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The Environmental Study on Characteristics Analysis of Packed Bed Split Cylinder Reactor based on Hydrodynamics and Mass Transfer

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Abstract

Hydrodynamic and mass transport in a split cylinder has been investigated. Tap water and Carboxy Methyl Cellulose with different concentration (0.1 to 0.7 %w/v) were used as test fluids. Air flow rate was varied from 5 to 50 lpm. It was found that the gas hold up is gradually or linearly increases with increasing of air flow rate for Newtonian fluid systems. In case of non Newtonian fluids, the gas hold up is increased with air flow rate gradually, but not in linearly. Similarly the gas hold up for non Newtonian fluid is decreased with increasing concentration at the same time the gas hold up also increased in the range of 0.3 to 0.5%. A correlation has been developed for time of mixing and mass transport in a split cylinder reactor.

Keywords: split cylinder reactor, gas holdup, mixing time, carboxymethyl cellulose

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INTRODUCTION

Multiphase reactors are widely used in the chemical process plant, bio processing and waste water treatment application. Such type of reactors are classified into three main types are called bubble column, gas-lift and fluidized bed reactor (Moraveji et al. 2012). Split cylinder reactor is a one such kind. Among them, the split cylinder reactor find more attractive for large scale application due to their simplicity in construction, with or without rotating devices (impeller), superior efficiency of heat and mass transfer, low operational and maintenance cost and also good mixing with low shear stress (Moraveji et al. 2011). It consists of a cylindrical column divided into a riser and a down comer by inserting flat baffles. The compressed gas is passed through a sparger in riser section. It creates a high gas hold up in the riser section and then in down comer, causes to generate sufficient amount of liquid circulation and also achieved high gas-liquid mass transfer rate (Kilonzo et al. 2004).

The studies of Hydrodynamic depends on the geometrical parameter of the reactor, are ratio of height to diameter, area of raiser to down-comer and operational fluid properties between gas and liquid (Li et al. 1995). From the literature it can be seen that, the majority of authors have investigated the airlift reactors with Newtonian fluids and there are few authors on non-Newtonian or high viscosity liquids (Chisti and Moo-Young 1987, Chisti 1988).

The circulation velocity of the liquid are increased by increasing the ratio of geometrical parameter (liquid height to diameter), is more than 10 and also increasing the heat and mass transfer in a reactor by increasing the oxygen residence time (Moraveji and Mousavi 2014). The wall shear stress for a pseudo plastic non-Newtonian was studied and it was found that fluid gas-liquid dispersion coefficient is a function of the Reynolds number and rheological parameters (Metkin and Sokolov 1982).

The contributions of pressure drop due to wall frictional losses to total gas holdup of two phase viscous non-Newtonian systems in a circulating loop bubble column was studied (Al-Masry 2001). The hydrodynamics and mass transport properties in an internal-loop airlift reactor with CMC solution. An increase in aeration velocity will lead to a wider bubble size and sauter diameter (Cerri et al. 2008, Moraveji et al. 2011). The volumetric oxygen coefficient was increased by increasing in aeration velocity and decreasing in CMC concentrations.

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Table 1. Properties of CMC solution

Con. % w/v	Density g/ml	Shear stress (D/cm²)	Rate of shear (1/sec)	Viscosity (cP)
0.1	1.0058	4.94	1125	0.456
0.2	1.0117	5.79	1125	0.53
0.3	1.0146	7.95	1125	0.72
0.4	1.0175	8.26	1125	0.74
0.5	1.0234	12.46	1125	1.11
0.6	1.0292	14.04	1125	1.26
0.7	1.0350	17.16	1125	1.52

The mean rising velocity of bubbles in a shear-thinning fluid in a rectangular bubble column reactor was measured and also the mean riser velocity of the bubbles was greater than that of an individual bubble (Shi et al. 1990, Zenit et al. 2011). The performance to bubble column equipment with metal porous sparger was investigated. Their aim was to formulate correlation than could apply for predicting the average gas of bubble column (Akita and Yoshida 1974, Asgharpour et al. 2010, Passos et al. 2013). The gas holdup and bubble behavior in a split cylinder reactor using CMC at various concentrations has been investigated and also found that the bubble diameter as a function of various superficial gas velocities (Wang et al 2010).

In the present work, a systematic work has been undertaken for investigation of hydrodynamic and mass transport properties using pseudo plastic fluid in a split cylinder airlift reactor with impeller.

EQUIPMENTS & MEASUREMENTS TECHNIQUES

Material

- Various concentrations of CMC solutions (0.1 to 0.7%) were prepared. The properties of CMC solution are listed below in **Table 1**.

Carboxy Methyl Cellulose (CMC) is one of the pseudo plastic non-Newtonian fluids and was characterized by Ostwald power law. It was defined as

$$\tau = K\gamma^n \tag{1}$$

- NaCl and sodium sulphide is used as a tracer liquid.

EXPERIMENTAL SETUP

The split cylinder reactor consisted of acrylic column having 1 m in height and 0.150 m in diameter is shown in **Fig. 1**. The column has divided into riser and down comer by using baffles inserting in it. The ratio of cross sectional area of riser and down comer was 1:1.

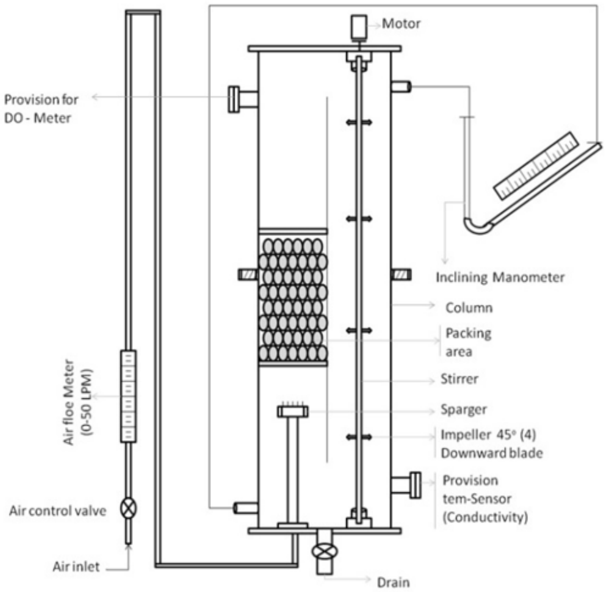

Fig. 1. Split cylinder reactor

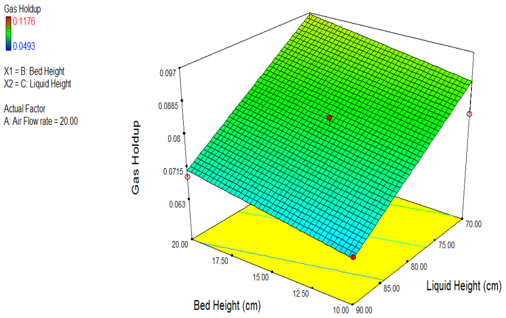

Fig. 2. Gas holdup vs bed height and liquid height

The air was sparged through a sparger. It was located at the bottom of the riser section. The above experiments and measurements carried out at standard operating conditions. The aqueous solution of CMC at various concentrations has been obtained from RO water.

RESULTS AND DISCUSSION

Gas Holdup

Gas hold up is important parameters for design and scale up of the reactor. The measurement of gas holdup in riser and down-comer zone was obtained by the height of dispersion method. The average gas holdup (Ɛ) was calculated as follows.

$$\varepsilon = \frac{hG - hL}{hG} \tag{2}$$

The equipment was optimized with air water system for different flow rate and bed height. The result is shown in **Fig. 2**. From the result, the gas hold up is linearly increases when increasing the bed height and

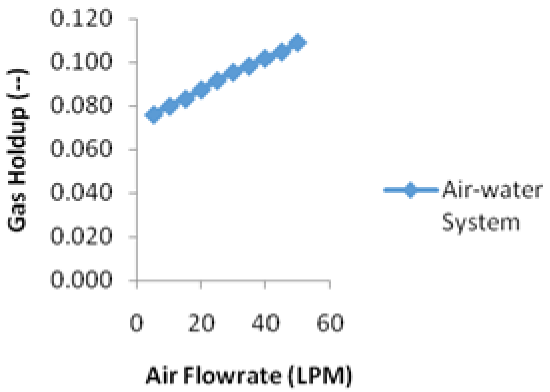

Fig. 3. Variation of Gas holdup with Air flow rate

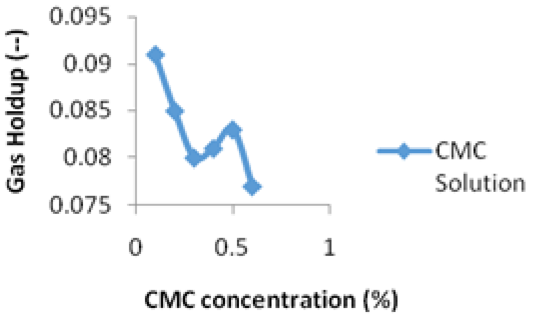

Fig. 4. Variation of Gas holdup with different concentration of CMC

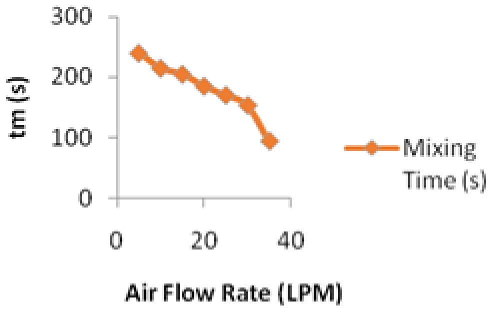

Fig. 5. Variation of mixing time with air flow rate

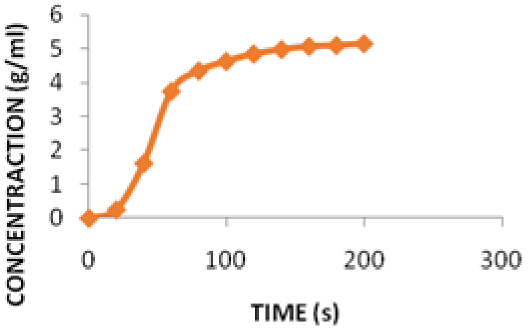

Fig. 6. Variation of mixing time with concentration

also increases with decrease in liquid height. This result was compared with non-Newtonian fluids of CMC solution. According to studies the gas holdup for Non-Newtonian fluid is slightly decreases and increased in its concentration.

From **Fig. 3**, the gas hold up is linearly increases when increasing of air flow rate for Newtonian fluid systems. In case of non Newtonian fluids, the gas hold up for non Newtonian fluid is decreased with increasing concentration at the same time the gas hold up also increased with the range of 0.3 to 0.5%. The comparison result of gas holdup is shown in **Fig. 3 & 4**.

Mixing time (t_m) is the time needed to achieve the desired (or) specified degree of homogeneity. The experiment of mixing time is performed in split cylinder reactor based on stimulus-response techniques. For this purpose, pulse input is used stimulus and the concentration of the liquid is recorded as the response. From the plot of concentration Vs time mixing time is predicated based on the Zwietering criteria (Zwietering 1957). Mixing time is determined for different flow rates and various concentration of solution. The effect of mixing time on different air flow rate and concentration is shown in **Fig. 5 & 6**. From the graph, mixing time is decreased with increase in air flow rate and concentration. A correlation for mixing time was developed based on the experimental studies.

$$t_m = 0.905 \cdot v_g^{2.57} \cdot \log(x_0/x_c)^{0.1} \tag{3}$$

Range:
Diameter = 150 mm
Height = 1000 mm
Gas velocity (Vg) = 5 to 50 lpm
Concentration of CMC = 0.1 to 0.7% (w/v).

The above correlation was valid within the error of ± 5%.

The volumetric mass transfer co-efficient is one of the most important parameter for the evaluation of performance of the split cylinder reactor. The dissolved oxygen meter can be used for measuring the oxygen concentration with respective time, consist of a membrane sensor. For this purpose, experiment were carried out to determine mass transfer co-efficient for optimized air flow rate of 25 lpm based on hydrodynamic studies. The result is shown in **Fig. 7**, finally a correlation was developed based on experimental results.

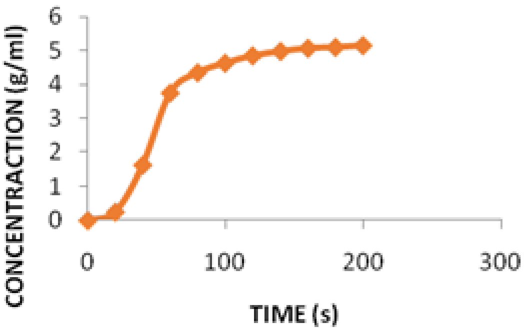

Fig. 7. Volumetric of oxygen transfer co-efficient vs time

Mass Transfer (Kla)

The volumetric mass transfer co-efficient is one of the most important parameter for the evaluation of performance of the split cylinder reactor. The dissolved oxygen meter can be used for measuring the oxygen concentration with respective time, consist of a membrane sensor. For this purpose, experiment were carried out to determine mass transfer co-efficient for optimized air flow rate of 25 lpm based on hydrodynamic studies. The result is shown in **Fig. 7**, finally a correlation was developed based on an experimental results.

$$kla = 1.06 \times 10^{-3} \cdot v_g^{0.12} \cdot D_2O^{0.12} \cdot g^{-0.51} \cdot N^{2.12} \qquad (4)$$

Range:
Diameter = 150 mm
Height = 1000 mm
Gas velocity (Vg) = 25 lpm

The above correlation was valid within the range of error of ± 4%.

CONCLUSION

The hydrodynamic parameter, mixing time and volumetric mass transfer were determined for an split cylinder reactor with rotating device such as impeller. The mixing time, the overall gas holdup and the volumetric oxygen transfer co-efficient also affected by height of the liquid in the reactor. Gas holdup for non-Newtonian fluid is decreased with increasing concentration in the range of 0.3 to 0.5%. The result of gas holdup was compared with that of air- water systems. From the results, it can be seen that mixing time is decreased with increase in air flow rate and concentration. An empherical correlation has been developed for hydrodynamic and mass transport with an error of ±5%.

Nomenclature

K_{La}	Overall volumetric gas-liquid mass transfer coefficient	s^{-1}
t_m	Mixing Time	s
h_G	Gas liquid dispersion height	m
h_L	Height of the liquid	m
V_g	Superficial gas velocity	lpm
g	Acceleration due to gravity	m/s^2
N	Speed of impeller	rpm

Greek Symbols

ξ	Overall gas hold-up	(-)
γ	Kinematic Viscosity	m^2/s
μ	Viscosity of phase	k/Pa.s
ρ	Density of phase	kg/m^3

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