Prediction of Riser Gas Holdup in Three- Phase External Loop Air Lift Fluidized Bed Reactor

Sivakumar Venkatachalam (Corresponding author)
Department of Food Technology, Kongu Engineering College
Perundurai, Erode-638052, TN, India
Tel: 91-4294-226-606 E-mail: drvsivakumar@yahoo.com

Kannan Kandasamy
Department of Chemical Engineering, Kongu Engineering College
Perundurai, Erode-638052, TN, India
E-mail: kannank@kongu.ac.in

Akilamudhan Palaniappan
Department of Chemical Engineering, Erode Sengunthar Engineering College
Thudupathi, Erode-638057, TN, India
E-mail: akilamudhan@yahoo.co.in

Abstract

Hydrodynamics is an important issue for design and development of three phase external-loop airlift fluidized bed. This paper deals on the experimental investigations on the effect of superficial gas and liquid velocities and properties of solids on the riser gas holdup of a three phase external-loop airlift fluidized bed reactor and it was characterized using Newtonian and non Newtonian systems. Water, 65% and 85% of glycerol and n-butanol were used as Newtonian liquids and different concentration of Carboxyl Methyl Cellulose (CMC) i.e., 0.2%, 0.5% and 1% were used as non Newtonian liquids. Spherical glass beads, bearl saddles and rasching rings of different sizes were used as solid phase. The phase flow rates and properties of solid particle had significant effect on the hydrodynamic characteristics of the external-loop airlift fluidized bed reactor such as riser gas holdup. Unified correlations have been developed to estimate the riser gas holdup as a function of superficial phase velocities, properties of solid particle and physical properties of both Newtonian and Non-Newtonian liquid systems. The predicting ability of the correlations were tested with the experimental data and found to be good fit with an absolute average relative error (AARD) of ± 9.7 % for riser gas holdup.

Keywords: External loop, Riser gas holdup, Newtonian, Non Newtonian systems

1. Introduction

Three phase external loop air lift fluidized bed reactors are increasingly used in the fields of chemical and biotechnology as simple and effective contactors for process involving gases, liquids and solids. External loop air lift fluidized bed reactor has found many applications in many industrial processes such as hydrogenation, desulfurization, coal liquefaction, Fisher Tropsch synthesis etc. The simplicity of their design and construction, better defined flow and low power inputs for requisite transport rate and difference over bubble columns are make them very attractive (Verlaan 1987, Chisti M.Y 1989, Merchuk J.C 1986, Al Masry et al 1993). Among different configuration of three phase reactors, the advantage of three phase external loop airlift fluidized bed reactors over three phase fluidized bed reactor is that it requires less liquid flow rate for complete suspension of solid. Apart from this, external loop airlift reactor provides excellent contact among the phases, easy removal or replenishment of particles, rapid mixing, reasonable interface mass transfer rates and easier scale up (Guo Y.X et al 1997, Malin Liu et al 2006,). External loop airlift reactors are found to be suitable in the area of bioprocess and bio environmental application where partial liquid circulation is necessary (Chisti and Moo-Young 1988 a,b, Kawase et al 1996, Carla Fretias et al 2000, Beun et al 2002**,** Kausthuba Mohanthy et al 2008, Yazdian et al 2009). External loop fluidized bed reactor have three different sections called as riser, down comer and gas liquid separator which is at the top of the column. The riser and down comer are connected each other at the top and bottom. In the riser the gas and liquid are passed by co current from the bottom, which results in a difference in static pressure in the two sections and it leads the circulation of the liquid. Gas hold up determines the residence time of the phases in the bed (Kastanek et al 1993). Merchuk (1986) found that there is no significant influence of distributor holes diameters on the hydrodynamic properties such as gas holdup and liquid circulation velocity. Carla Freitas et al (2000) also found the gas distributors had a negligible effect on riser gas holdup where as the air flow rate, solid loading and solid density had significantly affect the hydrodynamics characteristics of external loop air lift reactor (Snape et al 1995, Vial et al 2000). Kochbeck et al (1992) measured the hydrodynamic property such as liquid circulation velocity dispersion and phase holdup along the reactor axis and found that the gas holdup increased along the axis of the reactor regardless of gas input and solid loading. Many studies on airlift external loop fluidized bed reactors have been aimed at estimating the evaluation of gas hold up in each section of the reactor as a function of superficial gas velocity (Merchuk et al 1981, Merchuk et al 1986).

The gas holdup is one of the impartment parameter because it directly influence the mass transfer rate is function of the gas velocity (Bo Jin et al 2006). The proper design and scale up of an external loop air lift reactor still remain difficult because of the complex hydrodynamics behavior (Bentifrauine et al 1997). From the literature, it is found that most of the experiments have been carried out in a two phase external loop air lift fluidized bed reactor to determine gas holdup, however only a few experimental studies of the gas holdup have been reported for three phase and also those studies are restricted to stagnant liquid and Newtonian liquids systems (Douek et al 1994, Guo Y.X et al 1997, Freitas et al 1999, Jing Lin et al 2004). Most of the chemical and bioprocess fluids behaves as power law non-Newtonian characteristics, there is a need to study the hydrodynamic characteristics such as gas holdup of external loop three phase air lift fluidized bed reactor using Newtonian and non-Newtonian fluids for wide range of operating conditions and hence in the present research experiment has been carried out to analyze the influence of phase flow rates, particle dimensions and physical properties of liquid on gas holdup and also unified correlation has been developed to estimate the riser gas holdup for both Newtonian and non-Newtonian systems.

2. Experimental Setup and Procedure:

Figure 1 is a schematic diagram of experimental setup. All the experiments were carried out in an acrylic column of external loop airlift fluidized bed reactor having a total volume of 30 liters and height of 1.7 m. Riser and down comer diameters were 0.15 m and 0.03 m respectively. 0.15m diameter of the perforated plate of 2 mm in thickness and having diameter of 0.0008 m holes and 150 holes were arranged in triangular pitch was used for gas distribution. The separation of gas and liquid were carried out at the top of the reactor, so that the gas does not circulate through the down comer. The liquid and gas superficial velocities were varied from 0.000142 to 0.0674 m s^{-1}. The phase flow rates were measured by calibrated rotameters. Riser gas holdup was measured using the volume dispersion method (Chisti et al 1989, Hwang and Chang 1997, Garcia et al 2000, Bo Jin at al 2006, Yazdian et al 2009). All the experiments were carried out at the room temperature and atmospheric pressure. In the present study, water, glycerol of 65 and 85 vol% and n-butanol were used as Newtonian fluids and various concentrations of CMC (0.2, 0.5, and 1 vol %) were used as non-Newtonian fluids. Oil-free compressed air and eleven different particles were used as gas and solid phases respectively. The chemicals used in the present study were AR grade and procured from Loba Chem (P) Ltd., India. Brookfield Rheometer was used to measure the viscous properties of Newtonian and non-Newtonian fluids. The details of properties of solids and liquids used in the present study are given in Table1and 2.

3. Result and Discussion

The influence of operating variables such as gas and liquid flow rates, physical properties of the fluids, particle diameter and characteristics etc on riser gas holdup have been analyzed using the experimental data and the details are shown in Figures 2-6. For air-water system, the variation of riser gas holdup with respect to gas and liquid phase superficial velocities are shown in Figure 2, in which riser gas holdup are plotted for the particle 6. It was observed that there was no entrainment of gas bubble into the down comer of the proposed reactor. Hence the riser gas holdup measured was the overall gas holdup in the riser. Riser gas holdup in the external loop airlift reactor is dependent on the both liquid flow rate and gas flow rates. It is observed from the Figure 2, the riser gas holdup increases with the increase in the velocity of the gas and liquid phase velocity which is in accordance with the results obtained by other researches (Guo Y.X et al 1997, Freitas.C et al 2000, Al Qodah et al 2000, Malin Liu at al 2007). The effect of particle size and shape for an air-water system on riser gas holdup is shown in the Figure 3.

The effect of different spherical particle sizes on gas holdup is compared and plotted in the Figure 3. It is observed from the Figure 3, that the riser gas holdup decreases with increase in particle diameter. This trend indicates that more liquid is retained in the column when the particle size increases. In fact, the surface area per unit volume of the solid bed increases for smaller particle size and hence, gas bubbles break and the residence time of the gas bubble increases on the column and hence riser gas holdup increases. The gas holdup was found to increase with the increasing particle densities (Guo Y.X et al 1997). The effect of particle shape (sphericity) for an air-water system on riser gas holdup is shown in the Figure 4. The influence of sphericity of particle on riser gas holdup is shown in Figure 4, from which it is observed that an increase of sphericity of particle decreases the riser gas holdup and it is mainly due to decreasing surface area per unit volume of particle which leads to less bubble breakage. An increase of bubble rising velocity corresponds to a decrease of the riser gas holdup. Variations of bubble velocity are often related to their size change (Dhaouadi et al 2006).

The influence of liquid properties on riser gas hold up was analyzed using different liquid systems (water, n-butanol, and different concentration of glycerol) and is shown in Figure 5. For constant fluid phase velocities, the increase of riser gas holdup was observed when the liquid viscosity increases. Increasing liquid viscosity restricted the movement of the bubbles and hence gas holdup increases. The Figure 5 illustrates a strong influence of liquid properties on riser gas holdup (Kemblowski et al 1993). From the same figure it also observed that decreasing surface tension increase riser gas holdup and it mainly due to smaller bubbles size in low surface tension liquids (Snape et al 1992). The effect of non-Newtonian fluids of three different CMC concentrations on riser gas holdup is plotted in Figure 6. For non-Newtonian fluids the influence of fluid consistency index (k) on riser gas holdup is shown in Figure 6.

From the experimental results, it is observed that the increase of fluid constancy index (k) increases riser gas holdup (Bo Jin et al 2006). The fluid constancy index (k) increases means higher friction between gas bubble and liquid. So higher gas holdup for air-CMC than air-water (Garcia Calvo et al 1996). In this present investigation an attempt has been made to develop a unified correlation for the prediction of riser gas holdup by using dimensionless groups, which includes superficial gas and liquid velocity, particle size, its density and physical properties of liquid. The present experimental measurements of riser gas holdup (1132 data points) on different particles and various liquid systems were used for regression analysis, based on which the following correlations were developed.

Correlation was developed for the prediction of riser gas holdup by accommodating all the operating and fundamental variables using dimensionless group method. Regression analysis of the available riser gas holdup data yield the following correlation.

$$\varepsilon_g = 0.97(N_{\mathrm{Re}g})^{0.365}\left(N_{\mathrm{Re}lm}\right)^{0.67}\left(\frac{d_p}{d_c}\right)^{-9.9}\left(\phi_s\right)^{-0.02}\left(\frac{\rho_p-\rho_l}{\rho_l}\right)^{-0.99}(Mo)^{0.131} \quad \text{(Eq.1)}$$

An error analysis of the proposed correlation (Eq.1) for the prediction of riser gas holdup show an AARD of ± 9.7 %. Figure 7 indicates the plot of experimental and calculated values of riser gas holdup for the available data of Newtonian and non -Newtonian systems.

4. Conclusion

In the three-phase external loop air lift fluidized bed reactor riser gas hold up was studied for different properties of liquid and solid phases for Newtonian and non-Newtonian systems. It is observed that gas holdup in the external loop airlift fluidized bed reactor is dependent on the both liquid flow rate and gas flow rates. Gas holdup increases with the increase in the velocity of the gas and liquid. The riser gas holdup decrease with increase in particle diameter. It had found that the increase of sphericity of particle decreases the gas holdup. It is observed that the riser gas holdup increase with increasing viscosity and fluid constancy index of Newtonian and non-Newtonian liquids. Correlations were developed based on the properties of liquid and solid phases for riser gas holdup and found to be coinciding with the experimental results. This correlation could be used confidently for design of commercial reactors.

Nomenclature

AARD	absolute average relative deviation
Mo	Morton number, $\frac{We_l^{3}}{Fr_l N_{\mathrm{Re}\,lm}^{4}}$
d_p	particle diameter, m

d_c column diameter, m
g acceleration due to gravity, m/s^2
k flow consistency index, $kg/m/s^{2-n}$
n fluid behavior index
$N_{Re\,g}$ Reynolds's number of gas, $\frac{d_p U_g \rho_g}{\mu_g}$
$N_{Re\,lm}$ modified Reynolds's number of liquid, $\frac{d_p^{\,n} U_l^{2-n} \rho_l}{k}$
We_l Weber number of liquid $\frac{d_p U_l^2 \rho_l}{\sigma_l}$
Fr_l Froude number of liquid, $\frac{U_l^2}{g d_p}$
U_g superficial gas velocity, m/s
U_l superficial liquid velocity, m/s
Greek letters
ρ_l liquid density, kg/m^3
ρ_p particle density, kg/m^3
ρ_g gas density, kg/m^3
μ_g gas viscosity, kg/m/s
ϕ_s sphericity of particle
ε_g riser gas holdup
Abbreviation
CMC carboxymethyl cellulose

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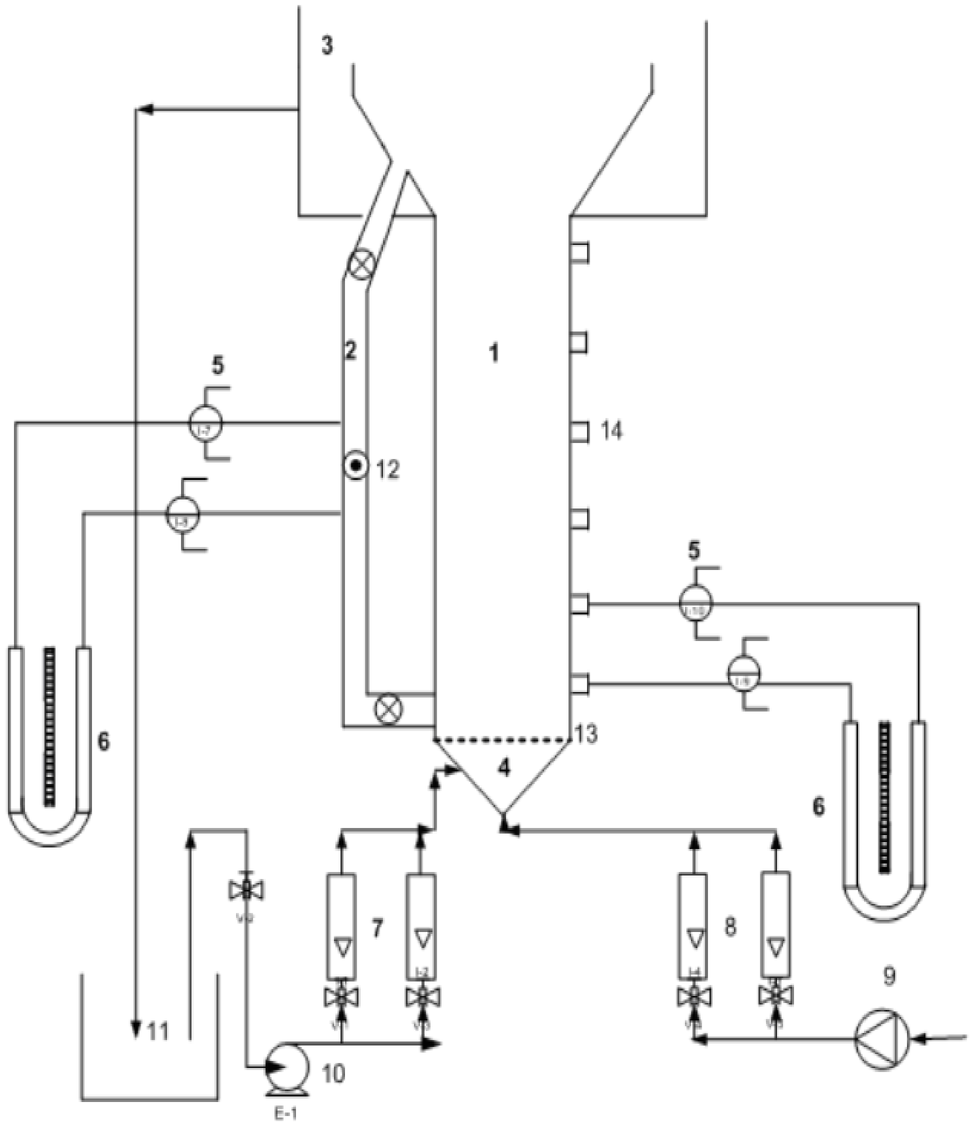
Table 1. Properties of solid particles used in the present system

Properties of solid particles		d_p (m)	ρ_p (kg/m^3)	ϕ_s
Particle. 1	Sphere-Porcelain	0.001	2480	1
Particle. 2	Sphere-Porcelain	0.002	2480	1
Particle. 3	Sphere-Porcelain	0.003	2480	1
Particle. 4	Sphere-Porcelain	0.004	2478	1
Particle. 5	Sphere-Porcelain	0.005	2478	1
Particle. 6	Sphere-Porcelain	0.006	2478	1
Particle. 7	Sphere-Porcelain	0.01036	2478	1
Particle. 8	Bearl saddles	0.00658	2213	0.33
Particle. 9	Bearl saddles	0.01150	2456	0.33
Particle. 10	Rasching rings	0.00351	2173	0.58
Particle. 11	Rasching rings	0.01360	2083	0.58

Table 2. Physical Properties of liquid system used in the present system

Properties of fluids		Density (kg/m^3)	Viscosity		Surface tension σ_l (N/m)
			k (kg/ m/s^{2-n})	n	
System 01	Water	1000	0.00085	1	0.072
System 02	n-Butanol	1010	0.001	1	0.039
System 03	85% Glycerol	1185	0.032	1	0.068
System 04	65% Glycerol	1158	0.019	1	0.069
System 05	0.2% CMC	1028	0.02	0.88	0.0738
System 06	0.5% CMC	1025	0.031	0.87	0.0741
System 07	1% CMC	1020	0.057	0.86	0.0745



1. Riser, 2. Down comer, 3. Gas liquid Separator, 4. Calming section, 5.Gas liquid Separator for Manometer, 6. Manometer, 7. Rota meter for Liquid flow rate, 8.Rota meter for Gas flow rate, 9. Gas in let valve 10. Liquid circulating pump, 11. Liquid Storage tank, 12. Orifice, 13. Supporting Screen, 14.Manometer Tapings

Figure 1. Schematic diagram of experimental setup

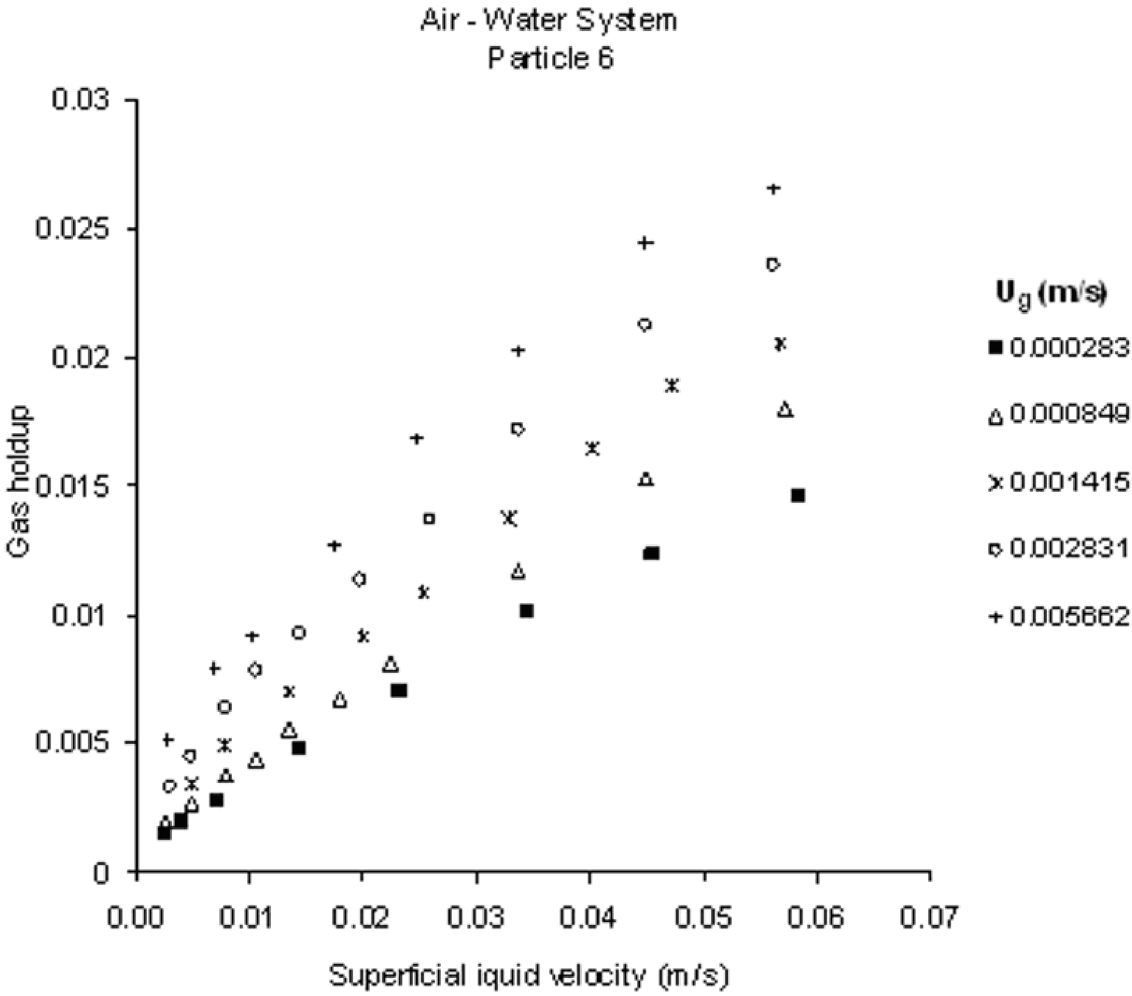


Figure 2. Effect of gas and liquid velocity on riser gas holdup

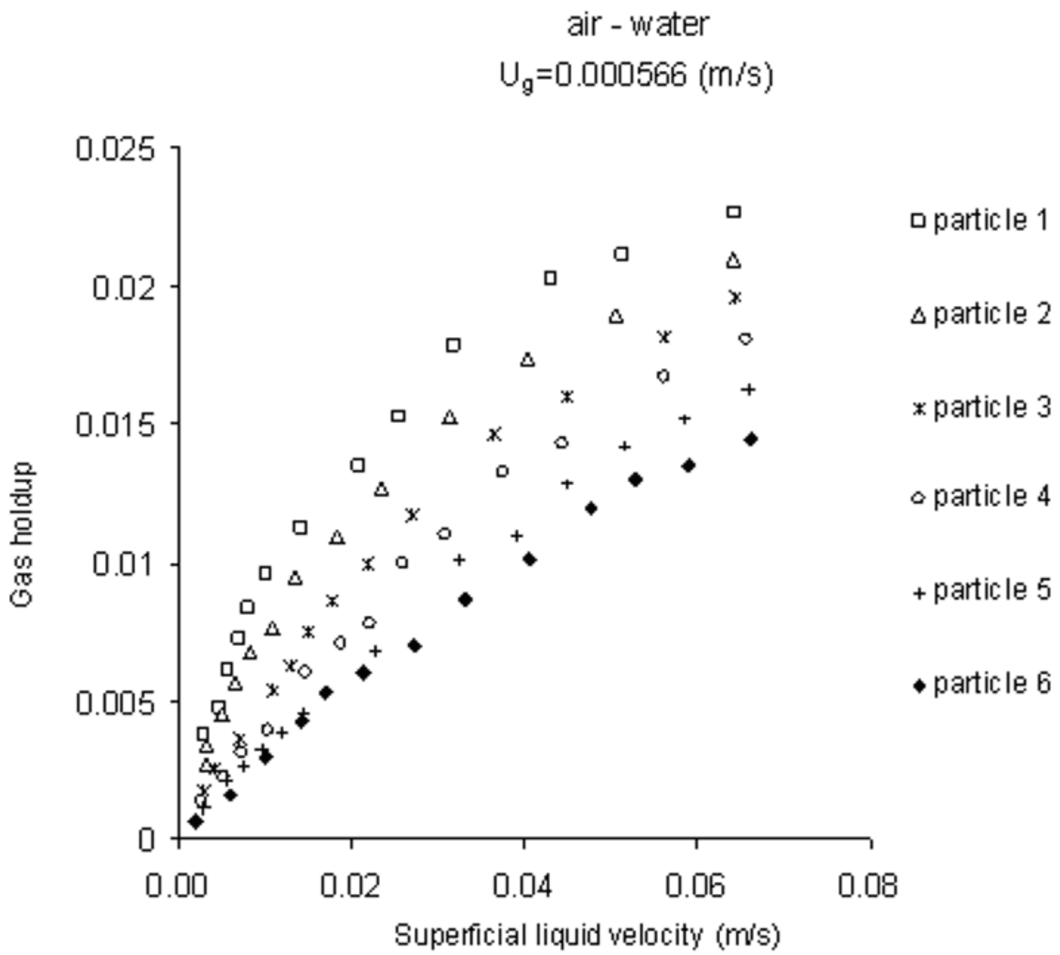


Figure 3. Effect of particle diameter on riser Gas holdup

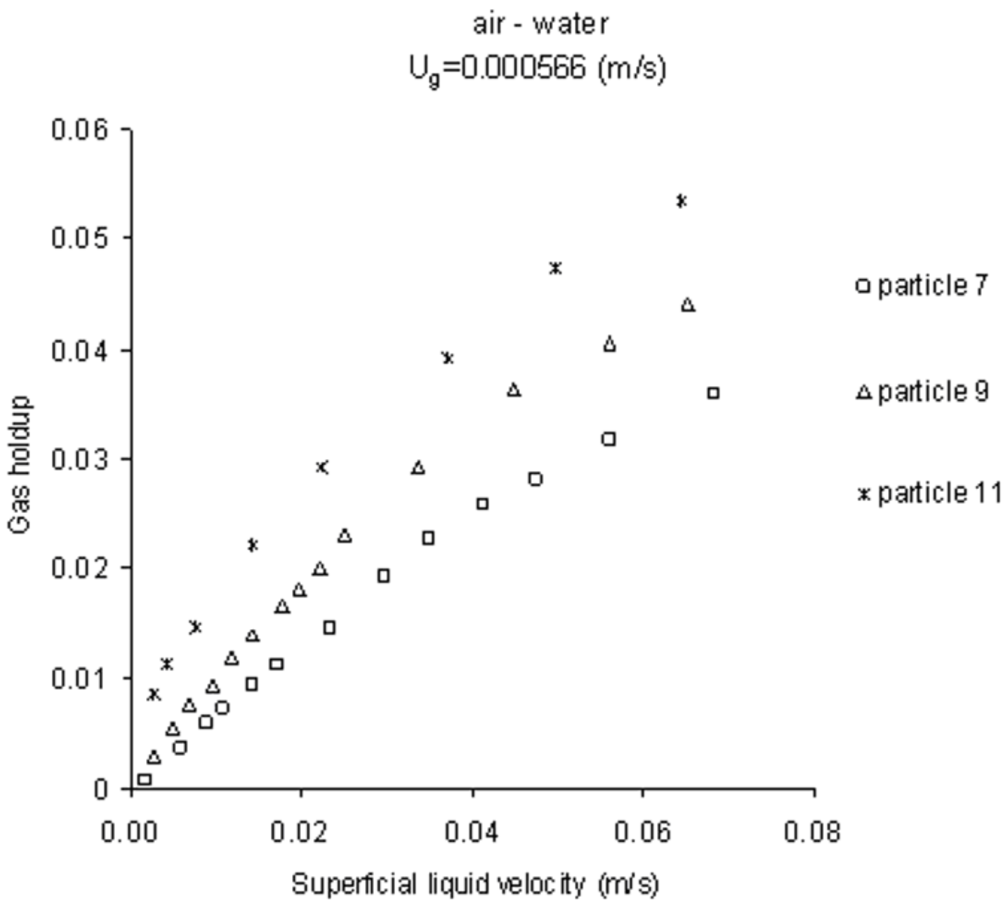


Figure 4. Effect of particle Shape on riser Gas holdup

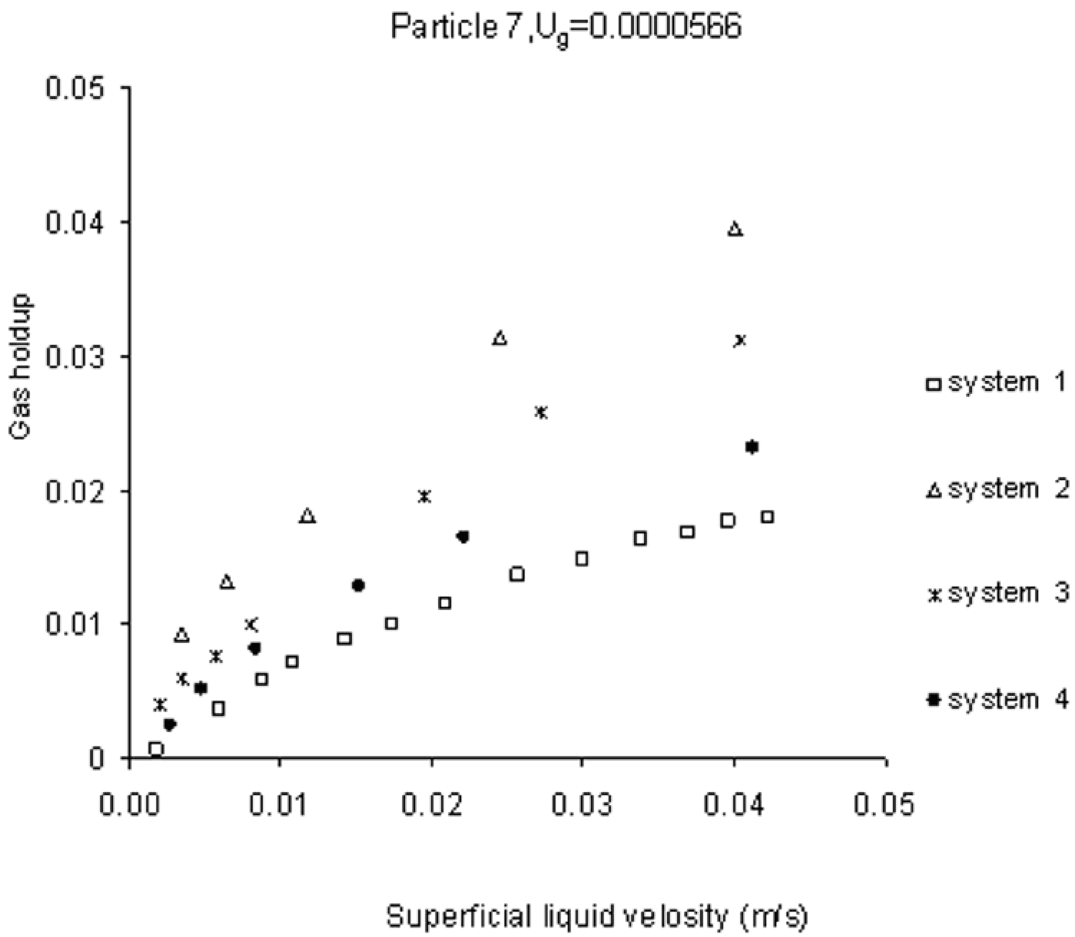


Figure 5. Effect of physical properties of Newtonian liquid on riser gas holdup

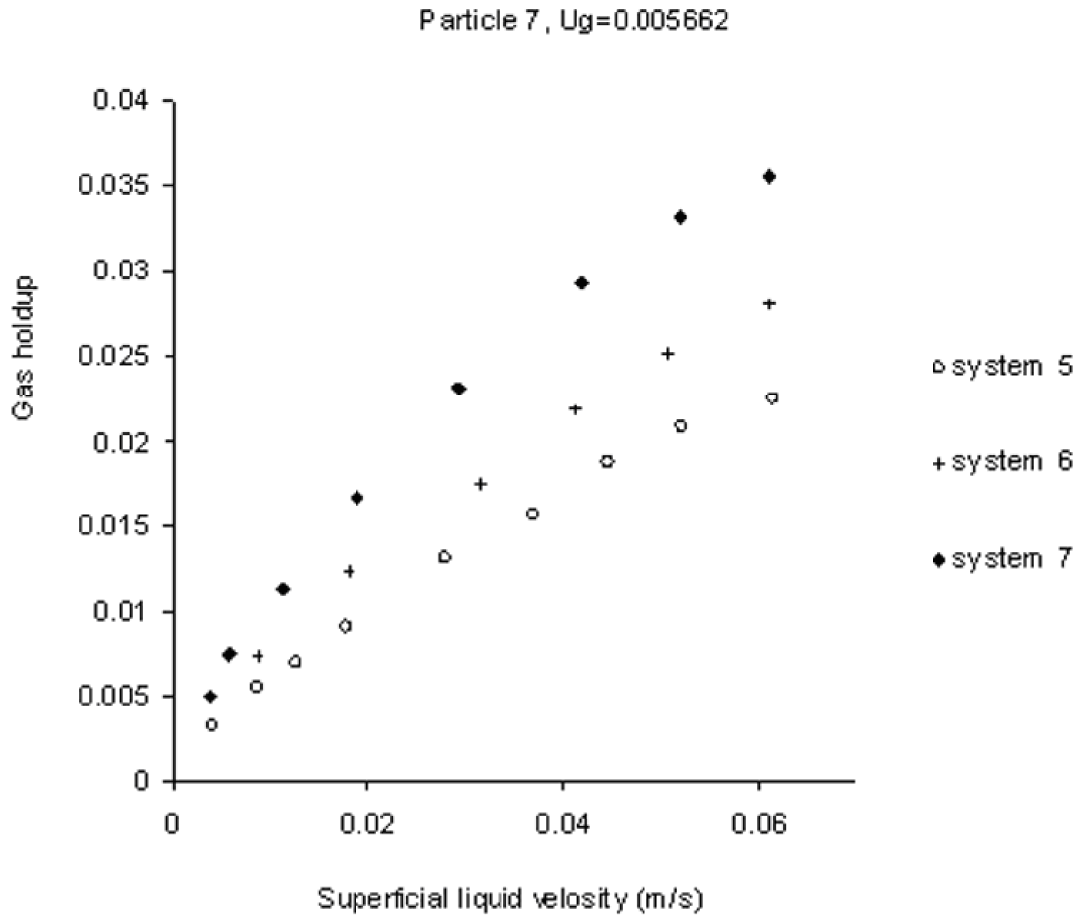


Figure 6. Effect of physical properties of non-Newtonian liquid on riser Gas hold up

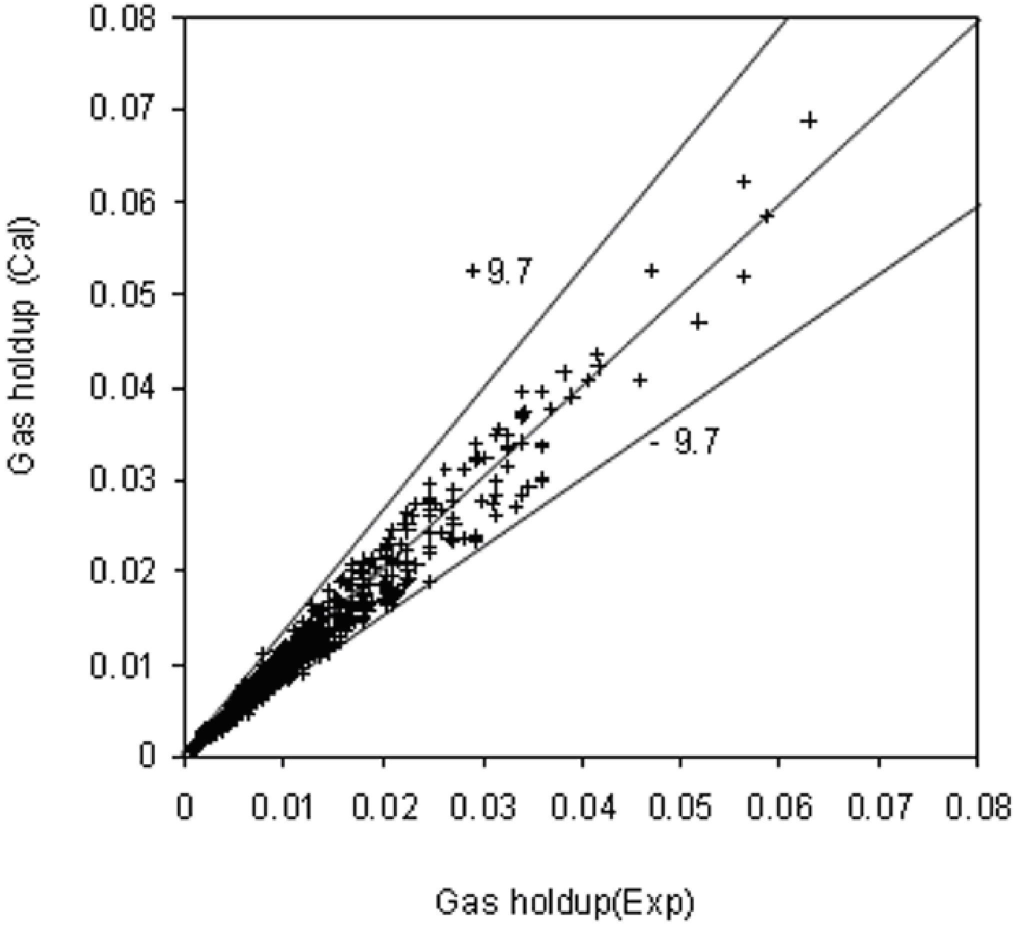


Figure 7. Comparison plot of Gas holdup (Exp) vs Gas holdup (Cal)