Electrodeposition Of Copper In Presence Of Carbohydrates

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ABSTRACT

The rate of electrodeposition of copper plates was determined by measuring cathodic limiting current in absence and in presence of carbohydrates as(Glucose, fructose, mannose, sucrose, lactose and maltose). It is found that the rate of electrodeposition decreases in presence of organic additives by amount ranged from 1.89% to 35.85% depends on the types of additives and their concentrations. The investigated adsorption isotherm indicates that the inhibition fits to the Langmuir adsorption isotherm and Flory -Huggins adsorption isotherm. It is found that the rate of electrodeposition decreases by increasing height and $CuSo_4$ concentrations. Thermodynamic parameters are given and show that electrodeposition process is diffusion controlled. The rate of deposition and its equations are represented as: $Sh=9.784\ Re^{0.5017}\ Sc^{0.33}$ for Glucose with an average deviation: $\pm0.0119\%$, $Sh=9.790\ Re^{0.5017}\ Sc^{0.33}$ for Fructose with an average deviation: $\pm0.0226\%$, $Sh=9.786\ Re^{0.5017}\ Sc^{033}$ for Mannose with an average deviation: $\pm0.0621\%$, $Sh=9.790\ Re^{0.5016}\ Sc^{0.33}$ for Sucrose with an average deviation: $\pm0.0234\%$, $Sh=9.790\ Re^{0.5016}\ Sc^{0.33}$ for Lactose with an average deviation: $\pm0.0075\%$, $Sh=9.799\ Re^{0.5016}\ Sc^{0.33}$ for Maltose with an average deviation: $\pm0.0126\%$ © 2007 Trade Science Inc. - INDIA

INTRODUCTION

Metals are deposited in a very rough or powdery form, when the electrolysis is carried out at limiting current. This seems to be a rather general rule[1] in the case of copper.

The possibility preventing powder formation at the limiting current by means of suitable additives is of interest electroplating[2] and electrometallurgy in general.

Some organic substances are used as additives in electroplating, electrowinning and electroforming to improve the quality of electrodeposit, since produce fine grained smooth bright deposit. Although the exact mechanism by which, the organic compound or surface active substance(SAS) added to improve the quality of the electrodeposit is not known, there is a consensus that adsorption of those substances on the metal is involved, where adsorption of those organic compounds on the

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cathode surface may block a part of the active electrode area and therefore reduce the limiting current.

In modern electrodeposition practice, it is well known that the addition of even small amounts of certain substances leads to significant changes in the properties and aspect of the deposit. Recent reviews have tried to summarize their different effects. Levelers have the ability to produce deposits relatively thick in small recesses and relatively thin on small prolusions. They act by adsorption at points where otherwise there would be a rapid deposition of the metal[3-8].

Previous studies have shown that SAS reduced the limiting current of uranium[9] and manganese[10] deposit from phosphoric acid and mercury cathode.

The object of this work is to study the effect of carbohydrates as(Glucose, fructose, mannose, sucrose, lactose and maltose) on the rate of electrodeposition . The effects of temperatures were also studied.

EXPERIMENTAL

Chemicals

Analar grade $CuSO_4 \cdot 5H_2O$ and $H_2SO_4(98\%w/w)$, supplied by BDH Chemicals Ltd., were used for the preparation of the electrolytes. Analar grade(Glucose, fructose, mannose, sucrose, lactose and maltose.) supplied by BDH chemicals ltd., were used as organic additives.

Cell and electrical circuit

Using rectangular electrode figure 1(a)

The cell consisted of a rectangular plastic container $(5.1 \times 5 \times 10cm)$ with electrodes fitting the whole cross section area. The cathode was rectangular copper sheet (10cm height and was 5cm width); the anode was copper sheet with an inter-electrode distance was 5cm. The electrical circuit consists of(6V D.C). Power supply connected in series with cell along and rheostat and(multi-range digital ameter). A voltameter is connected in parallel with the cell to measure the voltage.

Using rotating electrode figure 1(b)

The cathode consisted of copper metal cylinder (1cm) diameter and 10cm length. The unexposed area of the cylinder was covered by epoxy resin. The anode is made of cylindrical copper metal counter electrode

of 12cm diameter; it's acted as the reference electrode by virtue of its high surface area compared to that of cathode.

Measurement

Glvanostatic polarization curves, from which the limiting current was determined, were constructed by increasing the current stepwise through sliding the rheostat handle towards a lower resistance and measuring the steady state cathode potential against copper references electrode. The copper references electrode was $1cm^2$ copper sheet, which have the same composition of the cathode material, placed in the cup of luggin tube whose tip was placed at about 1mm far from the cathode surface. To avoid any erroneous readings of the voltage, the values of the limiting current were taken at constant value of the potential.
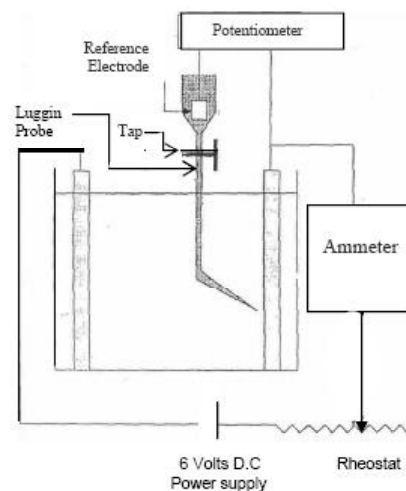

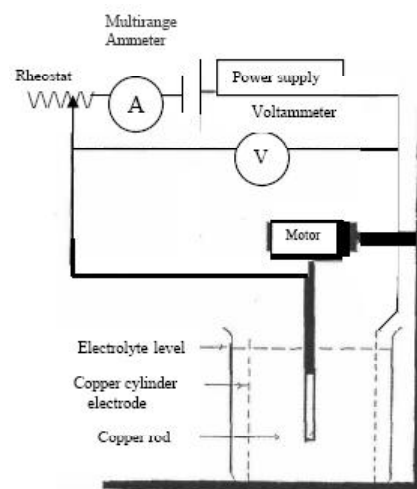**Figure 1(a) : The electric cell and circuit.**

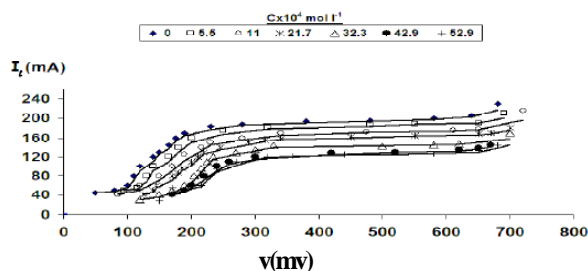**Figure 1(b) : The rotating cylinder electrode(RCE)**

Figure 2 : Effect of different concentration of glucose on limiting current at 298K in case of Cu-Cu
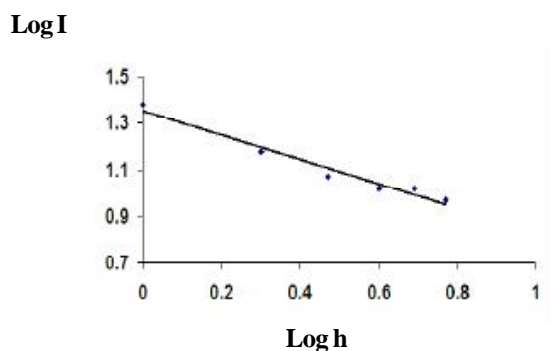

Figure 3 : The effect of different heights on the limiting Current density at 298k

At the beginning, the bake of the cathode and anode were coated with epoxy resin except at contact with the feed wires; electrode treatment before each run was similar to that previously reported in literature[11,12].

RESULTS AND DISCUSSION

TABLE 1 and figure 2 show the cathodic polarization curve for copper electrodeposition from sulphate solution under the influence of adding different amounts of glucose. It is obvious that in the organic free solution, the current, first increases linearly, then tends to exhibit limiting current plateau with increasing the cathodic potential.

Effect of electrode height on the limiting current

shows the effect of the electrode height on the limiting current. The limiting current density decreases with increase the height. In electrodeposition and generally for cathodic deposition of metals, the direction of flow of the hydrodynamic boundary layer is downwards, the thickness of the hydrodynamic boundary layer and the diffusion layer increases in the downward direction, i.e., the resistance to mass transfer increases in the

TABLE 1 : Limiting current of different organic compounds (mA) at different temperatures

Organic compounds	$C \times 10^4$ mol. l^{-1}	25^{0}C	30^{0}C	35^{0}C	40^{0}C
1. Glucose	0.000	190	265	300	330
	5.500	185	260	295	325
	11.00	175	250	280	320
	21.70	160	240	265	270
	32.30	140	230	250	255
	42.70	130	225	235	240
	52.90	130	215	220	225
2. Fructose	0.000	190	265	300	330
	5.500	190	230	265	300
	11.00	185	225	260	290
	21.70	180	200	250	280
	32.30	170	190	245	250
	42.70	165	180	235	245
	52.90	155	175	210	230
3. Mannose	0.000	190	265	300	330
	5.500	190	250	290	310
	11.00	185	240	285	295
	21.70	185	225	260	275
	32.30	175	220	250	260
	42.70	170	215	230	240
	52.90	160	210	220	230
4. Sucrose	0.000	190	265	300	330
	2.900	185	255	295	320
	5.700	185	240	280	300
	11.40	180	230	275	285
	17.00	170	225	265	270
	22.40	160	215	260	265
	27.80	145	205	240	245
5. Lactose	0.000	190	265	300	330
	8.720	185	250	280	290
	17.37	180	240	265	270
	34.39	175	220	240	260
	51.09	170	205	230	250
	67.47	170	190	215	240
	83.54	165	170	210	220
6. Maltose	0.000	190	265	300	330
	2.900	190	255	290	320
	5.700	185	245	280	310
	11.40	185	240	275	290
	17.00	180	215	260	270
	22.40	175	210	245	255
	27.80	170	200	230	250

downward direction, accordingly, the local limiting density increases in the upward direction of the anode. This explains why electrodeposition attained at the upper parts of the electrode before the lower parts at the limiting current region. This was confirmed by visual observation during electrodeposition. The average limiting current density decreases with the increase in the height according to the equation:
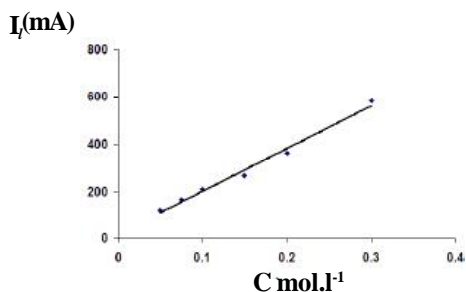
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Figure 4 : The effect of different concentration of CuSO$_4$ on the limiting current at 303K

TABLE 2 : Effect of organic compounds on the% inhibtion of limiting current at 303K

Organic compounds	$C \times 10^4$ mol. l^{-1}	(I_l) Org.	% Inhibition
	Copper anode(I_l) blank=265		
1. Glucose	5.500	260	1.886
	11.00	250	5.660
	21.78	240	9.433
	32.36	230	13.21
	42.73	225	15.09
	52.91	215	18.87
2. Fructose	5.500	230	13.21
	11.00	225	15.09
	21.78	200	24.53
	32.36	190	28.30
	42.73	180	32.08
	52.91	175	33.96
3. Mannose	11.00	250	5.660
	22.00	240	9.433
	43.57	225	15.09
	64.72	220	16.98
	85.47	215	18.87
	105.8	210	20.76
4. Sucrose	2.90	255	3.773
	5.70	240	9.433
	11.4	230	13.21
	17.0	225	15.09
	22.4	215	18.87
	27.8	205	22.64
5. Lactose	8.720	250	5.660
	17.37	240	9.434
	34.39	220	16.98
	51.09	205	22.64
	67.47	190	28.30
	83.54	170	35.85
6. Maltose	2.900	255	3.774
	5.700	245	7.547
	11.40	240	9.434
	17.00	215	18.87
	22.40	210	20.76
	27.80	200	24.53

$$\text{I}=C/h^{0.3 \pm 0.01} \tag{1}$$

Where C is constant, h is the height and(I) is the limiting current density.

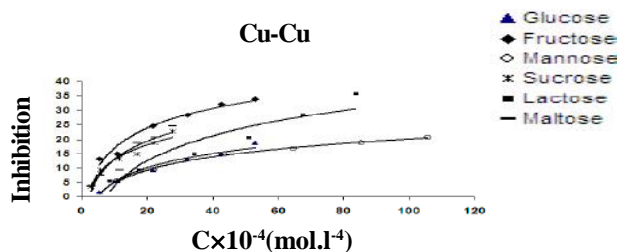## Effect of concentration of CuSO$_4$ on the limiting current

Figure 5 : The relation between % Inhibition and concentration for different organic compounds at 303

Figure 4 gives the effect of copper sulphate concentration on the limiting current. It is obvious that I_l increases as copper sulphate concentration increases. Increasing the CuSO$_4$ content in the bath decreases the cathodic polarization and increases the limiting current plateau. These results were expected due to an increase in the relative abundance of the uncomplexed Cu^{2+} ions in the solution[13,14].

Effect of organic substance on the limiting current

The limiting current in absence of organic compound (I_b) and in presence of organic compound (I_{org}), is related to the percentage of inhibition by the equation:

% Inhibition=$[(I_b - I_{org})/I_b] \times 100$ (2)

TABLE 2 and figure 5 show that the percentage inhibition caused by organic compounds ranges from 1.89% to 35.85% for cell using copper anode.

The percentage inhibition was calculated from equation 2 depending on the concentration and type of inhibitor. It is observable that percentage inhibition increased as concentration increased. The order of inhibition was as follow(Fructose>glucose>mannose) for monosaccharide,(Maltose>sucrose>lactose) for disaccharide.

The obtained results show that the presence of organic compound has an inhibiting effect on the kinetics of the copper discharge process, pointed out by the decrease of the exchange current density. The inhibition enhancing due to increasing the organic compound concentration could be related to the strong adsorption of organic compound constituents on the copper electrode surface, which is in agreement with the decay of the current intensity observed on the polarization curves.

The presence of organic compound changes the mechanism of the copper electrodeposition as it can be seen from the decreasing of the cathodic transfer coef-

ficient. A possible explanation for this fact consists in the increasing role of an additional reaction that produces the same chemical species Cu^+ as those involved in the rate determining reaction[15].

Adsorption isotherm

The electrochemical processes on the metal surface are likely to be closely related to the adsorption of the inhibitor[16] and the adsorption is known to depend on the chemical structure of the inhibitor[17-19]. The adsorption of the inhibitor molecules from aqueous solutions can be regarded as(quasi-substitution) process[17] between the organic compound in the aqueous phase,$(org._{(aq)})$ and water molecules at the electrode surface,$(H_2O_{(s)})$.

$$Org_{(aq)}+\times H_2O=Org_{(s)}+\times(H_2O) \qquad (3)$$
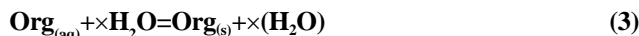
Where x(the size ratio) is the number of water molecules displaced by one molecule of organic inhibitor.

Adsorption isotherms are very important in determining the mechanism of organo-electrochemical reactions. The most frequently used isotherms are those of langmuir, frumkin, parsons, temkin, flory-huggins and bockris-swinkels[20-23]. All these isotherms are of the general form:

$$f(\theta,x) \exp(-a\theta)=K \, C \qquad (4)$$

Where $f(\theta,x)$ is the configuration factor depends essentially on the physical model and assumptions underlying the derivation of the isotherm[24]. The mechanism of inhibition of reaction is generally believed to be due to the formation and maintenance of a protective film on the metal surface[25]

Inhibitor adsorption characteristics can be estimated by using the Langmuir isotherm given as[26]:

$$K \, C=\theta/1-\theta \qquad (5)$$

Where K is the equilibrium constant of adsorption process, C is the concentration and θ is the surface coverage.

The degree of surface coverage(θ) at constant temperature was determined from[27]

$$\theta =(I_b-I_{org})/I_b \qquad (6)$$

A plot of$(\theta/1-\theta)$ vs(C) should yields straight line, Figure 6 shows straight line indicating that all the inhibitors verify Langmuir adsorption isotherm.

Figures 7 show the flory-huggins adsorption isotherm plotted as log θ/C vs. log(1-θ) for $CuSO_4 / H_2SO_4$ organic compounds 303K yield a straight line with slope x and intercept log xK. TABLE 3 shows the values of x
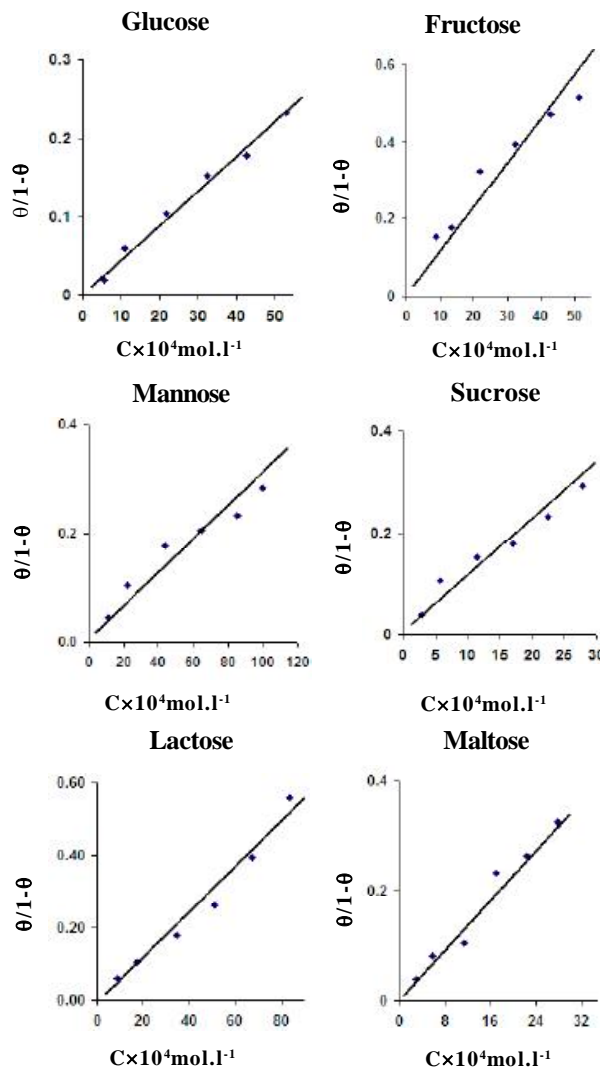
Figure 6 : The relation between(θ/1-θ) against(C) for different organic compounds at 303K

and K, The experimental data fits the Flory-Huggins adsorption isotherm which represented by:

$$log \, \theta/C=log \, x \, K+x \, log(1- \theta) \qquad (7)$$

Here x is the number of water molecules replaced by one molecule of the inhibitor. It is clear that the surface coverage data are useful for discussing adsorption characteristics. The adsorption of inhibitors at metal-solution interface may be due to the formation of either electrostatic or covalent bonding between the adsorbates and the metal surface atoms[28].

The free energy of adsorption ΔG_{ads}. at different concentrations was calculated from the equation[29]:

$$\Delta G_{ads}=- RT \, In(55.5 \, K) \qquad (8)$$

The value 55.5: is the concentration of water in the

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TABLE 3 : Values of K, X and $\Delta G_{ads.}$ of different organic compounds to langmuir, flory-huggins and free energy

Organic compounds	Langmuir K	Flory - Huggins	
		X	K
1. Glucose	42.54	2.52	22.79
2. Fructose	80.49	3.99	84.81
3. Mannose	20.45	5.59	13.40
4. Sucrose	91.99	2.35	61.13
5. Lactose	64.07	1.23	52.03
6. Maltose	116.5	1.70	85.49

Organic compounds	Langmuir	Flory-Huggins
	$-\Delta G_{ads}$ (kJ. mol $^{-1}$)	$-\Delta G_{ads}$ (kJ. mol $^{-1}$)
1. Glucose	19.242	17.697
2. Fructose	20.823	20.952
3. Mannose	17.428	16.381
4. Sucrose	21.153	20.972
5. Lactose	20.258	19.741
6. Maltose	21.738	20.972

solution.

The values of $(\Delta G_{ads.})$ are given in TABLE 3. In all cases; the $(\Delta G_{ads.})$ Values are negative and lie in the range of -14.525 to -21.791kJ/mol. The most efficient inhibitor shows the most negative $(\Delta G_{ads.})$ value. This suggests that they are strongly adsorbed on the metal surface. The negative values of $(\Delta G_{ads.})$ indicate the spontaneous adsorption of the inhibitor. This usually characteristic of strong interaction with metal surface It is found that the $(\Delta G_{ads.})$ values are more positive than -40kJ/mol indicating that inhibitors are physically adsorbed on the metal surface. Similar results have also been reported by Talati et.al[30].

Effect of stirring and applications of dimensional analysis

The effect of the speed of rotation on the rate of metal deposition can also be used to determine whether the electrodeposition process is diffusion or chemically controlled process. If the rate of electrodeposition increases by the speed of rotation, then the reaction is diffusion controlled. However, If the rate of electrodeposition is independent of rotation, so the reac-
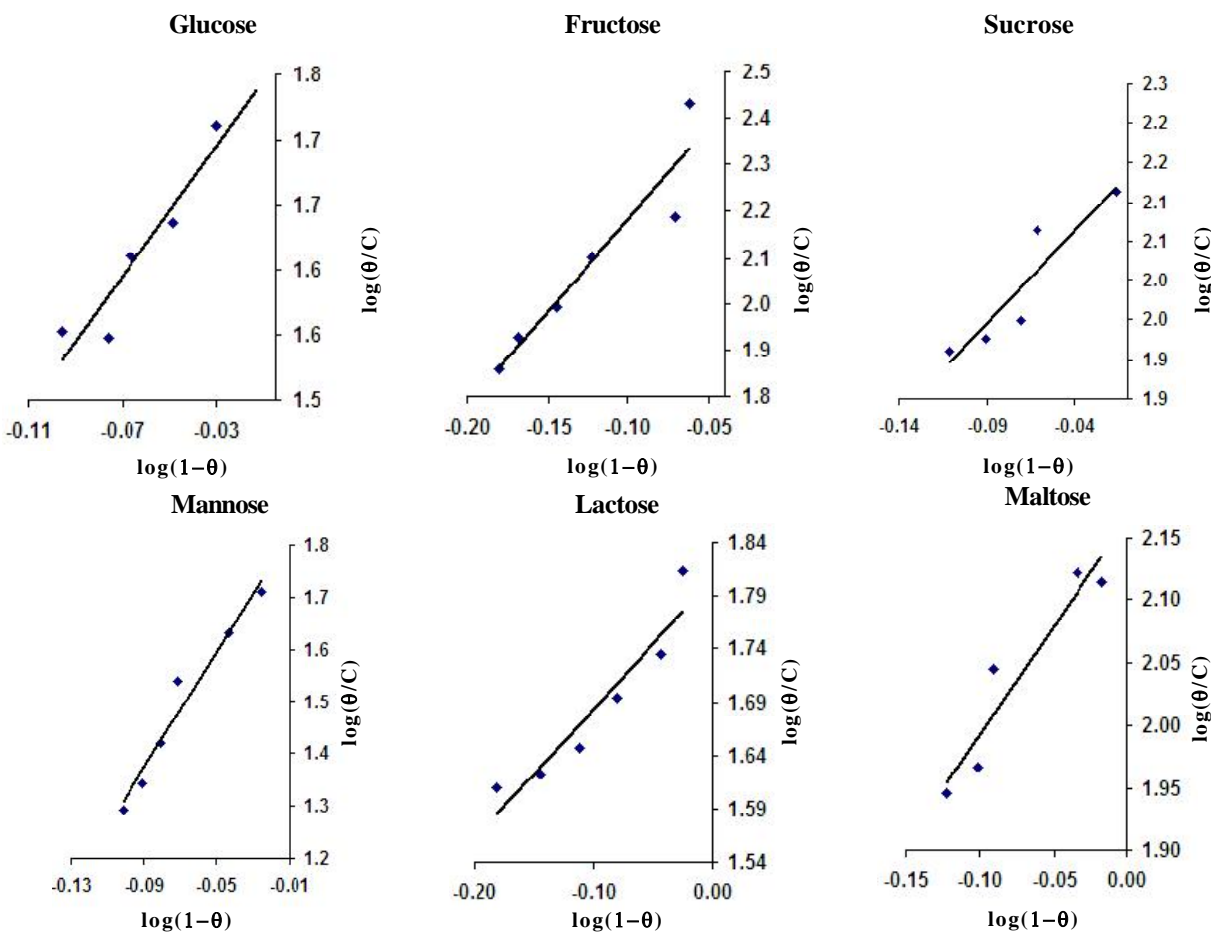

Figure 7 : The relation between log(θ/C) against log(-θ) for different organic compounds at 303K
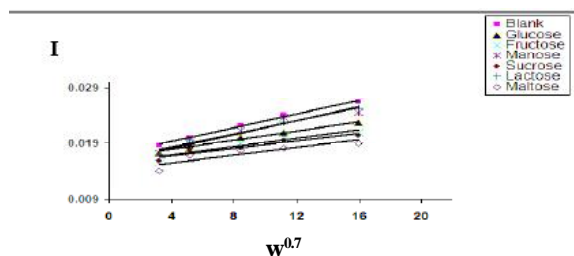
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Figure 8 : The relation between I and $\omega^{0.7}$ for all organic compounds with cylinder at 308K

tion is likely chemically controlled. The angular velocity ω is given by:

$$\omega=(2\pi \text{ rpm})/60 \tag{9}$$

Figure 8 gives the relation between the limiting current density I and the angular velocity(ω) to the power 0.7 at different concentrations of organic substance at 35^0C. Straight lines were obtained and the limiting current density increases by increasing the rotation which indicates that electrodeposition reaction of copper is a diffusion controlled reaction[31].

The values of(I_l) obtained at different temperatures permits the calculation of activation energy E_a according to Arrhenius equation:

$$\log I_\ell=-E_a/2.303RT+\log A \tag{10}$$

The plot of log I_ℓ against 1/T gave a straight line where A is a pre-exponential factor, R is the gas constant and T is the absolute temperature. The slope of which is proportional to E_a. The activation energy of the process is an important parameter for determining the rate controlling step. If the rate controlling step is the diffusion of species in the boundary layer then E_a is generally≤28kJ/mol[32], while E_a values usually>43kJ/mol when adsorption of species on the reaction surface and subsequent chemical reaction takes place.

TABLE 4 shows that the values of E_a are lower than 43kJ/mol; characterizing diffusion processes are controlling the electrodeposition reaction. However, the value of E_a of electrodeposition reaction is higher in presence of organic compound. This is attributed to that these compounds partly formed some chemical bond with copper, and this led to the fact that a part of the electrode remain covered even at higher temperature.

Thermodynamic treatment of the reaction:
The value of the enthalpy of activation ΔH*, entropy of activation ΔS* and free energy of activation ΔG* can

TABLE 4 : The thermodynamic parameters for electrodepositio of copper in presence of organic substance 298K

Organic compounds	$C\times10^4$ (mol.l^{-1})	E_a (kJ.mol^{-1})	ΔH* (kJ.mol^{-1})	-ΔS* (J.mol^{-1}.K^{-1})	ΔG* (kJ.mol^{-1})
1. Glucose	0.000	21.38	18.900	136.53	59.61
	5.500	22.28	19.802	133.70	59.67
	11.00	23.00	20.520	131.68	59.79
	21.70	20.89	18.410	139.38	59.97
	32.30	23.84	21.361	130.28	60.21
	42.70	24.21	21.735	129.51	60.35
	52.90	21.57	19.092	138.57	60.41
2. Fructose	0.000	21.38	18.900	136.53	59.61
	5.500	17.39	14.917	150.37	59.75
	11.00	17.26	14.780	151.03	59.81
	21.70	17.21	14.730	151.66	59.95
	32.30	16.00	13.523	156.13	60.07
	42.70	16.22	13.740	155.71	60.17
	52.90	15.41	12.929	158.94	60.32
3. Mannose	0.000	21.38	18.900	136.53	59.61
	5.500	19.27	16.793	143.78	59.66
	11.00	18.76	16.283	145.74	59.74
	21.70	15.68	13.189	156.35	59.81
	32.30	15.76	13.277	156.45	59.92
	42.70	13.48	11.002	164.37	60.01
	52.90	14.10	11.621	162.70	60.13
4. Sucrose	0.000	21.38	18.900	136.53	59.61
	2.900	21.43	18.949	136.60	59.68
	5.700	19.03	16.551	144.68	59.74
	11.40	18.47	16.018	146.90	59.82
	17.00	18.73	16.251	146.49	59.93
	22.40	20.48	18.001	141.03	60.05
	27.80	21.14	18.656	139.51	60.25
5. Lactose	0.000	21.38	18.90	136.53	59.61
	8.720	17.86	15.38	148.68	59.71
	17.37	16.23	13.75	154.45	59.80
	34.39	15.13	12.65	158.55	59.92
	51.09	14.79	12.31	160.04	60.03
	67.47	13.04	10.56	166.24	60.12
	83.54	11.71	9.234	171.10	60.25
6. Maltose	0.000	21.38	18.90	136.53	59.61
	2.900	20.15	17.67	140.79	59.65
	5.700	20.00	17.45	141.79	59.73
	11.40	18.00	15.29	149.09	59.75
	17.00	16.38	13.90	154.23	59.89
	22.40	15.08	12.59	158.86	59.96
	27.80	14.97	12.49	159.50	60.06

be obtained by using equation:

$$\Delta H^*=E_a–RT \tag{11}$$
$$\Delta S^*/ R=\ln A–\ln(BTe/h) \tag{12}$$
$$\Delta G^*=\Delta H^*–T\Delta S^* \tag{13}$$

TABLE 4 shows that the entropy ΔS* posses negative values, indicating a highly ordered organic species in the solution under investigation. From the TABLES it is also noticed that the weak dependence of ΔG* on the composition of the organic additives can be attributed largely to the general linear composition between ΔH* and ΔS* for the given temperature.

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The isokinetic relationship

Variation in the rate within a reaction series may be caused by changes in either, or both, the enthalpy or the entropy of activation. The correlation of ΔH^* with ΔS^* is a linear relationship may be stated algebraically;

$$\Delta H^* = \beta \Delta S^* + \text{Constant} \qquad (14)$$
$$\delta \Delta H^* = \beta \delta \Delta S^* \qquad (15)$$

The operator, δ, concerns difference between any two reactions in the series. Substituting from(15) into the familiar relationship:

$$\delta \Delta H^* = \delta \Delta G^* + T \delta \Delta S^* \qquad (16)$$

We obtain

$$\beta \; \delta \Delta S^* = \delta \Delta G^* + T \; \delta \Delta S^*, \qquad (17)$$

It follows that when $\delta \Delta G^*$ equal zero, β equals T. In other words, the slope in a linear plot of ΔH^* versus ΔS^* is the temperature at which all the reactions that conform to the line occur at the same rate. β is therefore known as the isokinetic temperature.

The isokinetic temperature β were estimated as 289, 281, 290.9, 278.8, 296K. for Fructose, mannose, sucrose, lactose, maltose. These values which are much lower than that of the experimental temperature 298K indicating that the rate of the reactions is entropy controlled[33], But the value of β which are much higher than 298K such as 308.9K for glucose indicating that the rate of the reaction is enthalpy controlled process[34].

1. Data correlation

To obtain an over all mass transfer correlation under the present conditions where a rotating cylinder is used the method of dimensional analysis was used. To identify the variables which affect the rate of mass transfer in the electrodeposition reaction, the mechanism of forced convection mass transfer should be recalled first. Forced convection takes place as a result of cylinder rotation. The thickness of this hydrodynamic boundary layer determines the thickness of the diffusion layer across which diffusion of Cu^{2+} from the solution bulk to surface of Cu takes place. The thickness of the hydrodynamic boundary layer at the rotating cylinder and the

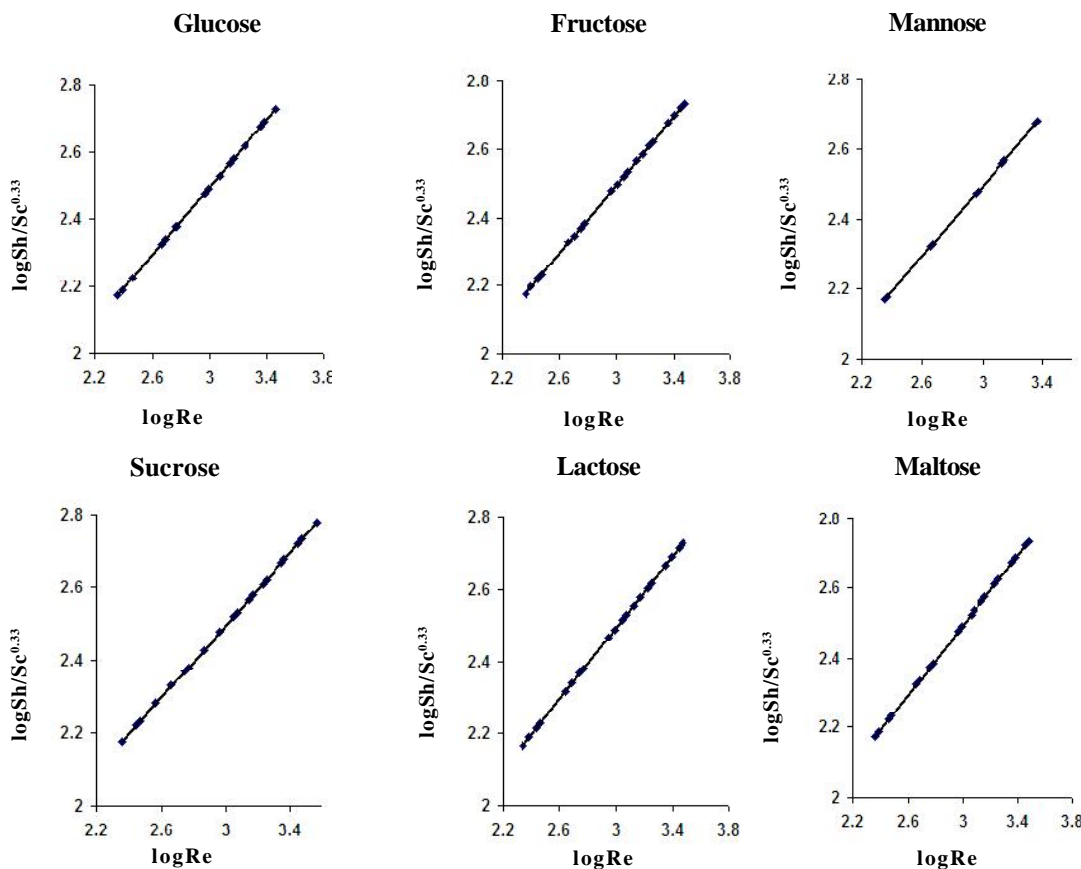Figure 9 : The relation between log Sh/(Sc) $^{0.33}$ and log Re for all organic compounds at different temperature

diffusion layer are determined by the physical properties of the solution, the geometry of the system(cylinder diameter) and cylinder rotation speed. This picture leads to the equation

$$K=f(\rho, \eta, D, U, d) \tag{18}$$

Where K=mass transfer coefficient, sec^{-1}. ρ= is density of bulk, gcm^{-3}. η=is viscosity of bulk, $cm^2.sec^{-1}$; D=is diffusion coefficient, $cm^2.sec^{-1}$; U= is cylinder linear velocity($U=\omega$ r); ω=is angular velocity ; d=is diameter of cylinder, cm.

Figures 9 gives the over all correlation for all organic compounds with copper cylinder electrode which correlates by the equation:

$$Log\ Sh/(Sc)^{0.33}= log\ a+b\ log\ Re \tag{19}$$

The exponents in the equation denotes a highly turbulent flow which agree with the previous mass transfer study in aqueous media.

In our present study, a forced convection mechanism[35] is obtained which agree very well with the relationship given by Eisenberg et al.[32] for mass transfer to a rotating cylinder in turbulent flow system.

$$Sh=0.0791\ Re^{0.7}\ Sc^{0.356} \tag{20}$$

Also, our results agree excellently with:

$$Sh=1.581Re^{0.725}\ Sc^{0.33} \tag{21}$$

Given by M.Nasser et al.[36] for mass transfer during cementation using rotating cylinder in an aqueous medium as well as with the equation $Sh=0.061\ Re^{0.833}\ Sc^{0.33}$ given by Ahmed et al.[37] for mass transfer during copper cementation from alcoholic water mixtures using rotating cylinder in turbulent system.

The over all correlation for all organic compounds. $Sh=9.784\ Re^{0.5017}\ Sc^{0.33}$ for Glucose with an average deviation: $\pm0.0119\%$, $Sh=9.790\ Re^{0.5017}\ Sc^{0.33}$ for fructose with an average deviation: $\pm0.0226\%$, $Sh=9.786\ Re^{0.5017}\ Sc^{0.33}$ for mannose with an average deviation: $\pm0.0621\%$, $Sh=9.790\ Re^{0.5016}\ Sc^{0.33}$ for sucrose with an average deviation: $\pm0.0234\%$, $Sh=9.790\ Re^{0.5016}\ Sc^{0.33}$ for lactose with an average deviation: $\pm0.0075\%$, $Sh=9.799\ Re^{0.5016}\ Sc^{0.33}$ for maltose with an average deviation: $\pm0.0126\%$

CONCLUSION

It is observed that the rate of electrodeposition in presence of cell using copper anode decreases by adding organic additives. This is attributed to the conductivity of solutions mixture decreases in presence of organic additives, and also viscosities of solutions are higher in presence of organic additives than in blank solutions.

Our results revealed that

i. The average limiting current density decreases by increase the electrode height.

ii. The limiting current density increases as $CuSO_4$ concentration increase.

iii. Organic substances have inhibition effect on the limiting current depending on the concentration and type of inhibitor.

iv. The rate of electrodeposition increases by increasing temperature.

v. When using RCE at 25^0C the rate of electrodeposition increases by increase of rotation number.

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