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Mass and heat transfer enhancement at the wall of cylindrical agitated vessel by turbulence promoters

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ABSTRACT

Rates of liquid–solid mass transfer at a wall of stirred tank reactor lined with an array of vertical tubes turbulence promoter were studied using the dissolution of copper in acidified dichromate technique. Parameters studied are physical properties of the solution, impeller geometry, impeller rotation speed, cylinder diameter, circumferential distance between the vertical cylinders, and the effect of drag reducing polymers. The presence of vertical cylinders at the reactor wall increased the volumetric mass transfer coefficient compared to the presence of the wall without the cylinders by an amount ranging from 12.5% to 214.5%. The presence of Polyox WSR-301 drag reducing polymer decreased the rate of mass transfer by an amount ranging from 3.5% to 32.26% depending on polymer concentration and impeller rotation speed. All data were correlated by dimensionless mass transfer equations. The importance of the present results in building high space time yield catalytic reactors suitable for conducting diffusion controlled reactions was highlighted, also the possible role of the vertical tube array as a secondary built in heat transfer facility which assists external cooling jacket was noted.

1. Introduction

In view of their high mixing efficiency agitated vessels are used widely in the chemical process industry to conduct a wide range of physical and chemical operations, the latter includes L–S catalytic diffusion controlled reactions which take place on a fluidized bed of catalyst particles (slurry reactors). Despite the high reaction area of slurry reactors they suffer from serious drawbacks such as catalyst attrition due to collision with the rotating impeller, erosion of the blades of the rotating impeller, low rate of mass transfer as a result of the low slip velocity, overflow of the catalyst particles in case of a continuous operation of the reactor, and sometimes it is difficult to separate the final product from the catalyst particles especially in case of highly viscous solutions. In view of these difficulties some studies have been carried out on the rate of heat and mass transfer at the wall of cylindrical [1–7] and rectangular agitated vessels [8,9] which can act as a catalyst support and a heat transfer surface in the mean time. In an attempt to increase the reaction area Mowena et al. [10] studied the mass transfer behavior of a packed bed of Raschig rings fixed to the wall of a cylindrical agitated vessel, the authors reported a remarkable increase in the volumetric mass transfer coefficient (kA) of the reactor over that of the wall alone. Fouad et al. [11] studied the heat and mass transfer behavior of a square array of vertical cylinders surrounding the rotating impeller of a square agitated vessel, the outer surface of the tube can act as a catalyst support while the inner surface can act as a cooler to remove excess heat in case of producing heat sensitive products or using heat sensitive catalysts such as immobilized enzymes.

The aim of the present work is to study the rate of mass and heat transfer (by analogy) at the wall of a cylindrical agitated vessel fitted with an array of vertical cylinders distributed uniformly around the wall, the cylinders act as attached turbulence promoters. Beside their role as turbulence promoters the inner surface of the tubes can serve as a supplementary internal cooler to absorb excess heat along with the external cooling jacket which alone fails to remove excess heat from large diameter stirred tank reactors [12]. The tubes can also act as a catalyst support along with the wall thus increasing the reaction area, the turbulence generated by the vertical tubes not only enhances the rate of mass transfer at the wall but also enhances the inner side heat transfer coefficient of the cooling jacket. In addition the baffling effect of the vertical tubes [12] would improve the mixing conditions in the agitated vessels via converting part of the swirl flow to the more effective radial and axial flow. The rate of mass transfer was

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List of symbols

A	active surface area (m^2)
a	constant
C	concentration at time t (mol/m^3)
C°	initial concentration (mol/m^3)
D	mass diffusivity (m^2/s)
d	turbulence promoting cylinder diameter (m)
d_c	container diameter (m)
d_i	impeller diameter (m)
g	acceleration due to gravity (m/s^2)
k	mass transfer coefficient (m/s)
L	turbulence promoting cylinder height (m)
N	impeller rotation speed (s^{-1})
n	number of turbulence promoting cylinder height
Q	solution volume (m^3)
S	circumferential distance between cylinders (m)
t	time (s)

Greek symbols

α	constant
β	constant
γ	constant
$\in$	specific energy dissipation (W/kg)
μ	solution viscosity (kg/m s)
υ	kinematic viscosity (m^2/s)
ρ	solution density (kg/m^3)
ω	rotational speed (revolution per minute)

Dimensionless groups

Fr	Froude number ($N^2 d_i/g$)
Sc	Schmidt number ($\mu/\rho D$)
Sh	Sherwood number (kd_c/D)
Re	Reynolds number ($\rho d_i^2 N/\mu$)

determined by using a technique which involves the diffusion controlled dissolution of copper in acidified dichromate, the technique has been used widely to study rates of mass and heat transfer (by analogy) in view of its accuracy and simplicity [13–18]. The present geometry is different from vertical tubes baffles studied before for their heat transfer behavior by different authors [19–21], vertical tube baffles consist of four rows of vertical tubes placed in place of the usual flat plate baffles in cylindrical agitated vessels with the double purpose of baffling and cooling the agitated vessels.

Since drag reducing polymers have the potential of being used to reduce mechanical power consumption in agitated vessels by virtue of their ability to damp the small scale high frequency energy dissipating eddies [22–24] it would be of interest to examine their effect on the rate of mass transfer. To this end polyethylene oxide (Polyox WSR-301) a product of Union Carbide was used. The proposed reactor can find applications in various areas such as: (i) catalytic organic synthesis [25], (ii) catalytic wastewater treatment to remove organic pollutants by wet oxidation [26], (iii) catalyzed biochemical reactions using immobilized enzyme to produce pharmaceuticals, food stuff, and to remove organic pollutants from wastewater [27,28], (iv) removal of heavy metals from waste water solutions by cementation on less noble metal [29,30], and (v) photocatalytic reactions using TiO_2 as a catalyst for waste water treatment [31,32].

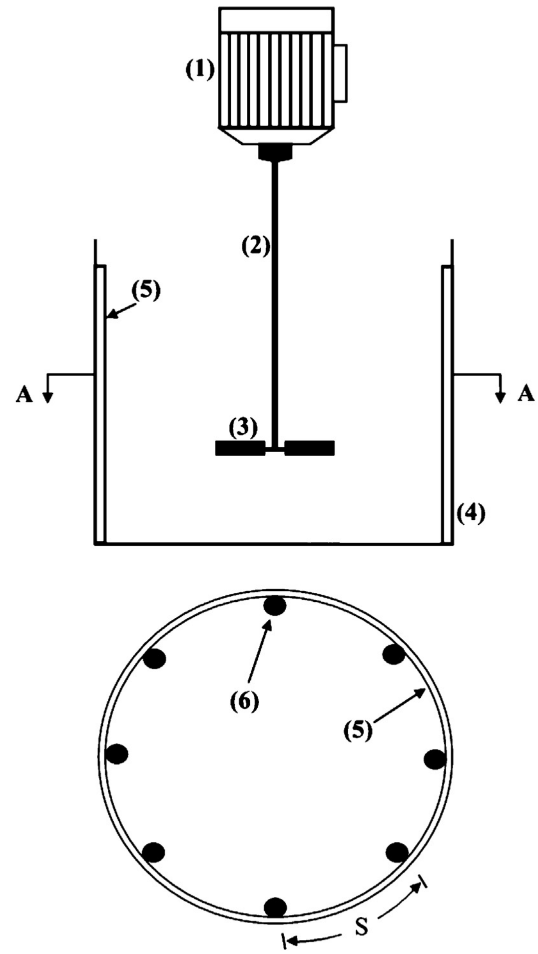

Fig. 1. Experimental setup. (1) motor (2) isolated shaft (3) impeller (4) Plexiglas tank (5) cylindrical copper sheet (6) copper cylinders.

2. Experimental technique

2.1. Setup

The experimental setup used in the present study is schematically presented in Fig. 1. The reactor consisted of a cylindrical Plexiglas container of 0.15 m diameter and 0.25 m height, the wall of the vessel was lined with a cylindrical copper sheet of 0.2 m height. Vertical copper cylinders contacting the copper sheet were uniformly distributed around the inner side of the sheet; each cylinder was fixed in position by brazing its ends to the copper sheet. The back of the cylindrical sheet facing the container wall was isolated with epoxy resin. Cylinder diameter and number of cylinders were variables. Four different cylinder diameters were used, namely; 0.06, 0.1, 0.16 and 0.19 m, and three different numbers of cylinders were used namely; 4, 8 and 16. Changing the number of cylinders made it possible to change the circumferential distances between the cylinders (0.1178, 0.589 and 0.295 m respectively). To appreciate the effect of the array of active copper cylinders on the mass transfer behavior at the vessel's wall, a similar vessel lined with copper sheet without vertical cylinders was used, the back of the copper sheet facing the vessel wall was isolated with epoxy resin to eliminate the possibility of copper dissolution from the back of the sheet in case of solution leakage to the back of the sheet. An isolated stainless steel impeller of 0.05 m diameter was connected to a 0.224 kW variable speed digital motor by means of an isolated steel shaft. The impeller was positioned at the center of the vessel 0.05 m from its bottom. Agitated vessel relative dimensions used