JOURNAL OF APPLIED ELECTROCHEMISTRY 9 (1979) 563–566

Mass transfer at rotating finned cylinders

G. H. SEDAHMED, A. ABDEL KHALIK,* A. M. ABDALLAH†

Chemical Engineering Department, Faculty of Engineering, Alexandria University, Alexandria, Egypt

M. M. FARAHAT

Chemical Engineering Division, Argonne National Laboratory, Argonne, Illinois, USA

Received 2 August 1978

Rates of mass transfer at rotating finned cylinders were studied by an electrochemical technique involving the measurement of the limiting current for the cathodic reduction of potassiun ferricyanide in a large excess of sodium hydroxide. The variables studied were fin height and Reynolds number. The ratio of the fin height to the cylinder diameter (e/d) ranged from 0·0185 to 0·075 while the Reynolds number ranged from 1047 to 10 470. Under these conditions, the mass transfer data could be correlated by the equation

$$J = 0{\cdot}714(Re)^{-0.39}(e/d)^{0.2}$$

Nomenclature

L_L		limiting current (A)
K		mass transfer coefficient ($\mathrm{cm\,s^{-1}}$)
Z		number of electrons involved in the reaction
C		ferricyanide concentration ($\mathrm{moles\,cm^{-3}}$)
F		Faraday's constant
A		projected cathode area ($\mathrm{cm^2}$)
u		dynamic viscosity ($\mathrm{g\,cm^{-1}\,s^{-1}}$)
ρ		density ($\mathrm{g\,cm^{-3}}$)
V		peripheral velocity at the rotating cylinder ($\mathrm{cm\,s^{-1}}$)
D		diffusion coefficient of ferricyanide ion ($\mathrm{cm^2\,s^{-1}}$)
d		cylinder diameter (cm)
e		fin height (cm)
J	=	$(St)(Sc)^{0.644}$ Colburn J factor
(Sc)	=	$u/(\rho D)$ Schmidt number
(Re)	=	$\rho Vd/u$ Reynolds number
(St)	=	K/V Stanton number

1. Introduction

Electrochemical reactors employing rotating cylinders as working electrodes are characterized by a uniform current distribution and high mass transfer coefficients.

Although some work on the mass transfer characteristics of the rotating cylinder electrode has been reported [1–7], little has been done to improve the performance characteristics of the electrode. Spencer *et al.* [8] used wiper blades to enhance the rate of mass transfer at a rotating cylinder electrode. Fahidy *et al.* [9] developed mass transfer correlations which predict the increase in the rate of mass transfer through the use of wiper blades.

The object of the present work is to improve the mass transfer characteristics of the rotating cylinder electrode through the use of fins. Finned surfaces have been used to enhance the rate of heat and mass transfer by many investigators [10–19] in the chemical engineering field. Kappesser *et al.* [20] studied the effect of surface roughness on the rate of mass transfer at rotating cylinders by measuring the limiting current of the cathodic reduction of dissolved oxygen; these authors used monel cylinders with staggered diamond knurls machined on their surface, they correlated their data with the equation

$$J = [1{\cdot}25 + 5{\cdot}76 \log (d/e)]^{-2}. \qquad (1)$$

The above equation is valid for Reynolds numbers above a critical value given by

$$(Re) = (11{\cdot}8d/e)^{1{\cdot}18} \qquad (2)$$

* Present address: Chemistry Department, Sulaimaniyah University, Iraq.
† Present address: Atomic Energy Establishment, Anshas, Egypt.

0021/891X/79/050563–04 $02·40/0

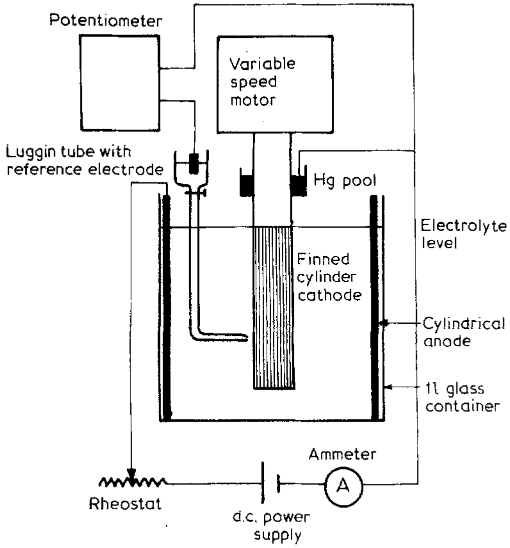

Fig. 1. Cell and electrical circuit.

2. Experimental technique

The cell (Fig. 1) consisted of two concentric cylinders made of nickel-plated copper and placed in a one litre cylindrical glass container. The outer cylinder served as the anode while the inner rotating cylinder acted as a cathode. The outer cylinder has a diameter of 10 cm and a height of 12 cm, the inner cylinder had a diameter of 1 cm and an active height (wetted) of 9 cm. The cathode was driven by a variable speed motor which gave a maximum speed of 2000 rev min^{-1}. Care was taken to avoid vibrations and eccentric rotation. An electronic tachometer was used to measure the speed of rotation. Six cathodes were used in the present study, one smooth and five finned. Fins were made by cutting longitudinal rectangular grooves in the cylinder. The fins had peak-to-valley heights (e) of 0·0185, 0·026, 0·053, 0·059 and 0·075 mm giving d/e ratios of 54, 38·5, 18·9, 17, and 13·3, respectively. In all cases, 28 grooves were cut in each cylinder. The fin spacing was 0·5 mm and fin width was 0·5 mm. The electrical circuit used consisted of a 6 V d.c. power supply with a voltage regulator, a multi-range ammeter and the cell. Polarization curves were constructed by increasing the applied current step-wise and measuring the corresponding steady state cathode potential against a reference electrode composed of a nickel wire placed in the cup of a luggin tube filled with the same solution as that used in the cell. The tip of the capillary of the luggin tube was placed 0·5–1 mm from the rotating cylinder. The electrolyte was

$$0{\cdot}025\ \text{M}\ K_3Fe(CN)_6 + 0{\cdot}025\ \text{M}\ K_4Fe(CN)_6 + 1\ \text{M NaOH}.$$

Before each run, dissolved oxygen was removed by bubbling nitrogen gas through the electrolyte. The cathodes were degreased with trichloroethylene, then washed with alcohol and distilled water. The flat end of the cathode was insulated by polystyrene lacquer. Electrolyte viscosity and density were measured with an Ostwald viscometer and a density bottle respectively, ferricyanide diffusivity

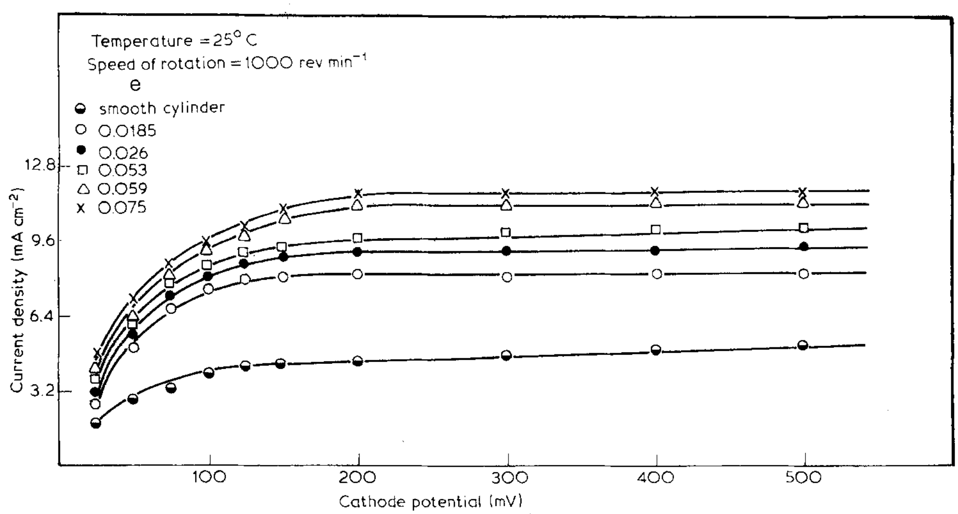

Fig. 2 Polarization curves for cylinders with fins of different heights.

was determined by the rotating disc technique [21].

3. Results and discussions

Fig. 2 shows typical polarization curves obtained with cathodes of different fin height. From these polarization curves the limiting current was determined and used in calculating the mass transfer coefficient according to the equation

$$K = \frac{I_L}{ZFAC}. \tag{3}$$

The projected (geometrical) area rather than the true area was used in calculating the mass transfer coefficient for the finned cathodes.

Fig. 3 shows the effect of Reynolds number on the Colburn J factor for cathodes with different fin height; the mass transfer data for a smooth cylinder is in agreement with that of Eisenberg *et al.* [1, 2]. The rate of mass transfer increases with increasing fin height. The percentage increase ranges from 30 to 140 depending on Reynolds number and fin height, the higher the Reynolds number the lower is the percentage increase in the rate of mass transfer for a given fin height. The increase in the rate of mass transfer caused by the presence of the fins can be attributed in part to the formation of vortices in the fin space when fluid from the main stream enters the fin space. Vortex formation in the fin space in surfaces with transverse rectangular fins has been demonstrated by many investigators who used different techniques [10, 16, 18, 19]. Apart from vortex promotion, fins increase the rate of mass transfer by increasing the available area of the mass transfer surface.

Fig. 4 shows that the mass transfer data at the finned rotating cylinder can be correlated by the following equation, with an average deviation of 5%:

$$J = 0{\cdot}714(Re)^{-0{\cdot}39}(e/d)^{0{\cdot}2}. \tag{4}$$

It is of interest to notice the difference in mass transfer behaviour between rough rotating cylinders as studied by Kappesser *et al.* [20] and finned rotating cylinders. Kappesser *et al.* found that after a certain critical Reynolds number given by Equation 2 the Colburn J factor becomes independent of Reynolds number and the mass transfer data is represented by Equation 1. For rotating finned cylinders, Fig. 4 shows that the Colburn J factor is a function of Reynolds number even for Reynolds numbers higher than the value given by Equation 2. The discrepency between the present work and that of Kappesser suggests that the pattern of surface roughness has a profound effect on the mass transfer behaviour of the rough surface.

Although the present study shows that fins have a beneficial effect on the rate of mass transfer at rotating cylinder electrodes, it is difficult at this

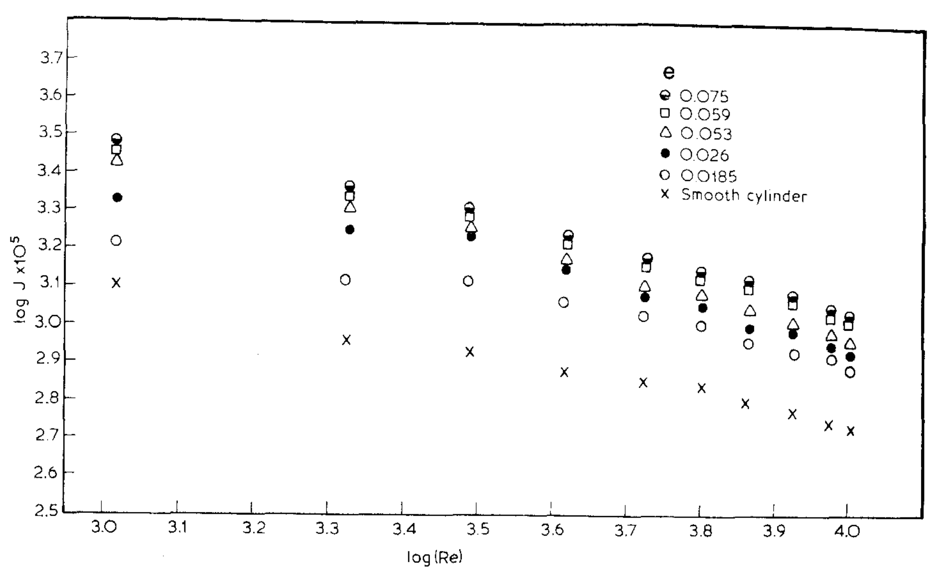

Fig. 3. Log J versus log (Re) for cylinders with fins of different heights.

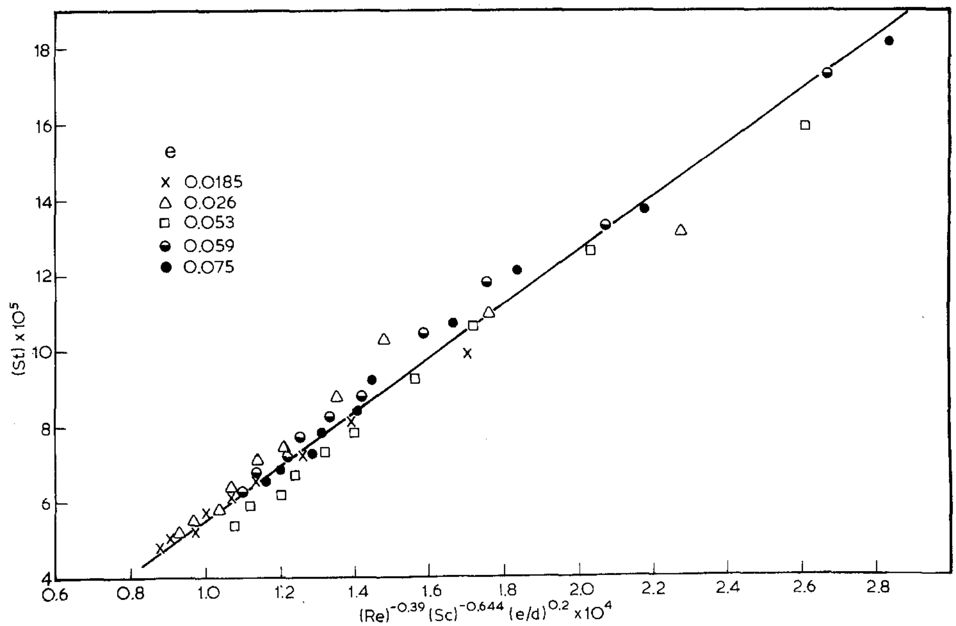

Fig. 4. Overall mass transfer correlation for finned rotating cylinders.

stage to recommend the use of rotating finned cylinders in practice. A final decision on the use of rotating finned cylinder in practice can be made after studying the momentum transfer characteristics of such surfaces and also studying the current distribution which may be affected by the surface roughness [22]. It should also be pointed out that the fin spacing was fixed and a more comprehensive study is needed to optimize the fin dimensions.

References

[1] M. Eisenberg, C. W. Tobias and C. R. Wilke, *J. Electrochem. Soc.* **101** (1954) 306.
[2] M. Eisenberg, C. W. Tobias and C. R. Wilke, *Chem. Eng. Prog. Symp. Ser.* **51** (1955) 1.
[3] D. J. Robinson and D. R. Gabe, *Trans. Inst. Met. Finish.* **48** (1970) 35.
[4] *Idem, Electrochim. Acta* **17** (1972) 1121.
[5] *Idem, ibid* **17** (1972).
[6] A. J. Arvia and J. S. W. Carrozza, *ibid* 7 (1962) 65.
[7] A. J. Arvia, J. S. W. Carrozza and S. L. Marchiano, *ibid* 9 (1964) 1483.
[8] M. S. Spencer, P. J. H. Carnell and W. J. Skinner, *Ind. Eng. Chem. Process Dec. Develop.* **8** (1969) 191.
[9] P. R. Nadebaum and T. Z. Fahidy, *Canad. J. Chem. Eng.* **53** (1975) 259.
[10] S. K. Stynes and J. E. Myers, *A.I.Ch.E.J.* **10** (1964) 437.
[11] E. L. Jarrett and T. L. Sweeney, *ibid* **13** (1967) 797.
[12] J. Fox, *Internat. J. Heat Mass Transfer* **8** (1965) 269.
[13] R. A. Seban, *ibid* 8 (1965) 1353.
[14] M. Avrami and J. B. Little, *J. Appl. Phys.* **13** (1942) 255.
[15] K. A. Gardner, *Trans. Amer. Soc. Mech. Engrs.* **67** (1945) 621.
[16] J. G. Knudsen and D. L. Katz, *Chem. Eng. Progr.* **46** (1950) 490.
[17] M. J. Harris and J. T. Wilson, *J. Brit. Nucl. Energy Conf.* **6** (1961) 330.
[18] D. J. Maull and L. F. East, *J. Fluid Mech.* **16(4)** (1963) 620.
[19] R. A. Seband and J. Fox, *International Developments in Heat Transfer. Proceedings 1961–62 Heat Transfer Conference* Amer. Soc. Mech. Engrs., New York (1963) p. 426.
[20] R. Kappesser, I. Corner and R. Greif, *J. Electrochem. Soc.* **118** (1971) 1957.
[21] V. G. Levich, 'Physicochemical Hydrodynamics', Prentice-Hall Inc, New York (1962).
[22] R. De Levie, 'Advances in Electrochemistry and Electrochemical Engineering' Interscience Publishers, New York (1967) Vol. 6.