Cathodic protection on structures of carbon steel using sacrificial anode method for corrosion control

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Abstract. The pipes for land or sea are generally made of carbon steel and susceptible to corrosion. Cathodic protection can be used to control metal corrosion in water and soil. Cathodic protection is a metal surface protection system bypassing adequate direct current to the metal surface and converting sacrificial anode area on the metal surface into cathodic region. The aim of this research was to study the effect of cathodic protection in controlling the corrosion rate of carbon steel and determine the best immersing time for sacrificial anode in 25,000 ppm sodium chloride solution to protect the cathode. Zinc was used as the sacrificial anodes for the cathodic protection. Then, the effect of immersion time (10, 20, and 30 days) and distance of the anode from the cathode (1, 2, and 3 cm) were investigated. The best protection for corrosion was obtained at immersion time of 10 days and electrode distance of 1 cm, allowing corrosion rate of 0.694 mpy with an efficiency of 81.8%.

1. Introduction
In industrial engineering, especially in the field of engineering construction, corrosion is a major factor influencing the shelf life of pipes that transport important energy sources in each country. Judging from the cost of treatment in the chemical and petrochemical industries, the cost of overcoming the corrosion problem could reach 70 to 80 percent of all maintenance costs. Experts and practitioners tend to agree setting the cost of corrosion around 3.5 percent of Gross National Product. Some countries have calculated the cost of corrosion on a national scale in different ways, where the range is between 1.5 - 5.0 percent of the Gross National Product [1].

Various methods of preventing corrosion in the aquatic area had been developed. One of them is cathodic protection using sacrificial anode and impressed current method. Cathodic protection using sacrificial anode is a metal surface protection system by passing adequate direct current to the metal surface that have a lower potential and converting all anode areas on the metal surface to cathodic areas. This system is only effective for systems that are immersed in water or in the soil. This protection system has successfully controlled the corrosion process for marine vessels, seaside structures, pipeline and underground or marine tank installations and so on. The use of sacrificial anodes has advantages including simpler, more stable and lower maintenance costs [2].

Corrosion is a decrease in the quality of metals due to electrochemical reactions with their environment [3]. Corrosion can occur if it has the following conditions [2]:

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a) Anode, where the oxidation reaction occurs where negative ions gather. Anodes are usually corroded by releasing electrons from neutral metal atoms to form ions.

b) The cathode, the site of the reduction reaction where positive ions gather at the cathode usually does not undergo corrosion, however it may suffer damage under certain conditions.

c) Electrolytes, which are solutions that have the property to conduct electricity. Electrolytes can be in the form of acid solutions, base solutions and salt solutions. Electrolyte solution has an important role in metal corrosion because this solution can make electrical contact between the anode and cathode.

d) Metal connections, between the anode and the cathode there must be a metal connection for electrical connections so that the current in the corrosion cell can flow.

The objectives of this research was to study the effect of cathodic protection in controlling the corrosion rate of carbon steel and determine the best immersing time for sacrificial anode to protect the cathode.

The effect of immersion time and distance of the anode from the cathode were investigated.

2. Methodology

2.1 Preparation of specimen and corrosion medium

The materials used in this research was ASTM 36 carbon steel as a cathode with a size of 3 cm x 4 cm x 0.17 cm. Zinc was used as an anode or as a corrosion protection material with a size of 3 cm x 4 cm x 0.04 cm. Corrosion media used were sodium chloride solution with a concentration of 25,000 ppm.

2.2 Weight loss study

The corrosion rate was determined from specimen weight loss of the carbon steel. Corrosion rate testing was carried out by anode and cathode pair dip test method connected by steel wires, referring to ASTM G 31-72 [4] and ASTM G1-90 [5] standards. The study was conducted on steel without protection and on steel with zinc protection (anode) mounted on the left and right sides of the cathode with the similar distance (1 cm). Experiments were also carried out for steel using 2 cathodes at a distance of 2 cm and 3 cm respectively. The length of immersed time of 10 days, 20 days and 30 days were also investigated.

2.3 Characterization of specimen

The morphology and type of corrosion of the unprotected carbon steel ASTM36 were characterized by Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray (EDX) to identification of its.

3. Results and Discussion

3.1 The corrosion rate of carbon steel without protection vs. sacrificial anode protection

Figure 1 shows a comparison of corrosion rate of protected versus unprotected carbon steel. The results of the immersion test on carbon steel without the protection of sacrificial anode tested on sodium chloride solution for 30 days showed the greatest weight loss and the corrosion rate was 9,252 mpy. This is due to the high dissolved salts causing an increase in the conductivity of the salt solution [6], the steel undergoes corrosion due to the presence of the Cl- ion where the Cl- ion will break the passive layer on carbon steel or prevent the formation of a passive layer on carbon steel [7]. With respect to protected carbon steel, less weight loss was observed than the unprotected carbon steel. It can be seen from Figure 1 that the rate of corrosion of steel protected by an anode of zinc sacrificed was slower compared to the rate of corrosion of unprotected steel.

Further corrosion of the carbon steel pipes in the salt solution with a protected structure (cathode) was observed at all distances of anodes (Figure 1). Corrosion rate with an immersion time of 10 days with the distance between the anode and cathode of 1 cm is 0.694 mpy. At the distance between the electrodes of 2 cm and 3 cm, an increase in corrosion in carbon steel occurs. Zinc sacrificial anode is not effective for protection with 2 cm and 3 cm distance between the electrodes because the energy produced by the ineffective sacrificial anode which affects the ion mobility becomes lower through the
electrolyte and the influence of the electrode connecting steel wire resistors so that the electrical conductivity is lower [8]. This shows the effect of the distance between the electrodes, where the farther the electrode distance, the corrosion rate obtained will be greater, this is due to the slower movement of ions and the reduced number of ions moving to protect the cathode or carbon steel [9]. This is according to Juliana et al [10] due to the presence of resistance from the electrolyte and the connecting wire between the electrodes which results in the ineffectiveness of the energy produced by the electrodes. Besides, the effect of the potential is not so negative when compared to the metal that wants to be protected and the zinc anode is quickly corroded by dissolved sodium chloride ions which causes not effective electric current to flow into the electrolyte solution. This is in accordance to theory [11] where the anode corrosion potential must be more negative to the protected metal to encourage the protection current through the electrolyte.

![Figure 1](image)

**Figure 1.** The rate of corrosion of steel to immersion time by comparison of the distance between the cathode and the sacrificial anode of zinc.

The farther from the anode to the cathode will cause an increase in the corrosion rate of carbon steel, it can be seen that there is an increase in the corrosion rate of carbon steel by increasing the distance between the electrodes. The high content of Cl-ions at a concentration of 25,000 ppm with a corrosion rate of 8.337 mpy with the distance between the anode to the cathode 3 cm results in corrosion attacks so that resistance to the cathode increases and decreases the current from the anode. In that event, the surface area and the electrode distance are influential because they play a role in removing and delivering current to protect the surface of the cathode and affect the conductivity of the electrolyte solution. The sacrificial anode protects the cathode by giving current to the cathode, called the galvanic current. Anodes that have a more negative potential can protect more positive specimens by exchanging ions where the anode and cathode release their ions. Ion exchange that occurs in the specimen can form a layer that will interfere with the entry of oxygen to the surface of the cathode so that it can slow the corrosion process [10]. In galvanic current transfer, anodes which have more negative potential have better performance in protecting the cathode [8].

### 3.2 Efficiency of Carbon Steel Corrosion Rate with Zinc as Sacrificial Anode

Corrosion rate calculation is based on weight loss from carbon steel specimens before the dip test is carried out after the dip test is carried out in accordance with the immersion time to be performed. The
corrosion rate efficiency is calculated by comparing the corrosion rate of unprotected carbon steel with the corrosion rate of carbon steel that is protected using a zinc as sacrificial anode.

Figure 2 shows the variation of the distance between the electrodes in sodium chloride solution 25,000 ppm to obtain the corrosion rate efficiency of carbon steel that is protected against unprotected carbon steel with the same immersion time for the same specimen. From the results of the study, it was found that the best protection on carbon steel protected by zinc sacrificial anode is at the time of immersion for 10 days with the anode to cathode distance of 1 cm with corrosion rate efficiency of 81.818%. From the decrease in corrosion rate, it can be seen that the decrease in corrosion rate is influenced by distance and time of immersion. According to Parthasarady [12] the amount of electric current flowing on the electrolyte is influenced by the potential difference given to the electrode, the resistance of the solution, the electrode distance and the electrode surface area.

A decrease in corrosion rate by using zinc sacrificial anode can occur because zinc metal has a more electronegative potential than steel metal [13]. Besides the influence of the distance between the electrodes also affects where the distance of the electrodes the lower the conductivity [8], this is due to the resistance of the electrolyte which results in ineffective energy produced by the electrodes [10]. In this study the longer the immersion time of the specimen, the higher the corrosion rate is due to the fact that the corrosion rate has not yet reached a certain point where it has not reached a critical point, so the corrosion rate tends to be constant [14].

The corrosion rate of carbon steel cannot be completely lost (zero corrosion rate) due to loss of protective current in the anode and cathode galvanic linkages. This can occur due to the following factors [10]:
- a. There is a resistance in a steel wire that connects the anode and the cathode.
- b. There is an electrolyte resistance between the anode and the cathode
- c. The existence of resistance that occurs in corrosion products on metal surfaces
- d. Effect of formation of hydrogen gas on the surface of the cathode, where the formation of hydrogen gas can increase resistance at the cathode which can reduce the current from the anode [4].
3.3 SEM-EDX analysis

SEM-EDX is a method of identifying morphology and functional groups in materials. Damage caused by corrosion can be in the form of metal oxides, morphological surface damage of metals, changes in mechanical properties and changes in chemical properties [15]. SEM-EDX analysis was conducted at the Integrated Laboratory of Diponegoro University, Semarang.

In the SEM test the analyzed specimens are carbon steel specimens with immersion time of 30 days namely unprotected carbon steel specimens and carbon steel specimens protected with zinc sacrificial anodes with anode distance to cathode is 1 cm. SEM test aims to determine the type of corrosion and EDX to determine the chemical composition contained in the material.

![Figure 3. Unprotected carbon steel surface morphology (a) magnification 3.000x (b) magnification 5.000x (c) magnification 7.500x (d) magnification 10.000x](image)

Figure 3 shows the results of SEM carbon steel which was exposed to corrosion due to immersion in a solution of NaCl for 30 days, where the solution is corrosive to the metal resulting in changes in the surface of the specimen due to corrosion. Figure 4 has a dark-colored part, this is often called pitting corrosion that occurs at grain boundaries that can be seen clearly in images with a magnification of 10,000x. In carbon steel, many dark-colored images are found which show that many are attacked by
corrosion on the surface of carbon steel without protection, this is clarified by using the ImageJ program in figure 4 where the surface structure of the carbon steel specimen is uneven caused by corrosion of the well and in the presence of changes in the chemical composition of the material on the surface where there is an element of oxygen contained in the material. In this case, the breakdown of the passive layer by the Cl-ions occurs in certain parts of the metal surface (unevenly) which is indicated by the black part in figure 4. When oxygen reacts with the steel surface, a reaction between oxygen and iron will occur. will form iron (II) oxide (FeO) proven from the Energy Dispersive X-Ray (EDX) test results. The reaction that occurs is an oxidation reaction, which is the combining of oxygen with ferrous metals that form iron rust [16].

![Figure 5](image)

**Figure 5** Surface carbon morphology with zinc protection (a) magnification 3.000x (b) magnification 5.000x (c) magnification 7.500x (d) magnification 10.000x

![Figure 6](image)

**Figure 6** Carbon Steel Surface Structure with Zinc Protection with magnification 10,000x using Image

Figure 5 shows the surface of the corroded specimen forming a needle that damages the specimen surface. The type of corrosion that is seen is pitting corrosion or corrosion where it arises and is concentrated in a particular area or locally caused by the deposition that acts as a center of corrosion [17]. Magnification to 10,000x, a number of needles were seen which indicated that the specimen was
corroded but not as much as what had happened to unprotected specimens, seen from not as much black picture in figure 3. In figure 6 it can be seen that the specimen surface at 10,000x magnification using Image J the steel surface structure is uneven due to the formation of holes due to the corrosion process that has occurred. In pitting corrosion the corrosive agent (Sodium Chloride solution) will previously damage the protective layer of the carbon steel surface which causes the pores of the steel to open so that it enters the inside and the corrosive substance will damage the metal so that it forms a needle-like hole [18]. EDX analysis results show that the compounds that cause rust, namely iron (II) oxide or FeO are more abundant in carbon steel without protection that is equal to 93.38%, while carbon steel with zinc protection is 68.22%.

4. Conclusion
The highest efficiency of corrosion rate on carbon steel protected by zinc sacrificial anode was 81.8%. The longer immersion time produced more cathode weight loss. Immersion time of 10 days resulted in better efficiency. The performance of zinc sacrificial anode was effective to protect carbon steel from corrosion when the distance between the anode and the cathode electrodes was the smallest.

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