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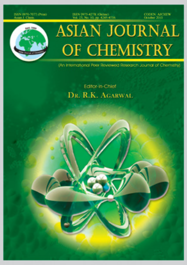

A Study on Pressure Coefficient in Co-Current Three Phase Fluidization by Linear Regression Analysis

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In this present work, a methodical study of the effect of fundamental and operating variables on pressure drop in a three-phase fluidized bed has been studied to detect the pressure coefficient. Pressure influences the hydrodynamics, heat and mass transfer properties of a three-phase fluidized bed considerably. Co-current three-phase fluidization using glass beads and gypsum as solid phase, water as liquid phase and air as gas phase was studied. By using dimensional analysis, pressure coefficient was determined for the fluidized bed with and without internals. The correlations constant are determined by linear regression using MATLAB program. The experimental values were compared and the equation is found to be valid. The correlation coefficient is estimated to be $R^2 > 0.9$.

Key Words: Hydrodynamics, Pressure drop, Dimensional analysis, Correlation, MATLAB, Internals.

INTRODUCTION

The three-phase fluidization plays a vital role in the industrial applications such as Fisher-Tropsch synthesis[1], coal liquefaction[2-8], biochemical fermentation[9-11] and biological wastewater[12-18]. The three-phase fluidization emphasizes the effect of contact among the three phases *viz*. solid-liquid-gas. Fluidization phenomena are greatly influenced by various hydrodynamic parameters such as bed porosity or bed voidage[19], bed pressure drop[20] and phase hold ups[21,22]. Bed porosity depends on the properties and velocities of the fluids. Also the pressure drop of the fluidized bed depends on bed porosity. Pressure drop increases when the porosity is less and decreases when the porosity is more. It also depends on the individual hold ups and its physical properties in three phase fluidization. Hence in order to determine the pressure drop and their correlations[23] with flow parameters, dimensional analysis is used. This study focused on a lab scale to perform a successful scale up[24] of three-phase fluidization to make it valid in the industries and to design three-phase fluidized beds based on the fluid flow model. The pressure coefficient in three-phase fluidized bed with and without internals are determined by using dimensional analysis method and the correlation constants are estimated by linear regression using MATLAB programme. Though several literatures show that most of the correlations were used for the prediction of minimum fluidization velocity and hold ups, limited literature has been shown on finding out pressure coefficient. Hence in the current study, an effort has been made to evaluate an integrated correlation to determine the pressure coefficient using the dimensionless groups, including all the fundamental and operating variables.

EXPERIMENTAL

A Perspex fluidized bed column with 0.054 m diameter and 1.6 m height was used. The experimental setup used in this study is shown in Fig. 1. The liquid and gas flow rates were measured by using rotameter (Krohne Marshall Make) and orifice meter respectively. The gas and liquid streams were merged by employing a sparger having nozzle diameter 1.2 mm and further it was passed through a perforated wire mesh containing 300 evenly spaced holes of 0.05 cm each before entering the bed of solid particles. The purpose of wire mesh is to provide uniform distribution and to retain the solid particles on the bed. A T-joint was provided at the top of the column to allow the gas molecules to escape and liquid to be recirculated inside the experimental set up as highlighted by their respective flow lines. Pressure tapings were provided at the top and bottom of the test section to measure the pressure drop as shown in Fig. 1.

The hydrodynamics studies were carried out for various sizes of glass beads and gypsum particles. Glass beads were preferred for its uniform size and shape and gypsum for its irregular size and shape. The physical properties of fluids and solid particles used in this study were shown in Tables 1 and

2. Initially, the liquid velocity was maintained constant and gas velocities were varied. After attaining steady state, at a particular gas velocity, the fluidized bed height and manometer readings were recorded for pressure drop estimation. The above mentioned procedure was repeated for four different liquid velocities in a fluidized bed with and without column internals. Column internals were placed coaxially with 10 spherical ceramic balls of 25 mm diameter fitted on a rod, which was used as a promoter to create turbulence for fluid flow. The effects of different particle sizes of glass and gypsum on pressure drop were studied in the fluidized bed. MATLAB version 7 was used to perform linear regression analysis and experimental values were verified with the same.

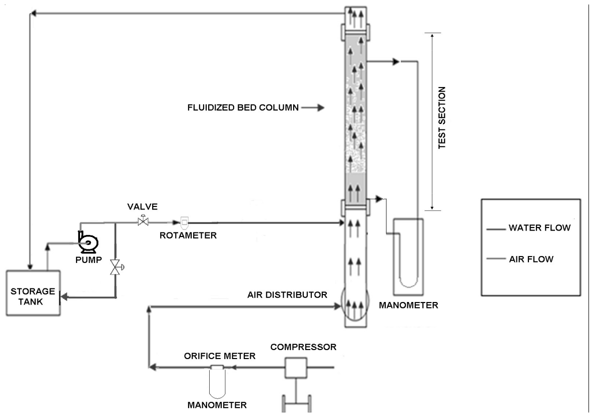

Fig. 1. Schematic diagram of the experimental setup

TABLE-1
PARTICLE SIZE DATA OF GLASS BEADS AND GYPSUM

Solid Particles	D_p (× 10^2 m)
Glass Beads	0.0842
	0.5000
	0.6000
Gypsum	0.0842
	0.1676
	0.2818

TABLE-2
PHYSICAL PROPERTIES OF FLUIDS

Fluid	ρ(density, kg m^{-3})	?(viscosity, kg m^{-1} s^{-1})
Water	995.6	0.00085
Air	1.15	0.000019

RESULTS AND DISCUSSION

The influence of the variation in pressure drop at different flow rates of fluids is much essential to determine the pressure coefficient and its significance in hydrodynamic flow equations.

Effect of flow rates and particle size: The particle size and velocity of the fluid has a key role in determining the flow regime. Reynolds number is proportional to the particle size and velocity. Hence, the increase in particle size and velocities of both gas and liquid phase will result in increase in the values of Reynolds number. It can also be observed from Fig. 2-5. An increase in Reynolds number results in decrease of pressure drop values. This is due to the fact that the increase in flow of gas and liquid will result in increased voids or bed porosity. Hence the pressure drop decreased with increase in modified Reynolds's number gas or liquid ($N_{Re,mg}$ or $N_{Re,mL}$). The available literature signifies that with increase in superficial liquid velocity, pressure drop increase and attains a steady value as reported by Meikap *et al.*[25]. In this study, a different approach of keeping liquid flow constant and varying the gas flow was used, hence a different observation was made.

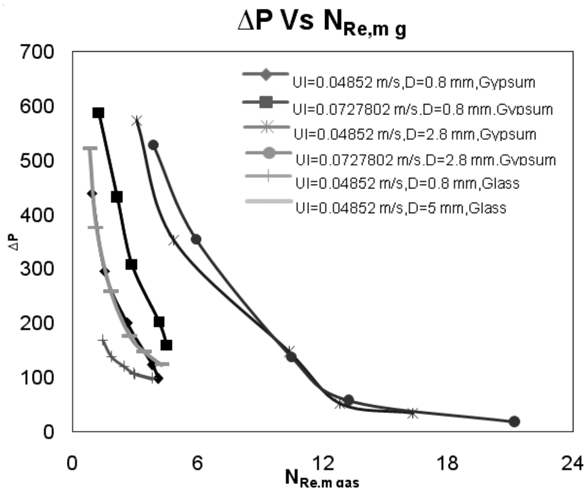

Fig. 2. Plot between pressure drop *versus* modified Reynolds number of gas ($N_{Re,\ mg}$) (without internals)

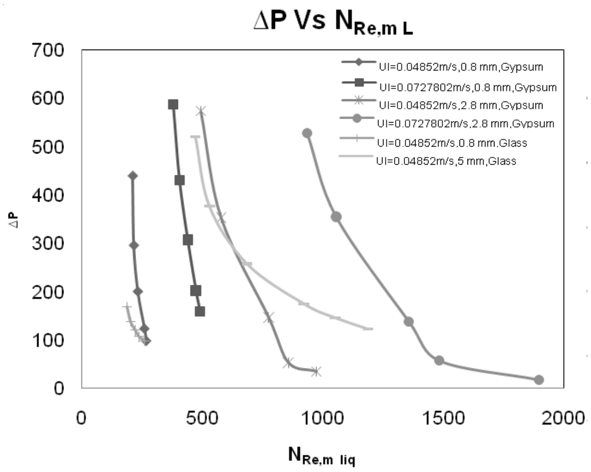

Fig. 3. Plot between pressure drop *versus* modified Reynolds number of liquid ($N_{Re,\ mL}$) (without internals)

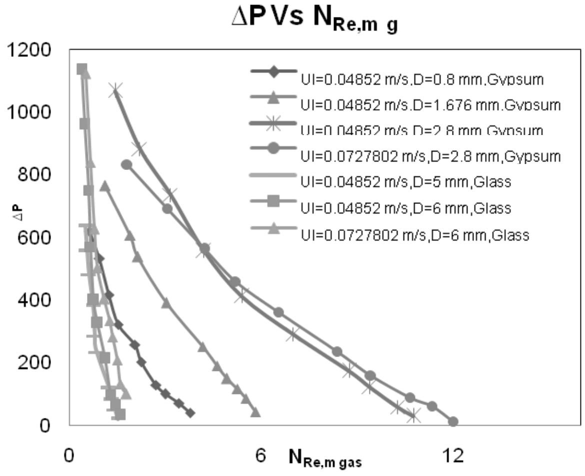

Fig. 4. Plot between pressure drop *versus* modified Reynolds number of gas ($N_{Re,\ mg}$) (with internals)

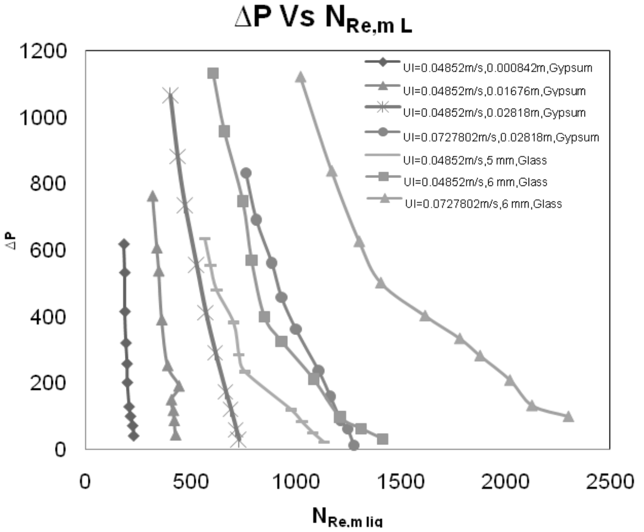

Fig. 5. Plot between pressure drop *versus* modified Reynolds number of liquid ($N_{Re,\ mL}$) (with internals)

Effect of column internals: When the column internals was placed in three-phase fluidized bed, there was a mild interruption in the fluid flow. The fractional volume occupied by the internals was comparatively smaller and does not produce significant bed voidage and hence no change in the values of Reynolds number of both gas and liquid as shown in the Fig. 4 and 5.

Estimation of pressure coefficient: Based on the study of variation of the pressure drop on the Reynolds number for both the gas and liquid phase a dimensionless model equation was developed to predict the pressure coefficient using Buckingham pi theorem by considering the parameters influencing the pressure coefficient. The correlation constants are determined through linear regression in MATLAB software version 7 and the equations obtained for with and without internals are:

Hydrodynamics without internals:

$$\frac{\Delta P}{(1-\varepsilon)(\rho_S-\rho_f)U_g^2}=10^{4.4137}(N_{Fr})^{-0.13}\left(\frac{U_1}{U_g}\right)^{1.2947}(N_{Rep,gas})^{-0.1485}(N_{Rep,liq})^{-0.3701} \quad (1)$$

Hydrodynamics with internals:

$$\frac{\Delta P}{(1-\varepsilon)(\rho_S-\rho_f)U_g^2}=10^{3.7354}(N_{Fr})^{-0.9107}\left(\frac{U_1}{U_g}\right)^{1.1991}(N_{Rep,gas})^{-0.0645}(N_{Rep,liq})^{-0.9584} \quad (2)$$

The equations (1) and (2) are tested with the set of experimental data and it was found to be valid for the different operating variables of the three-phase fluidization. The simulated and experimental values were compared as shown in Figs. 6 and 7.

Conclusion

In this present work, a systematic analysis of the effect of fundamental and operating variables on pressure drop in a three phase fluidized bed has been studied. Pressure drop decreases with increase in Modified Reynolds Number in gas and liquid. Thus the above correlation is valid to find the pressure coefficient irrespective of the constraints that affects the change in pressure drop and the correlation coefficient R2 is greater than 0.9 which depicts the most accurate values. In the conventional method the pressure drop is calculated using the experimental data. Whereas with the help of the above discussed correlation, the pressure drop can be determined easily with the operating variables which may help the future reseachers to proceed their voyage to their province of knowledge without much hurdles.

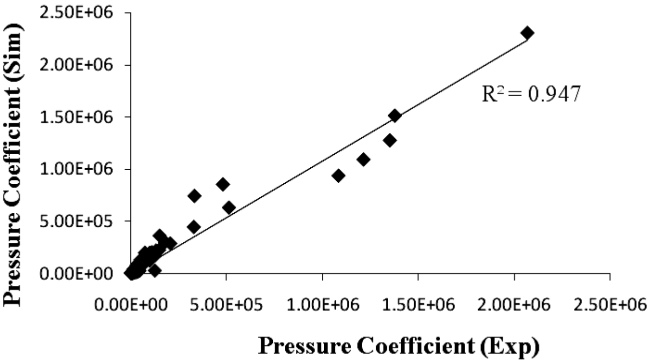

Fig. 6. Simulated *versus* experimental pressure coefficient (without internals)

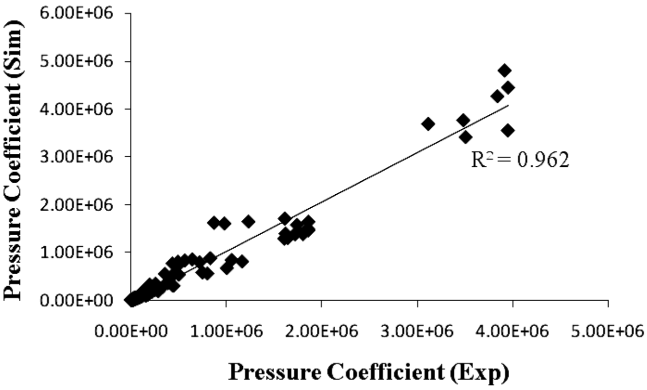

Fig. 7. Simulated *versus* experimental pressure coefficient (with internals)

Nomenclature

D_p	Particle diameter (m)
$N_{Re,mL}$	Modified Reynolds's number for liquid
$N_{Re,mg}$	Modified Reynolds's number for gas
N_{Fr}	Froude number
ΔP	Pressure drop (pa)
R^2	Correlation coefficient
u_L	Velocity of liquid (m s^{-1})
u_g	Velocity of gas (m s^{-1})

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