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Research Article

Studying the Corrosion Control of Low Carbon Steel in different Aqueous Media by Coating Method

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Abstract: The aim of study id to investigate the corrosion rate of low carbon steel in a saline aqueous media under different pH values being acidic, neutral and basic one and at different temperatures using weight loss technique. The maximum corrosion rate of low carbon steel was observed in acidic saline solutions which is being lower than those observed in basic one and insignificant in neutral one. It was noted that corrosion rates increased rapidly with increase in temperature and approached a maximum value in acidic media at 50°C. Maximum coating efficiency was 45.5% at pH 5, 0.25 g/L NaCl and 20°C.

Keywords: Aqueous solutions, coating, corrosion, pH, steel, temperature

INTRODUCTION

Corrosion specifically refers to any process involving the deterioration or degradation of metal components. Most metals corrode in contact with water (and moisture in the air), acids, bases, salts, oils, aggressive metal polishes and other solid and liquid chemicals. Metals will also corrode when exposed to gaseous materials like acid vapors and sulfur containing gases (Revie and Uhlig, 2008), so is the destructive attack of a metal by chemical or electrochemical reaction with its environment (Trethewey and Chamberlain, 1995; Philip, 2007).

There are three main reasons for the importance of corrosion which are; economic, safety and conservation. Loss of metal by corrosion is a waste not only by the metal, but also of the energy, the environment and the human effort that was used to produce and fabricate the metal structure in the first place (David and James, 1998). In addition, rebuilding corroded equipment requires further investment of all these resources, metal, energy, environment and human (Perez, 2004; Popoola *et al*., 2014). Therefore, the aim of the present investigation is to study the corrosion of low carbon steel and its prevention using coating method.

EXPERIMENTAL DETAILS

The corrosion rate of low carbon steel in various aqueous media (acidic pH 5, neutral pH 7, basic pH 9), in the presence of NaCl (0.25, 1.25, 2.25, 3.25 and 4.25 g/L) and different temperatures (20, 30, 40 and 50°C) in the absence and presence of coating using weight loss technique.

The materials and chemical used are: Sodium chloride, H_2SO_4, NaOH and distilled water were used to prepare the corrosive solution. Acetone and benzene were used for drying and cleaning of samples. Red oxide primer coating (Al-Marjan, made in Iraq) and thinner were used for sample coating. Carbon steel was used as test samples. Table 1 shows the composition of low carbon steel samples that used in the present work which was carried out in the Central Organization for Standardization and Quality Control (COSQS), Baghdad, Iraq.

Sample used: Samples with 1×0.1×3 cm dimension, exposing approximately 7 cm^2 surface area. Each sample dimensions was measured with a vernier to the second decimal of a millimeter. Steel sample were annealed in a furnace for 1 h at 600°C for stresses removal. Samples were abraded in sequence by using emery paper of 100, 200, 400 and 600 for scale removal. Before each test, steel sample were washed with tap water, then by distilled water, dried with a clean tissue, immersed in benzene for oil removal, then washed with acetone for moisture removal and finally dried with clean tissue and kept in desiccators until used.

CORROSION RATE WEIGHT LOSS MEASUREMENTS

All solutions were prepared from high purity analytical grade chemicals. Corrosion measurements

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Table 1: The properties of the low carbon steel

Element	% wt	Element	% wt	Element	% wt
C	0.119	Mo	0.0188	Ca	>0.005
Si	0.409	Ni	0.0512	Nb	>0.001
C	0.130	Ti	0.0008	Sn	0.0131
Mn	0.861	Al	0.0030	V	0.0016
P %	0.0203	As	0.0116	Zr	0.0030
S %	0.0164	B	0.0014	Fe	Balance
Cr %	0.0535	Co	0.0069		

Table 2: Corrosion rates values as a function of temperature and salt concentration in absence of coating

Salt concentration (g/l)	pH	Corrosion rate (gmd) 20°C	30°C	40°C	50°C
0.25	5	4.5	5.07	7.4	8.8
1.25		5.3	6.05	7.8	9.8
2.25		6.26	6.9	8.5	10.9
3.25		6.88	7.7	9.5	12.29
4.25		8.11	9.21	10.77	13.6
0.25	7	1.47	2.77	3.93	5.29
1.25		2.28	3.61	5.56	7.56
2.25		3.45	4.44	6.12	8.41
3.25		4.03	5.67	8.22	8.86
4.25		5.11	6.23	8.45	9.12
0.25	9	1.32	2.44	3.49	4.18
1.25		2.05	3.18	4.95	5.97
2.25		3.11	3.91	5.44	6.64
3.25		3.63	4.99	6.99	7.33
4.25		4.61	5.48	7.52	8.11

Table 3: Corrosion rate values as a function of temperature and salt concentration in presence of coating

Salt concentration (g/L)	pH	Corrosion rate (gmd) 20°C	30°C	40°C	50°C
0.25	5	3.00	4.32	5.53	6.28
1.25		3.13	5.12	5.95	6.91
2.25		3.61	5.20	6.31	7.32
3.25		3.75	5.47	6.71	8.01
4.25		4.56	5.87	7.41	9.13
0.25	7	1.04	2.04	2.95	4.09
1.25		1.63	2.68	4.21	5.94
2.25		2.54	3.38	4.75	6.74
3.25		3.18	4.59	6.75	7.46
4.25		4.22	5.24	7.19	7.92
0.25	9	0.73	1.57	2.42	2.98
1.25		1.21	2.22	3.53	4.44
2.25		1.99	2.78	4.08	5.15
3.25		2.54	3.66	5.36	5.73
4.25		3.38	4.24	5.97	6.58

were done by using the dipping method where each sample was dipped for one time in a studied medium sample by immersing it in a conical flask for six hours and removed and left to dry for 24 h at room temperatures and then weighted carefully with high accuracy digital balance.

The corrosion rate values were evaluated using the following formula:

$$\text{corrosionrate(gmd)} = \frac{W_1 - W_2}{A \times t} \quad (1)$$

where,
W_1 = Weight of sample before immersion (*gm*)
W_2 = Weight of sample after immersion (*gm*)
A = Sample surface area (m^2)
t = Time of experiment (*day*)

RESULTS AND DISCUSSION

The corrosion of low carbon steel which is the most important metal used in chemical and petrochemical industries was studied at different conditions of temperatures and aqueous media concentration. Corrosion can be controlled by several methods, such as, inhibitors (Yaro *et al*., 2013a), cathodic protection (Yaro *et al*., 2011), coating (Deyab *et al*., 2017), etc. coating is one of effective controlling methods that used to reduce the rate of metal loss. Generally, the corrosion rate increased with temperatures and salt concentration increase. Presence of coating reduces the values of corrosion rate. Table 2 shows the value of corrosion rates in absence of coating, the value increased with temperatures and salt concentration increase and with pH decrease. The same behavior was observed, to a less extent, in presence of coating (Table 3).

Effect of temperature: Figure 1 to 3 show the effect of temperature on the corrosion rate of low carbon steel in absence of coating. Figure 1, at pH 5, shows that the corrosion rate increased with salt concentration and temperatures increase. The same behavior can be observed at pH 7 and pH 9. In general, the temperature increases the rate of most chemical reaction (Khadom *et al*., 2009a). Rise in temperature has many effects, so that, the corrosion rate increased, the reduction in the solubility of gases in solutions and reduction in viscosity of liquids (Yaro *et al*., 2013b). These factors lead to different reaction paths with different corrosion products.

EFFECT OF pH: Figure 4 shows the effect of pH on the corrosion of low carbon steel in aqueous media at

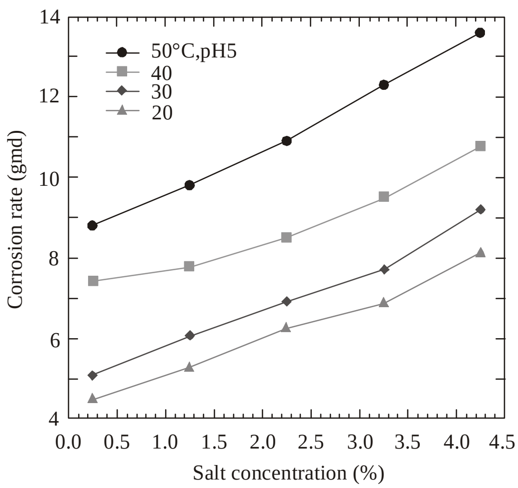

Fig. 1: Relation between corrosion rate and salt concentration at different temperatures with pH 5 in absence of coating

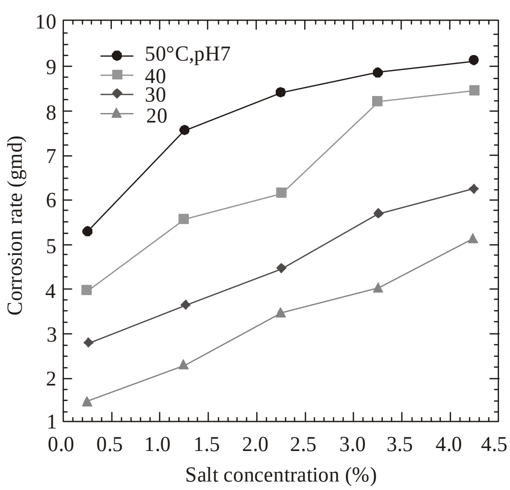

Fig. 2: Relation between corrosion rate and salt concentration at different temperatures with pH 7 in absence of coating

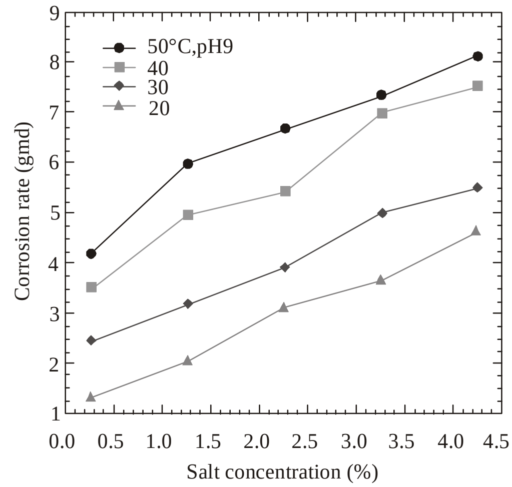

Fig. 3: Relation between corrosion rate and salt concentration at different temperatures with pH 9 in absence of coating

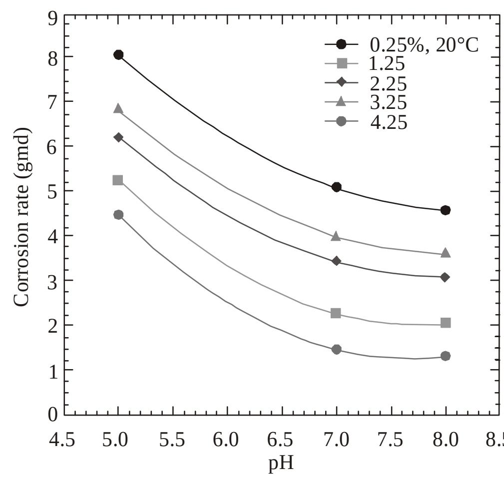

Fig. 4: Relation between corrosion rate and pH at different salt concentrations at 20°C in absence of coating

20°C. The rise in pH reduces the values of corrosion rates. The same behavior observed for other temperatures. The effect of pH is due to the effect of hydrogen ion in the solution. The higher hydrogen ion concentration, low pH values, hence higher corrosion rate values as shown in following reactions:

$$Fe \rightarrow Fe^{++} + 2e \quad (2)$$

$$2H^{+} + 2e \rightarrow H_2 \uparrow \quad (3)$$

Equation 4 represents an iron anodic reaction and Eq. (5) represents the cathodic one in acidic media. Presence of oxygen may leads to fast cathodic reaction as shown in Eq. (4):

$$O_2 + 4H^{+} + 4e \rightarrow 2H_2O \quad (4)$$

The cathodic reaction in neutral and basic solutions can be written according to Eq. (5):

Table 4: Coating efficiency values at different pH and salt concentrations

		Coating efficiency			
Salt conc. (g/L)	pH	20°C	30°C	40°C	50°C
0.25	5	45.5	34.8	31.2	28.9
1.25		43.7	33.2	29.4	26.8
2.25		42.3	32.5	25.9	23.7
3.25		40.9	29.7	24.7	16.7
4.25		33.3	28.6	23.7	14.7
0.25	7	29.3	26.4	24.9	22.5
1.25		28.5	25.7	24.2	21.4
2.25		26.4	23.8	22.4	19.8
3.25		21.1	18.9	17.9	15.8
4.25		17.5	15.8	14.8	13.1
0.25	9	44.5	35.4	30.5	28.7
1.25		41.4	30.6	28.6	25.6
2.25		35.7	28.9	24.9	22.4
3.25		29.9	26.6	23.3	21.8
4.25		26.6	22.6	20.5	18.8

$$O_2 + 2H_2O + 4e \rightarrow 4OH^- \quad (5)$$

This result agrees with several previous works such as, Khadom *et al*. (2009b) which stated that the corrosion rate increased with acid concentration increase (i.e., pH decrease).

Effect of salt concentration: Figure 1 to 3 and Table 2 show the effect of salt concentration on corrosion rates. Rise of salt concentration increases the rate of corrosion. This effect is due to the presence of chloride ion that act as catalyst to increase the oxidation process according to following equations (Mahmoudzadeh *et al*., 2012):

$$2Fe + 6Cl^- \rightarrow 2FeCl_3^- + 4e \quad (6)$$

$$2FeCl_3^- + 4OH^- \leftrightarrow Fe(OH)_2 + 3Cl^- \quad (7)$$

Same result was obtained by Mahmood and Khadom (2016), which found that salt concentration, has negative effect on the corrosion of steel in saline media.

Effect of coating: Coating technique was used to control the corrosion process in acidic media. Table 3 shows the corrosion rates in presence of coating at different operating conditions. It can be seen that the behavior of low carbon steel corrosion in the absence and presence of coating was the same, i.e., the corrosion rate increase with increase the temperatures and salt concentration and decrease with pH increase. The corrosion rates with presence of coating are lower, this due to presence of coating layer that act as a barrier between corrosion solution and metal surfaces. Coating efficiency can be calculated via Eq. (8):

$$\%\,\text{CoatingEfficiency} = \frac{C_R^o - C_R^c}{C_R^o} \times 100 \quad (8)$$

where, C_R^o and C_R^c are the corrosion rates in the absence and presence of coating. Table 4 shows coating efficiency values at different conditions. Coating efficiency decreases with temperature and salt concentration increase, while it decreases with pH decrease.

CONCLUSION

Factors affecting corrosion rate of carbon steel which is subjected to different environments in this study, were determined. Conclusions withdrawn in this research are:

- The corrosion rate of carbon steel increases with increasing chloride concentrations in solution. Increasing NaCl concentrations raises the conductivity of the solution and accelerated the corrosion process by affecting corrosion kinetics.
- Changing the acidity of the medium from acidic to alkaline, the corrosion rate of carbon steel decreases due to the decrease in solution corrosive effect.
- Corrosion rate increases with increasing temperature. The increase in oxygen diffusion leads to the decrease of liquid viscosity with increasing temperature.

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