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SHORT COMMUNICATION

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A MASS TRANSFER IN HETEROGENEOUS SYSTEMS BY THE ADSORPTION METHOD

A mass transfer coefficient between: a liquid and single sphere and a liquid and column wall in packed and fluidized beds of a spherical inert particle have been studied experimentally using the adsorption method. The experiments were conducted in a column 40 mm in diameter for packed and fluidized beds, and in a two-dimensional column 140 mm×10 mm for the flow past single sphere. In all runs, the mass transfer rates were determined in the presence of spherical glass particles, 3 mm in diameter, for packed and fluidized beds. The mass transfer data were obtained by studying transfer for flow past single sphere, 20 mm in diameter.
This paper discusses the possibilities of application of the adsorption method for fluid flow visualization. Local and average mass transfer coefficients were determined from the color intensity of the surface of the foils of silica gel. Correlations, Sh = f(Re) and j_D = f(Re), were derived using the mass transfer coefficient data.

Key words: mass transfer; single sphere; packed bed; fluidized bed; flow visualization; adsorption method.

The adsorption method is an experimental method for determination of local and average mass transfer coefficients between fluid and solid surface. Besides basic usage, this method is, also, suitable for fluid flow visualization [1]. The adsorption method is based on the dynamic adsorption of an organic dye onto a surface covered with a thin layer of a porous adsorbent. For this method, the value of the adsorbate surface concentration is necessary for data quantifycation. This method has been used since 1953 [2], but the determination of this parameter, which now can be done easily by using new software (Sigma Scan Pro), gives the absorption method new actuality [3,4].

This method is based on the experimentally determined fact that under certain conditions a mass transfer with adsorption can be treated as a stationary process governed by the mass transfer only. The adsorption from a much diluted solution and far from equilibrium conditions is a very fast process. If the exposure time is short (less than 10 min), the mass transfer rate depends only on the diffusion through the boundary layer; the concentration of the adsorbate just above the adsorbent surface is $c_i = 0$, so that the mass transfer coefficient is [2]:

$$k = \frac{c_p}{t\,c_0} \tag{1}$$

where c_p is the surface concentration of an organic dye on the adsorbent layer, c_0 is the bulk concentration of transferring species in the fluid and t is the exposure time.

This paper introduced the adsorption method as a very suitable method for the studies of mass transfer and for fluid flow visualization.

EXPERIMENT

The experiments were conducted in a two-dimensional column 140 mm ×10 mm ×200 mm (Figure 1, system A) for flow past single sphere (20 mm in diameter) and in columns 40 mm in diameter (Figure 1, system B) for packed and fluidized beds in the presence of inert glass particles 3 mm in diameter. The experimental systems are shown in Figure 1.

A very diluted solution of methylene blue (c_0 = 2.5×10^{-3} g/dm^3) was used as a fluid. The foils of silica gel were used as an adsorbent. ("Merck", DC-Alufolien Kie-selgel). The color intensity of the surface was determined by "Sigma Scan Pro 1" software.

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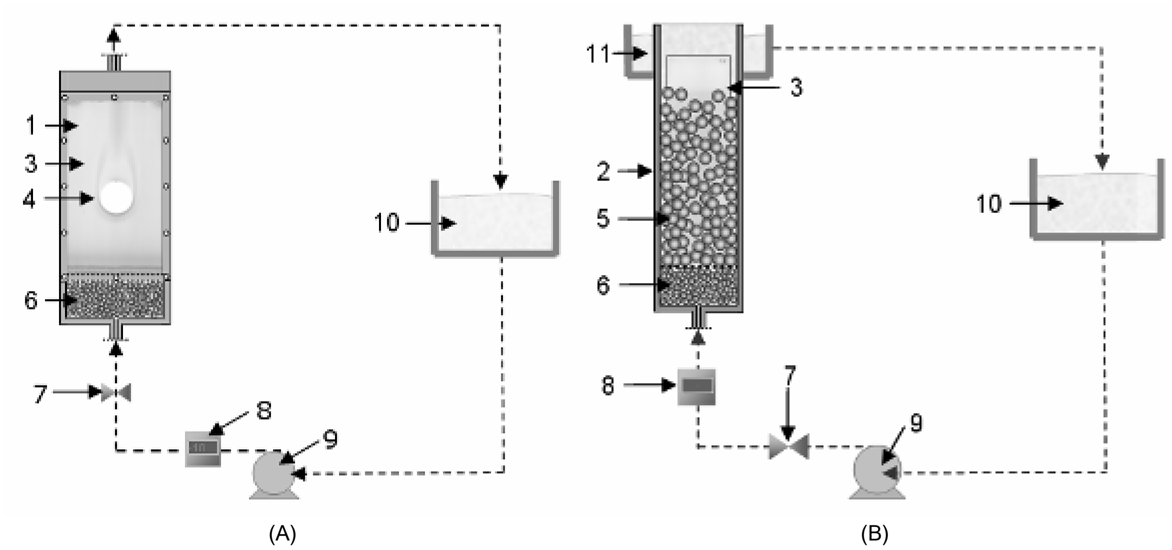

Figure 1. Schematic diagram of experimental system. 1 - two-dimensional column (140 mm ×10 mm ×200 mm), 2 - column 40 mm in diameter, 3 - foils of silica gel, 4 - single sphere, 5 - glass particles, 6 - liquid distributor, 7 - valve, 8 - flowmeter, 9 - pump, 10 - tank, 11 - water overflow.

RESULTS AND DISCUSSION

Figure 2 presents a boundary layer around a single sphere. As it can be seen, it is a typical picture of a discontinuous boundary layer around a bluff object. The color intensity of methylene blue was highest at the front of the sphere.

Figure 2. Boundary layer visualization for flow around single sphere ($Re_{p,0}$ = 2800).

The separation of the boundary layer can be easily seen and the disturbance in the fluid downstream from the sphere is indicated.

Figure 3 present local mass transfer coefficients as a function of an angle. The minimum at this plot represents an angle of separation. Sherwood number for the average mass transfer coefficient as a function of Reynolds number is shown in Figure 4.

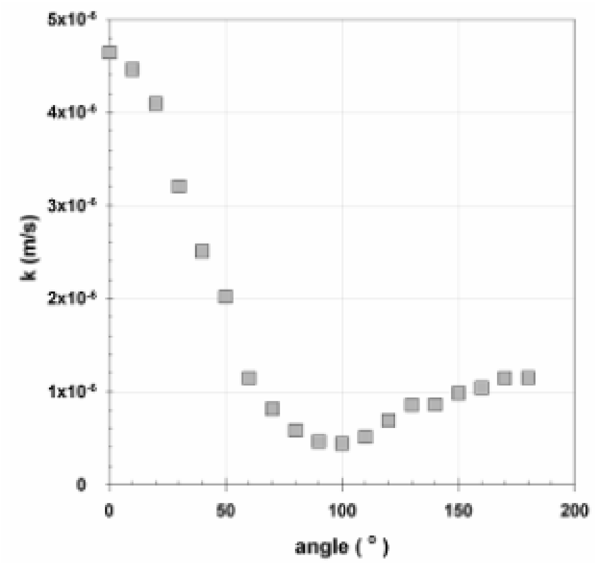

Figure 3. Local mass transfer coefficient as a function of angle.

Comparisons of our data with two literature correlations defined by Ranz and Marshal [5]:

$$Sh_{p,0} = 2 + 0.6 Re_{p,0}^{1/2} Sc^{1/3} \quad (2)$$

and Linton and Suterland [6]:

$$Sh_{p,0} = 0.582 Re_{p,0}^{1/2} Sc^{1/3} \quad (3)$$

are also presented in Figure 4. Our experimental results show very good agreement with both literature correlations (Eqs. (2) and (3)).

Chromatograms for the flow in a packed bed (a), in a fluidized bed at minimum velocity (b) and in a fluidized bed (c) are shown in Figure 5. The chromatogram 5a gives clear visualization of the fluid flow around particles in the packed bed. The color intensity is proportional to local mass transfer rates. Chromatograms 5b and 5c visualize fluidized beds for minimal velocity and for highly expanded fluidized bed. The uniform color intensity could be observed in both cases, with higher intensity for minimal fluidized bed velocity. This color uniformity indicates uniform mass transfer rates for fluidized beds. Lighter top parts of chromatograms 5b and 5c represent the mass transfer in the single phase flow.

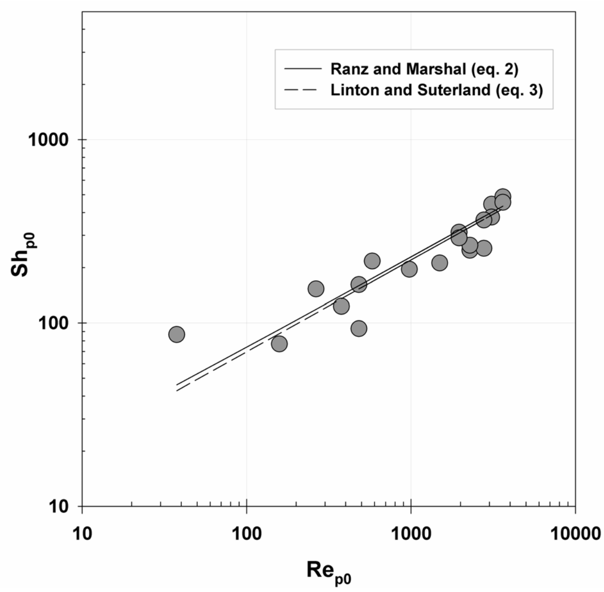

Figure 4. Sherwood number vs. Reynolds number.

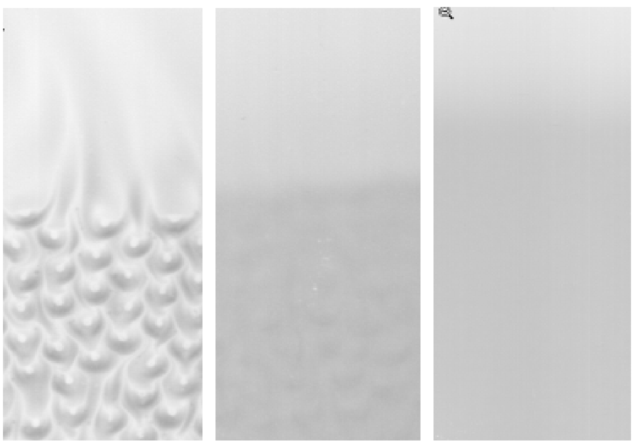

Figure 5. Chromatograms for flow in packed bed (a), in fluidized bed at minimum velocity (b) and in fluidized bed (c).

The experiments in packed and fluidized beds were conducted as a liquid-to-wall mass transfer. Figure 6 represents a relationship between a mass transfer factor and a particle Reynolds number in the packed and fluidized bed. Also, this picture gives the comparison of our experimental data with the correlation of Dwivedy and Upadhyay [7] who proposed the following correlation:

$$j_D = 1.1068 Re_p^{-0.72} \quad \text{for } Re_p < 10 \qquad (4)$$

$$j_D = 0.454 Re_p^{-0.4069} \quad \text{for } Re_p > 10 \qquad (5)$$

based on many different experimental data for the mass transfer of liquid in packed and fluidized beds.

As it can be seen, our data show a very good agreement with the correlation for packed beds, but not for fluidized beds.

The experimental research showed that the adsorption method is very suitable for visualization of the fluid flow and for determination of local and average mass transfer coefficients. The adsorption method could be easily employed by using novel software solutions.

CONCLUSION

The experiments were carried out in order to determine the mass transfer coefficient between the liquid and single sphere and the wall-to-liquid in packed and fluidized beds of spherical inert particles.

The adsorption method is introduced as a very suitable method for determination of local and average mass transfer coefficients and for fluid flow visualization.

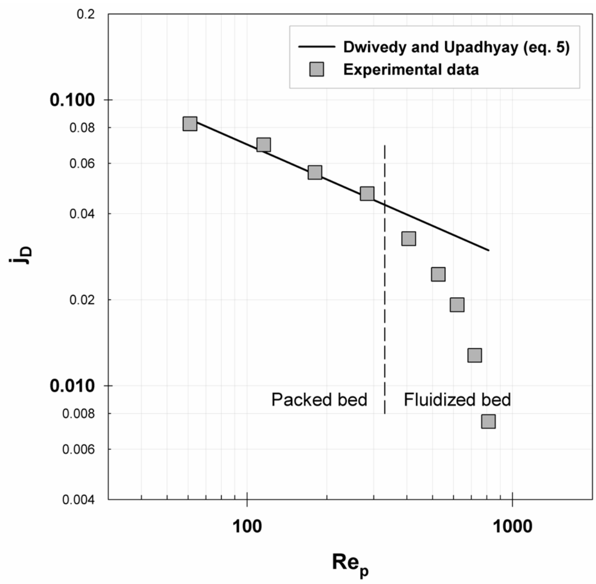

Figure 6. Mass transfer factor vs. particle Reynolds number (d_p = 3 mm).

The comparison between experimental results and literature correlations for the mass transfer coefficient shows a very good agreement for the flow past single sphere and for packed beds, and a disagreement for fluidized beds.

The result of the adsorption method gives a permanent picture – chromatograms of a diffusional boundary layer.

Acknowledgment

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Nomenclature

c_i equilibrium concentration, kg/m^3
c_0 concentration of methylene blue in fluid, kg/m^3
c_p surface concentration of methylene blue, kg/m^2
D molecular diffusion coefficient, m^2/s
D_c column diameter, m
d_p particle diameter, m
$d_{p,0}$ diameter of single sphere, m
j_D mass transfer factor, $Sc^{2/3}k/U$
k mass transfer coefficient, m/s
N_A mass flux, kg/(m^{2}s)
Re_p Reynolds number for particles, $Ud_p\rho_f/\mu$
$Re_{p,0}$ Reynolds number for single sphere, $Ud_{p,0}\rho_f/\mu$
Sc Schmidt number, $\mu/D\rho_f$
Sh_{p0} Sherwood number for single sphere, $kd_{p,0}/D$
t exposure time, s
U superficial fluid velocity, m/s

Greek letters

μ viscosity of the fluid, Pa s
ρ_f fluid density, kg/m^3.

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