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EFFECT OF REVOLVING MOTION ON THE MASS-TRANSFER AT ROTATING ELECTRODES

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A rotating electrode in an electrolytic system is studied. The revolving angle and the frequency of the rotating electrode vary from 0 to 20 degrees to the vertical axis and from 0 to 50 s^{-1} about the vertical axis, respectively. The current-potential and the limiting current-frequency dependences are measured under varying conditions of the revolving motion. It is found that the enhancement of mass transfer in the system can be achieved by increasing the revolving frequency and the revolving angle according to the empirical equation obtained from this experiment:

E (enhancement coefficient) $= 1 + (0.09 + 0.12\ \Theta^{0.29}) f^{0.85}$ where Θ is the revolving angle in deg and f, the revolving frequency in s^{-1}.

ВЛИЯНИЕ ВРАЩЕНИЯ НА ПЕРЕНОС МАССЫ В ЭЛЕКТРОЛИТИЧЕСКОЙ СИСТЕМЕ С ВРАЩАЮЩИМИСЯ ЭЛЕКТРОДАМИ

В работе приведены результаты изучения электролитической системы с вращ-аюшимися электродами. Угол наклона по отношению к вертикальной оси ва-рьирует от 0° до 20°, а частота вращающегося электрода вокруг вертикальной оси изменяется в пределах от 0 до 50 $с^{-1}$. Зависимости ток-потенциал и предельный ток-частота измерены при различных условиях вращения. Обнаружено, что увеличение переноса массы в системе может быть достигнуто за счет увеличения частоты вращения и угла наклона согласно эмпирическому уравнению, полученному из этого эксперимента:

E (коэффициент увеличения) $= 1 + (0,09 + 0,12\ \Theta^{0,29}) f^{0,85}$, где Θ — это угол наклона в градусах и f — частота вращения в $с^{-1}$.

I. INTRODUCTION

There have been many suggestions to achieve advances in electrochemical processes among which longitudinal vibration [1] and transverse oscillation [2] of the electrode have been reported to cause a pronounced effect on mass transfer. However, in general practice, the electrode is neither purely longitudinally

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vibrating nor transversely oscillating, but rather combines the two movements or is even rotating. Therefore, for more practical purposes, this fact has stimulated the present investigation of the effect of revolving motion of the electrode on mass-transfer in an electrolytic system.

II. EXPERIMENTAL

The schematic diagram of the experimental set-up is shown in Fig. 1. Stress-free polycrystalline copper-rod-electrodes of 1 cm diameter were used. One was used as

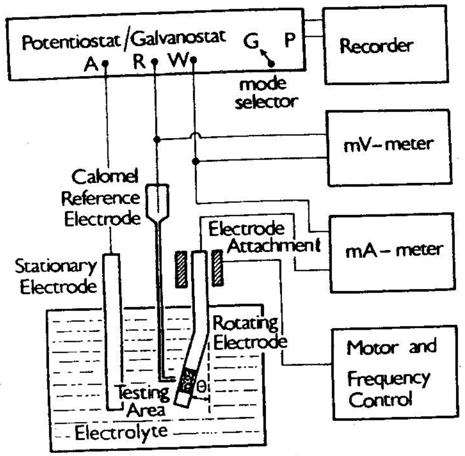

Fig. 1. The schematic block diagram of the experimental set-up.

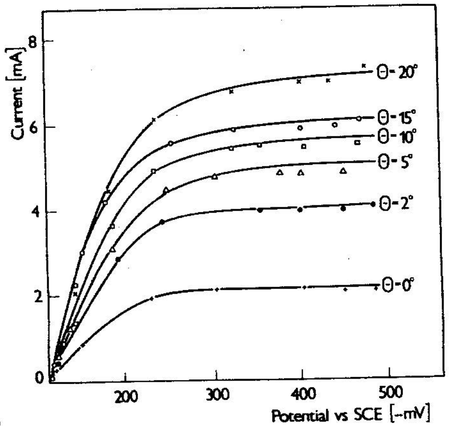

Fig. 2. The typical current-potential (vs SCE) me asurement for 20 s^{-1}.

a stationary electrode while the other was rotating, at the angle Θ with the rotating axis, driven by a motor of which the revolving frequency could be controlled accurately. The electrolytic in the cell was the acidic solution $CuSO_4/H_2SO_4$ (0.05 M $CuSO_4$, 1.5 M H_2SO_4). Following the standard potentiostatic -galvanostatic methods, a Princeton Potentiostat/Galvanostat, Model 173 with an external digital voltmeter and an mA-meter were used to measure in the galvanostat mode the current-potential correlation (Fig. 2) and to carry out the limiting current frequency dependence (Fig. 3) in the potentiostat mode.

The rod-electrodes, prior to each experiment should be properly polished and cleaned. The distance from the bending point to the end of the rotating electrode was about 10 cm. Leaving the desired conducting surface area of about 1.2 cm^2, at about 1 cm from the end of the electrode, the whole remaining surface should be insulated with epoxy casting resin. The edges of the bottom end of the rotating

electrode should be smoothed to minimize the unwanted hydrodynamic disturbance.

The current potential measurements were carried out under varying conditions of rotation. The frequency of the rotation of the electrode was varied up to 50 s^{-1} and the angle Θ was set between 0 and 20 degrees. Turbulence of high Reynold numbers could be observed in the system when Θ was higher than 20 degrees.

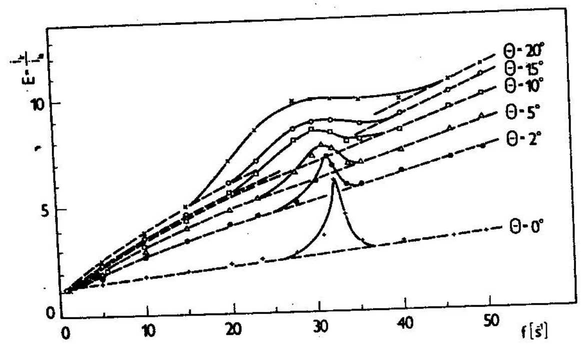

Fig. 3. Influence of revolving angle and rotating frequency on the limiting current ratio i_{1r}/i_{1s} for 400 mV.

III. RESULTS

The typical current-potential curve was given in Fig. 2 for different values of the revolving angle Θ, with a fixed revolving frequency of 20 s^{-1}. This showed that when the potential vs the reference electrode reached about 300 mV the cathode current generaly came to a plateau, corresponding to the limiting current which was in good agreement with the previous report done by Hepel [3].

In Fig. 3 the influence of the revolving angle Θ on the limiting current was studied with the potential fixed at 400 mV. In order to show the enhancement of mass transfer in this process, the ratio of limiting currents was plotted against the revolving frequency for each particular value of the angle Θ at a fixed potential. Since the enhancement of mass transfer, E, is defined as the ratio of limiting currents i_{1r}/i_{1s}, where i_{1r} is the limiting current during rotation of the electrode and i_{1s}, the limiting cirrent when steady the enhancement E was found to increase with the increasing frequency. At a range of frequency of about 27 s^{-1} to 34 s^{-1} peaks of i_{1r}/i_{1s} were observed. When the angle was getting bigger, the peak became flat.

IV. DISCUSSION

Previous works [4], [5] on a rotating disk suggested that the simple laminar flow might be responsible for the uniform accessibility of the mass transfer behaviour. It is understood that the flow patterns around rotating rods should be completely different from flow patterns around vibrating ones insofar as around rotating ones they are stationary, whereas around vibrating ones they must be non-stationary. However, in the present experiment, the revolving angle causes a considerable turbulence around the rotating electrode, particularly when the frequency is high and the angle is large. It should be this turbulence that causes the enhanced mass transfer [6]. Therefore the turbulence which occurs in the system due to the rotating electrode may be a desirable object for discussion. For example, experimentally this has been found to play an important role in the studies of corrosion [7], [8], [9].

In this work we consider that the rotation of the rod-electrode, with an angle to its rotating axis, will cause the combined effects of both the transverse oscillation and longitudinal vibration on the electrolytic system. When the revolving angle is zero, the electrode is just a rotating rod and can be considered virtually as a case of longitudinal vibration with a very large or infinite amplitude. This is why the sharp peak observed (see Fig. 3) is very much similar to the results reported before [2] for longitudinal vibrations at vibrating electrodes. A similar explanation may be used. However, when the revolving angle is getting larger, the motion of the electrode becomes more complex and the enhancement of mass transfer also becomes greater and reaches in this experiment a value that is comparable to the results due to pure transverse oscillation [1].

The enhancement coefficient, E, can be obtained by equating the dotted curves in Fig. 3 empirically, ignoring the peak-region. By means of computational techniques, we have,

$$E = 1 + (0.09 + 0.12\ \Theta^{0.29}) f^{0.85} \qquad (1)$$

where $E = i_{1r}/i_{1s}$, Θ is the revolving angle in degrees and f the rotating frequency in s^{-1}.

In equation (1) since E is a ratio, 0.09 and 0.12 are coefficients with the units of $s^{0.85}$ and $s^{0.85}\ deg^{-0.29}$ respectively to balance the dimensions of both sides and 0.29 and 0.85 are dimensionless constants without units. This equation (1) indicates that the enhancement of mass transfer in the system can be achieved by increasing either the frequency or the angle of the rotating electrode, or both. It should also be noted that increasing the frequency has a more influencial effect on the enhancement than the angle for its higher exponential power.

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