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SACRIFICIAL ANODES: SAFEGUARDING MARINE ASSETS

EMPOWERING PERFORMANCE

INDEX

INTRODUCTION

Corrosion of metals causes global economies to lose billions of dollars each year. A significant 33% of these costs could be prevented with the use of appropriate corrosion protection systems (Tezdogan and Demirel, 2014).

In particular, the marine industry is severely prone to corrosion from time to time, as seawater is a strongly corrosive electrolyte. Metallic structures that are submerged in seawater suffer severe corrosion if not properly protected. Ships and boats are on water for extended amount of time carrying passengers, cargo or performing offshore operations. Preventing corrosion is thus important to avoid any potential water leaks that could hamper the safety of personnel and operations.

In this whitepaper, we focus on the basic idea of corrosion, factors affecting it and methods that prevent corrosion in the marine sector. A special focus is drawn on corrosion in sea chest areas that use box coolers as a cooling solution and corrosion prevention method as sacrificial anodes - their design and lifetime.

CORROSION – AN EVIL FOR MARINE APPLICATIONS

Metals that are extracted from their primary ore tend to revert to that state under the action of oxygen and water. This action is called corrosion and the most common example is the rusting of the steel. Corrosion is an electro-chemical process that involves the passage of electrical currents on a micro or macro scale (Harvey 2019). Figure 1 [1] shows the electro-chemical process.

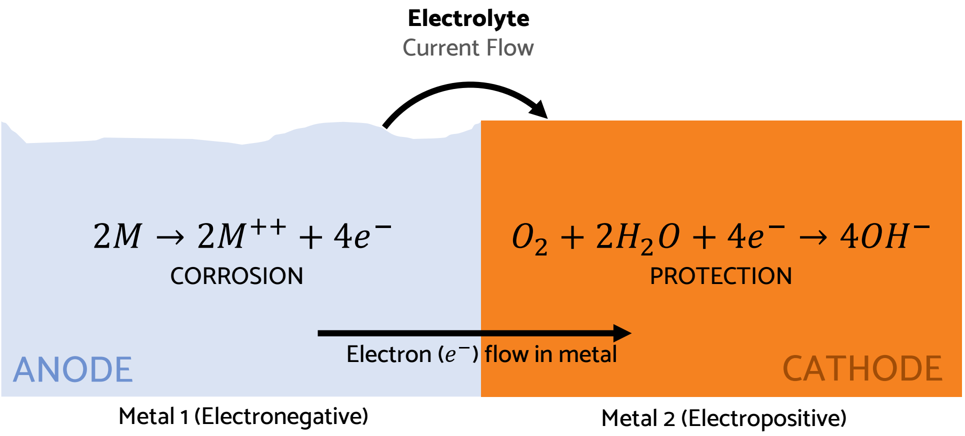

Figure 1 Electro-chemical reaction of Corrosion

The anode and cathode are two different metals connected, or as in case of rusting of steel, they may be close together on the same surface. Important to understand is that metals corrode because of a medium and presence of another metal.

'Galvanic Series' decides which metals corrode in presence of other metals. It basically determines the electrochemical potential and nobility (property to resist corrosion) of metals.

When two metals are submerged in an electrolyte, while also being electrically connected (electron flow passage available), the less noble metal becomes the anode experiencing galvanic corrosion and starts to corrode faster than it would by itself, while the other metal becomes cathode and corrodes slowly than it would alone (Harvey 2019). Figure 2 shows the potential of different metals with Zinc as a reference.

METAL/ ALLOY	POTENTIAL (mV) vs. ZINC
Gold	+1600
Platinum	+1300
Titanium	+1000
Stainless steel (316)	+950
Lead	+800
Brass	+700
Bronze	+680
Copper	+680
Carbon steel	+500
Cast iron	+420
Aluminium (pure)	+300
Zinc (anode alloy)	0
Aluminium (anode alloy)	-40

Figure 2 Galvanic Series

[1] http://eprintspublications.npl.co.uk/id/eprint/8402

As per the series, the least noble metal will act as an anode and go through corrosion. In this case, carbon steel will start degrading giving away electrons to the brass metal, thus corroding the carbon steel.

Sea chests and box coolers are of particular interest when talking about corrosion prone surfaces in ships. Sea chests are compartments within the submerged part of a ship's hull that draw raw seawater for ballasting, engine cooling, firefighting, etc. Box coolers, located within sea chests, were first invented by NRF - a leader in supply and manufacturing of cooling solutions in the maritime industry[3].

NRF is the Inventor of Box Coolers, an effective and environmentally friendly unit requiring minimal maintenance and used worldwide. Being a sustainable and economical solution, box coolers are highly preferred.

Box cooler tubes are generally made up of aluminum brass which are then further coated to restrict galvanic corrosion within the sea chest area. However, the damage scenario is complex within the sea chest area. The level of galvanic corrosion depends upon several factors such as coating of box coolers, hull and sea chest paint, salt content and temperature of water.

Corrosion in the sea chest area can lead to leakages and could be as catastrophic as flooding of the engine room resulting into a lost ship. Additionally, the cooling effect of box coolers can reduce as ions get deposited on the tubes because of the hull's steel corrosion, reducing further the engine efficiency.

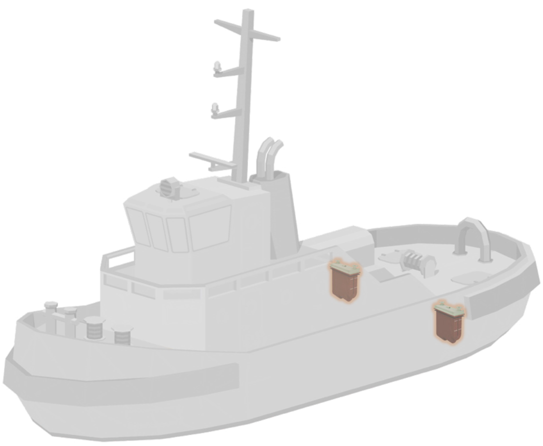

Figure 3 Tugboat with Box Coolers

Figure 4 Box Cooler by NRF

2. https://cathwell.com/safety-risk-due-to-severe-corrosion-related-to-box-cooler-arrangements/
3. https://www.nrf.eu/nl/industries/marine/

HOW TO PREVENT CORROSION?

The marine industry uses several prevention methods to reduce the effects of corrosion and avoid potential damage costs. The system of corrosion prevention is called cathodic protection. The four primary types of corrosion prevention measures used are:

- Paint
- Galvanizing
- Coating
- Sacrificial Anodes

Paints containing high level of active Zinc are used for corrosion prevention. However, painting is costly and time consuming. Paints breakdown quicker due to the water, sunlight, and heat, exposing the steel areas much faster, as compared to other prevention methods (Precision Coating Tech, no date).

Galvanizing is the process of applying layers of Zinc onto the surface to be prevented from corrosion. This includes a long process of chemical baths to remove scale, grease, and rust before the dipping into molten Zinc. However, the process can be ineffective if the chemical bath doesn't remove all impurities, making the Zinc coating weakly adhered to the surface. Weakly adhered Zinc could strip away easily under harsh environment exposing the steel quicker (Precision Coating Tech, no date).

Powder coating is another way of preventing corrosion by dipping hot steel into the powder bath. Just like galvanizing, the steel must be stripped off all impurities for the measure to be effective. Additionally, this is highly time consuming and costly considering large hulls of giant ships (Precision Coating Tech, no date).
Sacrificial anodes are strips of metals and are largely used as standard protection method in sea chest areas and other hull compartments. Anodes act as givers and sacrifice themselves to prevent corrosion. Sacrificial anodes help prevent the sea chest area and box cooler tubes from corroding. Sacrificial anodes are easy to install and inspect and on top of that do not require any external power for working. The only main downside of sacrificial anodes is if the electrical conductivity (electrolyte) is lacking, which results into ineffective working of the anodes (Precision Coating Tech, no date).

In summary, sacrificial anodes stand out as a reliable and feasible corrosion prevention method for sea chests and overall hull area.

WHAT ARE SACRIFICIAL ANODES?

Anodes are strips of metals in the lower order of noble (and galvanic) series used for cathodic protection. While they may appear to be simple pieces of metal, they are a result of sophisticated anti-corrosion engineering (see Figure 4[4]). When the anode and the surface to be protected from corrosion are dipped into electrolyte such as seawater, the anodes slowly dissolve protecting the structure against corrosion.

Figure 5 Sacrificial Anode (Photo provided by our partner CORROSION)

Some of the most used anode materials are Magnesium (Mg), Aluminum (Al), Zinc (Zn), Chromium (Cr), Iron (Fe) and Nickel (Ni).

On top of that, Zinc and Aluminum anodes are much more widely used. However, Aluminum anodes have greater benefits over Zinc. When choosing the material for anode, it is important to keep in mind the grade and composition which determines their effectiveness. Aluminum anodes are significantly lighter (by a factor of 2.5) as compared to Zinc anodes. Also, they have electrochemical capacity of almost 3 times higher than Zinc and carry a better environmental footprint. Finally, reduced weight requirements of the Aluminum anodes make them a cheaper option (Anish 2021).

Anodes can be casted in different shapes and sizes depending upon protection and mounting requirements. Hence, anodes can be designed according to the shape of the structure or hull area. Mounting of anodes is easy and is usually done by bolts, weld, or brackets; welding being the widely used option (Anish 2021).

Most importantly, anodes can be designed and sized according to specific time periods highlighted in the next chapter. All of this makes anodes a highly techno-economic feasible option.

[4] https://cathwell.com/design-lifetime-of-sacrificial-anodes/

LIFESPAN OF SACRIFICIAL ANODES

The design and lifespan of anodes for cathodic protection go hand in hand. For this, several factors must be considered. Two types of information are crucial as per (Tezdogan and Demirel, 2014):

Background information:
- General structure plan
- Current structure condition (damage, paint breakdown, etc.)
- Surrounding environment
- Material to be protected
- Expected damage

Dimensioning information:
- (A) Area (m2) to be protected
- Coating breakdown %
- (i) Mean current density of structure (mA/m2)
- Anode material current output (A/kg)
- (C) Anode consumption rate (kg/A/yr)
- (w) Weight of individual anode (kg)
- (W) Total net anode weight (kg)
- (N) Total number of anodes

The current density (i) is dependent on the type of vessel and conditions of the hull. The following formulas are adapted from (Tezdogan and Demirel, 2014).
First the total anode weight can be calculated considering the total number of anodes and individual weight:

$$W = N \times w$$

Next the lifespan of anodes can be calculated according to the following formula:

$$T = 1000 \times \frac{W}{A \times i \times C}$$

Typically, anodes are designed for a dedicated lifespan depending upon the type of structure to be protected (Breive, 2023).
- For ships: 1-5 years
- For harbors: 15-30 years
- For offshore subsea structure: 10-50 years

Hence, for a given lifespan the weight and number of anodes can be sized accordingly.

EXAMPLE

Anode specifications:

Type: Aluminum
Weight (W): 10 anodes of 20 kg each (200 kg)
Consumption rate (by supplier) (C): 3.39 kg/A/yr.

Vessel Specifications:

Type: Newly built and coated
Current density requirements (i): 10 mA/m2
Total hull area to be protected (A): 1000 m2

Anodes lifesspan (T): $1000 \times \frac{200}{1000 \times 10 \times 3.39}$ = 5.8 years

Since anodes have a limited lifetime, they must be replaced once corroded, to continue providing cathodic protection. In case of ships that are constantly on the move, the checks and replacements of anodes becomes challenging. One of the ways to ensure maximum effectiveness of anodes and continued cathodic protection of hulls is to adapt the anode design life as per the dry-docking periods of ships. Generally, ships dry dock every 5 years for overall health checks and maintenance, which becomes an excellent opportunity to replace the corroded anodes with new ones. The dry-docking period consists of repainting of hulls and sea chest areas, replacement of anodes and cleaning of box coolers.

NRF, in addition to supplying wide range of box cooler parts, also specializes in appropriate cleansing of box coolers and re-coating of its tubes.

The overall anode usage and size can be reduced by implementing NRF's Box Coolers with dedicated Anti-Fouling (AF) systems . These integrated systems help box coolers to prevent biological marine growth on the tubes which protects the tube coating. Damage to tube coating may create a galvanic cell between the tubes and the hull structure causing corrosion. This means more and more anodes may be required. NRF's Box Coolers with Anti-Fouling system are an optimal solution to reduce the need for extensive number of anodes.

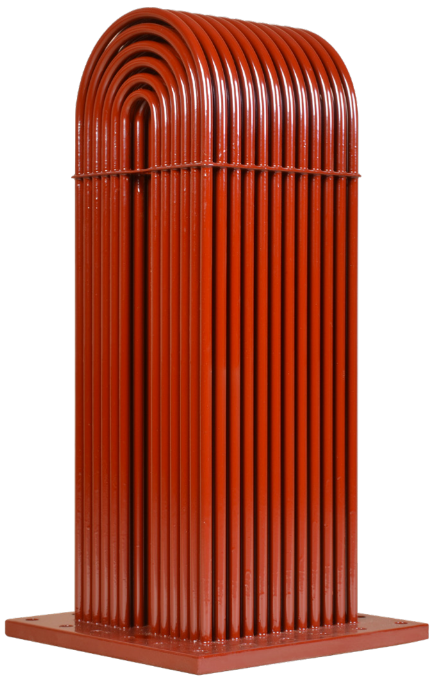

Figure 6 Box Cooler tube bundle

[5] https://www.nrf.eu/nl/industries/marine/marine-producten/#box-coolers-nl

CONCLUSION

Damage and costs from corrosion can have a huge impact. Within the marine industry, sea chest areas of ships and boats with box coolers suffer corrosion on a high level. In general, corrosion is driven by several factors like presence of metals, coating, paints and surrounding environmental conditions. The less noble metals or metals which are at the bottom of galvanic series corrode to protect other metals. Sacrificial anodes are metal strips usually made up of Zinc and Aluminum that are used for cathodic protection. They are an economical and reliable choice as compared to other corrosion prevention methods, owing to their simple and flexible design. Most importantly, **the lifespan of sacrificial anodes can be adapted to certain time periods like dry docking of ships.**

Sacrificial anodes are crucial for corrosion prevention in sea chests and box coolers. They help prevent corrosion in ship hulls that ultimately avoid leakages in the structure. They also help reduce damage to box coolers tubes which maintains the cooling efficiency of the engine. Sacrificial anodes play an important role in corrosion prevention in ships and vessels and must be considered by all vessel owners and operators while designing cathodic protection systems.

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CORROSION has been in the business of protecting offshore wind farms, vessels and onshore applications since 1993. From their humble beginnings in the small town of Moerkapelle in the Netherlands, they have grown into an internationally recognized leader in creative, sustainable, state-of-the-art solutions in corrosion and cathodic protection.

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