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EFFECT OF INORGANIC ACID SOLUTIONS ON ELECTROCHEMICAL BEHAVIOR OF TIN ELECTRODE

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Abstract

The electrochemical behavior of tin metal was studied in some inorganic acid solutions; HCl, HNO₃, H₂SO₄ and H₃PO₄, using the open circuit potential measurements and the potentiodynamic polarization technique. In addition, the metallographic structure of tin electrode was examined before and after immersion in test solution by using scanning electron microscope (SEM). The identification of the elements presented in the surface of specimen after immersion in different solutions was performed using an energy dispersion X-ray analysis (EDAX). The obtained results demonstrated that the aqueous dilution of HCl, H₂SO₄ and H₃PO₄ retarded the corrosion of tin electrode, (hydroxyl ion plays a part in basic salt formation), while dilution of HNO₃ acid accelerated the corrosion. It is evident from SEM image that, there were grain boundaries and the surface was more active and rougher in case of mechanically polished electrode. In non-polished electrode, the surface was covered with a protective layer; generally SnO₂. In potentiodynamic polarization study, the formation of basic salt Sn(OH)Cl was preference to any other oxide in HCl solutions. The increase in NO₂ concentration was responsible for the increase in the rate of dissolution in HNO₃. The tin dissolution in sulphuric acid occurred through an intermediate of (SnHSO₄OH) species.

Introduction

The study of tin is important because tin represents the most widely used metallic material, primarily due to the fact that it can be manufactured relatively cheaply. The main use of tin is in the canning industry, solders, bronze and dental amalgam. It is now possible to characterize at the nanoscale the chemical composition, structure and electronic properties of oxide films that grow on the surface of metals, while keeping them in solution and under potentiostatic control ⁽¹⁾. The kinetics of electrode processes on chemically pure and technical tin in solutions of sulfuric and hydrochloric acids at various temperatures were investigated ⁽²⁾. In both acids, anodic polarization resulted in a film on the Sn electrode. It was dark-brown in H₂SO₄ (apparently SnO₂) and grayish in HCl ⁽³⁾. The rate of corrosion of tin in H₂SO₄ decreased slightly when the acid concentration rose from 0 % to approximately 80 %. Above 80 % acid concentration, the reaction was very vigorous⁽⁴⁾. Under the conditions of anodic behavior and passivation of tin in solutions containing H₃PO₄ acid, normally a SnO₂ film covered the Sn electrode ⁽⁵⁾. Effects on passivation when the solution additionally contains nitric acid or potassium nitrate have also been studied ⁽⁶⁾.

The rate of corrosion in nitric acid attained its maximum value at about 4 M. The slow rate at high acid concentration was attributed to the formation of the stable oxide film ⁽⁷⁾. The rate of corrosion was apparently controlled by the rate of decomposition of the nitrate ions or the diffusion of HNO₃ acid ⁽⁸⁾. Iodides of Na and K retarded the reaction between HNO₃ and Sn. This retardation might be due to the specific action of the alkali ions ⁽⁹⁾. The influence of some organic acids was also studied. In citric and maleic acids the polarization curves exhibit an active /passive transition ⁽¹⁰⁻¹³⁾. The pitting sensitivity of tin in a synthetic medium similar to industrial water was not affected by pH variation ⁽¹⁴⁾. Addition of oxo-anions to the synthetic medium leads to retard a breakdown of passivation and the inhibition of pitting process of tin ⁽¹⁵⁾.

The knowledge of the anodic behavior of tin is therefore of great interest. The present work was mainly concerned with the study of the behavior of tin electrode in different acids solutions.

Experiment

Materials:

The material used in the present study was spectroscopically pure tin rod electrode (99.999 % pure) with an apparent exposed area of 2 cm². Tin rod was fixed to glass tubing with araldite adhesive. The electrical contact was made through a thick copper wire soldered to the inner side of the electrode. Prior to each experiment, the surface of the working electrode was prepared by polishing with different grades emery papers, then diamond paste (1μm), washing by distilled water, drying and quickly inserting it in the cell. For non polished electrode, it was prepared by the same way but after polishing, washing and drying it was left in air for 48 hour then it was inserted in the cell. The counter electrode was a platinum sheet.

Adopted techniques:

I- Open-circuit potential measurements:

The potential of tin electrode was measured in different concentrations of test solutions ranging from (1x10⁻⁵ to 2 M). All measurements were carried out in conventional glass cell at room temperature. The potential was recorded as a function of time till steady state values were observed by using electronic multimeter (Type E scord- EDM-2116). The potentials were recorded relative to a saturated calomel electrode (SCE).

II- Potentiodynamic polarization measurements:

Anodic and cathodic potentiodynamic polarization scans were performed with electronic potentiostatic (Volt Lab PGZ 301 Dynamic EIS Voltammetry). The polarization cell used was multinecked (100 ml) flask. The multiple necks were used to introduce working, auxiliary, reference electrodes and Luggin capillary. All measurements were performed in freshly prepared aerated solutions at room temperature ($25 \pm 2^\circ\text{C}$). The anodic E/I curves for all solutions were swept from -1500 to 1500 mV at scan rate 20 mV/s.

Results And Discussion

I-Open-circuit potential measurements:

(i) Behavior of mechanically polished electrode:

The behavior of tin electrode in different acidic solutions (HCl, HNO₃, H₂SO₄ and H₃PO₄) was studied.

In low concentrations of HCl (10^{-5} to 10^{-3}M), the potential was shifted with time towards more positive values. This was in accordance with Evans⁽¹⁶⁾ where the oxide film was self-healing. In low concentrations, the passivity increased with decreasing concentration, and the potential-time curves are characterized by a rapid rise in potential followed by steady state potential values (E_{SS}). The initial rise in potential was believed to be connected with the anodic removal of adsorbed surface hydrogen as well as with the charging up of the electrical double layer at the metal/solution interface. The steady state portion might be attributed to the formation of stannic oxide SnO₂ on the electrode surface; this increases the resistance of anodic area which led to passivation. However, at higher concentrations of acid solution (10^{-2} to 2M), the potential drifted with time towards more negative values denoting the destruction of the pre-immersion oxide film formed on the surface of the electrode (Figure 1). The same behavior was observed for H₂SO₄ and H₃PO₄ solutions.

In HNO₃ acid solution, curves revealed that the steady state potentials approached from more negative values to the positive direction in all concentrations. The extent of the potential rise depends, primarily on solution concentration, being greater with increasing the acid concentration.

Within the whole test solutions and concentrations, the immersion potential values, E_{im} , lay negative side of the hydrogen/ hydrogen ion electrode system. This may indicate that the nature of the cathodic reaction occurring at the electrode surface is mainly hydrogen ion discharge (Equation 1) and the depolarization effect of oxygen was less manifested.

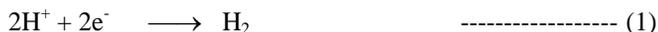


Figure (2) demonstrated the variation of the steady state potentials with the logarithm of the molar concentration of test solutions. Invariably straight lines are obtained according to the equation:

$$E_{ss} = a - b \log C \quad \text{----- (2)}$$

where; (a) and (b) are constants depending on the type of test solutions. In equation 2, (a) represented the potentials of 1 M concentration, being -418, -231, -370, and -429 mV for HCl, HNO₃, H₂SO₄ and H₃PO₄ respectively.

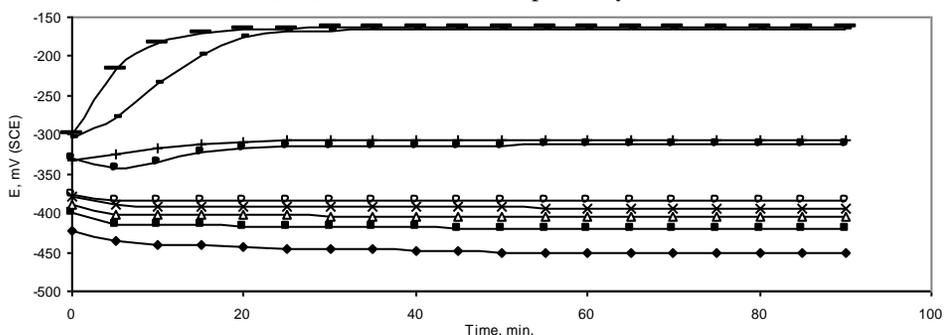
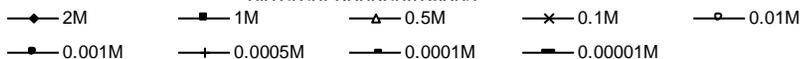


Figure (1): Potential- time curves of tin electrode in HCl solutions of different concentrations



According to the change of the steady state potentials with the logarithmic concentration, the studied acids may be classified into two behaviors. The first one comprised (HCl, H₂SO₄ and H₃PO₄) which retarded the corrosion of tin electrode as the concentration of the acids decreased.

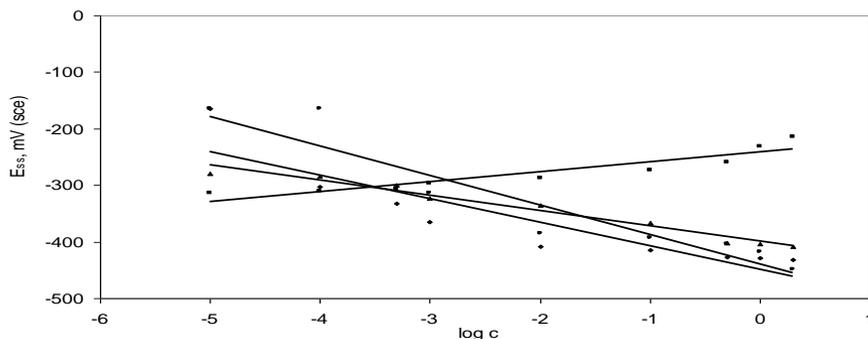
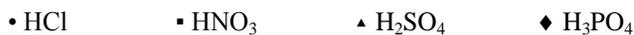


Figure (2): E- logC relations of mechanically polished Sn electrode in different acid solutions



The second behavior belong (HNO_3) acid which accelerate the corrosion as the concentration decreased.

The more negative values of steady state potential, the more aggressive is the corresponding acid. Subsequently the corrosivity of these acids is assumed to increase in the following order: $\text{HNO}_3 < \text{H}_2\text{SO}_4 < \text{HCl} < \text{H}_3\text{PO}_4$

(ii) *Behavior of non polished electrode*

The general features of the potential- time curves for non polished electrode were materially the same as those for mechanically polished electrode but with higher potential values. This behavior was obtained for all acids studied. This may be facilitated by the presence of inner oxide film (SnO_2) due to exposure to air for a long period of time (48 hour) compared with that polished by mechanical way. Also, a linear relation held between the steady state potential and the logarithm of acid concentration (Figure 3). The order of corrosivity was similar to that of mechanically polished electrode.

The immersion potential and steady state potential values for tin electrode in all acidic solutions by using two methods are tabulated in Table (1).

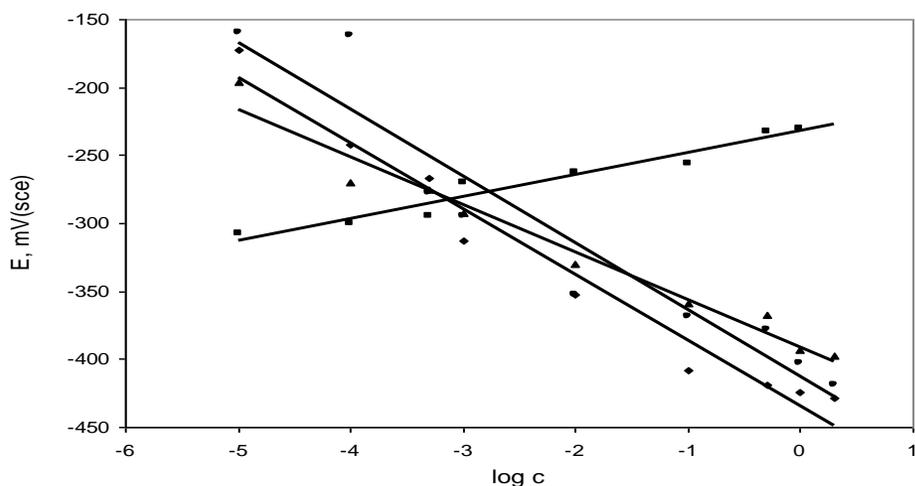


Figure (3): E – log C relations of non polished Sn electrode in different acids solutions

• HCl ▪ HNO₃ ▲ H₂SO₄ ◆ H₃PO₄

(iii) Oxide film thickening

The potential of the tin electrode varied linearly with the logarithm of the immersion time until a steady state potential was attained. The straight lines obtained satisfying the relation ⁽¹⁷⁾:

$$E = \text{Constant} + 2.303 \delta^- / \beta \log t \quad \text{-----} \quad (3)$$

where; t , is the time from the moment of immersion in solution, δ^- , is the rate of oxide film thickening per unit decade of time, and β was given by:-

Table (1): Values of E_{im} . and E_{SS} in mV(SCE) for tin electrode in different acids solutions.

Surface treatment	Conc. M	HCl		HNO ₃		H ₂ SO ₄		H ₃ PO ₄	
		E_{im}	E_{SS}	E_{im}	E_{SS}	E_{im}	E_{SS}	E_{im}	E_{SS}
Mechanically polished electrode	2.0	-423	-448	-225	-215	-405	-408	-428	-431
	1.0	-400	-418	-247	-231	-400	-403	-422	-429
	5×10^{-1}	-390	-404	-274	-260	-394	-402	-420	-427
	1×10^{-1}	-380	-393	-286	-274	-345	-366	-407	-414
	1×10^{-2}	-377	-385	-290	-287	-315	-335	-405	-409
	1×10^{-3}	-330	-314	-310	-296	-298	-323	-398	-365
	5×10^{-4}	-333	-307	-327	-306	-355	-299	-397	-333
	1×10^{-4}	-304	-165	-332	-310	-332	-284	-395	-303
	1×10^{-5}	-300	-164	-336	-314	-322	-280	-302	-164
Non polished electrode	2.0	-401	-419	-200	-105	-388	-398	-405	-429
	1.0	-388	-403	-235	-230	-372	-393	-410	-424
	5×10^{-1}	-360	-378	-248	-232	-352	-368	-408	-419
	1×10^{-1}	-335	-369	-269	-256	-339	-359	-393	-408
	1×10^{-2}	-316	-352	-275	-263	-300	-330	-312	-352
	1×10^{-3}	-301	-295	-290	-270	-315	-292	-332	-313
	5×10^{-4}	-310	-277	-308	-295	-290	-275	-291	-267
	1×10^{-4}	-298	-162	-313	-300	-276	-270	-280	-242
	1×10^{-5}	-295	-160	-334	-308	-232	-196	-220	-172

$$\beta = n F / RT \alpha \delta' \quad \text{-----} \quad (4)$$

Where α was a transference coefficient similar to that encountered in normal electrochemical reactions where ($0 < \alpha < 1$), and δ' was the width of the energy

barrier surrounded by the ion during transfer. Assuming α had the value of 0.5 and δ' equal 1.0 nm, "n" was set equal to 2, then β acquired the value of 39 nm/V. From the slopes of the E – log t relations, the values of δ^- , have been calculated.

The value of the rate of film thickening in case of mechanically polished electrode was increased by decreasing acid concentration in case of HCl, H₂SO₄ and H₃PO₄ while in HNO₃ the rate was increased by increasing the concentration (Table 2). For non- polished electrode, the rate values are not affected regularly by concentration for all acids examined. It is clear that the rate was very high compared with mechanically polished electrode. This may be attributed to the presence of inner oxide film (SnO₂) resulted from long exposure to air.

Table (2): Slopes b in (mV/ log t) of the E vs. log t relations, and the rates of oxide film thickening δ^- in (nm/ log t) of tin electrode in different acidic solutions

Surface treatment	Conc. M	HCl		HNO ₃		H ₂ SO ₄		H ₃ PO ₄	
		b	δ^-	b	δ^-	b	δ^-	b	δ^-
Mechanically polished electrode	2.0	7.20	0.12	14.10	0.23	4.30	0.07	1.44	0.02
	1.0	6.60	0.11	12.80	0.21	4.30	0.07	3.30	0.05
	5x10 ⁻¹	9.60	0.16	6.410	0.10	11.5	0.19	3.30	0.05
	1x10 ⁻¹	11.1	0.18	5.120	0.08	14.2	0.24	4.30	0.07
	1x10 ⁻²	11.1	0.18	3.840	0.06	14.4	0.24	5.70	0.09
	1x10 ⁻³	10.0	0.16	2.560	0.04	30.4	0.51	28.2	0.47
	5x10 ⁻⁴	16.2	0.27	1.280	0.02	35.8	0.60	51.7	0.87
	1x10 ⁻⁴	70.6	1.19	1.280	0.02	38.4	0.64	83.5	1.41
	1x10 ⁻⁵	85.0	1.43	1.280	0.02	42.3	0.71	89.6	1.51
Non- polished electrode	2.0	15.72	266.3	0.44	7.46	6.96	117.8	5.39	91.41
	1.0	3.63	61.55	0.88	14.92	7.01	118.7	5.04	85.48
	5x10 ⁻¹	6.55	110.9	2.64	44.77	5.24	88.85	0.88	14.92
	1x10 ⁻¹	9.87	167.2	0.88	14.92	2.64	44.75	4.51	76.49
	1x10 ⁻²	23.12	391.5	2.18	36.96	12.36	209.4	50.33	852.3
	1x10 ⁻³	3.63	61.55	18.17	307.8	4.82	81.72	21.55	365.1
	5x10 ⁻⁴	17.00	287.9	11.36	192.5	4.40	74.61	1.30	22.03
	1x10 ⁻⁴	119.9	2032	12.93	218.9	6.58	111.5	21.17	358.5
	1x10 ⁻⁵	54.15	916.9	14.27	241.7	6.58	111.5	21.84	396.9

II-Spectroscopic analysis

The morphological changes of tin electrode surface were studied using scanning electron microscope (SEM) and energy dispersive X- ray analysis (EDAX). Figure (4) illustrated the morphology of tin electrode surface before exposure to corrosion media (Blank). The specimens were subjected to microscopic examination at x 1000.

The photo-micrographs obtained for the specimen in (1 M) nitric acid with polishing and non-polishing surface treatment are illustrated in Figures (5 and 6). In the two cases, the surface was subjected to three different microscopic examinations at x500, x1000 and x 1500. It is evident from SEM image that, there were grain boundaries and the surface was more active and rougher in case of mechanically polished electrode. While in non-polished electrode the surface is covered with a protective layer, generally SnO_2 .

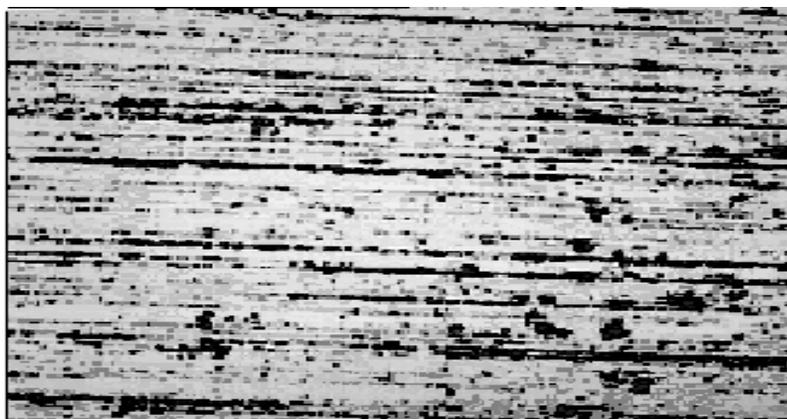


Figure (4): SEM micrograph of tin electrode (Blank) (X 1000)

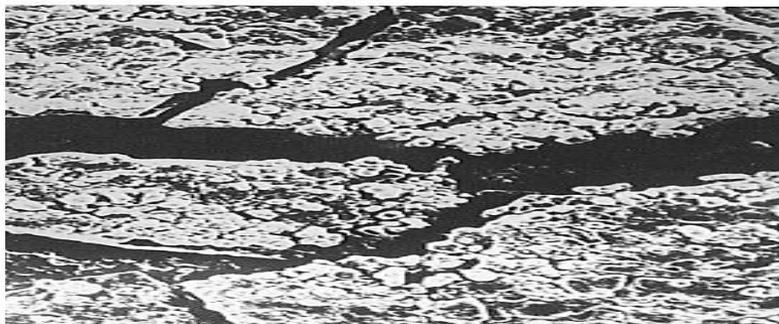


Figure (5): SEM micrograph of polished tin electrode in 1 M HNO_3 (X 1000)

The EDAX spectra of tin electrode in (1 M) of different acids solutions showed that the elements presented on the surface of tin electrode are Sn, O₂, S, P and Cl (Table 3). The higher percentage of oxygen in case of nitric acid may be due to the adsorption of NO₂ on the tin surface. While, in other media the electrode surface is covered with unstable complex compound.

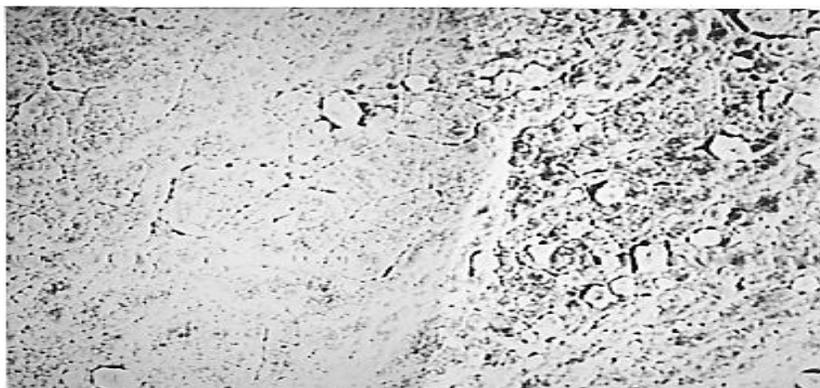


Figure (6): SEM micrograph of non- polished tin electrode in 1 M HNO₃ (X 1000)

Table (3): The percentage of the elements presented on the surface of tin electrode in different acids solutions

Medium	Sn %	O ₂ %	S %	P %	Cl %
HCl	87.73	10.73	—	—	1.54
HNO ₃	58.98	40.73	—	—	—
H ₂ SO ₄	83.52	16.33	0.15	—	—
H ₃ PO ₄	62.79	30.09	—	7.18	—

III- Potentiodynamic polarization measurements

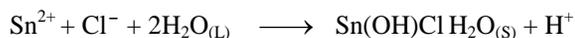
(a)- Behavior of tin electrode in hydrochloric acid

Figure (7) showed potentiodynamic polarization curves of tin electrode in various concentrations of HCl in the potential ranging from -1500 to 1500 mV vs. SCE at scan rate of 20 mV/s.

The passivation produced by hydrochloric acid solution is probably due to formation of a basic salt, Sn(OH)Cl⁽¹⁸⁾. The concentration of the acid played a part; when the dilution increased, there is a rapid rise in the critical potential (above

which the regular dissolution of the metal ceases and the current density falls abruptly)⁽¹⁸⁾, which can be attributed, in case of the halogen acid to that, the tendency for insoluble basic salt to be formed diminishes as the dilution increases. The two beaks of $(10^{-2} - 10^{-5})\text{M}$ with maximum reflected points that appeared at $E \approx 0.35\text{V}$ correspond to passive potential domain E_p considering $\text{Sn}(\text{OH})_2$ & $\text{Sn}(\text{OH})_4$ formation⁽¹⁹⁾, in presence of Cl^- the basic chloride salt is preference. The passivation phenomenon is accompanied by a darkening of the electrode. This is caused either through an irregular attack by the solution giving rise to finely divided metal, or through the appearance of impurities in the tin electrode.

By establishing a potential- pH diagram representing the equilibrium potentials of the systems Sn/SnO , Sn/SnO_2 and $\text{Sn}/\text{Sn}(\text{OH})\text{Cl}$, Hoar⁽²⁰⁾ reported that, the basic salt $\text{Sn}(\text{OH})\text{Cl}$ is formed in preference to any other oxide when the pH is below 2.5. Under these conditions, the passivation film will be constituted partially of basic salt and at a lower potential constituted entirely of oxide. Accordingly, the development of a dense tin oxy chloride film occurred by the reaction⁽²⁰⁾:



This reaction involved the following steps:

- a- Adsorption of Cl^- on the oxide/ solution interface in competition with OH^- or H_2O molecules for surface sites on the hydrated oxide surface.
- b- Formation of the basic tin- hydroxy chloride salt with tin oxide cations on the hydrated oxide surface⁽²⁰⁾.

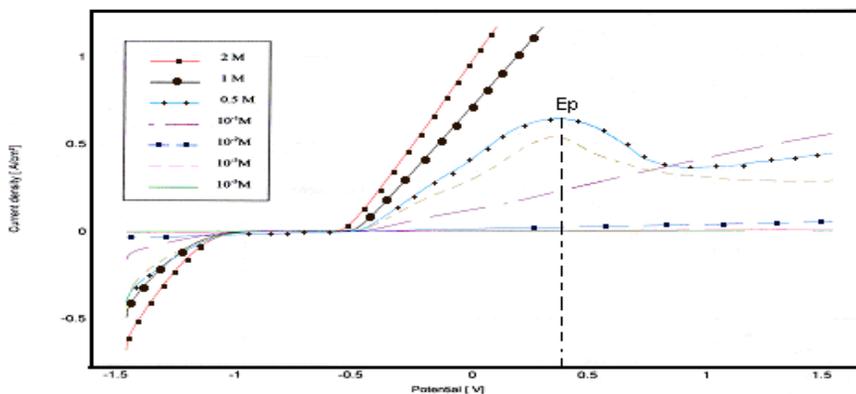


Figure (7): Potentiodynamic anodic and cathodic polarization curves of tin electrode in different concentrations of HCl acid solutions

(b)- Behavior of tin electrode in nitric acid

A cathodic minimum, which increased in depth by increasing the acid concentration, is observed in all concentrations of HNO₃ solution (Figure 8). The rate of anodic dissolution is very slow at low acid concentrations and increased considerably with increasing concentration.

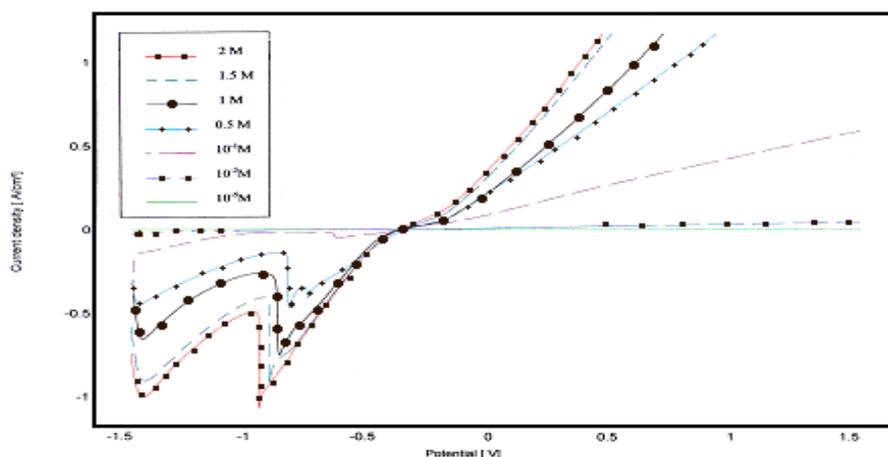
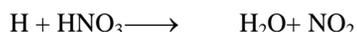


Figure (8): Potentiodynamic anodic and cathodic polarization curves of tin electrode in different concentrations of HNO₃ acid solutions

Mechanism for dissolution of tin in nitric acid solutions is assumed to take place according to an autocatalytic mechanism involving the formation of HNO₂. The primary process is the displacement of H⁺ from the solution,



The nitrogen dioxide produced would be adsorbed on the metal surface where it would be reduced according to,



This reaction would be followed by,



At high acid concentrations the undissociated HNO₂ will react with HNO₃.



In this mechanism two (NO_2) molecules are produced while one is consumed. This increase in NO_2 concentration was responsible for the increase in the rate of dissolution.

(c)- Behavior of tin electrode in sulphuric acid

The E– I curves of Figure (9) illustrated clearly that the current increased sharply by increasing the potential at high concentrations of acid. In low concentrations, the current increased smoothly by increasing potential to the limiting current corresponding to the passive region. With respect to (H^+) and (SO_4^{2-}) ions, it was suggested that (SO_4^{2-}) ion participated in the tin dissolution reaction. In sulphuric acid solutions, the Sn^{2+} ion forms complex anions.

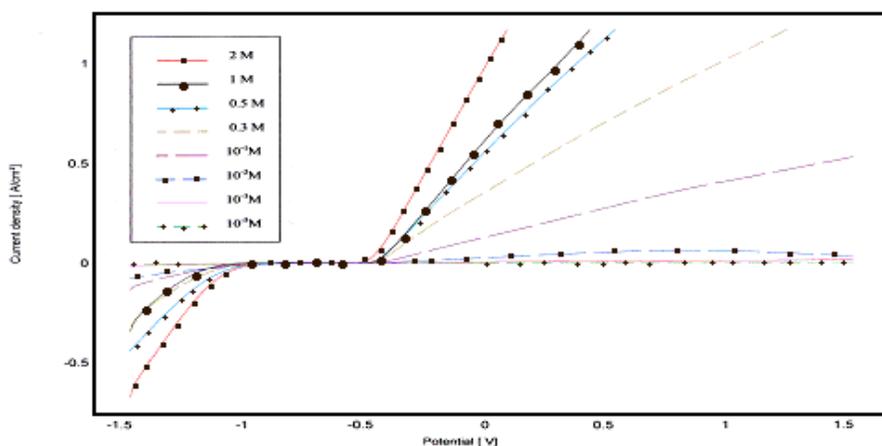
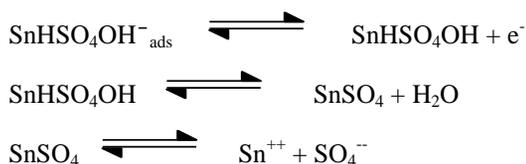


Figure (9): Potentiodynamic anodic and cathodic polarization curves of tin electrode in different concentrations of H_2SO_4 acid solutions

There is some dispute about the nature of these anions. Both $\text{Sn}[\text{Sn}(\text{SO}_4)_2]$ and $\text{H}_2\text{Sn}_2(\text{SO}_4)_3$ groups have been proposed. Another authors⁽²¹⁾ proposed $\text{Sn}(\text{OH})^+$ ion and $[\text{Sn}(\text{OH})\text{SO}_4]^-$ complexes. There are an equilibrium between Sn^{2+} and $[\text{Sn}(\text{OH})_4]^{2-}$ in dilute sulphuric acid⁽²²⁾. These results indicated that both OH^- and sulphate groups could interfere with the electrode reaction.

The reaction scheme for anodic tin dissolution can be given as⁽²³⁾:





From the above reactions, it can be concluded that the tin dissolution in sulphuric acid occurs through the participation of both OH^- and SO_4^{--} ions through an intermediate of $(\text{SnHSO}_4\text{OH})$ species⁽²³⁾.

(d)- Behavior of tin electrode in phosphoric acid

When the potential is raised, dissolution of tin electrode take place and then the current started to oscillate followed by the appearance of anodic peak (Figure 10). The peak potential (E_p) did not occur significantly in 10^{-5} M or in 10^{-3} and 10^{-2} M solution. Whereas increasing concentration enhanced the height of the peaks and their potential shifted towards negative values. These observations can be explained by the formation of soluble phosphate complex ions such as $\text{Sn}(\text{HPO}_4)_2^{2-}$ or $\text{Sn}(\text{H}_2\text{PO}_4.\text{HPO}_4)$ ⁽²⁴⁾.

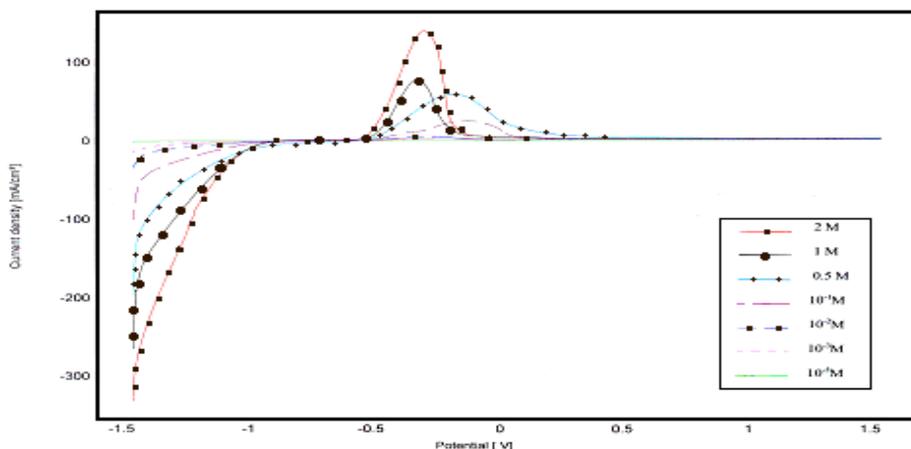
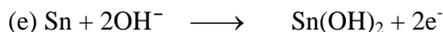
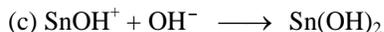
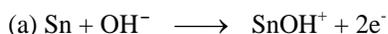


Figure (10): Potentiodynamic anodic and cathodic polarization curves of tin electrode in different concentrations of H_3PO_4 acid solutions

The current oscillations are weak and generally disappear in dilute solutions. This phenomenon is consistent with the formation of oxides of higher valences and oscillatory behavior is observed as a result of transition between the different states of over passivity.

The following reactions are proposed to account for the oxidation behavior of tin electrode in phosphoric solution ⁽²⁵⁾:



Reactions (a) and (b) accounted for the formation of soluble products. The formation of the passive film seemed to occur by reactions (c), (d) and (f). As an alternative to (c), reaction (e) was proposed which accounted for the direct formation of stannous hydroxide from tin electrode. Analysis of the anodic layer suggested that Sn(OH)_2 or (SnO) and Sn(OH)_4 or SnO_2 is present on the electrode surface at the beginning of the polarization.

Table (4) illustrated the electrochemical parameters calculated from Tafel relations in different acid solutions. Decreasing concentrations of the studied acids led to decrease of the corrosion rate (except for HCl). Also the corrosion potential shifted to more positive values but at lower concentrations of nitric acid, decreasing concentration would shift E_{corr} towards more negative values. It was also noted that the values of corrosion rate of nitric acid were very high compared with other studied acids indicating the high corrosivity of nitric acid under potentiodynamic conditions.

Table (4): The electrochemical parameter of tin electrode in different acid solutions and concentrations

Solution	Conc. M	$E_{\text{corr.}}$ mV(SCE)	$i_{\text{corr.}}$ mA/cm ²	Tafel Slopes (mV/ decade)		Corrosion rate mm/y
				B_c	B_a	
HCl	2.0	-911.7	0.422	126	-101.9	5.017
	1.0	-907.9	0.524	208	-136.0	8.590
	0.5	-881.9	0.554	289	-127.4	6.577
	0.3	-876.6	0.463	165	-129.1	5.494
	1x10 ⁻¹	-623.5	0.624	467	-146.4	7.412
	1x10 ⁻²	-477.5	1.460	318	-327.4	17.41
	1x10 ⁻³	-437.7	1.590	350	-338.8	18.962
1x10 ⁻⁵	-436.0	1.510	341	-319.0	18.992	
HNO ₃	2.0	-453.2	53.27	324	-329.2	632.1
	1.5	-401.2	29.76	311	-209.0	353.1
	1.0	-390.0	23.61	292	-198.7	280.2
	0.5	-369.6	17.07	284	-181.5	202.5
	1x10 ⁻¹	-391.2	16.74	407	-531.2	198.6
	1x10 ⁻²	-484.8	0.913	470	-578.7	10.83
	1x10 ⁻⁵	-531.5	0.274	358	-451.7	3.257
H ₂ SO ₄	2.0	-979.0	0.700	153	-104	7.98
	1.0	-970.6	0.660	426	-123	7.920
	0.5	-843.4	0.300	131	-114	3.563
	0.3	-824.0	0.300	274	-125	3.400
	1x10 ⁻¹	-563.4	0.330	63.0	-685	3.922
	1x10 ⁻²	-517.0	0.310	125	-420	3.680
	1x10 ⁻³	-486.9	0.274	292	-113	3.631
1x10 ⁻⁵	-474.0	0.195	400	-328	2.319	
H ₃ PO ₄	2.0	-889.7	0.799	206.4	-138.8	9.488
	1.0	-876.7	0.753	217.1	-144.0	8.943
	0.5	-587.3	0.796	96.20	-423.0	9.450
	1x10 ⁻¹	-585.2	0.357	114.0	-746.0	4.230
	1x10 ⁻²	-587.4	0.349	171.0	-883.0	4.140
	1x10 ⁻³	-567.0	0.340	265.6	-326.0	4.059
	1x10 ⁻⁵	-536.0	0.170	345.5	-330.0	0.208

Conclusion

From the aforementioned results of open circuit potential measurements it could be concluded that depending on steady state potential values the corrosivity of acids used for mechanically polished and non- polished electrodes was assumed to increase in the following order: $\text{HNO}_3 < \text{H}_2\text{SO}_4 < \text{HCl} < \text{H}_3\text{PO}_4$.

Potentiodynamic techniques revealed that, tin electrode might be safely used in low concentrations of H_2SO_4 and H_3PO_4 acids (10^{-1} to 10^{-5}M) where the corrosion rate was low. At high concentrations it could be protected. In HCl acid the metal reflex its behavior, consequently it may be used safely at high concentrations (0.3 to 2M) only. HNO_3 registered very high corrosion rate at all concentrations due to increase in NO_2 concentration.

References

1. ISMAEL DIEZ- PEREZ, FAUSTO SANZ AND PAU GOROSTIZA; Current Opinion in Solid state and Materials Science, 10 (3-4) pp. 144 (2007).
2. HIKOZÔ ENDÔ AND GORÔ YOKOYAMA; Science Repts. Research Insts., Ser. A 2 pp. 449 (1950).
3. V. A. KHITROV AND V. I. SHATALOVA; (Teachers Inst. Voronezh), Zhur. Priklad Khim., 34 pp. 2106 (1961).
4. HIKOZÔ ENDÔ AND GORÔ YOKOYAMA; Science Repts. Research Insts., Ser. A 2 pp. 456 (1950).
5. D. W. JONES; J. Soc. Chem. Ind., 47 pp. 161 (1928).
6. A. RAGHEB AND L. A. KAMEL; Corrosion, 18 pp. 153 (1962).
7. AL-SUHYBANI AND A. ABDULAZIZ; Surf. Coat. Technol., 34(4) pp. 463 (1988).
8. HIKOZÔ ENDÔ AND GORÔ Yokoyama; Science Repts. Research Insts., Ser. A 2 pp. 637 (1950).
9. F.OTTWATER; Mater.Protect.,4 (11) pp. 65 (1965).
10. K. GAMAL GOMMA; Energetics Chemistry Earth Environmental and Biomedical Problems, 50(1- 3) pp. 39 (1995).

11. C. M. ALMEIDA, T. RABOCZKAY AND B. F. GIANNETTI; *Journal of Applied Electrochemistry*, 29 (1) pp.123 (1999).
12. S. S. ABD EL-REHIM, S. M. SAYYAH AND M. M. EL- DEEB; *Materials Chemistry and Physics*, 80 (3) pp.696 (2003).
13. S. S. ABD EL-REHIM, H. H. HASSAN AND F. N. MOHAMED; *Corrosion Science*, 46 (5) pp. 1071 (2004).
14. E.H. AIT ADDI, L. BAZZI, M. ELHILALI, ZINE EL-ALAMI, R. SALGHI, AND EL-ISSAMI SOUAD; *Canadian Journal of Chemistry*, 81(4) pp. 297 (2003).
15. E.H. AIT ADDI, L. BAZZI, M. ELHILALI, R. SALGHI, B. HAMMOUTI AND M. MIHIT.; *Applied Surface Science*, 253(2) pp. 555 (2006).
16. U. R. EVANS; "An Introduction to Metallic corrosion", third Edition, Edward Arnold, London (1981).
17. J. M. ABD EL-KADER AND A. M. SHAMS EL-DIN; *BR. CORROSION J.*, 14 (1) pp. 40 (1979).
18. R. STEINHERZ; *Ueber Passives Zinn, Z. Elektroch* , 30 pp. 279 (1924).
19. BOURBAIX pp. 479 (1974).
20. T. P. HOAR; *Trans. Faraday Soc.*, 33 pp. 1152 (1937).
21. G. GORDON AND C. H. BRUBAKER; *J. Am. Chem. Soc.*, 82 pp. 4448 (1960).
22. T. ITO AND M. ABE; *KOGYO Kagaku Zasshi*, 63 pp. 1699 (1960).
23. M. Natesan and S. Venkatakrisna Iyer; *Key - Engineering-Materials*, (20-28) pp. 531 (1988).
24. S. A. AWAD AND A. KASSAB; *J. Electroanal. Chem.*, 20 pp. 203 (1969).
25. H. DO DUC AND P. TISSOR; *Corrosion Science*, 19 pp. 179 (1979).