Hydrodynamic Characteristics Effect of Foam Control in Multiphase Column

Mohammad Fadhil Abid [*] **and Ahmed Ali Hadi** [**]

[*] **Department of Chemical Engineering, University of Technology Baghdad, Iraq.**

[**] **Ministry of Oil, Baghdad, Iraq.**

ABSTRACT

Foaming is an undesirable phenomenon in chemical reactors because foaming strongly decreases the liquid residence time and in hydrocracking reactors foaming promote the formation of coke resulting in high deficiency of reactor performance. The effects of various operating parameters (i.e. superficial gas (1-10 cm/s) and liquid (0.1-0.45 cm/s) velocities, type (Hydrophilic – Hydrophobic) and size (0.25, 0.50, 0.80 and 1.25 mm) of solid particles, volume percentage of particles (0, 10 and 20 %vol.) loaded in the column) on formation of foams were studied and also a simple process for foam suppression was investigated. From the present work it was found that: when an aqueous mixture of water/hydrocarbons was employed in the operating column, foam can be exist depending on the input parameters. Bubbly and foamy regimes were presented at the same time in the column; the foam regime above was separated from the bubbly regime below by a very clear interface that moved down sharply when the gas velocity was increased gradually occupying almost all the reactor volume. A mathematical correlation was found to relate the inception of foams with the operating parameters and the type of foaming system. A modified method was utilized in the present work to convert the solid hydrophilic particles into hydrophobic. The fluid mechanism of foam suppression with hydrophilic particles was enhanced by a direct attack on the foam by hydrophobic particles. The smaller particles expanded so well and penetrated the foam so easily, that the accumulation of particles at the top of the reactor was produced. It was that the hydrophobic particles of 0.25 mm average diameter and 10V% loading in the reactor could reduced foaminess fraction from 0.85 to 0.15 if the liquid velocity was 0.3 cm/s. the foaminess fraction could be reduced to zero if the liquid velocity was increased to 0.4 cm/s. the results of this study may have abroad applications in petroleum and petrochemical industries where liquid hydrocarbons are processed.

Keywords: Multiphase reactor, hydrodynamics, foam suppression, hydrophobic.

INTRODUCTION

Foams and foaming pose important questions and problems for the chemical industry in general. As a material, foam is almost unique in that is desired product while also an unwanted byproduct within industry Joshi et.al.[1981]. Foam can be desirable such as in bioreactors where it acts as a cushion preventing bursting bubbles from damaging the cells at the liquid surface, Prins [1986]. In protein separation, proteins acting as surfactants concentrate in the foam that is collected to produce a solution with higher protein concentration, Ozturk et.al.[1995]. In the oil industry, foams are used in under-balanced drilling, for reservoir clean-up and for enhanced oil recovery in porous sand Bikerman [1973].

On the other hand, excessive foaming might create serious problems in many industrial processes. Foam can reduce throughput and separation performance or can even cause contamination of products due to takeover of foam from other vessels Kister [2003], Thiele et. al. [2003]. In hydrocracking and other foaming reactors, the foam rises to the top because it has a higher gas fraction than the bubbly mixture from which it comes. The high gas hold-up in foams is undesirable in chemical reactors because it strongly decreases the liquid residence time and in hydrocracking reactors also promotes the formation of coke Guitian et. al. [1999]. In food processes or in glass melting furnaces, foam is undesirable since it may disrupt the production and significantly affect the product quality and the energy efficiency of the process. Whether foam is desirable or not, it is of fundamental and practical interest to understand the foaming process and to predict the conditions under which foam starts forming in order to operate a process under the most favorable conditions Pilon et. al. [2001].

The design and scale-up of multiphase reactors generally depend on the quantification of three main phenomena: mixing characteristics; heat and mass transfer characteristics; chemical kinetics of the reacting system. Thus, the reported studies emphasize the requirement of improved understanding of the multiphase fluid dynamics and its influence on phase holdups, mixing and transport properties Herbolzheimer et. al. [2006]. The hydrodynamics in a multiphase reactor are characterized by different flow regimes, namely, the homogeneous, transition, and heterogeneous regimes, mainly depending on the superficial gas velocity. The homogeneous regime exists at low superficial gas velocities and changes to the heterogeneous regime with an increase in the superficial gas velocity. The industrial interest for gas-liquid-solid processes is in the heterogeneous flow regime Miller [1980], Krishna [2000]. The hydrodynamics, heat and mass transfer, and mixing behavior are quite different in different regimes Hyndman et. al.[1997].

All studies examine gas holdup because it plays an important role in design and analysis of bubble columns Hikita et. al. [1980], Fan et. al.[1985]. Li and Prakash [2000], correlated the gas holdup with the static pressure drop along the bed height in a three phase slurry bubble column as:

$$\varepsilon_g = 1 - \frac{1}{g\left(\rho_l \varepsilon_l + \rho_s \varepsilon_s\right)} \frac{\Delta P}{\Delta H} \qquad (1)$$

The superficial gas velocity is the dominant factor that influences gas holdup. With increasing superficial gas velocity, gas holdup increases, less pronounced in the heterogeneous regime than in the homogeneous regime. Numerous experimental studies reported these findings [Letzel et. al. [1999], Jordan and Schumpe [2001],Behkish et. al. [2002], Vandu et. al. [2004], Lau et. al. [2004], Chaumat et. al. [2005], Yang et. al [2005]], Tang and Fan [1989] found that increasing the liquid velocity significantly increased volumetric mass transfer coefficient but only slightly increased the gas holdup. Yang et al. [1999] and Chaumat et al. [2005] found a slight increase in gas holdup with increasing superficial liquid velocity. The enhancement of mass transfer at higher liquid velocities is probably due to the turbulence induced by the liquid flow. Lau et al. [2004] found that the influence of the liquid velocity on gas holdup became more pronounced at high pressures.

The effect of solid concentration on gas holdup has been investigated by a number of researchers [Kato et al. [1973], Deckwer et al. [1980], Kara et al. [1982], Sada et al. [1984],Pino et.al. [1992], Krishna et al. [1997]] who concluded that an increase in solids concentration generally reduced the gas holdup. Sada et al. [1984] also reported that for low solids loading (<5 vol. %), the behavior of the slurry bubble column is close to that of a solid free bubble column. Contrarily, Kara et al. [1982] found a strong dependence of gas holdup on solids concentration at low solids concentrations. Kato et al. [1973] reported that the effect of solid concentration on gas holdup becomes significant at high gas velocities (>10–20 cm/s).

Foam control agents can be classified as antifoams and defoamers. Although the two terms are often used interchangeably, strictly speaking, antifoams prevent the formation of stable foams, while defoamers act by destabilizing already existing foams. Foam control agents must be insoluble in the foaming medium. They function by being more surface active than the surfactant stabilizing the foam so that they are able to enter the surface layers of the potentially foaming liquid and displace it from the gas/liquid interface Hill and Fey [1999]. However, these agents are cracked under the severe condition present in the reactors. For example, in hydrocracking reactor, anti-foam agents are exposed to hydrogen pressures over (100 bar) and temperature of(140° C)or higher. Anti-foaming agents tend to crack into different chemical products which contaminate the liquid and gas in the reactor. In addition to requiring more frequent catalyst replacement in the downstream hydrodesulphurization reactor, such cracking of anti-foaming agents also tends to increase the operating costs of the over all process Dargar et al. [2006].

Prior literature (Bikerman, [1973], Garret, [1993], Prud'homme & Khan, [1996]) on the use of particles to destroy foam described effects of hydrophobic particles which attack the foam. Armstrong et al., [1976] observed adhesion of air bubbles to Teflon-coated glass beads fluidized in water. They suggested that the phenomenon of bubble adhesion to the non-wettable particle leads to a decrease in the apparent density of the particle, which in turn is responsible for a larger bed expansion and smaller gas holdup compared with wettable particle systems. Frye and Berg, [1989] have shown that non-wettable particles can be used to thin or reduce foam layers, and consequently reduce foam formation. Tsutsumi, Dastidar and Fan, [1991] studied the characteristics of water-air-solid fluidization with non-wettable (hydrophobic) particles and classified the flow pattern according to the motion of the particle-bubble aggregates.

Guitian and Joseph, [1997] proposed fundamental studies of their observations on foam suppression experiments they carried out in a cold slit bubble reactor. They found that foaming may be strongly suppressed by fluidizing hydrophilic particles in the bubbly mixture below the foam. They suggested that the suppression is achieved by increasing the wetted area of solids surface.

The aim of the present work was to understand the role of fluidized particulates in a hydrocarbon stream flowing in a three phase contactor, and to develop a simple and inexpensive process for foam suppression which can be employed in the petroleum industries especially in the hydroconversion reactor without requiring excessive additional materials.

MATERIAL AND METHOD

Experiments were carried out at the Department of Chemical Engineering laboratory at the University of Technology in Baghdad, Iraq and ended in January 2010. The schematic layout of the process used in this work is shown in figure (1), Ahmed A. Aldalawi [2010].

The operating column was a cylindrical Plexiglas column of 12.5 cm in diameter and 125 cm in height. The column had (5) sample ports and also (5) pressure tapes located along the column height. All pressure taps were connected to a pressure difference transmitter (Rosemont® 4-20mA, 0-2500 mmH$_2$O) which converted the pressure signal to a mV, and via an interface to digital signal which converted by a PC computer (P4) to pressure time a

verage signal. At the bottom of column a gas distributor was installed with (88) holes each hole was (2 mm) diameter. Air and liquid flow rates were adjusted with needle valves and calibrated rotameters.

The foaming system is selected to give a maximum foaminess in the operating column. To specify desired foaming system; different types of alcoholic aqueous solution were tested using the

shaking test bottle, Bikerman [1973], Tetra butanol, propanol, and glycerin were prepared in different concentrations with water, and 0.1wt. % glycerin in water which gave the maximum foaminess was used in the present work. The result of the shaking test is shown graphically in figure (2). Table (1) represents the specification of the surfactants used in this work.

According to Guitian et al, [1999], the particle size and density are preferably selected so as to provide ($U_{mf} < U_1$) and ($U_t > U_1$). This advantageseously serves to cause the particles to expand the fluidized bed in bubbly liquid mixture below the foam. In the present work, sands which happen to be hydrophilic were used as solid phase. The properties of sand particles are shown in table (2).

Hydrophilic sands were converted into hydrophobic using the method of Maloney and Oakes [1984]. Maloney and Oakes reported that particulate siliceous materials having significant surface hydroxylation or surface silanol content which can react chemically with hydrophobic alcohols to form hydrogen bonds which appear to be more stable at high operating temperature which is equivalent to the operating temperature of the hydroconversion reactor.

In the present work, octanol was used as the liquid reactant with the sand particles. The resulting mixture was heated below the boiling point of octanol (i.e. 178 ºC) for a time period of (4 hrs) which was sufficient to cause the silica to chemically react with the substantially hydrophobic alcohol.

To examine the degree of hydrophobicity of surface treated particles, a method suggested by Mata and Joseph, [1997] was utilized to verify the particles affinity to the 0.1wt% glycerin in water solution, they characterized of the used particles by simple observation.

In the present work, factorial design method was used for planning the experiments because of its reliability in finding out the effects and interaction between the controlled variables of the operating system. The real values of controlled variables (F) and their corresponding levels (L) are shown in table (3). Every experimental run was repeated two to three times to increase the precision of the results. The relative error for the data obtained between the repetitions was less than 10%

THEORTICAL ASPECT

Axial local gas holdup along the operating column was measured using the pressure drop between two adjacent points separated by a distance $\left(h_{i-j}\right)$ which is measured directly by the $\left(\Delta P\right)$ transmitter:

$$\varepsilon_{g_{i-j}} = 1 - \frac{\Delta P_{i-j}}{g\rho_l h_{i-j}} \qquad (2)$$

When $\Delta P_{i-j} = \Delta P_t$ and $h_{i-j} = L$, equation (2) can be used to evaluate the total average gas holdup:

$$\varepsilon_g = 1 - \frac{\Delta P_t}{g\rho_l L} \qquad (3)$$

5

The foaminess is calculated as follows, Bikerman, [1973]:

$$\varepsilon_f = \frac{X_f}{H} \tag{4}$$

Minimum fluidization velocity of particle and particle terminal velocity were estimated using equations (5) and (6) respectively, Missen et al. [1999].

$$U^2{}_{mf} + \frac{150(1-\varepsilon_{mf})\mu_f}{1.75\rho_p d_p}U_{mf} - \frac{g(\rho_p - \rho_g)\varepsilon_{mf}^3 d_p}{1.75\rho_g} = 0 \tag{5}$$

$$U_t = \frac{150(1-\varepsilon_{mf})}{18\varepsilon_{mf}^3}U_{mf} \tag{6}$$

RESULTS AND DISCUSSION

The effects and interactions of five operating variables (i.e. superficial gas velocity, superficial liquid velocity, solid particle type, loading of particles and particle size) on the gas holdup and foaming were considered during the course of the experimental run.

For multiphase system, the literature identifies a bubbly-churn behavior in increasing order of U_g Gamal and Smith [2003], and the local gas holdup helped too much in determining those regimes and their extension along the column height. Effects of gas velocity on local gas holdup along the column height can be seen in Figures (3)-(5). In these figures the local gas holdup increases gradually with increasing gas velocity. Location of transition point from bubbly flow to churn one is clearly observed from the local gas holdup profile at each tested section of the column. The effect of column height on local gas holdup is also noted in these figures. In the bubbly flow regime, a proportional effect between column height and local gas holdup is established, this may be explained due to the kinetic energy of bubbles which has maximum value near the gas sparger and bubbles have higher rise velocity which means lower residence time through the first section of the column and consequently a lower local gas holdup. In the turbulent region and due to the increasing rate of bubble production a higher number of small bubbles per unit volume is existed in the lower section of the column which means higher gas holdup. The effect of solid particles on stability of the bubbly flow regime is shown in figures (4) and (5), the transition region starts at lower gas velocity compared to the system shown in figure (3). This early inception is attributed to bubble coalescence enhanced by the presence of smaller solid particles. Bubble coalescence causes a lower local gas holdup. Analysis of figures (4) and (5) shows that the effect of hydrophilic and hydrophobic solid particles respectively on the stability of the bubbly flow regime, the inception of the transition region starts at a lower gas velocity, this early inception is attributed to bubble coalescence enhanced by the presence of smaller solid particles This finding is in

6

agreement with Serapkara, et al. [1982]. Figures (6) and (7) show the effect of the gas velocity on the average gas holdup at liquid velocities of 0.152 cm/s and 0.30 cm/s, respectively. As can be seen the average gas holdup decreases with increasing liquid velocity. This can be explained by the mass conservation rule in the multiphase system, which stated that for a three-phase dispersion mixture the sum of the phases fraction is equal to one, so increasing of a specified phase is on the account of other phases. Effects of particle diameter and solid concentration on average gas holdup are illustrated in Figures(8) and(9) respectively. As can be seen in Figure (8), the average gas holdup decreases with decreasing particle diameter, since the presence of smaller particles has an enhancement effect on bubble coalescence which reduces the average gas holdup. In Figure(9), it is noted that the average gas holdup decreases with increasing solid concentration. This can be attributed to the increase in slurry viscosity which promotes bubble coalescence The same findings were reported by Krishna et al. [1997].

Figures (10) and (11) show the effect of the gas velocity on the foam fraction at liquid velocities of 0.152 cm/s and 0.30 cm/s, respectively. It may be observed from these plots that the hydrophobic particles suppressed the foam substantially better than their hydrophilic particles. Evidently the fluid mechanics of foam suppression with hydrophilic particles are enhanced by a direct attack on the foam by hydrophobic particles. This enhancement is attributed to the decreasing of the apparent density of the hydrophobic particles comparing with that of the hydrophilic ones, resulting in easily attack to the foamy region which appeared at the top of the reactor. The experimental results which is presented in figure (12); for a 10% volume fraction of the hydrophilic sands and with a mean size of (700-900) μm. verified the previous observation which indicating a better foam suppression by the hydrophobic particles at liquid velocity of 0.152 (cm/s). Figure (13) illustrated the effect of gas velocity on foam fraction at liquid velocity of 0.152 cm/s, for hydrophilic and hydrophobic sands, with a mean size of (400-600) μm. As can be seen, the hydrophobic particles suppress foam fraction better than their hydrophilic counterparts. It can be seen that the formation of foam increases with increasing particles diameter, but it decreases with increasing liquid superficial velocity comparing with figure (11).

In figure (14), the foam fraction as a function of the gas velocity at a liquid velocity of 0.152 cm/s are compared for three mean size ranges of the hydrophobic particles. As can be seen the smaller particles suppressed better the foam formation. Foam fraction seems to reach a plateau and even a change of slope in the foam curve at a gas velocity of approximately 8 cm/s. The hydrophobic particles expanded so well and penetrated the foam so easily, that a large accumulation of particles was observed at the top of the column.

Figure (15) and (16) illustrate the effects of gas and liquid velocities on the axial concentration profiles at constant particle diameter and solid loading of the hydrophilic and hydrophobic particles respectively. As can be seen in figure (15), the solid particles are not present at the bottom of the bed. The axial concentration profiles reach a maximum value which depends on fluidization conditions. It is also noted in this figure that the axial dispersion gradient increase as the velocity of the liquid increases. The axial concentration profile of the hydrophobic particles can be seen in figure (16). This figure shows that the bulk density of the solid bed at each point along the column is shifting to a higher level compared with that of hydrophilic counterparts. This is due to the reduction in apparent density of hydrophobic particles which enhances the capability of particles to move upwards more easily and attack the foam which exist at the upper parts of the reactor.

CONCLUSIONS

In this study, we have shown the following:

1. Flow regimes of multiphase system can be easily determined by utilizing local gas holdup profile measured by pressure drop transducer method.

2. The transition from the homogenous to heterogeneous regime is advanced with increasing solid concentration and decreasing particle diameter.

3. When the superficial gas velocity is greater than a critical value, a foamy regime appears above the bubbly mixture of water and surfactant. The two regimes are separated by a very clear interface that moves down when the gas velocity is increased. At any fixed gas velocity U_g, foam may be eliminated by increasing the liquid velocity U_l.

4. Sands particles which happen to be hydrophilic could be converted to hydrophobic by chemical surface treatment with aliphatic hydrophobic alcohols.

5- The fluid mechanism of foam suppression with hydrophilic particles are enhanced by a direct attack on the foam by hydrophobic particles (i.e. hydrophobic particles are more effective in retaining liquid – destroying foam- than the hydrophilic particles) and they may have a greater industrial application.

6- The foam fraction decreases with increasing solid loading in the column, but it increases with increasing particle diameter.

7- At a fixed particle diameter, the axial concentration profiles of the hydrophilic and hydrophobic particles have the same trend, but the local concentration of the hydrophobic particles shifts axially to higher levels in the column. The axial concentration profiles of the solid particles would be a useful guide to predict qualitatively the kinetic behavior in the reactor where the local bulk density of the catalyst particles along the reactor has an impact on the rate of reaction.

NOMENCLATURE

d_b : Particle diameter (mm).

F: Number of factors of factorial method (-).

g: Gravitational acceleration $\left(m/s^2 \right)$.

h_{i-j} : Height between two pressure taps (m)

H : Total height of column (cm).

L: Number of levels of factorial method (-).

U_{mf} : Minimum fluidization velocity (cm/s).

U_l : Superficial liquid velocity (cm/s).

U_g : Superficial gas velocity (cm/s).

U_t : Terminal velocity (cm/s).

X_f :Height of foam (cm).

ΔP_{i-j} : Pressure between two pressures taps (mbar).

ΔP_t : Pressure difference along the bed (mbar).

ε_f : foaminess (-)

ε_{gi-j} : Gas holdup between two pressure taps (-).

$\varepsilon_{gav.}$: Average gas holdup for bubble column (-).

ε_l : Liquid holdup (-).

ε_{mf} : Minimum fluidization bed porosity (-)

ε_s : Solid holdup (-).

ρ_g : Density of the gas (gm/cm^3).

ρ_l : Density of the liquid (gm/cm^3).

ρ_p : Density of the particle (gm/cm^3).

REFERENCES

1. Ahmed. A. Aldalawi (2010) " Hydrodynamic characteristics effect of foam control in three phase bubble column" M.Sc. thesis University of Technology, Baghdad, Iraq.

2. Armstrong, E. R., C. G. J. Baker, and M. A. Bergougnou. (1976). *Effects of Solids Wettability on the Characteristics of Three-phase Fluidization*. Fluidization Technology, 127, p.405, Hemisphere, Washington, DC

3. Behkish, A.; Men, Z.; Inga, J. R.; Morsi, B. I.(2002) *Mass Transfer Characteristics in a Large-Scale Slurry Bubble Column with Organic Liquid Mixtures*. *Chem. Eng. Sci.*, *57*,P. 3307.

4. Bikerman J.J., (1973) *Foams*, Springer Verlag, 1st edition New York p 223 - 243.

5. Chaumat, H.; Billet-Duquenne, A. M.; Augier, F.; Mathieu, C.; Delmas, H.(2005) *Mass Transfer in Bubble Column for Industrial Conditions - Effects of Organic Medium, Gas and Liquid Flow Rates and Column Design*. Chem. Eng. Sci., 60, P.5930.

6. Dargar, P.; Macchi, A.(2006)*Effect of Surface-Active Agents on the Phase Holdups* of Three-Phase Fluidized Beds. *Chem. Eng. Process.*, *45*,P. 764.

7. Deckwer WD, Louisi Y, Zaidi A, Ralek M.(1980) *Hydrodynamic properties of the Fisher–Tropsch slurry process*. Ind Eng Chem Process Des Dev;19:PP.699–708.

8. Fan LS, Matsuura A, Chern SS.(1985) *Hydrodynamic characteristics of a gas–liquid–solid fluidized bed containing a binary mixture of particles.* AIChE J;31:P.P1801–10.

9. Frye, G. and John C. Berg (1989). *Antifoam Action by Solid Particles*. Journal of Colloid and Interface Science, 127, No. 1, P.P222-238.

10. Gamal M. El-Din and D. W. Smith (2003) "*measurement of size, rise velocity and specific interfacial area of bubbles in an impinging jet bubble column*". J. Environ. Eng. Sci. 2, PP. 127-138.

11. Garrett P. (1993) *Defoaming. Theory and Industrial Applications*. New York: Marcel Dekker, Inc.

12. Guitian, J. and D. Joseph (1997*). How Bubbly Mixtures Foam and Foam Control Using a Fluidized Bed*. International Journal of Multiphase Flow, Vol. 24, No. 1 PP.1-16.

13. Guitian, J., and Joseph, D.(1999) "*Process for suppressing foam formation in a bubble column reactor*" US patent no. 5922190 dated Jul. 13.

14. Herbolzheimer, E. Bedminster, N.J.(US), and Iglesia, E. Moraga, CA (US).,(2006) "*Slurry Bubble Column*" Patent Number US RE39, 073 E, Apr. 18.

15. Hikita H, Asai S, Tanigawa K, Segawa K, Kitao M.(1980) *Gas holdup in bubble column*. Chem Eng J;20:PP.59–67.

16. Hill R.M. and K.C. Fey, in *Silicone Surfactants* (R.M. Hill, ed.), Marcel Dekker, Inc., New York, NY, 1999, p. 165.

17. Hyndman CL, Larachi F, Guy C.(1997) *Understanding gas-phase hydrodynamics in bubble columns: a convective model based on kinetic theory.* Chem. Eng Sci; 52:PP.63–77.

18. James E. Maloney and Thomas R. Oakes (1984) "*hydrophobic silica or silicate composition*" for making US patent number 4443357 in Apr. 17,.

19. Jordan, U.; Schumpe, A. (2001) *The Gas Density Effect on Mass Transfer in Bubble Columns with Organic Liquids*. *Chem. Eng. Sci.*, *56*, P.6267.

20. Joshi, J., B., Abichandani, J., S., Shah, Y., T., Ruether, J., A., and Ritz, H., J.(1981), *"Hydrodynamics and axial mixing in a three-phase bubble column"*AICHE, J., 27:PP.937-945.

21. Kara S, Kelkar BG, Shah YT, Carr NL.(1982) *Hydrodynamics and axial mixing in a three-phase bubble column*. Ind Eng Chem Process Des Dev;21:PP.584–94.

22. Kato Y, Nishiwaki A, Kago T, Fukuda T, Tanaka S.(1973) *Gas holdup and overall volumetric absorption coefficient in bubble columns with suspended solid particles*. Trans Inst Chem Eng;13:562–7.

23. Kister, H.Z.(2003) *What Caused Tower Malfunctions in the Last 50 Years?* Chem. Eng. Res. Des., 80 (1), pp. 5-26.

24. Krishna, R.; Sie, S. T. (2000) *Design and Scale-up of the Fischer-Tropsch Bubble Column Slurry Reactor*. Fuel Process. Technol, 64, P.73.

25. Krishna R, De Stewart JWA. Ellenberger J, Martina GB, Maretto C.(1997) *"Gas holdup in slurry bubble columns: effect of column diameter and slurry concentrations"*. AIChE J;43:311–6.

26. Lau, R.; Peng, W.; Velazquez-Vargas, L. G.; Yang, G. Q.; Fan, L. S. (2004) *Gas-Liquid Mass Transfer in High-Pressure Bubble Columns. Ind. Eng. Chem. Res.*, *43*, P. 1302.

27. Letzel, H. M.; Schouten, J. C.; Krishna, R.; van den Bleek, C. M.(1999) *Gas Holdup and Mass Transfer in Bubble Column Reactors Operated a elevated Pressure. Chem. Eng. Sci.*, *54*, P.2237.

28. Li, H.; Prakash, A. (2000) *Influence of Slurry Concentrations on Bubble Population and Their Rise Velocities in Three-Phase Slurry Bubble Column. Powder Technol.*, *113*, P.158.

29. Maloney James E. and Oakes Thomas R. (1984) *"Hydrophobic silica or silicate composition"* U.S patent number 4443357.

30. Mata C. and D.D. Joseph, (1997) *Foam control using a fluidized bed of hydrophobic particles*. Int. J. Multiphase Flow, Vol.25, No.1, PP. 63-85.

31. Miller DN.(1980) *Gas holdup and pressure drop in bubble column reactors*. Ind. Eng Chem. Process Des Dev; 19:P.371–7.

32. Missen R.W.; Mims C.A.; Saville B.A. (1999) "Introduction to chemical reaction engineering and kinetics"1st ed., John wiley & Sons Inc. , USA.

33. Ozturk B., R.J. Fruehan, (1995) *Effect of temperature on slag foaming*, Metallurgical and Materials Transactions B 26B PP.1086–1088.

34. Perry, R.H., Green, D.W., and Moloney, J.O., (1987)*"Perry's Chemical Engineer's Handbook"*, McGraw Hill, 6th edition.

35. Pilon L., A.G. Fedorov, R. Viskanta, (2001) *Steady-state foam thickness of liquid–gas foams*, Journal of Colloid and Interface Science 242 PP.425–436.

36. Pino LZ, Solari RB, Siuier S, Estevez LA, Yepez MM, Saez AE. (1992) *"Effect of operating conditions on gas holdup in slurry bubble columns with a foaming liquid"*. Chem. Eng Commune; 117:367–82.

37. Prins A., ed. E. Dickinson(1986) "*In Food Emulsions and Foams"*, Royal Society of Chemistry Special Publication, Vol. 58, Cambridge, P. 30.

38. Prud'homme R.K. and S.A. Khan (1996) *Foams: Theory, Measurements and Applications*, Surfactant Science Series, Vol. 57, Marcel Dekker, New York.

39. Sada E, Katoh S, Yoshil H.(1984) *Performance of the gas–liquid bubble column in molten salt systems*. Ind Eng Chem Process Des Dev;23:PP.151–4.

40. Serapkara, Baimohan, G., Kelkar and Yatish, T., Shah. (1982) *"Hydrodynamic and Axial mixing in a Three-Phase Bubble .Column"*. Ind. Eng. Chem. Process, Des. Dev., 21:554-594.

41. Tang, W. T.; Fan, L. S.(1989) *Hydrodynamics of a Three-Phase Fluidized Bed Containing Low-Density Particles*. *AIChE J.*, *35*, P.355.

42. Thiele, R.; Brettschneider, O.; Repke, J.-U.; Thielert, H.; Wozny, G.(2003) *Experimental Investigations of Foaming in a Packed Tower for Sour Water Stripping*. Ind. Eng. Chem.Res. 7 (42), pp. 1426-1432.

43. Tsutsumi, A., A. Ghosh Dastidar and L. Fan (1991)*: Characteristics of Gas-Liquid- Solid Fluidization with Nonwettable Particles*. AIChE Journal, 37, No. 6, PP. 951- 952.

44. Vandu, C. O.; Koop, K.; Krishna, R. (2004) *Volumetric Mass Transfer Coefficient in a Slurry Bubble Column Operating in the Heterogeneous Flow Regime*. *Chem. Eng. Sci.*, *59*, P.5417.

45. Yang, W. G.; Wang, J. F.; Zhou, L. M.; Jin, Y.(1999) *Gas-Liquid Mass Transfer Behavior in Three-Phase CFB Reactors*. *Chem. Eng. Sci.*, *54*, P.5523.

46. Yang, W. G.; Wang, J. F.; Wang, T. F.; Jin, Y.(2005) *Experimental Study on Gas -Liquid Interfacial Area and Mass Transfer Coefficient* Chem. Eng. Sci..

تأثير الخواص الهايدروديناميكية للسيطرة على الرغوة في العمود المتعدد الاطوار

أ.م.د. محمد فاضل عبد* و أحمد علي هادي**

* قسم الهندسة الكيمياوية ، الجامعة التكنولوجية، بغداد ـ العراق.

** وزارة النفط، بغداد ــ العراق.

الخلاصة

الرغوة هي ضاهرة غي مرغوب بها في المفاعلات الكيمياوية التي تعمل بالسوائل الهيدروكربونية وذلك لان الرغوة تقلل الزمن اللازم لبقاء السائل داخل المفاعل وتؤدي في مفاعلات التكسير الحراري الى تفحم المنتوج وبالتالي تقلل من كفاءة اداء المفاعل. تم اجراء دراسة عملية لتاثير الظروف التشغيلية (السرع السطحية للغاز (1-10 cm/s) والسائل(0.1-0.45 cm/s)، حجم الدقائق الصلبة (0.25, 0.50, 0.80 and 1.25 mm)، النسبة الحجمية (.vol% 0, 10 and 20) للدقائق المحملة في العمود ونوع (Hydrophilic – Hydrophobic) تلك الدقائق) على تكون الرغوة في مفاعل يعمل بسائل هيدروكربوني وكذلك دراسة ايجاد طريقة بسيطة لتقليلها. من خلال البحث الحالي تم استنتاج الاتي : عند اضافة المواد الهدروكربونية السائلة داخل المفاعل يمكن للرغوة ان تظهر اعتمادا على الظروف التشغيلية.منطقتي الفقاعات والرغوة تظهران في نفس الوقت داخل العمود، منطقة الرغوة تبدأ بالتكون اعلى العمود ومفصولة عن منطقة الفقاعات بحد فاصل واضح، حيث تبدأ بالنزول الى اسفل العمود عند زيادة سرعة الغاز. تم ايجاد علاقة رياضية تربط بدء تكون الرغوة بالظروف التشغيلية ونوع الخليط الهيدروكربوني. كما وجد ان ميكانيكية المائع لتقليل الرغوة باستخدام الدقائق الصلبة (Solid particles) المحبة للماء (Hydrophilic) يمكن تسريعها لمهاجمه فقاعات الرغوة بتحول الدقائق الـ (Hydrophilic) الى دقائق كاره للماء (Hydrophobic) وقد استخدمت طريقة لتحويل الدقائق الصلبة الى (Hydrophobic) حيث تم تقليل الحجم اللابعدي للرغوة من 0.85 الى 0.15 عند استخدام دقائق كارهه للماء (Hydrophobic) ذات القطر 0.25 ملم وسرعة سائل 0.3 cm/s ، ان بزيادة سرعة السائل الى 0.4 cm/s يتم التخلص من الرغوة تماما.يعتقد بان نتائج هذه الدراسة لها تطبيقات واسعة في مجال الصناعات النفطية والبتروكيمياوية.

الكلمات الافتتاحية: مفاعلات متعددة الاطوار، جريان موائع، تعويق الرغوة، الدقائق الكارهة للماء.
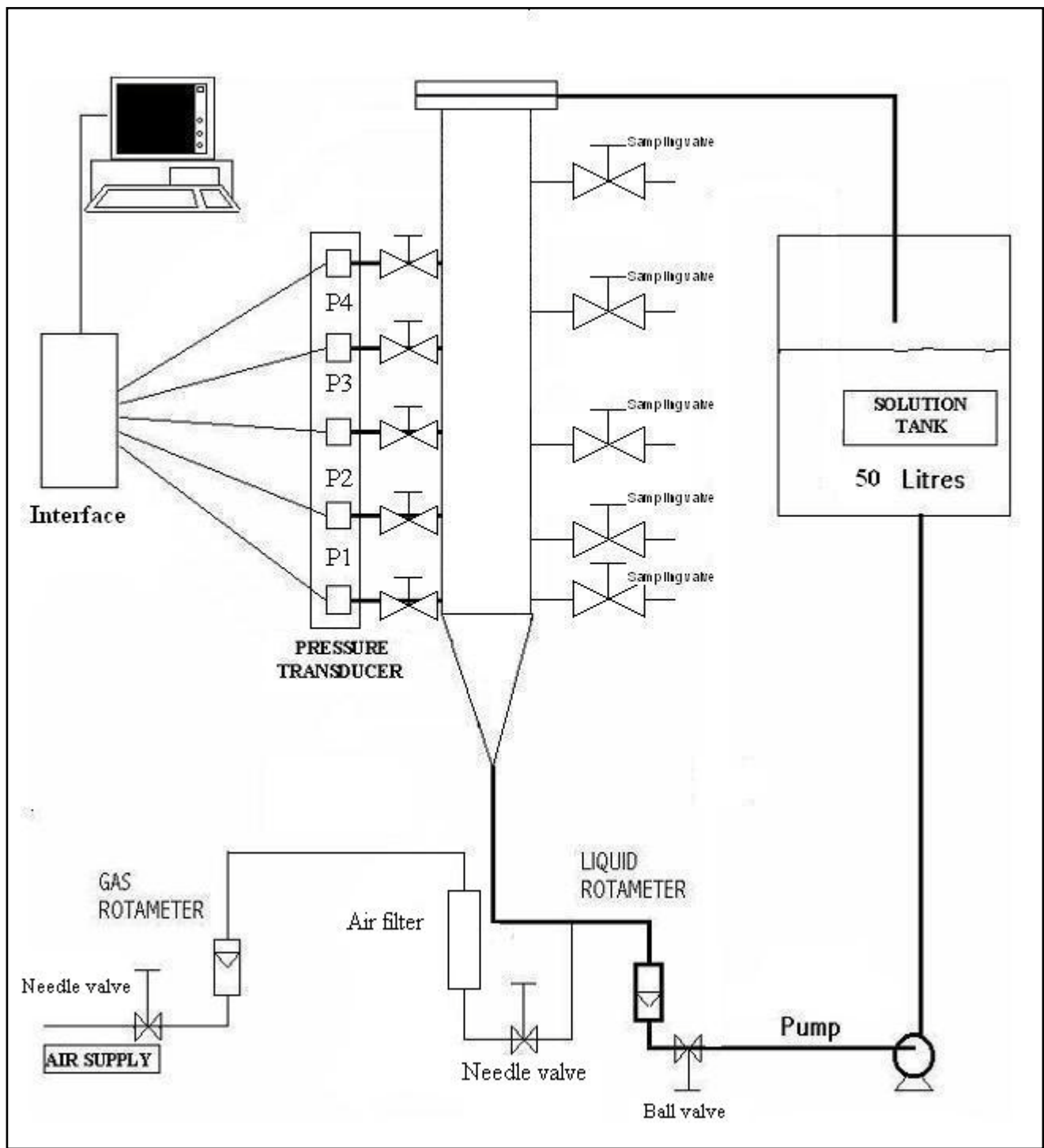
Figure (1): schematic of the bubble column apparatus used in the experiments

**Table (1):** Surface active agents used in experiment Perry and Moloney [1987].

Surfactant name	Purity% (min)	M.wt.	Density [gm/cc] At 20 ($^\circ C$)	Boiling point ($^\circ C$)	Supplier
Tetra.Butanol	99	74.12	0.77	83	Riedel-DeHAën AG Sleeze Hannover
Propanol	99	60.1	0.80	97.1	Riedel-DeHAën AG Sleeze Hannover
Glycerin	99	92.092	1.26	290	Riedel-DeHAën AG Sleeze Hannover

Table (2): The properties of sand particles

d_b (mm)	$\rho_p \left[gm/cm^3\right]$	U_t (cm/s)	$U_{mf}\left(cm/s\right)$
0.2-0.3	2.50	8.2-10.3	0.114-0.192
0.4-0.6	2.50	12.2-14.5	0.277-0.464
0.7-0.9	2.50	15.6-18.9	0.565-0.778
1.0-1.5	2.50	20.6-26.4	0.89-1.49

Table (3): Selected levels and factors

L \ F	Real variables			
	Average particle diameter (mm)	Liquid flow rate $L\,min^{-1}$	Gas flow rate $L\,min^{-1}$	Solid concentration vol. %
1	0.25	0.75	22	0
2	0.50	1.50	44	10
3	0.80	2.95	73.5	
4	1.25	4.42	117.5	20
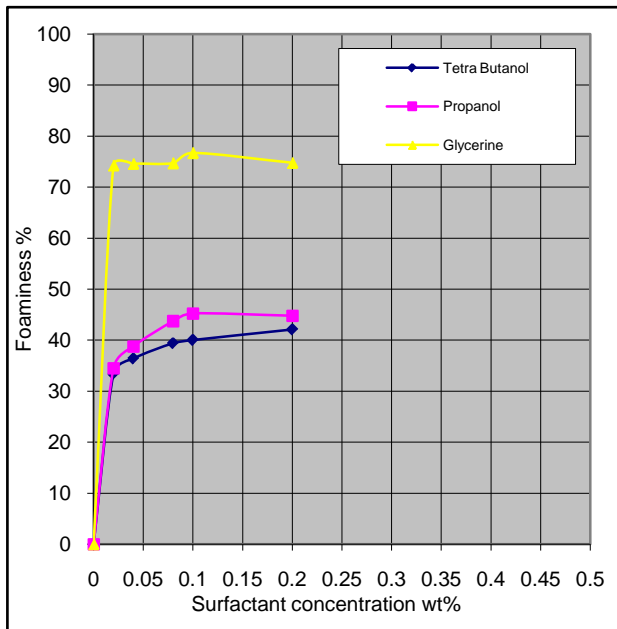
**Figure (2):** Foaminess of different type of surface active agents as a function of concentration.
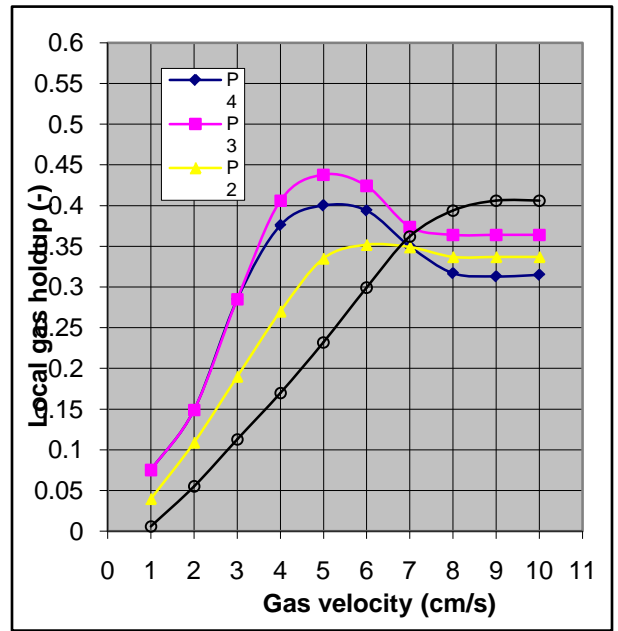
Figure (4): Local gas hold-up versus superficial velocity in various sections of the column obtained by pressure transducers at a liquid velocity of 0.152 (cm/s) and with 10% volume fraction of hydrophilic particles of mean size (200-300).
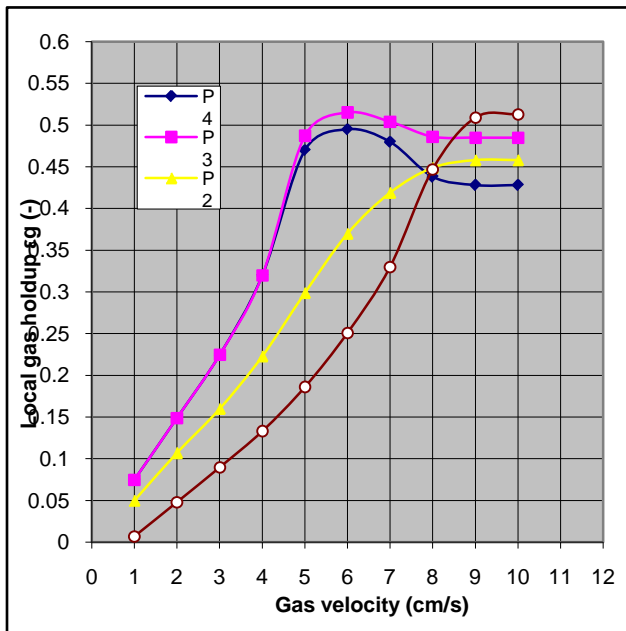

Figure (3): Local gas hold-up versus superficial velocity in various sections of the column obtained by pressure transducers at a liquid velocity of 0.152 (cm/s) and without particles.
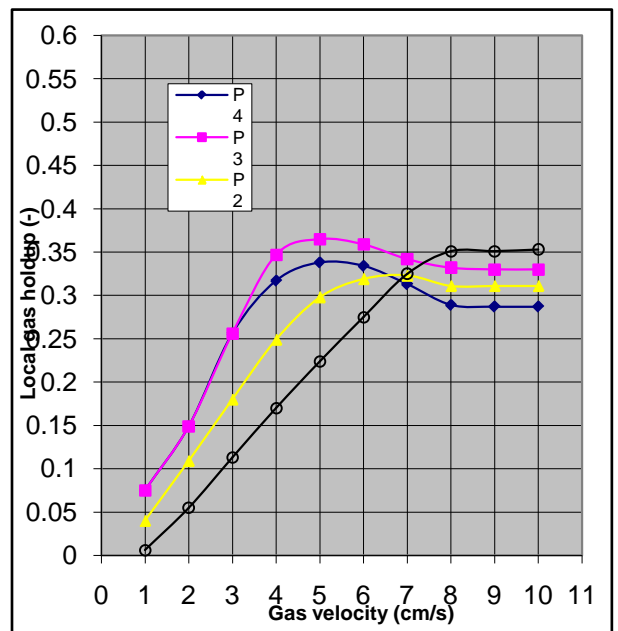
Figure (5): Local gas hold-up versus superficial velocity in various sections of the column obtained by pressure transducers at a liquid velocity of 0.152 (cm/s) and with 10% volume fraction of hydrophobic particles of mean size (200-300).
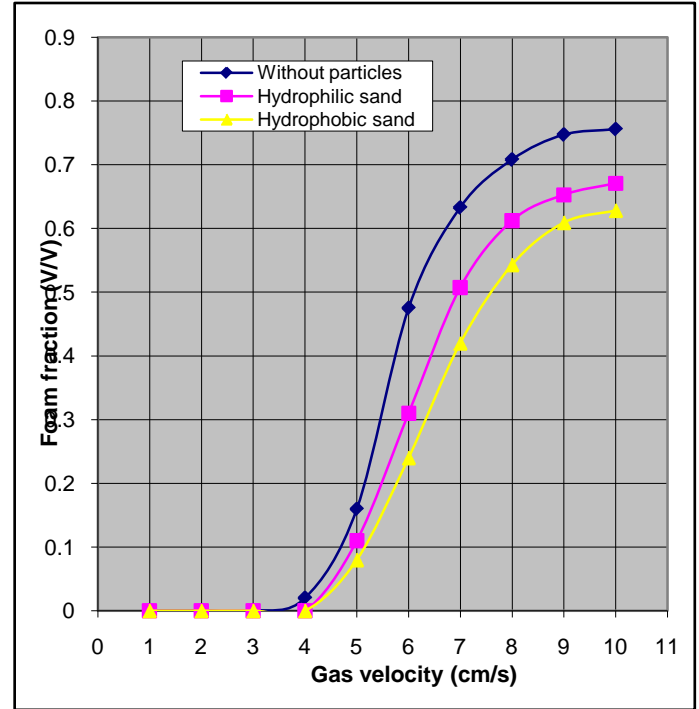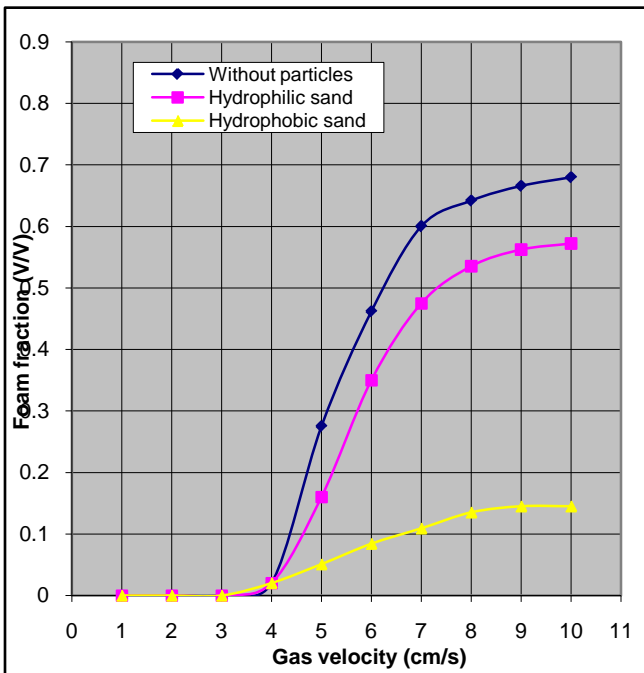
16
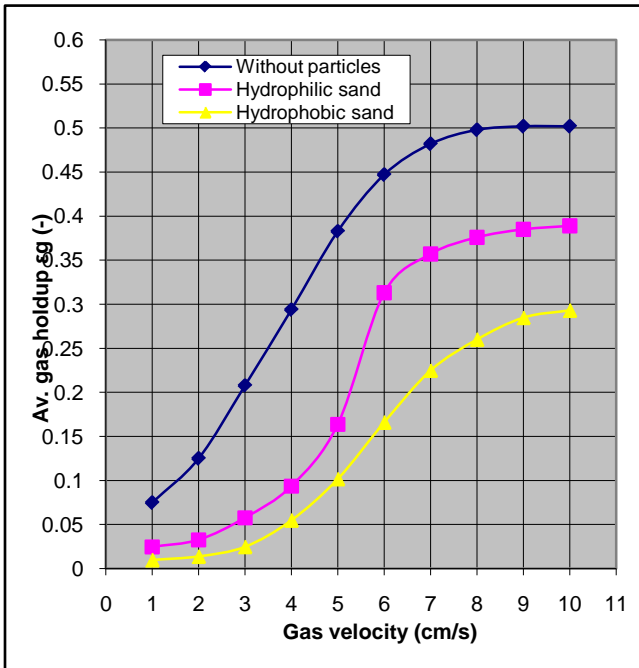
Figure (6): Average gas holdup as a function of gas velocity at a liquid velocity of 0.152 cm/s, for 1%wt.Glycerine solution without particles and, with 10% volume fraction of particles hydrophilic and hydrophobic sand mean size (200-300 μm).
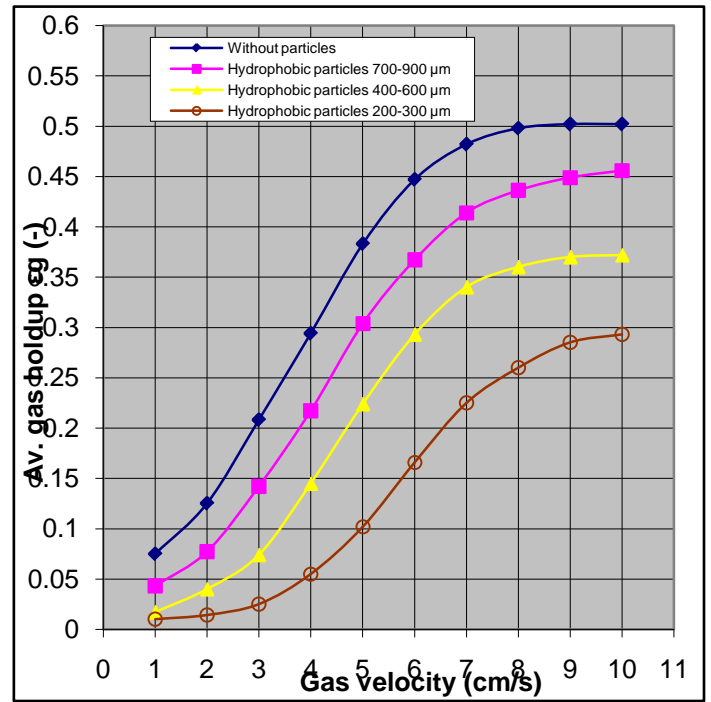
Figure (8): Average gas holdup as a function of gas velocity a liquid velocity of 0.152 cm/s, for a 1%wt. Glycerin solution without particles and, with 10% volume fraction of particles hydrophobic sand (mean size = 200-300 μm), (mean size = 400-600 μm) and (mean size = 700-900 μm).
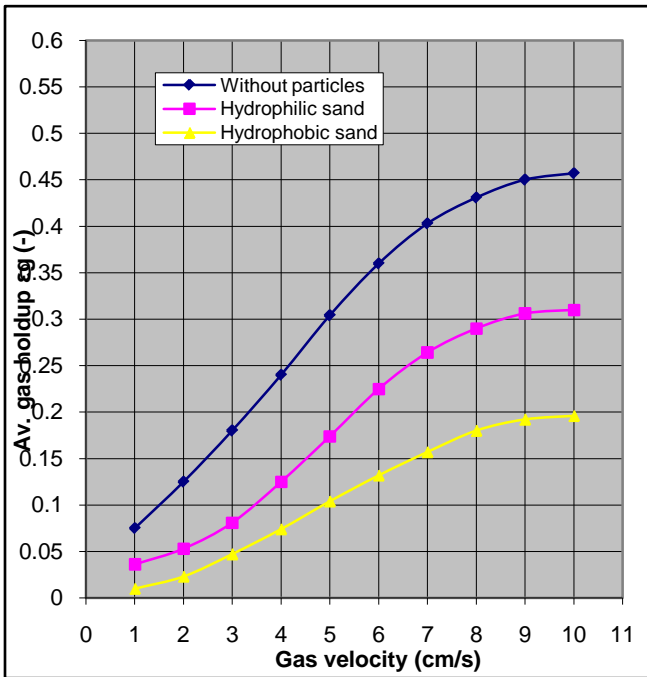
Figure (7): Average gas holdup as a function of gas velocity a liquid velocity of 0.3 cm/s, for a 1%wt. Glycerin solution without particles and, with 10% volume fraction of particles hydrophilic and hydrophobic sand (mean size = 200-300 μm).
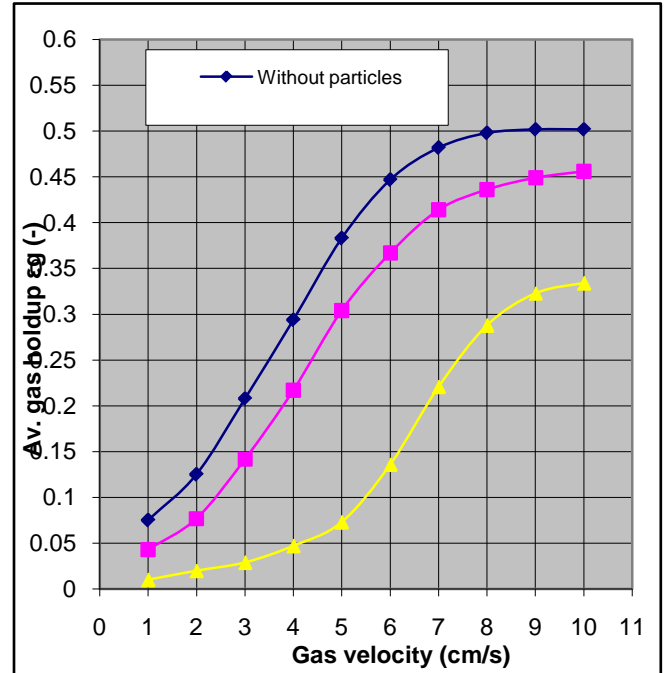
Figure (9): Average gas holdup as a function of gas velocity a liquid velocity of 0.152 cm/s, for a 1%wt. Glycerin solution without particles and, with 10% and 20% volume fraction of particles hydrophobic sand (mean size = 700-900 μm).
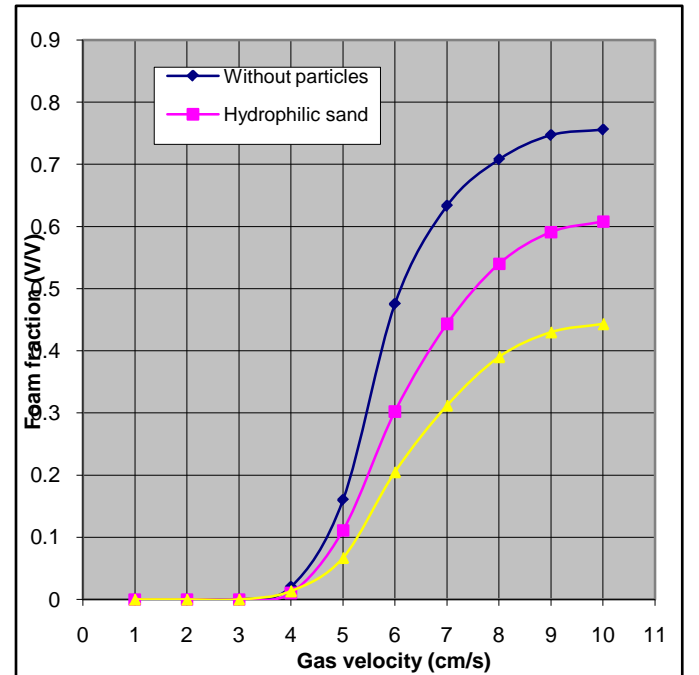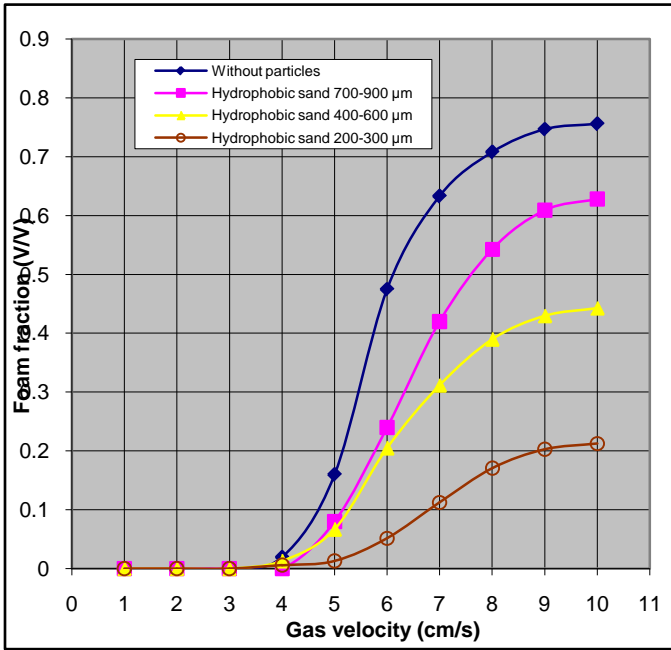
17
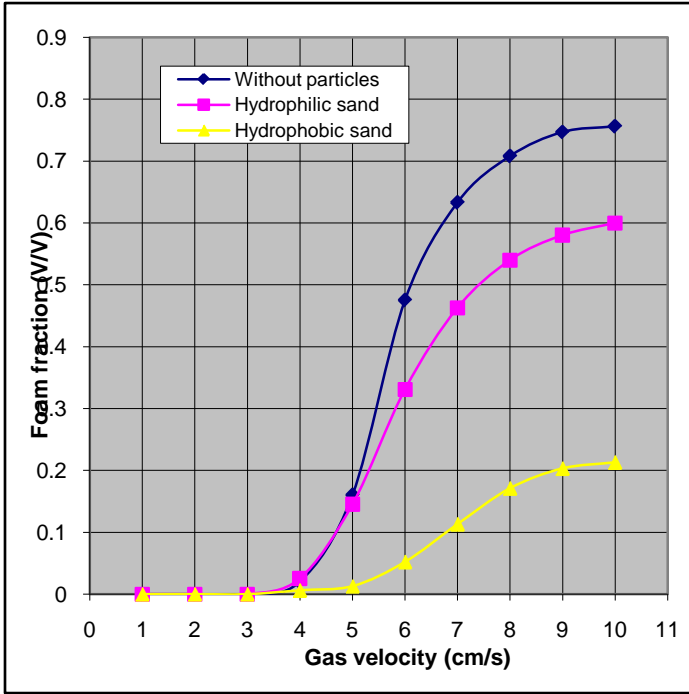
Figure(10): Foam fraction as a function of gas velocity at a liquid velocity of 0.152 cm/s, for 1%wt.Glycerine solution without particles and, with 10% volume fraction of particles hydrophilic sand and hydrophobic sand (mean size = 200-300 μm).


Figure (12): Foam fraction as a function of gas velocity a liquid velocity of 0.152 cm/s, for a 1%wt. Glycerin solution without particles and, with 10% volume fraction of particles hydrophilic sand and hydrophobic sand (mean size = 700-900 μm).

Figure (11): Foam fraction as a function of gas velocity a liquid velocity of 0.3 cm/s, for a 1%wt. Glycerin solution without particles and, with 10% volume particles hydrophilic sand and hydrophobic sand (mean size = 200-300 μm).


Figure (13): Foam fraction as a function of gas velocity a liquid velocity of 0.152 cm/s, for a 1%wt. Glycerin solution without particles and, with 10% volume fraction of particles hydrophilic sand and hydrophobic sand (mean size = 400-600 μm).

Figure (14): Foam fraction as a function of gas velocity a liquid velocity of 0.152 cm/s, for a 1%wt. Glycerin solution without particles and, with 10% volume fraction of particles hydrophobic sand (mean size = 200-300 μm), (mean size = 400-600 μm) and (mean size = 700-900 μm).
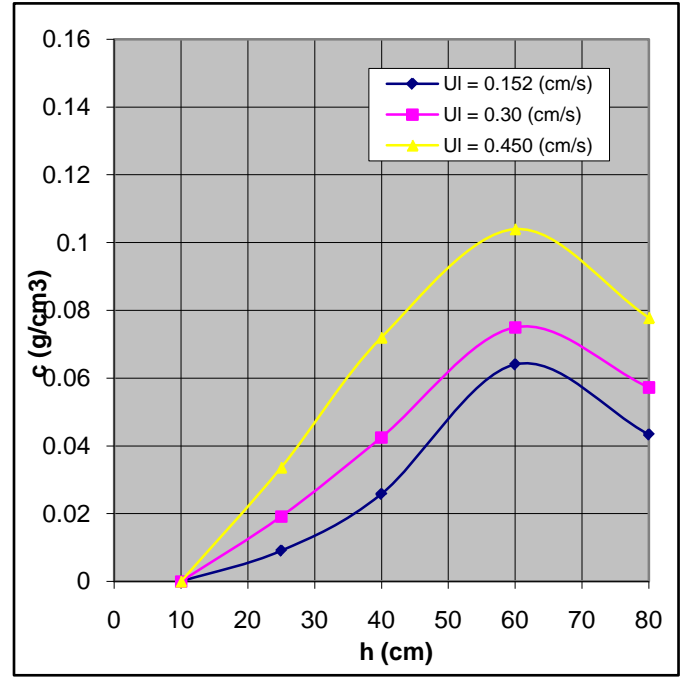
Figure (16): Axial concentration profiles for 10%vol hydrophobic particles (200-300 μm) diameter at different liquid velocities and u_g =4 (cm/s)
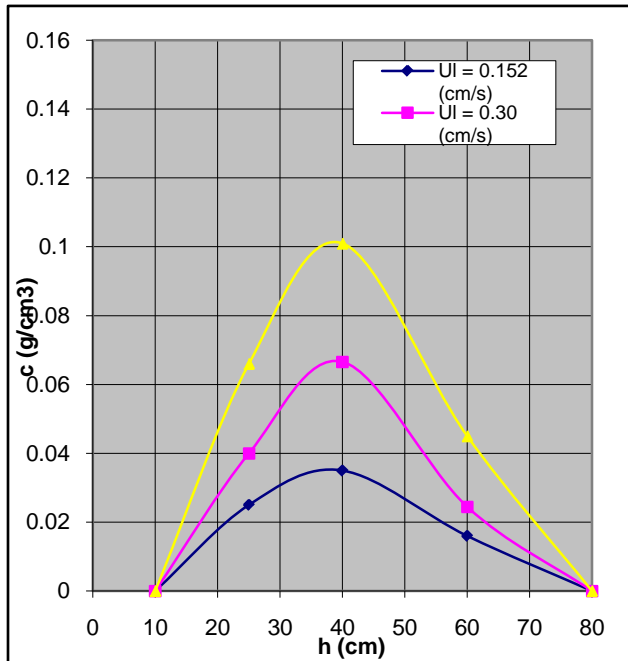
Figure (15): Axial concentration profiles for 10%vol hydrophilic particles (200-300 μm) diameter at different liquid velocities and u_g = 2 (cm/s).