Since mid-2008, ocean-going freight companies have felt the pinch of the worldwide recession with a dramatic decline in orders for transport. The decline has affected almost every type of vessel, including oil tankers, cargo vessels, cruise ships, and even luxury yachts. It is estimated that over 1,000 ships are in either hot or cold storage all over the world, and about half of these are container vessels while 200 are bulkers. Additionally, many cargo ships are leaving port at 50% to 70% capacity, which negatively affects the profitability of their trips. Recently, low demand in crude oil left many oil tankers at sea with no apparent destination. The shipping industry is in a crisis.

Given the recession and the enormous operating costs of ships, laying up underutilized vessels and running fewer vessels with higher loadings to maximize profit per sailing often makes more economic sense. Therefore, it was no surprise to see an increasing number of ships being laid up in 2009. With the increase, cost-effective, corrosion-prevention strategies for long-term cold lay-ups are essential.

This article will discuss the use of temporary desiccant dehumidification and climate control equipment as a strategy to prevent corrosion and other damage to ballast tanks, electronic systems, engine rooms, and other parts of a ship during cold lay-up, thereby reducing maintenance painting and other costs and protecting one’s investment in a ship. The article will look at the science of psychrometrics and discuss how its use can help predict the optimal conditions to effectively control moisture in a ship indefinitely. The article will also discuss the corrosion cell and how it can be manipulated with climate control technologies. Finally, the article will compare different types of climate control methods used for mothball applications and make recommendations for what technologies are best for certain seasons.

Why Lay-Up?
The laying up of a vessel makes sense when consumer demand is low. Low demand will reduce the profit for the
owner and will eventually create a financial burden. Often, laying up the vessel provides a solid business case by reducing excessive deterioration (and subsequent repair) of the ship’s mechanical and electrical systems. Additionally, only a small crew is required to maintain a laid up ship, thus reducing overall costs to the owner. Other benefits include reduced costs for fuel, oil, maintenance, equipment replacement, and insurance.

Typically two types of lay-up procedures are used: hot and cold. This article will define both processes but will concentrate primarily on the cold lay-up process, in which, compared to hot lay-up, will define both processes but will concentrate primarily on the cold lay-up process, in which, compared to hot lay-up, are used: hot and cold. This article will define both processes but will concentrate primarily on the cold lay-up process, in which, compared to hot lay-up, ships are more affected by the destructive nature of long-term moisture infiltration.

**Hot Lay-Ups**

In hot lay-ups, the machinery is kept in operation for the sake of fast re-commissioning. However, measures are still taken into consideration to lower the overall operational costs, including reducing crew size or eliminating some mechanical operations such as heating and ventilation systems. The length of time that the vessel is laid up will determine the required restart protocol. For example, a ship that has been laid up for 1 month would require a 24-hour restart procedure.

**Cold Lay-Ups**

In cold lay-ups, the machinery is taken out of service, and the vessel is kept electrically dead, except for its emergency power. This condition usually implies a three week re-commissioning time or more depending on the preservation and maintenance during lay-up. Minimum manning covering fire, leakage, moorings, and security watches should be kept. The lay-up site is usually in a remote area and access is limited. Power is kept to a minimum but is sufficient to ensure that emergency equipment and other essential systems, such as navigation lighting, winches, and mooring equipment, are operable. Re-commissioning after an extensive lay-up period (over 5 years) might require more than 30 days.

The cold lay-up process is an arduous task, with an extensive checklist of procedures. The procedures are intended to ensure that the preservation of the vessel is done in the most cost-efficient way possible. The lay-up site is usually well-sheltered from heavy winds, strong currents, and swells. It should not be in tropical cyclone areas, and the seabed characteristics should be able to provide adequate anchoring. In most cases, the vessel will be kept in “blacked out” mode with minimal crew on board and power being supplied to essential equipment from a portable generator placed on deck. All of this careful planning is done in anticipation for the day when the ship is called back to duty so that it can be brought up and running in the shortest possible time without the need for major repair caused by corrosion, mold, or material rot.

**Challenges during Cold Lay-Up**

There are many challenges to protecting a ship during a long-term lay-up, including vandalism, natural disasters, and general deterioration. However, the biggest threat to the well being of a vessel in cold storage might come from the abundance of moisture at sea. Continuous high levels of moisture (relative humidity) can provide the catalyst to corrosion on these vessels, which are made up primarily of steel. During re-commissioning, corrosion can create havoc by causing motor and drive trains to seize up, which results in costly and potentially long-term repairs. Additionally, excess corrosion can severely damage the onboard computers and navigational equipment inside the control rooms. Whereas body panels can be replaced relatively easily, the brains and heart of the ship, such as the navigation electronics and engine components, are not as easily replaced (Fig. 1).

Mold can also create costly remediation efforts due to these long-term lay-ups. Typically, where there is moisture and an organic food source such as dirt in unprotected areas, there is mold. Mold can damage materials on the ship and create health risks for the crew when the ship returns to service. Additionally, excess moisture can lead to the rotting of materials on board. Again, the replacement of these items will be costly and may lengthen the amount of time required to re-commission the ship. When the ship is ready to return to normal trade, dry preservation is recommended, and all preservation actions should be carefully documented.

**The Corrosion Cell Simplified**

So moisture presents a major challenge for protecting a vessel at sea. How does moisture affect the corrosion process and what can be done to predict its onset?

Corrosion is an electrochemical reaction. The typical corrosion cell consists of an electrolyte as well as a cathode and an anode (which steel contains and helps conduct electricity for the reaction). Corrosion occurs only when all three parts are present. Moisture is the
electrolyte that provides the conduit for the reaction to occur. If any of the three parts of the cell can be controlled, corrosion growth will be limited but will never stop unless a structure or component is in a vacuum. The rate of corrosion depends on the amount of moisture present. For example, relative humidity—the percentage of moisture that air can hold at a specific temperature—will lead to less corrosion at levels below 50% than at 70%. Relative humidity above 50% creates conditions that accelerate corrosion exponentially, leading to flash rusting. As such, the key to corrosion control is to control the moisture level or relative humidity (Fig. 2).

Moisture Analysis: The Science of Psychrometrics
To understand how moisture might affect the steel, it is important to understand psychrometrics, the science of moisture in air. Psychrometrics is relied on heavily when engineering a moisture-control method. Psychrometrics can predict, with certainty, the ambient conditions that will provide the greatest chance of corrosion occurring on the vessel. The psychrometric chart has eight indices to measure the moisture levels within the air. Dew point temperature, relative humidity, dry bulb temperature, and wet bulb temperature are the most commonly used indices when calculating moisture levels in a space. By knowing any two of the eight variables on the psychrometric chart (Fig. 3), you can calculate any of the other values. For example, by knowing the relative humidity and the dry bulb temperature, you can easily find the dew point temperature or vapor pressure.

The use of psychrometrics allows ship owners to make critical decisions about the best time to install the temporary climate control equipment and to determine the type and quantity of equipment needed to safely protect their ships. Correct sizing is vital to ensure that a ship owner gets the exact conditions demanded from the specifications so that costs are not incurred for unnecessary equipment and fuel. Psychrometrics is the tool that ensures that the moisture is managed and thus will keep the corrosion cell in check as much as possible.

The Concept
The general concept behind the use of temporary dehumidification or climate control equipment to lay up a ship is to create an environment that reduces the relative humidity in the space below 50%. The conditioning process should create a differential between the dew point temperature in the space and the temperature of the actual surface. If the surface temperature reaches the interior dew point temperature, moisture vapor from the air will condense on the surface. The steel surface will then be at risk...
for corrosion. In the control rooms, excess moisture can corrode electronic components, resulting in short outs when restarted.

As noted above, mold can also grow in these confined areas, creating remediation concerns. Often, typical air conditioners providing cool air cannot create effective conditions to ensure that condensation will not form.

Dehumidification equipment is fundamental to bringing air in the enclosed areas of the ship, such as ballast tanks, storage tanks, and control rooms, to a relative humidity not exceeding 50%.

Dehumidifiers
Dehumidification is the process by which moisture is removed from the air. There are primarily two methods of dehumidification:

- Refrigerant—Removing moisture by passing wet air over a refrigerated coil
- Desiccant—Using substances that attract moisture (desiccants) to remove the moisture by vapor pressure differential

Refrigerant Dehumidification
Refrigerant dehumidification is an effective way to remove moisture from the air in small, confined spaces (Fig. 4). With refrigerant dehumidification, moist air is passed directly over refrigeration coils and cooled below the dew point; the moisture condenses from the air. The air comes off the coil saturated and must be reheated to lower the relative humidity. It is then pushed into the space. This type of unit typically can provide a relative humidity range of 15% to 20%. Additionally, most refrigeration units are too small to condition large areas and are limited in their ability to significantly change dew point in a space. They can be used effectively in control rooms and living quarters, especially to reduce the threat of mold.

Desiccant Dehumidification
Desiccant dehumidification is the work-
horse for moisture removal from the air in large spaces (Fig. 5). Desiccants attract moisture from the air by creating an area of low vapor pressure at the surface of the desiccant. The pressure exerted by the water in the air is higher, so the water molecules move from the air to the desiccant, and the air is dehumidified. In one type of dehumidifier, as the process air passes through what is called the desiccant wheel, moisture is absorbed and trapped. As the wet wheel rotates, it is dried out by heated reactivation air (Fig. 6). Once the wheel is dried, it is ready to absorb more moisture. Desiccants in this application are based on silica gel, which is ideal for highly saturated air streams. The desiccants have very good moisture removal capacity over a broad range of humidity levels. Because desiccant dehumidifiers are available in large capacities, they are the most appropriate for use in lay-ups. Depending on the time of year of the lay-up, different measures should be taken to control the temperatures in the vessel. For example, an air conditioning package can be combined with the desiccant to optimize the controlled climate if there is a need to work in the space in warmer climates.

Power is always an issue on a ship that has been laid up. Often, the dehumidification equipment has to share the same generators that provide power to all the other onboard utilities (such as fire suppression systems). The units selected will have to be energy efficient to reduce the overall running costs of the vessel during the lay-up period. Also, the equipment selected must be extremely reliable to minimize unplanned downtime.

**Designed Dehumidification Systems**

Dehumidifiers can be placed inside the controlled space, or they can be placed on the deck outside, with temporary ducting used to move the air into the protected areas. Often, refrigerant units are placed directly in the smaller spaces to be controlled, and the condensate is disposed of through a hose to a nearby drain. The desiccant units are extremely large and often cannot be placed in the space that is being controlled.

**Closed Loop Dehumidification System**

Closed loop system dehumidification is used where the enclosed air volume is recirculated through the dehumidifier (Figs. 7 and 8). Often the moisture load outside is so great that recirculation is the only viable way to create a cost-effective dehumidification system. A closed sys-
tem works most efficiently when all openings in the space are sealed to minimize air infiltration from the outside. Air from inside the space is returned to the dehumidifier to be dried again. The reprocessed air is then redistributed to the space through an air distribution manifold. Due to this continual drying process, the air is extremely dry (<1% RH). The manifold should be placed in the center of an internal room, such as the engine room, or a hold for best results. The distribution hoses need to be spread out evenly to cover all the sensitive parts of the vessel without using lengthy hoses.

Navigation and Radio Room Accommodations
The navigation and radio rooms are usually above deck, where they are directly exposed to the elements. The exposure environment creates varying temperatures and relative humidity levels throughout the day. Since these locations all contain electronic equipment, woodwork, and textiles, it is important to control the humidity by placing humidistats where they can accurately read the relative humidity levels. Using humidistsats, the dehumidification can be turned on when humidity rises above 50% and can be turned off once a safe humidity level is achieved. Controlling the humidity will protect woodwork and textiles from cracking and splitting. These locations are normally linked by the air conditioning system, which, when turned off and properly sealed, can be used to distrib-

Unique, patented low temperature catalyst purifies compressed breathing air.
- for continuous use to remove carbon monoxide
- no expensive desiccant drying equipment needed
- helps provide comfortable, humidified compressed air to meet Grade-D requirements
- by far, the most economical CO-removal alternative

Don't Just Filter...Purify!

FMP Coating Thickness Instruments
The Flexible Solution for your Measurement Applications

- Optimum accuracy
- High precision probes
- Instant base material recognition
- USB communication
- Large, bright display
- Ultra shock resistant case

Fig. 8: Closed loop dehumidification system with even distribution set up
ute dehumidified air throughout the accommodation, navigation, and radio rooms.

**Closed System Dehumidification for Engine Room Spaces**

Emphasis is placed at the lowest section of the engine room where moisture may gather; the heated dry air will dry the low area and then rise to other parts of the engine room.

Humidistats are placed in the dehumidified space to keep the relative humidity levels from exceeding the set value. Reactivation air is obtained from the air vent leading to the outside of the ship, and the wet air is vented out through a similar vent.

**Case Study**

A 3500 TEU (twenty-foot equivalent units) container ship was laid-up in the sea of Batam because of decreased demand for her services. The owner made the decision to complete a cold lay-up application for an unspecified period. (Due to privacy policies, the name of the vessel cannot be disclosed.)

**Challenges**

The key challenge for the completion of the project included power supply for the units and the distribution of the air into the affected areas. The power was to be supplied by an onboard generator; however, there was concern that there would not be enough capacity to power the dehumidifiers and the necessary equipment to maintain the lay-up. The solution included a dehumidifier that provided an energy-efficient design to reduce the overall capacity needed. The equipment provided a 30% decrease in overall use, helping to reduce the overall power required and the long-term fuel costs for the generator. The logistics problem was solved by creating a unique labyrinth of ducting, manifolds, and plenums to effectively distribute the air in all the protected areas (Figs. 9 and 10).

**Solution**

The solution involved entry of the dry air system into two specific areas:

A) One desiccant dehumidifier that provided 2500 cfm (4000 m³/h) of dehumidified air and had a gas burner reactivator, making it less energy intensive, was dedicated to the engine room and accommodations deck
  - Unit was placed on deck next to power generator.
  - Dry air was channeled to the engine room and accommodation decks via flexible tubing connected to a butterfly joint with air damper.
  - Flexible tubing was connected to an air distribution manifold which distributes the air to various parts of the engine room via lay-flat temporary ducting.
  - Air was channeled to various parts of the accommodation deck utilizing the air conditioning vents.
  - Doors to rooms were sealed to prevent any air leakages.

B) One desiccant dehumidifier that provided 600 cfm (1000 m³/h) of air and also had a gas burner reactivator was dedicated to the forward mechanical room
  - Dehumidifier was placed in the forward bow thruster room.
  - 20 m of flexible ducting was used to channel air into the bow thruster area via air vent.

**Costs for System**

- Installation, shipping, and fabrication: $8,300K (US)
- Monthly rental rate (DH equipment only): $6,900K
- Estimated fuel for generators (per month): $3,400K

**Conclusions**

The shipping industry is laying up more ships than ever because the worldwide economic recession has reduced the overall demand for shipping goods and services. Ship owners are finding that laying up ships is a viable and profitable option for protecting their ships when not in use. Cold lay-up applications can create costly re-commissioning issues due to corrosion and mold created by excess moisture on board the vessel. The use of psychrometrics is the only true way to ensure that you are controlling the corrosion cell by eliminating moisture during a cold lay-up. The use of temporary dehumidification systems can effectively control moisture onboard, thus reducing these costly problems even for the longest lay-ups. Energy efficient units and engineered distribution systems provide an economical alternative to other lay-up alternatives. Desiccant dehumidifiers are the most effective and efficient equipment for controlling moisture in large areas such as container ships.

**Sources Consulted**

DNV Interim Guideline on Lay-up of Ships: A systematic and cost-effective approach to laying up ships, DNV Maritime Advisory Services, January 2009.

Russ Brown is currently the Global Business Development Manager for Munters Moisture Control Services and is based out of Indianapolis, Indiana. Brown has worked in the paint and coatings industry for the past 25 years in several capacities and for the Munters Corporation for the past 13 years. Within his current position, he has been active in the expansion of the core products and services for Munters Moisture Control Services on a global basis. Brown has a BS in Liberal Arts and Sciences from the University of Illinois. He is currently serving as President Elect on the Board of Governors of SSPC: The Society for Protective Coatings (SSPC) and is also active in the Construction Specification Institute (CSI), American Water Works Association (AWWA), and the American Institute of Architects (AIA).

www.paintsquare.com