Ventilation and Dehumidification of Ship Ballast Tanks for Blasting and Coating Work

Fig. 1: Ballast tank showing multiple bays (Courtesy of Hempel Coatings)

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Ship ballast tanks present very corrosive exposures. The surfaces are subject to frequent wetting, drying, and a salt water environment. In addition, the surfaces are difficult to properly clean and coat because of their tight spaces and irregular configurations (Fig. 1). The structure includes rat holes, welds, stiffeners, and many edges and corners. Without proper coating protection, corrosion occurs readily (Fig. 2).

Because a ballast tank is a confined space, it must be thoroughly ventilated for blast cleaning, coating application, and curing of the coating. In addition, because of the wet environment, the dew points are relatively high, especially if the ship is in the water. As a result, it is often necessary or advisable to also dehumidify the tank for blasting and coating operations.

The design of a ventilation and dehumidification system can be a very involved process, requiring sophisticated engineering. (Two separate systems, one for ventilation and one for dehumidification, may be called for, or one integrated system may be needed.) Many variables must be accounted for:

- the condition of the surface,
- ambient temperature and humidity,
- equipment available,
- the size and configuration of the tank (e.g., number and depth of bays),
- access to the tank from the ship, and
- facilities, equipment, and general layout of the shipyard.

This article describes the basic parameters and equipment for ventilating and dehumidifying tanks

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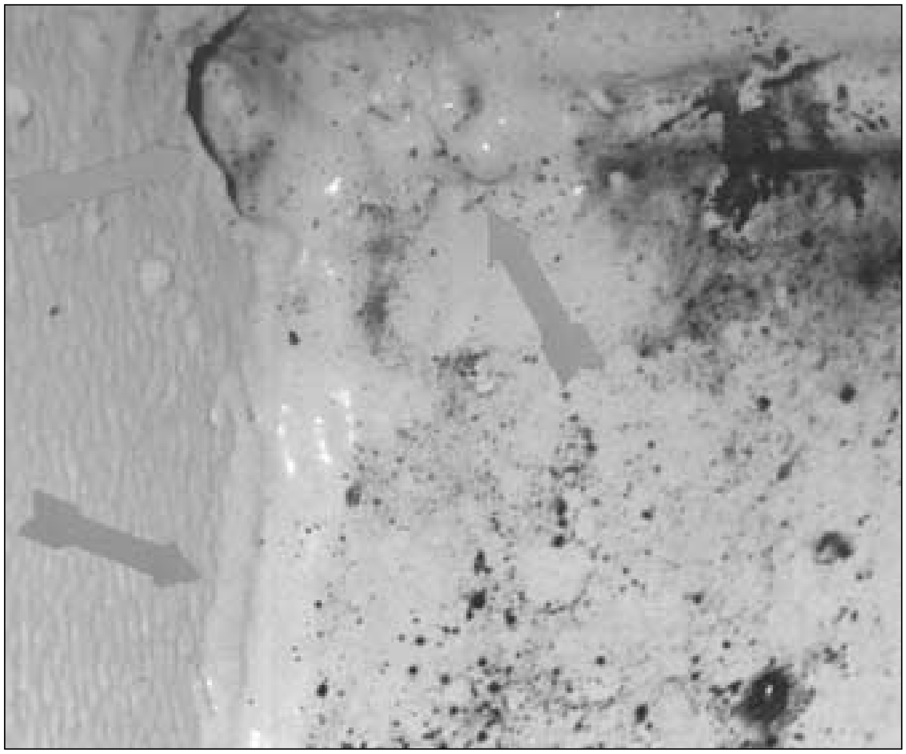

Fig. 2: Corrosion in ballast tank (Courtesy of Sherwin-Williams)

that are to be cleaned and coated. Sample calculations are provided. The article is based on a report prepared for the U.S. National Shipbuilding Research Program (NSRP). (See bibliography items 4 and 6.)

Reasons for Ventilating

There are three primary purposes for ventilating tanks and enclosed areas during cleaning and coating operations: operator health and safety, operator visibility, and curing of coating. Ventilation is required during each stage of the process: blast cleaning, application of coating, and curing of coating. The same ventilation, in most cases, is utilised for both blasting and painting operations, including the paint curing process.

Ventilation can be described in terms of airflow and the exchange of clean incoming air and dirty outgoing air. The balancing of incoming and outgoing air is an important aspect of a ventilation system. If a high volume of clean air is blown into the tank while a lower volume of dirty air is being extracted, air turbulence results. The dirty air will subsequently be blown out any opening in the tank.

Ventilation during Blast Cleaning

During abrasive blasting, the air is filled with dust from the abrasive breaking down as it hits the painted surface and dust from the surface that is being cleaned. The dust creates visibility problems for workers as well as risks to their respiratory systems and to their eyes. In addition, any dust that settles back on the surface after blasting can interfere with proper adhesion of the coating to be applied. (Fig. 3 shows the proper set-up of blasting equipment in a ballast tank.)

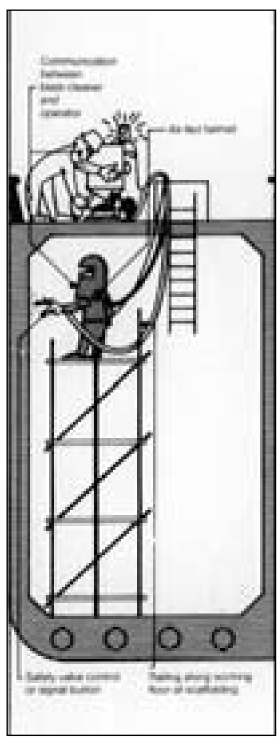

Fig. 3: Set-up of blasting equipment in ballast tank (Figs. 3-5 courtesy of Sigma Coatings)

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.

The more complete air changes there are, the better the visibility and the cleaner the air in the tank will be.

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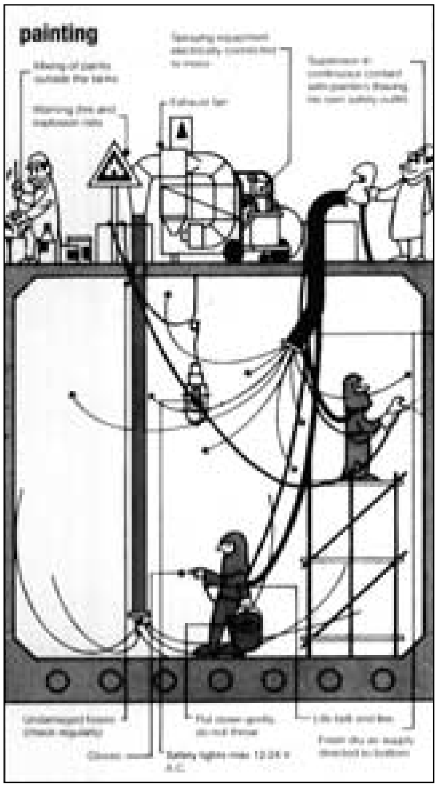

Fig. 4: Set-up of ventilation system during painting

There are no set rules for air changes required. Ventilation requirements for one shipyard are as follows.

• Spaces 2,000 ft^3 (60 m^3) and less shall have an air change every minute.
• Spaces from 2,000 ft^3 to 30,000 ft^3 (60 m^3 to 850 m^3) shall have an air change every three minutes.
• Spaces from 30,000 ft^3 to 100,000 ft^3 (850 m^3 to 2,800 m^3) shall have an air change every five minutes.
• Spaces over 100,000 ft^3 (2,800 m^3) shall have an air change every ten minutes.

Ventilation during Application and Curing

During painting operations in confined spaces, the air becomes laden with paint overspray and solvent vapour. Like dust from abrasive blasting operations, airborne overspray particles can create respiratory risks for workers. In addition, overspray particles that settle on the surface as it is being coated can interfere with the adhesion of the coating. Solvent vapours can pose health risks ranging from brain damage to cancer. They can also create fire and explosion hazards as well as suffocation hazards. The health and safety hazards presented by these conditions dictate that ventilation requirements be carefully calculated and that the air inside the space be subsequently monitored throughout the painting operation.

The ventilation rate should be sufficient to dilute solvent vapour to 10% or less of the lower explosive limit (LEL) of the specific solvents being sprayed. LEL is the lower limit of flammability or explosiveness of a gas or vapour at ordinary ambient temperature. It is expressed in percent of the vapour in air by volume. For example, for toluene, the LEL is 1.4% (i.e., 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%).

The volume of air required during abrasive blast cleaning will, in most cases, also maintain solvent vapour concentrations below 10% of the LEL. It will also maintain good visibility.

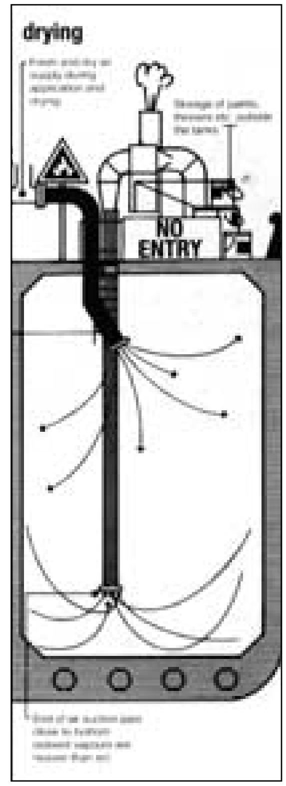

Fig. 5: Set-up of ventilation system during curing

Ventilation Equipment

Proper ventilation is obtained with equipment for moving air, equipment for directing or channeling the air, and the efficient set-up of the equipment. The major air movement components of a ventilation system are fans, ducting, and system layout. Figures 4 and 5 show the set-up of a ventilation system for painting work and curing.

Fans

The two preferred types of fans for marine ventilation are duct-axial and centrifugal.

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 ft (15 to 30 m) of ducting at low static pressure. Duct-axial fans can be mounted vertically or horizontally.

Centrifugal fans (Fig. 6) are capable of moving large volumes of air at high static pressure, and, therefore, are used with dust collection and dehumidification systems. These fans can operate efficiently when connected to long runs of ductwork.

Regardless of the type of fan selected, three factors must be considered for proper use of the fans: fan capacity, static pressure, and placement of fans.

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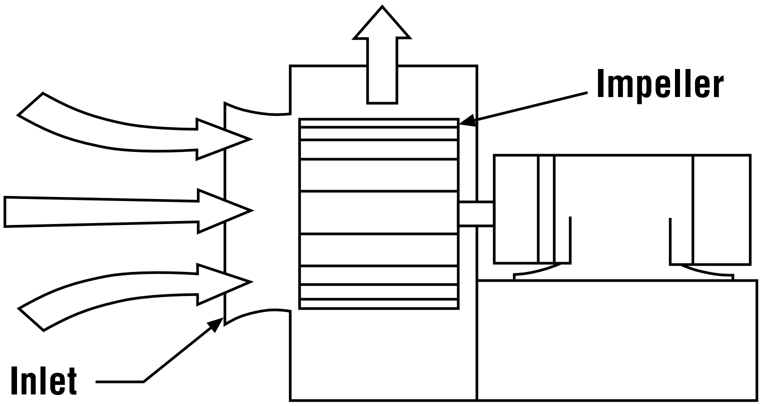

Fig. 6: Centrifugal fan (NSRP Procedure Handbook, Bibliography item 6)

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

$$\text{Airflow rate} = \frac{\text{volume of tank x changes/ hr}}{\text{60 min/hr}}$$
$$= \text{volume/min}$$

For example, an air change every three minutes in a 30,000 ft^3 (850 m^3) tank would require a fan capacity of 10,000 cubic feet per minute (CFM) or 280 cubic metres per minute (CMM).

• 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. The static pressure requirement for a fan should be determined after the ducting and equipment layout for the ventilation system has been designed. (See chapter 5 of Bibliography item 3.)

Generally, duct-axial fans in single-purpose ventilation systems have 1 to 2 inches (0.25 to 0.50 kPa) of static pressure capability. Centrifugal fans used with dust collection equipment should have a minimum 12 inches (3.0 kPa) static pressure rating.

• Placement of Fans: Normally, the fan should be placed as close to the tank as possible to reduce the amount of ductwork required. In a well-designed, permanently installed air handling system, fans can be located at practically any distance from the tank and still operate efficiently (Fig. 7).

Ducting

Well-designed and properly laid-out ductwork is essential to an efficient air handling system.

The two main areas of design criteria for ducting are sizing and layout. Sizing includes airflow rate, 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 that combines the lowest practical static pressure requirements with sufficient velocity to transport the airborne materials.

Sizing is the most critical consideration in selecting ducting because it determines whether the volume of airflow in CFM (CMM), static pressure, and velocity of the airflow in the finished ventilation system meet established design objectives.

Four factors must be considered when selecting duct size: 1) air volume, 2) distance air is to be moved,

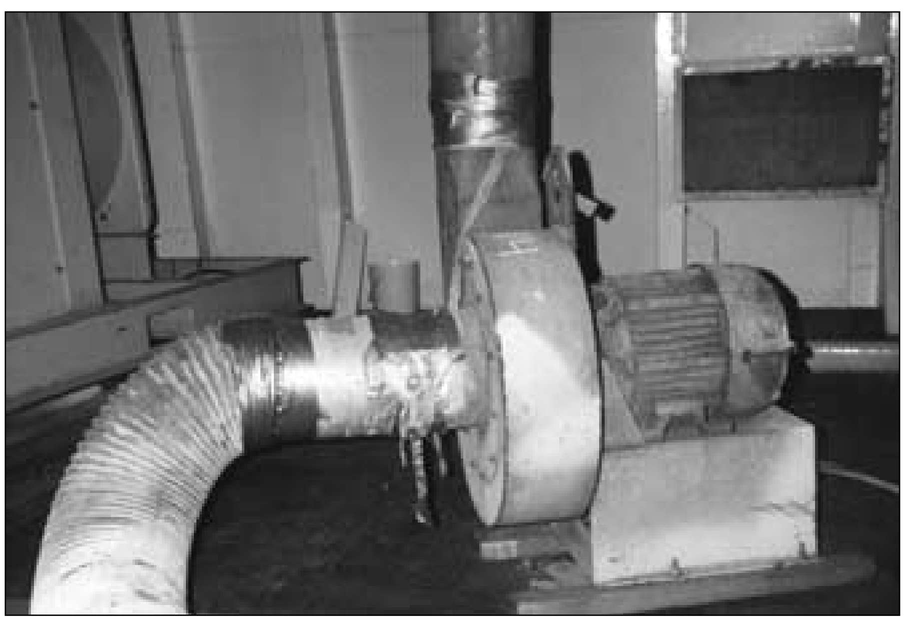

Fig. 7: Fan and ducting for ventilation of tank (Courtesy of Todd Shipyard)

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Fig. 8: Ventilation inlet tube inside tank (Courtesy of Todd Shipyard)

3) static pressure limitation of available fans, and 4) air velocity requirements.

Air volume requirements are based on the size of the confined area and the characteristics of the material requiring removal. The distance the air is to be moved is simply the length of the ducting.

Static pressure loss along the length of the ducting is directly related to the size (internal cross-sectional area) of the duct. It must be remembered that as static pressure requirements increase, more energy is required to operate the system.

Velocity calculations are based on the characteristics of each type of material to be removed from the air. As a rule, airborne dust resulting from abrasive blasting requires a minimum particle velocity of 3,500 ft (1,200 m) per minute.

Ventilation System Layout

When blasting marine tanks, the operator faces many different types of tank configurations around which the ducting layout must be designed. The yard should stock ducting components in a variety of sizes and configurations. 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 throughout 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 upper region of the tank (Fig. 8). Because the heavier airborne dust particles tend to settle to the bottom of the tank, the dirty air removal duct should be positioned near the tank bottom. This arrangement permits the dust particles to naturally fall toward the bottom of the tank and be exhausted much more rapidly than if the pick-up point were positioned higher in the tank. The duct inlet and outlet openings should be separated as much as possible.

Proper ventilation of a ballast tank is necessary but not usually sufficient to create ambient conditions that are

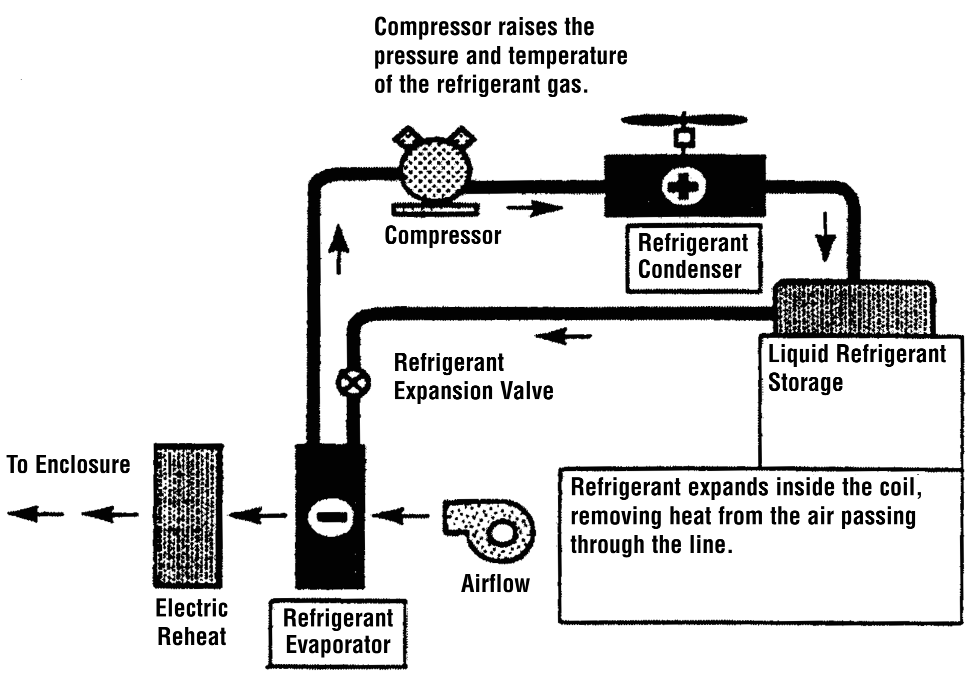

Fig. 9: Schematic of refrigerant dehumidification unit (Courtesy of Enviro-Air Control Corporation)

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Fig. 10: 2250 CFM dehumidification unit on deck of ferry ship (Courtesy of Todd Shipyard)

appropriate for blasting, coating, and curing operations. Dehumidification, the process of removing moisture from the air, may also be required inside the tank.

Reasons For Dehumidification

Dehumidification may be required or desired for three reasons.

One reason is that a coating specification may require a maximum relative humidity (RH) that is below the ambient RH of the tank. For example, U.S. Navy specifications allow a maximum RH of 50% during application and cure of solvent-free epoxies. For most shipyards in the USA, Europe, and Asia, the ambient RH will normally be higher than 50%, so dehumidification is needed to meet the specification.

A second reason for requiring dehumidification is to prevent condensation on a steel substrate. Condensation will occur when the dew point is at or above the surface temperature. Most coating specifications require the surface temperature to be at least 5 degrees F (3 degrees C) above the dew point temperature. If these conditions are not met, dehumidification can be used to lower the dew point. These conditions will then allow blasting and painting to proceed. Some shipyards prefer a spread of 10 or 15 degrees F (6 or 8 degrees C), especially for tanks. In many locations, the surface temperature is less than 5 degrees F (3 degrees C) above the dew point temperature, so without dehumidification, there would be a substantial risk of condensation.

A third reason for requiring dehumidification is that it can create working conditions that can improve productivity and reduce downtime. Dehumidification can raise or lower the ambient temperature while reducing the RH in a tank. Coating work on tanks under dehumidification can continue despite cooler ambient temperatures and high RH. Dehumidification can also lower the ambient air temperature, so it can alleviate hot and humid conditions inside a tank that contribute to worker fatigue. With causes of worker fatigue reduced, productivity can increase.

Types of Dehumidification

There are essentially two types of systems suitable to dehumidify atmospheric air in enclosed spaces. One—a refrigerant system—chills air below the dew point, causing moisture to condense on cool surfaces. The other—a desiccant system—uses substances called desiccants to absorb moisture from the air passing over them.

In a refrigerant system, ambient air is circulated over a system of refrigeration coils (Fig. 9). The air cools and reaches saturation, and condensation occurs within the unit. The air exits the cooling coil section of the dehumidifier at a reduced temperature, dew point, and absolute humidity.

Desiccants are substances with a very high affinity for water. They can draw moisture directly from the surrounding air. The most commonly used desiccants are silica gel and lithium chloride. In desiccant dehumidification, air is passed through beds or layers of desiccant, which absorb moisture from the air stream, turning the desiccant into a hydrated salt. Periodically, the moisture-laden desiccant can be heated to drive off the water of hydration. This process regenerates the desiccant salt, which can then be reused in another job. The desiccation reaction typically raises the temperature of the exiting air stream by 10 to 15 degrees F (6 to 8 degrees C) or more. Figure 10 depicts a desiccant dehumidification unit on a ferry ship.

In hot climates, refrigeration-type dehumidifiers are frequently used in combination with desiccant dehumidification to cool the hot, humid air entering the space. The refrigerant unit dehumidifies and cools the hot, humid ambient air. The desiccant unit further removes moisture but also increases the temperature. Because the refrigerant unit pre-cools the air, air exiting the desiccant unit into the work space is more comfortable for the workers.

Dehumidification System

A dehumidification system can be characterised by the following parameters:

- volume of airflow,
- air velocity through the dehumidifier,
- power requirements,
- external static pressure,
- moisture removal capacity, and

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• initial and final temperatures.

Volume of Airflow: The most common designation of the capacity of the dehumidification unit is volume of conditioned air that can be delivered to a tank per unit time (CFM or CMM). However, this information alone is not necessarily adequate to define the end-user's needs.

Air Velocity through the Dehumidifier: It is often useful to know the velocity of the air exiting the dehumidification unit and entering the work area. In general, velocity depends on the cross-sectional size opening of the air exhaust ducts (plenum) of the dehumidification unit. Velocity affects how large a duct size can be used to convey the dehumidification air.

The speed at which the air moves through a dehumidifier has a significant impact on the machine's ability to lower the dew point 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 change (rise or fall) will also be increased by slowing the air velocity. Performance for most dehumidifiers is stated at a particular airflow rate.

Power Requirements: Dehumidification units are powered by electricity, gas, or steam. In the USA, most units use a 480-volt, three-phase electric power source. The current (number of amps) varies with the capacity and other factors. (Smaller capacity dehumidification units consume less current. For example, one yard prefers the 2,250 CFM [64 CMM] desiccant unit because the unit draws only 52 amps.)

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 difference in pressure is referred to as static pressure loss.

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 dehumidification unit that has enough capacity to reduce and maintain the moisture level required for the project. (See the examples in the Appendix, pp. 51-52.)

Initial and Final Temperatures: Dehumidification units differ in how they operate under different temperatures and humidities. For example, refrigerant units are effective at very high temperatures. Also, dehumidification units change the temperature as well as the moisture content of the treated air. Recall that desiccant dehumidification 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 temperatures for proper coating application and cure.

Procedure for Dehumidification

Several types of data are needed for determining the dehumidification requirements of a ballast tank. These include tank and ship factors, weather factors, and required end conditions.

Tank and ship factors include 1) tank size and configuration, and 2) location and space available for equipment. Weather factors include 1) ambient temperature range of air and of ship surfaces during application and curing, and 2) moisture in air (absolute humidity).

Dehumidification can be broken down into a step-by-step process. The NSRP handbook includes a multi-step procedure and flow chart for the dehumidification of a ship's tank or other space. (See Bibliography item 4.) These steps are summarised in Table 1.

Conclusion

Effective cleaning and painting of ballast tanks is essential for the preservation and economical operation of commercial and Navy ocean-going ships. This article emphasises the importance of proper ventilation and dehumidification of a tank during the blasting, coating application, and curing stages. Ventilation improves the visibility for the blasting and coating operation and permits proper curing of the coating. In addition, ventilation is essential to provide adequate fresh air for inspectors and other workers who are not fitted with air-supplied respirators. (Even with ventilation, these individuals will probably require half-face or full-face air-purifying respirators, depending on the specific atmosphere.)

Dehumidification prevents moisture from condensing on the blasted surface where it may cause flash rusting. On the coated surface, moisture may interfere with the coating adhesion or curing. Also, dehumidification can dramatically improve worker productivity by increasing the comfort level within the work area and by extending the time available for blasting and coating work.

The equipment needed for these operations is well established and readily available in various types, sizes, capacities, and degrees of sophistication. As with any other technology, the equipment must be designed, selected, and operated in accordance with good engineering principles and based on specific shipyard experience.

The information presented in this article and in the NSRP handbook is not intended to produce instant

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Table 1:
Steps for Dehumidification (DH) of a Tank

Step	Description of Activity	Comments
A	Determine whether DH is specified.	Source: specifications
B	Determine whether dew point, RH, or temperature is specified.	Source: tank procedures and manufacturer's data sheets
C	Determine whether DH is required for temperature or RH control.	Determine if specified conditions are exceeded.
D	Determine whether DH is required for production or scheduling.	Estimate impact of DH on down time and efficiency.
E	Determine who normally designs DH.	Paint department or other group
F	Determine whether DH requires complex design.	Determine if paint department needs additional assistance.
G	Determine CFM (CMM) needed and type (e.g., desiccant or refrigerant).	Based on volume of tank, air changes per hour, and surface temperature expected and required
H	Determine availability of equipment.	Identify size and other parameters of in-house units.
I	Determine whether in-house units are adequate.	Compare available DH units with CFM (CMM), moisture, and other parameters needed.
J	Acquire additional units if needed.	Rent or purchase units as needed.
K	Determine layout of DH system.	Includes placement, inlets, outlets, and ducting
L	Design DH using outside assistance.	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.	4 methods: check proper unit function; measure RH and temperature; measure airflows; assess coating cure

expertise in the reader or user. Rather, it is to provide an overview of the major factors involved in these practices and to instill an appreciation for the complexity of this aspect of the corrosion control of ballast tanks.

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Appendix

Examples of Calculations for Dehumidification (DH) Requirements

Calculations are given in imperial units first. Metric equivalents are given in parentheses.

Estimating Moisture Removal Rates

Step A – Determine quantity of moisture to remove.
- Measure ambient temperature of air.
- Determine relative humidity and hence moisture content of incoming air (from psychrometric chart).
- Define required temperature and humidity in tank (from specification) and hence calculate moisture content (from psychrometric chart).

Step B – Determine volume of airflow (CFM [CMM]) through tank.
- If airflow (CFM [CMM]) is stated in specification, use that volume.
- Otherwise, determine by multiplying volume of tank by number of air changes/hr.

Step C – Determine moisture removal rate required.
- Multiply moisture content to be removed (from Step A) by airflow through tank (from Step B).
- Convert moisture content to lbs of water/hr (kg of water/hr).

Data
- Assume ambient air temperature = 85 F (30 C)
- Assume ambient relative humidity = 80%
- Assume required air temperature in tank = 70 F (21 C)
- Assume required relative humidity = 50%
- Assume volume of tank = 30,000 ft^3 (850 m^3)
- Assume that 4 changes/hr are needed

Step A – From above relative humidity and temperatures, determine moisture content of inlet air and air in tank (from psychrometric chart).
- Incoming air = 145 grains of water/lb of air or GPP (20.7 grams of water/kg of air)
- Required air in tank = 54 GPP (7.7 grams of water/kg of air)
- Moisture to be removed = 145 - 54 = 91 GPP (20.7 - 7.7 = 13.0 grams of water/kg of air)
- Convert to volume of air by dividing by density of air, 14.2 ft^3/lb (0.886 m^3/kg)

  91/14.2 = 6.41 grains/ft^3

  (13/0.886 = 14.7 grams/m^3)

Step B – Air flow required in CFM (CMM) = $\frac{\text{Volume of air x number of changes/hr}}{60}$

$$\frac{30{,}000\ ft^3 \times 4\ \text{changes/hr}}{60} = 2{,}000\ \text{CFM}$$

$$\left(\frac{850\ m^3 \times 4}{60} = 56.6\ \text{CMM}\right.$$

Step C – Moisture to be removed is:
- Amount of moisture in air x airflow rate
- 6.41 grains/ft^3 x 2,000 CFM = 12,800 grains/minute (14.7 grams/m^3 x 56.6 CMM = 830 grams per minute)
- Round to 13,000 grains/minute (842 grams per minute)
- Divide by number of grains of water/lb of water, i.e., 7,000 (1,000 grams of water/kg of water) and multiply by 60 min/hr

$$= \frac{13{,}000 \times 60}{7{,}000} \left(\frac{842 \times 60}{1{,}000}\right)$$

= 111.4 lbs of water/hr (50.5 kg of water/hr)

Rounded to 110 lbs/hr (50 kg/hr)

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Estimating Exit Air Temperature of DH Unit

This section shows how to estimate the temperature of the air exiting a specified dehumidification unit. This information is needed to determine if the air in the work space will be at an acceptable temperature for the workers.

Data Needed

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

Procedure

Step A – Using Fig. A, locate the point on the X 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 (vertical axis) for this intersection. This number will be the exiting air temperature.

Input Data

- Moisture content of incoming air: Assume 80 grains/lb (11.4 grams/kg).
  (Note: This condition corresponds to a wet bulb temperature of about 67.5 F (19.7 C) and relative humidity of 61%.)
- Temperature of incoming air: Assume 75 F (24 C) dry bulb temperature
- Face velocity: 400 ft/min (122 m/min) from manufacturer's data sheet (The curves in Fig. A relating moisture content to exit air temperature are based on a DH unit with a specific face velocity of 400 ft/min (122 m/min). Manufacturers provide such charts for DH units based on each unit's face velocity.)

Step A – Go to point 80 on X axis of Fig. A
Step B – Move up vertically to intersect 75 F (24 C) curve
Step C – Move left horizontally to read approximately 128 F (53 C)

(Note: 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. A similar procedure is used to estimate moisture content of exiting air. A series of charts from suppliers provides similar data with a few variations.)

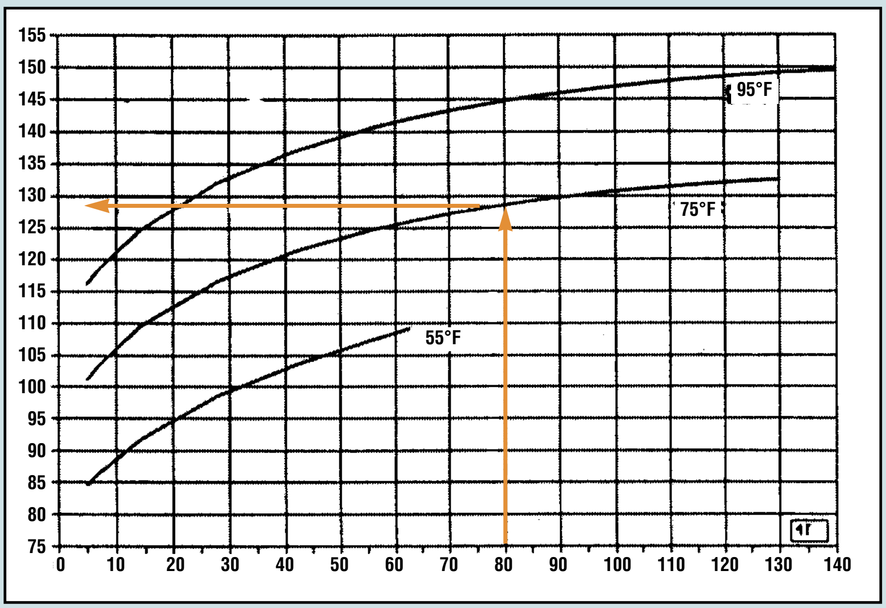

Fig. A: Moisture removal capacity for 400 ft/min (122 m/min) process air velocity (Courtesy of AST, Inc. [Bibliography item 1])

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