investigation the effect of ICCP and SACP on carbon steel corrosion in salt solution at different parameters

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Abstract Cathodic protection has wide applications in various structures and is an effective electrochemical technique for mitigating or preventing corrosion of metal structures. To apply this technique, open circuit voltage (ocp) was measured under all conditions. The experiments consisted of samples of carbon steel immersed in solutions of NaCl concentrations (0.5, 1.5, 3) g / L at (20 and 30) °C, different pH values (4-7-10) and different potentials (-). Application of 700, -900, -1000, -1200 mv in forced current cathodic protection (ICCP). The anodic cathodic protection (SACP) (AL alloy) was also implemented with the same parameters. The density of the protective current increases with increasing temperature and concentration due to the increase in the mobility of ions in the solution, as the conductivity of the solution increases and with the decrease in the pH. The experimental results showed that increasing the DC current leads to an increase in the cathodic protection current. Therefore, the ICCP method is more effective than the SACP method, the higher the DC power supply.

1. INTRODUCTION

Cathodic protection has been used to reduce the corrosion rate to zero. Cathodic protection is an effective electrochemical method for buried metal structures immersed in electrolytes such as water and soil. The CP principle can be expressed through the polarization which is change the voltage of the structure to located in in cathodic region with almost zero corrosion current or in the immune region (3).

SACP that uses a more active and negative voltage anode material than the structure to be protected to provide the electrons required for cathodic polarization and achieve protection. The anodes used in this method are magnesium, zinc and aluminum alloys (4).
ICCP is widely used for protecting large, poorly painted and unpainted structures. This system requires the use of an external DC source connected to the structure and inert anode such as graphite (auxiliary electrode) and reference electrode (5).

This work includes an experimental investigation to study the status of the protection system, as this field is still so far an active field for many researchers. Ajil et al, 2008 (6), designed a cathodic water system for the induced current to protect a steel tube under conditions (temperature, pH, distance between the electrodes, and the conductivity of the solution) and noted the effect of each of these conditions on the water current and it was found that the effect of temperature is higher than all other variables. Jabur, 2014 (7) proposed a study aimed at elucidating the effect of both the conductivity of the environment and the distance between the anode and the cathode on the protection current required to provide complete protection for bare and coated tubes. Khan et al, 2018 (8), focused on reducing the corrosion rate of buried underground pipelines by using three DC sources (generator transformer, heat generator, and solar power system) and help companies choose the appropriate type of external DC source. Hanif et al, 2019 (9) compared the two cathodic protection systems using a sample of steel. It was found that the ICCP system is better for highly corrosive environments than the sacrificial system. BAWA, et al, 2020 (10) presented the importance of selecting an appropriate anode material for an impressed current cathodic protection system. Four anodes of different materials were used to evaluate their performance (Aluminum 90.6% / Copper 9.4%, Copper 90%, Aluminum 10%, Copper 95%, Aluminum 5%, Lead 100%). It was concluded that the lead anode has a low dissolution rate and is the ideal material among other materials for an ICCP system, and is cheap and available for buried and submerged structures in aggressive environments.

2. EXPERIMENTAL WORK

A) Materials:

The material used in this work is a sheet of carbon steel with dimensions (100 x10 x6) mm and with a chemical composition (C = 0.25, P = 0.04, Mn = 0.00, S = 0.05, Si = 0.4, Cu = 0.2). The glass bath with dimensions (60 x 30 x 20 cm) with a thermal heater and a glass thermometer to adjust the temperature of the solution. The working electrodes are placed at the same level with the graphite electrodes common used in the ICCPS method, and aluminum alloy (AL=99.31% and Mn=0.680%) in the SACPS system, as shown in Fig. (1.1).
B) solutions:

The corrosion solution was prepared from distilled water with the addition of different weights of NaCl (0.5, 1.5 and 3 g) per liter of water with a pH (4, 7 and 10).

C) Cathodic protection system installation and measurements:

The protection system was installed as shown in the fig. (2). The anode and the cathode fixed by plastic holder, the distance between them is 50 cm, 5 cm under the surface of the water and 1.7 cm from the bottom. The volume of solution used in each experiment is 12 liters. Dc power supply was used for changing the potential of the specimen to (-700, -900, 1000 and -1200) mv which measured against copper / copper sulfate reference electrode. In the SACP system, a aluminum alloy is used as an anode, and represents the source of electrons to provide protection for the structure. The current and voltage are also read every quarter of an hour for two hours. The arrangements of the four parameters studied for both ICCP and SACP.

3. RESULTS AND DISCUSSION

In this work, three parameters affect the rate of corrosion are temperature, salt concentration (conductivity), open circuit potential and pH:

3.1 Effect of Conductivity
It was found that the higher the electrical conductivity of the solution, the higher the required CP current, because sodium chloride is an ionic compound. The salt (NaCl) dissolved in water dissociated to negative and positive ions which increases the conductivity of the solution due to ions movement and thus the current density increases, which leads to increase current density required for cathodic protection. Figures show an increase in conductivity leads to an increase in the protection current under different conditions.

**Figure (2)** Concentration Vs current density at -700mv

**Figure (3)** Concentration Vs current density at -900mv
**Figure (4)** Concentration Vs current density at -1000mv

**Figure (5)** Concentration Vs current density at -1200mv

**Figure (6)** Concentration Vs current density at the sacrificial anode system
3.2 Effect of Temperature

The diagrams below show the relationship of the cathodic current with the temperature of the solution. When the temperature increases, it leads to an increase in the cathodic protection current under the different operating conditions studied in this paper. As the increase in the temperature of the solution causes an increase in the movement of solution ions to reach the cathode surface and thus increases the rate of the chemical reaction.
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Protective Current vs Temperature at concentration 1.5 g NaCl%

Figure (9) Protective Current vs Temperature at ICCP system

Protective Current vs Temperature at concentration 0.5 g

Protective Current vs Temperature at concentration 1.5 g

Protective Current vs Temperature at concentration 3 NaCl%
4 **Effect of pH**

The current density increases with decreasing pH. If the density of the cathodic protection current is a function of temperature and pH, the effect of temperature is higher than that of pH. Through the diagrams below, we notice that the current density is higher at pH = 4 due to the presence of hydrogen ions, which need to draw a more direct current to release the hydrogen gas and to obtain the required protection condition for the structure. At pH = 10, it is close to or less than pH = 4. As the predominant reaction in basic media is oxygen reduction, which leads to a decrease in the dissolved oxygen in the electrolyte and an increase in the pH at the interface of the electrolyte / structure, so it needs to draw a direct current. Less for protection.
Figure (9) Current density vs. PH at -900mV.

Figure (10) Current density vs. PH at -1000mV.

Figure (11) Current density vs. PH at -1200mV.
5 Conclusions

Some conclusions could be summarized as follows:

1- The values of the density of the cathodic protection current increase directly with the increase in conductivity due to the increase in the movement of ions resulting from the addition of NaCl in the water.

2- The current density increases with the decrease in the pH and the increase in the temperature of the electrolyte solution.

3- The life of the anode in the melt anode system depends on the amount of current emitted from the anode (aluminum alloy) to the negative electrode to protect it from corrosion and the size of the anode.

4- ICPP system is preferred over the sacrificial anode system (SACP) because it has a long protection life for the structure and does not need to be replaced by the anode (because it is consumed in the sacrificial anode system and needs periodic replacement).

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Table (1) The conditions for the calculation of ICCP for both the impressed current and sacrificial anode system

| Conductivity (mS/cm) | Temperature (°C) | PH | Current density (mA/cm²) |
|----------------------|-----------------|----|-------------------------|
|                      |                 |    | -700mv | -900mv | -1000mv | -1200mv |
| 1                    | 1.76\0,5g       | 20 | 7      | 0.0161 | 0.0301  | 0.0364  | 0.25     |
| 2                    | 2\0,5g          | 20 | 4      | 0.0258 | 0.0372  | 0.0432  | 0.376    |
| 3                    | 2.3\0,5g        | 20 | 10     | 0.0233 | 0.0348  | 0.0392  | 0.294    |
| 4                    | 1.7\0,5g        | 30 | 7      | 0.0281 | 0.0351  | 0.0515  | 0.407    |
| 5                    | 2.1\0,5g        | 30 | 4      | 0.0361 | 0.0552  | 0.0602  | 0.439    |
| 6                    | 2.8\0,5g        | 30 | 10     | 0.0348 | 0.0577  | 0.0548  | 0.416    |
| 7                    | 3.9\1,5g        | 20 | 7      | 0.0257 | 0.0351  | 0.0408  | 0.316    |
| 8                    | 6.1\1,5g        | 20 | 4      | 0.0301 | 0.0467  | 0.0477  | 0.467    |
| 9                    | 6.4\1,5g        | 20 | 10     | 0.0291 | 0.0431  | 0.0464  | 0.377    |
| 10                   | 4.2\1,5g        | 30 | 7      | 0.0342 | 0.0371  | 0.0669  | 0.507    |
| 11                   | 6.3\1,5g        | 30 | 4      | 0.0342 | 0.0602  | 0.0719  | 0.565    |
| 12                   | 6.5\1,5g        | 30 | 10     | 0.0358 | 0.0589  | 0.0696  | 0.529    |
| 13                   | 9.1\3g          | 20 | 7      | 0.0271 | 0.0385  | 0.0418  | 0.437    |
| 14                   | 9.3\3g          | 20 | 4      | 0.0341 | 0.0507  | 0.0552  | 0.586    |
| 15                   | 11\3g           | 20 | 10     | 0.0301 | 0.0448  | 0.0478  | 0.467    |
| 16                   | 10.4\3g         | 30 | 7      | 0.0391 | 0.0405  | 0.0830  | 0.621    |
| 17                   | 10.6\3g         | 30 | 4      | 0.0416 | 0.0731  | 0.100   | 0.861    |
| 18                   | 11.6\3g         | 30 | 10     | 0.0384 | 0.0621  | 0.0860  | 0.835    |
### Sacrificial anode cathodic protection

| Conduction (mS/cm) | Temperature (°C) | PH | Current density (mA/cm²) |
|-------------------|------------------|----|--------------------------|
| 1                 | 1.76±0.5g        | 20 | 7                        | 0.0602 |
| 2                 | 2±0.5g           | 20 | 4                        | 0.0633 |
| 3                 | 2.3±0.5g         | 20 | 10                       | 0.0753 |
| 4                 | 1.7±0.5g         | 30 | 7                        | 0.0753 |
| 5                 | 2.1±0.5g         | 30 | 4                        | 0.0813 |
| 6                 | 2.8±0.5g         | 30 | 10                       | 0.117  |
| 7                 | 3.9±1.5g         | 20 | 7                        | 0.127  |
| 8                 | 6.1±1.5g         | 20 | 4                        | 0.136  |
| 9                 | 6.4±1.5g         | 20 | 10                       | 0.211  |
| 10                | 4.2±1.5g         | 30 | 7                        | 0.136  |
| 11                | 6.3±1.5g         | 30 | 4                        | 0.160  |
| 12                | 6.3±1.5g         | 30 | 10                       | 0.205  |
| 13                | 9.1±3g           | 20 | 7                        | 0.181  |
| 14                | 9.3±3g           | 20 | 4                        | 0.205  |
| 15                | 11±3g            | 20 | 10                       | 0.211  |
| 16                | 10.4±3g          | 30 | 7                        | 0.205  |
| 17                | 10.6±3g          | 30 | 4                        | 0.244  |
| 18                | 11.6±3g          | 30 | 10                       | 0.259  |