



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 12, Issue 7, July 2023

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.423

9940 572 462

6381 907 438

ijirset@gmail.com

www.ijirset.com

Experimental Studies on Hydrodynamics of Rotating Bed Reactor

S.Raajamurugan¹, M. Monishkanth²

^[1] Assistant Professor, Gnanamani College of Technology, Pachal, Namakkal, Tamilnadu, India

^[2] P.G. Student, Gnanamani College of Technology, Pachal, Namakkal, Tamilnadu, India

ABSTRACT: Rotating Bed reactor (RBR) is a novel equipment which holds a bed fixed within a hollow tubular casing. It uses centrifugal force in addition to other conventional principles of packed bed reactor to increase mass transfer and heat transfer. Rotating Bed reactor has been in research for its efficient usage /application in several industries. It is ideal for process intensification, which aims to integrate multiple process/operations to enhance internal mass, heat transfer and kinetics at micro-level and thereby improve mixing. Rotating Bed reactors significantly reduce the equipment volume and improves selectivity. These merits can effect intense micro mixing and internal mass, heat transfer. It can also provide more contact between reactant and catalyst and thus resulting in more product formation. Desired products can also be produced by adjusting the variable speed of rotation. The mass-transfer coefficient is greatly influenced by the hydrodynamics of gas and liquid phase which is very different from that in the conventional column. In the proposed work, it has been intended to study Superficial Velocity and Gas Holdup for different concentrations of Feed. Higher the gas Holdup, greater will be the conversion. It also has come up with some disadvantages like channelling of inlet stream, side reactions, tedious heat transfer to/from the reactor and control of temperature gradient.

KEYWORDS: Process intensification, Mixing, Rotating Bed Reactor (RBR).

I. INTRODUCTION

This experiment discusses the concept of Process Intensification (PI) and the need to improve mass and heat transfer equipment. PI aims to reduce the size of individual plant modules to achieve cost reduction, efficiency enhancement, and inherent safety. The Rotating Bed Reactor (RBR) is introduced as a multi-phase reactor that utilizes centrifugal force instead of gravity to enhance mass transfer. RBR shows promise in absorption, distillation, stripping, and extraction processes, offering higher efficiency and smaller equipment size compared to conventional packed bed reactors.

The primary goal of the study is to investigate the hydrodynamics and pressure drop of RBR using different fluid systems, including Newtonian, Non-Newtonian, viscous, electrolyte, and Nano particles. Gas holdup measurements provide insights into fluid residence time and chemical reaction times. Pressure drop calculations determine the equipment's feasibility, and the relationship between pressure drop, holdup, superficial velocity, and power consumption in RBR is analyzed for various solutions.

II. NEED FOR RBR

As there is a need for more efficient and feasible operation, it is very important to overcome every minute limitations caused by the equipment or process. As we look deep into the conventional reactors (Packed Bed and CSTR) there are lot of limitations that are to be carried with them like a) Development of dead zones b) Bypassing c) Channeling d) Creation of hotspots e) Low conversion per unit volume of reactant and many more. In order nullify the all those limitations caused by them Rotating Bed Reactor serves as a handy solution and can be considered as a hybrid/combination of those two-equipment mentioned above.

Rotating Bed Reactor is used as a process intensifier, Process Intensification here is defined as improvements of a process in unit operational, functional, phenomena levels that can be obtained by integration of unit operations, integration of functions and phenomena's or targeted enhancement of the phenomena for a set of target operations. In a way to adhere to the above definition Rotating Bed Reactor combines the principle of flow resistance in packed bed and the principle of using a agitator in CSTR to bring out a new process intensification equipment called Rotating Bed Reactor

III. RELATED WORKS

Rotating Bed Reactors can be used for various applications ranging from distillation, absorption, stripping, adsorption, extraction and as a process intensifying equipment. There are several incidents where scholars have done a extensive research about the flow behavior, application, design, hydrodynamics and mass transfer characteristics of Rotating Bed Reactor.

As Rotating Bed Reactor is a process intensifier equipment it is very important to know the comparative study and pros and cons of both CSTR and Packed Bed. An extensive of comparison between the Rotating Bed Reactor and their counter parts have been studied by Hwai-Shen Liu, Chia-Chang Lin, Sheng-Chi Wu, and Hsien-Wen Hsu in the year of 1996. Wei-Der Sung Yu-Shao Chen in the year of 2012 compared the experimental study about the use of blade packings and baffles in both Rotating Bed Reactor and conventional packed bed and came out with a conclusion that in conventional packed bed it was found that gas and solids exchange continuously between the two phases by disintegration of particle aggregates and coalescence of dispersed phase solids. But in Rotating Bed Reactor these problems don't tend to occur as a result of rotating motion and centrifugal action of Rotating Bed Reactor.

In the late 1970's, there appeared in the European and U.S. patents literatures a series of patents assigned to Imperial Chemical Industries (ICI London) introducing the HIGEE packed bed rotor for absorption and distillation applications. The HIGEE packed bed was operated at mean acceleration fields of 200 to 500g, and the reported volumetric mass transfer coefficients were up to 100times larger than the values obtained in conventional packed columns. The reported volumetric mass transfer coefficients varied with the gravitational force to the 0.14 to 0.54 powers. ICI, in spite of extensive tests, published very little information. Glitch Inc. (Dallas), which has acquired worldwide marketing rights, also reported a test history of HIGEE with various systems at wide range of process conditions and physical properties.

Recently, Dudukovic et al reported theoretical and experimental work on rotating packed beds. They reported separately the effect of rotational speed on gas-liquid interfacial area and liquid side mass transfer coefficient to explain the overall enhancement of volumetric mass transfer coefficients in rotating packed beds. Their findings show that the volumetric mass transfer coefficient increases with the rotational speed as a fractional power of .61 to .89 which is in agreement with the data of Vivian et al and within the range estimated by ICI. Their theoretical framework was based on film flow on a rotating blades and rotating disks. Their flooding tests with air-water system showed the Sherwood correlation for the dumped rings is conservative by 40-70%. The bed in this study was 3 mm glass beads which had a specific surface area of 120m²/m³ and a porosity of 0.4.

In all the above work, no attempt was made to model the pressure drop characteristics of the rotating packed bed. There is no information available about residence time distribution on rotating packed beds. No work has been reported in the literature on power requirement of rotating packed bed.

IV. EXPERIMENTAL STUDIES

4.1 LIQUID DISTRIBUTION

In Rotating Bed Reactors (RBR), proper liquid distribution is a critical factor for achieving better performance with any type of packing material. The assumption that the entire surface area of the packing is entirely active due to wetting can lead to poor performance if liquid maldistribution occurs, resulting in lower surface area flow patterns like rivulets. Effective lateral spreading from the liquid source is essential for good liquid distribution and optimum mass transfer performance.

Studies have shown that for every packing material, some degree of maldistribution or channelling known as natural flow develops. Good initial liquid distribution can disintegrate to natural flow quickly, while inadequately distributed liquid may take longer to do so. To measure the tendency of packing material to spread a liquid stream radially as it trickles down the bed, the concept of radial spreading coefficient was introduced. A higher radial spreading coefficient leads to faster initial distribution becoming a natural flow and improved mass transfer performance for maldistributed liquid.

The quality of liquid distribution can be assessed based on three factors: the distribution density (number of distribution points), the geometric uniformity of the distribution points' location, and the uniformity or quality of liquid flow from the distribution points. A distributor with poor quality can result in inefficient Rotating Bed Reactors. Ensuring proper liquid distribution is crucial to achieving optimal performance and efficiency in RBR applications.

4.2 APPLICATION OF RBR'S

1. **Water Deaeration:** A tentative economic comparison, between existing technologies and RBR'S, was presented in terms of capital cost, energy consumption, footprint area, weight and height. Apart from the energy consumption which may be in conflict, all other factors showed significant savings.
2. **Gas Desulfurization:** To produce ammonium sulphite and bisulphate by absorbing SO₂ in ammonia or ammonium bicarbonate. Significant savings in process time and energy consumption were achieved.
3. **Production of Ultrafine Particles** (Nano scale) using RBR'S as a reactive precipitator to produce CaCO₃ particles from CO₂ and lime Ca (OH)₂. Significant reduction in process time and a tighter and small size distribution were reported.

Xumei et al investigated the application of RPBs in an oxygen consuming fermentation process with liquid film mass transfer limitations. The process was to oxidise, sodium sulphite anhydrous in xanthan gum aqueous (XGA) which is a pseudoplastic nonnewtonian fluid, by means of aeration. They investigated the effect of XGA's apparent viscosity and surface tension, for different concentrations, on mass transfer. The volumetric mass transfer coefficient was found to be higher by 5-20 folds than that in a stirred tank reactor.

4.4 SCOPE AND OBJECTIVE

Process Intensification is a new concept, and hence the literature about the rotating packed beds is very limited. A better understanding of the interaction between the phases involved (gas-liquid-packing) is therefore needed in order to develop RBR's and any other process intensification equipment. The concept of PI (Process Intensification) is to improve heat and mass transfer characteristics hence generating better contacts between fluids. The advantage of fast mixing properties can create improved heat and mass transfer rates. Thus, systems with limitations in mixing, reaction times and heat and mass transfer could significantly benefit from PI.

“TO EXPERIMENTALLY STUDY THE HYDRODYNAMIC CHARACTERISTICS OF ROTATING BED REACTOR WITH NEWTONIAN AND NON-NEWTONIAN”

In this project it has been intended to study the characteristics and various aspects of mixing in Rotating Bed Reactor system which includes the experimental study of influence of various parameters like gas flow rate, liquid flow rate, mixing time, solids composition and bed height and speed of rotation of reactor.

V. MATERIALS AND METHODS

5.1 EQUIPMENT DESCRIPTION

Cylindrical acrylic column of diameter 20cm, height 40 cm and thickness of about 6 mm is readily taken which are inferred from previous researches and design calculations in order to withstand the pressure built with in the reactor. The top of the reactor is sealed up permanently with the same acrylic material of proper diameter, but the bottom is covered with a temporary flange in order to dismantle the rotating bed for cleaning or replacement.

The rotating bed is made up of sheet metal with a diameter and height of 10cm, a protecting casing is provided around the rotating bed and the rotating bed is provided with proper liquid inlet, distribution and liquid outlet provisions. A wired mesh of around 90 microns is wound in the inner periphery of rotating bed to increase the reactive surface area. Both rotating bed and stator of the motor is connected by a rotating shaft. Air inlet is provided at perpendicular angle to the rotating bed in order to have an increased efficiency. Liquid inlet and gas outlet are provided at the top of the reactor and liquid outlet and sample collection valve is provided at the bottom of the reactor. Pressure gauge is also provided at the liquid inlet and outlet.

5.2 EQUIPMENT DIMENSIONS

<i>RBR DIMENSIONS</i>	
<i>DETAILS</i>	<i>MEASUREMENT</i>
COLUMN LENGTH	400 mm
COLUMN DIAMETER	200 mm
PACKED BED HEIGHT	100 mm
PACKED BED DIAMETER	100 mm
SPEED OF ROTATION	1000-1200 RPM
TYPE OF PACKING	STRUCTURED PACKING (wire mesh)

TABLE 5.2.1 EQUIPMENT DIMENSIONS

5.3 CHEMICALS USED

- Air
- Water
- Glycerol, Polyethylene Glycol
- Carboxy Methyl Cellulose, Xanthan Gum

5.4 SELECTION OF CHEMICALS

Chemicals chosen for this experiment is purely based on the properties and Economy. Newtonian fluids chosen for the process is Glycerol and Ethylene Glycol. The properties of both fluids were similar to that of water. As we have done comparative studies using Water, usage of these chemicals would give better results. The usage of Non-Newtonian fluids CMC and Xanthan is tedious process because of its properties and most researchers don't tend to work with these chemicals due to their complex flow behavior. In order to take up that challenge we tried to work with those non-Newtonian fluids and got better results.

5.5 EXPERIMENTAL SETUP

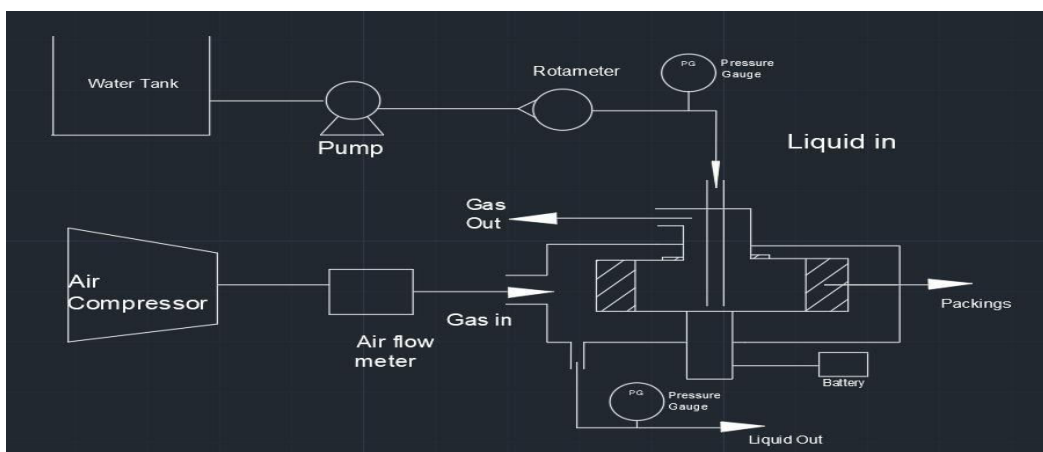


FIG:5.5.1 AUTO CAD DIAGRAM OF EXPERIMENTAL SETUP

5.6 EXPERIMENTAL PROCEDURE

Hydrodynamic studies are to be conducted with various solutions. At first, the experiment is carried out between air-water systems to get the optimized readings. The water is fed into the Rotating Bed Reactor from the top and the flow is controlled using a rotameter, then compressed air is fed perpendicularly to the rotating bed. Liquid outlet and air vent is also provided at the bottom and top respectively. The rotor is driven by the motor where the centrifugal force acts on air-water systems to accelerate the reaction. At first the liquid level in the reactor is noted as H₁. Then the rise in liquid level is noted as H₂, H₃ for particular timings. The various liquid level rise-up is noted for different flow-rates of air and water separately. Then similarly the experiment is done with various solutions such as Polyethylene Glycol, Glycerol, Carboxymethyl Cellulose and Xanthan Gum with various concentrations. At a same time, the barometer readings are also noted for different flow-rates for different solutions with various concentrations. This is especially used for determining the pressure drop. The experiment may also be conducted with different kinds of packing materials.

VI. RESULTS AND DISCUSSION

6.1 HYDRODYNAMIC STUDIES

Hydrodynamic studies were carried out between Air-Water mixture by varying the Liquid and Gas flow rates. Corresponding values of Superficial velocity and Gas Holdup are obtained.

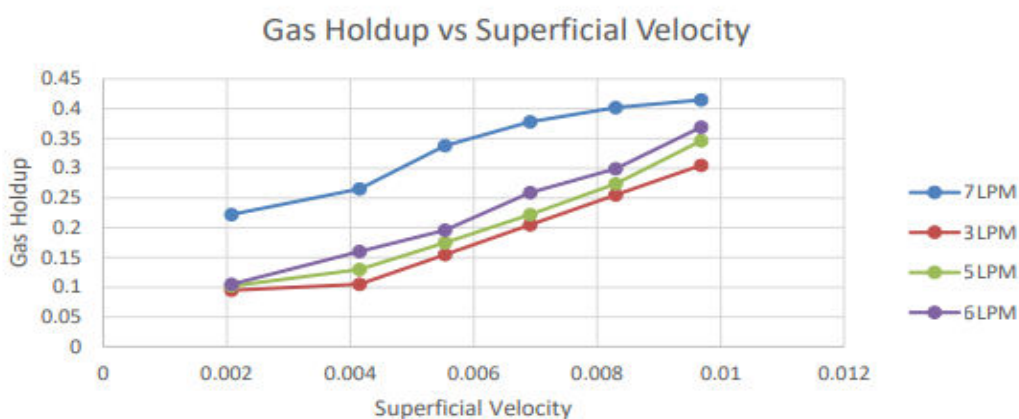


FIG:6.1.1 Gas Holdup Vs Superficial Velocity for variable water and constant airflow rate

Above graph is obtained by keeping air flow rate as a constant and varying the liquid flow rate, from the above graph it is inferred that there is maximum gas holdup when the liquid flow rate is 7 LPM. The same is experimented for varying gas flow rate and keeping liquid flow rate as constant, but it doesn't have a much effect on gas holdup so the former method is preferred and considered to be the optimized condition for this experiment and further proceedings are carried out in Newtonian and Non-Newtonian fluids.

6.2 OPTIMIZATION STUDIES

The main goal optimization is to increase economic potential of a process with certain level of safety, ethical and environmental boundaries. The objective here was to increase the conversion by increasing the surface contact area between the reactants at optimum flow rate of both air, liquid and selected packing materials. The optimized condition is found by measuring the DO in the product stream by using a DO meter which would serve as a direct measure of reactant being converted into a product.

EFFECT OF SUPERFICIAL VELOCITY ON GAS HOLDUP

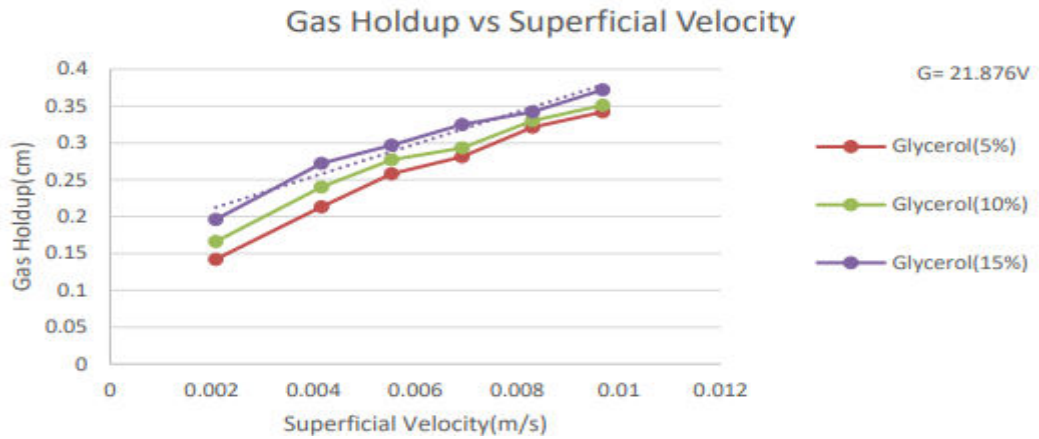


FIG:6.1.2 Superficial Velocity vs Gas Holdup for different concentrations of Glycerol

Above graph (6.1.2) shows that when concentration of glycerol increases, gas holdup gets increased. When increasing the superficial velocity, the gas holdup gets increased with increase in concentration. This is due to interaction between two phases is high, the micro mixing efficiency is also high.

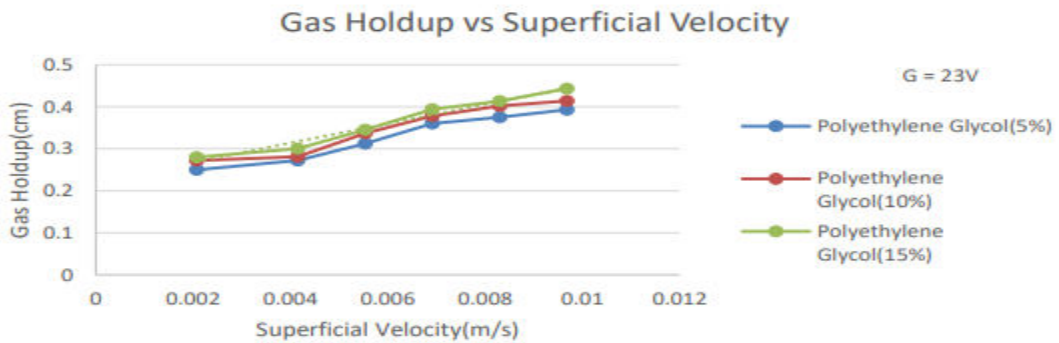


FIG:6.1.3 Superficial Velocity vs Gas Holdup for different concentrations of Polyethylene Glycol

It illustrates that, when concentration of polyethylene increases, gas holdup gets increased. With increasing the superficial velocity, the gas holdup gets increased with increase in concentration. From both the Newtonian fluids (Glycerol and Polyethylene Glycol) it shows that increase in concentration, Gas holdup gets increased with increasing the superficial velocity.

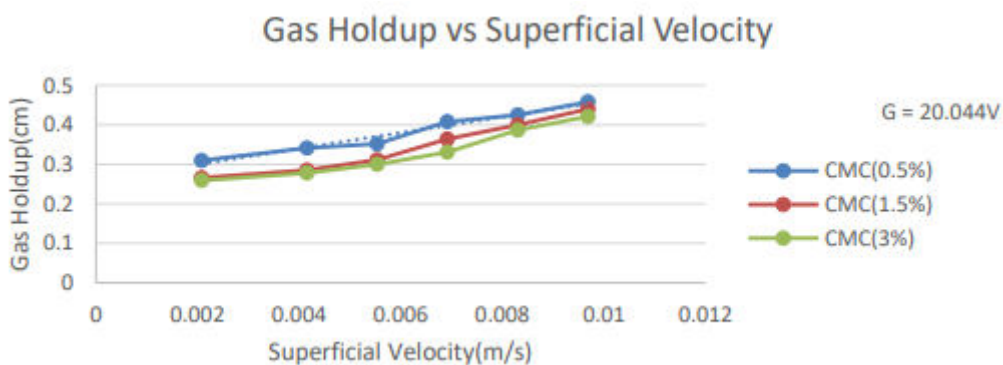


FIG:6.1.4 Superficial Velocity vs Gas Holdup for different concentrations of CMC

Carboxymethyl Cellulose (CMC) is normally a low viscosity fluid, from the above graph it illustrates that when increasing in concentration of CMC, the holdup gets decreased while increasing the superficial velocity this is because shear rate gets decreased when increasing the concentration of CMC.

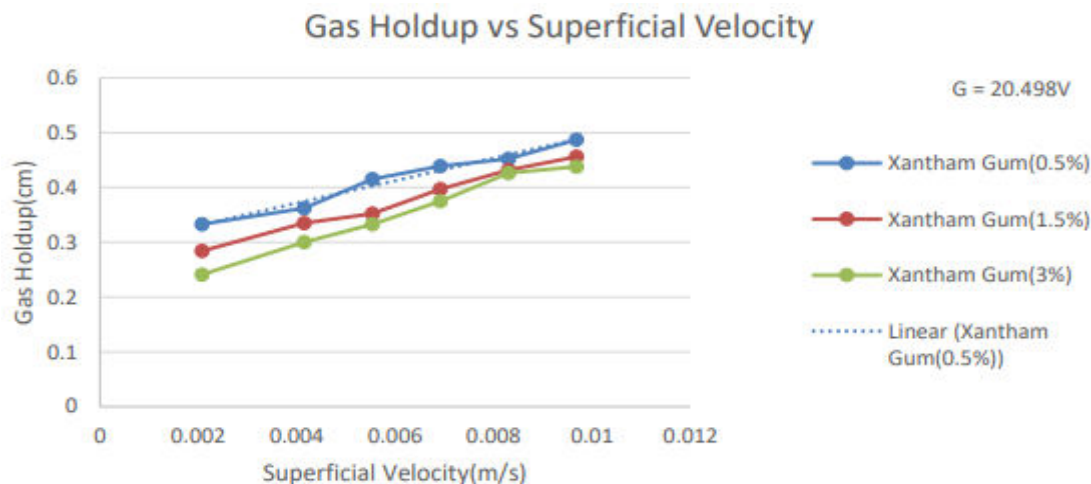


FIG:6.1.5 Superficial Velocity vs Gas Holdup for different concentrations of Xanthan Gum

From the above graph 6.1.5, it conveys that when increasing in concentration of Xanthan Gum, the holdup gets decreased while increasing the superficial velocity this is because shear rate gets decreased when increasing the concentration of Xanthan Gum. From both the Non-Newtonian fluids (CMC & Xanthan Gum) it clearly explains that when increasing the concentration, the holdup gets decreased with increasing the superficial velocity due to decreasing the shear rate.

VII. CONCLUSION

In rotating packed bed reactor, various hydrodynamic characteristic studies have been carried out by using different fluid systems with various concentrations. Because this parameter is sensitive to the reactor design configuration as well as operating variables such as superficial velocity, rotational speed etc, using structured packing, it was observed that gas holdup is larger in RPB reactor of constant rotational speed when compared with conventional packed bed reactor. Rotating bed reactor shows higher holdup than a conventional packed bed reactor. In hydrodynamics studies, superficial velocity increases, gas holdup and power also increase. From both the Newtonian fluids (Glycerol and Polyethylene Glycol) it shows that increase in concentration, Gas holdup gets increased with increasing the superficial velocity. From both the Non-Newtonian fluids (CMC & Xanthan Gum) it clearly explains that when increasing the concentration, the holdup gets decreased with increasing the superficial velocity due to decreasing the shear rate. When increasing superficial velocity, power gets increased when increasing the concentration of Non-Newtonian fluids. In hydrodynamics studies, Xanthan Gum shows higher gas holdup than other fluids In this RPB reactor, the average shear rate increased with increase in superficial velocity and decrease with the increase in concentration of non-Newtonian fluids (CMC and Xanthan Gum). It also shows that the apparent viscosity decreased with increase in superficial velocity for all the concentrations of CMC and Xanthan Gum.

REFERENCES

- (1) Kelleher, T.; Fair, J. R. Distillation studies in a high-gravity contactor. *Ind. Eng. Chem. Res.* 1996, 35, 4646.
- (2) Lin, C. C.; Liu, W. T.; Tan, C. S. Removal of carbon dioxide by absorption in a rotating packed bed. *Ind. Eng. Chem. Res.* 2003, 42, 2381.
- (3) Dipendu, S. Prediction of mass transfer coefficient in rotating bed contactor (Higee) using artificial neural network. *Heat Mass Transfer* 2009, 45, 451.
- (4) Munjal, S.; Dudukovic, M. P.; Ramachandran, P. Mass-transfer in rotating packed beds I. Development of gas-liquid and liquid-solid mass transfer correlations. *Chem. Eng. Sci.* 1989, 44, 2245.
- (5) Munjal, S.; Dudukovic, M. P.; Ramachandran, P. Mass-transfer in rotating packed beds. II. Experimental results and comparison with theory and gravity flow. *Chem. Eng. Sci.* 1989, 44, 2257.
- (6) Thomas, S.; Faghri, A.; Hankey, W. Experimental analysis and flow visualization of thin liquid film on a stationary and rotating disk. *ASME J Fluids Eng.* 1991, 113, 73.
- (7) Zhang, J. Experiment and modelling of liquid flow and mass transfer in rotating packed bed. Ph.D. Dissertation, Beijing University of Chemical Technology, 1996.

- (8) Guo, F. Characteristics of hydrodynamics and mass transfer in cross flow rotating packed bed. Ph.D. Dissertation, Beijing University of Chemical Technology, 1996.
- (9) Guo, K. A study on liquid flowing inside the Higce rotor. Ph.D. Dissertation, Beijing University of Chemical Technology, 1996.
- (10) Guo, F.; Zheng, C.; Guo, K.; Feng, Y.; Gardner, N. C. Hydrodynamics and masstransfer in cross flow rotating packed bed. Chem. Eng. Sci. 1997, 52, 3853.
- (11) Zheng, C.; Guo, K.; Feng, Y.; Yang, C.; Gardener, N. C. Pressure drop of centripetal gas flow through rotating beds. Ind. Eng. Chem. Res. 2000, 39 (3), 829.
- (12) Sandilya, P.; Rao, D. P.; Sharma, A. Gas-phase mass transfer in a centrifugal contactor. Ind. Eng. Chem. Res. 2001, 40, 384.
- (13) Rao, D. P.; Bhowal, A.; Goswami, P. S. Process intensification in rotating packed beds (HIGEE): An appraisal. Ind. Eng. Chem. Res. 2004, 43, 1150.
- (14) Liu, H. S.; Lin, C. C.; Wu, S. C.; Hsu, H. W. Characteristics of a rotating packed bed. Ind. Eng. Chem. Res. 1996, 35, 3590.
- (15) Yan, Z.-y., Q. Ruan, and C. Lin, Hydrodynamics in a rotating packed bed. II. A mathematical model. Industrial & engineering chemistry research, 2012. 51(31): p. 10482- 10491.
- (16) Burns, J. and C. Ramshaw, Process intensification: visual study of liquid maldistribution in rotating packed beds. Chemical Engineering Science, 1996. 51(8): p. 1347-1352.
- (17) Bašić, A. and M.P. Duduković, Liquid holdup in rotating packed beds: examination of the film flow assumption. AIChE Journal, 1995. 41(2): p. 301-316.
- (18) Yang, H.J., et al., Characterization of micromixing efficiency in rotating packed beds by chemical methods. Chemical Engineering Journal, 2006. 121(2-3): p. 147-152.
- (19) Liu, Y., et al., 3D numerical simulation of a rotating packed bed with structured stainless-steel wire mesh packing. Chemical Engineering Science, 2017. 170: p. 365-377.
- (20) Chandra, A., P. Goswami, and D. Rao, Characteristics of flow in a rotating packed bed (HIGEE) with split packing. Industrial & engineering chemistry research, 2005. 44(11): p. 4051-4060



Impact Factor: 8.423



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

 9940 572 462  6381 907 438  ijirset@gmail.com



www.ijirset.com

Scan to save the contact details