International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 10, October-2019

Experimental and CFD Simulation Study of a Trickle Bed with Foaming Liquid at Different Concentrations

Rahul Omar*, Dinesh Mishra, R. S. Nigam
Department of Chemistry
AKS University, Satna-485001
Madhya Pradesh, India

Abstract:- **The objective of the present study is to experimentally and numerically investigate the effect of liquid and gas velocities of foaming liquid solutions with varying liquid surface tension on pressure drop and dynamic liquid saturation in a trickle bed. Experiments were carried out on a 10 cm diameter cylindrical plexiglas column, packed with glass beads of 4 mm with a height of 128 cm. Water and Sodium Lauryl Sulphate solutions in water at different concentrations (15 ppm, 30 ppm, 45 ppm and 60 ppm) were used as the liquid phase. CFD simulations were carried out on the system by using two-dimensional Eulerian two phase porous media model. Experimental and simulation results indicate higher pressure drop with higher superficial liquid and gas velocities, lower surface tension of the liquid, the dynamic liquid saturation increase with increase in liquid velocity, decrease with increase in gas velocity and decrease with decrease in surface tension. These general hydrodynamic behaviours are quantified with foaming liquids as the liquid phase. A fairly good agreement between the experimental and CFD simulation values and those predicted from literature correlations were observed.**

Keywords: Trickle bed; CFD; Dynamic liquid saturation; Pressure drop; Foaming liquid

1. INTRODUCTION

Trickle bed is a gas-liquid-solid contacting device in which gas and liquid flow co-currently downward or in counter-current manner over a fixed bed of catalyst or non-catalytic solid particles. The gas phase may flow in upward or downward direction depending on the type of application, whereas the liquid phase always flows in a downward direction. Solid particles are randomly packed or structured packings are used in a bed through which gas and liquid phases flow. In most of the industrial trickle bed reactors, catalyst particles are basically porous and are of different shapes such as spherical, cylindrical etc. [1-6]. Trickle bed is extensively used in chemical process industries mainly in petrochemical and refinery process since it provides flexibility and simplicity of operation.

Pressure drop and dynamic liquid saturation are important parameters in the design of the trickle bed. Pressure drop affects the energy requirements and hence the operating cost [7]. For high heat generated during exothermic, liquid saturation controls and enables the better wetting efficiency and prevents the hot spot formation [8]. Thus characterization of pressure drop and dynamic liquid saturation is necessary for successful design, scale-up and operations of a trickle bed system.

In petroleum industry, foaming plays an important role in petroleum recovery and productivity. Literature survey reveals that very few works have been reported with foaming liquids [8-12], although most of the liquids in petroleum process industries and other applications are foaming in nature [13]. Thus it is necessary to characterize the trickle bed system with foaming liquid and study the effect of liquid surface tension on pressure drop and dynamic liquid saturation.

The experimental findings need to be verified with theoretical approach. In this regards computational fluid dynamics (CFD) is a powerful tool for the prediction of the fluid dynamics in various types of systems, thus, enabling a proper design. Because of interaction of three phases (particle–particle, liquid–particle and particle–bubble), the hydrodynamics of trickle bed is complex and not well understood by the experimentally. For this reason, CFD is treated as a useful tool for understanding trickle bed systems for precise design and scale up. Literature review reveals that, there is hardly any work on CFD simulation of trickle bed where liquid phase of varying surface tension is dealt. Thus in the present work an attempt is made to validate the experimental findings with the CFD simulation results.

In the present work Sodium Lauryl Sulphate is used produce a moderate to extensive foam formation by varying its concentration in water. Water and Sodium Lauryl Sulphate (SLS) solutions in water at different concentrations are used as the liquid phase. CFD simulations are carried out on the system by using two-dimensional Eulerian two phase porous media model.

2. EXPERIMENTAL AND CFD SIMULATION OF A TRICKLE BED

Experiments were carried out in a 10 cm diameter cylindrical Plexiglas column, packed with glass beads of 4 mm with a height of 128 cm. Entry for gas and liquid phases were from the top of the column. The packing in the column was supported on a stainless steel mesh. Firstly gas (air) was injected into the column at a desired flow rate using air rotameter and then the liquid was pumped at a desired flow rate using water rotameter. For each run the gas flow was kept constant and the liquid flow rate was gradually increased in steps. Water and Sodium Lauryl Sulphate (SLS) solutions in water at different concentrations were used as the liquid phase.

To model the trickle bed hydrodynamics under foaming condition a two–dimensional Eulerian two phase porous media model was implemented. The gas phase (air) is treated as continuous and liquid phase (water and Sodium lauryl sulphate solution) is treated as the secondary phase. A two dimensional rectangular geometry of width 0.1 m and height 1.28 m is made by using DESIGN MODELLER of ANSYS software. For the gas and liquid phases, source terms in the form of viscous and inertial resistance terms were specified. Inlet boundary conditions were specified in terms of inlet mass flux of gas and liquid phase. At the outlet, the gauge pressure is specified to zero by default. No slip boundary condition for the wall was specified.

In order to solve these model equations the following assumptions were taken:- (a) Bed porosity is constant and uniform; (b) Capillary pressure is neglected; (c) There is no inter-phase mass transfer. Unsteady state simulations were carried out with the time step of 0.01 s for 30 seconds (the time higher than the achieved quasi-steady state). For the calculation of inter-phase drag force between the gas-liquid interaction Schiller and Neumann drag model was used. Standard two equation k-ε model was used for calculating the turbulent kinetic energy k, and its dissipation rate ε.

3. RESULTS AND DISCUSSION

Experiments were conducted at different gas and liquid velocities in the range of 0.026-0.128 m/s and 0.003-0.023 m/s respectively. To ensure steady state in operation at least ten minutes were allowed, after which the readings for bed pressure drop and dynamic liquid saturation were noted down. Simulations were conducted at the same experimental conditions. The results obtained from the experiment and simulations are presented graphically.

3.1. Effect of liquid and gas velocity

Figure 1 shows the variation of pressure drop with liquid velocity at various constant gas velocities for air-water system. The bed pressure drop found to increase with both the liquid and the gas velocities. The increase in pressure drop is due to the increase in interfacial shear stress with both the gas and liquid flow rates. As the liquid velocity increases, liquid saturation of the bed increases, which creates less void space for the flow of air. This leads to more gas–liquid interfacial shear stress and increase in pressure drop. In Figure 1 at lower superficial gas velocity it is observed that there is a sudden increase in the slope of the curve. This sudden change in gradient indicates the transition from trickle flow to pulse flow regime.

Figure 2 shows the variation of pressure drop with liquid velocity at various constant gas velocities for air-60 ppm SLS aqueous solution system. Surface tension of SLS solution is less than water, thus results in foaming, which is severe at higher concentration of SLS. Hence the study is limited to a SLS concentration of 60 ppm above which experimentation was difficult. Figure 2 gives a similar trend of variation in pressure drop with the gas and liquid velocities as observed in Figure 1.

Figure 3 shows the variation of dynamic liquid saturation with superficial liquid velocity for air-30 ppm SLS solution system at various superficial gas velocities. It is observed that with an increase in superficial liquid velocity, the dynamic liquid saturation increases and increase in gas velocity, there is a significant decrease in dynamic liquid saturation for foaming systems. It may be when liquid velocities are small, more space is occupied by the gas, and if liquid velocity is increased, the liquid will occupy a higher volume fraction of the voids available.

3.2. Effect of surface tension

Figure 4 shows the effect of surface tension on two-phase pressure drop. Different concentrations of the Sodium lauryl sulphate (SLS) in water were used to vary the surface tension of the liquid. The pressure drop is found to increase with the increase in surfactant concentration i.e. decrease in surface tension of the liquid. The observed pressure drop in case SLS solution is higher than that observed for water as the liquid. High liquid-side shear stress at the gas-liquid and liquid-solid interface leads to increases pressure drop with increase in surfactant concentration.

Figure 5 shows the influence of surface tension on dynamic liquid saturation. With increase in surfactant concentration the dynamic liquid saturation is found to decrease because of excessive foam formation in the column.

From the simulation result, Figure 6 shows the radial variation of pressure drop at bed heights 0.32 m, 0.64 m, 0.96 m and 1.28 m for gas velocity 0.077 m/s and liquid velocity 0.013 m/s. It is observed that bed pressure drop is constant along the radial direction (because of hydrostatic equilibrium) and it increases with increase in bed height. Figure 7 shows the variation of bed pressure drop along the height of the column for superficial gas velocity 0.077 m/s and superficial liquid velocity 0.013 m/s. There is a linear variation in pressure drop along the column height. This indicates that there is uniform flow of the fluid in the in the column. At bottom, the pressure drop is zero and it is maximum at the top of the column.

Figure 8 shows a comparison of the variation of the bed pressure drop with superficial liquid velocities at a constant superficial gas velocity, obtained from the simulation, experiment and those predicted from the correlations proposed by [11,14]. The simulation data agrees with predicted from the correlation of [11]. The experimentally measured values of bed pressure drop are found to be more than those predicted from the correlations. This may be due to the difference in packing materials and different operating conditions.

Figure 9 shows the variation of dynamic liquid saturation with column height at superficial gas velocity 0.077 m/s and superficial liquid velocities 0.013 m/s. It is observed that dynamic liquid saturation is constant except at the top entry region.

Figure 10 shows a comparison of the variation of the dynamic liquid saturation with superficial gas velocities at a constant superficial liquid velocity, obtained from the experiment, simulation and those predicted from the

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 10, October-2019

correlation proposed by [12]. The simulation data agrees well with experimental and predicted from the correlation.

4. CONCLUSION

The hydrodynamic parameters in trickle bed using foaming liquid are focused in the present work. The influences of liquid and gas velocities, different concentration of Sodium Lauryl Sulphate (SLS) solutions on the dynamic liquid saturation and two-phase pressure drop were studied. From the present study on the trickle bed system it is concluded that: For same superficial liquid velocity, the bed pressure drop is found to increase with decrease in surface tension, but in the dynamic liquid saturation found to decrease with decrease in surface tension.

CFD simulations of three phase trickle-bed are carried out by employing Eulerian-Eularian approach for same experimental operating conditions and flow conditions. The CFD simulation results are shown good agreement with experimental data and literature correlations for dynamic liquid saturation and pressure drop. The dynamic liquid saturation is lower at the top of the column and remains constant for a certain height. Pressure drop is constant along the radial direction and it increases with increase in bed height. There is linear variation of pressure drop along the column height which indicates that there is uniform flow of the fluid in the in the column. Slope of this linear variation can be used to represent the pressure drop per unit length.

REFERENCES

[1] Ellman, M. J., N. Midoux, A. Laurent, and J.C. Charpentier. 1990. A new improved liquid holdup correlation for trickle bed reactors. Chemical Engineering Science 45: 1677–1684.
[2] Yamada, H., T. Naruse, and S. Goto. 1999. Trickle bed reactor diluted with fine particles and coiled tubular flow-type reactor for kinetic measurements without external effects. Catalysis Today 48: 301-306.
[3] Nemec, D., G. Bercic, and J. Levec. 2001. The hydrodynamics of trickling flow in packed beds operating at high pressures: The relative permeability concept. Chemical Engineering Science 56: 5955-5962.
[4] Miller, C., and G. Kaibel. 2004. Packings for fixed bed reactors and reactive distillation. Chemical Engineering Science 59: 5373-5379.
[5] Schubert, M., H. Kryk, and U. Hampel. 2010. Slow-mode gas/liquid-induced periodic hydrodynamics in trickling packed beds derived from direct measurement of cross-sectional distributed local capacitances. Chemical Engineering and Processing 49: 1107-1121.
[6] Dietrich, W., L. Anadon, A. Sederman, L. Gladden, and D. Agar. 2012. Simulation studies on the performance enhancement in periodically operated trickle-bed reactors based on experimental local liquid distribution measurements. Industrial & Engineering Chemistry Research 51: 1672-1679.
[7] Bansal, A., R. K. Wanchoo, and S. K. Sharma. 2008. Two-phase pressure drop in a trickle bed reactor involving newtonian/non-newtonian liquid phase. Chemical Engineering Communications 195: 1085-1106.
[8] Sodhi, V., and A. Bansal. 2011. Analysis of foaming flow instabilities for dynamic liquid saturation in trickle bed reactor. International Journal of Chemical and Biological Engineering 4: 44-50.
[9] Sodhi, V., and R. Gupta. 2011. Pressure drop hysteresis of hydrodynamic states in packed tower for foaming systems. Bulletin of Chemical Reaction Engineering & Catalysis 6: 115-122.
[10] Midoux, N., M. Favie, and J.C. Charpentier. 1976. Flow pattern, pressure loss and liquid holdup data in gas-liquid down flow packed beds with foaming and non-foaming hydrocarbons. Journal of Chemical Engineering of Japan 9: 350-356.
[11] Sai, P. S. T., and Y.B.G. Varma. 1987. Pressure drop in gas–liquid down flow through packed beds. AIChE Journal 33: 2027–2035.
[12] Sai, P. S. T., and Y.B.G. Varma. 1988. Flow pattern of the phases and liquid saturation in concurrent down flow through packed beds. The Canadian Journal of Chemical Engineering 60: 353–360.
[13] Renbao, Z., H. Yongli, K. Wenqi, and Y. Xiang'an. 2009. Stability and water control of nitrogen foam in bulk phase and porous media. Petroleum Science 6: 181-187.
[14] Rao, V. G., M.S. Ananth, and Y.B.G. Varma. 1983. Hydrodynamics of two-phase co- current down flow through packed beds. AIChE Journal 29: 467-473.

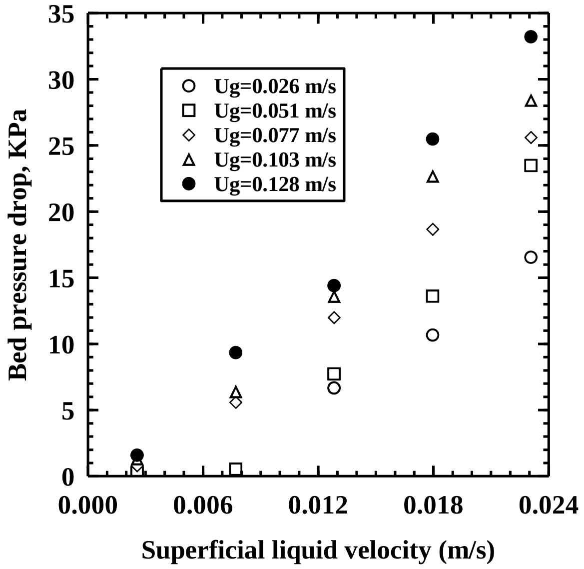

Figure 1 Variation of two-phase pressure drop with superficial liquid velocity for different values of superficial gas velocity (air-water-glass beads system)

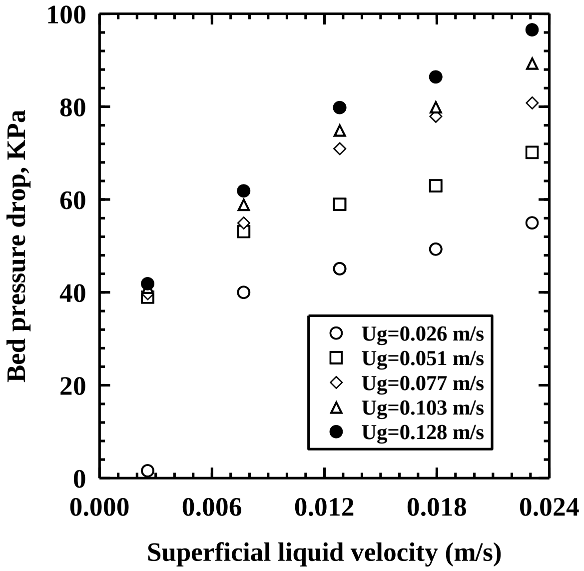

Figure 2 Variation of two-phase pressure drop with superficial liquid velocity at different superficial gas velocities (for air-60 ppm SLS solution)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 10, October-2019

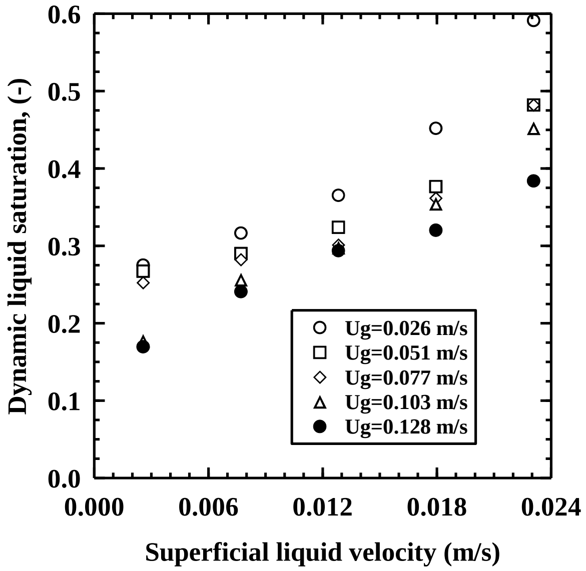

Figure 3 Variation of dynamic liquid saturation with superficial liquid velocity at different values of superficial gas velocities (for air-30 ppm SLS solution)

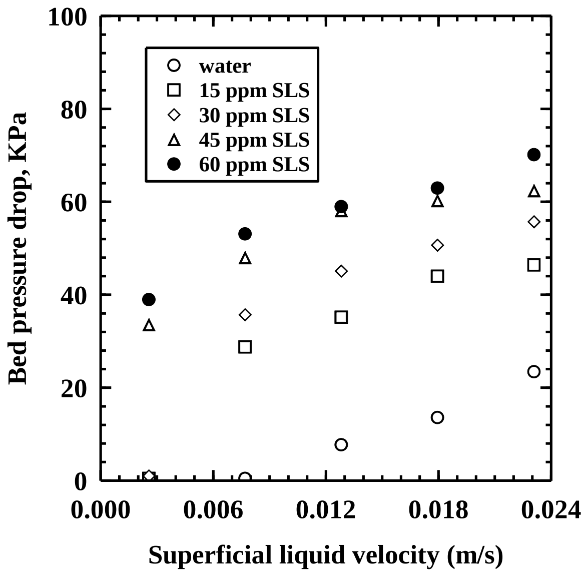

Figure 4 Effect of surface tension on two-phase pressure drop at 0.051 m/s superficial gas velocity

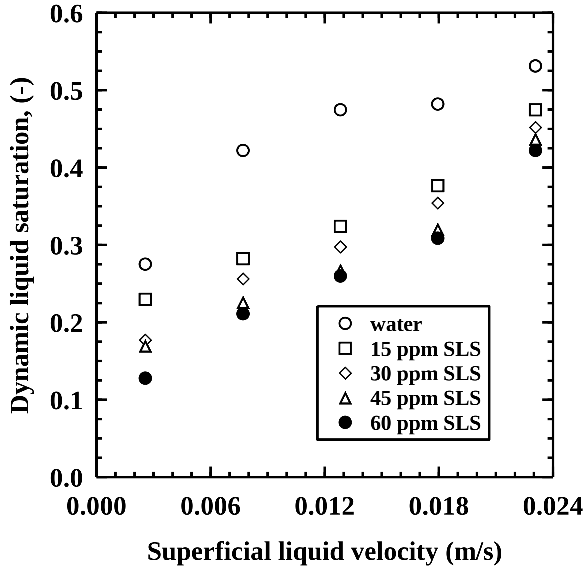

Figure 5 Effect of surface tension on dynamic liquid saturation at 0.103 m/s superficial gas velocity

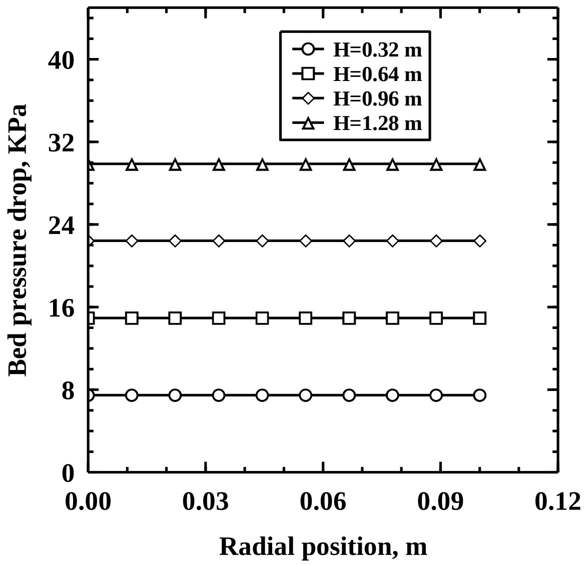

Figure 6 Radial variation of pressure drop at different bed heights for gas velocity 0.077 m/s and liquid velocity 0.013 m/s (for air-60 ppm SLS solution)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 10, October-2019

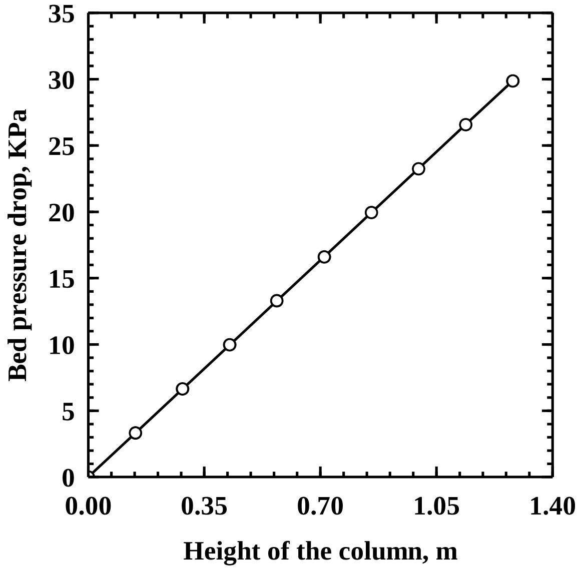

Figure 7 Variation of pressure drop along column height for gas velocity 0.077 m/s and liquid velocity 0.013 m/s (for air-60 ppm SLS solution)

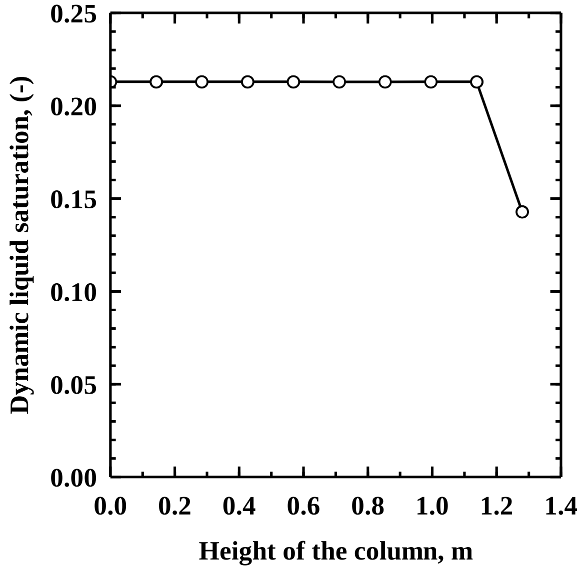

Figure 9 Variation of dynamic liquid saturation with column height for air velocity 0.077m/s and liquid velocity 0.013 m/s (for air-60 ppm SLS solution)

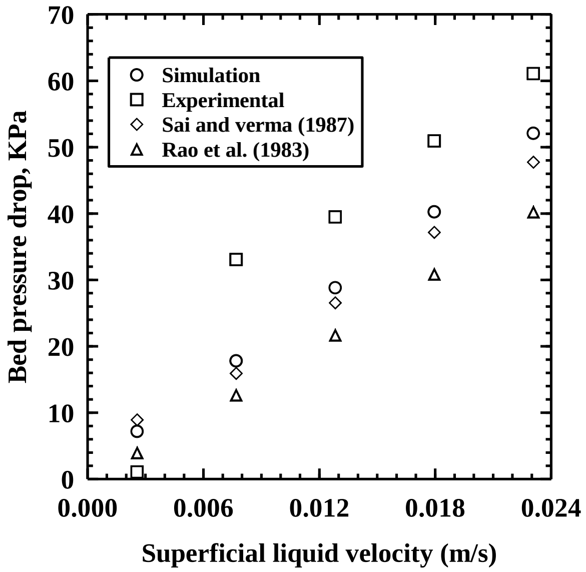

Figure 8 Comparison of bed pressure drop (Ug=0.077 m/s) from literature correlations with present investigation (for air-15 ppm SLS)

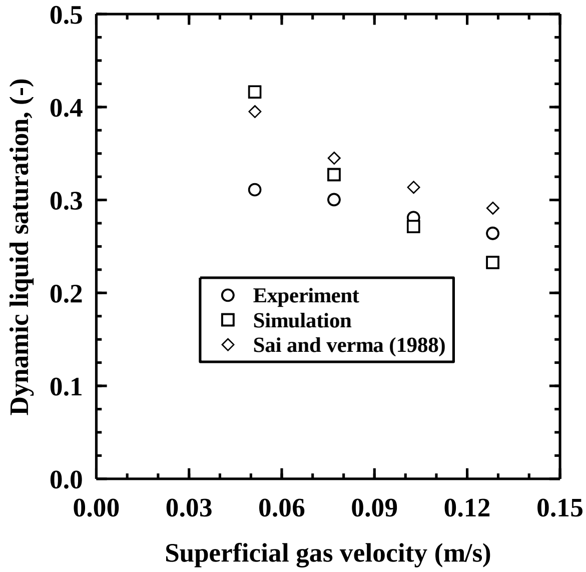

Figure 10 Comparison of dynamic liquid saturation (U_l=0.023 m/s) from literature correlations with present investigation (for air-15 ppm SLS)