TECHNICAL FEATURE

Controlling Corrosion

In Marine Refrigeration Systems

By Amey S. Majgaonkar, M.E.

Corrosion problems are severe in marine refrigeration and air-conditioning plants. Although corrosion can affect production in commercial applications, in naval warships and submarines, corrosion can affect the crew's survival. This article discusses corrosion control in marine refrigeration systems, but similar methodologies to control corrosion are applicable for any refrigeration system.

The main types of corrosion occurring in marine refrigeration systems are electrochemical, galvanic, pitting, cavitation, stress concentration cracking, crevice, and fouling. Present and surrounding moisture also cause marine refrigeration systems to experience corrosion.

Electrochemical Corrosion

In metals, corrosion is caused by the loss of electrons reacting with water and oxygen. Rusting, the weakening of iron due to oxidation of the iron atoms, is a well-known example of electrochemical corrosion. This type of damage typically produces oxide(s) of the original metal. The corrosion can be uniform or localized and is not stable or self-healing.

With heat exchangers and pressure vessels, designers usually follow the guidance in various standards from such groups as the American Society of Mechanical Engineers (ASME) and the Tubular Exchanger Manufacturers Association (TEMA), etc. To control electrochemical corrosion, isolate the corroding metal from the corrosive environment using paint and a protective coating. Regular inspection and repair of the coating are necessary to achieve reliable and lasting protection.

Materials such as aluminium, titanium, stainless steel and alloys are used in heat exchangers, pressure vessels, piping, valves and accessories. In this case, a thin film of corrosion can form on the surface spontaneously. The oxide film is tightly adherent, stable and self-healing and isolates the surface from the corrosive environment. The film acts as a barrier to further oxidation.

When the film stops growing at less than a micrometer thick, the metal becomes passive toward further corrosion and the phenomenon known as passivation occurs. In conditions where chlorine atoms are present (i.e., seawater), the ability to form a passivating film is hindered, and the film destabilizes, causing pitting corrosion. Pitting corrosion

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is dangerous because it is less visible than rust. It often escapes notice, and components fail inconspicuously. Care must be taken not to entirely trust passivation as a corrosion control mechanism. Periodic inspections are mandatory.

Galvanic Corrosion

Galvanic corrosion is an electrochemical reaction between two or more metals. One metal must be chemically more active (or less stable) than the others for a reaction to take place in presence of an electrolyte. Seawater, by virtue of its chloride content, is an efficient electrolyte. Galvanic corrosion of a chemically more active metal (anode) can occur in the presence of seawater. Anode material breaks away into the seawater to produce oxides. These oxide molecules either drift away in the water or settle on the surface of the anode.

In marine refrigeration systems, galvanic corrosion occurs in heat exchangers, especially in seawater-cooled condensers, line valves and instruments such as pressure gages, and flow meters, which may be made of dissimilar materials.

Shell-and-tube condensers with shell-side fluid as the refrigerant and tube-side fluid as seawater are generally used in marine refrigeration systems. To avoid galvanic corrosion, ideally, the same construction material should be used for tubes, tube sheets and water heads. However, in practice, a designer must choose different construction materials because of other constraints such as required heat transfer coefficients, malleability, ductility, castability, ease of manufacturing and cost. The construction material of seawater piping connected to the condenser also influences the galvanic corrosion and material selection. From a corrosion point of view, consideration given in the design of marine condensers can similarly be applied for brine chillers.

If the chosen materials differ widely in their electrode potentials, galvanic cells can form and destroy the anodic material. If copper is used for tubes and cupronickel is used in tube sheets in seawater-cooled condensers, copper tubes will corrode. Therefore, cupronickel tubes are used. Similarly, avoid threaded joints for materials that are far apart in the galvanic series.

The rate of corrosion depends on the ratio of areas of anode to cathode, water speed, temperature, alkalinity/acidity (pH of the water). However, the main factor is the difference in electrical potential of the two metals. The relative position of a pair of metals in *Table 1* shows whether a corrosion problem exists and whether an alternative choice of metal could be made sensibly. The relative surface areas of anode and cathode have a major effect on the rate of corrosion. If a large anode is connected to a small cathode, the anode will corrode slowly. However, if a large cathode is connected to a small anode, the anode will corrode rapidly. *Table 1* also shows the varying potential of metals in seawater.[1]

Changing the potential of the metal to a point where corrosion ceases can control galvanic corrosion. Impressed current cathodic protection (ICCP) systems or sacrificial anode systems are used to change the potential.

Potentials In Seawater Against A Silver/Silver Chloride Electrode

Material	Potential (V)
Magnesium	(–) 1.6
Zinc	(–) 1.0
Aluminum Alloys	(–) 0.9
Cadmium Plating	(–) 0.8
Mild Steel	(–) 0.6
Cast Iron	
Stainless Steel	(–) 0.5
Brass	(–) 0.3
Copper	
Aluminum Brass	
Nickel Aluminum Bronze	(–) 0.2
Aluminum Silicon Bronze	
Gunmetal and Cupro Nickel	
Nickel	(–) 0.1
Silver	
Stainless Steel (Passive)	
Monel	0
Titanium	(+) 0.1
Ferralium	
Platinum	(+) 0.2
Graphite	(+) 0.3

Table 1: Galvanic series shows varying potential of metals in seawater.[1]

ICCP systems use anodes connected to a dc power source. The current to the anodes must be controlled to maintain the set voltage required. An ICCP system is used when the protective cathodic current requirement is high. Since marine refrigeration systems are relatively smaller than other larger marine structures (such as the underwater hull surface), an ICCP system normally is not used.

In a sacrificial anodes system, anodes enable the potential of the system to be changed. The system provides temporary protection to metal, which is made to behave as a cathode. It is most suitable for marine refrigeration systems as it does not require an external electric power supply nor any control by operating staff.

The first step in the design of a condenser cathodic protection system is the estimation of protective cathodic current requirement.[2,3,4] The procedure involves calculation of exposed water box and tube sheet areas. Current flows in an elliptical path inside a tube or pipe. The effective length of the tube/pipe, to be taken in area calculation, is approximately twice the diameter of the tube/pipe. The design current density needs to be determined from past experimental data or from performing actual field experiments. This is complex and designers prefer to use past experience for their determination.

The range of current outputs for different sacrificial anode materials with standard dimensions is generally known or can be obtained from the anode manufacturers. The number of anodes can be determined from total estimated current requirement divided by current per anode. It is important to maintain electrical continuity of the anode during installation.

Considering the feasibility for accommodating the number of anodes in the water heads, suitable anode material can be chosen to restrict the number of anodes. Selection of sacrificial anode material also depends upon the degree of protection required, cost of anode material and its rate of consumption by corrosion. Carefully balanced zinc alloy, which corrodes evenly at a steady rate, is preferred as sacrificial anodes in marine condensers. Magnesium anodes can also be used but because of their higher driving voltage they are quickly spent. Systematic location of the anodes is critical to their overall effectiveness. The location of anodes is generally decided using past experience, ease of maintenance and symmetry. The anodes must be regularly serviced and replaced when spent.

In seawater cooled shell-and-tube condensers, anode rods are provided in the water heads, typically in two ways, as shown in *Photos 1* and *2*.

Photo 1 shows the anode rods completely inside the water head. The advantages of such an arrangement are that the depth of water heads can be minimized to reduce the overall length of the condenser and leakages through the anode holding holes in water heads can be avoided. The length limitations are critical for naval duty as less space is available onboard. The leakages can be severe in some cases, such as with seawater-cooled condensers onboard a submarine, because seawater pressure is in the range of 20 to 30 bars (2000 to 3000 kPa).

The major disadvantage is that you must open the condenser water heads to know the status of the anode rod corrosion.

In *Photo 2,* a provision is made to insert the anode rods in the water head from the outside. The advantage is that the operator can easily determine the corrosion status of the anode rod by removing only the anodes. The disadvantage is the depth of water heads are increased, causing an increase in the overall length of the condenser and the chance of leakages through the anode holding holes in the water heads.

Photo 1 (top): Anode rods inside water head. **Photo 2 (bottom):** Provision to insert anode rods in water head from outside.

A common maintenance problem with this arrangement occurs when operation and maintenance staff use these anodes as handholds and footholds. The staff must be trained and prohibited from doing so, as the anodes may break inside the waterhead.

In some cases, anodes are provided even after using the same construction material for tube sheets, tubes, water heads and seawater piping. The corrosion of anodes in these cases does not indicate any sacrifice, as galvanic corrosion of the base metal is not probable even if anodes are absent. Thinking that the anode rods are protecting condenser corrosion, the operator will continue to replace the consumed rods unnecessarily. Designers should avoid such redundant selections, which confuse operators.

Seawater pipelines may be made of a variety of materials: titanium, copper, nickel, etc. When connecting pipelines of different materials, use flange joints with gaskets to electrically insulate the two materials. Electrical discontinuity must be maintained between the two pipes. Therefore, flange bolts must be rubber coated, plastic/rubber washers should be used and the pipe should be supported using clamps with internal rubber lining. The electrical discontinuity between metals prevents electrons from flowing and causing galvanic corrosion. Over a period of time, a salt bridge can form in a flanged joint, which allows galvanic corrosion. The pipe should be cleaned periodically from the inside to avoid salt deposition.

Pitting Corrosion

Pitting corrosion is a form of extremely localized corrosion that leads to the creation of small holes in the metal. This kind of corrosion is insidious. It causes little loss of material, showing a small effect on its surface, while it damages the metal deep inside. Corrosion often obscures the pits on the surface and makes pitting difficult to detect.

All forms of pitting are caused by the same basic mechanism. During corrosion, the protective film may not form or local destruction of film may occur. This local void in the protective surface can set up a galvanic cell. In a local galvanic cell, lack of oxygen around a small area creates an anode. The area with excess oxygen becomes a cathode. The corrosion penetrates the mass of the metal, with limited diffusion of ions, further pronouncing the localized lack of oxygen.

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In marine refrigeration systems, the pitting corrosion is observed in piping, valves, pumps, and condenser water heads, etc. Pipes welded together may have a variation in composition, causing pitting. The paint and coating on pipelines usually breaks on the support because of vibrations. Therefore, this discontinuity causes pitting. If possible, provide pipe clamps with an internal rubber lining to avoid friction damage to pipes. Polished surfaces display higher resistance to pitting. During a prolonged shutdown of a plant, the seawater remains stagnant in condenser water heads, inducing pitting. Properly located and sensibly operated drains help avoid pitting. Weep holes on the pass partition plate (*Figure 1*) allows the water to fall in the lowest pass where it can be drained.

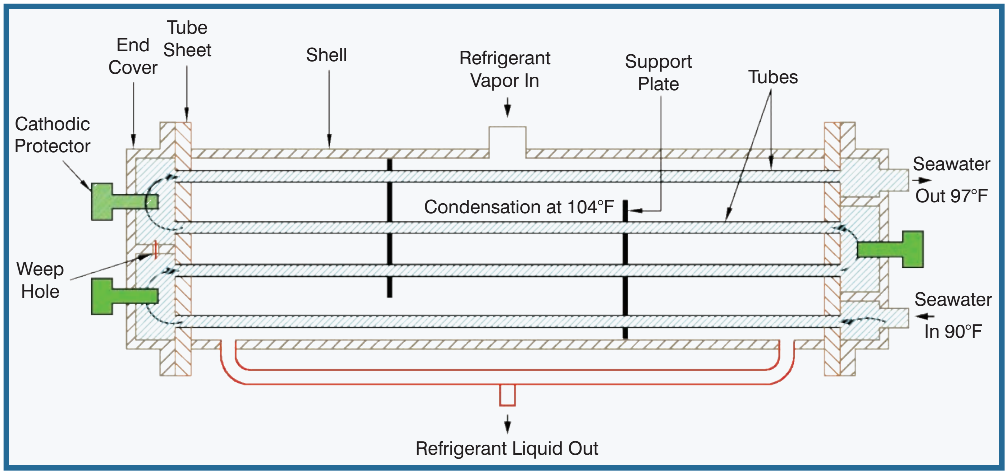

Figure 1: Typical marine condenser.

Metals with impurities caused by cold working, welding, or alloys with microstructures consisting of two different metallurgical phases are generally more prone to pitting. Alloys most susceptible to pitting corrosion are where corrosion resistance is caused by a passivation layer such as stainless steels, nickel alloys or aluminum alloys. Metals susceptible to uniform corrosion tend to not have pitting. Regular carbon steel corrodes uniformly in seawater, while stainless steel will pit. The addition of about 2% of molybdenum increases pitting resistance of stainless steels. Corrosion inhibitors, when present in sufficient amounts, provide protection against pitting. However, if the level is too low, they can aggravate pitting by forming local anodes.

Another type of pitting corrosion rarely found in marine refrigeration systems is formicary corrosion, which forms on refrigerant copper pipelines and heating cooling coils. The corrosion appears as multiple pinhole leaks at the surface of the copper tube that are invisible to the human eye. Upon microscopic examination, the formicary corrosion pits show networks of interconnecting tunnels through the copper wall. This network resembles an ant nest.

Formicary corrosion occurs in the presence of moisture and organic acids such as formic and acetic acid. These acids are present in insulation, adhesives and paint. Using formic and acetic acid-free insulation, adhesives and paint can minimize such corrosion. Other sources of formic and acetic acid include plants onboard in dry dock, as well as smoke, fumes and paint particles, which may be trapped below the insulation. Properly ventilate the compartment before insulating the refrigerant copper lines.

Cavitation

Cavitation is the formation of vapor bubbles of a flowing liquid in a region where the pressure of the liquid falls below its vapor pressure. Cavitation is the process where a void or bubble in a liquid rapidly collapses, producing a shock wave. Strong shock waves formed by cavitation removes the metal by erosion. Such cavitation often occurs in pumps, propellers and impellers.

Cavitation occurs in the seawater or chilled water pumps used in marine refrigeration systems. The operator will know cavitation is occurring when the pump produces a knocking noise and vibrations while increasing power input and decreasing pump output. The pump must be stopped immediately to avoid damage to the impeller and casing. Before stopping the pump, always remember to stop the compressor to avoid damage to it. The pump can then be inspected for damage.

The pressure required to operate a pump without causing cavitation is called net positive suction head (NPSH). The pressure head available at the pump inlet should exceed the required NPSH. The pump manufacturer specifies the NPSH.

As cavitation relates only to the suction side of the pump, all prevention measures should be directed at this area. The following guidelines should be used:

- Minimize the pressure drop in pump suction line;
- Minimize number of valves and bends in the pump suction line;
- Suction length (lift) should be as short as possible;
- Suction pipe should be at least the same diameter as the pump inlet connection;
- Use long radius bends;
- Increase the size of valves and diameter of pump suction pipe;
- Do not allow air into the pump suction line;
- Ensure adequate submergence over the foot valve;
- Try to install the pumps always below the water line;
- If possible, make self-priming provisions; and
- One solution may be to reduce the required net positive suction head. Lowering the pump speed can do this. However, this will also result in reduced output from the pump, which may not be suitable for the system.

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If cavitation cannot be eliminated at the design stage, select suitably resistant alloys. For detailed guidelines for pump design and material selection, refer to the U.K. standard in Reference 5.

Stress Corrosion Cracking

Stress corrosion cracking (SCC) is the unexpected sudden failure of normally ductile metals subjected to a tensile stress in a corrosive environment, especially at an elevated temperature in the case of metals. It is more common among alloys than pure metals. High levels of stress in service, or residual stress from manufacturing may result in selective corrosion of more highly stressed regions of an otherwise corrosion resistant structure. In the aggressive marine environment, even the more resistant alloys may be affected by hydrogen-induced cracking, or by chloride or sulphide stress corrosion cracking.

The stresses can be the result of the crevice loads due to stress concentration, or can be caused by the type of assembly or residual stresses from fabrication (e.g., cold working). Annealing can relieve the residual stresses.

Although not a widespread problem, failure from stress corrosion can occur where both stress, internal or external, and a corrosive environment are present. The corrosion is specific to the material and its environment, and stress, whether imposed or residual internal, must be tensile. The mechanism differs according to the material and the environment but failure would not occur if either stress or corrosion were absent.

Cupronickel has a good resistance to stress corrosion cracking and is not susceptible to chloride or sulphide or ammonia in seawater, which is why it is normally used in seawater piping for marine refrigeration systems. The refrigerant piping can be provided with flexible vibration eliminators to avoid pipe stresses during operation.

It is generally understood that stress corrosion cracking occasionally can affect high-pressure vessels in ammonia refrigeration systems. But research suggests that it is not restricted to high-pressure vessels and may affect copper pipe work in fluorocarbon refrigeration systems.[6] One method to reduce the probability of stress corrosion cracking is to control the temperature. Using liquid refrigerant injection with screw compressors can control discharge temperature. Removing non-condensable gases by proper purging reduces the condensing pressure and temperature. Titanium and its alloys are resistant to stress corrosion cracking in most media, including marine environments. However, certain titanium alloys are susceptible to stress corrosion when in contact with chlorinated hydrocarbons or fluorinated sealants.[7]

Crevice Corrosion

Crevices can develop a local chemistry, which is different from that of the bulk fluid. For example, in boilers, concentration of non-volatile impurities such as sodium, sulfate or chloride may occur in crevices near heat-transfer surfaces because of the continuous water vaporization. Fouling of heat exchangers also can cause crevice corrosion in marine refrigeration systems. Common locations for crevice corrosion in heat exchangers are at gaps between the tube and tube sheet or at gasket joints.

Two factors are important in the initiation of active crevice corrosion. First, the higher concentration of the electrolyte in the crevice. And, second, the differential electrolyte chemistry inside and outside the crevice (a single metal part undergoing corrosion is submerged in two different environments).

Both factors are caused by deoxygenation of the crevice. Some of the phenomena occurring within the crevice may be somewhat reminiscent of galvanic corrosion.

To prevent crevice corrosion, you need to eliminate the crevices by using welded butt joints instead of riveted or bolted joints, performing continuous welding or soldering, rather than lap joints, as well as using non-absorbent gaskets such as Teflon can reduce crevice corrosion.

Fouling

Fouling is accumulation of unwanted material on solid surfaces, most often in an aquatic environment. In marine refrigeration systems, fouling can occur in heat exchangers, especially in a shell-and-tube condenser and an evaporator and water pipelines. Fouling phenomena are common, complex and diverse. Unlike corrosion, fouling leads to high operational losses by inefficient heat transfer and increased pressure drop. To compensate for fouling, heat exchangers are liberally sized, which results in higher capital cost. There are also increases in inspection and maintenance costs.

The indirect damages arise from using biocides and increased energy or fuel consumption. Fouling also causes many additional problems like corrosion damage, flow blockages/redistribution, flow induced vibrations, etc. The fouling material can consist of either living organisms (biofouling) or a non-living substance (inorganic or organic).

Biological Fouling. Biological fouling is an undesirable accumulation of organisms such as algae, bacteria, diatoms, plants, and animals on surfaces. Calcareous organisms attach to the base surface using different types of glues. These are sticky holding mediums for other types of fouling, which otherwise would not adhere to clean surfaces.

Biofouling of marine heat exchangers, water pipelines, etc., promote corrosion. Filtration, chlorination and biocides are necessary to prevent frequent shutdowns.

Non-Biological Fouling. This fouling may occur by precipitation, sedimentation, coagulation and chemical reaction. At a higher temperature, calcium bicarbonate present in the water decomposes to form calcium carbonate and its precipitates. The scaling is higher at the hotter outlet of a heat exchanger than at the cooler inlet. Maintaining lower discharge and condensing temperature can help delay scaling.

A chemical fouling inhibitor can interfere with the crystallization, attachment, or consolidation steps of the fouling process. In addition, additives may alter the structure of the fouling layers so that they can be removed easily. However, chemical cleaning methods are not practical in marine refrigeration systems as cooling water is continuously pumped from and discharged into the sea. If this method is used, only evironment-friendly chemicals should be used. Chemical cleaning must be followed by passivation of the surfaces.

Fouling Control

Temperature Control. As the discharge gas/condensing temperature increases, the amount of fouling increases. Operating the plant at a lower discharge/condensing temperature can delay scale buildup.

Velocity Control. Marine condensers are often a shell-and-tube design, using seawater as the condensing medium; refrigerant flows on the shell side, and seawater flows through tubes. Higher seawater velocities reduce the tendency to foul; however, velocities are limited by erosion. Using harder tube materials such as cupronickel and titanium can allow higher velocities to be used without much erosion.[8,9] The higher velocities also increase pressure drop and pumping power. Therefore, the designer must optimize capital cost, operating cost, erosion and corrosion.

The stagnant regions in the water heads require properly located drain plugs. Because of rolling and pitching, the size and number of drain plugs must be sufficient to drain the seawater freely. Webs, or pass partition plates, are used for making passes on the tube side in the condenser. The provision of weep holes on the webs in water heads allows the water to flow to a lower pass from where it can be drained out. (*Figure 1*).

Direct expansion (DX) chiller packages are often used in marine refrigeration systems; water flows on the shell side and refrigerant flows through tubes. High velocities on the shell side are limited by flow-induced vibration. Properly spaced baffles help minimize the dangers of flow induced vibrations.

Material Selection. Selection of tube material is important for the required heat transfer rate and is significant from a corrosion point of view. Copper bearing tube materials can lessen certain kinds of biological fouling. Generally, copper tubes are used for a DX evaporator with fresh water flowing outside the tubes. Cupronickel/titanium tubes are used in condensers with seawater flowing through the tubes.

Because the refrigerant side governs the heat transfer coefficient, the condenser tubes are externally finned and the evaporator tubes are internally finned. The surface finish also influences the rate of fouling and ease of cleaning. The heat exchangers must be situated so that enough space is available for tube cleaning. This is particularly important in warships and submarines.

In some applications where seawater is used on the shell side, tube sheets and tubes can be constructed using cupronickel. Since cupronickel is a hard material, internal finning can be difficult. Plain tubes require more surface area for the same heat transfer duty.

Filtration helps in removing macroparticles and preventing deposition and fouling. The filters must be inspected and cleaned periodically; partially clogged filters can cause huge operational losses. A clogged condenser water filter results in increased condensing temperature and compressor power. Higher surface temperatures cause increased fouling deposits.

Prevention of Biological Growth. Fluid treatment is commonly carried out to prevent corrosion and/or biological growth. However, the effect of biocides on the environment should never be ignored.

Place More Fouling Fluid on Tube Side. Two benefits occur from placing more fouling fluid on the tube side. There is less danger of low velocity or stagnant flow regions, and it is generally easier to clean the tube side than the shell side. It is often possible to clean the tube side with the exchanger in place, however, it may be necessary to remove the bundle to clean the shell side.

Design Fouling Resistances ($ft^2·h·°F/Btu$). The values of fouling resistances do not recognize the time-related behavior of fouling with regard to specific design and operational characteristics of a particular heat exchanger. Fouling resistance, as per TEMA, is generally used if any other value is not specifically mentioned. Advanced heat exchanger design software allows for the design of better heat exchangers.

Corrosion by Moisture Present in the System

Reasons for presence of moisture in any refrigeration system are incomplete drying of components during manufacturing, moisture left in the system after evacuation or dehydration during installation, moisture content in refrigerant and oil and formation of moisture or water due to a chemical reaction within the system.

Moisture in the system can react with halogenated refrigerant and form hydrochloric or hydrofluoric acids. These acids, particularly hydrofluoric acids, are very active and highly corrosive, and they attack various parts of refrigeration systems. The compressor motor winding in a sealed unit is usually the first to be affected by acids and moisture. A peculiar pungent smell coming from the gas of a burned-out, sealed-unit system is due to the presence of hydrofluoric acid.

Because chemical reactions due to acids and moisture are accelerated at higher temperatures, discharge valve reed and seats become corroded easily. Damaged discharge valve reed and seats will cause a decrease in compressor efficiency and allows hot discharge gas to flow back to the suction side. This raises the compressor body temperature and causes further corrosion. Corrosion products can contaminate the lubricating oil and deteriorate its lubricating properties. The life of bearings and journals will decrease, and even compressors can completely fail.

In a low-temperature application, such as refrigeration plants, the presence of moisture in the system is quickly detected by the freezing of moisture at the throttling device and consequent malfunctioning of the refrigeration system. In applications such as air conditioning, the evaporating temperature is above 0°C (32°F) and the presence of moisture in the system is not evident at all. The system components are affected, but is only evident when the system fails. It is important to remove the moisture from the system. Following deep dehydration and evacuation of a refrigeration system during installation can significantly remove the moisture from the system. Any traces of moisture can further be countered by providing a filter drier in the refrigerant liquid line. The core of the driers should be regularly replaced.

Corrosion by Moisture Surrounding the System

In marine refrigeration plants moisture present outside the system also causes considerable corrosion. Corrosion under insulation (CUI) of carbon steel pipes and the evaporator shell[10] is a typical example of corrosion by moisture surrounding the system. Unfortunately, CUI is difficult to detect as the metal surface is covered under insulation. The water formed from condensation of moisture expands during freezing and damages the insulation. The damaged insulation becomes more susceptible to further corrosion. All joints and surfaces should be carefully sealed to keep out atmospheric moisture. Applying corrosion resistant paint and installing a good closed cell insulation material that is tightly bound to the pipe can help control CUI.

During maintenance, the damaged insulation should be inspected, repaired or replaced. In refrigeration applications below 0°C (32°F), a proper drain arrangement with defrost heaters must be provided. The electrical panels should incorporate space heaters. The cable entry[11] to electrical panels should be placed to avoid any chances of water dripping inside. The IP Codes or International Protection Rating for electrical equipment must be followed.

Corrosion Control in Piping and Ducts

Corrosion affects refrigerant piping, chilled and seawater piping and HVAC&R ducts.

The higher flow rates in chilled and seawater piping and in seawater tubes are limited by erosion. But low flow rates are also damaging and cause under deposit corrosion.[12] Erosion problems in condenser water heads can be minimized by sizing the water heads for 10% to 15% extra capacity and carefully deciding the nozzle entry.

Selecting suitable corrosion resistant construction material controls corrosion of chilled water and seawater piping. Titanium and cupronickel pipes allow higher velocities without erosion problems. However, these materials are costly. The pipes can be joined together by flanges and stubends. With this arrangement, flanges are prevented from coming in contact with seawater. Therefore, carbon steel flanges and cupronickel stubends are common for marine applications. This also helps reduce capital costs considerably.

Steel sheets are used to make air ducts. To inhibit corrosion during transportation and storage of the ducts, they are coated with a thin film of oil. However, this coating may trap dirt particles and cause problems with ensuring acceptable indoor air quality. Before installation, remove the oil coating by washing with a soap solution. Routinely inspect the duct for moisture-induced corrosion damages.

Refrigerant piping is joined by welding and brazing. Both processes are heterogeneous and are susceptible to microgalvanic corrosion. The joints retain residual stresses and matrix heterogeneity. Heating these joints to appropriate temperatures, which are below the transformation temperature range, may reorganize the microstructure uniformly and deactivate the highly stressed sites. Such structural uniformity and stress matching reduces the microgalvanic corrosion.

Summary

Designers can tackle corrosion problems by designing heat transfer processes better, controlling the flow behavior of fluids involved, selecting corrosion resistant construction materials and choosing appropriate manufacturing methods. In addition, designers also need to consider ease of inspection and maintenance and optimization of capital and operating costs. A designer's dream can become a reality only by proper installation and operation of a system. Hence, care must be taken during installation and operation to minimize corrosion.

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