Table (1): Concentration of the Sn-electroplating baths used:

Bath No.	Concentration (g/L)			Concentration (g/L)		
	$SnCl_2.2H_2O$	NaCl	HCl	5-sulphosalicylic acid $C_6H_3(OH)(COOH).SO_3H.2H_2O$	Anthranilic acid	Sodium dodecyl sulphate (SDS) $C_{12}H_{25}OSO_3Na$
Sn-1	60	30	115	-	-	1.94×10^{-3}
Sn-2	60	30	115	-	-	3.88×10^{-3}
Sn-3	60	30	115	-	-	-
Sn-4	60	30	115	0.015	-	-
Sn-5	60	30	115	0.02	-	-
Sn-6	60	30	115	0.025	-	-
Sn-7	60	30	115	-	8.22×10^{-3}	-
Sn-8	60	30	115	-	0.01	-
Sn-9	60	30	115	-	0.013	-
Sn-10	60	30	115	0.025	0.013	1.94×10^{-3}
Sn-11	20	30	115	-	-	1.94×10^{-3}
Sn-12	40	30	115	-	-	1.94×10^{-3}
Sn-13	80	30	115	-	-	1.94×10^{-3}
Sn-14	25	30	115	-	-	1.94×10^{-3}
Sn-15	50	30	115	-	-	1.94×10^{-3}
Sn-16	30	30	115	-	-	1.94×10^{-3}
Sn-17	70	30	115	-	-	1.94×10^{-3}
Sn-18	60	30	115	0.025	-	1.94×10^{-3}
Sn-19	60	30	115	-	0.013	1.94×10^{-3}
Sn-20	60	30	115	0.012	6.85×10^{-3}	1.94×10^{-3}

pH of each of these baths ≈ 1.4.

Table (2): Concentration of the Ni-electroplating baths used:

	Concentration (g/L)		Concentration (g/L)
Bath No.	$NiCl_2.6H_2O$	HCl	SDS
Ni-1	150	115	-
Ni-2	150	115	1.94×10^{-3}
Ni-3	150	115	3.88×10^{-3}
Ni-4	50	115	1.94×10^{-3}
Ni-5	100	115	1.94×10^{-3}
Ni-6	75	115	1.94×10^{-3}

pH of each of these baths ≈ 1.5.

Table (3): Concentration of the tin-nickel alloys electroplating baths used:

	Concentration (g/L)			Concentration (g/L)
Bath No.	$NiCl_2.6H_2O$	$SnCl_2.2H_2O$	HCl	SDS
(Sn-Ni)-1	150	50	115	1.94×10^{-3}
(Sn-Ni)-2	100	50	115	1.94×10^{-3}
(Sn-Ni)-3	50	50	115	1.94×10^{-3}
(Sn-Ni)-4	150	10	115	1.94×10^{-3}
(Sn-Ni)-5	150	20	115	1.94×10^{-6}
(Sn-Ni)-6	150	30	115	1.94×10^{-3}
(Sn-Ni)-7	150	70	115	1.94×10^{-3}
(Sn-Ni)-8	200	50	115	1.94×10^{-3}
Sn*	-	50	115	1.94×10^{-3}
Ni*	150	-	115	1.94×10^{-3}

pH of each of these baths ≈ 1.52.

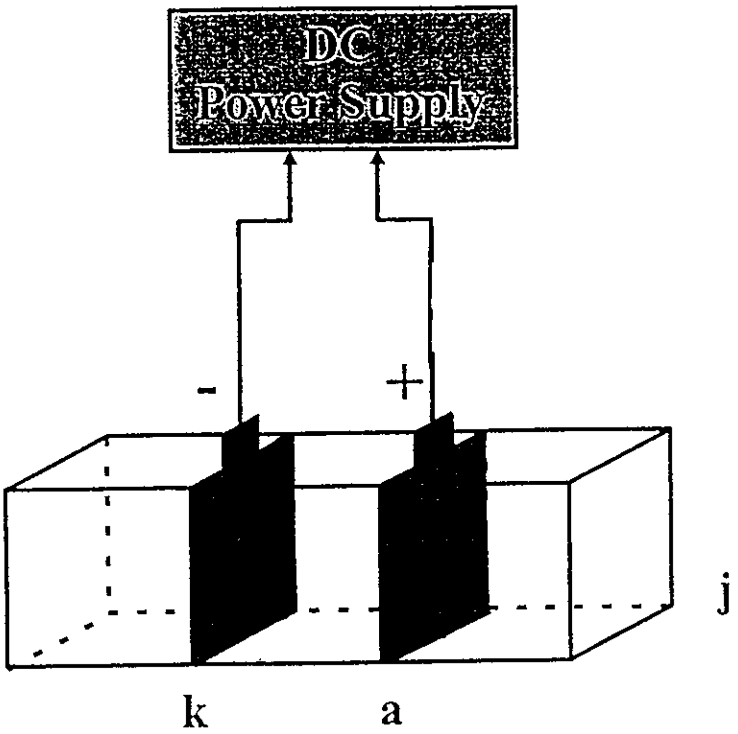

Fig.(5): The electroplating cell and the electrical circuit for measuring the cathodic current efficiency.

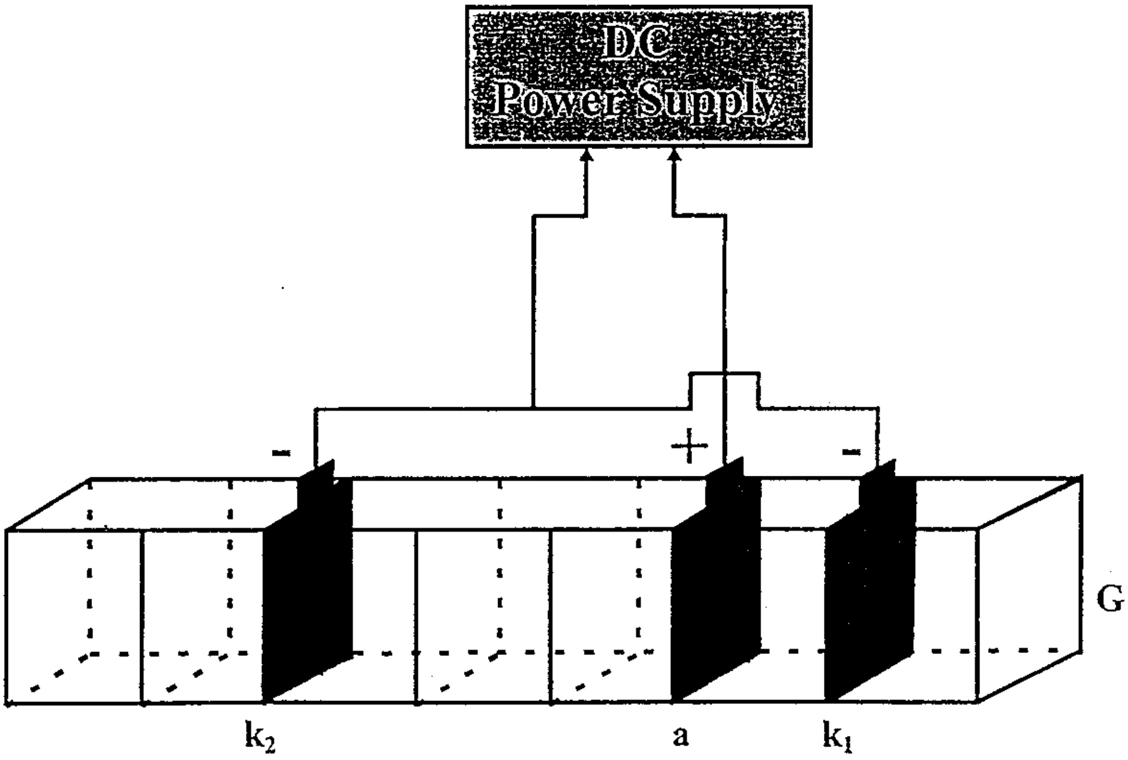

Fig.(6): The electroplating cell and the electrical circuit for measuring the throwing power and throwing index.

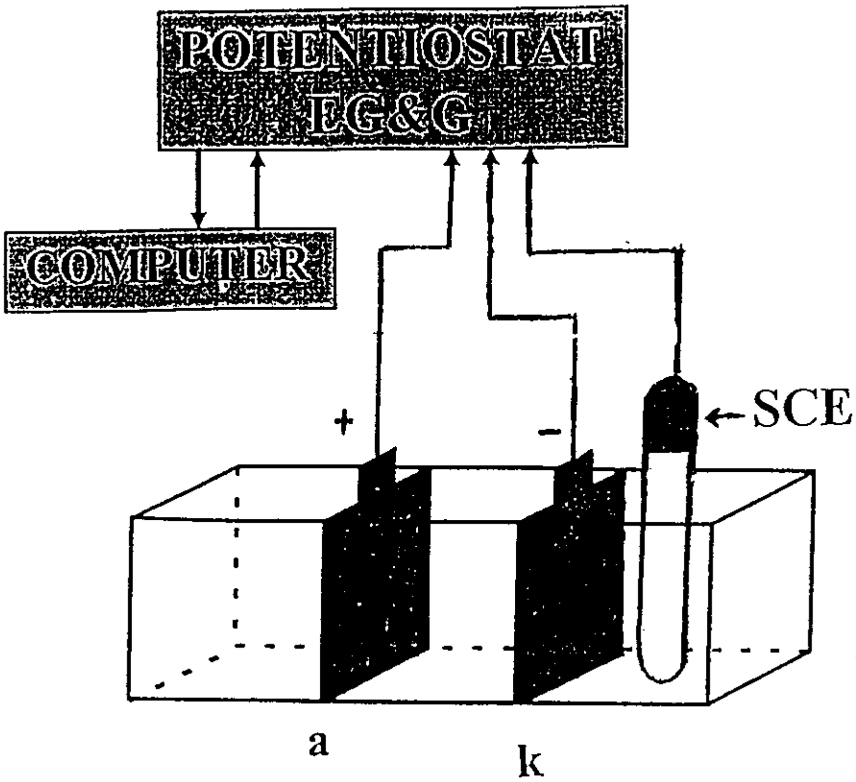

Fig.(7): **The electroplating cell and the electrical circuit for measuring the potentiodynamic cathodic polarization**

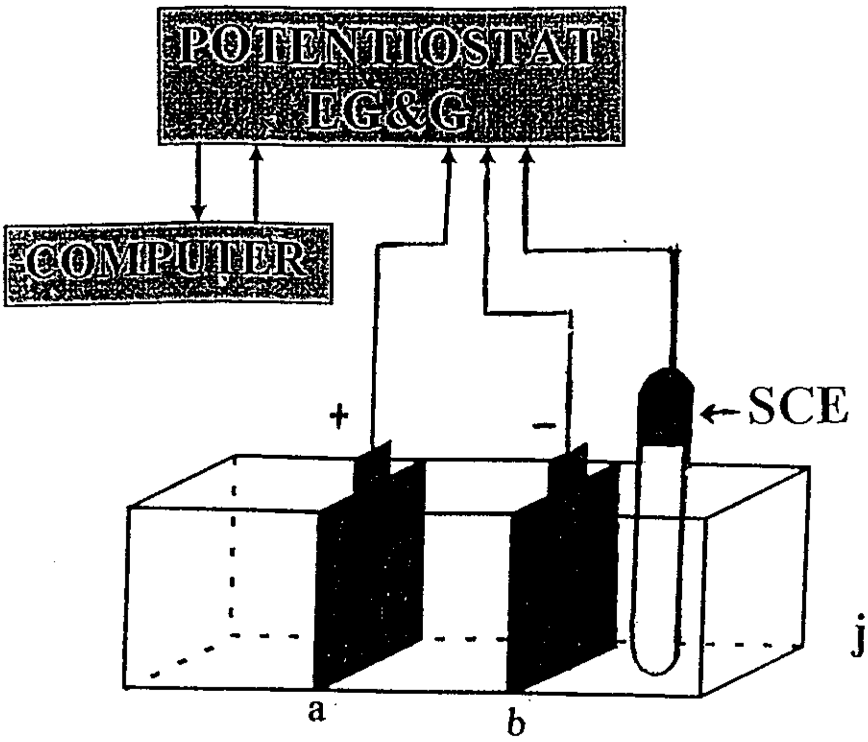

Fig.(8): The electroplating cell and electrial circuit for measuring linear anodic stripping.

Electroplating of Tin from Acid Stannous Chloride Solutions Containing Additives

The aim of the present chapter is to find the optimum conditions for producing smooth, bright and adherent tin coatings onto mild steel substrates from baths containing stannous chloride, hydrochloric acid and some additives namely: sodium dodecyl sulphate (SDS), anthranilic acid, and 5-sulphosalicyclic acid . Electrodeposited tin obtained from acid stannous chloride baths in the absence of these additives was dendritic, needle-like or columnar and not covering all the substrate surface. However, in the presence of these additives the electrodeposited tin was compact, smooth and uniform over the whole surface of the substrate.

Potentiodynamic cathodic polarization curves:

Figs. (9-14) represent the potentiodynamic cathodic potential current density (E/i) curves during electrodeposition of tin onto mild steel substrates from solutions containing stannous chloride and hydrochloric acid under different experimental conditions. The curves were swept from the rest potentials to more negative potential values with scan rate of 20 mV s^{-1}.

Fig.(9) shows the cathodic polarization curves during deposition of tin from the acid stannous chloride solutions in the absence and presence of the additives. It is observed that the current increases starting from the rest potential at about (-447 mV, SCE) with increasing the potential and reaching a limiting value at about

-800 mV. Eventually, the current rises rapidly with further increase in cathodic potential. Inspections of the results reveal that the electrodeposition of tin (reduction of Sn^{2+} ions) occurs within the limiting current plateau region. These results also indicate that the electrodeposition of tin is under diffusion control. The rapid rise in current beyond the current plateau is due to simultaneous deposition of tin and evolution of hydrogen gas. These results indicat that tin is the nobler element with respect to hydrogen in the present system.

The presence of either of the additives in the bath increases the cathodic polarization, decreases the limiting current density and shifts the potential range of the limiting current towards the more negative values. These changes indicate that the presence of these additives inhibits the electrodeposition of tin and retards the evolution of hydrogen. The additives may adsorb on the cathode surface and therefore increase the cathodic polarization. Another interpretation suggests the formation of a permeable barrier that hinders the transport of cations and protons to the surface of the electrode(89). The formation of this film of adsorbed molecules on the electrode surface constitutes a simple energy barrier. It is seen that the inhibitory effects on the cathodic reduction processes decrease in the order:

5-sulphosalicylic acid > anthranilic acid > sodium dodecyl sulphate.

Figs.(10-12) illustrate the influences of increasing the concentration of sodium dodecyle sulphate, anthranilic acid, and

5-sulphosalicylic acid on potentiodynamic polarization curves respectively.

The data show that the limiting current density decreases with increasing the concentration of the additives as shown in Fig.(10-12) It was observed that the presence of 1.94 x 10^{-3} g/L SDS into the bath gives, smooth, bright and adherent deposits. Therefore this concentration of SDS was chosen for further investigation.

Fig.(13) shows the effect of increasing the concentration of $SnCl_2$ on the cathodic polarization curves. Increasing $SnCl_2$ concentration enhances the limiting current density. This result may be attributed to the increase in the relative concentration of Sn^{2+} ions, particularly in the cathodic diffusion layer and this is reflected in the decreasing of concentration type of polarization, associated with Sn^{2+} reduction. Consequently, an increase in the cathodic current efficiency, f %, for tin electrodeposition is expected from baths containing high content of $SnCl_2$.

Fig.(14) shows the influence of bath temperature on cathodic polarization curves. It is obvious that an increase of bath temperature increases the limiting current density and decreases the potential at which hydrogen evolution reaction commences. These changes are apparently due to the depolarization effect of temperature on the activation overpotential of both Sn^{2+} and H^+ reduction reactions. Moreover, an increase of temperature enhances the concentrations of Sn^{2+} and H^+ in the diffusion layer as a result of increasing their diffusion rates. It seems that the effect of temperature on the