ABSTRACT

The research was about void fraction measurement of gas-liquid (air-water) two-phase flow in upward co-current vertical pipe. The diameter of the pipe was 24 mm, with 2250 mm length of the measurement.

The goal of the research is to have special study of the void fraction measurement's performance while the hand operated quick closing valve technique was used. The determination of the performance was measured by using theoretical models as analytical tools, i.e. the homogeneous model, the Lockhart-Martelli separated flow model, and the drift flux model. The way of more than one theoretical models were to have complete analysis and comparison between each models to the others and each models to the experimental method. The observation was made by altering the liquid flow rate, and for each liquid flow rate the gas flow rate was also altered.

The result of the research indicates that the void fraction increased for the increasing of gas flow rate. It was also found that the performances of the quick closing valves possessed distinct results occur for each of theoretical models depend on the regimes of the stream.

Keyword: gas-liquid, void fraction, homogeneous, separated flow, drift flux.

INTRODUCTION

The void fraction measurement often exists in the two-phase flow observation. The void fraction itself described the magnitude of the gas contained in the channel, and is very important component of the pressure drop within the channel.

There have been some modern accurate tools to measure the void fraction within the two-phase gas-liquid flow, instead the hand operated quick closing valves technique, i.e. the solenoid quick closing technique, neutron scatter, electrical-resistivity probes, X-ray, etc. The operation of each of them depend on the condition of the observe flow, whether they are steady or transient, and also in what position of the observation must be made, whether it is channel average, cross-sectional average, chordal average, or local measurement, as Hewitt (1982) in Hestroni (1982) has mentioned.

Indeed, the hand operated quick closing technique was the simplest and cheapest one, compared to the others, hence its application is quite attractive in first level research of gas-liquid two phase flow in laboratory.

THEORETICAL MODELS

There were three that were compared to the experimental method, i.e., homogeneous flow model, Lockhart-Martelli separated flow model, and drift flux model. The use of more than one theoretical models was meant to have appropriate complete analysis between each of them, since none of theoretical models yield the best prediction (Hewitt, 1982 in Hestroni, 1982).

As the homogeneous model assumes that the liquid and the gas phase are completely mixed, and flow with the same velocity, the void fraction formula then becomes (Wallis, 1969):

\[ \alpha_{\text{hom}} = \frac{Q_g}{Q_g + Q_l} \]  

(1)

Instead, the Lockhart-Martelli separated flow model contains much more formulas compared to the homogeneous model, since the separated flow model assumes that each of the phase flow individually with different velocity. Martinelli-Nelson proposed the...
empirical formula for the void fraction as shown by Hewitt (1982) in Hestrom (1982):

\[ \alpha_{np} = \frac{\phi_L - 1}{\phi_L} \]  

(2)

where \( \phi_L \) is the two-phase multiplier, yielded from:

\[ \phi_L = \left[ 1 + \frac{C}{X} \right]^{\frac{1}{X^2}} \]  

(3)

and C is the Chisholm constant, its magnitude is definitely confirmed by the type of the combination of the flow, which are:

- a. Turbulent liquid and turbulent gas (subscript \( \alpha \)), \( C_\alpha = 20 \)
- b. Laminar liquid and turbulent gas (subscript \( \beta \)), \( C_\beta = 12 \)
- c. Turbulent liquid and laminar gas (subscript \( \alpha \)), \( C_\alpha = 10 \)
- d. Laminar liquid and laminar gas (subscript \( \beta \)), \( C_\beta = 5 \)

X is the Lockhart-Martinelli parameter, formulated as:

\[ X^2 = \left( \frac{dp_T}{dp_T} \right) \frac{dp_T}{dp_T} \]  

(4)

where subscript \( T \) indicated the friction component of the pressure drop of each phase:

\[ \left( \frac{dp}{dx} \right)_T = \frac{2G^2}{\rho_D} \]  

(5)

\[ \left( \frac{dp}{dx} \right)_L = \frac{2G^2}{\rho_L} \]  

(6)

and lastly the Reynolds number was define base on each phase to decide the type of the Chisholm constant, as were described formerly:

\[ Re_T = \frac{GD}{\mu_T} \]  

(7)

\[ Re_L = \frac{GD}{\mu_L} \]  

(8)

Wallis (1969) proposed the correlation distribution value of radial dimension, \( Co \), and was defined as the average of the product of flux and concentration to the power of averages, mathematically:

\[ Co = \left( \frac{\phi_L}{\alpha_L} \right) \]  

That is, it becomes more convenient to introduced the average velocity for gas phase:

\[ \bar{\nu}_g = \left( \frac{j_L}{\alpha} \right) \]  

(10)

and the average of the drift flux:

\[ \langle j_g \rangle = \langle j_L \rangle - \langle \phi \rangle \]  

(11)

hence, Eq. (10) can be rewritten:

\[ \bar{\nu}_g = Co \rho_L j + \frac{\langle j_L \rangle}{\alpha} \]  

(12)

by using these formulation:

\[ \langle \bar{\nu} \rangle = \frac{Q_\alpha + Q_\beta}{A} \]  

(13)

\[ \langle j \rangle = \frac{Q_\alpha}{A} \]  

(14)

\[ \langle j_L \rangle = \frac{Q_\alpha}{A} \]  

(15)

the void fraction for drift model then becomes:

\[ \alpha = \frac{1}{Co} \frac{Q_\alpha}{Q_\alpha + Q_\beta} \]  

(16)

if \( \langle j_L \rangle \) is small compared to \( Q_\alpha/A \) Eq. (16) then reduces to:

\[ \alpha = \frac{1}{Co} \frac{Q_\alpha}{Q_\alpha + Q_\beta} = \frac{1}{Co} \alpha_{tot} \]  

(17)

EXPERIMENTAL SETUP AND METHOD

The setup of the experimental installation was shown in Fig. 1, below:
Fig. 1. The Sketch of the Experiment's Installation

A double 1" ball valves were installed into the clycle test section pipe. To have quick, sophisticated ad good closing or opening of the valves at the same time, the handles of both of the valves, must be bent exactly the same at nearly 30° and 45° from their centerline. The handles then were connected using 4 in thick, and 2 cm width steel plate. Their ends were filed 7 mm in diameter to tie them with nut and bolt.

The liquid water was pumped to the test section at .8, 12, 16, 20, 24.5/min flow rates. To vary flow gimeos, for each liquid flow rate, the gas flow rate was based on 1.66 – 60.37 l/min. For each of the gas flow rate, the gas was trapped, by quickly pulling down at connecting rod, thus, the valves would completely closed, and then the height of the gas column was started with the metering tools that had been inserted at the test section before, divide, the height with 225 m, the existing void fraction then would be available to be obtained. The measurements were made for three five times to have representative data.

SCUSSION

Some figures below, shown the interesting impression of the result of the experimental to the theoretical models.

Fig. 2. The experimental results of void fraction and its predictions using homogeneous model

Fig. 3. The experimental results of void fraction and its predictions using separate flow model

Fig. 2 show the homogeneous's results fit the data better to the diagonal line for high liquid flow rate. It is obvious from the assumption that the velocity of both phases are the same and mixed well, indeed, the slip factor (the ratio of the velocity) is unity, but, as the liquid and the gas actually flow with different rate, and even gas phase was mixed by the injector, it will always tends to rise up faster because of their buoyancy gravity effect (Dias et. al., 1992, Sree et. al., 1996), hence, the former assumption is definitely hard to be achieved.

As consequence, the homogeneous yielded much greater results than the experimental ones, and having much great error at low gas and liquid flow rate. The increasing in the liquid flow rate reduced the former effect, and further improve the absolute error even
for low void fraction, hence the prediction of the homogeneous model was better for high liquid and gas flow rate, as shown in Table 1.

Table 1. Absolute Error from the Homogeneous Model

<table>
<thead>
<tr>
<th>Q0</th>
<th>Bubblers</th>
<th>Slag</th>
<th>Char</th>
<th>Annular</th>
<th>Wipps</th>
<th>Flow Regimes</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.6600</td>
<td>0.3021</td>
<td>0.2391</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.5614</td>
<td>0.0799</td>
<td>0.2193</td>
<td>0.22837</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0.3697</td>
<td>0.2994</td>
<td>0.0988</td>
<td>0.1609</td>
<td>0.2041</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>0.2742</td>
<td>0.2042</td>
<td>0.0759</td>
<td>0.0743</td>
<td>0.1353</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.19</td>
<td>-</td>
<td>0.1647</td>
<td>0.0268</td>
<td>0.0864</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>0.1344</td>
<td>-</td>
<td>0.0554</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E=</td>
<td>0.3293</td>
<td>0.3115</td>
<td>0.1722</td>
<td>0.1471</td>
<td>0.1203</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Absolute Error from the Separated Model

<table>
<thead>
<tr>
<th>Q0</th>
<th>Bubblers</th>
<th>Slag</th>
<th>Char</th>
<th>Annular</th>
<th>Wipps</th>
<th>Flow Regimes</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>-</td>
<td>0.297</td>
<td>0.1436</td>
<td>0.0312</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.3437</td>
<td>0.6122</td>
<td>0.3039</td>
<td>0.1015</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0.4146</td>
<td>0.5817</td>
<td>0.4442</td>
<td>0.1881</td>
<td>0.1300</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>0.6402</td>
<td>0.668</td>
<td>0.6122</td>
<td>0.3551</td>
<td>0.2051</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.7808</td>
<td>-</td>
<td>0.6519</td>
<td>0.3588</td>
<td>0.2530</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>0.5414</td>
<td>-</td>
<td>-</td>
<td>0.2797</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>E=</td>
<td>0.4707</td>
<td>0.5397</td>
<td>0.5312</td>
<td>0.1864</td>
<td>0.2101</td>
<td></td>
</tr>
</tbody>
</table>

The other interesting phenomenon is arrived from the Lockhart-Martelli separated flow model when the separated model's results yielded the higher absolute error if the liquid flow rate was increased, as was shown by Fig. 3 and Table 2. As better known from theoretical prevew, the Lockhart-Martelli separated flow formed its formulation based on X, C, and φ, and literally the magnitudes of them depend on the liquid's Reynold number. The behavior of the trend that was yielded there definitely also depend on it as well. Since the liquid flow rate increased, the Reynold number significantly rise up, indicating that the flow became more turbulent, therefore, the 'separation' between each phase was disturbed by the phase that made bridges between each other. The separation somehow denied its assumptions that the slip factor governed the separated flow assumption above unity (Kooiester & Proborini, 1984) would less if the liquid rate had been increased. The two types slip factor results yield from the simple Hewitt formula (original separated flow formula) and the Premoli's formula obtained in Hewitt (1982) in Hestroni (1982) which are:

\[
S = \frac{\frac{\partial y}{\partial x}}{Q_0 \alpha} (1 - \alpha) \tag{18}
\]

\[
S_{\text{hewitt}} = 1 + E_2 \left[ \frac{y}{1 + \beta y E_2} \right]^{1/2} \tag{19}
\]

Where \( y \) is the volume flow ratio (homogeneous' void fraction), and:

\[
E_1 = 1.578 \left( \frac{GD}{\mu_0} \right)^{-0.019} \frac{p_0}{\rho_0} \tag{20}
\]

\[
E_2 = 0.0273 \left( \frac{GD}{\sigma p_0} \right)^{-0.019} \frac{p_0}{\rho_0} \tag{21}
\]

The separated flow model also performant unsatisfactory result for transition region from bubbly to churn regimes. In these transition regimes the separation also has not completed yet since the two phase flow from another was change time to time, and was not completely in good arrangement also to from the individual flow. The performance was improved as the regimes react annular to wipps, where the separation however must complete; the gas phase concentrate at the core, surrounded by liquid film at the wall. It is then obvious that some parameters in the Lockhart-Martelli separated flow model such as X, C, φ, could not cover the uncertainty situation in the last section; the undesired great error that were yielded from the Martelli's correlation was possibly caused by the condition of the experimental situation, considering that the Martelli's formula was an empirical one. The using of the empirical Martelli's correlation could not completely match to the experimental situation held by this research.

The final comparison of the theoretical model and the experimental models from the hand operated quick closing technique is the performance of the drift flux model. The theoretical preview formerly has mentioned how the drift flux's results carried out. It is also understood that because of the unknown of the inter-related parameters and variables of the could not be attempted, and was dropped as being appeared in Eq. (16), (17). Zuber and Findlay phase Ali et. al., (1995) mentioned that the drift flux velocity obtained vertical 25.4 mm ID pipe was about 0.25 ~ 0.3 m/s, and was indeed small if compared with the \( \beta \) which is in the case varied from 0.5-2.25 m/s. The small value of drift velocity (especially for narrow channel) is because of the inability of the bubbles to rise through the stagnant liquid due to the surface tension force. Ali et. al. (1993) and Walfis (1969) also mentioned that if the drift velocity was taken as zero, the Eq. (17) is certainly equivalent to the Bankof's formula:

\[
a = K \beta \]

where \( K \) is equivalent to the inverse of the \( C \), and \( \beta \) is equivalent to the homogeneous' void fraction. Fig. 3
Fig. 4. The experimental results of void fraction and its predictions using drift flux model

Fig. 5. The average absolute error of the three models for void fraction

Table 3. Absolute Error from the Drift Flux

<table>
<thead>
<tr>
<th>Qc (l/min)</th>
<th>Bubbles</th>
<th>Slugs</th>
<th>Churn</th>
<th>Annular</th>
<th>Slug</th>
<th>Wavy</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.1548</td>
<td>0.3565</td>
<td>0.0980</td>
<td>0.0915</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>0.0355</td>
<td>0.2792</td>
<td>0.2871</td>
<td>0.1572</td>
<td>0.1300</td>
<td>-</td>
</tr>
<tr>
<td>16</td>
<td>0.0253</td>
<td>0.41</td>
<td>0.3149</td>
<td>0.2035</td>
<td>0.1583</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>0.2831</td>
<td>-</td>
<td>0.3742</td>
<td>0.27538</td>
<td>0.2530</td>
<td>-</td>
</tr>
<tr>
<td>24</td>
<td>0.3543</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>E∞</td>
<td>0.1702</td>
<td>0.3296</td>
<td>0.2165</td>
<td>0.1563</td>
<td>0.1822</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 4. The Slip Factor's Comparison for Model Altering Liquid Flow Rate

<table>
<thead>
<tr>
<th>Qc (l/min)</th>
<th>G (l/min)</th>
<th>Spref</th>
<th>S</th>
<th>E∞</th>
<th>Eturbo</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.6</td>
<td>4</td>
<td>3.83</td>
<td>3.409</td>
<td>0.1116</td>
<td>0.0686</td>
</tr>
<tr>
<td>21.8</td>
<td>8</td>
<td>2.749</td>
<td>1.954</td>
<td>0.15401</td>
<td>0.1376</td>
</tr>
<tr>
<td>21.6</td>
<td>12</td>
<td>2.319</td>
<td>2.3184</td>
<td>0.26566</td>
<td>0.2655</td>
</tr>
<tr>
<td>21.6</td>
<td>16</td>
<td>2.077</td>
<td>1.3359</td>
<td>0.28258</td>
<td>0.2924</td>
</tr>
<tr>
<td>21.6</td>
<td>20</td>
<td>1.901</td>
<td>1.4309</td>
<td>0.32359</td>
<td>0.3459</td>
</tr>
<tr>
<td>21.6</td>
<td>24</td>
<td>1.733</td>
<td>1.354</td>
<td>0.34057</td>
<td>0.3798</td>
</tr>
</tbody>
</table>

Table 5. The Slip Factor's Comparison For Altering gas flow rate (Qg = 4 l/mm)

<table>
<thead>
<tr>
<th>Qg (l/min)</th>
<th>Sref</th>
<th>Spref</th>
<th>Eref</th>
<th>Eref</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.66</td>
<td>2.9831</td>
<td>1.7906</td>
<td>0.4449</td>
<td>0.0627</td>
</tr>
<tr>
<td>1.78</td>
<td>3.0203</td>
<td>1.187</td>
<td>0.5358</td>
<td>0.06326</td>
</tr>
<tr>
<td>1.91</td>
<td>3.0501</td>
<td>1.8413</td>
<td>0.3262</td>
<td>0.12922</td>
</tr>
<tr>
<td>4.31</td>
<td>3.5289</td>
<td>2.7229</td>
<td>0.253</td>
<td>0.46482</td>
</tr>
<tr>
<td>6.42</td>
<td>2.5252</td>
<td>2.7975</td>
<td>0.1632</td>
<td>0.35339</td>
</tr>
<tr>
<td>21.56</td>
<td>3.4098</td>
<td>3.8905</td>
<td>0.1116</td>
<td>0.06861</td>
</tr>
<tr>
<td>34.49</td>
<td>4.1041</td>
<td>4.5643</td>
<td>0.0434</td>
<td>0.00883</td>
</tr>
<tr>
<td>43.12</td>
<td>4.5021</td>
<td>4.9737</td>
<td>0.0606</td>
<td>0.03164</td>
</tr>
<tr>
<td>60.37</td>
<td>5.1952</td>
<td>5.6740</td>
<td>0.0531</td>
<td>0.03083</td>
</tr>
</tbody>
</table>

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Table 6. The Mean Absolute Error of Each Models Against Flow Regimes

<table>
<thead>
<tr>
<th>Models</th>
<th>Bubble</th>
<th>Slug</th>
<th>Churn</th>
<th>Annular</th>
<th>Wavy</th>
</tr>
</thead>
<tbody>
<tr>
<td>S'/nu</td>
<td>0.3292</td>
<td>0.311</td>
<td>0.1722</td>
<td>0.1470</td>
<td>0.1203</td>
</tr>
<tr>
<td>Lock-Mar.</td>
<td>0.4707</td>
<td>0.541</td>
<td>0.4312</td>
<td>0.29636</td>
<td>0.2161</td>
</tr>
<tr>
<td>Drift flux</td>
<td>0.1702</td>
<td>0.33</td>
<td>0.2165</td>
<td>0.15626</td>
<td>0.1852</td>
</tr>
</tbody>
</table>

CONCLUSION

The behavior of each theoretical models have been discussed briefly in the former section related to the use of the hand operated quick closing valves technique as an experimental tool. It is then available to withdraw some conclusion as the final results, i.e.,

1. The homogenous model showed good prediction at high velocity of both liquid (high liquid and gas flow rate).
2. The prediction of the Lockhart-Martellini separated flow model and Martinellis’s empirical formula fell into inaccuracy for bubbly to churn regimes, and was improved as the regimes reach annular to wavy regimes (low liquid rate and high gas flow rate).
3. The drift flux model reach good result relatively for bubbly flow regimes and at low liquid flow rate, and this model could be recommended to be used for churn to wavy annular regimes at relatively low to medium liquid flow rate.
4. The overall results from absolute error data is:
   - Average error for homogeneous model = 0.2161
   - Average error for Lockhart-Martellini model = 0.3688
   - Average error for drift flux model = 0.2115
   Hence, the generally the flux yield the best prediction from the other two models.
5. Based on the latest paragraph of discussion, the quick closing technique was unavailable to cover complete changes of gas and liquid manner at high void fraction, also posses weakness of visual restriction at low void fraction. The accuracy could be improved, especially at low void fraction measurement, by reducing the test section’s length (space between the two-valves) to decrease the possible complexity that must be covered and by adding the amount of the data measurements to provide higher certainty.

ACKNOWLEDGEMENT

Special thanks is presented to Prof. Nur Yuwono the Director of IUC-ES UGM and Dr. Stuardja the Head of Heat and Mass transfer Lab. for the permission to use of the facilities of HMT Lab of IUC-ES UGM also to Anang PY for his assistance.

INDEX AND SYMBOL

C = Chisholm-constant
Cf = friction factor
Co = Zuber-Findlay distribution factor
D = tube diameter, m
g = gravity constant, m/s<sup>2</sup>
G = mass flux, kg/m<sup>2</sup>s
J = superficial velocity/total volume flux, m/s
J<sub>11</sub> = drift flux velocity
Re = Reynolds number
S = slip factor
W = mass flux, kg/s
X = Lockhart-Martelli parameter
ρ = density, kg/m<sup>3</sup>
μ = dynamic viscosity, kg/ms
v = actual velocity, m/s
α = surface tension, N/m
Φ = two-phase-multiplier
α = void fraction
I<sub>2</sub> = index for liquid phase and gas phase
l/b,g = index for liquid phase and gas phase
F = index for friction pressure drop

REFERENCE