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Engineering

DETERMINATION OF LOOP FLOW RATE IN AN EXTERNAL AIR-LIFT LOOP WITH MIDDLE RISER USING DRIFT FLUX MODEL

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ABSTRACT External Air-Lift loop consists of a single riser in the middle and two down comers on either sides of the riser connected to the separator tank at the top and a horizontal pipe at the bottom. The reliable prediction of hydrodynamic behaviour is essential for the safe design of Multi-External Air-Lift Loop (ALL). A theoretical model based on the drift flux model was developed to predict the loop flow rate. In order to validate the developed model, a series of experiments were performed on an external ALL to measure the loop flow rate in two down comers and pressure drop in riser. Theoretically liquid circulation rate was predicted with drift flux model by using Jowitt void fraction correlation and Filiminov et al. void fraction correlation coupled with the Friedel two phase multipliers. Experimentally liquid circulation rate in the two downcomers is measured by using ultrasonic flow meter and the predicted results from drift flux model was found to be in excellent agreement with the experimental results. The water coming into the riser increased which is the result of increase of loop flow rate by introducing the two downcomers to External Air-Lift loop.

KEYWORDS : External Air-Lift Loop with single riser and double downcomer, Drift-Flux model, Jowitt void fraction correlation, Friedel two phase multiplier

INTRODUCTION

The Air-Lift Loop operation was first patented for the use as a bioreactor. Since then, many advances are reported describing the Air-Lift loop performance, design and operation [1].

Air-lift loops in general consist of riser, separator tank, downcomer and horizontal conduit resulting into closed loop. In air-lift loop a lighter phase (generally a gas) is injected in the denser loop fluid (generally a liquid) at the bottom of riser. The lighter fluid passes through the riser, enters and disengages in a separator which is situated at a higher elevation. The flow from the downcomer completes the circulation due to the density difference between the bubbly mixture in the riser and liquid in the downcomer. The circulation and mixing are achieved by bubbling air or dispersed bubbly flow [2].

Air-lift loops have many industrial applications such as in aerobic fermentation, waste water treatment and other multiphase operations requiring low shear stresses. Inspite of their simple usage and construction, their usage is limited because the hydrodynamic behavior of the device depends on geometrical shape, dimensions and operating parameters such as gas/air and liquid flow rates. The dependency of hydrodynamic behavior is not fundamentally unclear [3]. In this work a mathematical model based on drift flux model is developed to predict the hydrodynamic behavior in a novel external air-lift loop with riser in middle and two downcomers on either side of it.

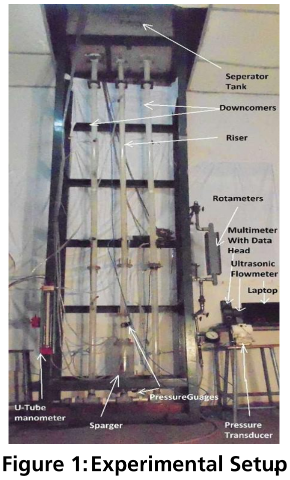

Figure 1: Experimental Setup

MATHEMATICAL MODELING

For the safe design and control of air-lift loop, an accurate simulation of the loop performance is essential [4]. There are three different methodologies, homogeneous model, drift flux model, separated flow model that are available to predict the perform ance of the device theoretically. In this paper, a reliable hydrodynamic model based on drift flux model has been developed to predict the performance of this device as it is capable to predict accurately the loop behavior for all flow regimes. In air -lift loops, the main difficulty in elaborating a mathematical model is to describe gas hold-up as a function of superficial liquid and gas velocities which are not independent [3].

Drift-Flux Model

Due to its accuracy and flexibility drift flux model is recommended for its application to predict the hydrodynamic behavior of Air-Lift loop. The Drift Flux model was first introduced in which it is assumed that two phases flow with different velocities, which considers the relative motion of one phase with respect to the other phase. Drift Flux model is essentially a separated flow model in which attention is focused on relative motion rather than on motion of individual phases [5].

Assumptions

Air-lift loop always operates in steady state. Gas used in the loop is ideal gas. Mass transfer between gas and liquid is negligible. Gas and liquid flows are constant but not with equal velocities. The use of empirical correlations or simplified concepts to relate the two phase frictional multiplier and void fraction to the independent variables of the flow.

Model for loop flow rate

Loop flow rate is predicted by developing a simple theory once loop geometry, fluid properties and air flow rate is given. For determining the loop flow rate, there are two approaches, energy balance and momentum balance approach. In the present work momentum balance approach is adopted. The External Air-Lift loop can be divided into two loops as it contains two downcomers on either sides of the riser.

Loop 1 consists of left downcomer, riser along with the bottom horizontal section and its top left side separator portion. As the Air-Lift loop represents a closed loop, the summation of all the pressure drop terms of the loop 1 equal to zero.

$$\left(\frac{dp}{dz}\right)_R + \left(\frac{dp}{dz}\right)_{ST} + \left(\frac{dp}{dz}\right)_D + \left(\frac{dp}{dz}\right)_{HT} + \left(\frac{dp}{dz}\right)_F = 0 \quad (1)$$

In the above equation, determining the pressure drop in riser is more crucial as two phase flow occurs in this region and the selection of a proper model guarantees the accurate prediction of pressure drop and loop flow rate.

In the riser mixture momentum balance equation has been employed to predict the pressure drop as given in eqn. 2.

$$\begin{aligned} & pA_g - (p+dp)A_g - dF_g - S - A_g dz\rho_g \\ & = \begin{bmatrix} (W_g + dW_g)(V_g + du_g) - \\ W_g V_g - dW_g V_l \end{bmatrix} \end{aligned} \quad (2)$$

By differentiating and simplifying the above equation we get, riser pressure drop

$$\begin{aligned} & \left(\frac{dp}{dz}\right)_R = \left(\frac{W_g}{A}\right)\frac{du_g}{dz} + \left(\frac{W_l}{S}\right)\frac{du_l}{dz} \\ & + (P\,\tau_w) + \left[g\,A(\rho_l + \rho_g)\right] \end{aligned} \quad (3)$$

On further simplifying the above equation we get the pressure drop in riser as the sum of frictional pressure drop, gravitational pressure drop and acceleration pressure drop and is represented as in eqn. 4. In the frictional pressure drop equation, the fluid flowing in the riser is considered as single phase and two phase multiplier is introduced.

$$\begin{aligned} & \left(\frac{dp}{dz}\right)_R = -\left[\frac{0.158\,G^{1.75}\,\mu_l^{0.25}}{\rho_l\,D^{1.25}} \times \varphi_{lo}^2\right] \\ & -\left[\alpha\rho_g + (1-\alpha)\rho_l\right]g \; - G^2\,\frac{d}{dz}\left(\frac{x^2}{\alpha\,\rho_g}\right) \end{aligned} \quad (4)$$

In drift flux model, challenge lies in predicting the two phase multiplier. There are three commonly used correlations which are, Lockhart-Martinelli, Chisholm-Baroczy, Friedel correlation. Based on the recommendations given by James R. Couper [6], Friedel correlation has been selected to predict the two phase multiplier as the mediums in our study are water and air and the ratio of dynamic viscosity of water and air falls below 1000 [6].

$$\left(\frac{dp}{dz}\right)_R = -\frac{0.158\, G^{1.75}\, \mu_l^{0.25}}{\rho_l\, D^{1.25}}\left[E + \frac{3.24\, F\, H}{F_H^{0.045}\, We_L^{0.035}}\right] - \left[\alpha\rho_g + (1-\alpha)\rho_l\right]g - G^2 \frac{d}{dz}\left(\frac{x^2}{\alpha\,\rho_g}\right) \tag{5}$$

For the calculation of liquid circulation rate the riser pressure drop has been computed in a more precise manner. For this, the riser has been divided into discrete number of elements of length 'dz'.

$$(dp)_R = -\frac{0.158\, G^{1.75}\, \mu_l^{0.25}}{\rho_l\, D^{1.25}}\left[E + \frac{3.24\, F\, H}{F_H^{0.045}\, We_L^{0.035}}\right]dz - \left[\alpha\rho_g + (1-\alpha)\rho_l\right]g\,dz - G^2 \frac{d}{dz}\left(\frac{x^2}{\alpha\,\rho_g}\right)dz \tag{6}$$

The total pressure drop can be expressed as,

$$(dp)_R = \sum_{i=1}^{N}\left[(dp)_R\right]_i - p^* \tag{7}$$

Where, N is the total number of discrete elements, and the pressure at the top of the riser is $p^* = \rho_l g Z$

In predicting the frictional pressure drop as void fraction is unknown, predicting this with good accuracy results in better results. For predicting void fraction 'α' in eqn. Findlay's approach has been adopted.

$$\alpha = \frac{U_{SG}}{C_o U_M + U_{GM}} \tag{8}$$

From the above expression, it is observed that the void fraction is a function of drift velocity and distribution parameter which is related to the distribution of bubbles over a pipe's cross section. Distribution parameter is introduced to consider the effect of non-uniform distribution in the two phase flow. Therefore to improve the drift-flux model prediction abilities an accurate prediction of the distribution parameter is essential. Therefore, a challenge appears in deciding the values of C_o. There are many correlations given by various researchers to predict drift velocity (U_{GM}) and distribution parameter. Some of the notable correlations collected and are tested with the developed mathematical model. 18 void fraction correlations based on drift flux model are collected from literature and are used in model.

In downcomer and horizontal tube, there is a single phase flow. So, pressure drop equations for these two sections are developed and are depicted in equations 8 and 9 respectively.

$$(dp)_{DC1} = \frac{2^{5-2b} a \mu_l^b Q_{l1}^{2-b} \rho_l^{1-b}}{\pi^{2-b} D^{5-b}} L_D - \rho_L g L_D + p^* \tag{8}$$

$$(dp)_{HT1} = \frac{2^{5-2b} a \mu_l^b Q_{l1}^{2-b} \rho_l^{1-b}}{\pi^{2-b} D^{5-b}} L_{HT1} \tag{9}$$

The pressure drop in the separator tank is developed as depicted in equation 9 assuming it as an open channel

$$(dp)_{ST1} = \frac{21.248}{D_H D^3}\left(\frac{Q_{l1}}{\pi}\right)^{1.5}\left(\rho_l \mu_l L_{ST1}\right)^{0.5} \tag{10}$$

There are number of pipe fittings in the loop, pressure drop due to these type of losses is given as

$$(\Delta p)_{Fittings} = \frac{8 Q_{l1}^2 \rho_{l1}}{\pi^2 D^4}\left(K_{Tee1} + K_{Tee2} + K_{Exit1} + K_{Entrance1}\right) \tag{11}$$

In the second down comer, second half of horizontal tube, separator tank the equations from 8 to 11 are same except that the subscripts are replaced by 2.

Solution Methodology

The pressure drop in different components of the loop has been calculated by substituting 18 drift flux void fraction correlations. Out of 18 correlations, 4 correlations predicted the trend closely. Jowitt void fraction correlation is the one which followed the trend very closely. Now, the predicted pressure drop values were substituted in equation 1. This gives a nonlinear equation for the liquid circulation rate. Solution of this equation is very difficult. So, to simplify the process, an iterative method has been adopted where initially a low liquid flow rate is assumed. The assumed value of liquid flow rate is corrected continuously till the loop momentum equation is balanced. The assumed value in loop1 in turn loop 2 is incremented till the set (pre-defined) error criterion is satisfied. The computational code is developed in FORTRAN language to solve the mathematical equations iterative.

EXPERIMENTAL SETUP

The experimental setup is a vertical external air-lift loop. It consists of two downcomers on the extreme ends of separator tank and riser is placed in the middle of the two downcomers. Separator tank is placed at the top and horizontal tubes are connected in the bottom to form a closed loop. All the tubes of riser, down comer and horizontal sections are of uniform diameter. The experimental setup is shown below in Figure (1).

RESULTS AND DISCUSSION

Loop Circulation Rate

From the results obtained it is observed that, as the air flow rate is increased liquid circulation rate also increased correspondingly. Jowett void fraction correlation coupled with Friedel two phase multiplier gave a better prediction when compared with the experimental results with the error percentage of 9% which is in the acceptable range. The results are shown in Figure (2) below. However, the mathematical model developed based on the drift flux model over predicted because of the assumption made to simplify the process and unaccounted losses. Also, the exit loss coefficient considered in the developing the mathematical model is for single phase flow which may effect in predicting total liquid circulation rate

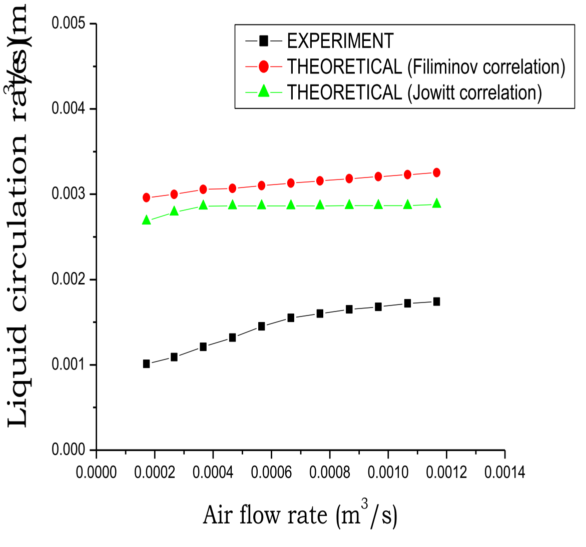

Figure 2:Comparison of theoretical and experimental liquid circulation rate

CONCLUSIONS

A mathematical model based on the drift flux model for unique experimental setup was developed. The total liquid circulation rate in two downcomers was predicted by using 18 void fraction correlations collected from the literature. A computational code was developed in the FORTRAN language to solve the mathematical equations developed. An iterative process was adopted to predict the total liquid circulation rate. Two correlations. Jowitt void fraction correlations were seemed to be in close agreement with the experimental results. However, Jowitt void fraction correlation coupled with the Friedel two phase multiplier gave very close agreement with the experimental results with an error percentage of 9%.

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