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A parameter characterizing the geometry of expanded metal. I. A general mass transfer correlation for flow-by electrodes of expanded metal and wire cloth

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A dimensionless parameter characterizing the geometry of expanded metal is presented and successfully applied in the correlation of mass transfer results obtained by other authors with flow-by electrodes of this material. The geometric term seems to apply also to nets arranged parallel to the flow.

1. Introduction

Recently, several investigations of the behaviour of expanded metal electrodes have been published. For instance, expanded metal electrodes were found to be very effective in diverting gas bubbles in water electrolysis, thus decreasing the ohmic potential drop across the electrolyte [1]. In a new electrochemical cell, recently patented, sheets of expanded metal are used as one of the electrodes, allowing high mass transfer coefficients at low flow rates [2].

Expanded metal electrodes present a higher specific area than conventional planar electrodes, they promote turbulence in the electrolyte flowing over them and are easy to produce. Stacks of expanded metal sheets, working as three-dimensional electrodes are also promising. In this case two more advantages can be added when they are compared with granular bed electrodes: their high mean porosity and the rigid structure, which makes them easy to handle.

Leroux and Coeuret [3–5] examined the behaviour of such stacks, having both axial and perpendicular configurations. They studied the potential distribution within the flow-through and flow-by electrodes experimentally, finding good agreement with results calculated from an approximate theoretical model. They also examined the mass transfer between the electrolyte and the expanded metal and the current distribution across the stack, demonstrating the influence of the mode of arrangement of the sheets with respect of each other and with respect to the general electrolyte flow direction.

The mass transfer results were given in terms of mass transfer coefficient, k, versus velocity, u. Unfortunately no empirical correlations could be found because it seemed to be impossible to define a characteristic dimension for the stack of grids. Nevertheless, a general correlation between the mass transfer coefficient and the other variables involved may be of great interest for the design of electrochemical reactors.

According to dimensional analysis of liquid–solid mass transfer in fixed beds, results may be correlated by a dimensionless relationship relating the Sherwood number (Sh) to the Reynolds (Re) and Schmidt (Sc) numbers, including a dimensionless parameter characterizing the geometry of the bed.

The aim of the present work is to find an appropriate form of the latter term for the geometry of expanded metal sheets. The analysis is limited to the case of flow parallel to the grids since this system was found to yield higher conversions and more uniform potential distribution, being more appropriate for scale-up than the flow-through system.

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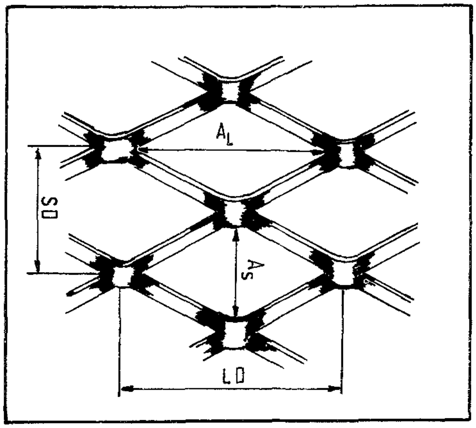

Fig. 1. Characterization of expanded metal.

2. Characteristic geometric parameter

It is well known from the literature that in isotropic beds formed by spherical or similar particles the particle diameter is the most commonly used dimension for characterizing the system. For irregular packings difficulties arise from the inhomogeneities and other geometric parameters have to be introduced. Thus, for packed beds of irregular shaped particles the characteristic dimension of the flow cross-section will be the hydraulic radius, R_h, which can be calculated from the mean porosity and the specific surface of the bed: $R_h = \varepsilon/\phi$. It relates the volume of the liquid filling the voids to the transferring surface area.

Bearing in mind the turbulence-promoting nature of the expanded metal and the influence of the mesh orientation with respect to the flow direction found by Leroux and Coeuret, it was assumed that the mean aperture of the mesh (A) in the flow direction will affect mass transfer. It is a measure of the distance between consecutive turbulence promoters and transferring material. The diffusion layer, built up along the metallic portion of the electrode, breaks down and is dissipated in the opening of the expanded metal, starting to grow again on the next metallic portion. Therefore, the geometric factor entering the general correlation should be R_h/A.

3. Application to data correlation

To confirm the validity of this reasoning the original mass transfer results obtained for parallel flow with stacks of expanded metal [6] and those obtained with a single sheet of the same material [7] were correlated in the form

$$Sh = f(Re, Sc, R_h/A) \quad (1)$$

Since no other dimension of the expanded metal seems to predominate, the hydraulic radius was used for the definition of the Sherwood and Reynolds numbers.

Fig. 1 shows the various parameters which describe the geometry of a mesh. Table 1 lists the experimental conditions and Table 2 lists the most important characteristics of the electrode materials. Information related to another investigation [8], dealing with stacks of nets, is also included.

In Fig. 2 the experimental data obtained with stacks and single sheets are presented as Sh versus Re. As stated before, the results can not be expressed by relations between these dimensionless numbers only, but when the term for the geometry of the system is included, a non-linear regression analysis yields the following single expressions.

For stacks of expanded metal sheets:

$$Sh = 0.71 Re^{0.54} Sc^{0.33} (R_h/A)^{0.38} \quad (2)$$

with a mean deviation of 3.63%. For single

Table 1. Experimental conditions

Reference	*Material**	*Viscosity,* $\bar{\nu} \times 10^2$ *(cm^2 s^{-1})*	*Diffusivity,* $D \times 10^6$ *(cm^2 s^{-1})*	*Velocity,* u *(cm s^{-1})*	*Schmidt number*
[6]	I, II	0.92	6.5	2–15	1430
[7]	I, II	0.94	8.8	2–5	1070
[8]	III, IV	0.914	8.8	2–50	1040

* See Table 2 for details.

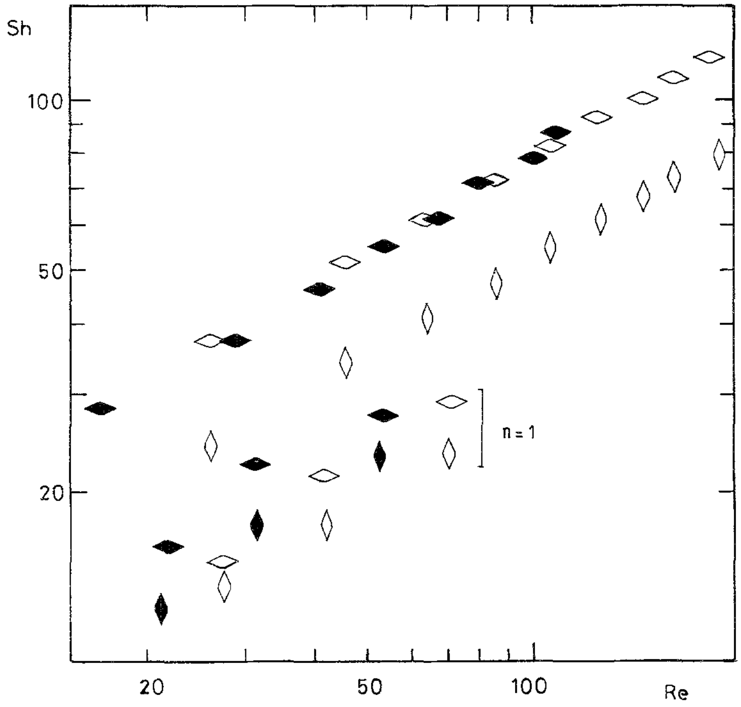

Fig. 2. Experimental mass transfer results for single sheets ($n = 1$) and stacks of expanded metal taken from the literature. Material I: ◇, LD parallel to flow; ◇, SD parallel to flow. Material II: ◆, LD parallel to flow; ◆, SD parallel to flow. Material III, ○; material IV, ●.

sheets of expanded metal:

$$Sh = 0.375 Re^{0.56} Sc^{0.33} (R_h/A)^{0.36} \quad (3)$$

with a mean deviation of 5.13%. (The experimental results differing by more than 20% from the correlation value were excluded from the regression analysis. In the latter case, 3 of 12 values had to be rejected.)

Because of the rhomboidal shape of the opening of a mesh, the mean aperture was taken to be equal to $A_L/2$ when the sheet was arranged with the long dimension (LD) parallel to the flow direction, and equal to $A_S/2$ when the small dimension (SD) was oriented in the flow direction. Adopting the exponent 0.38 for the geometric term for both cases considered, Equation 3 can be modified, yielding:

$$Sh = 0.377 Re^{0.515} Sc^{0.33} (R_h/A)^{0.38} \quad (4)$$

with a mean deviation of 4.67%.

Equations 2 and 4 are plotted in Fig. 3, together with the data points. The mass transfer rates between the electrolyte and the stacks are about 50% higher than those obtained with the single sheets. This may be explained by the fact that in the former case the neighbouring sheets, all promoting turbulence, interact with each other, thus enhancing mass transfer.

From the results presented here, derived on the basis of a few available data, it seems that the geometric factor R_h/A is an appropriate and helpful parameter for correlating the experimental

Table 2. Electrode characteristics

Material	*LD (mm)*	*SD (mm)*	*A_L (mm)*	*A_S (mm)*	*ϕ (mm^{-1})*	*ε*	*d (mm)*	*R_h (mm)*
I	16	6.5*	12*	4*	0.656	0.863	–	1.31
II	10	4.7*	8*	3.7*	0.862	0.855	–	0.99
III	–	–	0.27	0.27	7.25†	0.71†	0.16	0.098
IV	–	–	1.41	1.41	2.40†	0.73†	0.45	0.304

* Estimated from photographs [7]; † estimated following Blass [9].

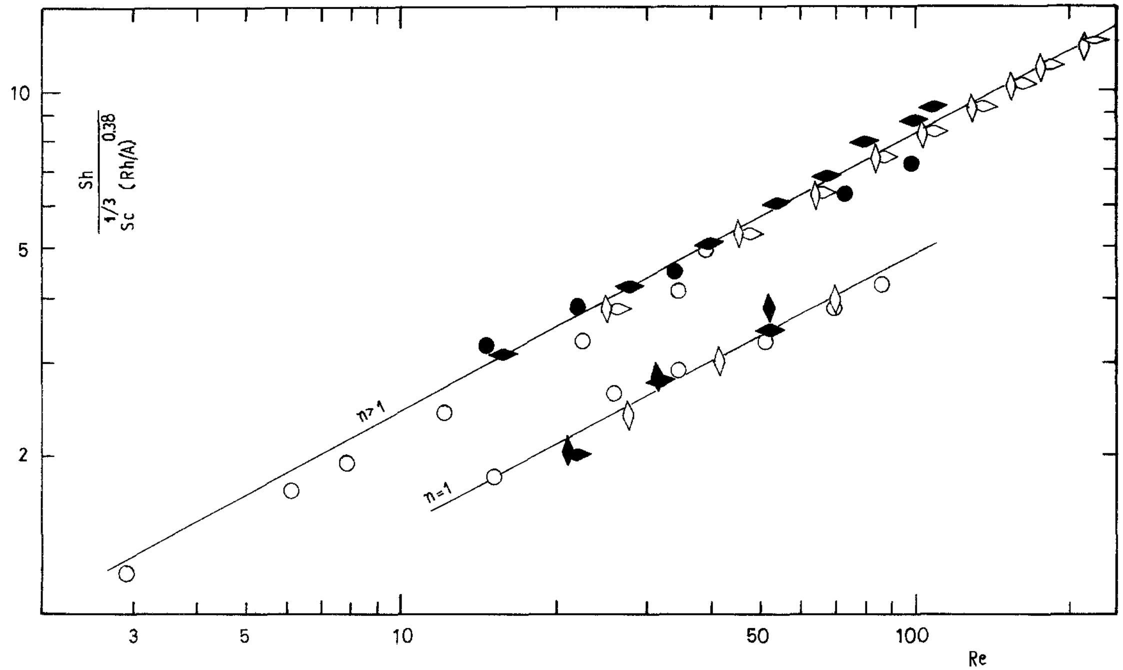

Fig. 3. Correlation of forced convection mass transfer results for flow-by electrodes of expanded metal and wire cloth. Symbols as in Fig. 2.

mass transfer results obtained with flow-by electrodes of expanded metal.

Storck *et al.* [8], who studied mass transfer to stacked net electrodes with the electrolyte flowing in the longitudinal direction, also commented on the difficulty of finding an exact representation of the results. They stated that the wire diameter is one of the most significant quantities affecting the mass transfer, but is insufficient for describing the geometry of the system. The porosity of the nets was introduced as a second parameter, although it is known that it varies little from gauze to gauze. An attempt was therefore made to correlate the results of these investigators with the help of the geometric factor encountered for the expanded metal, the wire diameter being retained for the definition of the Sherwood and Reynolds numbers. Fig. 3 includes some of the data obtained with stacks of nets and also with a single net. The result is quite encouraging; however, the availability of more data is necessary to confirm the applicability of the proposed geometric factor for the case of woven nets arranged parallel to the flow direction.

Acknowledgements

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