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Technical Note

Free convective mass transfer at up-pointing pyramids of constant inclined length

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1. Introduction

In previous work the mass transfer rate in free convection conditions was measured at up-pointing pyramids [1] and down-pointing pyramids [2] with constant pyramid base and varying pyramid length using the limiting diffusion current technique. The present paper describes an extension of the work to mass transfer in free convection at up-pointing pyramidal electrodes with constant length of the inclined surface and varying length of the horizontal base. A wide range of angle of inclination from the vertical, between 10 and 50° is encompassed in the work.

2. Experimental

The experimental arrangement was as described previously [1], the mass transfer experiments being performed in a glass tank. A polarization curve for each cathodic pyramid/solution combination was constructed so that the potential at which the limiting current occurred could be determined and the value of the limiting current identified. Varying density differences between electrode surface and bulk fluid were achieved by varying the cupric sulphate concentration in the electrolyte between 0.017 and 0.23 M.

Table 1 shows the geometric characteristics of the pyramids used. This work considers a set of pyramids with constant inclined length, varying inclination angle from the vertical θ (10–50°) and varying pyramid base (1.2–5.2 cm). For experiments with single surfaces active only, the surface required to be inactive was stopped off with lacquer. The geometric parameters of the up-pointing pyramid are illustrated in Fig. 1.

3. Results and discussion

For each experiment the mass transfer coefficient was calculated from the measured limiting current using the equation:

$$k = \frac{I_L}{AnFc_b} \quad (1)$$

The area in this equation was the total available for mass transfer for the particular experiment. The correction for the attachment of the supporting conducting wire was small, never being more than 1.5% of the exposed area and usually being much less.

The dependence of total mass transfer coefficient on inclination angle θ and pyramid aspect ratio L/b is shown in Fig. 2a and b, respectively, for the five different cupric sulphate concentrations. It can be seen that the total mass transfer rate decreases with the increase in inclination angle from (10–30°) and then increases slightly as inclination increases from 30 to 50°. The change in mass transfer is not very high but the data exhibit the same trend for all five cupric sulphate concentrations. From Fig. 2b it is clear that the mass transfer rate firstly decreases with L/b, passes through a minimum and then increases steadily.

The presence of a minimum on the mass transfer rate dependence, which is more visible in Fig. 2b, can

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Nomenclature

A_t	total surface area of pyramid
A_i	area of single inclined surface of pyramid
A_{it}	area of all inclined pyramid surfaces
A_h	area of horizontal base of pyramid
b	base of pyramid (Fig. 1)
c_b	bulk concentration of cupric sulphate
F	Faraday constant
H_p	height of pyramid (Fig. 1)
H_h	vertical height of pyramid triangular base (Fig. 1)
I_L	limiting diffusion current
k	mass transfer coefficient
L	length of inclined surface of pyramid (Fig. 1)
n	charge number of cupric ion.

Greek symbol

θ	inclination angle from the vertical (see Fig. 1).

Table 1
Electrode geometries

Pyramid	b/cm	L/cm	θ/°	H_p/cm	H_h/cm	A_i/cm^2	A_{it}/cm^2	A_t/cm^2	A_{it}/A_h	L/b
6	1.16	1.96	10	1.93	1.00	1.14	3.41	4.02	5.81	1.69
7	2.31	1.97	20	1.85	2.00	2.28	6.83	9.14	2.95	0.85
8	3.39	1.96	30	1.70	2.94	3.22	10.00	14.98	2.00	0.59
9	4.34	1.98	40	1.52	3.76	4.30	12.90	21.05	1.58	0.46
10	5.22	1.99	50	1.28	4.52	5.20	15.58	27.38	1.32	0.38

be explained as follows. Total mass transfer is strongly affected by the behavior of the down-facing horizontal surface. This effect was already mentioned in [1]. The down-facing horizontal surface (associated with the up-pointing pyramid) not only has a significantly lower mass transfer performance than an up-facing surface, but also feeds depleted solution to the 'leading edges' of the inclined up-facing surfaces, thus decreasing their contribution to the total behavior. This effect means that the total mass transfer rate should decrease with increasing ratio of horizontal to total inclined surface area and, therefore, in the case of constant inclined pyramid length, with increasing inclination angle or with decreasing L/b ratio.

There is another effect which has to be taken into the consideration—the effect of inclination angle on the mass transfer rate at the up-facing inclined surfaces of the pyramid. This effect means that the total mass transfer rate should increase with increasing inclination of the up-facing surface from the vertical as demonstrated for inclined planes by Patrick et al. [3]. Thus,

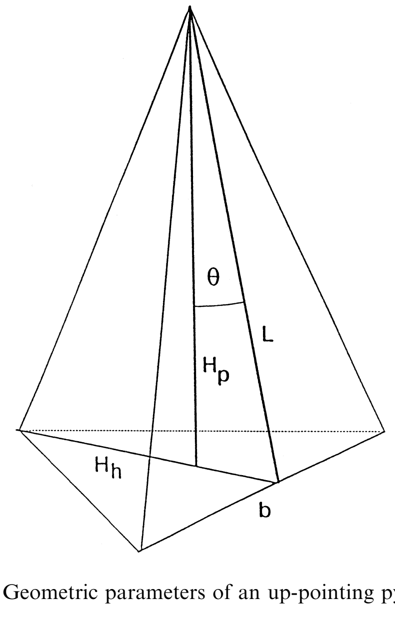

Fig. 1. Geometric parameters of an up-pointing pyramid.

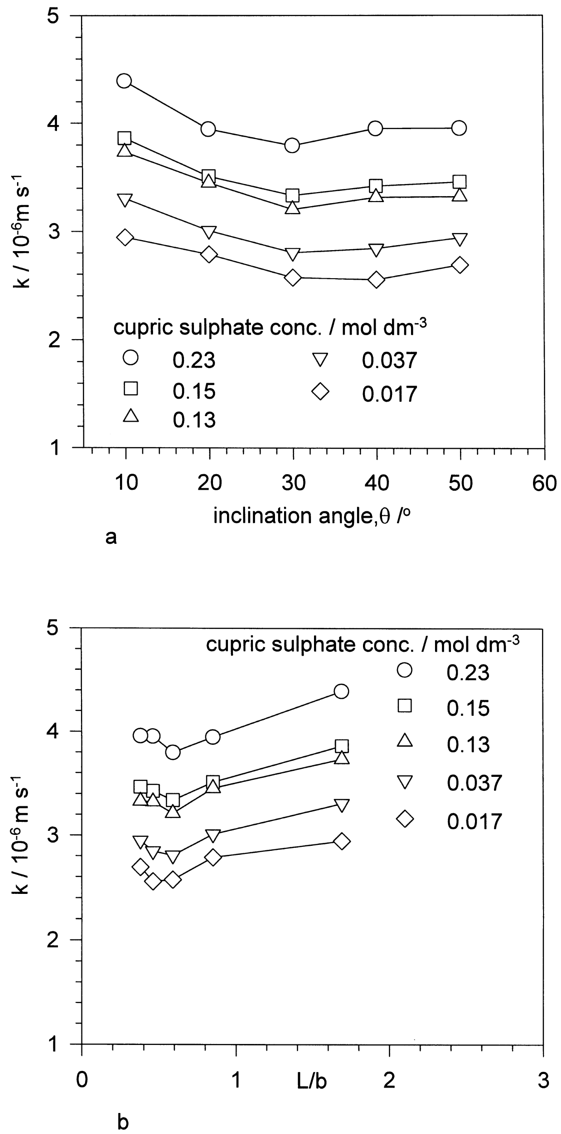

Fig. 2. (a) The effect of the inclination angle on the total mass transfer coefficient for an up-pointing pyramid of constant pyramid length; (b) the effect of inclined length to base ratio on the total mass transfer coefficient for an up-pointing pyramid of constant pyramid length.

in the case of constant inclined pyramid length, there are two opposed effects on the total mass transfer rate; firstly, the ratio of horizontal to total inclined surface area and, secondly, the inclination angle. It was not possible to observe the influence of these effects in the case of pyramids with constant base [1] where the length of inclined surface increased together with a decrease in inclination angle and these two effects led to a decrease in mass transfer rate.

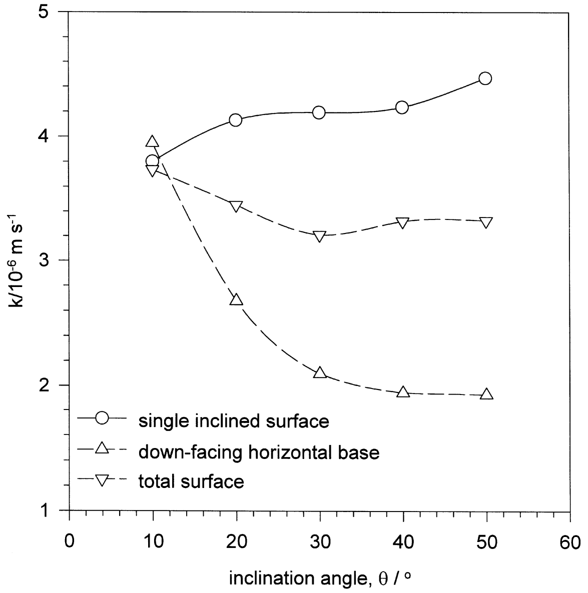

Fig. 3. The effect of the inclination angle on mass transfer coefficient for different surfaces of up-pointing pyramid (constant pyramid length) for a single concentration of cupric sulphate (0.13 mol dm^{-3}).

The influence of the above effects on the total mass transfer rate was investigated in more detail by measuring the transfer rates at the separate surfaces of the present pyramids and comparing these data with the total mass transfer rate. The results are shown in Fig. 3. The mass transfer rate for a single inclined surface increases with the inclination angle and is, except for the pyramid with inclination 10°, significantly higher than that for the down-facing horizontal base. The mass transfer rate for the down-facing horizontal surface decreases with the increasing pyramid inclination angle. The reason is that with an increasing inclination angle and constant pyramid length, the pyramid base increases from 1.16 to 5.22 cm. The decrease in mass transfer coefficient with increasing pyramid base indicates laminar flow at down-facing horizontal surfaces and was previously correlated by Eq. [1]

$$Sh_{H_h} = 0.39(Ra_{H_h})^{0.25} \quad (2)$$

for Ra_{H_h} in the range 1×10^8 to 1×10^{11} and with the height of the triangular horizontal base (H_h) as the characteristic dimension in the Sherwood and Rayleigh numbers.

The total mass transfer is a result of the contributions of three inclined up-facing and one down-facing horizontal triangular surfaces. These separate surfaces not only have significantly different mass transfer rates but also an opposite dependence on inclination angle which thus governs the shape of the total mass transfer dependence on inclination angle and L/b ratio (Fig. 2a and b).

Acknowledgement

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