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ELECTROCHEMICALS

CALCULATION AND EXPERIMENTAL VERIFICATION OF IR DROP IN TSIA ELECTRODES OF CHLOR-ALKALI CELLS

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ABSTRACT

A computer program to analyse the current distribution in a chlor-alkali cell using Titanium Substrate Insoluble Anode (TSIA) has been developed. The program takes into account the polarisation resistance characteristics of anode and cathode and the electrolyte resistance, in addition to anode nodal resistance. The results are compared with the experimental data.

Key Words: Metal anodes, Chlor-alkali, current distribution

INTRODUCTION

The problem of potential drop in a chlor-alkali cell electrode is well known. In addition to wasting of power it may also give nonuniform current distribution resulting in lower production capacity per unit electrode area. In designing an electrolytic cell, care is therefore taken on the resistance and in turn, dimension of the electrodes to minimise the cost. Various steps are taken in reducing the potential drop in cathode, anode, electrolyte media, diaphragm, anode structure and contact structure. An attempt is being made here to develop a computer program to estimate the IR drop at the anode structure. The model and computer program are expected to be useful in predicting and optimizing the performance of an electrode design. The effects of other cell characteristics like conductivity of electrolyte and electrodes welded or strip type anode structure, polarisation characteristics of the electrodes and other parameters are also analysed critically with the developed program.

MODEL

The problem of arranging the macroscopic elements of the anode to minimize IR drop and current distribution has been attacked in many ways. A few [1-3] have considered the problem of current distribution in electrodes of homogenous resistances, adopting the situations where the symmetry of the electrodes allows the problem to be reduced to a two-dimensional one. It was analysed using finite difference technique. In battery studies [4] Kirchoff's law has been used to solve the current distribution; the same technique has also been used [5] in solving current distribution in anodes of chlorine-caustic cells.

Following this approach [5], the mesh electrode (Fig.1) is represented by resistances connected to grid points. Each node is connected to four sourrounding electrode points and one electrolyte resistance. Taking nodal voltage and resistances, Kirchoff's law could be represented as

$$\sum_{i=1}^{n} \frac{(E_i-E_0)}{r_{io}} = 0 \quad \text{.............................(1)}$$

where Eo is the potential of the analysed node and Ei is the potential at the other end of the resistance attached to the specific node and r_{io} is the resistance between the two nodal points.

If there are 'm' grid points in the X-direction and 'n' grid points in the Y-direction on an electrode, nxm equations can be written. Taking r_{ij} as the resistance in the X-direction of the grid and R_{ij} as the resistance in Y-direction of the grid, the Kirchoff's law for an interior grid point can be written as

$$E_{i,j} = \frac{\frac{E_{i+1,j}}{r_{i,j}} + \frac{E_{i,j+1}}{R_{i,j}} + \frac{E_{i-1,j}}{r_{i-1,j}} + \frac{E_{i,j-1}}{R_{i,j-1}}}{\frac{1}{r_{i,j}} + \frac{1}{R_{i,j}} + \frac{1}{r_{i-1,j}} + \frac{1}{R_{i,j-1}}} \quad \text{.........(2)}$$

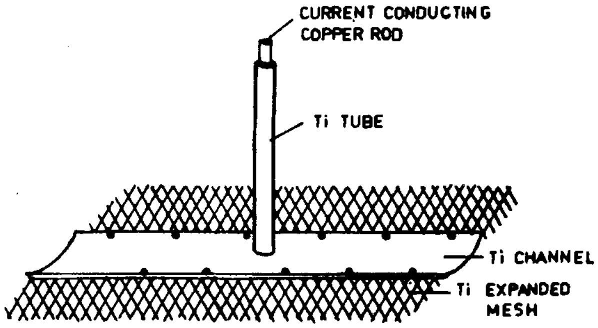

Fig. 1. The Mesh Electrode

These equations can be solved to evaluate the nodal voltages. Figure 2 briefs the representation of resistive network of that electrode. For the selected electrode, we have 7 rows of 47 nodes for each row.

SOLUTION TO THE MODEL

The above equations can be solved by iteration assuming an initial potential for each grid point and using new iterated values. Here the subscript variables i and j were converted to a single subscript variable 'L'. The convention of the single subscript starts from top left corner of the vertical anode in the X-direction and successively reads the next row below, so that the final subscript is in the bottom right corner.

$$\text{Taking } L = (j-1)m + i \quad \text{.............. (3)}$$

the equation for an interior grid point with a single subscripted variable can be written as

$$E_L = \frac{(C_l E_{L+1} + C_{l-1} E_{L-1} + C_{L-M} E_{L-M} + C_L E_{L+M})}{K_L} \quad \text{.........(4)}$$

$$C_l = 1/r_l \,;\; C_L = 1/R_L$$

$$K_L = C_l + C_{l-1} + C_{L-M} + C_L + CE$$

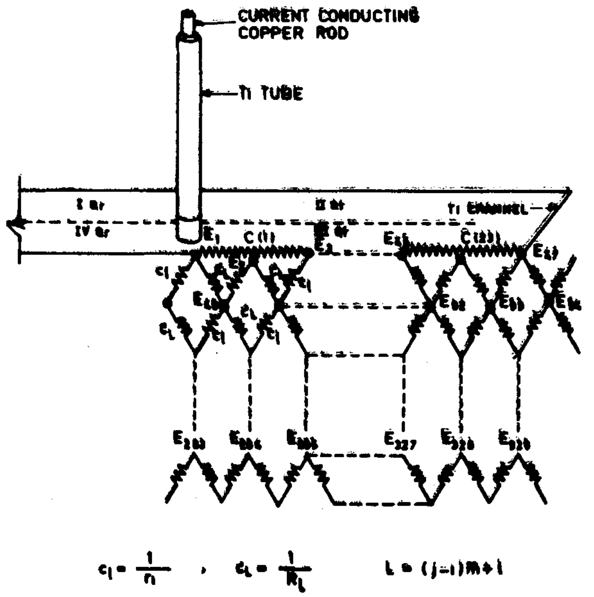

Fig. 2. Equivalent Resistive Network

Here CE is the anode to cathode conductivity. It is assumed that current is fed to the electrode through a stem having the conductivity value 'CON'.

In one quarter of the experimental anode, there are 7 rows and 47 columns and it works out to be 329 grid points. Appropriate computer programs to generate 329 equations of the type (4) and to solve by Gauss Seidal method[6] have been evolved.

By varying the error limit, the desired level of accuracy can be obtained. Figure 3 shows the flow chart.

By varying parameters r_l, R_L, C_E and CON, one can predict the current distribution in a more precise way.

EXPERIMENT

To test the model, a laboratory experimental arrangement has been set up. Instead of mercury, a flat lead electrode is used as cathode. The electrolyte used in NaCl at a concentration of 300 g/l. Plastic spacers to a height of 3mm and 6mm are used for gap separation. The complete test arrangement is housed in a leak proof PVC tray.

The TSIA electrode and lead cathode are connected to a DC power supply unit and the current through the cell is controlled using the variac in the power unit. A current shunt is used to measure the magnitude of current. Since gas evolution is taking place, great care is taken to get reproducible results. A platinum wire probe is used to sense the potential at the nodes with a high impedance DPM. The results are plotted in Figure 4 for spacings 6mm and 3mm.

MEASUREMENT OF PARAMETERS

Estimation of CON value

The experimental electrode consists of a hollow Ti tube of thickness 1mm encircling a copper rod of diameter 22mm with a length of 300mm for Ti

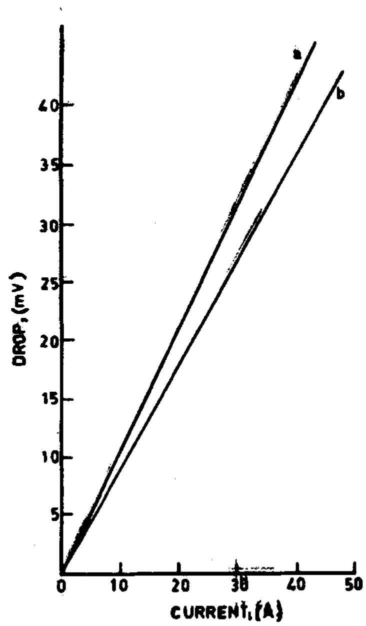

Fig. 4. Experimental Potential Drop at two Extreme Nodal Points (1 & 329)
a)for 3 mm spacing b) for 6 mn. spacing

and 340 mm for copper. The conductivity of the respective metals is measured using the four probe technique. The value of resistivity for Ti was found to be 49.266 x 10-Ω-m. The net conductance of the rod was calculated as 60350 ℧.

Estimation of C_l and C_L

The geometrical dimension of the grid is estimated and C_l and C_L are calculated as 57.9942-℧ for the grid of width 2mm, length 7 mm and thickness 1 mm.

Estimation of CE

The CE value includes the electrolyte conductivity between the electrodes, anodic polarisation resistance and cathodic polarisation resistance. The above values are estimated separately. The electrolyte resistivity was found by conductivity bridge to be equal to 2.82x10-Ωm. Using potenitoscan, anodic polarisation of Ti and cathodic polarisation of lead are measured on 1 cm^2 sample of the respective electrodes using platinum as counter electrode. The I/V characteristics are plotted in Figure 5.

Hence CE value for 6 mm space works out to be

$$\frac{(3.789\times10^{-4} + 4.293\times10^{-4} + 2.82\times10^{-4})}{(0.7\times0.7)\times10^{-4}} \quad \text{i.e. } 0.045\ ℧$$

and that for 3 mm space is

$$\frac{(3.789\times10^{-4} + 4.293\times10^{-4} + 1.5\times10^{-4})}{(0.7\times0.7)\times10^{-4}} \quad \text{i.e. } 0.051\ ℧$$

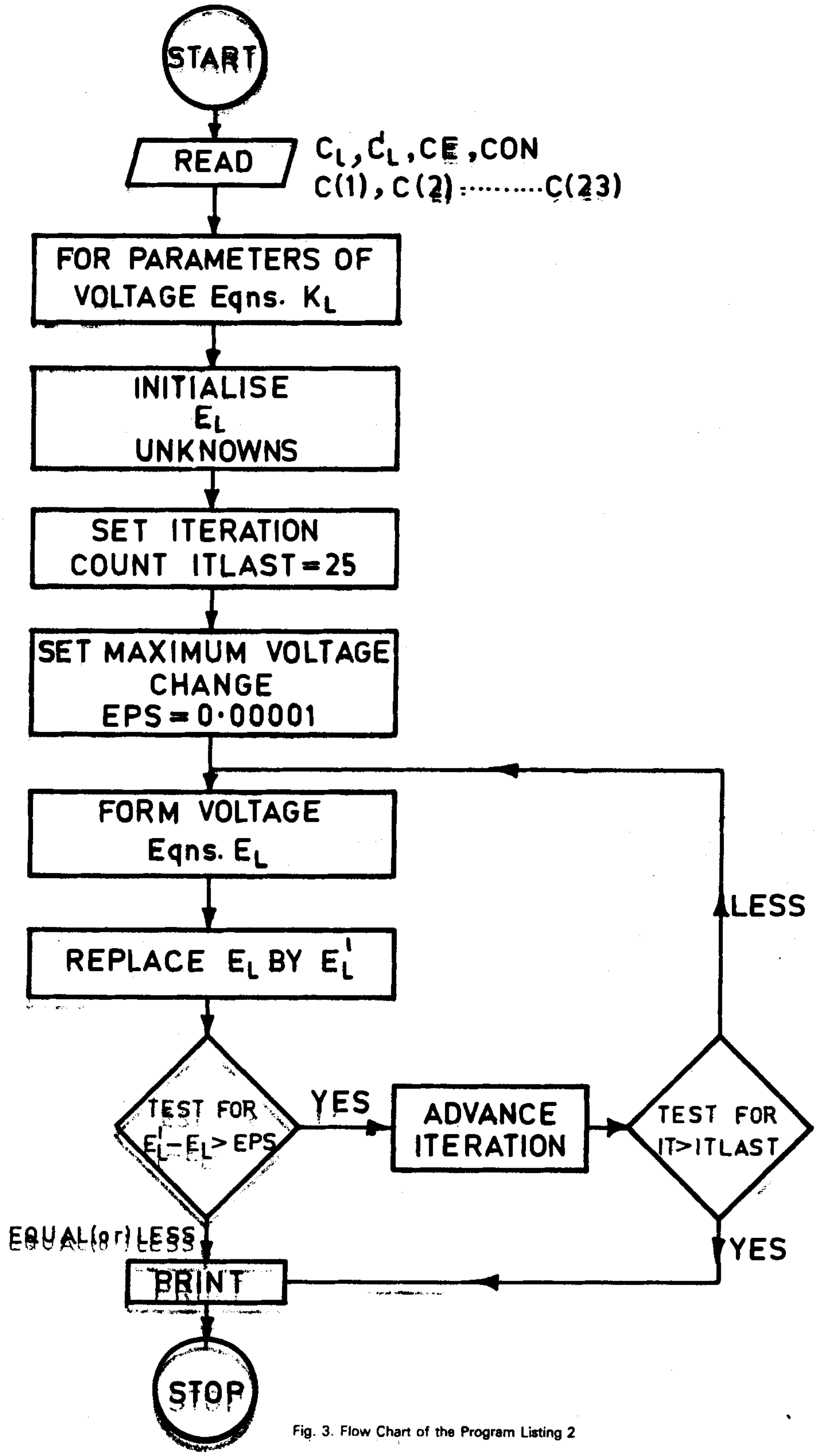

Fig. 3. Flow Chart of the Program Listing 2

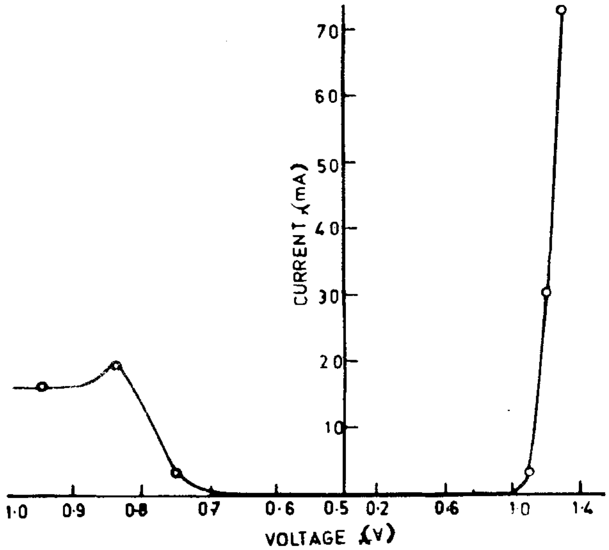

Fig. 5. Polarisation Characteristics of the Electrodes

a) Cathode
S_l = 5.3 ohm
A = 0.81 × $10^{-4} m^2$
R_p = 4.293 × 10^{-4} ohm m

b) Anode
S_l = 4.21 ohm
A = 0.9 × $10^{-4} m^2$
R_p = 3.789 × 10^{-4} ohm m

Estimation of C(1), C(2)...Ċ(23)

The central vented plate portion of the experimental anode is divided into 23 strips, corresponding to welded portion of the mesh as shown in Figure 2. By knowing the thickness and length, its conductivity is calculated.

ANALYSIS

The computer program is run for the above estimated parameters. The program has the flexibility of varying C_l, C_L, C_E, CON.... etc. The drop at the extreme points (1 and 329), one at the centre and the other at the diametrically opposite (at the electrode boundary) are presented for comparison. Actual current flowing in theoretical model is estimated from the drop across 'CON' value. The best match has been obtained for a CON value 60350 ℧ and CE value 0.045 with a minimum error of 6.6%.

In the above model, the effect of varying CE and CON and the corresponding computer predicted potential and the experimentally observed results are indicated in Table I.

Table I: Data on design optimisation : Effect of varying CE and CON on predicted IR drop

CE (℧)	CON (℧)	Computer predicted potential drop (v)	Experimentally obtained potential drop (v)
0.051	3000	0.00625	0.00525
	10000	0.00655	0.00575
	30000	0.00665	0.00590
	60350	0.00667	0.00625
0.045	10000	0.00578	0.00500
	30000	0.00587	0.00525
	60350	0.00589	0.00550

CONCLUSION

It could be seen that the above model and analysis can be used more effectively to study the current distribution on any type of mesh electrodes used in electrolysis cell. The effects of varying each parameter like conductance of material used, electrolyte conductivity, electrode polarisation characteristics etc. could be predicted for design optimization.

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