

Effect of Molybdate Anions On Corrosion Behavior of Stainless Steel 304 In 0.1M NaCl Solution

Dr. Rana A. Majed*

Received on: 29 / 3/2009

Accepted on:2 /7 /2009

Abstract

The research was aimed to study the effect of molybdate ions (MoO_4^-) on corrosion behavior of SS 304 in 0.1M NaCl solution with six different concentration of molybdate ion in the range (0.01 – 0.3 M) at room temperature. Corrosion parameters such as open circuit potential (E_{ocp}), corrosion potentials (E_{corr}), corrosion current density (i_{corr}) and Tafel slopes (b_c & b_a) were measured and discussed. The polarization resistance (R_p) and rate of the corrosion in (mpy) values were calculated, the protection efficiency (P%) in solution NaCl containing molybdate anions was also estimated. All these parameters indicated role of molybdate as inhibitor material of corrosion SS 304 in NaCl solution and exhibit that the 0.03M MoO_4^{2-} has the best values of R_p , rate (mpy) and P%. The inhibition by molybdate was observed through adsorption process and formation of oxide layer on surface of Stainless Steel.

Key Word: Corrosion of SS 304, Effect of Molybdate ions.

تأثير أيونات المولبيدات على السلوك التآكلي للحديد المقاوم للصدأ (٣٠٤) في محلول ٠.١ مولاري كلوريد الصوديوم

الخلاصة

يتضمن البحث محاولة لدراسة تأثير أيونات المولبيدات على سلوك التآكل لسبيكة ٣٠٤ في محلول (0.1M NaCl) بستة تراكيز من المولبيدات ضمن المدى (٠.١ - ٠.٣ مولاري) بدرجة حرارة الغرفة. تم قياس ومناقشة بعض متغيرات التآكل مثل جهد التآكل (E_{corr}) وكثافة تيار التآكل (i_{corr}) وميول تافل الكاثودية والانودية (b_c & b_a). كما تم حساب مقاومة الاستقطاب (R_p) ومعدل سرعة التآكل بوحدة (ميل / سنة)، بالإضافة الى تقدير كفاءة الحماية في محلول كلوريد الصوديوم الحاوي على أيونات المولبيدات. هذه البيانات بينت دور المولبيدات كمنشط لتآكل الفولاذ المقاوم للصدأ ٣٠٤ في محلول كلوريد الصوديوم ووضحت بان اضافة تركيز ٠.٠٣ مولاري من المنشط اعطى افضل قيم لمقاومة الاستقطاب ومعدل السرعة المقاسة وكفاءة الحماية. ان دور التنشيط كان واضحا من خلال عملية الامتزاز وتكوين طبقة السلبية على السطح المعدني. ان جميع القياسات تمت في درجة حرارة الغرفة.

1- Introduction

The main reason for the existence of the stainless steels is their resistance to corrosion. Chromium is the main

alloying element, and the steel should contain at least 11%. Chromium is a reactive element, but it and its alloys passivate and exhibit excellent resistance

* Materials Engineering Department, University of Technology / Baghdad

to many environments. A large number of stainless steels are available. Their corrosion resistance, mechanical properties and cost vary over a broad range. For this reason, it is important to specify the exact stainless steel desired for given application[1].

There are four basic methods for corrosion control and corrosion protection:

1-Noble materials resistant to corrosion, 2-Protective coatings, 3-Cathodic protection, and 4- Corrosion inhibitors-Modify the operating environment.

The definition of corrosion inhibitor favored by National Association of Corrosion Engineers (NACE) is "a substance which retards corrosion when added to an environment in small concentrations".

Corrosion inhibitor functions by one or more of the following mechanisms:

- Adsorption as a thin film on the surface of a corroding material.
- Inducing formation of a thick corrosion product.
- Forming a passive film on the metal surface.
- Changing characteristics of the environment either by producing protective precipitates or by removing or inactivation an aggressive constituent.

If corrosion is viewed as the consequence of an electrochemical cell composed of anode, cathode, electrolyte, and electronic conductor, inhibitors retard corrosion by: Increased polarization of the anode, Increased polarization of the cathode, and Increased electrical resistance of the electrolyte circuit resulting from the formation of deposit on the surface of the metal.

Polarization renders a cathode more anodic and an anode more cathodic. Inhibitors fall into several classes. The

most important corrosion inhibitors are passivating, cathodic, organic, precipitate-inducing, and vapor-phase corrosion inhibitors[1].

Addition of molybdate as inhibitors was attracting attention many authors to use it in different media for various metals and alloys by using different techniques. Zhang and co-workers[2] study modification of passive film on SS by molybdate under alternating electric field, while Denise and co-workers[3] study the corrosion behavior of iron and AISI 304 SS in tungstate aqueous solution containing chloride ion by cyclic voltammetry, open circuit measurement and impedance spectroscopy.

Boucherit M.N. and co-workers[4] study the pitting corrosion in presence of inhibitors and oxidants. The results showed that efficiency of molybdate and tungstates were comparable. The presence of iodate, which plays an oxidizing role, can be synergistic to the inhibitor but harmful if the concentration ratio is not adequate.

Inhibition of stress corrosion cracking of AISI 304 SS by molybdate ions was studied by Cansever and co-workers[5] at elevated temperature under salt crust. While Rabacal and Vieira[6] study localized corrosion inhibition of 304 SS in pure water by oxyanions tungstate and molybdate. Ayse and Mubeccel[7] study the inhibition effect of single, binary and ternary mixture of chromate, molybdate, nitrate, tetraborate, orthophosphate, benzoate, acetate, ascorbic acid in neutral aqueous solution containing Cl^- at room temperature. The electrochemical behavior of 316 SS in $\text{H}_3\text{OP}_4\text{-Cl}^-$ solutions containing nitrate, dichromate, tungstate, and molybdate anions as inhibitors were studied by H.A. El-Dahan uses potentiodynamic and potentiostatic

polarization[8] and Auger electron spectroscopy techniques[9].

This work was attempt to inhibition corrosion of stainless steel 304 in 0.1M NaCl solution by addition of sodium molybdate with six different concentrations as inhibitor.

2- Experimental Part

The material used for this study was Stainless Steel (304) which cut into cylinder shape with (1.2 cm) diameter, and made into electrode by pressing a copper wire into a hole on one side and then insulating all but one side with an epoxy resin. The open side was polished mechanically to a mirror finish, rinsed in distilled water and stored in desiccators.

The basic solution was 0.1M NaCl solution prepared by distilled water (specific conductivity 1×10^{-6} S.m⁻¹). Study effect of molybdate ions were performed by perpetration six different concentrations of Na₂MoO₄ (M.wt 241.95 g.mol⁻¹). The various concentrations ranged from 0.01M up to 0.3M of molybdate anion.

Polarization experiments were performed in WINKING M Lab 200 Potentiostat from Bank-Elektronik with electrochemical standard cell with provision for working electrode (SS 304), auxiliary electrode (Pt electrode), and a Luggin capillary for connection with an SCE reference electrode.

Electrochemical measurements were performed with a potentiostat by SCI electrochemical software at a scan rate 3 mV.sec⁻¹. Polarization experiments were started when the rate at which open circuit potential (E_{ocp}) changed was less and more 200mV. The main results obtained were expressed in terms of the corrosion potentials (E_{corr}) and corrosion current density (i_{corr}) in addition to measure the Tafel slops.

3- Results and Discussion

3-1- Open Circuit Potential (E_{ocp})

The potential of the sample was followed as a function of time in order to study the evolution of the film chemistry as it came to equilibrium with solution. The variation of potentials with time for AISI 304 Stainless Steel in absence and presence of molybdate ions in the 0.1M NaCl solution were shown in Figures (1) to (7).

The interaction of the molybdate anion with 304 SS was studied over a range of inhibitor concentration from 0.01M to 0.3M. Figure (8) shows the effect of the inhibitor anion on (E_{ocp}) in a solution of 0.1M NaCl. The value of (E_{ocp}) for 0.1M NaCl solution in the absence of MoO₄⁼ was -397mV. In general, the addition of molybdate anion shifts E_{ocp} towards more noble value with different range according to concentrations of additive MoO₄⁼ as show in the following sequece.

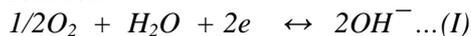
Conc. of MoO ₄ ⁼ (Molarit y)	0.0	0.0	0.0	0.1	0.3	0.5
	1	3	5	0	0	0
$-E_{ocp}$ (mV)	25	20	27	23	27	26
	8	5	7	0	7	7

These values of E_{ocp} were recorded after same time for all experimental solutions. The more noble values for solutions after addition of MoO₄⁼ indicates the film chemistry changes as the potential approaches the steady – state value. The most noble value of E_{ocp} was for (0.1M NaCl + 0.03 M MoO₄⁼) solution which indicates the most stable film on the surface of SS 304.

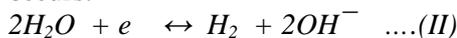
3-2- General Corrosion behavior

The polarization behavior of 304 SS in 0.1M NaCl solution (in the absence of molybdate anions) was shown in Figure (9) at room temperature (298K).

This behavior shows the cathodic and anodic regions. At cathodic region represent the reduction of oxygen can occur according to the following reaction:



In cases where the potential is more negative, a second cathodic reaction occurs:

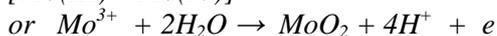
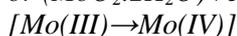
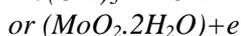


After corrosion potential value, the anodic region was began where the dissolve of iron can occur according to the following reaction:



Figures (10) to (15) show the polarization behavior of 304 SS in 0.1M NaCl solution in the presence of six different concentrations of molybdate anions (MoO_4^-). With cathodic polarization, molybdates can be in form of many state between Mo(III) and Mo(VI)[10]. It has been suggested [11] that cathodic polarization at -2V (vs SCE) produces the unstable compound $Mo(OH)_3/Mo_2O_3$.

The $Mo(OH)_3$ formation at this potential has been attributed to the availability of OH^- ions formed on the electrode surface. The $Mo(OH)_3$ compound is not stable and changes into more stable compound by the successive reaction[12]:



The presence of MoO_4^- in solution containing Cl^- effect partially on the shape of polarization curve while the most effect appear in the measured parameters of corrosion which observed in the Table (1).

The addition of MoO_4^- to solution shifts the corrosion potential (E_{corr}) in noble direction, this behavior ensure that the presence of MoO_4^- in solution lead to interaction between the molybdate and surface and produce a thin film.

The best interaction were occur when add 0.03M and 0.1 M of MoO_4^- which has value of $E_{corr} = -258.1$ mV and 275.6 mV respectively. In same behavior the corrosion current densities (i_{corr}) decrease in the presence of MoO_4^- to solution compared with the value of current density in the absence of MoO_4^- ($2.48 \mu A \cdot cm^{-2}$).

3-3- Effect of Molybdate Anions on Corrosion Protectiveness

The corrosion potential (E_{corr}) of a material in a certain medium at a constant temperature is a thermodynamic parameter which is a criterion for the extent of the corrosion feasibility under the equilibrium potential (in opposite sign) of the cell consisting of the working electrode and the auxiliary electrode when the rate of anodic dissolution of working electrode material becomes equal to the rate of the cathodic process that takes place on the same electrode surface.

Generally, the presence of molybdate anions in 0.1M NaCl solution shift E_{corr} towards more noble values such as shown in the relation between E_{oc} and concentration of molybdate anion in solution.

When (E_{corr}) becomes more negative, the potential of the Galvanic cell becomes more positive and hence the Gibbs free energy change (ΔG) for the corrosion process becomes more negative. The corrosion reaction is then expected to be more spontaneous on pure thermodynamic ground.

When the measured value of (E_{corr}) becomes less negative, the potential of

the corresponding Galvanic cell becomes less positive, hence the (ΔG) value for the corrosion process becomes less negative, and the process is thus less spontaneous.

It is thus shown that (E_{corr}) value is a measure for the extent of the feasibility of the corrosion reaction on purely thermodynamic basis. The change in free energy (ΔG) is a direct measure of the work capacity or maximum electric energy available from a system. The free-energy change accompanying an electrochemical reaction can be calculated by the following equation [13]:

$$\Delta G = -nFE \quad \dots\dots(1)$$

where ΔG is the free – energy change, n is the number of electrons involved in the reaction, F is the Faraday constant (96484 C.mol^{-1}), and E is the corrosion potential and its sign is reversed prior to its use in equation (1) to represent the potential of the reversibly operating cell and not the applied potential from the potentiostat.

The values of calculated free – energy change were shown in Table (2), the negative sign of ΔG refers to spontaneous of corrosion process of 304 SS in experimental solutions.

The value of ΔG for NaCl solution which containing molybdate anions has less negative value than the NaCl solution without additive molybdate (as shown in Fig. 16) and the least value of ΔG was observed in solution containing 0.03M MoO_4^{2-} ($49.80504 \times 10^{+3} \text{ Joul.mol}^{-1}$) followed by the solution containing 0.1M MoO_4^{2-} ($53.18198 \times 10^{+3} \text{ Joul.mol}^{-1}$).

Thermodynamic principles can help explain a situation in terms of the stability of chemical species and reactions associated with corrosion process. In general, there are two sources

of energy to be considered in corrosion processes. The first is a driving force that determines whether corrosion will take place under certain conditions. If the free energy oxidation is less than zero, then oxidation will occur spontaneously, as in the metals in the alloys.

The second source of energy occurs when positive and negative charges (metal ions and electrons, respectively) are separated from one another during corrosion. The ions are released to solution or go on to form an oxide or another compound, and the electrons are left behind in the metal undergo other electrochemical reactions, such as reduction of oxygen or hydrogen or hydrolysis of water.

This between the charges contributes to what is known as the electrical double layer and creates an electrical potential across the metal – solution interface (much like a capacitor), as expressed by equation (1).

The corrosion current density (i_{corr}) is a kinetic parameter and represents the rate of corrosion under specified equilibrium condition. Any factor that enhances the value of (i_{corr}) results in an enhanced value of the corrosion rate on pure kinetic ground.

The rate (R) of corrosion in a given environment is directly proportional with its corrosion current density (i_{corr}) in accordance with the relation[14]:

$$R_{(\text{mpy})} = 0.13 \times (e/r) \times i_{\text{corr}} \quad \dots\dots(2)$$

where (R_{mpy}) is the rate of corrosion in mil per year, (e) is the equivalent weight of the metal and (r) is its density. The values of rate were shown in table (2).

The presence of molybdate anion on solution decreases the rate of corrosion in different behavior as shown in Fig. (17).

The least values of rate were observed in solution containing 0.03 and 0.1M MoO_4^{2-} which has (0.011791×10^{-2} and 0.011617×10^{-2} mpy) respectively.

The coexistence of Mo^{+6} and Mo^{+4} in near-neutral solutions is predicated by the Pourbaix diagram for Mo (Figure 18)[15]. The amount of Mo^{+4} in solution limits by its solubility. At low concentrations of molybdate ions, the amount of Mo^{+4} in solutions can be significant relative to that of Mo^{+6} . In the case of these 304 SS surface, the Mo^{+4} species is preferentially absorbed and a MoO_2 film nucleates and grows.

At higher concentration of molybdate ions, the fraction of Mo as Mo^{+4} decreases due to its low solubility. In this case MoO_4^{2-} is able to adsorb on the surface in sufficient amount to control the chemistry of the film. The formation of a thick MoO_2 layer is therefore limited and the passive film that forms under these conditions is thin and consists mainly of molybdate.

In solutions containing higher molybdate concentrations, the MoO_3 also initially forms on the 304 SS as the air – formed film interacts with the solution. However, as stated earlier, the concentration of molybdate anions in the solution appears sufficient to rapidly adsorb onto the surface and form a thin molybdate layer, which inhibits the growth of a MoO_2 film. In this case, film growth is controlled by the diffusion of the anion through the oxide. The restriction of anion diffusion by the presence of molybdates in the film would lead to less corrosion.

From deep analysis of the cathodic and anodic regions of the polarization curves which have been obtained for 304 SS in 0.1M NaCl solution in the absence

and presence of molybdate anion, it was possible to derive data concerning :

a- The cathodic (b_c) and anodic (b_a) Tafel slopes.

b- The cathodic (α_c) and anodic (α_a) transfer coefficients.

Values of α have been calculated from the corresponding values of the Tafel slope (b) using the relations[16]:

$$a_c = \frac{2.303RT}{b_c F} \dots\dots(3)$$

$$a_a = \frac{2.303RT}{b_a F} \dots\dots(4)$$

The values of cathodic and anodic Tafel slopes and transfer coefficients were shown in Table (1).

The reduction of the H_2O molecule is a common cathodic reaction for the corrosion of metals in neutral and alkaline solutions (equation II). The hydrogen evolution reaction has been the most widely studied electrode reaction.

However, it is important to note that the discharge step involves adsorption of hydrogen atoms at available sites on the metal surface, and is followed by desorption that may be either a chemical step, or an electrochemical step in which further charge transfer occurs. A value of the cathodic Tafel slope of ($-120 \text{ mV.decade}^{-1}$) may be diagnostic of a proton discharge-chemical desorption mechanism in which the proton discharge is the rate-determining step.

In chemical desorption step the adsorbed H atom diffuse about on the metal surface, either by threading their way through adsorbed water molecules or by pushing them aside, until two collide to form an H_2 molecule which escapes into the solution.

This chemical step will be independent of overpotential, since charge transfer is not involved, and the rate will be proportional to the concentration or

coverage θ_H of adsorbed H_{ads} and may occur at coverage that range from very small to almost complete. If the discharge process is followed by a rate-determining step involving chemical desorption, the expected value of the cathodic Tafel slope should be (-30 mV.decade⁻¹).

On the other hand, the electrochemical desorption step is far more complex since it involves reaction between an adsorbed H atom, a hydrated proton H_3O^+ and an electron, and for desorption to occur the proton must discharge onto a hydrogen atom adsorbed on the metal surface. Under these circumstances the probability of collision will be low unless the coverage θ_H is high. When electrochemical desorption becomes the rate-determining step for on the cathode, the expected value of b_c will be (-50 mV.decade⁻¹).

Generally, the values of Tafel slops which shown in Table (1) indicates that the rate-determining step ranged between diagnostic of a proton discharge-chemical desorption mechanism and electrochemical desorption mechanism.

The polarization resistance (R_p) may be defined as [17, 18]:

$$R_p = \frac{dh}{di} = \frac{d(E-E_{corr})}{di} = \frac{E_{corr}}{i_{corr}} = \frac{RT}{Fi_o} \dots\dots(5)$$

Where E and E_{corr} are the applied and corrosion potential (Volt) respectively, I is the current density (A.cm⁻²).

The ratio (E_{corr}/i_{corr}) thus corresponds to the resistance of the metal/solution interface to charge-transfer reaction. It is also a measure of the resistance of the metal to corrosion in the solution in which the metal is immersed.

i_o is the equilibrium exchange current density (A.cm⁻²).

The reaction resistance (R_p), which mainly depends upon the

equilibrium exchange current density (i_o) determines what may be termed the polarizability, i.e., what overpotential ($\eta=E-E_{corr}$) a particular current density needs or produces[19, 20].

The polarization resistance (R_p) was also determined in another way from Stern- Geary equation, where[21, 22]:

$$R_p = \left(\frac{dE}{di} \right)_{i=0} = \frac{b_a b_c}{2.303(b_a + b_c) i_{corr}} \dots(6)$$

The values of R_p have been calculated from eq.(10), which are presented in table (1).

The results of table (1) indicate that the polarization resistance R_p of 304 SS in 0.1M NaCl solution with out addition is lower than its value in the presence of inhibitor in solution. The highest R_p value was shown in NaCl solution containing 0.03M of molybdate.

The adsorption of molybdate anions on surface of 304 SS and then growth of molybdate oxide layer on the surface decreases the corrosion and increasing the resistance of the metal or alloy to attack of ions in solution.

3-4- Protection Efficiency

The corrosion current densities in the presence (i) and absence (i_o) of inhibitor in the corrosion medium have been used to determining the protection efficiency (P%) by using the relation[23]:

$$P\% = 100 \left[1 - \frac{i}{i_o} \right] \dots\dots\dots(7)$$

The results in table (2) indicate that the values of P% are positive which indicates the inhibition of corrosion was occur by the added molybdate to 0.1N solution of NaCl. Addition of molybdate to base solution give good protection efficiency but the best protection effect was shown with add 0.03M MoO_4^{2-} to NaCl solution. The later result

accordance with the results of ΔG , $R_{(mpy)}$ and R_p .

Molybdate prevents corrosion through its ability to be adsorbed by a metal oxide layer, filling gaps and so promoting the formation of an adherent oxide layer. Corrosion of the underlying substrate is prevented it become passivated. Molybdate solutions protect against rusting of steel parts during machining.

4- Conclusion

The results of this work indicated that the film that formed on 304 SS surface in solution containing molybdate anions is dependent upon its concentration. At low MoO_4^{2-} solution concentrations and near neutral pH, the film is thick and consists of high concentration of MoO_2 , whereas at higher MoO_4^{2-} solution concentrations, the film that forms is a thin layer consisting mainly of molybdate.

This suggests that the MoO_2 state does not play a significant role in protecting the substrate. Rather, the important component is the molybdate layer that selectively impedes the ingress of anions. This species not only limits the growth of the passive film by restricting the movement of oxygen and hydroxyl anions from penetrating the film and reaching the metal/film interface, it also restricts Cl^- anions pitting.

5- References

- 1- Pierre R. Roberge, "**Corrosion Basics**", Part IV: Methods of control, 2nd edition, July 2005.
- 2- Zhang Jun, Yan Li, and Wei Zeng, *Corrosion Science and Protection Technology* Vol.(18), No.(3), May 2006.
- 3- S. Denise, M. Emilse, and L. Iduvirges, *J. Baraz. Chem. Soc.* Vol.(14), No.(4), July/Aug. 2003.
- 4- M.N. Boucherit, A. Sid Ahmed, A. Fahd, H. Salah, and H. Abdennour, *Anti-*

corro. Methods and Materials, Vol.(55), No.(3), 2008, P.115-122.

- 5- N. Cansever, A. Cakir, and M. Urgan, *Corrosion Sci.*, Vol.(41), No.(7), 1999.
- 6- A.C. Rabacal and A.I. Vieira, *Elec. Acta*, Vol.(49), No.(17-18). 2004, P.362.
- 7- T. Ayse and E. Mubeccel, *Tournal of Materials Science*, Vol.(19), No.(3), 2006, P. 149-154.
- 8- H.A. El-Dahan, *Journal of Materials Science*, Vol.(34), No.(4), February 1999, P.851-857.
- 9- H.A. El-Dahan, *Journal of Materials Science*, Vol.34, No.4, February 1999, P.859-868.
- 10- G.D.Wilcox, D.R.Gabe, and M.E. Warwick, *Corrosion Sci.*, Vol.28, 1988, P.577.
- 11- K.C. Emregul and A.A. Aksut, *Corrosion Sci.*, Vol.45, 2003, P.2415.
- 12- C.V. Krishnan, M. Garnett, B. Hsiao, and B. Chu, *Int. J. Electrochem. Sci.*, Vol. 2, 2007, P.29-51.
- 13- L.L.Sherir, "**Corrosion**", Metal/Environment Reactions, second ed. vol.1, 1976.
- 14- J. M. Saleh, K. A. Saleh, and N. A. Hikmat, *Iraqi J. Sci.*, Vol.36, 1995, P.803.
- 15- M. Pourbaix, *Atlas of Electrochemical Equilibria* (Oxford, England: Pergamon Press, Ltd., 1966), P.227.
- 16- H.H. Uhlig, "**Corrosion and Corrosion Control**", Wiley, New York, 2000.
- 17- K. B. Oldham and F. Mansfeld, *Corrosion Sci.*, Vol.14, 1973, P.813.
- 18- M . Periassamy and P. R. Karishnaswamy, *J. Electronal Chem.*, Vol.61, 1975,P.349.
- 19- J. Janko Wisk and R. Juchniewicz, *Corrosion Sci.*, Vol.20, 1980, P.841.
- 20- I. Qamor and S. W. Hausion, *British Corrosion J.*, Vol.25, 1990, P.202.

21- Stern, M., Method for Determining Corrosion Rates from Linear Polarization Data, *Corrosion*, Vol.14, No.9, 1958, P.440–444.

22- Stern M., and Geary, A. L., Electrochemical Polarization I: A Theoretical Analysis of the Slope of Polarization Curves, *Journal of the*

Electrochemical Society,Vol.104, No.1, 1957, P.559–563.

23- Pierre R. Roberge, "Handbook of Corrosion Engineering" , Ch. 5 : Corrosion Inhibitors, Mc Graw – Hill, 2000, P.834 .

Table (1) : Values of corrosion potentials E_{corr} , corrosion current densities i_{corr} , cathodic and anodic Tafel slopes b_c and b_a , cathodic and anodic transfer coefficients α_c and α_a , polarization resistances R_p for the polarization of 304 SS in aerated 0.1M NaCl solution in the absence and presence of Na_2MoO_4 at room temperatures.

Conc. of MoO_4^{2-}	Corrosion		b ($mV.decade^{-1}$)		α		$R_p \times 10^{-6}$ $m\Omega cm^{-2}$
	$-E_{corr}$ (mV)	i_{corr} ($\mu A.cm^{-2}$)	$-b_c$	$+b_a$	α_c	α_a	
0.00	437.0	2.48	88.7	87.5	0.6667	0.6758	0.007712
0.01	309.1	0.3804×10^{-3}	62.0	97.8	0.9538	0.6046	43.31311
0.03	258.1	0.2566×10^{-3}	70.6	95.6	0.8376	0.6185	68.71966
0.05	318.4	0.3094×10^{-3}	41.1	54.1	1.4388	1.0931	32.77841
0.10	275.6	0.2528×10^{-3}	56.8	101.3	1.0411	0.5837	62.51078
0.20	322.1	0.5284×10^{-3}	60.0	138.7	0.9856	0.4263	34.41701
0.30	297.2	1.18	75.1	94.6	0.7874	0.6251	0.015405

Table (2) : Values of free – energy change (ΔG) and the rate of corrosion in mil/year for the polarization of 304 SS in 0.1M NaCl solution in the absence and presence of Na_2MoO_4 at room temperatures.

Conc. of MoO_4^{2-}	$-\Delta G \times 10^{+3}$ ($J. mol^{-1}$)	Rate of Corrosion $\times 10^{-2}$ (mpy)	Protection Efficiency P%
0.00	84.32702	113.9623	-
0.01	59.64641	0.01748	99.98468
0.03	49.80504	0.011791	99.98964
0.05	61.44101	0.014218	99.98427
0.10	53.18198	0.011617	99.98980
0.20	62.15499	0.024281	99.97871
0.30	57.35009	54.22399	52.41935

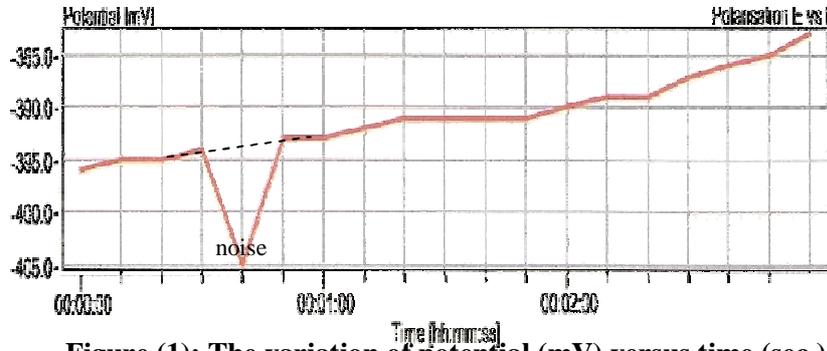


Figure (1): The variation of potential (mV) versus time (sec.) plot for 304 SS in 0.1M NaCl solution at room temperature.

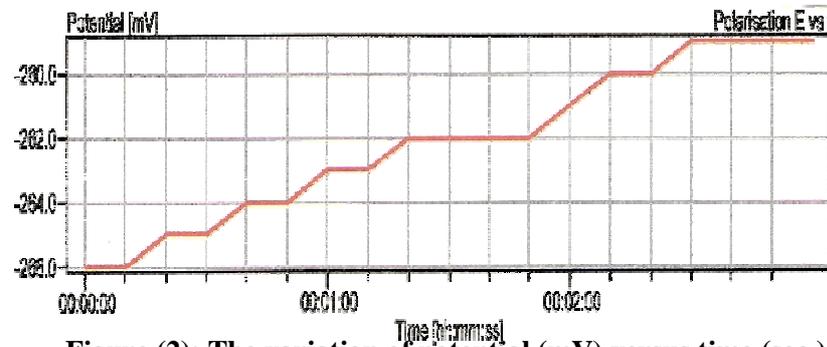


Figure (2): The variation of potential (mV) versus time (sec.) plot for 304 SS in 0.1M NaCl solution in presence of 0.01M Na_2MoO_4 at room temperature.

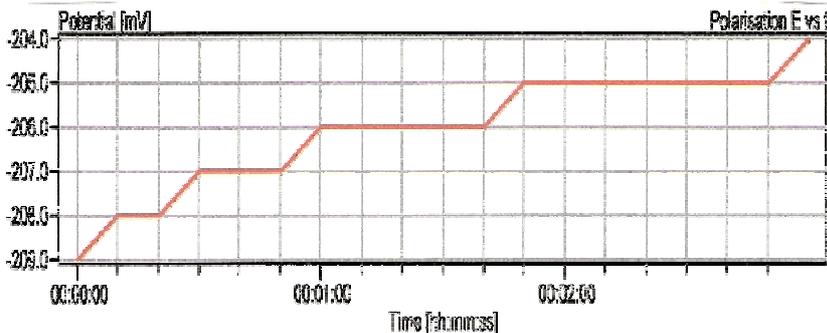


Figure (3): The variation of potential (mV) versus time (sec.) plot for 304 SS in 0.1M NaCl solution in presence of 0.03M Na_2MoO_4 at room temperature.

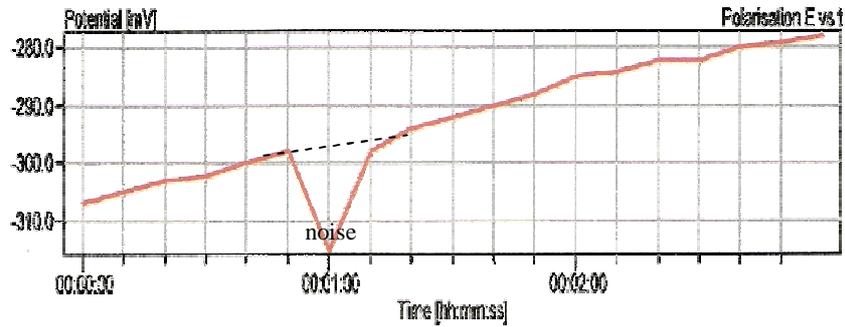


Figure (4): The variation of potential (mV) versus time (sec.) plot for 304 SS in 0.1M NaCl solution in presence of 0.05M Na_2MoO_4 at room temperature.

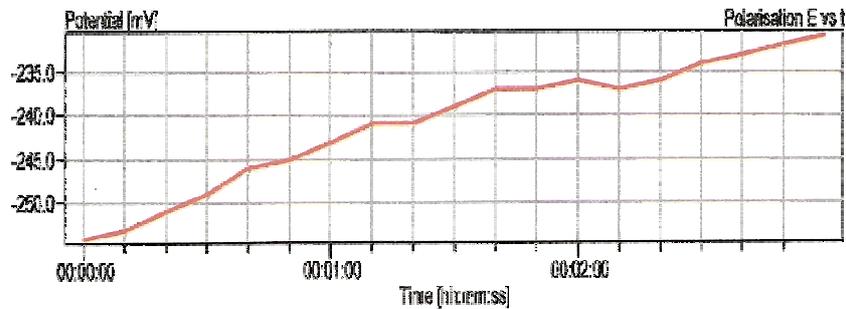


Figure (5): The variation of potential (mV) versus time (sec.) plot for 304 SS in 0.1M NaCl solution in presence of 0.1M Na_2MoO_4 at room temperature.

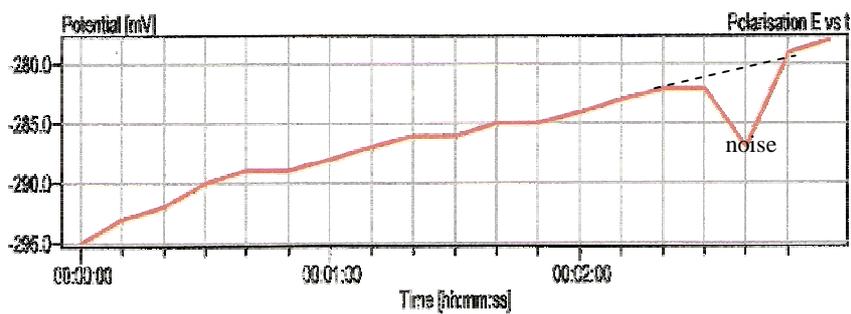


Figure (6): The variation of potential (mV) versus time (sec.) plot for 304 SS in 0.1M NaCl solution in presence of 0.2M Na_2MoO_4 at room temperature.

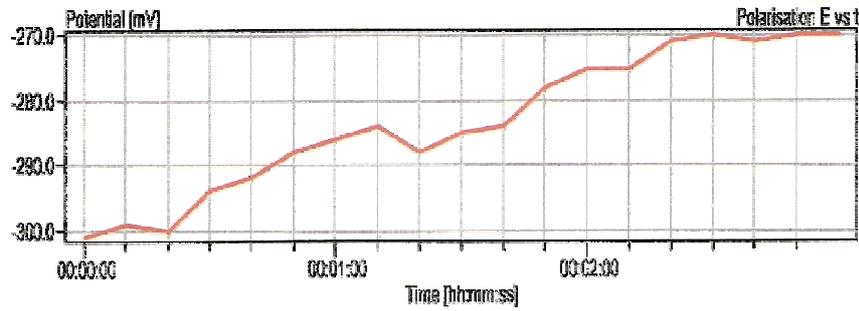


Figure (7): The variation of potential (mV) versus time (sec.) plot for 304 SS in 0.1M NaCl solution in presence of 0.3M Na_2MoO_4 at room temperature.

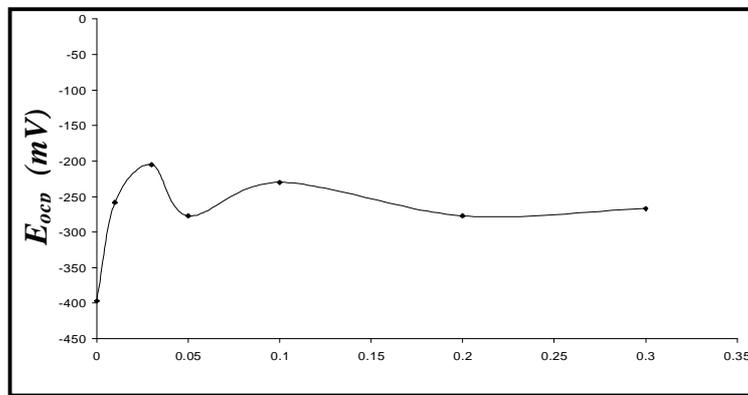


Figure (8): The relationship between open circuit potential (E_{ocp}) and concentration of molybdate anion in 0.1M NaCl solution for 304 SS against SCE at room temperature.

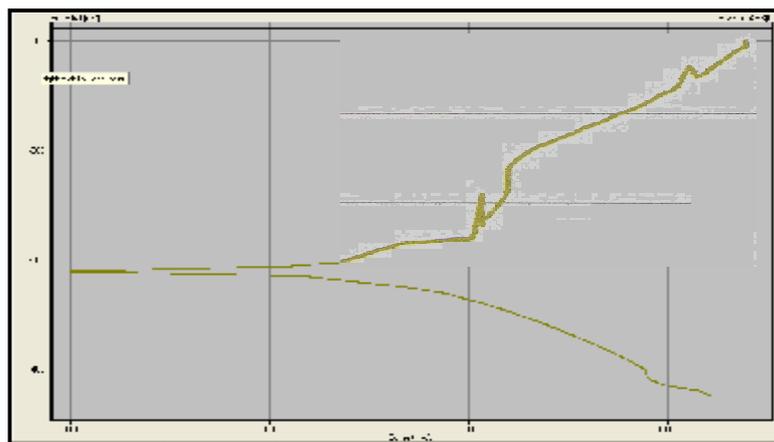


Figure (9): The polarization curve of 304 SS in 0.1M NaCl

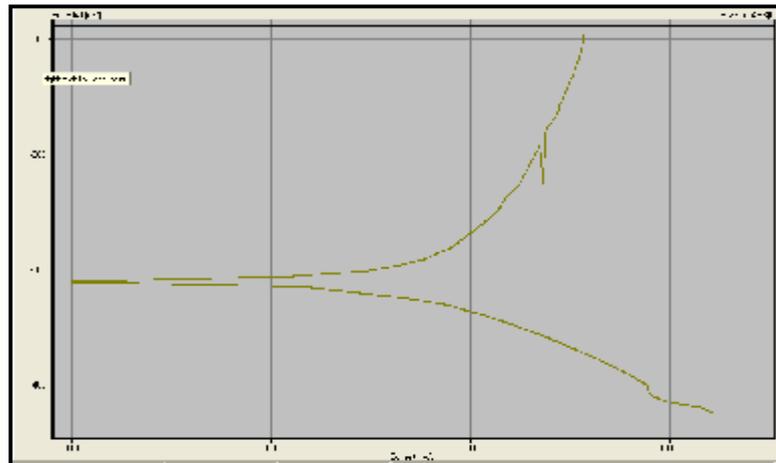


Figure (10): The polarization curve of 304 SS in 0.1M NaCl solution in presence of 0.01M Na₂MoO₄ at room temperature.

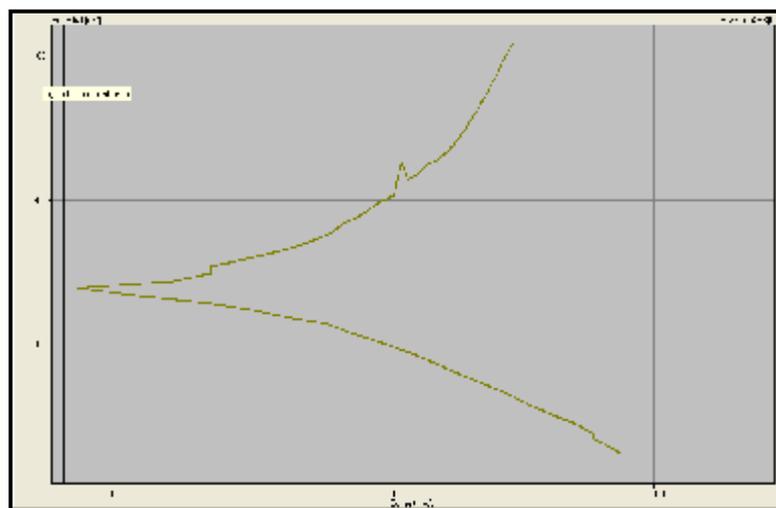


Figure (11): The polarization curve of 304 SS in 0.1M NaCl solution in presence of 0.03M Na₂MoO₄ at room temperature.

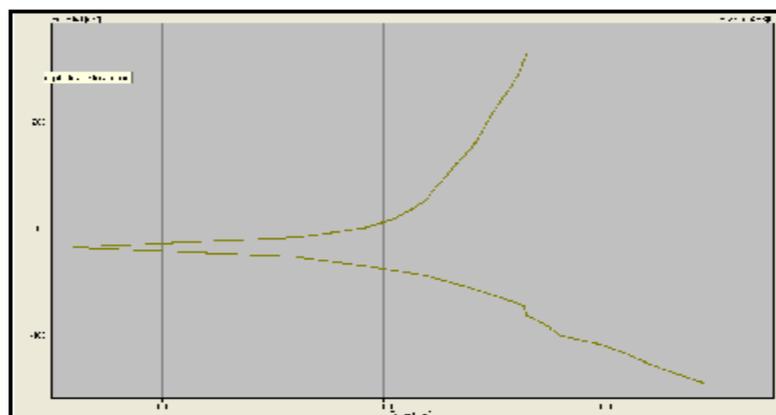


Figure (12): The polarization curve of 304 SS in 0.1M NaCl solution in presence of 0.05M Na₂MoO₄ at room temperature.

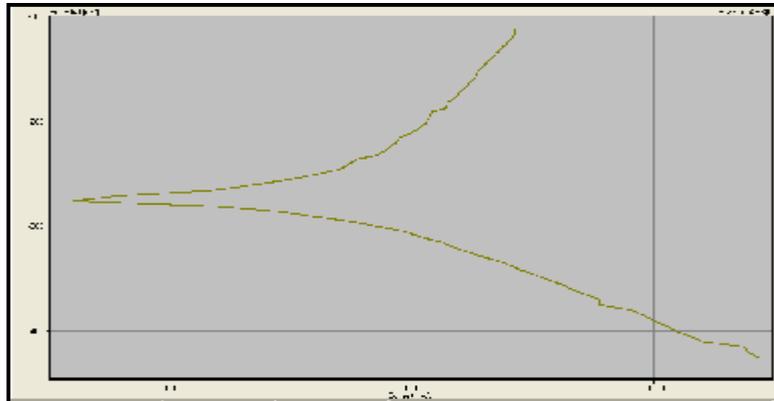


Figure (13): The polarization curve of 304 SS in 0.1M NaCl solution in presence of 0.1M Na₂MoO₄ at room temperature.

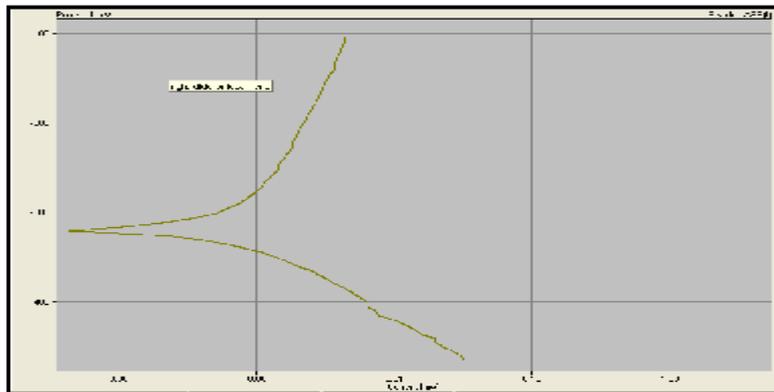


Figure (14): The polarization curve of 304 SS in 0.1M NaCl solution in presence of 0.2M Na₂MoO₄ at room temperature.

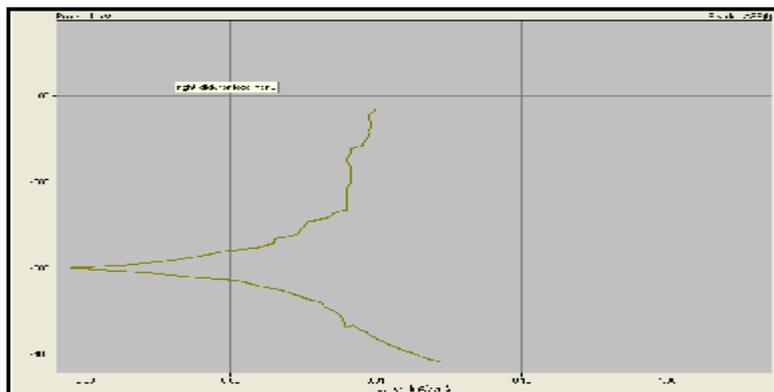


Figure (15): The polarization curve of 304 SS in 0.1M NaCl solution in presence of 0.3M Na₂MoO₄ at room temperature.

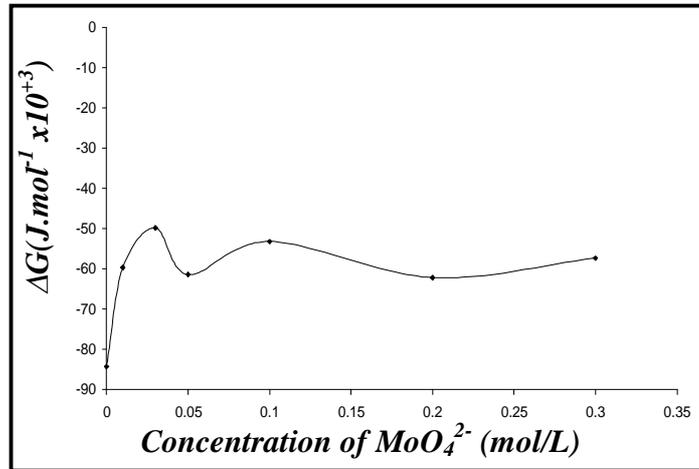


Figure (16): The relationship between Gibbs free energy (ΔG) and concentration of molybdate anion in 0.1M NaCl solution for 304 SS at room temperature.

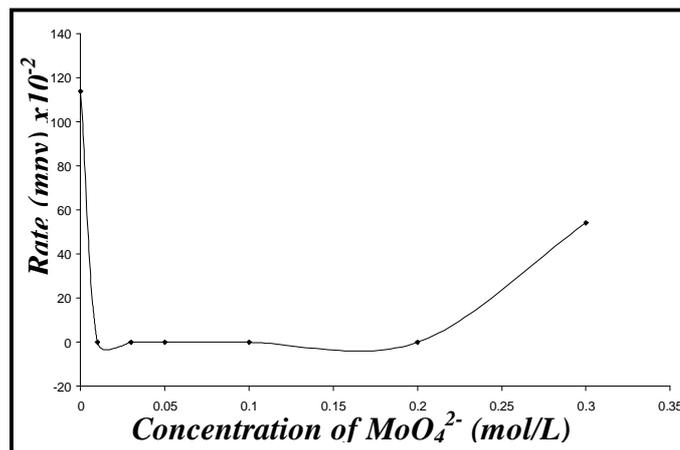


Figure (17): The relationship between rate of corrosion (mpy) and concentration of molybdate anion in 0.1M NaCl solution for 304 SS at room temperature.

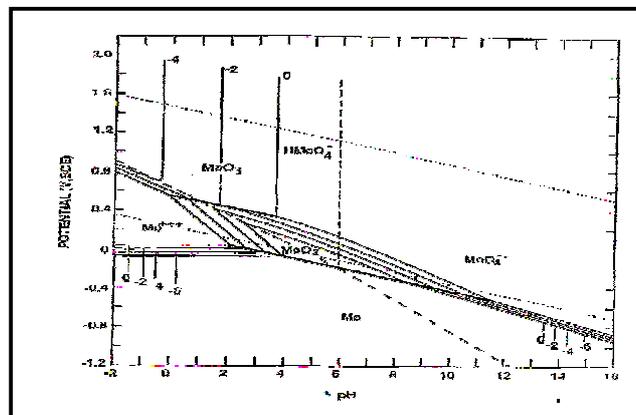


Figure (18): Pourbaix (pH-potential) diagram for Mo in water[13].