SHORT COMMUNICATION

# *Mass transfer at rough surfaces: reconsideration of data reported by Sedahmed* et al.

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## 1. Introduction

It is well established that surface roughness can increase the rates of mass transfer, and in recent papers [1, 2] we have discussed the systematic use of roughness as a technique to enhance mass transfer at rotating cylinder electrode surfaces. Artificial roughness of various regular geometrical patterns – notably 'V' grooves and knurled pyramids – has been used to determine the degree of enhancement precisely [1, 2]. Only one set of data to which this methodology can be satisfactorily applied has been found in the literature: this is work reported by Sedahmed *et al.* [3] using finned cylinder electrodes.

Sedahmed *et al.* [3] used cylinders in which fins were produced by machining rectangular grooves at a constant pitch of 1.0 mm but with varying groove depths from 0.0185 to 0.075 cm. Their mass transfer data covered a relatively narrow range of rotation, i.e. $1000 < Re < 10\,000$ and was correlated according to:

$$j_D = 0.714 Re^{-0.39}(e/d)^{0.2}$$

where $e$ is the fin height, $d$ the cylinder diameter, $j_D$ the Chilton–Colburn J factor $= StSc^{2/3}$, and $Re$ is defined as $Ud/\nu$ in the usual way.

## 2. Modification of data

The data can be modified by considering the geometric form (see Fig. 1), with symbols defined as follows:

$d$, electrode diameter = 1.0 cm
$l$, electrode length = 9.0 cm
$N$, number of square grooves = 28
$w$, groove width (fixed) = 0.05 cm
$\varepsilon$, groove depth (variable) = 0.0185–0.075 cm

We may now calculate

(a) Apparent surface area, $A_p = \pi dl = 28.27\ \text{cm}^2$.

(b) Minimum diameter, $d' = (d - 2\varepsilon) = 0.894$ cm when $\varepsilon = 0.053$ cm.

(c) True perimeter per pitch dimension = ABCDE when the nominal circumference = $\pi d = 28(w + y)$, $y$ being slightly curved. Setting $28(w + y) = 28.27$, $y \approx 0.05$ and hence $\text{ABCDE} = 2(w + \varepsilon) = 0.206$. Thence the effective electrode area $A_R = nl \times 0.206 = 51.96\ \text{cm}^2$.

(d) The roughness area factor is $A_R/A_p$ and for this example is equal to 1.836.

(e) The apparent Reynolds number is

$$Re = Ud/\nu = k\omega d^2$$

where $k$ is a constant and $\omega$ is the angular velocity. Modifying this quantity on the basis of the effective diameter, $d'$, we have

$$Re' = k\omega d^2(d'/d)^2$$

Typically, if $\varepsilon = 0.053$ cm, $Re' = 0.7992 Re$.

(f) An approximate modification of the $j_D$ factor necessitates multiplication by the ratio $A_p/A_R$.

## 3. Data representation

The data of Sedahmed *et al.* [3] have been

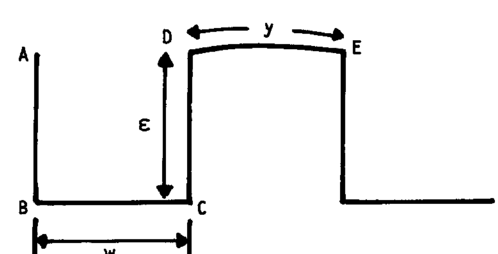


Fig. 1. Schematic geometrical form of a square groove.

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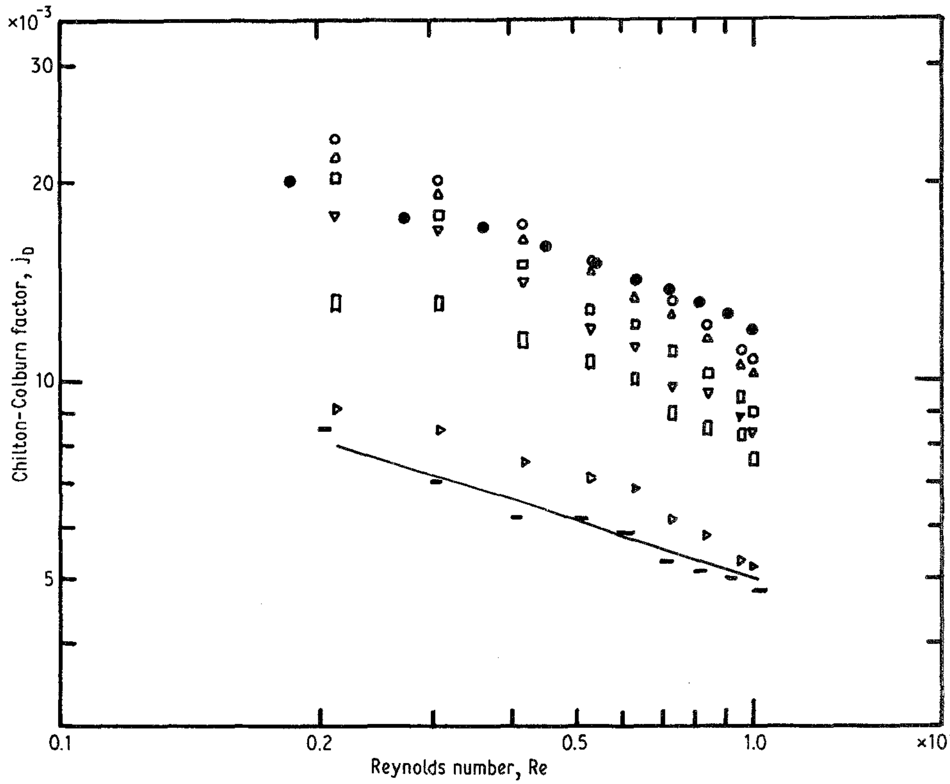


Fig. 2. Comparison of modified data for 'V' grooves with conventional data for square grooves. —, Correlation of Eisenberg *et al.* [6] for a smooth cylinder; –, smooth electrode S2; ●, longitudinally grooved cylinder (PL4); ▷, data of Sedahmed *et al.* [3]; ▫, rough cylinder, $E$ = 0.0185 cm; ▿, rough cylinder, $E$ = 0.026 cm; □, rough cylinder, $E$ = 0.053 cm; △, rough cylinder, $E$ = 0.059 cm; ○, rough cylinder, $E$ = 0.075 cm.

modified according to the procedure detailed above and plotted graphically as $j_D'$ versus $Re$ in Fig. 2, together with data from our own work for 'V' grooves machined into an electrode of diameter 1.5 cm. However, to provide the fairest comparison in behaviour between cylinders of varying true area and diameter, $Re'$ should be employed for all the data; this procedure is used in Fig. 3 for the same set of data.

At first glance the results in both studies would seem to follow a similar pattern, but a closer study of Fig. 3 shows some interesting differences. The electrode with the smallest groove depth (i.e. 0.0185 cm) corresponds to an optimum roughness height for $Re < 4000$, but above a height of 0.026 cm the performance declined sharply, falling below that observed for a smooth cylinder at $Re > 6000$. Thus, on an equivalent area basis no enhancement occurred. It appears, therefore, that square-grooving is less efficient than 'V' grooving in providing mass transfer enhancement.

The deeper the cavity the less likely it is that eddy penetration will occur over the full depth. Thus, beyond a certain depth, the contribution of a large proportion of active area becomes less effective in providing surface microturbulence. Furthermore, it may also be noted that keeping the rib or fin spacing (i.e. the pitch) constant while increasing the groove depth does not increase the mass transfer coefficient, because the groove merely acts as a reservoir for the reagent and does not provide effective turbulence promotion. This is, in fact, in accord with mass transfer studies using microelectrodes [4].

A further observation from Fig. 3 is that electrode PL4 is more effective at enhancement than the square-grooved electrodes (PL4 was longitudinally knurled with a diameter of 1.512 cm and roughness height of 0.05 cm). This suggests

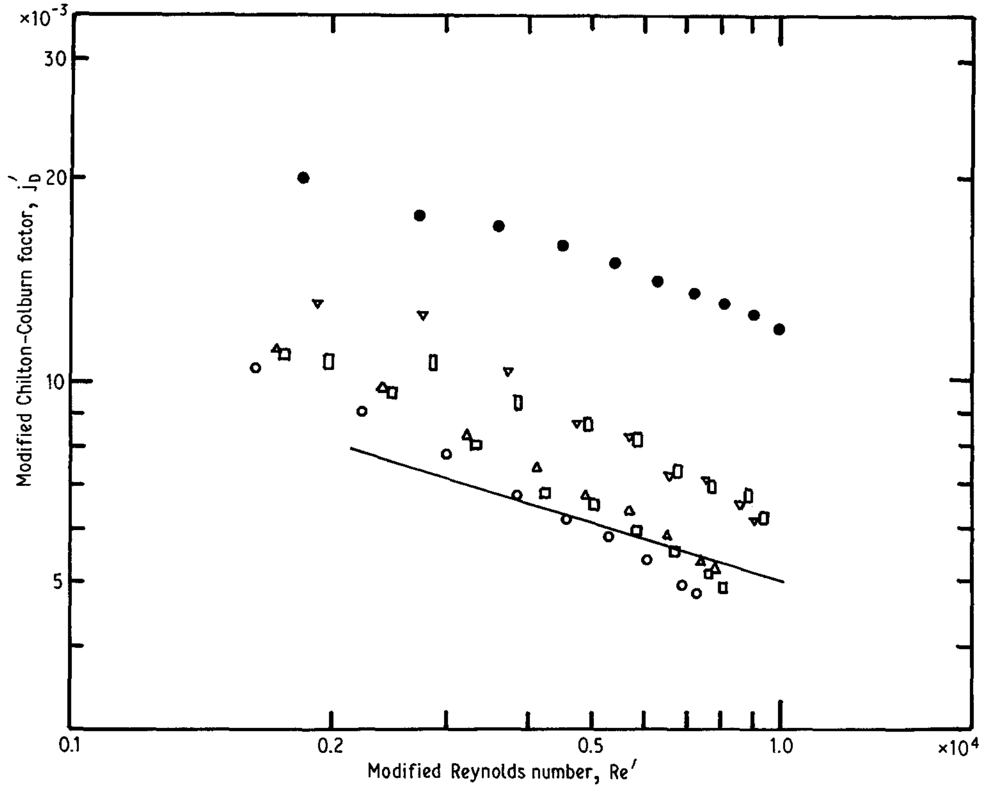


Fig. 3. Comparison between modified data for 'V' and square grooves. Symbols as in Fig. 2.

that there is an optimum form of 'V' groove roughness, of which square grooves are an extreme form; this is substantiated by heat transfer studies of Han *et al.* [5] who showed that the optimum angle of flow attack was 45°, this angle being clearly superior to 22°, 75° or 90° for flow across a rough planar surface.

## Reference


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