

# *Effect of vibration on the rate of mass transfer*

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Received 13 April 1974

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The rate of mass transfer at vibrating electrodes was measured using an electrochemical technique. The system chosen was stress-free polycrystalline electrolytic copper in  $\text{CuSO}_4/\text{H}_2\text{SO}_4$  solution. The concentration of the electrolyte was  $0.05 \text{ mol dm}^{-3} \text{ CuSO}_4$  and  $1.5 \text{ mol dm}^{-3} \text{ H}_2\text{SO}_4$ . Electrodes ( $160 \text{ mm} \times 25 \text{ mm} \times 3 \text{ mm}$ ) were subjected to vertical vibrations and the limiting current density was determined at a section not subjected to end effects. The electrodes were especially designed so that the results would be unaffected by the turbulence generated at the leading vibrating edge. This enabled the investigation of the effect of parallel fluid vibrations without interference from the other factors.

The vibration frequency was varied up to 48 Hz while amplitudes of up to 8 mm were used. The rate of mass transfer was found to increase upon the application of vibration and enhancements of up to six fold were obtained. It was observed that when large amplitudes were used, a pronounced peak in the limiting current occurred. This is attributed to the amplification of fluid vibrations around the natural frequency of the boundary layer.

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## 1. Introduction

Vibrations and pulsations play an important role in many industrial processes [1, 2]. This arises from the enhancement of both the rate of mass transfer and heat transfer due to the increase of the degree of mixing or agitation. This increase of mass and heat transfer rates depends on the environmental conditions. Recently, work has been performed which indicates the importance of agitation in technical processes [3, 4]. Generally agitation could be brought about either by mechanical means or by vibration; the latter yields better surface processes. Ultrasonic waves [5] and electric and magnetic fields [6, 7] have increased the rate of mass transfer in electrolytic technologies where mechanical stirring of the electrolyte is impractical. Vibrations are quite popular in mixing in view of their advantages over the other techniques. Besides all these advantages, vibrations play an important feature in corrosion processes [8, 9].

The present work is directed towards the study of the effect of amplitude and frequency of vibrations on the rate of increase of mass transfer at vertical electrodes subjected to vertical vibrations.

## 2. Experimental

The system chosen was stress-free polycrystalline electrolytic copper in  $\text{CuSO}_4/\text{H}_2\text{SO}_4$  solution. The acid acts as an indifferent electrolyte. The excess sulphuric acid used eliminates the effect of ionic migration of the reacting ions towards the electrodes due to the electrical field. The concentration used was  $0.05 \text{ mol dm}^{-3} \text{ CuSO}_4$  and  $1.5 \text{ mol dm}^{-3} \text{ H}_2\text{SO}_4$ . The chemical polarization involved in the reaction is negligible, the electrode surface is unaffected and attainment of equilibrium is rapid. The systems selected are solely diffusion-controlled and were used by several workers in mass transfer investigations [6, 10–13]. Vertical vibration is chosen since it is preferred

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for treatment of small articles because it is relatively simple and easy to operate.

The equipment employed (Fig. 1) consisted of an electrolytic cell and a vibrator. The cell is similar to that used in earlier studies [14]. The container was made of pyrex glass ( $35 \times 15 \times 25 \text{ cm}^3$ ). The vibrator consists of a variable speed motor, a variable eccentric, and an oscillating shaft connected to a table (vibrating table). The frequencies vary from 0 to 60 cycles per second (cps) and the amplitude could be varied from 0 to 8 mm by means of the variable speed motor and the variable eccentric respectively. The electrodes ( $15 \times 2.5 \times 0.3 \text{ cm}^3$ ) were annealed electrolytic copper especially designed so that the results would be unaffected by the turbulence generated at the leading vibrating edge (Fig. 1). The electrode was insulated with a thin layer of resin (collodion) except for the test section (active area). The electrode holder is fixed in the vibrating table.

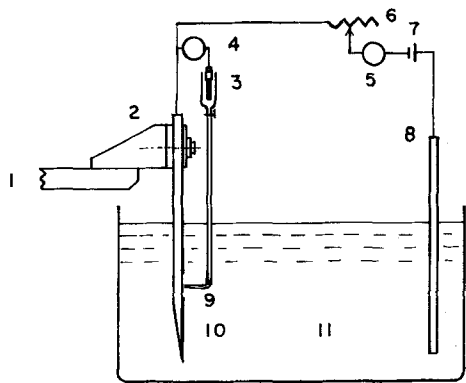


Fig. 1. Schematic diagram of the experimental set-up. 1, Oscillating table; 2, vibrating copper electrode attachment; 3, reference electrode (SCE); 4, potentiometer; 5, ammeter; 6, rheostat; 7, battery (6V); 8, stationary copper electrode; 9, active surface; 10, resin isolated surface; 11, electrolyte ( $0.05 \text{ mol dm}^{-3} \text{ CuSO}_4 / 1.5 \text{ mol dm}^{-3} \text{ H}_2\text{SO}_4$ ).

The rate of mass transfer was expressed in terms of limiting current density which is determined from the current-potential diagrams under the experimental conditions. The limiting current at each frequency and amplitude was determined in a manner similar to that described earlier [14] by applying a voltage between the test electrode and the other electrode of the electrolytic cell

and recording the current in the circuit. All runs were performed at a temperature of  $20 \pm 0.1^\circ \text{C}$ . All electrodes have the same initial surface finish and are subjected to the same surface treatments (mechanical polishing with the same technique,...). Chemicals used were A'R' grade.

### 3. Results and discussion

The rate of mass transfer is expressed by the limiting current value which is determined from the current-potential curve. Typical current-potential curves obtained during this work are shown elsewhere [14]. The plateau due to the limiting current gradually disappears, and evolution of hydrogen gas is observed at potentials corresponding to the upper part of the curve, as the frequency of the vibration increases. At higher vibrational frequencies it is difficult to obtain definite values for the limiting current. This is attributed to the turbulent conditions which are more pronounced in the vicinity of the cathode. In this way the rate of the electrode reaction proper, which is mainly due to the evolution of hydrogen and deposition of copper, is becoming more pronounced and important in comparison with the diffusion and convection rates [6, 13].

The limiting current increases with increase in both frequency and amplitude (Figs. 2–3). This is due to the increased turbulence in the vicinity of the vibrating surface and is in qualitative agreement with the results previously reported [15, 16]. The same enhancement in mass transfer was observed for other transport processes occurring at vibrating surfaces such as the sublimation of naphthalene [16–18] and the dissolution of benzoic acid into water [18].

The increase in rate of mass transfer tends to a maximum which increases with increase in amplitude of vibration while the frequency, at which this maximum in mass transfer occurs, decreases as the amplitude increases (Fig. 3). For the maximum rate of mass transfer in this process, the use of low amplitudes coupled with higher frequencies is preferred. If higher amplitudes are to be used, then lower frequencies lead to the maximum rates of mass transfer as demonstrated from Fig. 3.

The circulation causing an increase of the mass transfer rate increases with increase in frequency and amplitude up to a certain limit where apparently a change in the circulation pattern takes place

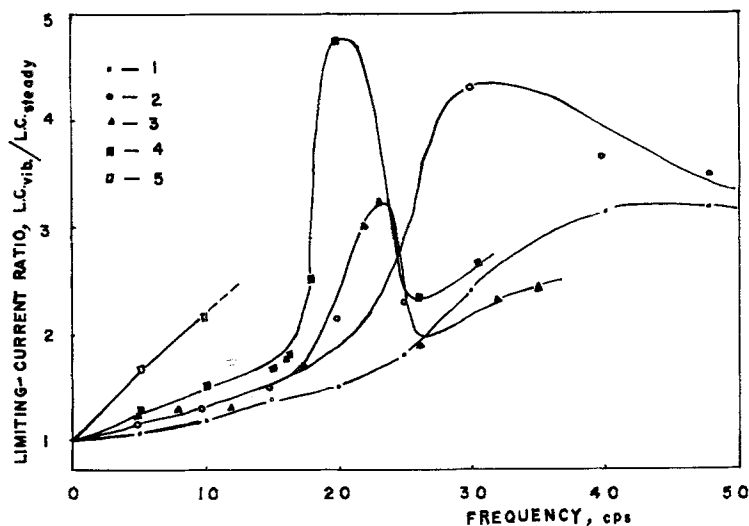


Fig. 2. Effect of vibration on the rate of mass transfer. Amplitude, 1, 1.5 mm; 2, 3 mm; 3, 4 mm; 4, 7 mm; 5, 8 mm.

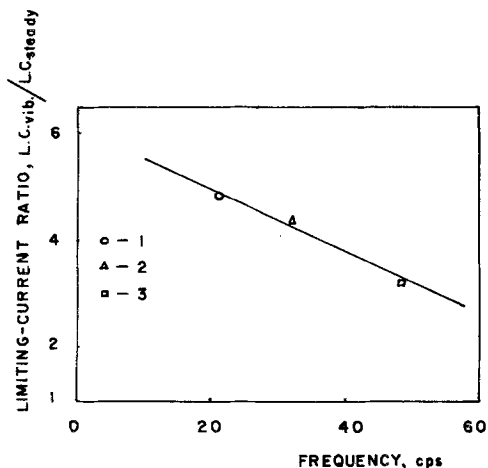


Fig. 3. Maximum rate of mass transfer and vibrating conditions. Amplitude, 1, 7 mm; 2, 3 mm; 3, 1.5 mm.

leading to a decrease of the mass transfer rate. Lemlich and Levy [19] have reported the existence of the two types of streaming based on experimental mass transfer data. Wragg [20] in his work on the flow through an annulus in which he generated both upward flowing natural convection, and downward flowing forced convection, found that an increase in forced convection is the cause of a decrease in the rate of mass transfer. Robinson [21] has observed this phenomenon of interaction

of flows. His experimental conditions were a laboratory electrowinning cell, where there was upward-flowing convection generated by the anodic evolution of oxygen bubbles, and the swirling forced convection of a propeller stirrer located below the electrode. He reported that the effect of propeller agitation is to decrease the bubble effect at the top of the electrode. Both the Wragg and Robinson works show a similar effect-destructive interference, which can be proved to be general to all systems where opposing flows are involved [22].

The role of this phenomenon in commercial processes is important. More work needs to be done on this little-known phenomenon.

#### Acknowledgement

I wish to thank Professor J. A. A. Ketelaar for valuable discussions. Thanks are also due to Professors M. Pourbaix, P. Cavellotti, K. Volenik, and H. E. Hintermann for helpful discussions. The help of Lab. Chim. Minér., University of Limoges, Limoges-87, France in the preparation of the manuscript is most gratefully acknowledged.

#### References

- [1] S. Bretsznajder, M. Jaszczak and W. Pasiuk,

- Khimicheskaya Promyshlennost*, 3 (1963) 51;  
*Int. Chem. Eng.* 3(4) (1963) 496.
- [2] E. C. Chen and W. Y. Chon, *Br. Chem. Eng. Process Technol.*, 16 (1971) 919.
- [3] N. Ibl, *Trans. SAEST* 5 (1970) 89.
- [4] D. R. Gabe and D. J. Robinson, *Electrochim. Acta*, 17 (1972) 1129.
- [5] H. S. Fogler and K. D. Timmerhaus, *AIChE J.* 12 (1966) 90.
- [6] S. Mohanta and T. Z. Fahidy, *Canad. J. Chem. Eng.* 50 (1972) 248.
- [7] S. Mohanta and T. Z. Fahidy, *ibid.* 434.
- [8] T. K. Ross and A. F. Aspin, *Corros. Sci.*, 13 (1973) 53.
- [9] R. Wall and L. C. F. Blackman, *Nature*. 202 (1964) 285.
- [10] A. N. Kvytkovskii, G. G. Vdovkin and B. V. Kudinov, *Sb. Tr., Nauch.-Issled. Proekt.* 2 (1971) 64; *Chem. Abstr.* 78:78952s.
- [11] M. G. Fouad and A. M. Ahmed, *Electrochim. Acta*, 14 (1969) 651.
- [12] N. Ibl and K. Schadeegg, *J. Electrochem. Soc.*, 114 (1967) 54.
- [13] N. Ibl, P. H. Javet and F. Stahel, *Electrochim. Acta*, 17 (1972) 733.
- [14] M. C. Fouad, F. N. Zein and M. I. Ismail, *Electrochim. Acta*, 16 (1971) 1477.
- [15] C. S. Lin, E. B. Denton, N. S. Gaskil and G. L. Putnan, *I.E.C.* 43 (1951) 2136.
- [16] C. V. Rama Raju, G. J. V. Jagannadha Raju and C. Venkata Rao, *Indian J. Technol.* 5 (1967) 305.
- [17] T. Venugopala Rao, *ibid.* 4 (1966) 223.
- [18] T. Sripathi and K. Somasundara Rao, *ibid.* 4 (1966) 27.
- [19] R. Lemlich and M. R. Levy, *Amer. Inst. Chem. Eng. J.*, 7 (1961) 240.
- [20] A. A. Wragg, *Electrochim. Acta*. 16 (1971) 373.
- [21] D. J. Robinson, *Electrochim. Acta*, 17 (1972) 791.
- [22] A. M. Al-Taweel and M. I. Ismail, AIChE C.S. Ch. E. Conference, Vancouver (Canada), September 9-12 (1973).