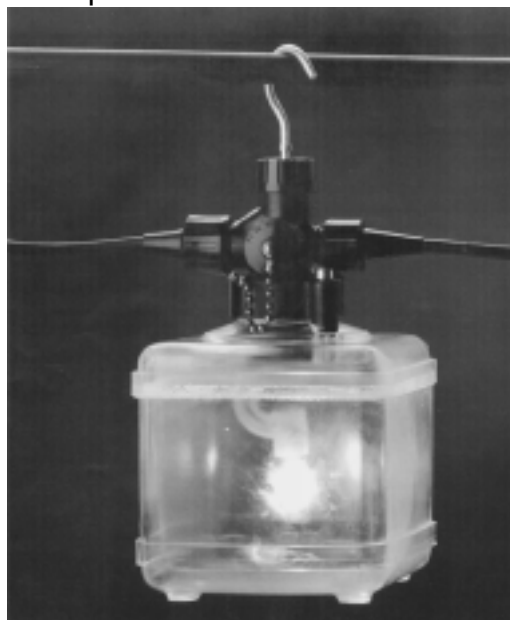


Figure 9-7: Hanging Explosion-Proof Light Box
(Courtesy of Western Technologies)

General guidance is available in SSPC-Guide 12 “Guide for Illumination of Industrial Painting Projects”. This guide provides information on the quantity and quality of lighting on industrial painting projects to achieve effective coatings work and to prevent accidents. The guide classifies locations for lighting as hazardous, non-hazardous, and wet, and provides specific recommendations for lighting under these conditions. Guidance is also given on the proper use and maintenance of lighting equipment including lighting fixtures, power cords and connectors, and repairs. An appendix to the guide defines the different types of hazardous locations (Figure 9-8).



Figure 9-8: Lighting in Tank
(SSPC File Photo)

9.5 Utilities

Utility support for coating work must be planned well in advance so that it will be available when needed.

9.5.1 *Air supply*

Compressed air must be available in pressures and volumes necessary for abrasive blasting and spray application of coatings. Normally, shipyards use large compressors and blast machines on the dock to meet all needs. On aircraft carriers and other large ships, they are sometimes placed on decks. They are not placed in interior spaces because of the toxic fumes generated. It may be necessary to cut holes in the hull to reach inaccessible places.

9.5.2 *Electric*

Electricity service must be available to meet the specific needs of all electrically powered equipment. Lighting normally requires 110 volts. Dehumidification equipment, compressors, and ventilation may require 220 or 440 volts, because these higher voltages are more economical. These units require from 20 to 100 amps.

9.5.3 *Water, fresh and salt water*

Fresh water must be available for water jetting and other cleaning operations in the required volumes and pressures. Sea-water is not normally used in these operations but may be used in aftercoolers for compressors or other special equipment.

UNIT 10 TREATMENT AND DISPOSAL OF WASTE

This unit presents the following topics:

- Sources of Waste
- Disposal and Treatment of Abrasive Waste
- Minimizing Solvent and Thinner Waste
- Reducing Paint Waste

10.1 Sources of Waste

Surface preparation and coating operations typically generate a variety of wastes. Some of these waste streams may be large (e.g., spent abrasives). These materials are listed in Table 10-1.

Table 10-1
Shipyards Wastes from Surface Preparation and Coating

Operation	Description/Composition of Waste
Blast cleaning with disposable abrasives	Spent abrasive (fractured particles, fines, and dusts), rust, millscale, old paint
Blast cleaning with recyclable abrasives	Reusable abrasive particles*; spent abrasive (fractured particles, fines, and dusts), rust, mill scale, old paint
Power and hand tool cleaning	Rust, mill scale, old paint
Chemical/solvent stripping	Liquid stripper residue, rust, mill scale, old paint
Wet abrasive blasting	Sludge consisting of water, spent abrasive (fractured particles, fines, and dusts), rust, mill scale, old paint
Water jetting	Water (if contained), with suspension of rust, mill scale, old paint
Cleaning paint equipment	Spent solvent and thinner
Solvent cleaning	Spent solvent, containers of oil- and grease-contaminated solvents; Rags and cloths contaminated with oil, grease, dirt and solvents
Solvent distillation	Still bottoms
Manual painting	Paint disposables (brushes, rollers)
Storing paint	Containers of partially used mixed/unmixed 2 pack paints or expired paint containers
Covering work area	Cloth, canvas and other materials used to contain coating operation
Containment	Tarps, panels and other materials used to contain surface preparation operation
Paint spraying in booths and dust collection	Filters contaminated with paint or dust and particles

* The recovered steel grit and shot particles are not considered waste.

Waste materials, like any shipyard materials, must be handled properly to protect the workers from health or safety hazards. Some wastes are considered hazardous wastes because they have the potential to seriously pollute the environment. EPA and local regulatory agencies have established very stringent procedures for handling hazardous wastes and for discharging water containing hazardous materials.

The procedures entail the following:

- Special protection of areas where hazardous waste is generated and stored
- Warning signs about the presence of hazardous waste
- Limits on the amount of hazardous waste that can be stored on site and the time it can be stored
- Special containers and labels for the waste
- Methods for sampling and testing the waste
- Training for workers who will handle the waste
- Preparing and retaining records of the type, amount and properties of the waste
- Restriction on treating or using the waste for other purposes

The shipyard, as generator of the waste, is responsible for complying with these rules. Even if a contractor removes the paint, the owner of the facility is responsible for hazardous waste. Almost all shipyards will have some individual specifically designated and trained to deal with the requirements of the hazardous waste. But it is useful to be familiar with the requirements that affect the surface preparation and coating operation. It is normally desired to minimize the amount of waste produced, especially hazardous waste. The need to reduce hazardous waste is often a factor in the selection of surface preparation methods and coating material and methods.

Which wastes are hazardous?

It is important to recognize which wastes are most likely to be classified as hazardous. The following shipyard materials may be hazardous wastes:

- Spent abrasives or paint waste: These wastes may be hazardous if the paint contains hazardous material, such as lead, chromate or organotin. Lead and chromate containing material is hazardous if the concentration in an acidic solution exceeds a specified minimum level. These concentration levels are most likely to be exceeded when using power tools or other non-abrasive blast methods to remove old coatings. In these instances, the lead or other hazardous material is more highly concentrated than when it is mixed with spent abrasive. For certain high-lead paints such as those pigmented with red lead, the entire volume of spent abrasive may be classified as hazardous. These paints are not commonly used in ballast and other tanks on ships.

Note: Organotin is not designated as a hazardous waste by EPA. However, because of its potential toxicity to humans and aquatic organisms, local and state regulatory agencies may impose special restrictions in handling and disposing of organotin-containing waste.

- **Used solvent or thinner:** Many commonly listed solvents are specifically listed by EPA as hazardous wastes because of their toxicity (e.g., many chlorinated solvents). Even non-listed solvents would most likely be classified as hazardous waste because of their ignitability. The materials should be placed in appropriate containers and labeled.
- **Partially used cans of paint:** These are designated as hazardous waste if the paints contain volatile solvents. The minimum volume required is 1 inch (25 mm) at the bottom of the container. If the paint is dried in the can, the container is not hazardous.
- **Still bottoms:** These are residues from distillation units used to recover solvent. The still bottoms of listed wastes are classified as hazardous waste.



Figure 10-1: Hazardous Waste Storage Area
(Courtesy of Todd Shipyard)

10.2 Disposal and Treatment of Abrasive Waste

As noted, if the waste is determined to be hazardous, it falls under a special section of EPA regulation known as Resource Conservation and Recovery Act (RCRA). Handling and disposal of such waste is much more costly for shipyards

10.2.1 *Determining if Waste is Hazardous*

If it is known or suspected that the waste may be hazardous, precaution must be observed in accordance with RCRA. SSPC Guide 7 "Guide for the Disposal of Lead-Contaminated Surface Preparation Debris" outlines the procedure for disposal of abrasive and other debris from surface preparation.

The first regulated activity is the collection of the waste. Precautions must be taken to prevent release of the hazardous material into the air, water or soil.

The waste must be placed in specially approved containers. Typical containers are leak-proof drums, portable bins, gondolas, supersacks or roll-offs. The containers must be kept out of flood plains. The containers must be labeled with the contents and their hazards using indelible ink. Waste may be transported to a temporary storage site. The storage site must be well drained and secured (e.g., fenced in). The containers must be arranged so the labels are visible at all times.

The waste can be stored at the generation site (the shipyard) for a maximum of 90 days for operations producing 2200 lbs. (1000 kg) or more of waste per month. A contingency plan and procedures for use in an emergency must be developed. Workers involved in handling and storage of hazardous waste must successfully complete a program of classroom instruction or on-the-job training that teaches them to comply with the regulations and to respond to emergencies.

The shipyard is also responsible for testing and analysis of the waste to determine if it is hazardous and to identify the hazardous constituents. This process is not necessary if it is previously known that the waste is hazardous.

The EPA has very specific rules for how to acquire a uniform representative sample. Normally a minimum of four samples is required for testing. The samples are sent to an accredited lab for analysis.

The EPA does not permit the direct disposal of hazardous waste. The options for a shipyard are:

- Ship the waste to a permitted treatment and disposal facility.
- Treat the waste on-site in accumulation containers to render it non-hazardous and then dispose of it as a non-hazardous waste.
- Reuse the waste as a raw material for another process with proper approval.

Each of these is discussed below.

10.2.2 *Off Site Disposal of Hazardous Waste*

The waste may be shipped to a permitted TSD (Treatment, Storage, Disposal) facility. In the vast majority of cases, the generator (i.e., the shipyard) does not have the resources, knowledge, or inclination to treat waste on-site and will use an outside service. The shipyard must inform the treatment facility of the quantity and hazardous nature of the waste. The waste must be hauled by a transporter licensed for hazardous waste. The generator must also prepare the paperwork (manifest) to document the full process for waste management. The generator is also required to obtain an EPA waste identification number from state or local officials. Additionally, the accepting companies may require testing to verify the spent abrasive is non-hazardous for metals.

Typical costs for off site disposal of hazardous waste range from \$100 to \$400 per ton (\$110 to \$440 per metric ton (tonne)). These costs depend on the distance to the disposal site, state fees, the specific contents, the weight and number of competitors.

10.2.3 *Treat Waste On-Site*

Generators can treat the waste on-site in 90-day holding containers or tanks. This operation must be approved by the state or regional EPA office. A waste analysis plan must be submitted prior to treatment.

A number of treatment methods have been used on lead-containing debris. These procedures are required to result in the treated waste having leachable lead levels below 5 mg/liter when measured by TCLP (Toxicity Characteristic Leaching Procedure). These processes are typically based on mixing the waste with Portland cement, lime, lime-fly ash, or silicates. Proprietary commercial treatments are available.

10.2.4 *Reuse Waste*

Another recycling option for spent blast abrasive is use of the material as an ingredient in a manufacturing process. In particular, spent blast abrasive has been used as an ingredient in the production of cement, asphalt, and concrete. Although this option may be viable, shipyards must be aware of the regulatory consequences of using hazardous, spent abrasive in this manner. Shipyards must demonstrate that spent blast abrasive is a legitimate ingredient for the product, that the material is not being reclaimed, and that the product is not being used in a land-applied manner.

Several shipyards have reported shipping waste abrasives for reuse at asphalt plants or concrete kilns. The collected abrasive may require some special handling in order to remove shipyard debris (welding rods, fasteners, grinding

wheels, etc.). Some wastes may contain enough lead to make it economical to recycle at lead smelters. The waste is incinerated and the lead re-melted for use in batteries. A recent NSRP report (0529) analyzed the economics of reusing abrasive. The analysis indicated a potential savings for reuse of coal slag versus disposal.

10.2.5 *Disposal of Non-Hazardous Waste*

Federal EPA does not regulate non-hazardous waste. Accordingly, the waste can be disposed of in an industrial landfill. Some states, however, have restrictions on disposal of industrial waste (e.g., California, Virginia).

Typical costs for disposal of non-hazardous waste range from \$20 to \$100/ton (\$22 to \$110/tonne). These costs must be included in the overall cost of using abrasive for blast cleaning. Large yards generating 10,000 - 20,000 tons (9,000 to 18,000 tonnes) of abrasive per year spend an average of \$30 to \$40/ton (\$33 to \$44/tonne) for disposal. This overall average is about \$55/ton (\$61 tonne).

Caution on disposal of steel grit containing lead paint

Recyclable steel grit is often used to remove lead paint. Because the abrasive is recycled 50 or more times, the volume of waste is greatly reduced. This waste may have a relatively high concentration of lead. This waste, however, often tests as non-hazardous, based on EPA's designated test (TCLP). In this test, a chemical reaction between the lead and the steel grit results in a very low concentration of lead in the acidic solution, so the waste is "non-hazardous". EPA has, however, noted that this reaction may be reversed when the waste is placed in a landfill. This reaction eventually may result in an increased likelihood of lead leaching from the landfill. To avoid this potentially risky scenario, some organizations handle and treat all lead waste mixed with steel grit as hazardous. These organizations believe this practice avoids the potential risk of being held liable for cleaning up a landfill at some future time in which lead leaches as the steel oxidizes and resolubilizes the lead.

10.2.6 *Reducing the Volume of Abrasive Waste*

Minimizing the amount of waste produced will significantly reduce the cost and time of waste disposal. Recent studies have demonstrated that more efficient operation of blast machines (e.g., by proper use of abrasive metering valves) can reduce the consumption of abrasives by 30% or more. As discussed previously, abrasives can be recycled ranging from three or four times for garnet to 50 or more times for steel grit. This recycling results in a proportionate reduction in waste.

Waste disposal costs can also be reduced by segregating wastes. Following abrasive blasting, the spent media is usually contaminated with trash and other industrial debris (welding rods, scrap, wood, pallets, etc.). Personnel involved in

cleanup should remove any trash or debris that will be entrained with the blast medium during clean-up. Gross trash removal can be accomplished by placing screens over skip boxes/containers in the drydock or abrasive blasting area. Trash and debris will be removed by the screen as the spent media is loaded into skip boxes.

10.3 Minimizing Solvent and Thinner Waste

Shipyards use solvents in a variety of cleaning and degreasing operations including parts cleaning, process equipment cleaning, and surface preparation for coating applications. Some of the major solvents used are petroleum distillates, oxygenated solvents (esters, ethers, ketones, and alcohols), and halogenated solvents.



Figure 10-2: Solvent Waste Storage Area
(Courtesy of Todd Shipyard)

10.3.1 *Eliminating or Reducing the Use of Solvents*

Eliminating the use of solvents avoids any waste generation associated with spent solvent. Elimination can be achieved by utilization of non-solvent cleaning agents or eliminating the need for cleaning altogether. Non-solvent based paint stripping methods are viable substitutes for solvent stripping. The alternatives to solvent stripping agents include aqueous stripping agents, use of plastic media, cryogenic stripping, and thermal stripping.

Methods of reducing solvent usage can be divided into three categories: control of air emissions at the source, efficient use of solvent and equipment, and maintaining solvent quality. Source control of air emissions addresses ways in which more of the solvent can be kept inside a container or cleaning tank by reducing the chances for evaporation loss. Efficient use of solvent and equipment through better operating procedures can reduce the amount of solvent required for cleaning. Maintaining the quality of solvent will extend the life-cycle effectiveness of the solvent.

10.3.2 *Solvent recycling*

There are several options available for recycling solvent waste. The final cost of solvent used for various cleanup operations is estimated at nearly twice the original purchase price of the virgin solvent. The additional cost is primarily due to the extra costs for disposal, transportation, and manifesting. With the rising cost of solvents and waste disposal services, combined with continuously developing regulation, recycling waste solvents has become more important.

Increasing the recyclability of solvents can be achieved by maintaining the quality of the solvent, standardizing the solvents used, and consolidating the use of solvent within the facility. Maintaining solvent quality can be viewed as a measure that will reduce the amount of solvent used, as solvent quality is much more critical when solvents are recycled.

Solvents can be recovered either on-site or off-site. The decision to recycle on-site or off-site usually depends upon the capital outlay and operating cost, volume of solvent waste generated and personnel requirements.



Figure 10-3: Solvent Recycling Unit
(Courtesy of Waste Management, Inc.)

10.3.3 *On-Site Recovery*

The decision to procure, install, and operate an on-site recovery system must be based on a complete analysis of the technical and economical feasibility of the system. The analysis must also consider operational issues such as ease and safety of operation.

Advantages of on-site recycling are:

- ` reduced solvent purchase demand
- ` less waste leaving the facility, and thus reduced disposal cost
- ` owner's control of the purity of the reclaimed solvent
- ` reduced liability and cost of transporting off-site
- ` reduced reporting (manifesting)
- ` possible lower unit cost of reclaimed solvent

Disadvantages of on-site recycling are:

- ` initial capital outlay for recycling equipment
- ` liabilities for worker health, fires, explosions, leaks, spills, and other risks as a result of improper equipment operation
- ` need for operator and worker training
- ` additional maintenance and operation cost
- liability and insurance costs

There are various methods available for solvent recovery. The feasibility of most methods depends upon operational requirements and upon the ways in which the wastes are generated.

Distillation is the oldest and by far the most commonly used technique utilized for solvent recovery. There are many different stills that are commercially available. Capacities range from 0.8 to 100 gallons (3.0 to 380 liters) per cycle and clean solvent output rates from 1 to 120 gallons (3.8 to 450 liters) per hour.

In most cases, the purchase of a solvent still will result in almost immediate savings. Shipyards generating large amounts of solvent waste will realize the most benefits. If the facility produces very small amounts of solvent waste, it may not be practical to purchase a still. According to a recent NSRP study, on-site solvent recycling can be cost justified for shipyards that generate as little as 200 gallons (760 liters) of waste solvents monthly. This survey confirmed that a broad selection of distillation equipment is available to meet shipyard needs. An equipment supplier has suggested that this amount can be as low as 50 gallons (190 liters) per month.

The study further noted that:

- all respondents with recycling systems are utilizing the distillation method, either with or without vacuum assistance,
- still capacities range from 15 to 65 gallons (57 to 250 liters), and the average capacity is 35 gallons (130 liters),
- the average production efficiency, or recovery rate, for the distillation units is about 70%. That is, for every 10 gallons (38 liters) of liquid solvent waste put in, 7 gallons (27 liters) are recovered as reusable solvent. Manufacturers typically advertise (ideal) recovery rates over 90%.

No special license is required by the EPA to operate a solvent still on-site. If the still has a capacity of more than 5 gallons (19 liters), it may be regulated by the local Air Pollution Control District (APCD) and a permit may be required.

One jurisdiction required a shipyard to produce MSDS sheets for each batch of solvent waste produced. The regulatory agency considered each batch to be a new product. This requirement greatly increased the shipyard's cost for onsite recycling. Another concern is increased fire risk and liability.

10.3.4 *Off-Site Recycling*

Off-site commercial recycling services are well suited to small quantity generators, which do not create sufficient volumes of waste solvent to justify on-site recycling. Off-site recycling is also used by generators who prefer to avoid the technical, economic, and managerial requirements of on-site recycling. The disadvantages of off-site recycling are the high transportation and liability costs. Additionally, liability associated with the disposal of the still bottoms is another concern.

10.3.5 *Solvent Treatment and Pretreatment*

Treatment refers to the processes that alter the waste and yield waste streams that pose little or no environmental risk. The increasing cost for disposal and the associated liabilities can make treatment a feasible option. Waste treatment systems are often costly and the decision to rely on treatment should only be made after considering all available source reduction and recycling options.

Treatment technologies involve the removal of solvents from wastewater streams by physical means, the destruction of solvents in wastewater by biological or chemical means, and the destruction of solvent waste by thermal techniques.

10.4 **Reducing Paint Waste**

In many shipyards, paint waste may account for more than half of the total hazardous waste generated. Paint waste at a shipyard may include leftover sludge in paint containers, overspray, paint that is no longer usable (non-spec paint), still bottoms from recycled cleaning solvents, and rags and other materials contaminated with paint. In many cases, the amount of paint waste generated

can be reduced through the use of improved equipment, alternative coatings, and good operating practices.

Through the use of paint application equipment with high transfer efficiencies, the amount of paint lost to overspray is minimized. A good manual coating application technique is very important in reducing waste. Most shipyards rely primarily on spraying methods for coating application. If not properly executed, spraying techniques have a high potential for creating waste; therefore, proper application techniques are very important.

One of the most common means of producing paint waste at shipyards is overspray. Overspray not only wastes some of the coating, it also presents environmental and health hazards. It is important that shipyards try to reduce the amount of overspray as much as possible.

A major effort must be made to keep inventories at a minimum. Large inventories of paint can lead to a large disposal cost of paint that has aged and no longer meets specifications. Regulatory changes to the allowable VOC emissions limits may make a coating obsolete. Small quantities are often lost daily due to poor housekeeping techniques. There are various ways to control and minimize spills and leaks. Specific approaches to product transfer methods and container handling can effectively reduce product loss.

The potential for accidents and spills is at the highest point when thinners and paints are being transferred from bulk drum storage to the process equipment. Spigots, pumps, and funnels should be used whenever possible. Evaporation can be controlled by using tight fitting lids, spigots, and other equipment. The reduction in evaporation will increase the amount of available material and result in lower solvent purchase cost.

A large amount of paint waste is generated by the paint that remains inside empty cans, and by paint that becomes outdated or non-spec. Shipyards should try to consolidate paint use to facilitate the purchase of paint in bulk. Since a large bulk container has less surface area than an equivalent volume of small cans, the amount of drag-on paint waste is reduced. Large bulk containers can sometimes be returned to the paint supplier to be cleaned for reuse.

If the purchase of paint in bulk containers is not practical, the paint should be purchased in the smallest amount required to minimize leftover paint. Workers should not have to open a gallon can when only a quart is required. Usually, any paint that is left in the can will require disposal as hazardous waste.

There are some fairly inexpensive technologies available for the minimization of solid and liquid waste that result from the use of water wash spray booths. In the past, the waste water from spray booths was disposed of in the sewer.

Regulatory changes now require these wastes to be disposed of at a proper treatment facility.

The water used to capture overspray should not be disposed of as hazardous waste except in extreme cases. The paint particles can usually be extracted and the water reused. By using a centrifuge separator, the paint sludge can be removed.

Dry filter booths are increasingly replacing the conventional water wash booth. Dry filter panels are used only once before requiring disposal. The filters themselves will often constitute more of the volume of a drum of waste than the paint.

UNIT 11 OTHER TOPICS

This unit discusses the following topics:

- Safety in Confined Spaces
- Pressure Testing of Tanks
- Microbiologically Influenced Corrosion (MIC)

11.1 Safety in Confined Spaces

11.1.1 *Introduction*

Working in tanks and other confined spaces at shipyards presents significant safety and health hazards. The activities of blast cleaning and coating application are also inherently hazardous. All the greater caution is therefore needed when these operations are conducted inside tanks. All shipyards have dedicated safety departments or programs which provide detailed protocols and training on various shipyard operations.

This section will review major points for working in confined spaces. Other units in this handbook provide some information for other safety and health issues. For further guidance, please consult the shipyard safety manuals and OSHA standards and guidance documents.

The following shipboard and land-based spaces are considered to be confined spaces:

- Spaces that have been sealed;
- Spaces that have been coated or painted and closed up, or non-ventilated spaces that have been freshly painted;
- Spaces that contain materials or residues of materials that create an oxygen-deficient atmosphere;
- Spaces and adjacent spaces that contain or have contained combustible or flammable liquids, gases, or solids;
- Spaces and adjacent spaces that contain or have contained liquids, gases, or solids that are toxic, corrosive, or irritant;
- Spaces and adjacent spaces that have been fumigated.

11.1.2 *Overview of OSHA Standard*

Shipyard activities are specifically regulated under OSHA Title 29 CFR 1915. The portions that pertain to work in confined space are designated “Confined and Enclosed Spaces and Other Dangerous Atmospheres in Shipyard Employment; Final Rule - 59:37816-37863”.

The subparts 1915.11 through 1915.16 are listed in Table 11-1 below.

Table 11-1
OSHA Subparts for Confined Space Work at Shipyards

SUBPART	TITLE
1915.11	Scope and Application
1915.12	Precautions and the order of testing before entering confined spaces
1915.13	Cleaning and other cold work
1914.14	Hot work
1914.15	Maintenance of safe conditions
1914.16	Warning signs and labels

The following summary is derived from OSHA's web site:

Subpart B of Part 1915 sets out requirements for safe entry into and work in shipyard confined spaces, enclosed spaces, and other dangerous atmospheres. The provisions of this subpart apply to spaces that might contain oxygen-deficient, oxygen-enriched, flammable, or toxic atmospheres. Examples of such spaces include spaces that have been sealed, spaces that contain or have contained materials that are flammable, toxic, corrosive, or irritant, and spaces that are adjacent to these spaces.

The revised subpart B uses a two-tiered approach for evaluating the hazards posed by confined spaces. The initial evaluation of all spaces is performed by a shipyard competent person. When this evaluation discovers hazards greater than those that a competent person is capable of handling, the services of a Marine Chemist or certified industrial hygienist are necessary.

If the tests demonstrate that it is safe, then employees may enter the space. If the tests show that it is not safe, then the space must undergo further evaluation by a Marine Chemist or certified industrial hygienist. This space must be designated as "Not Safe for Workers - Enter with Restrictions," for example when ventilation is necessary to maintain flammable concentrations below 10 percent of the lower explosive limit of a gas or vapor. (See Unit 6.)

Employees who enter confined or enclosed spaces or dangerous atmospheres must be trained to perform their work safely. In addition, employers must provide for rescue, either by having an on-site rescue team or by arranging for the use of outside rescue services.

A space that has contained a flammable or toxic substance must be cleaned before it can be made "Safe for entry" without restrictions. The final rule sets requirements for performing the necessary cold work (such as cleaning, scraping, inspecting the structure, and surveying the space). This work is often done to prepare the spaces for hot work.

First, residues of hazardous materials must be removed (for example, flammable liquids are pumped out, then the space is cleaned). The atmosphere within the space must be tested for flammability. These tests must be repeated as often as necessary throughout the course of work to ensure that the concentration of flammable gases and vapors is in a safe range.

If hot work is to be performed, confined spaces are classified in two groups. If the spaces contain or have contained flammable liquids or gases or if the spaces are adjacent to such spaces, then a Marine Chemist or Coast Guard authorized person must test and certify the space as safe for hot work. Other types of confined and enclosed spaces and hazardous atmospheres must be tested for safety by a competent person before hot work is allowed.

The standard also contains provisions for maintaining safe conditions. The space must be tested periodically to ensure that safe working conditions are maintained.

The standard sets requirements for the posting of confined and enclosed spaces and dangerous atmospheres. The signs must be understood by all employees working in the area. The signs must be posted at the means of access to the work area.

11.1.3 *OSHA Compliance Assistance Guidelines*

The following guidelines were extracted from Appendix A of 1915 Subpart B: [59 FR 37816, July 25, 1994]

This Appendix is a non-mandatory set of guidelines provided to assist employers in complying with the requirements of this subpart. This Appendix neither creates additional obligations nor detracts from obligations otherwise contained in the standard. It is intended to provide explanatory information and educational material to employers and employees to foster understanding of, and compliance with, the standard.

Sections 1915.11 through 1915.16. are minimum safety standards for entering and working safely in vessel tanks and compartments.

- Section 1915.11(b) Definition of “hot work.” There are several instances in which circumstances do not necessitate that grinding, drilling, or abrasive blasting be regarded as hot work. Some examples are:
 1. Abrasive blasting of the hull for paint preparation does not necessitate pumping and cleaning the tanks of a vessel.
 2. Prior to hot work on any hollow structure, the void space should be tested and appropriate precautions taken.

- Section 1915.12(a)(4). After a tank has been properly washed and ventilated, the tank should contain 20.8 percent oxygen by volume. This is the same amount found in our normal atmosphere at sea level. However, it is possible that the oxygen content will be lower. When this is the case, the reasons for this deficiency should be determined and corrective action taken.
- Section 1915.12(b)(4) Flammable atmospheres. Atmospheres with a concentration of flammable vapors at or above 10 percent of the lower explosive limit (LEL) are considered hazardous when located in confined spaces.

Atmospheres with flammable vapors below 10 percent of the LEL, however, are not necessarily safe. Such atmospheres are too lean to burn. Nevertheless, when a space contains or produces measurable flammable vapors below the 10 percent LEL, it might indicate that flammable vapors are being released or introduced into the space and could present a hazard in time. Therefore, the cause of the vapors should be investigated and, if possible, eliminated prior to entry.

- Section 1915.12(b)(6) Flammable atmospheres that are toxic. An atmosphere with a measurable concentration of a flammable substance below 10 percent of the LEL may be above the OSHA permissible exposure limit for that substance. In that case, refer to 1915.12(c) (2), (3), and (4).
- Sections 1915.13(b)(4), 1915.15(c), and 1915.15(e). Monitoring. The frequency with which a tank is monitored to determine if atmospheric conditions are being maintained is a function of several factors that are discussed below:
 1. Temperature. Higher temperatures will cause a combustible or flammable liquid to vaporize at a faster rate than lower temperatures. This is important since hotter days may cause tank residues to produce more vapors. That situation may result in the vapors exceeding 10 percent of the LEL or an overexposure to toxic contaminants.
 2. Work in the tank. Any activity in the tank could change the atmospheric conditions in that tank. Oxygen from an oxy-acetylene hose or torch could result in an oxygen-enriched atmosphere that would more easily propagate a flame. Manual tank cleaning with high pressure spray devices can stir up residues and result in exposures to toxic contaminants.
 3. Period of time elapsed. If a period of time has elapsed since a Marine Chemist has certified a tank as safe, the atmospheric condition should be rechecked by the competent person prior to entry and starting work.

4. Unattended tanks or spaces. When a tank or space has been tested and declared safe, then subsequently left unattended for a period of time, it should be retested prior to entry and starting work.
5. Work break. When workers take a break or leave at the end of the shift, equipment sometimes is inadvertently left in the tanks.

11.1.4 *Shipyard Guidelines*

The following guidelines are reprinted with permission from Module 2, “Housekeeping and Safety” of Newport News Shipbuilding training manual on “Coating & Application Systems.”

- Hot Work Permits are required for any operation involving an electric arc or open flame from a torch, such as during aluminum wire spray. Additionally, grinding and sand blasting can be considered hot work under certain conditions as defined in the Fire Prevention and Control Manual. An example of this is grinding and sand blasting on the boundaries of tanks containing combustible or flammable liquids.
- Cold Work Permits are required for operations involving the use of flammable or combustible materials. Cold work permits are not required unless work involves the use of paint containers larger than one gallon (3.8 liters), or spray painting.
 - * Prior to completing a cold work permit, the requesting supervisor shall personally inspect the space to ensure that safe working conditions exist and that the appropriate precautionary methods have been taken.
 - * In areas that do not specifically require the use of a cold work permit (e.g., off-ship sites/buildings), the immediate supervisor and the controlling departments are responsible for ensuring that cold work is performed in a safe and responsible manner.
- Marine Chemist Permits are required for:
 - * Entry into confined spaces (sign posted at entry)
 - * The use of paints with a flash point below 80°F (27°C)
 - * Approving Hot Work Permits under certain conditions

Lastly, before sending workers out to the job site, consider and address the following issues:

1. Have the Occupational Hazard Assessment (OHA) and Job Safety Analysis (JSA) been reviewed?

2. Is a new JSA needed?
3. Do you need to review the Industrial Hygiene Manual?
4. Are the appropriate shipboard areas posted?

11.2 Pressure Testing of Tanks

There are two basic types of pressure tests which are used to prove tank tightness (leak free condition). These are:

- Compressed Air
- Water

In most cases, the tank tightness test must be accomplished after the tank has been welded out but before the coating system has been applied. Most owners and regulatory agencies allow for primer application prior to tank testing. The full coating system is perceived to mask pin holes in welds and thus possibly invalidate the pressure test. In addition, if leaks are discovered after the full coating system has been applied, repair of the coating system is more difficult.

Compressed air or other compressible gas results in less corrosion of bare weld areas. They have the least effect on the subsequent coating system application provided oil and moisture free air is used for the test. Filters should be used on the compressed air line providing air to the tank to reduce contamination to the primer coat. Filtering reduces the man-hours required to clean the primed substrate prior to finish coating activities. Many times the light coat of fine oil mist will not be visible on the primed or bare surfaces.

If water is used, and if allowed by the contract, pressure testing should be accomplished after the tank lining operation is complete and cured (generally seven days).

When the tank is pressure tested prior to lining application, care must be exercised in the selection of the test water. Only treated, potable fresh water should be used. Salt water will contaminate the substrate and require a fresh water rinse prior to beginning the lining application. This fresh water rinse is not always effective in removing all salt contamination. Untreated water can result in biological and other forms of contamination. A biocide treatment may be necessary along with the fresh water rinse.

The important point when selecting the pressure test technique is to reduce the level of contamination of the primed substrate which can occur during the test. Reduced contamination and rusting of weld areas equate to reduced surface preparation prior to lining application.

11.3 Microbiologically Influenced Corrosion (MIC)

Microbiologically influenced corrosion (MIC) commonly occurs on most alloys used in industry. It may significantly corrode the steel in ship tanks and other confined spaces. Its extent and associated costs have only relatively recently been considered. This is because MIC is difficult to detect and measure using traditional corrosion monitoring technology.

What is MIC?

MIC is a specific type of corrosion resulting from the activities of microbiological communities, not single types of organisms. These communities prefer to exist in “slimes” or “biofilms”. The sources of these organisms may be the ground, sea water, or crude oils.

MIC microorganisms in biofilms generally consist of a mixture of aerobic (oxygen-requiring) and anaerobic (requires no oxygen) species. The aerobic microorganisms usually utilize hydrocarbons as fuel to produce corrosive organic acids and gases. Anaerobic microorganisms reduce sulfate that is naturally present in sea water to produce corrosive sulfides.

MIC producing communities prefer to live attached to metal surfaces rather than in a hydrocarbon or water phase, although they require each for growth. Condensation water in tanks may provide some of the necessary water.

How do MIC microorganisms get their energy (food)?

MIC producing microorganisms most commonly use hydrocarbon fuels as a source of energy. Others may utilize hydrogen, simple organic acids, or sulfur containing organic material.

What does MIC look like?

MIC usually causes localized corrosion (pitting) rather than general corrosion. While this may not result in the loss of significant amounts of metal weight, it may cause serious penetration of bulkheads and piping.

Where is MIC likely to occur?

MIC most commonly occurs in oil production and distribution facilities. The responsible organisms can thrive in the bottom water layer of oil cargo tanks and in sediments at the bottom of ballast tanks. Sulfate-reducing bacteria can only grow in oxygen deficient areas.

How can MIC be controlled?

- Chlorination and the biocide glutaraldehyde may be used to kill MIC-producing microorganisms in an empty tank or other confined space. However, it is not practical to use either of these methods in filled ballast tanks.
- Cleanliness (housekeeping) that prevents accumulation of dirt or sludge will also discourage the introduction and growth of MIC producing microorganisms. They are not usually found in clean tanks of distilled fuels.
- As water is necessary for growth of these microorganisms, steel surfaces should be kept as dry as possible.
- Anaerobic sulfate reducing bacteria cannot grow in the presence of oxygen, so oxygenation may control their growth.
- Durable coatings such as epoxy or coal-tar epoxy may provide protection against MIC by isolating destructive microorganisms from steel surfaces, as long as these coatings remain intact.

What is the effect of MIC on cathodic protection?

The presence of microbiological films on cathodically protected metal surfaces appears to increase the current density requirements necessary to polarize the metal to the protection potential. It does not seem, however, that these microorganisms accelerate corrosion during periods when the cathodic protection is interrupted or discontinued.

UNIT 12 RESOURCE MATERIALS & ACKNOWLEDGMENTS

12.1 National Shipbuilding Research Programs (NSRP) Reports

- NSRP 0272, Peart, J.W. for National Steel and Shipbuilding Company (NASSCO), Prototype Mineral Abrasive Reclaimers, Shipyard Operation, March 1, 1987
- NSRP 0378, National Shipbuilding Research Center and Petersen Builders, Solvent Recycling for Shipyards, May 1993
- NSRP 0387 National Shipbuilding Research Center and Petersen Builders;, Feasibility Study: Tank Blasting Using Recoverable Steel Grit, July 1, 1993
- NSRP 0418 National Shipbuilding Research Center and Petersen Builders, National Steel and Shipbuilding Company, Hazardous Waste Minimization Guide for Shipyards, January 1, 1994
- NSRP 0447 National Shipbuilding Research Center and Petersen Builders; Levine Fricke, Inc. The Effectiveness of Power Tool Cleaning as an Alternative to Abrasive Blasting, June 1, 1995
- NSRP 0499 National Shipbuilding Research Center and Petersen Builders, Hitzrot, H. W. for Avondale Industries, Reduced Volume of Spent Abrasive in Open Air Blasting, December 1, 1997
- NSRP 0515 National Shipbuilding Research Center and Petersen Builders, Austin Environmental Inc. Solid Waste Segregation and Recycling, March 1, 1998
- NSRP 0520 National Shipbuilding Research Center and Ocean City Research Corporation. Productivity Study Hydroblast Removal of Coatings, December, 1998
- NSRP 0529 National Shipbuilding Research Center, US Naval Surface Warfare Center, and National Steel and Shipbuilding Company. Feasibility and Economics Study of the Treatment, Recycling and Disposal of Spent Abrasives, April 1999.
- NSRP Procedure Handbook Surface Preparation and Painting of Tanks and Closed Areas, US Department of Transportation and Avondale Shipyards, Inc., 1981

12.2 SSPC Publications

12.2.1 SSPC Guides and Standards

- SSPC SP 1- Solvent Cleaning
- SSPC SP 2 – Hand tool Cleaning
- SSPC SP 3 – Power Tool Cleaning
- SSPC SP 5 -/NACE 1 – White Metal Blast Cleaning
- SSPC SP 6/NACE 3 – Commercial Blast Cleaning
- SSPC SP 8 – Pickling
- SSPC SP 10/NACE 2 – Near-White Blast Cleaning
- SSPC SP 11 – Power Tool Cleaning to Bare Metal
- SSPC-SP 12 / NACE No. 5 - Surface Preparation and Cleaning of Steel and Other Hard Materials by High- and Ultrahigh-Pressure Water Jetting Prior to Recoating
- SSPC-AB 1 - Mineral and Slag Abrasives
- SSPC-AB 2 - Specification for Cleanliness of Recycled Ferrous Metallic Abrasives
- SSPC-AB 3 – Newly Manufactured or Re-Manufactured Steel Abrasives
- SSPC/NACE TU 7 on “Dehumidification & Temperature Control During Surface Preparation, Application, and Curing for Coatings/Linings of Steel Tanks, Vessels, and Other Enclosed Spaces”
- SSPC-TR 2 / NACE 6G198 - Joint Technical Report, Wet Abrasive Blast Cleaning
- SSPC-Guide 7 - Guide for the Disposal of Lead-Contaminated Surface Preparation Debris

- SSPC-Guide 12 – Guide for Illumination of Industrial Painting Projects

12.2.2 *Other SSPC Documents*

- SSPC T-25 Tutorial on “Controlling Humidity and Temperature for Abrasive Blasting, Coating, and Curing, 1995
- “Hand and Power Tool Cleaning” (Chapter 2.6), Steel Structures Painting Council Manual, Vol. 1 Good Painting Practice, 1995
- SSPC C-3, Supervisor/Competent Person Training for Deleading of Industrial Structures, 1995 version
- SSPC C-7, Fundamentals of Dry Compressed Air Abrasive Blast Cleaning (Training Course, 1999)

12.3 **Technical Articles**

- Caldwell, Mike, “Selecting and Maintaining Air Dryers for Use with Blast Equipment,” Journal of Protective Coatings and Linings, September 1994, pp. 56-63
- Eia, Bjarne, “Re-Coating of Tanks at Sea,” The Proceedings of PCE '99 Conference and Exhibition, Achieving Quality in Coating Work, Brighton, England, March 10-12, 1999, p. 357
- Fultz, Benjamin S., “Retaining Preconstruction Primers under Standard Lining Systems,” Journal of Protective Coatings and Linings, February 1999, pp. 30-44
- Henderson, M., “UHP Waterjetting on Vessels While at Sea,” Protective Coatings Europe, November 1998, pp. 16-19
- JPCL Staff, “Portable Dust Filter Used To Clean Exhausted Blasting Air,” Journal of Protective Coatings and Linings, October 1987. p. 7
- Kline, Eric; Mort, Greg; and LeComte, Jerry, “Improved Productivity from New Blast Nozzle Geometry,” The Proceedings of the 1987 SSPC Symposium, Improving the Field Reliability of Protective Coatings, Orlando, FL, Nov. 2-5, 1987, pp. 114-131

- Kuljian, Gordon G. and Melhuish, Darren C., "Water-Jetting Productivity Study for the Marine Industry," The Proceedings of SSPC 98 Seminars, Increasing the Value of Coatings, Orlando, FL, November 15-19, 1998, pp. 220-231
- Lee, Rick, "Keeping Abrasive Dry: A Review of Recent Technology," Journal of Protective Coatings and Linings, September 1993, pp. 52-58
- PCE Staff, "Preparing Ballast Tanks by Electrolytic Descaling," Protective Coatings Europe, November 1997, pp. 9-11
- Ray, Kevin, "Tips on Installing and Maintaining Compressed Air Filters: Maintenance Tips," Journal of Protective Coatings and Lining, July 1994, pp. 85-88, 91-95
- Seavey, Marshall, "Abrasive Blasting Above 100 PSI," Journal of Protective Coatings and Linings, July 1984, pp. 26-37
- Seavey, Marshall, "Dust Collector Efficiency: A Model for Suggested Standards," Journal of Protective Coatings and Linings, November 1996, pp. 40-43
- Settles, Gary S. and Geppert, Stephen T., "Redesigning Blasting Nozzles to Improve Productivity," Journal of Protective Coatings and Linings, October 1996, pp. 64-72
- Shannon, Michael J., "Maintenance Tips: Understanding and Selecting Dust Collectors," Journal of Protective Coatings and Linings, May 1996, pp. 37-42
- Wyatt, Charles H. and Crowe, Andrew R., "Dehumidification in Closed Loop Systems," Materials Performance, May 1996, pp. 34-38

12.4 Other Resources

12.4.1 *Manuals and Product Literature*

- Industrial Ventilation: A Manual of Recommended Practice, 21st Edition, American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 1992
- ATS Inc. Brochure on Series 2000 Desiccant, ATS, 1572 Tilco Drive, Frederick, MD 21704, November 1996
- Carrier Psychrometric Chart: Normal temperatures (definitions and examples), Carrier Corporation, P.O. Box 4808, Syracuse, NY

- “Clean Alternatives to Sandblasting”, Lt. Kent W. Kettell, Shipyard Report Puget Sound Naval Shipyard, December 1995
- “Lead-Containing Paint Removal, Containment, and Disposal”, (L. Smith and G. Tinklenberg) FHWA Report RD 94-100, Federal Highway Administration, McLean, VA, 1994
- Naval Ships’ Technical Manual 631, US Naval Sea Systems Command, Crystal City, VA
- Uniform Industrial Process Instruction (UIPI) No. 6311.455, US Naval Sea Systems Command, Crystal City, VA
- Munters Bulletin 400 - Psychometric Chart and Performance Figures, Munters Moisture Control Services, 79 Monroe Street, Amesbury, MA, 01913, 1978
- “Blast-Off: Your Guide to Safe and Efficient Abrasive Blasting”, Second Edition, Clemco Industries, One Cable Car Drive, Washington, MO, 63090, 1994

12.4.2 *OSHA Standards Cited:* (OSHA, 200 Constitution Avenue, Washington, DC 20210)

- 29 CFR 1910 Occupational Safety and Health Standards for General Industry
 - * Subpart G - Ventilation (1910.94)
 - * Subpart I - Respiratory Protection (1910.134)
- 29 CFR 1926 Safety and Health Regulations for Construction
 - * Subpart K - Electrical (1926.402 to 1926.408)
 - * Subpart L - Scaffolds (1926. 450 to 1926.454)
 - * Subpart X - Ladders (1926.1050 to 1926.1060)
- 29 CFR 1915 Safety and Health Regulations for Shipyard Employment
 - * Subpart B - Confined and Enclosed Spaces and Other Dangerous Atmospheres in Shipyard Employment (1915.11 to 1915.16)

12.4.3 *Other Safety Standards Cited*

- ANSI American National Standard Institute, Z117.1 “Safety Requirements for Working in Tanks and Other Confined Spaces (1819 L Street, N, Washington, DC 20036)

- Underwriters Laboratory Standards (Underwriters Laboratories, 333 Pfingsten Road, Northbrook, IL 60062-2096)
 - * UL 298 Portable Electric Hand Lamps
 - * UL 1570 Fluorescent Lighting Fixtures
 - * UL 1571 Incandescent Lighting Fixtures
 - * UL 1572 High Intensity Discharge Lighting
- National Fire Protection Association (NFPA) 70 National Electric Code (1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101)

12.4.4 *ASTM Standards Cited* (ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959)

- ASTM C566 Test Method for Total Moisture Content of Aggregate by Drying
- ASTM D3335 Test Method for Low Concentrations of Lead, Cadmium, and Cobalt in Paint by Atomic Absorption Spectroscopy
- ASTM D4940 Test Method for Conductimetric Analysis of Water Soluble Ionic Contamination of Blasting Abrasives
- ASTM D4752 –98 Test Method for Measuring MEK Resistance of Ethyl Silicate (Inorganic) Zinc-Rich Primers by Solvent Rub

12.4.5 *Department of Defense and Military Standards*

- MIL-P-24441 General Specification for Paint Epoxy Polyamide
- MIL-P-23236 Paint Coating Systems, Fuel and Salt Water Ballast Tanks (Metric)
- MIL-E-24635 Enamel, Silicone Alkyd Copolymer (Metric)
- MIL-E-24607 Enamel, Interior, Nonflaming (Dry) Chlorinated Alkyd Resin, Semigloss (Metric)

12.4.6 *Training Materials*

- “Coatings & Application Systems”, Training Manual for Foremen & General Foreman, Module 2, Newport News Shipbuilding, 1999
- Industrial Painting, Wheels of Learning Craft Training, Prentice Hall/National Center for Construction Education and Research, Old Tappan, NJ, 1998
 - * “Ladders, Scaffolds, Lifts, and Fall Protection”, Module 07402
- Suspended Scaffold Handbook, Scaffold Industry Association, Woodland Hills, CA,, March 1991
- “Safety Program for Suspended Scaffolds”, Scaffold Industry Association, Woodland Hills, CA, March 1991

12.5 Metric Conversion Chart (see attached)**12.5.1 Additional Conversion Factors**

Table 12.1
Additional Conversion Factors

English Unit	Conversion Factor	Metric (SI) Unit
1 lb/gal	7.481	g/liter
1 lb/ft ³	16.02	kg/m ³
1 lb/ft ²	4.882	kg/m ²
1 ton	0.9072	Mg (tonne)
1 ft ³	0.02832	m ³
1 ft ³ /gal	0.007481	m ³ /liter
1 ft ³ /lb	0.06243	m ³ /kg
1 ft ³ /min (CFM)	0.7646	m ³ /minute
1 grain/ft ³	2.288	gram/m ³
1 grain/lb	0.1429	g/kg
1 horsepower	746	watts
1 psi	6.895	Kilopascals (kPa)
1 psi/ft	22.62	kPa/m
1 inch water	0.2489	kPa

Other Conversions are:

- 1 psi = 2.036 inches Hg column
- 1 psi = 27.71 inches water column

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