SHORT COMMUNICATION

Natural convection mass transfer at expanded metal electrodes of different structures

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Received 16 August 1988; revised 6 January 1989

Nomenclature

A	mean mesh aperture
c_0	electrolyte concentration
D	diffusivity
g	acceleration due to gravity
Ga	Galileo number $= gL^3/\nu^2$
Gr	Grashof number $= g\Delta\varrho L^3/\varrho\nu^2$
k	mass transfer coefficient
L	electrode height
LD	long dimension of expanded metal
R_h	hydraulic radius $= \varepsilon/\phi$
Sc	Schmidt number $= \nu/D$
SD	small dimension of expanded metal
Sh	Sherwood number $= kL/D$
α^*	densification coefficient $= \frac{1}{\varrho}\frac{d\varrho}{dc}$
ε	gas void fraction
ε_M	porosity of expanded metal
μ	dynamic viscosity
ν	kinematic viscosity
ϱ	density
ϕ	electrode area per unit volume
ψ	electrode area per unit net area

1. Introduction

In a previous investigation [1] mass transfer to expanded metal electrodes in bubble columns was studied employing a variety of materials. It was found that materials of fine structure, resembling wire gauzes, yielded higher mass transfer rates than materials of large structure whose aspect tends to planar electrodes. The former present a small relation of working area to projected area, $\psi \leqslant 1.5$; for the latter $\psi > 1.5$. Nevertheless, when the parameter ψ was included, a single correlation could be derived using the experimental data of both types of materials. This relation is:

$$Sh = 0.92(ScGa)^{0.33}\psi^{-0.6}\varepsilon^{0.3} \quad (1)$$

In view of these results it appeared to be of interest to extend another previously published investigation [2] which dealt with natural convection mass transfer at expanded metal electrodes, but using only materials of fine structure. So, experiments on natural convection mass transfer were undertaken with materials of large structure in order to correlate the experimental data of both types of materials together.

2. Experimental details

Mass transfer coefficients were determined by measuring limiting currents for the reduction of ferricyanide ions in alkaline solutions (all 2 M in NaOH). Five concentrations of the redox couple potassium ferri-ferrocyanide (ranging from 0.025 to 0.2 M) were used. Viscosities and densities of the solutions were measured by conventional methods. The diffusivity and the densification coefficients were obtained as indicated in Refs [3] and [4], respectively. The properties of the solutions at 25° C are summarized in Table 1.

The parameters characterizing the geometry of the different electrodes employed in this investigation are listed in Table 2. The electrodes were constructed from expanded metal of large structure ($\psi > 1.5$) presenting rhomboidal or hexagonal designs. Different mesh orientations were tested. For orientation I the long dimension is arranged parallel to the flow direction; for orientation II the small dimension is in this direction and for orientation III the long dimension of the rhombus formed an angle of 70° with the vertical.

The greater part of the investigation was carried out with materials E, F and G. Materials H and I, commercially called 'microexpanded metals', were only used to determine the applicability of the general correlation to these materials.

3. Results and discussion

Figure 1 shows the experimental results obtained with the electrodes E, F and G, of large structure, together with the relationship which had been derived for electrodes of fine structure:

$\psi \leqslant 1.5$:

$$Sh = 1.29(ScGr)^{0.27}(R_h/A)^{0.46} \quad (2)$$

It should be pointed out that for both types of

Table 1. Electrolyte properties at 25° C

$c_0 \times 10^3$ (mol cm^{-3})	ϱ (g cm^{-3})	$\mu \times 10^2$ (g cm s^{-1})	$D \times 10^6$ (cm^2 s^{-1})	α^* (cm^3 mol^{-1})
0.025	1.08	1.28	5.80	16.8
0.05	1.095	1.39	5.34	14.5
0.10	1.117	1.49	4.98	11.75
0.15	1.134	1.57	4.74	10.0
0.20	1.154	1.64	4.54	8.9

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Table 2. Characteristics of expanded metal electrodes

Material	LD-N-E	*Width* (cm)	*Height* (cm)	ψ	SD (mm)	A (mm)	ε_M	ϕ (cm^{-1})	R_h (mm)	R_h/A	*Orientation*
E	16–2.0–1.0	3.175	4.0	1.56	7.3	2.1	0.827	5.11	1.62	0.77	I
	(rhomboidal)	2.22	3.18	1.56	7.3	6.11	0.827	5.11	1.62	0.265	II
		2.04	3.20	1.56	7.3	2.0	0.827	5.11	1.62	0.81	III
F	16.3–2.5–1.0	2.27	3.19	2.02	6.0	1.2	0.664	8.08	0.82	0.68	I
	(hexagonal)	2.23	3.25	2.02	6.0	5.7	0.664	8.08	0.82	0.14	II
G	28.5–2.0–1.0	2.25	2.90	1.85	6.5	2.35	0.803	5.6	1.43	0.61	I
	(hexagonal)	2.38	3.35	1.85	6.5	12.8	0.803	5.6	1.43	0.11	II
H	2.5–0.4–0.2 (rhomboidal)	1.44	3.58	2.33	1.0	0.5	0.653	58.3	0.11	0.22	II
I	1.5–0.3–0.2 (rhomboidal)	1.51	3.52	2.69	0.7	0.35	0.565	134.6	0.04	0.114	II

materials the exponent of the group ($ScGr$) was almost the same, but the exponent of the geometric parameter (R_h/A) varied considerably. The mass transfer data obtained in this investigation can be well correlated by the equation:

$\psi > 1.5$:

$$Sh = 0.936(ScGr)^{0.27}(R_h/A)^{0.204} \quad (3)$$

Again the mass transfer rates for the materials having an electrode area per unit net area less than 1.5 are higher than those achieved with expanded metal having $\psi > 1.5$. This result may be explained by the fact that in the latter case the density of the turbulence promoters over the electrode surface is smaller than in the former case. But it also indicates that the parameter (R_h/A) introduced in an early paper [5] for describing the turbulence-promoting nature of expanded metal, is insufficient for characterizing the geometry of these materials. When the geometric parameter, ψ, is added to the dimensionless groups in Equations 2 or 3, it is possible to derive a single mass transfer correlation for natural convection at expanded metal of fine and large structure. This correlation is:

$$Sh = 1.43(ScGr)^{0.265}(R_h/A)^{0.19}\psi^{-0.6} \quad (4)$$

with a standard deviation of 8.11%.

The similarity among correlations 1 and 4 relates to a model developed by Sigrist *et al.* [6] for mass transfer in bubble columns. According to these authors the motion of the bubble dispersion can be considered to be analogous with turbulent-free convection. The gas void fraction ε on one hand and the parameter (R_h/A) on the other hand are related to the turbulence promotion; the Galileo number and the Grashof number describe the motion due to buoyancy of the bubble dispersion and of the electrolytic solution respectively.

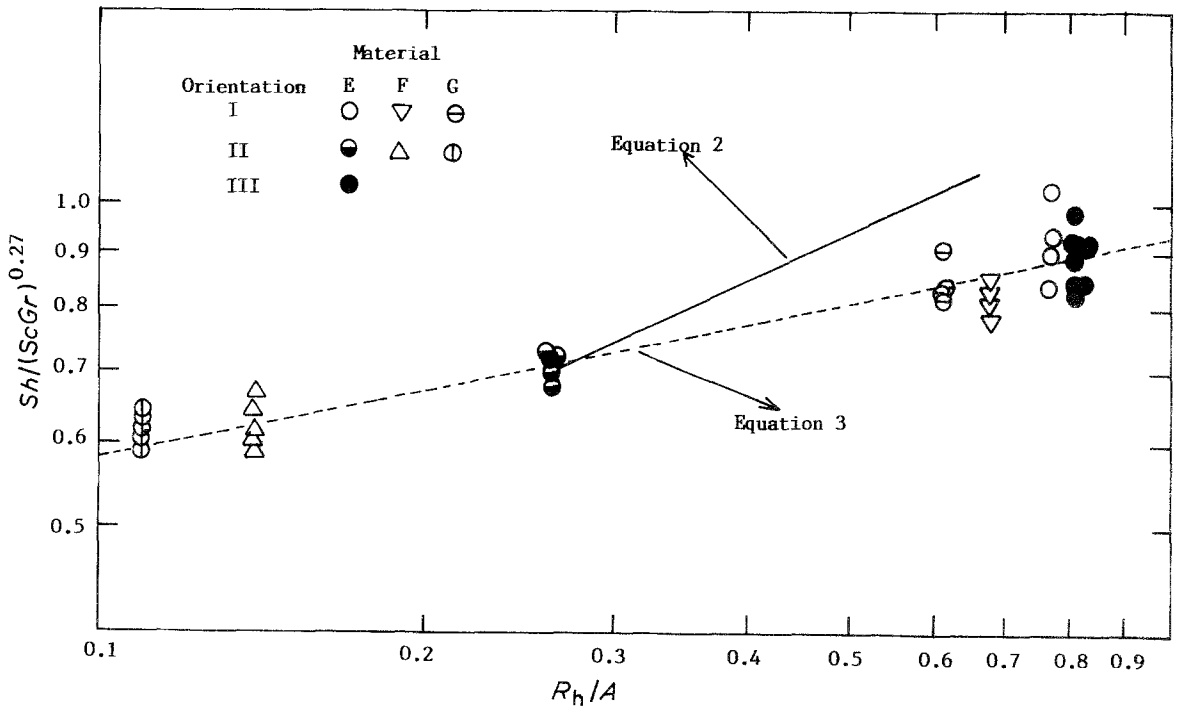

Fig. 1. Natural convection mass transfer results for expanded metal electrodes.

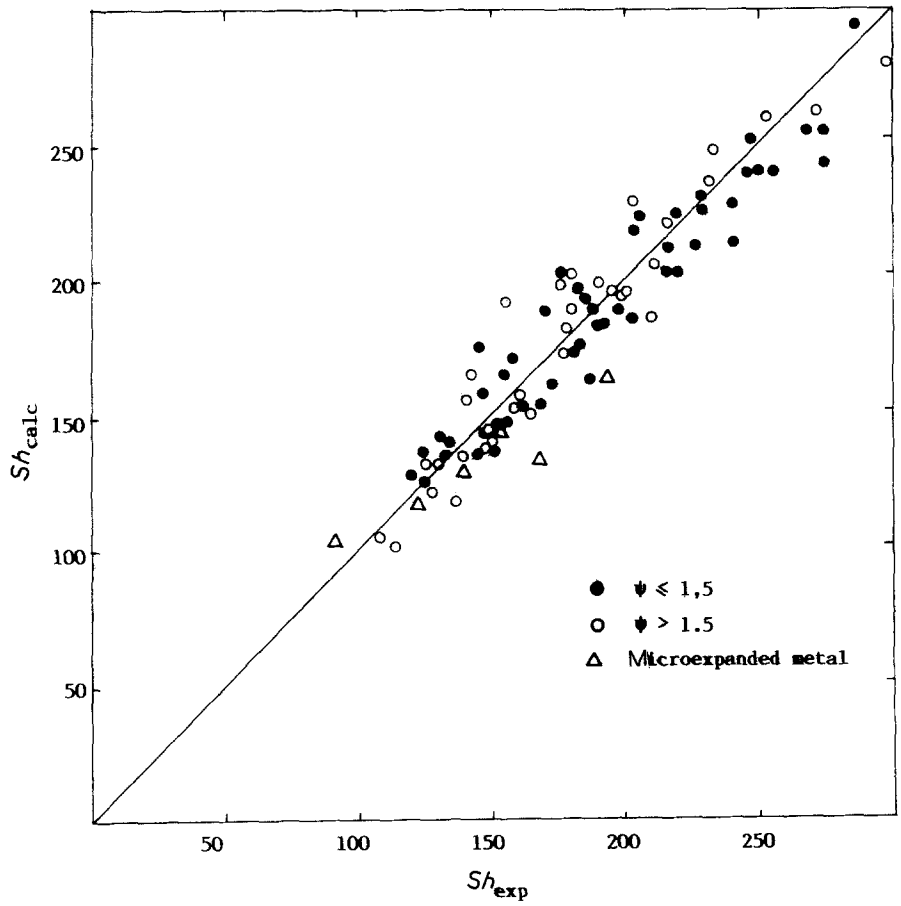

Fig. 2. Comparison between calculated and experimental values of Sherwood numbers for expanded metal of large and fine structure and for microexpanded metal.

In order to test the applicability of correlation 4 to another type of expanded metal a few experiments were carried out with electrodes of microexpanded metal (materials H and I). As can be seen from Table 2, these materials exhibit very different dimensions and specific area; however the geometric parameter (R_h/A) is similar to that of materials E, F and G.

Figure 2 compares the Sherwood numbers deduced from Equation 4 to the experimental values obtained in the previously mentioned work [2] with electrodes of fine structure and the values of the present investigation corresponding to expanded metal of large structure and to microexpanded metal. The correlation is seen to hold quite satisfactorily for all types of materials tested.

References

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