



Liquid–solid mass transfer behavior of V-corrugated surfaces under two phase flow



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ABSTRACT

Rates of mass transfer at V-corrugated surfaces in a rectangular duct were measured under two phase flow by the limiting current technique. Variables studied were groove angle and peak to valley height of the corrugated surface, solution velocity and superficial gas velocity. For a given solution velocity and superficial gas velocity the mass transfer coefficient was found to increase with increasing groove angle and decrease with increasing groove peak to valley height. The volumetric mass transfer enhancement ratio compared to the smooth surface ranged from 3.7 to 7.58 depending on the operating conditions. The mass transfer data at the corrugated surface were correlated by the equation: $Sh = 1.52Sc^{0.33}Re_L^{0.285}Re_g^{0.28}(d_e/P)^{0.375}$.

For a batch gas sparged reactor with an active corrugated surface the data were correlated by the equation: $j = 0.047(Re \cdot Fr)^{-0.15}(d_e/P)^{0.6}$.

Implications of the present results for the design and operation of compact continuous two phase and batch gas sparged heat and mass transfer equipments such catalytic reactors, electrochemical reactors, and heat exchangers was noted.

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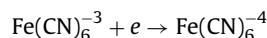
1. Introduction

Study of heat, mass and momentum transfer at corrugated surfaces is important for the rational design and operation of equipments which employ such surfaces as heat exchangers, membrane separation equipments, catalytic and electrochemical reactors used to conduct diffusion controlled reactions. Corrugated surfaces owe their wide use in equipment design to their ability to enhance the rate of heat and mass transfer under laminar flow conditions with a consequent decrease in the pumping power requirements beside decreasing the size of heat and mass transfer equipments. Besides, corrugated surfaces can be used to build modular (multicell) reactor of high space time yield contrary to other competing turbulent flow devices such as the rotating cylinder electrode [1–3]. The majority of previous studies [4–17] on the rate of heat and mass transfer have dealt with single phase flow. The aim of the present work is to study the mass transfer behavior of corrugated surfaces under two phase (gas–liquid) flow. Two phase flow is frequently encountered in conducting catalytic and electrochemical reactions involving gaseous

reactants, catalytic reactions include hydrogenation [18] and air oxidation [19] while electrochemical reactions include reactions such as H₂O₂ synthesis by cathodic reduction of atmospheric oxygen [20], flue gas desulphurization by anodic oxidation of SO₂ to H₂SO₄ [21], electrolytic production of propylene oxide from propylene [22] and anodic oxidation of NO_x to nitric acid [23,24]. Besides, biochemical reactors using immobilized enzymes catalysts [25], photocatalytic reactions using TiO₂ catalyst [26] and membrane processes employing two phase flow [27] can also benefit from the present study. In view of the analogy between heat and mass transfer the present study is of relevance for the design and operation of heat transfer equipments using two phase flow.

2. Experimental technique

The mass transfer coefficient was obtained from the limiting current of the cathodic reduction of K₃Fe(CN)₆ according to the reaction:



The reverse reaction takes place at the anode. A nickel plated copper cathode was used because the above reaction is fully diffusion controlled on nickel. A large excess of NaOH supporting electrolyte was used to eliminate the transfer of Fe(CN)₆⁻³ by convective diffusion without migration makes the present mass

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List of symbols

A	area of the corrugated surface
A_s	area of the smooth surface
C	bulk concentration of $K_3Fe(CN)_6$
D	diffusivity
d_e	equivalent diameter $d_e = (4 \times \text{cross sectional area}) / (\text{wetted perimeter})$
F	Faraday's constant (96,500 C/equiv.)
h	V-groove slant height ($h = P / \cos(\theta/2)$)
I_L	limiting current
k	mass transfer coefficient
n	number of grooves in the corrugated surface
P	peak to valley height
V_g	superficial gas velocity
V_L	solution velocity
w	width of the groove
Z	number of electrons involved in the reaction
Fr	Froude number ($V_g^2 / g d_e$)
j	mass or heat transfer j factor ($St \cdot Sc^{0.66}$)
Re_g	gas Reynolds number ($\rho V_g d_e / \mu$)
Re_L	liquid Reynolds number ($\rho V_L / \mu$)
Sc	Schmidt number ($\mu / \rho D$)
Sh	Sherwood number ($k d_e / D$)
St	Stanton number (k / V_g)
θ	angle of the V-groove
μ	solution viscosity
ρ	solution density

Table 1
Geometric parameters of the corrugated surfaces.

Surface	Groove angle, θ°	Peak to valley height, cm	Area (A), cm^2	Area ratio (A/A_s)
I	30	1	352.18	3.61
II	45	1	226.8	2.33
III	60	1	180.18	1.85
IV	75	1	157.7	1.62
V	45	0.5	226.8	2.33
VI	45	0.75	222	2.28
VII	45	1.5	226.8	2.33

were fixed in position by inserting their side edges into grooves machined in the cell walls. The bottom of the cell which was made of sintered glass (G2) was fitted to a plexiglass conical gas inlet. Solution was circulated between the cell and 20 L plastic storage tank using a plastic centrifugal pump, solution entered the cell through an inlet plastic tube located just above the cell bottom and exited the cell through an overflow weir. Solution flow rate was controlled by means of a bypass and was measured by a calibrated rotameter. Nitrogen gas was admitted to the cell through the sintered glass gas distributor from a nitrogen cylinder; gas flowrate was controlled by a valve and was measured by a calibrated gas flow meter. The electrical circuit consisted of 10 volt d.c power supply with a voltage regulator and a multirange ammeter connected in series with the cell. The solution used in the present study consisted of 0.01 M $K_3Fe(CN)_6$, 0.1 M $K_4Fe(CN)_6$ and 2 M NaOH supporting electrolyte, distilled water and A.R chemicals were used in preparing all solutions. The limiting current of the cathodic reduction of $K_3Fe(CN)_6$ was determined at different solution and gas flow rates by increasing the current stepwise and measuring the cathode potential against a reference electrode by means of a high impedance voltmeter. The reference electrode consisted of a nickel wire placed in the cup of a Luggin tube which was filled with the cell solution; the tip of the Luggin tube was placed at a distance 0.5–1 mm from the cathode surface. Solution temperature was $25 \pm 1^\circ C$.

3. Results and discussion

Fig. 2 shows typical current cathode potential curves with a well defined limiting current plateau obtained under different conditions; the mass transfer coefficient was calculated from the limiting current using the equation [28]:

$$\frac{I_L}{ZF} = kAC \tag{1}$$

transfer results analogous to heat transfer [28]. The apparatus (Fig. 1) consisted of the cell and electrical circuit. The cell was a plexiglass rectangular container with the dimensions of 6.5 cm \times 6.5 cm for the base and 25 cm height. The cathode was made of nickel plated copper cathode had the dimensions 6.3 cm \times 14 cm, one smooth and seven V-corrugated cathodes were used (see Table 1). The anode was made of stainless steel with dimensions similar to that of the cathode; the back of the cathode and the back of the anode were isolated with epoxy resins. The cathode and the anode

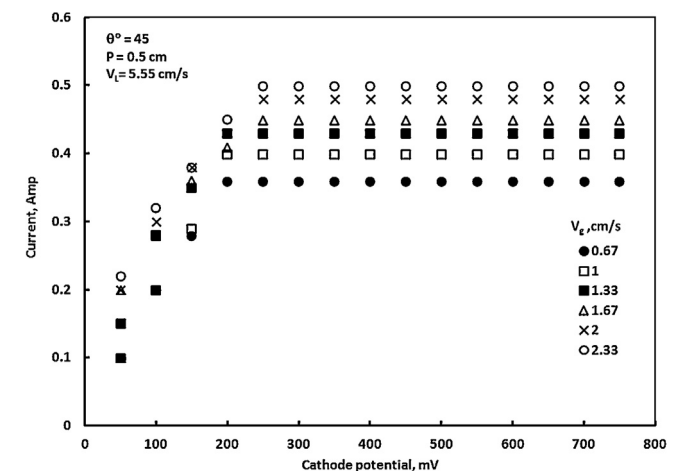


Fig. 2. Typical polarization curves at different superficial gas velocities.

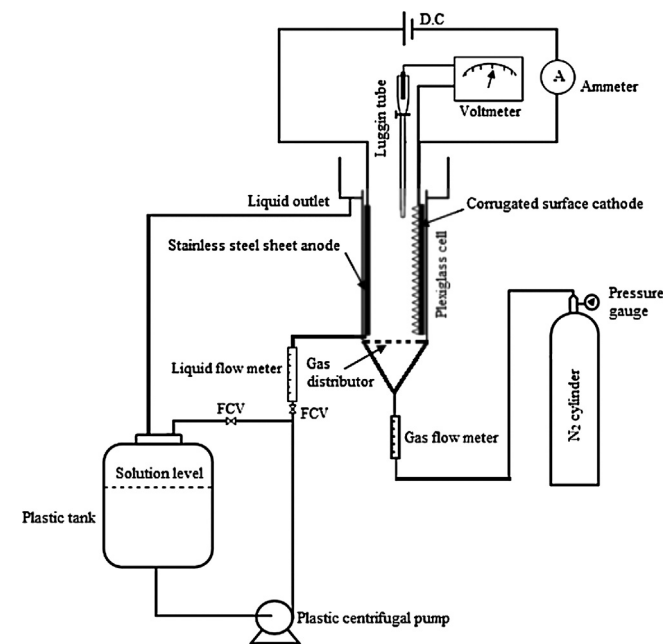


Fig. 1. Experimental apparatus.

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