International Journal of Chemical Studies 2016; 4(4): 38-42

International Journal of Chemical Studies

P-ISSN2349–8528
E-ISSN 2321–4902
IJCS 2016; 4(4): 38-42

Received: 05-05-2016
Accepted: 06-06-2016

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Chemical absorption in Couette Taylor reactor with micro bubbles generation by rotating porous plate

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Abstract

In this work the concept of gas-liquid Couette- Taylor Flow reactor with micro bubbles generation by a rotating porous plate have been investigated. The oxidation of benzaldehyde was used in this study. The volumetric mass transfer coefficients K_La have been determined and the influence of the gas and liquid phase mass flow rates and the rotational speed of the inner cylinder on the mass transfer coefficient have been investigated. The obtained mass transfer coefficients in the Couette Taylor reactor with micro bubbles generation by rotating porous plate were found to be approximately twice the value of the mass transfer coefficient for the normal Couette Taylor reactor and two order of magnitude higher than those observed in a stirred tank reactor. The collected experimental data have been correlated and a high values of the mass transfer coefficients, K_La, of the order of 1-2 s^{-1} have been obtained.

Keywords: micro bubbles, rotating porous, absorption, Couette

Introduction

Couette Taylor reactors have gain high interest in the last few years due to the high interfacial area and the well mixing of the reactive phases due to the hydrodynamic instability and the generation of micro vortices by the flow which enhance the mixing of the reactive species. The flow in an annular space between two concentric rotating circular cylinders (Couette Taylor Flow reactor, CTF, is a combination of two simple flows: the axial Poiseuille flow and the rotating Couette flow. This type of flow is a rare flow type combining intense local mixing with an axial dispersion due to the hydrodynamic flow instability (vortices) occurring in the CTF reactor (also called helicoidal flow). This type of flow has a very advantageous feature of the CTF reactor. Recently, due to this advantageous properties, a significant increase interest in this type of reactors have been seen. Problems of mixing and dispersion effects have been presented by Desmet *et al.* (1996a, b, c, d) [4-7], Djeridi *et al.* (1999) [8], Shiomi *et al.* (1993) [13] and Berger *et al.* (1981) [3]. Also, the mass transfer in the two-phase gas-liquid systems in the membrane and gap helicoidal reactors have been investigated by Wronski *et al.* (1999a) [14], Dluska, and Hubacz (2000) [16]. These experiments indicated high values of the mass transfer coefficients (K_La = 0.1-1 s^{-1}), even in highly viscous liquids. A comparison of K_La values for different types of reactors is given in Table 1.

Table 1: Comparison of Mass Transfer Coefficient for Different Contactors

Type of Reactor	**Mass Transfer Coefficient K_La (s^{-1})**
Packed bed	0.002
Bubble column	0.004
Stirred contactor	0.02
CTF	0.1-1
CTR with micro bubbles generation	1-2

The helicoidally flows is significantly affect the values of the mass transfer coefficients as compared to those observed in the ordinary annular gap flow (without rotating rotor). Because of a tubular shape of the apparatus the helicoidally membrane reactor can be applicable to accomplish processes between a gas and liquid or suspension, in particular in the case of the more viscous fluids and in the range of the elevated pressures. The visual observations have revealed an interesting structure of the two phase flow. Distinct spirals of the Taylor vortices in the liquid phase have been observed as well as a thin region of the well-mixed gas between the vortices have been marked. These enabled to suggest a model of the process based on a concept of a perfectly mixed cascade of the liquid reactors contacting with vigorously stirred gas phase. A gas substrate can be fed into the membrane reactor along its entire tubular length. If such a supply of gas is not necessary it is possible to consider a zonal feeding with a gas substrate introduced over a defined area. In the limiting case, i.e. feeding with a gas substrate at the inlet cross-section, the reactor would work as a gap helicoidal one. An intensive mass transfer at the membrane surface may result in its deactivation caused by deposition of crystals at the membrane. During investigations on hydrodynamics and mass transfer, Wronski *et al*. (2000) [16], Dluska and Wronski (2001) [10] were found that a large effect of the axial velocity on the values of the mass transfer coefficients as compared with that of the rotational speed of the rotor and, the limiting values of the rotational speed establishing above which the effect of this parameter becomes insignificant.

2- Experimental Setup

The experiment set up is shown in Figure 1. All experiment were done at 25 ^{o}C. Owing to its tubular construction the CTF reactor is suitable to operate in a continuous process under an elevated pressure, e.g. to oxidize organic liquids. Under such circumstances the reactor would be applicable to aerate slurries and suspensions. The mass transfer coefficients have been determined using oxidation of benzaldehyde by air and by oxygen (in view of the perspectives of the reactor application for organic liquid oxidation. The length of the reactor is 90 cm, rotor diameter 5 cm, and the annular gap is 10 cm. The gas and the liquid were introduced into the inlet cross-section. For the axial flow the values of the Reynolds numbers ranged from 100 to 1600, while those for the rotating flow were ranged from 0 to 10000. The concentration of the exit benzoic acid in the liquid was measured using chromatographic analysis.

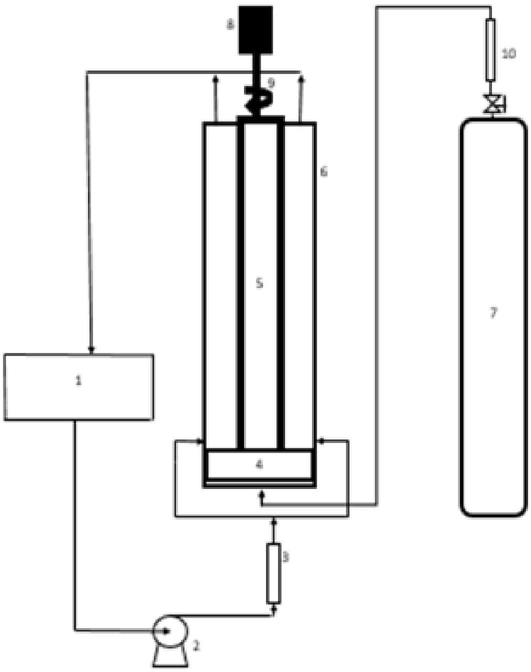


Fig 1: Sketch of the experimental setup, 1-Liquid circulation Tank, 2- Pump, 3- Liquid Flowmeter, 4- Rotating Porous Plate, 5-Inner Rotating Cylinder, 6- Outer Fixed Cylinder, 7-Gas Cylinder, 8-Motor, 9- Rotating Shaft, 10- Gas Flow meter

Calculations

Due to the vertical position of the reactor axis it could be assumed that both phase holdups can be determined based on the volumetric flow rates at the inlet cross section. Therefore the density and viscosity of the two-phase flow were calculated from the expression asp

$$\frac{1}{\mu} = \frac{x}{\mu_l} + \frac{1-x}{\mu_g} \quad (1)$$

and

$$\frac{1}{\rho} = \frac{x}{\rho_l} + \frac{1-x}{\rho_g} \quad (2)$$

Where, x is the mass fraction of the liquid phase. Based on the results of chromatographic analyses (concentration of benzoic acid) in the liquid samples, the reaction rate and hence the values of the volumetric mass transfer coefficient accompanied by chemical reaction have been determined from

$$N = K_l a\,(\bar{c_l} - c_o) \quad (3)$$

Where $\bar{c_l}$ is the mean equilibrium oxygen concentration at the interface and co is the oxygen concentration in the bulk liquid, $c0 \approx 0$. The value of $\bar{c_l}$ in equation (3) was calculated from Henry's law as

$$\bar{c_l} = H\,P_{O2} \quad (4)$$

In the case of absorption of pure oxygen the value of P_{O2} will remain constant, while using air instead the average partial pressure of oxygen was determined from the mass balance of the spent oxygen. The value of the Henry's law constant H was estimated from the Hildebrand-Scatchard method based on the solubility coefficients (Fogg and Gerrard, 1990) [11] as H=5.24 × 10-3 mol/dm3 bar. A mass balance of benzoic acid in the Vessel will lead to

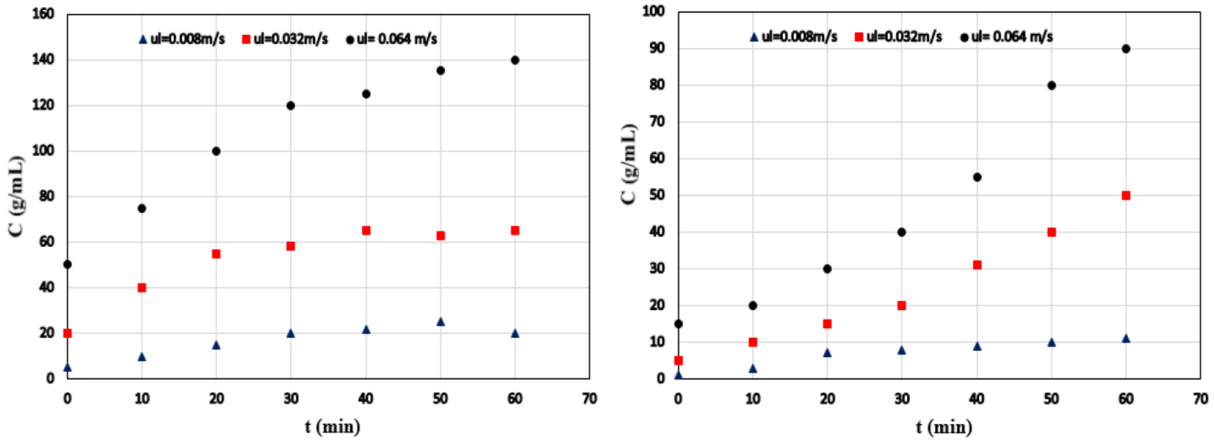
$$V_t \frac{dc}{dt} = k\,(K_L a)\,\bar{c_l}\,V \quad (5)$$

Where, $k$is the stoichiometric coefficient of the reaction which is equal 2 in this case. Hence, the volumetric flow rates at the inlet cross section. Therefore

$$K_L a = \frac{1}{2}\left(\frac{\Delta C}{\Delta t}\right)\frac{V_t}{V}\frac{1}{\bar{c_l}} \quad (6)$$

Results and Discussion

The course of the oxidation process of benzaldehyde at the various flow rates has been demonstrated in Fig. 2. It is evident from these figures that the process rate is controlled by diffusional regime and that the conversion factor is proportional to time. The deviation of benzoic acid concentration from linear dependence on time can be observed, this difference can result from changing of the reaction mechanism or fluid properties, e.g oxygen solubility.



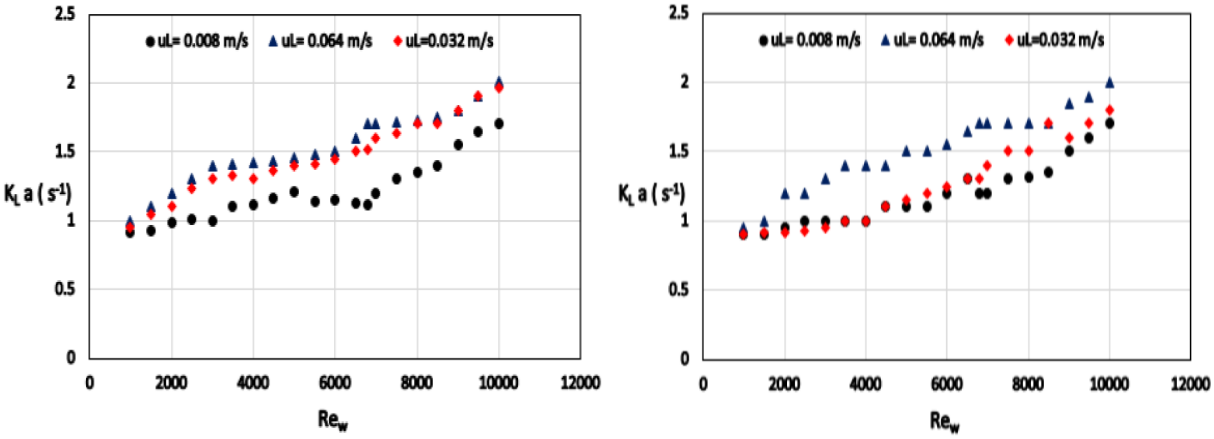
(a) (b)

Fig 2: Concentration of benzoic acid vs. time in (a) oxygen and (b) in air

The results of the mass transfer experiments in a two-phase (gas-liquid) system have been plotted in Figs. 4-6 for CTF reactor with microbubble generator. As it was expected, high values of the volumetric mass transfer coefficients *KLa*, of the order of 1-2 s-1 have been obtained. The mass transfer results indicate that the two-phase CTF reactor should be effective to oxidize organic liquids. As shown in Fig. 4 the values of these coefficients for oxidation of benzaldehyde with oxygen or air (derived from eq. (2)) correspond (a little higher) to those obtained for physical absorption. Based on the data of Figures 4-6, the mass transfer coefficient can be correlated as follows:

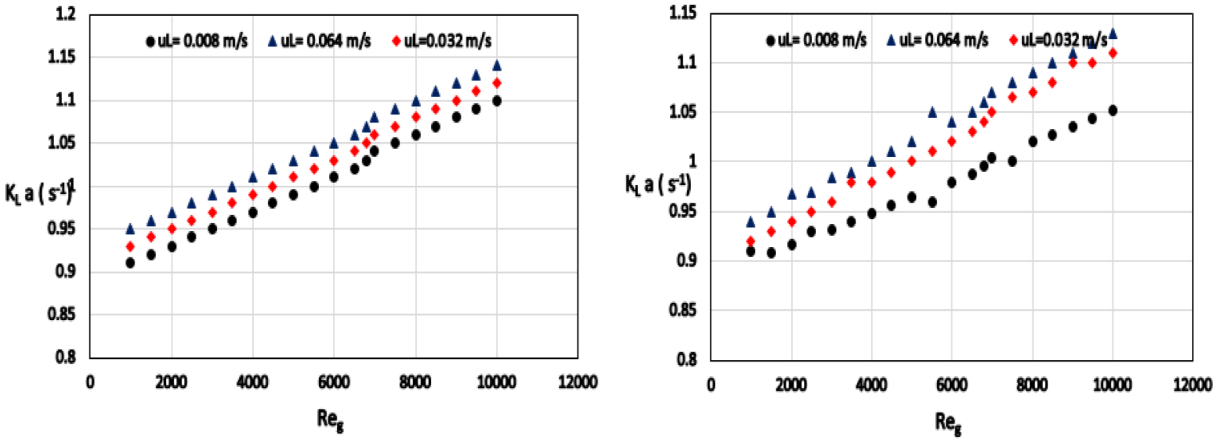
$$Sh = \frac{(K_L a)\, d^2}{D} = 10^{-6}\left(\frac{Re_g}{Re_l}\right)^{0.5}\left(1.3 + {Re_w}^{0.71}\right) \qquad (7)$$

Hence the results of benzaldehyde oxidation were correlated with this equation and presented in Fig.7. At small rotational Speed of the rotor the gas phase structure is characterized by a non-uniform bubble dispersion. Under such conditions the CTF reactor does not operate at fully helicoidal flow, resulting in the smaller developed interfacial area. In consequence, the value of mass transfer coefficient is lower than that for higher rotational speed.



(a) (b)

Fig 4: The mass transfer coefficient vs. Rotational Reynolds number, Ug =0.003m/s, (a) in Oxygen and (b) in air



(a) (b)

Fig 5: The mass transfer coefficient vs. gas Reynolds number, (a) in oxygen and (b) in air

Conclusions

The mass transfer coefficients in the two-phase: air/O2-benzaldehyde system using CTF with microbubble generation were determined and compared to other contactors. High values of the volumetric mass transfer coefficients, of the order of 1-2 s-1 have been obtained. The values are two order of magnitude higher than those in stirred tank reactor. This result gives rise to practical application of the tubular reactor in oxidation of organic liquids and suspensions at normal and elevated pressures. Taking into account the requirements that are encountered in the Wet Air Oxidation (WAO) method (high temperature, high pressure) the gap CTF reactor could be applicable to aerate pollutants in particular when contaminants are present in highly viscous liquids. Owing to the potential perspectives of the reactor application for liquid oxidation the model investigations using WAO method are in progress.

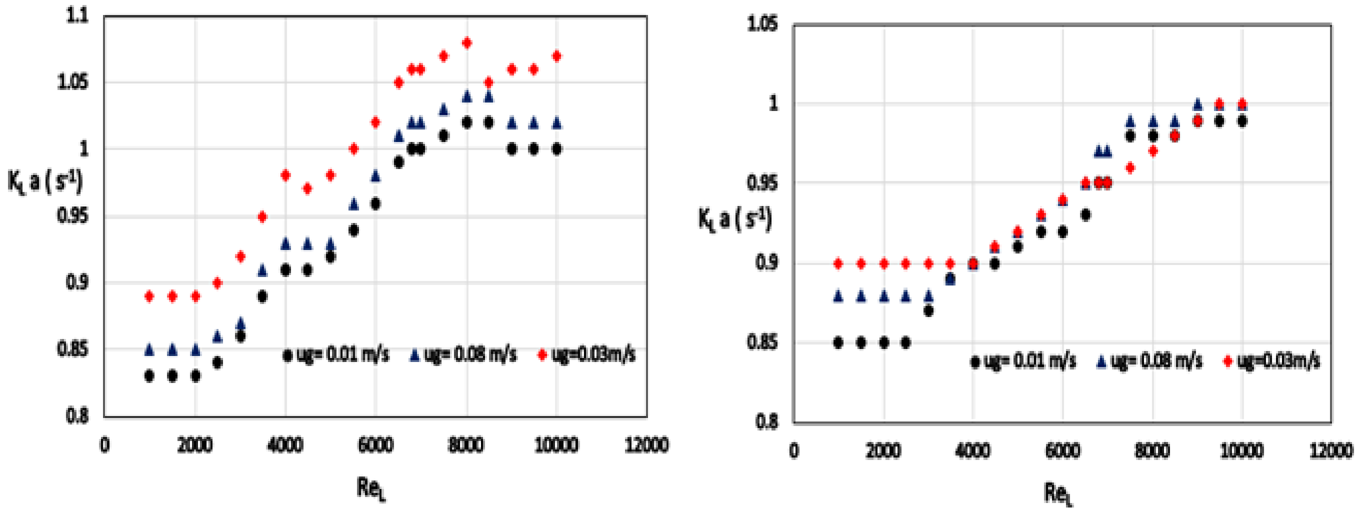


Fig 6: The mass transfer coefficient vs. liquid Reynolds number, (a) in oxygen and (b) in air

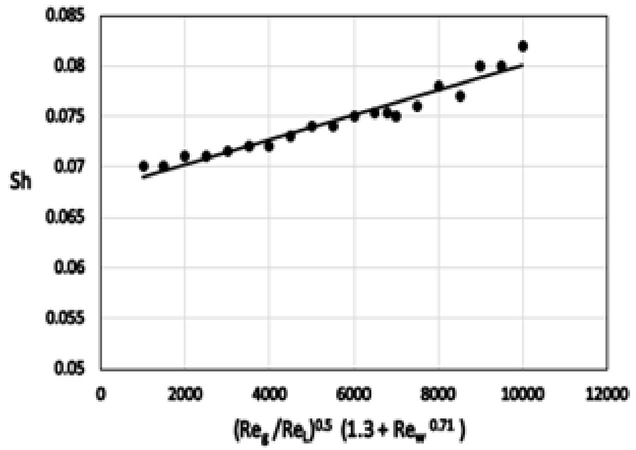


Fig 7: The mass transfer correlation for Couette-Taylor Flow reactor with microbubble generation.

Nomenclatur

μ: Viscosity
ρ: Density
x: Mass fraction of the liquid phase.
Kla: Volumetric mass transfer coefficient
N: Mass transfer rate
C: Concentration
H: Henry's constant P: Pressure
V: Volume u: Velocity
Re: Reynolds Number Sh: Sherwood number
D: Outer diameter of reactor
d: Inner diameter of reactor

Subscripts

L: liquid
g: Gas
t: Tank
w: Rotational

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