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Sacrificial Cathodic Protection of River Boats in Freshwater: An Investigation on the Effect of Water chemistry and Anode Material

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ABSTRACT

River boats currently in operation lack adequate protection against corrosion. Historically, iron and steel have been the primary materials employed in boat construction. The cathodic protection techniques for boats involve the use of sacrificial anodes to mitigate hull corrosion. This paper will elucidate the sacrificial cathodic protection of boats operating in fresh water, specifically focusing on those in Basrah's fresh water. The influence of water composition and the materials used for sacrificial anodes on the efficiency of the river boat protection system has been thoroughly investigated, particularly concerning magnesium and aluminum anodes. The analysis and calculations revealed that for magnesium anodes weighing 2.3 kg, a total of 17 sacrificial anodes are required, distributed over a span of 1.5 m. In contrast, for 2.3 kg aluminum anode, 13 aluminum anodes are necessary, spread over a distance of 2 m. Furthermore, the impact of fresh water pollution directly affects cathodic protection, accelerating the consumption rate of the anodes.

INTRODUCTION

Corrosion can have a devastating impact on boats, regardless of the type of water they are in. Therefore, it is essential to utilize sacrificial anodes for their protection. A sacrificial anode is a metal or alloy affixed to the hull of the vessel, possessing a lower noble potential than steel when submerged in water. These anodes provide cathodic protection current, but they are gradually consumed in the process, necessitating their replacement to ensure ongoing protection. Currently, zinc, aluminum, and magnesium alloy anodes are in use, and high-purity zinc anodes are also available (Shehadeh *et al.*, 2013).

A sacrificial anode is a type of anode connected to the metal parts of boats, designed to draw corrosion away from these components, thereby safeguarding them from damage due to its composition of a metal that ranks higher in the galvanic series. The quantity and dimensions of sacrificial anodes utilized are determined by the material of the boat's hull and the specific area that requires protection. Furthermore, factors such as the size of the boat, the type of water it is in, and the length of time it remains submerged all influence the frequency with which anodes need to be replaced (Wen *et al.*, 2023).

LITERATURE REVIEW

Galvanic anodes composed of Al, Zn, or Mg are predominantly utilized for the cathodic protection of steel structures owing to their high efficiency, low density, substantial electrochemical equivalent, availability, and cost-effectiveness. Umoru *et al.* (2008) examined the impact of tin composition on Al-Zn-Mg alloy as a sacrificial anode in seawater. Their findings indicate that varying microstructures of Al-Zn-Mg-Sn alloys affected their anode efficiency, with an increase in tin concentration enhancing this efficiency. Zhang *et al.* (2014) explored the corrosion behavior and operational performance of zinc sacrificial anodes under conditions simulating marine fouling. They observed a significant decrease in the corrosion rate during the initial attachment phase of fouling organisms on the zinc anode. William *et al.* (2014) developed a method to predict the performance of low voltage aluminum sacrificial anodes based on their chemical composition. They investigated the individual effects of alloying elements and their interactions. The microstructures of the as-cast alloys and the corrosion surfaces were analyzed using electron microscopy. Ole *et al.* (2024) researched the cathodic protection of various aluminum alloys in seawater, revealing that the current demand for cathodic protection of aluminum is influenced by the alloy's chemical composition.

The aims of this study were to elucidate the procedure for cathodic protection of boats and ships in freshwater. The procedure was applied to assess the two sacrificial cathodes, aluminum and magnesium, in freshwater, evaluating their corrosion protection and consumption.

MATERIALS AND METHODS

Sacrificial Anode Materials

Aluminum and magnesium serve as the most effective anodes for freshwater vessels, offering enhanced protection in environments with low conductivity. The use of zinc anodes in freshwater is discouraged due to their tendency to develop a hard, dense coating over time, which diminishes their effectiveness Philippe *et al.* (2022).

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Consequently, two sacrificial anodes made of aluminum and magnesium was utilized in the studies.

The aluminum anode is produced by Zibo Deyuan Metal Material Co. Ltd., China, and is identified as type DY-VJ, with dimensions of 300 * 100 * 35 mm and a weight of 2.3 kg. Additionally, the rectangular magnesium hull anode, featuring a single strap, is manufactured by Jennings Anodes Co. LTD., USA. Figure 1 illustrates the aluminum and magnesium anodes.

Table 1: The characteristic of rectangular magnesium hull anode with single strap [Chris, J. (2025), and Chris, J. (2026)]

Model	Weight	Anode dimension (L*W*H)	insert size
JA –MG –5L	5 lbs (2.3 kg)	10"× 5" (254 × 127mm)	13 1/4" ×1/4" (337×6.35mm)

Figure1: Magnesium and Aluminum sacrificial anodes

Estimating Wetted Surface Area of Boat Hulls

To determine the quantity of anodes required for a vessel, it is essential to ascertain the ship's wetted surface area (WSA), defined as the portion of the hull that comes into contact with the water. The WSA is typically expressed in square meters (Jari *et al.*, 2006).

W S A = 1.0 LWL x (Beam + Draft) for full displacement vessels (motor yachts and sail boats)

WSA = 0.75 LWL x (Beam + Draft) for medium displacement vessels

WSA = 0.50 LWL x (Beam + Draft) for light-displacement vessels

The LWL (Length of Water Line) value is obtained from the equation

$$LWL = (2\%)\ LBP + LBP \quad \dots (1)$$

Figure 2 and Table 2 displays the type of length on the ship's hull to clarify Equation 1 and the advanced standards used for the calculation process of the required anode weight.

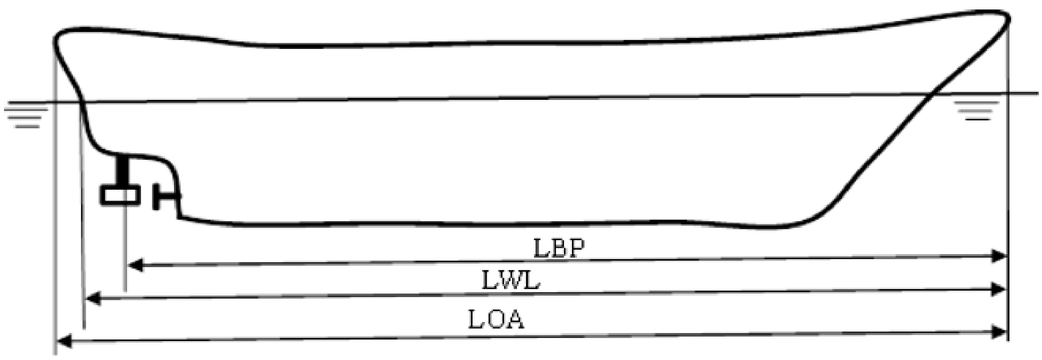

Figure 2: Ship's hull Specification

Table 2: Boat's dimension data and specification

Specification Type		**Value**
1	Length over all L.O.A.	13 m
2	Length between Perpendicular (LBP)	11.2 m
3	Width (B)	3.6 m
4	Height (H)	2.8 m
5	Speed	12.00 Knot
6	Engine Power	500 HP
7	Laden (Draft)	1.7 m

Calculation Total Anode Weight

The necessary level of cathodic protection for a vessel can be established by calculating the anode weight value. For boat hulls made of steel and aluminum (or for underwater structures), the subsequent formula can be utilized to determine the total weight of sacrificial anodes needed (Bakker *et al.*, 2017, Wenyuan, *et al.*, 2024).

total Anode Weight=

$$\frac{(\text{Wetted Surface Area}) \times (\text{Current Density}) \times (\text{Immersion})}{[(\text{Energy Content}) \times (1000\ \text{mA/Amp})]} \quad \ldots (2)$$

Table 3: The characteristic of magnesium, and zinc anode with single strap (Xu, *et al.*, 2021)

Wetted Surface Area (sq-ft):	Actual or Estimated Wetted Surface of Metal
Current Density (mA per sq-ft):	1.5 – 5.0 for painted Steel hull / structure 0.2 – 3.0 for painted Aluminum hull / structure
Immersion (hours):	Number of hours in water per replacement interval (8766 hours per year)
The capacity of an anode (amp-hours per kg):	1100 for magnesium anodes 750 for zinc anodes 1500 for aluminum

The total quantity of anodes required to safeguard the wetted surface area is determined using the following equation:

$$Number\ of\ Sacrificial\ Anode = \frac{Total\ anode\ wight}{anode\ weight} \quad \ldots (3)$$

The installation of sacrificial anodes on ships is arranged according to the area of the ship's hull plate or the area below the waterline and divided according to the distance between the

anodes. The distance between anode placement points (DAP) is as follows (Sade *et al.*, 2024).

$$DAP = \frac{2*LWL+2\ Draft}{numbe\ of\ anodes\ in\ hull} \quad \ldots (4)$$

Fresh water of Basrah River

Fresh water is a highly intricate and heterogeneous solution. It encompasses a significant quantity and variety of dissolved solids, gases, and different forms of biological matter (Bellezze, *et al.*, 2013). The composition of fresh water, measured in mg/L, is analyzed using a Spectrophotometer, with the results presented in Table 4. The pH level of the water was assessed with a pH meter, yielding an average range of 7.1 to 7.9.

Table 4: Ion compositions of Basrah fresh water in (mg/L)

Ions	(Cl-)	(Na+)	(SO42-)	(Ca2+)	NH3	(HCO_3^-)	Oil and grease	NO2
Value mg/L	713	15.85	3786	315	8.82	142	1.35	1.76

RESULTS AND DISCUSSIONS

The LWL (Length of Water Line) value is obtained as followers:

LWL = (2%) (11.2) + 11.2 = 11.424 m

In the design of boat in fresh water are made according to the standard light displacement vessel because the installation of cathodic protection is always under an empty boat draft. A light displacement vessel is an empty ship's weight including the ship's hull, ship's machinery, and ship's fixed equipment

WSA = 0.50 LWL x (Beam + Draft) for light-displacement vessels

WSA = 0.50 * 11.424 * (3.6+1.7) = 30.3 m2

Immersion or contact time is taken for design as 3 years and carried out as:

Immersion = (Total hours/year) x (Target anode life)

= (8766 hours/year) x (3 year) = 26298 hours

The magnesium hull anode is designed to comply with the American standard ASTM B843 – AZ63C anode, which has an energy content value of 1100 A.h/kg, as indicated in Table 2. The selected current density, according to Table 2, is 5 mA/ft² (53.8 mA/m²). Based on the established variables, the subsequent results pertain to the calculation of the requirements for magnesium sacrificial anodes.

$$total\ anode\ weight = \frac{(30.3) \times (53.8) \times (26298)}{[(1100) \times (1000\ \text{mA/Amp})]} = 38.973\ kg$$

The weight of the magnesium anode according to Table 1 is 2.3 kg., so, the total number of magnesium anode is as followers:

$$Number\ of\ Sacrificial\ Anode = \frac{38.972}{2.3} = 16.944\ pieces$$

There are 17 per 30.3 m2 of sacrificial anodes will be placed on the hull of the boat.

The distance between anode placement points (DAP) is as follows.

$$DAP = \frac{2*LWL+2\ Draft}{numbe\ of\ anodes\ in\ hull} = \frac{2*11.424+2*1.7}{17}\ 1.544\ m$$

Table 5. Comparison of calculation results for magnesium and aluminum anodes utilized in boats. As shown in Table 5, the total requirement for aluminum anodes is 13 pieces, which is fewer than the 17 pieces needed for magnesium anodes at the same selected weight.

Table 5: list of calculation for maximum and aluminum anode.

	Magnesium	Aluminum
Wetted Surface Area (WAS)	30.3 m2	30.3 m2
LWL	11.424 m	11.424 m
Total anode weight	38.972 kg	28.579 kg
Total Anode weight (kg)	2.3 kg	2.3 kg
Number of sacrificial anode	17 pieces	13 pieces
DAP	1.5 m	2 m

The effectiveness of Mg anodes compared to Al in fresh water can be attributed to the greater driving voltage provided by Mg anodes. Fresh water exhibits significantly lower conductivity for ionic current flow, meaning it has a considerably higher resistivity than salt water. Consequently, the elevated driving voltage of Mg enables it to deliver more current than Zn. In simpler terms, it is more feasible to surmount the resistance of the current pathway in fresh water using Mg anodes than with an equivalent number, size, and shape of Zn anodes. Additionally, Zn anodes pose a risk of potential reversal at higher temperatures in specific water conditions. Al anodes also present a risk of "passivation" in fresh waters; if the driving voltage is negatively impacted, it may result in inadequate current delivery for effective cathodic protection.

The pH levels of fresh water, as indicated in Table 4, range from 7.1 to 7.9 (Cruz, *et al.*, 2023) demonstrated that variations in water pH influence the efficacy of cathodic protection, with these effects becoming more pronounced as temperature rises. Due to contamination from heavy waste and crude oil, the concentration of Cl- is notably high, which accelerates the consumption rates of anodic electrodes, as shown in Table 4. Conversely, the SO42− ion is a critical factor influencing cathodic processes at the metal-seawater interface (Alessandro, *et al.*, 2009). The substantial concentration of SO42− (3786 mg/L) contributes to increased anodic consumption rates. Other pollutants, including oil and grease, exhibit similar effects.

CONCLUSION

Following the analysis and calculations conducted to determine the quantity of sacrificial anodes required for a cathodic protection system on the boat, the findings indicated that for magnesium anodes, a total of 38.972 kg is necessary, comprising 17 anodes distributed at intervals of 1.5 m, with each magnesium anode weighing 2.3 kg. In contrast, for aluminum anodes weighing 2.3 kg each, the total weight required is 28.579 kg, consisting of 13 anodes spaced 2 m apart. Additionally, the impact of freshwater pollution directly affects cathodic protection and leads to an increased consumption rate of the anodes utilized.

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