Sirte University Scientific Journal (Applied Sciences) Vol. 7 (1), 33–49, June 2017

Study of Galvanic Corrosion of Carbon Steel Pipelines Versus Some Types of Stainless Steel

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Abstract

In petroleum industry under special conditions (NaCl concentration of 70,000 ppm and temperature of 70 C°) a significant galvanic corrosion problems are appeared . The conditions in the petroleum wells in the eastern region in Libya regarding the characteristics of formation water, which has concentration of NaCl ranging between 40,000 to 70,000 ppm and varied temperature degrees between 40 C° and 70 C° The constructing materials of these wells are connected with piping system made essentially from carbon steel .The piping system contains for special purposes some joints of stainless steel of grades 304 as well as 316 . The connection points between carbon steel and stainless steel considered as focal points for galvanic corrosion due to the potential difference between both materials in the electromotive series . The objective of this work is to study the galvanic corrosion in such case and the evaluation of rates of corrosion (for carbon steel) by laboratory tests . The experimental technique used in this study is the weight loss method.

Keywords: *galvanic corrosion ,carbon steel, SS304,SS316,NaCl concentrations.*

1. Introduction

In many practical applications the contact of dissimilar metals is unavoidable in complex process streams and piping arrangements. Different metals and alloys are frequently in contact with each other due to mechanical and economic consideration. But the connection of metals or alloys together leads mostly to its corrosion due to its difference in galvanic potential . So, its electrical contact will lead to "galvanic corrosion". the magnitude of galvanic corrosion depends not only on the potential different of dissimilar metals, but also on kinetic parameters such as corrosion rate and anode to cathode area ratio. The most common method of predicting galvanic corrosion is by immersion testing of the galvanic couple in the environment of interest.

Although time-consuming, this is the most desirable method of investigating galvanic corrosion. [1]

2. Experimental work

Before selecting a corrosion test measurement technique, it is important to define the reason for doing so. This increases the chances of selecting the best method. The main reasons for measuring corrosion are to:

- Monitor corrosion as it occurs in the plant.
- Evaluate materials and environment effects for future application.
- Test the quality of a specific material of known behavior .
- Study the mechanisms of corrosion [2]

Corrosion tests are divided into two broad categories: (1) tests made in the laboratory under controlled conditions, and (2) tests made in the field under natural or service conditions.

The primary purpose of galvanic couple tests is to obtain useful information in predicting or controlling the extent to which galvanic couple action occurs when dissimilar metals are in contact under given conditions of service .

In order for galvanic couple action to occur, the two or more metallic elements of the couple must be in contact while exposed to an electrolyte; and a difference in the potential must exist between them. When these basic requirements are satisfied, galvanic couple action can and will occur.

2.1 cell of measurements:-

Resume about the set:

The capacity of the set is 20 litter, its function is to stir the liquid and making the liquid running continuously to the samples where the samples are submerged wholly and also making a control in the required temperatures by a special key .

This set is connected to a vessel by tubes where the liquid goes into and out of the vessel through these tubes. The Samples were put into this vessel where a plastic insulator between C

S samples and SS.304 sample, will be placed. The two samples are tied and hanged by a plastic wire inside the vessel.

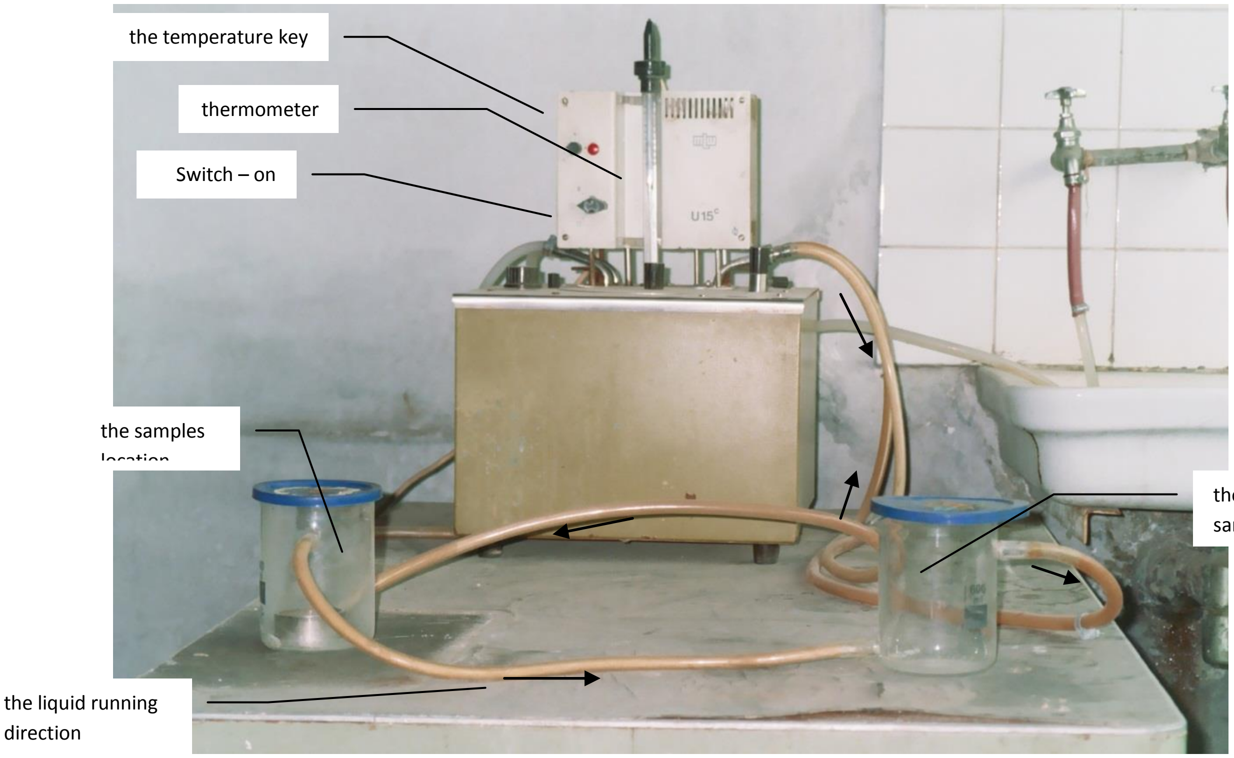

Figure 1. Picture of instrument used.

2.2 Raw materials:-

- **Samples:**

1-The under test carbon steel samples have the chemical composition shown in the following table :-

Table 1. The carbon steel samples have the dimensions (7x2x0.25 cm)

Composition of carbon steel, wt%								
C	Si	Mn	P	S	Cr	Mo	Ni	Cu
0.031	0.013	0.249	0.0139	0.0055	0.008	0.005	0.013	0.0015
Sn	Al	Co	Nb	Ti	V	Zr	B	Zn
0.0004	0.0354	0.006	0.0024	0.0018	0.0035	0.0002	0.0001	0.0001

2.The stainless steel samples (SS.304,SS.316) have two dimensions which are (7x2x0.25 cm) and (3.5x2x0.25 cm) .

3.Just before the experiments the investigated samples were mechanically polished using emery papers with grades up to 40-60 80.The polished samples were degreased by acetone and a thoroughly washed by distilled water ,dried and weighed.

- **Chemicals:**

All solutions are prepared from commercial sodium chloride salt by dissolving the weighed masses in distilled water .

3. Conditions of Working

These are selected to undergo the experiments under the following working conditions :

1. anode to cathode area ratio 1:1,2:1.
2. concentration of NaCl solutions (20,40,50,60,80)g/L.
3. The distance between the anode and the cathode are 1 cm and 3 cm.
4. Temperature of solutions (20,40,60,80) C°.
5. Time of experiments (2,4,6)hours.
6. pH 7

4. Weight Loss Experiments

The samples to be tested are prepared , weighed , then the samples are fixed in the previously mentioned apparatus for the desired test time, after that the sample is withdrawn from the cell, cleaned, and reweighed .From this weigh loss (mg) is calculated .

The mpy is calculated from the weight loss determinations and plotted in different manners .

The plotted examined samples are subjected to additional investigations to identify the corrosion products .

4.1 Corrosion rate calculations:

The famous formula for expressing corrosion rate was applied :[3]

$$\text{mpy} = \frac{534 \times W}{DAT}$$

where mpy = mils per year

W = weight loss, mg

D = density of specimen, g/cm³

A= area of specimen, sq. in

T= exposure time, hr

The experiments were doubled to make sure of results . The results for each case was calculated and recorded regularly.

5. Results and Discussion

The plotted results are obtained through many trials of experiments taking into account the change of sodium chloride solution of concentrations between 40-80 g/L, experiment temperature ranging between 20-80 C, surface ratio of anode to cathode 1:1,2:1, and the separation distance between the electrodes which may be one or three cm.The first category of results are presented in Figs (2) pointed out the change of temperature against rate of corrosion at different immersion times (2,4,6 h) and at constant sodium chloride concentration of 40g/L. Figs (2, 3) presents the results obtained at anode to cathode area ratio 1:1 and for separation distance between the electrodes 1, 3 cm .

Figs (4 , 5) present the results obtained at anode to cathode ratio of 2:1 for the same separation distance between electrodes (1 , 3 cm) . It is clear from the results of Figs (2 - 5) that the corrosion rate increases with increasing temperature up to 60 C˚ and then decreases at temperature of 80 C˚. This means that maximum rate of corrosion was observed at 60 C˚ . Apart from temperature, and looking to the time of experiment, the rate of corrosion are proportional directly to the time of experiments at 20, 40 and 60 C˚ ,but it is inversed at 80 C˚ as shown in Figs (2 - 5)

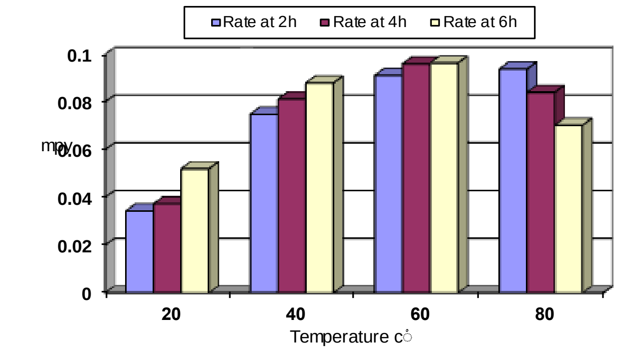

Figure 2 corrosion rate of carbon steel versus SS.304 at concentration(NaCl) 40g/L (Anode to cathode aera ratio 1:1,the distance between the anode and the cathode 1cm)

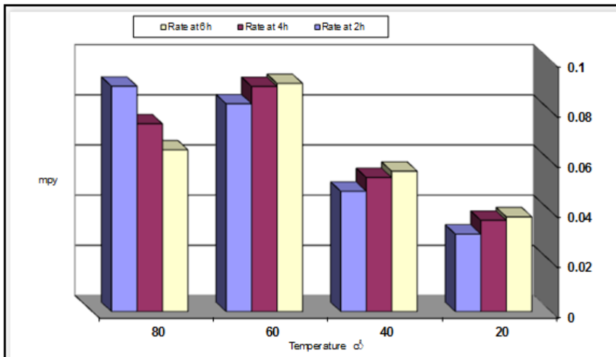

Figure 3 corrosion rate of carbon steel versus SS.304 at concentration"NaCl"40g/L (Anode to cathode area ratio 1:1,the distance between the anode and the cathode3cm)

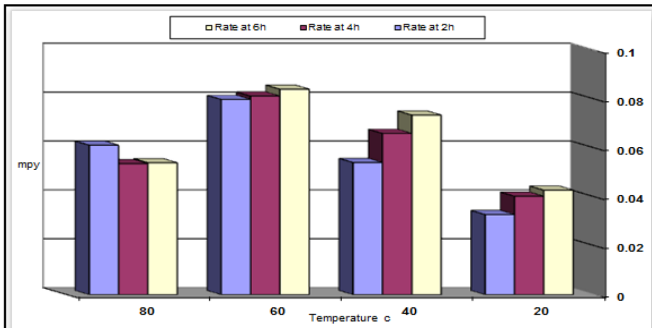

Figure 4 corrosion rate of carbon steel versus SS.304 at concentration "NaCl"40g/L(Anode to cathode area ratio2:1,the distance between the anode and the cathode 1cm)

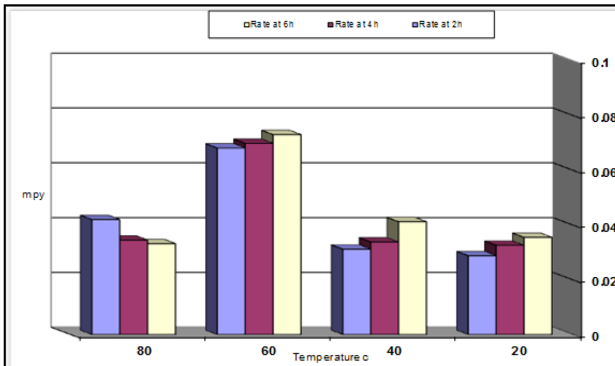

Figure 5 corrosion rate of carbon steel versus SS.304 at concentration"NaCl"40g/L(anode to cathode area ratio 2:1,the distance between the anode and the cathode 3cm)

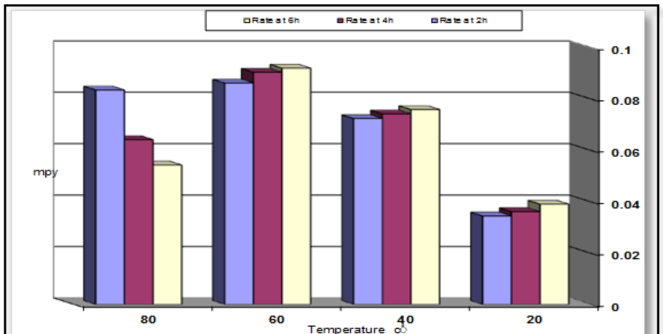

Figure 6 corrosion rate of carbon steel versus SS.304 at concentration"NaCl"50g/L (anode to cathode area ratio 1:1,the distance between the anode and the cathode 1cm)

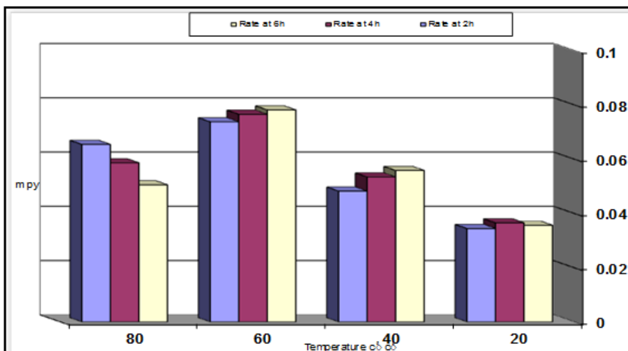

Figure 7 corrosion rate of carbon steel versus SS.304 at concentration"NaCl"50g/L(Anode to cathode area ratio 1:1,the distance between the anode and the cathode 3cm)

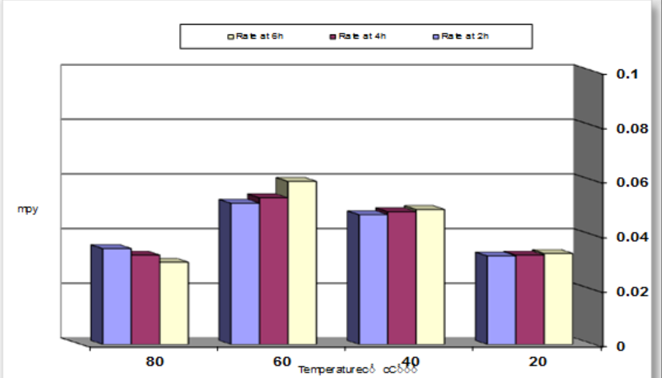

Figure 8 corrosion rate of carbon steel versus SS.304 at concentration "NaCl"50g/L(anode to cathode area ratio2:1,the distance between the anode and the cathode1cm)

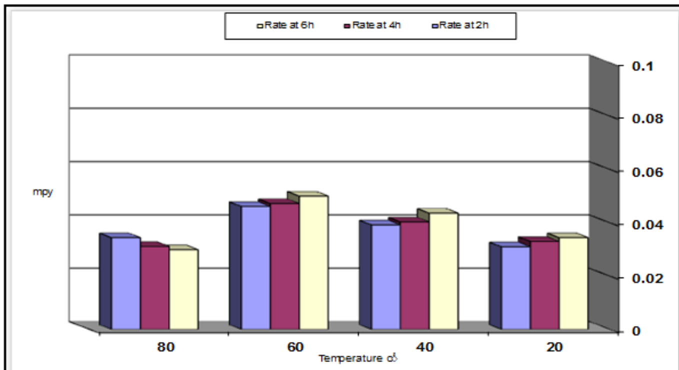

Figure 9 corrosion rate of carbon steel vers SS.304at concentration"NaCl"50g/L (anode to cathode area ratio 2:1,the distance between the anode and the cathode3cm)

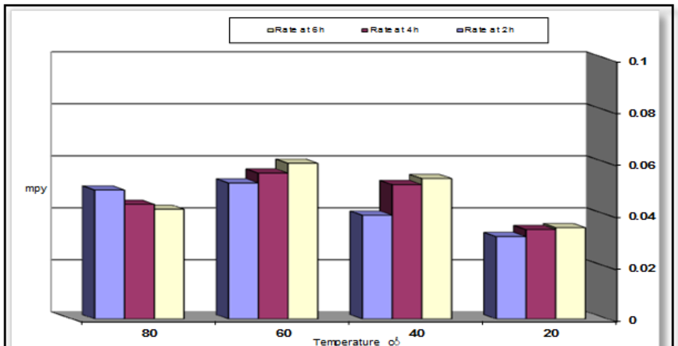

Figure 10 corrosion rate of carbon steel versus SS.304 at concentration"NaCl"60g/L (anode to cathode area ratio 1:1,the distance between the anode and the cathode 1cm)

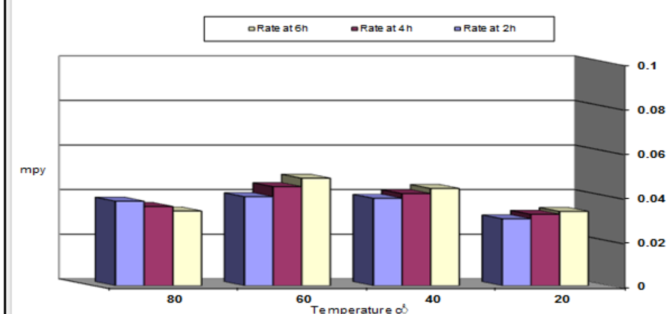

Figure 11 corrosion rate of carbon steel versus SS.304 at concentration "NaCl"60g/L(anode to cathode area ratio 1:1,the distance between the anode and the cathode 3cm)

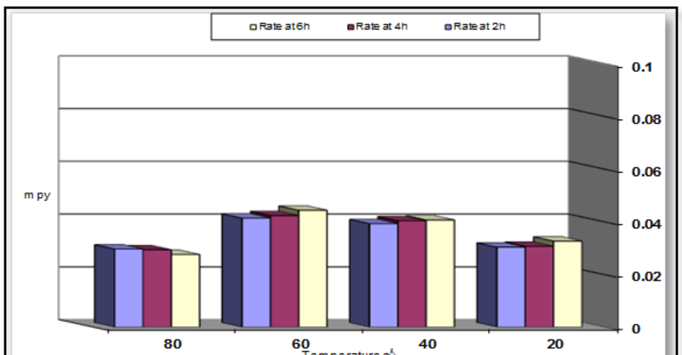

Figure 12 corrosion rate of carbon steel versus SS.304 at concentration"NaCl"60g/L (anode to cathode area ratio 2:1,the distance between the anode and the cathode 1cm)

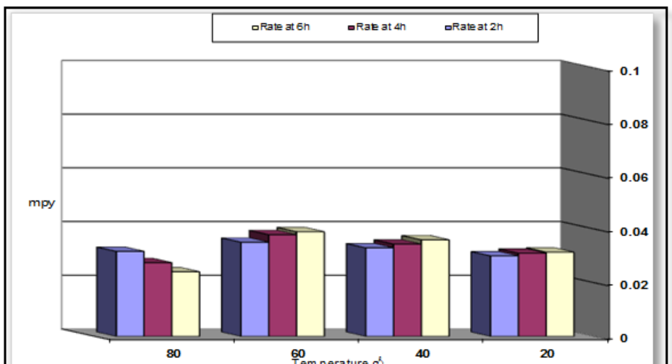

Figure 13 corrosion rate of carbon steel versus SS.304 at concentration"NaCl"60g/L (anode to cathode area ratio 2:1,the distance between the anode and the cathode 3cm)

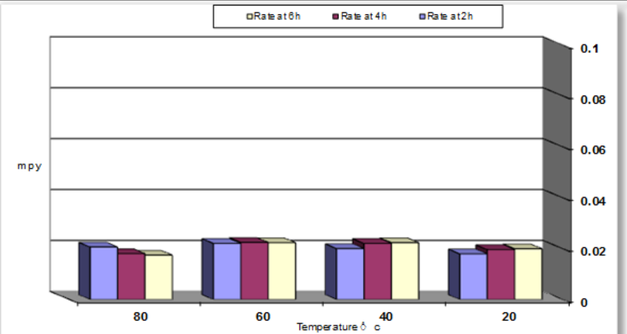

Figure 16 corrosion rate of carbon steel versus SS.304 at concentration"NaCl"80g/L (anode to cathode area ratio2:1, thedistance between the anode and the cathode 1cm)

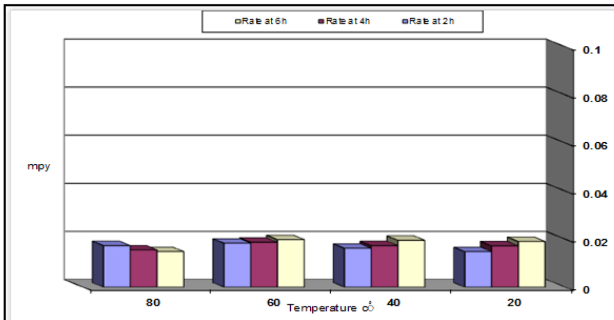

Figure 17 corrosion rate of carbon steel versus SS.304 at concentration"NaCl"80g/L (anode to cathode area ratio 2:1,the distance between the anode and the cathode 3cm

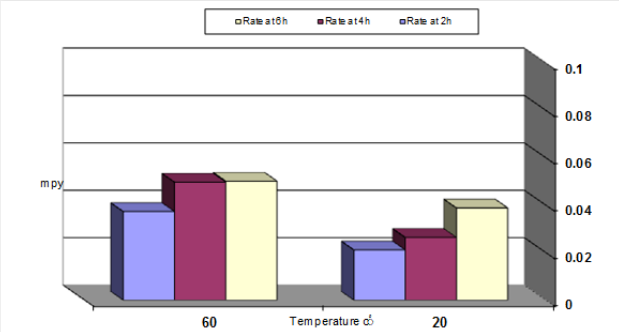

Figure 18 corrosion rate of carbon steel versus SS.304 at concentration"NaCl"20g/L (anode to cathode area ratio 1:1,the distance between the anode and the cathode 1cm)

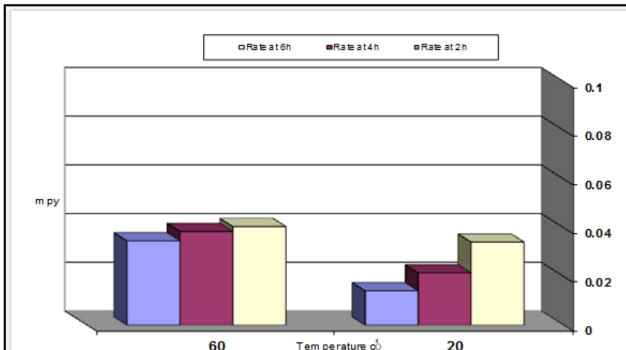

Figure 19 corrosion rate of carbon steel versus SS.304 at concentration"NaCl"20g/L (anode to cathode area ratio 1:1,the distance between the anode and the cathode 3cm)

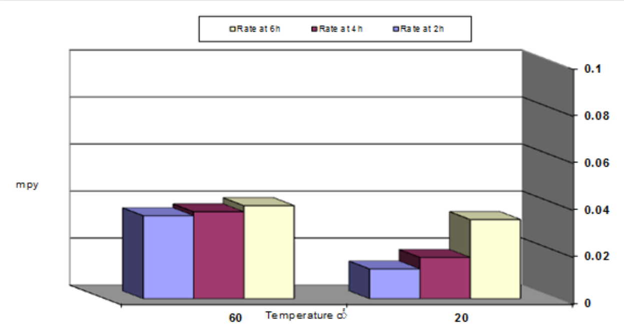

Figure 20 corrosion rate of carbon steel versus SS.304 at concentration"NaCl"20g/L (anode to cathode area ratio2:1,the distance between the anode and the cathode 1cm)

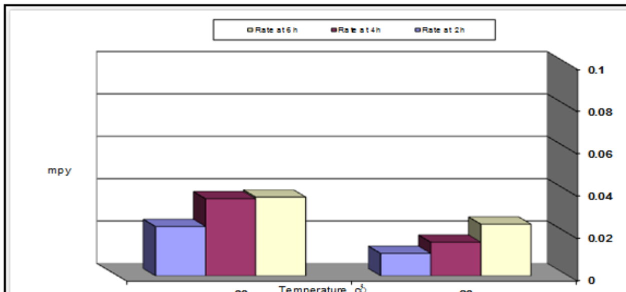

Figure 21 corrosion rate of for carbon steel versus SS.304 in concentration"NaCl"20g/L (anode to cathode area ratio 2:1 ,the distance between the anode and the cathode 3cm)

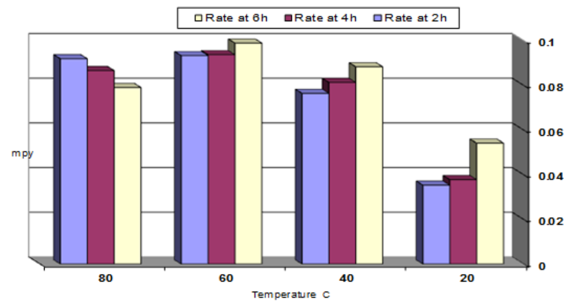

Figure 22 corrosion rate of carbon steel versus SS.316 at concentration"NaCl" 40g/L (anode to cathode area ratio 1:1, the distance between the anode and the cathode 1 cm)

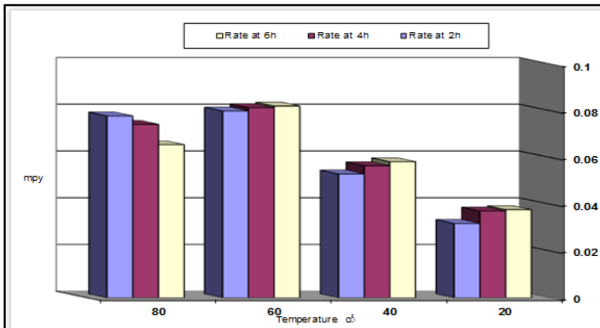

Figure 23 corrosion rate of carbon steel versus SS.316 at concentration"NaCl"40g/L (anode to cathode area ratio1:1,the distance between the anode and the cathode 3cm)

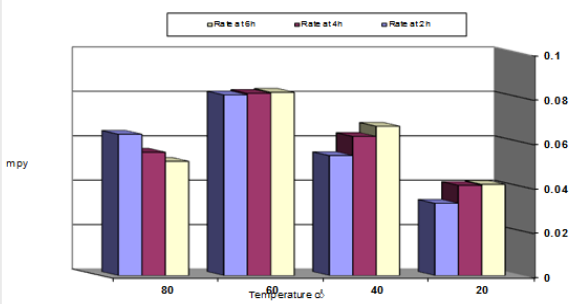

Figure 24 corrosion rate of carbon steel versus SS.316 at concentration"NaCl"40g/L (anode to cathode area ratio2:1,the distance between the anode and the cathode 1cm)

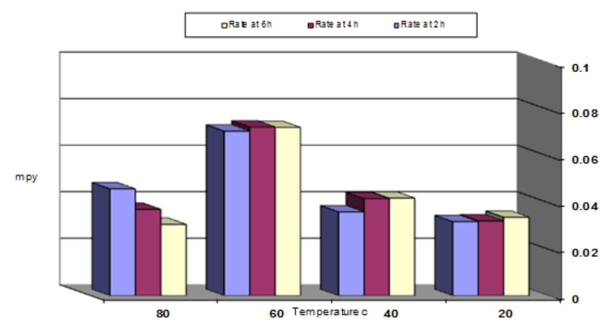

Figure 25 corrosion rate of carbon steel versus SS.316 at concentration"NaCl"40g/L (anode to cathode area ratio 2:1,the distance between the anode and the cathode 3cm)

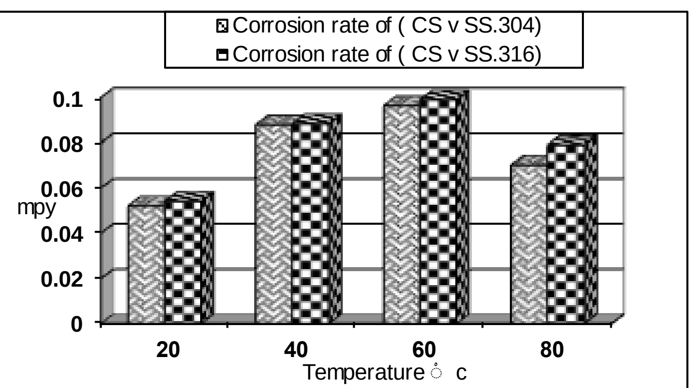

Figure 26 corrosion rate of carbon steel versus SS.304 comparing with corrosion rate of CS versus SS.316 at (NaCl) 40g/L (Anode to cathode aera ratio 1:1,the distance between the anode and the cathode 1cm , in 6h)

The other observation is the decrease of maximum rate of corrosion rate from Fig(2) to Fig(5) which observed at 60 C˚ for all samples .this may be attributed to the change in the anode to cathode ratio and separation distance between the anode and cathode.

Figs (6 - 9) rate of corrosion versus temperature at 50g/L concentration of NaCl . Figs (6 , 7) represent the anode to cathode ratio 1:1 and Figs. (8 , 9) represent the anode to cathode ratio 2:1 for separation distance 1 , 3 cm between anode and cathode. The plots of these figures have the same general features of those obtained in figures (2 - 5) in the electrolyte containing 40g/L NaCl .

Figures (10 - 13) represents the corrosion rate versus temperature at applied concentration of 60g/L of NaCl and with different area ratio of anode to cathode which are 1:1 , 2:1 Figs (10 , 11) and with separation distance of 1cm , 3 cm for Figs (12 , 13) .

The plots of Figs (10 - 13) have the same general features of the previously mentioned plots in Figs (2 - 5) . These figures indicate that the corrosion rate of the carbon steel electrodes increases with the increase of temperature up to 60 C˚ and then decreases with the increase of temperature . Also , the rate of corrosion the carbon steel electrodes increases with the decrease of area ratio (anode : cathode) and decrease of separating distance .

The last group of figures (14 - 17) which represent the change of corrosion rate with the change of temperature from 20 – 80 C˚ at constant concentration of sodium chloride (80g/L) .

The general features of the plots of Figs (14 - 17) are the same as the previously mentioned plots of Figs (2 - 13) obtained at different sodium chloride concentration (40,50,60 g/L) . In the presence of 80g/L the rate of corrosion of the carbon steel as given conditions is less than those obtained at other sodium chloride concentrations (40,50,60 g/L).

Figures (18 - 21) represent the variation of the corrosion rate of the carbon steel anodes with temperature (20, 60 C˚) in sodium chloride of concentration of 20g/L .The cathode was stainless steel 304 . The anode : cathode area ratio was 1:1 and 2:1 . the separating distance was 1 , 3 cm . These plots indicate that the corrosion rate of the carbon steel anodes increases with increase of temperature , and with the decrease of separating distance. On the other hand, the corrosion rate decreases with increase of anode : cathode area ratio from 1:1 to 2:1 .

Figures (22 - 25) represent the variation of corrosion rate of carbon steel with temperature (20 - 80) in 40g/L sodium chloride solution. The cathode was stainless steel 316. the anode : cathode area ratio was1:1 and 2:1 .The separating distance was 1, 3 cm. The general features of the plots of these figures are the same as those obtained in the case of use of stainless steel 304 as a cathode . The plots of Figs (22- 25) indicate that the corrosion rate of carbon steel increases with increase of temperature from 20 to 60 C$^{\circ}$ and then decreases with increases of temperature to 80 C$^{\circ}$. Also, the rate of corrosion increases with the decrease of separating distance from 3 to 1 cm. On the other hand the corrosion rate decreases with the increases of anode : cathode area ratio from 1:1 to 2:1. In this series of experiments the effect of the type of cathode (SS.304 , SS.316) on the corrosion rate of carbon steel anode in sodium chloride solution was studied , the first set of experiments was carried out using stainless steel 304 as a cathode ,while in the second set of experiments stainless steel 316 was used as a cathode ,the results indicates that under the given condition ,the corrosion rate of carbon steel nodes in the case of using of SS.316 as a cathode was higher than that obtained in the case of using SS.304 as a cathode (figure 26).

6. Conclusion

From the obtained results of the studies of the effect of different operating conditions the galvanic corrosion of the carbon steel in sodium chloride solutions the following conclusions can be drawn :

1. The rate of corrosion of carbon steel anodes (mpy) greatly depends on the operating conditions of the experiments .
2. The lowest corrosion rates of carbon steel anodes were obtained in solutions with low and high concentrations of sodium chloride (20, 60,80 g/L). On the other hand the highest corrosion rate is obtained in NaCl solution of 40 g/L .
3. The lowest corrosion rates of carbon steel in NaCl solutions were obtained at low (20 C$^{\circ}$) and high (80 C$^{\circ}$) temperatures .
4. The lowest corrosion rates of carbon steel anodes were obtained at long exposure time ,high temperature and high concentrations of NaCl .

5. The increase of separating distance between anode and cathode greatly decreases the corrosion rate of carbon steel in NaCl solution.
6. The increase of anode : cathode area ratio greatly decreases the corrosion rate of carbon steel in NaCl solution .
7. The narrow the difference between the galvanic potentials of anodes and cathodes the lower the corrosion rate was obtained .

4. References

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[2] Materials engineering 1 selecting materials for process equipment. Edited by Kenneth j . McNaughton and the staff of chemical engineering.

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[4] J.X. Jia and others, “Simulation of galvanic corrosion of magnesium coupled to a steel fastener in NaCl solution,” *Materials and Corrosion*, vol. 56, no. 7, 2005.

[5] K.B. Despade, “Validated numerical modelling of galvanic corrosion for couples: Magnesium alloy (AE44)-mild steel and AE44-aluminium alloy (AA6063) in brine solution,” *Corrosion Science*, vol. 52, pp 3514–3522, 2010.

TC°	W	Test period								
		2h			4h			6h		
		W1	W-W1	mpy	W2	W-W2	mpy	W3	W-W3	mpy
20	28.3475	28.3424	0.0051	0.0343	28.3364	0.0111	0.0373	28.3243	0.0232	0.052
40	27.4555	27.4445	0.011	0.0748	27.4322	0.0233	0.0812	27.4167	0.0388	0.0879
60	27.5900	27.5767	0.0133	0.0911	27.5620	0.028	0.0959	27.5478	0.0413	0.0963
80	27.1380	27.1246	0.0134	0.0938	27.1140	0.024	0.0840	27.1080	0.0300	0.0702

Appendix

Table 1. carbon steel versus SS.304

- Concentration "NaCl"40g/L

Tc°	W	Test period								
		2h			4h			6h		
		W1	W-W1	mpy	W2	W-W2	mpy	W3	W-W3	mpy
20	26.8905	26.8860	0.0045	0.0309	26.8799	0.0106	0.0364	26.8740	0.0165	0.0378
40	27.1370	27.1300	0.007	0.048	27.1214	0.0156	0.0535	27.1125	0.0245	0.0560
60	26.2620	26.2500	0.012	0.0829	26.2360	0.026	0.0898	26.2225	0.0395	0.091
80	28.3430	26.3295	0.0135	0.0899	26.3205	0.0225	0.0749	26.3140	0.029	0.0645

- Anode to cathode area ratio 1:1
- The distance between the anode and the cathode 1cm

Table 2. carbon steel versus SS.304

- Concentration "NaCl"40g/L
- Anode to cathode area ratio 1:1
- The distance between the anode and the cathode 3cm

Tc°	W	Test period								
		2h			4h			6h		
		W1	W-W1	mpy	W2	W-W2	mpy	W3	W-W3	mpy
20	28.5028	28.5980	0.0048	0.0328	28.5910	0.0118	0.0403	28.5840	0.0188	0.0428
40	28.8530	28.8450	0.008	0.0541	28.8335	0.0195	0.066	28.8204	0.0326	0.0735
60	27.9896	27.9780	0.0116	0.0799	27.9660	0.0236	0.0813	27.9530	0.0366	0.0841
80	25.9225	25.9140	0.0085	0.0612	25.9076	0.0149	0.0536	25.90	0.0225	0.054

Table 3. carbon steel versus SS.304

- Concentration "NaCl"40g/L
- Anode to cathode area ratio 2:1
- The distance between the anode and the cathode 1cm

Table 4 . carbon steel versus SS.304

- Concentration "NaCl"40g/L
- Anode to cathode area ratio 2:1
- The distance between the anode and the cathode 3cm

Table 5. carbon steel versus SS.304

- Concentration "NaCl"50g/L
- Anode to cathode area ratio 1:1
- The distance between the anode and the cathode 1cm

Tc°	**W**	**Test period**								
		2h			**4h**			**6h**		
		W1	**W-W1**	**mpy**	**W2**	**W-W2**	**mpy**	**W3**	**W-W3**	**mpy**
20	28.4140	28.4098	0.0042	0.0288	28.4045	0.0095	0.0326	28.3988	0.0152	0.0348
40	25.9493	25.9450	0.0043	0.0312	25.9398	0.0095	0.0338	25.9347	0.0146	0.0353
60	28.8700	28.8600	0.0100	0.0681	28.8495	0.0205	0.0698	28.8440	0.0026	0.0590
80	28.7162	28.7100	0.0062	0.0420	28.7060	0.0102	0.0345	28.7050	0.0112	0.0253

Table 6. carbon steel versus SS.304

Concentration "NaCl"50g/L

- Anode to cathode area ratio 1:1
- The distance between the anode and the cathode 3cm

Tc°	**W**	**Test period**								
		2h			**4h**			**6h**		
		W1	**W-W1**	**mpy**	**W2**	**W-W2**	**mpy**	**W3**	**W-W3**	**mpy**
20	29.9170	29.9120	0.005	0.0344	29.9065	0.0105	0.0361	29.9000	0.017	0.0390
40	29.9710	29.9605	0.0105	0.0723	29.9495	0.0215	0.0741	29.9380	0.033	0.0758
60	29.6360	29.6235	0.0125	0.0861	29.6098	0.0263	0.0903	29.596	0.04	0.0919
80	29.7886	29.7765	0.0121	0.0834	29.7700	0.0186	0.0641	29.7650	0.0236	0.0543

Tc°	**W**	**Test period**								
		2h			**4h**			**6h**		
		W1	**W-W1**	**mpy**	**W2**	**W-W2**	**mpy**	**W3**	**W-W3**	**mpy**
20	27.75	27.7470	0.003	0.0212	27.7438	0.0062	0.0219	27.7406	0.0094	0.0221
40	27.7815	27.7784	0.0031	0.0219	27.7752	0.0063	0.0222	27.7720	0.0095	0.0224
60	27.3615	27.3580	0.0035	0.0247	27.3542	0.0073	0.0258	27.3500	0.0115	0.0271
80	27.4225	27.4191	0.0032	0.0226	27.4167	0.0056	0.0198	27.4145	0.0078	0.0183

Table 7 .carbon steel versus SS.304

- Concentration "NaCl"80g/L
- Anode to cathode area ratio 1:1

Tc°	W	Test period								
		2h			4h			6h		
		W1	W-W1	mpy	W2	W-W2	mpy	W3	W-W3	mpy
20	29.1100	29.1050	0.005	0.0344	29.0994	0.0106	0.0365	29.0945	0.0155	0.0356
40	29.4050	29.3980	0.007	0.0482	29.3895	0.0155	0.0534	29.3807	0.0243	0.0558
60	29.9867	29.9760	0.0107	0.0737	29.9645	0.0222	0.0765	29.9527	0.034	0.0781
80	29.7350	29.7255	0.0095	0.0654	29.7180	0.017	0.0586	29.7130	0.022	0.0505

- The distance between the anode and the cathode 1cm

Table 8. carbon steel versus SS.304

- Concentration "NaCl"80g/L
- Anode to cathode area ratio 1:1
- The distance between the anode and the cathode 3cm

Tc°	W	Test period								
		2h			4h			6h		
		W1	W-W1	mpy	W2	W-W2	mpy	W3	W-W3	mpy
20	28.7715	28.7685	0.003	0.0206	28.7652	0.0063	0.0217	28.7625	0.009	0.0206
40	28.8680	28.8624	0.0031	0.0213	28.859	0.0065	0.0224	28.8563	0.009	0.0211
60	29.2070	29.2038	0.0032	0.022	29.2003	0.0067	0.023	29.1970	0.0096	0.0229
80	29.0576	29.0545	0.003	0.0213	29.0520	0.0056	0.0193	29.0509	0.0067	0.0153

Table 9 . carbon steel versus SS.316

- Concentration "NaCl"40g/L
- Anode to cathode area ratio 1:1
- The distance between the anode and the cathode 1cm

Tc°	W	Test period								
		2h			4h			6h		
		W1	W-W1	mpy	W2	W-W2	mpy	W3	W-W3	mpy
20	27.2100	27.2050	0.005	0.0353	27.1993	0.0107	0.0378	27.187	0.023	0.0541
40	27.8380	27.8270	0.0110	0.0776	27.8150	0.023	0.0813	27.8005	0.0375	0.0883
60	26.942	26.9291	0.0129	0.0912	26.9155	0.0265	0.0937	26.900	0.042	0.0989
80	27.6600	27.647	0.013	0.0919	27.6353	0.0245	0.0866	27.6265	0.0335	0.0790

Table 10. carbon steel versus SS.316

- Concentration "NaCl"40g/L
- Anode to cathode area ratio 1:1
- The distance between the anode and the cathode 3cm

Tc°	W	Test period								
		2h			4h			6h		
		W1	W-W1	mpy	W2	W-W2	mpy	W3	W-W3	mpy
20	29.7040	29.6995	0.0045	0.0318	29.6935	0.0105	0.0371	29.6880	0.016	0.0377
40	27.8665	27.8590	0.0075	0.053	27.8505	0.016	0.0565	27.8418	0.0247	0.0582
60	27.851	27.8397	0.0113	0.0799	27.828	0.023	0.0813	27.8162	0.0348	0.082
80	27.8505	27.9395	0.011	0.0778	27.8295	0.021	0.0742	27.8227	0.0278	0.0655