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Experimental Study of Magnesium Anode Voltaic Cell as Electrical Source of Impressed Current Cathodic Protection for Ship Hull

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Abstract
Impressed Current Cathodic Protection (ICCP) is one of the methods to protect a metal from corrosion by utilizing electricity supply. In this paper, a renewable energy-based electrical source in the form of magnesium anode voltaic cell is proposed to supply ICCP system. Based on the experiment results, the proposed voltaic cell can generate 0.6 Volt voltages and 0.023 Ampere electric current. According to those potential, the required number of voltaic cell to protect the object of Live Fish Carrier "Wellboat" is 2849 cell, connected 37 in series and 77 in parallel.

Keywords: Corrosion, impressed current cathodic protection, magnesium, voltaic cell

INTRODUCTION

Indonesia is an archipelago nation which relies on ships to distribute goods between islands. Most of the ship is made from metal alloy which is very vulnerable to corrosion since it always immersed in water. If the corrosion process is not slowed down, the hull will be damaged and it will take high cost to repair it. Therefore a corrosion protection system needs to be applied in ship [1].

One of the methods to protect the hull from corrosion is cathodic protection. The hull is connected to other metal which is more anodic so the hull becomes the cathode. Cathodic protection consists of two methods, sacrificial anode cathodic protection (SACP) and impressed current cathodic protection (ICCP). In SACP, the anode is sacrificed and will be eroded because it is supplying electron to protect the cathode. Therefore it is not economically beneficial due to the need to change the anode in certain period. In ICCP, the anode will not be eroded because it receives supply of electron from the electric current source [2].

Since the main electrical supply in the ship is diesel generator which is consuming high price fuel oil and not environmentally friendly, the utilizing of renewable energy resources for small application in the ship will be very appreciated [3-9]. In this paper an experimental study to develop a renewable energy-based electricity producer for supplying ICCP system is conducted. The proposed method is using voltaic cell with magnesium anode. The voltaic cell is suitable to be used in ship application because it is using abundant sea water as the electrolyte cell [10]. Magnesium is chosen as anode in this system due to its higher energy capacity than other anodic metal [11-13]. After the potential energy of the proposed voltaic cell has been investigated, the number of required cell is calculated based on the electricity needs to protect the ship from corrosion.

METHODS

This research is based on laboratory scale experiment. The experiment is conducted by putting the magnesium anode into a container of electrolyte, then measured the voltage and the current generated by voltaic cell using multi tester. The electrolyte used in this experiment is sea water which is added with mass variation of salt. The objective of the experiment is to determine how much the salinity which is optimum as electrolyte and to observe the optimum voltage and current. The experiment setup is shown in Fig. 1. The equipment and materials used in this experiment is as follow.

Equipment:

- A water container
- Cable with alligator clamp
- Digital gold scales (up to 200 gr)
- Digital kitchen scales (up to 5 kg)
- Refractometer
- Multimeter

Materials:

- Magnesium alloy as anode
- Copper alloy as cathode
- Sea water
- Salt

The complete procedure is as follow:

- Prepare all the equipment and materials
- Put the container above digital kitchen scale to measure the weight of the container
- Turn on the scale
- Put the salt into the container. The first experiment is using pure sea water, while the second is using 75 gram salt as the addition of the sea water. In the third experiment, the mass of the salt is further increased into 150 gram, and the last experiment using 225 gram salt.
- Pour the sea water into the container until the mass of the mixture reach 1 kg.
- Put the salt into the water and stir it until dissolves.
- Measure the salinity using refractometer.
- Put in the anode and cathode into the container.
- Connect anode to negative pole of multi meter and cathode to positive pole of multi meter

After the potential of voltaic cell has been obtained, then the required voltage and current for ICCP system is calculated. The object of the ship used for the calculation is live fish carrier "Wellboat" which the principle dimension is shown in

Table 1. Then, the number of required voltaic cell is calculated.

Figure 1: Experiment Setup

Table 1: Principle Dimension of Live Fish Carrier "Wellboat"

Parameter	Value	Unit
Lpp	30.6	m
Lwl	32.8	m
Breadth	7.5	m
Depth	5.7	m
Draught	4.2	m
Wetted Area	396.08	m^2
Speed	14	Knot

RESULTS AND DISCUSSION

The results of the experiment with varied salinity is shown in Table 2.Based on the results, the highest obtained power is when the voltaic cell is used pure sea water as electrolyte. The pure sea water electrolytes also give the less eroded anode, resulting longer lifetime. Therefore, the addition of salt is unnecessary to do if this proposed system is applied on the ship.

Table 2: Experiment Results

Parameter	Addition of Salt (Gram)			
	0	75	150	225
Eroded Mass (Gram)	1.08	1.17	1.69	2.09
Current (mAmpere)	22.58	15.5	15.33	19.43
Voltage (Volt)	0.6	0.34	0.36	0.49
Power (mWatt)	13.55	5.27	5.52	9.52

In order to calculate the required electricity, first thing that has to be calculated is coating breakdown factor. Equation (1) is used to calculate the coating breakdown factor.

$$f_c = (a+b)\times t_c \qquad (1)$$

with:
f_c = Coating breakdown factor
t_c = Coating lifetime desing = 2 years
a = 1st coating constant = 0.02
b = 2nd coating constant = 0.012

then

$$f_c = (a+b)\times t_c = (0.02+0.012)\times 2$$

$$f_c = 0.064$$

The next calculation is for the required protection current. The formula to calculate the required protection current is shown in equation (2).

$$I_c = A_c \times i_c \times f_c \qquad (2)$$

with:
I_c = Required current protection
A_c = Protected area = 396.08 m^2
i_c = Average current density = 0.07 A/m^2
then

$$I_c = A_c \times i_c \times f_c = 396.08\times 0.07\times 0.064$$

$$I_c = 1.77A$$

In order to calculate the required voltage, first, we have to calculate the total resistance. The total resistance consists of two part, anode resistance and cable resistance. The equation to calculate anode resistance is shown in equation (3) while equation to calculate cable resistance is shown in equation (4). Then, the total resistance can be calculated using equation (5).

$$R_a = \frac{0.315\times\rho\times N_a}{\sqrt{A_a}} = \frac{0.315\times\rho\times N_a}{\sqrt{2\left(l_a\times w_a + w_a\times h_a + h_a\times l_a\right)}} \qquad (3)$$

with:
R_a = Anode resistance
ρ = Sea water resistivity = 1.3 ohm.m
N_a = Number of anode in one cell = 8
A = Anode surface area
l_a = anode length = 0.4 m
w_a = anode width = 0.1 m
h_a = anode height = 0.04 m

then

$$R_a = \frac{0.315 \times \rho \times N}{\sqrt{2\left(l_a.w_a + w_a.h_a + h_a.l_a\right)}}$$

$$R_a = \frac{0.315 \times 1.3 \times 8}{\sqrt{2\left(0.4 \times 0.1 + 0.1 \times 0.04 + 0.04 \times 0.4\right)}}$$

$$R_a = 9.46\,\Omega$$

For cable resistance

$$R_c = \frac{l_c \times R_e}{N_c \times C_c} \quad (4)$$

with:
R_c = Cable resistance
l_c = cable length = 122.54 m
R_e = Cable specific resistance = 0.0122 Ω/m
N_c = Number of parallel cable = 8
C_c = Number of cable core = 2

then

$$R_c = \frac{122.54 \times 0.0122}{8 \times 2}$$

$$R_c = 0.0934\,\Omega$$

Total resistance

$$R_t = R_a + R_c \quad (5)$$

$$R_t = 9.46 + 0.0934$$

$$R_t = 9.55\,\Omega$$

After the total resistance value has been obtained, the value of required voltage can be calculated. The formula to calculate the required voltage is shown in equation (6)

$$V_c = [(I_c \times R_t) \times (1 + SF)] + B_{emf} \quad (6)$$

with:
V_c = Required voltage protection
SF = Safety factor = 0.2
B_{emf} = Back electromotive force = 2 V

$$V_c = [(I_c \times R_t) \times (1 + SF)] + B_{emf}$$

$$V_c = [(1.74 \times 9.55) \times (1 + 0.2)] + 2$$

$$V_c = 21.94V$$

Since the required current and voltage for ICCP has been obtained, the number of voltaic cell can be calculated. The number of parallel voltaic cell can be calculated using equation (7), based on the required current, while the number of series voltaic cell can be calculated using equation (8) based on the required voltage.

$$N_{pp} = \frac{I_c}{I_{1cell}} \quad (7)$$

with:
N_{pp} = Number of parallel voltaic cell

$$N_{pp} = \frac{1.77}{0.023}$$

$$N_{pp} = 77$$

$$N_{ss} = \frac{V_c}{V_{1cell}} \quad (8)$$

with:
N_{ss} = Number of series voltaic cell

$$N_{ss} = \frac{21.94}{0.6}$$

$$N_{ss} = 37$$

Therefore, the total number of required voltaic cell to supply the ICCP is 77 x 37 or 2849 cell

CONCLUSION

In this research, a potential energy of voltaic cell is observed through experiment in laboratory scale. By varying the salinity, the highest potential of the voltaic cell is obtained when there is no salt added to the sea water. The maximum voltage of one cell is 0.6 V and the maximum current is 0.023 A. Through the calculation, the required voltage and current for ICCP system to protect live fish carrier “Wellboat” are 21.94 V and 1.77 A respectively. Therefore the required number of voltaic cell is 2849, consist of 37 series and 77 parallel cell. Although the number of required voltaic cell is relatively big, however this proposed electric source is very promised because it is utilizing renewable energy which is sea water.

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