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A Study of Two-Phase Air-Water Flow in Horizontal and Inclined Pipelines

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In this paper, we experimentally investigate two-phase air-water flow in horizontal pipeline with internal diameter (ID) of 0.0254 m. Inclination effects on the two-phase flow are investigated by means of a 30° upward inclined pipe with the same ID. Multiphase Simulation of the experimental test matrix in OLGA using the OLGAS point model is also conducted. Results obtained from experimental campaign shows a good agreement between the new OLGAS Point Model and experiments thus validating that the model is good and thereby eliminates the necessity of setting up Multiphase Dynamic simulation in OLGA for short, straight pipes with steady state flow (hence saving money and computational time).

Index Terms— Annular Flow, Flow Patterns, Multiphase Flow, OLGAS Point Model, Plug Flow, Pressure Gradient, Slug Flow

1 Introduction

Concurrent flow of gas and liquid in closed conduits are a common occurrence in the nuclear, chemical, process and oil & gas industries. During two-phase gas-liquid flow in pipelines (depending on the superficial flow rates of the gas and liquids, pipeline size, pipeline geometry and the fluids physical properties) the fluids may take up different spatial arrangements in the flowing conduits. These arrangements are termed *flow patterns or flow regimes*. Flow patterns are critical parameter that determines the pressure gradient and liquid holdup in the conduit. They are also essential in designing equipment and pipelines in which multiphase flow occurs. Many researches have been conducted over the years on various aspects of two-phase flow with mostly air and water used as test fluids. These studies have led to several findings with new correlations and models developed for the estimation of the various flow characteristics such as mean liquid holdup, slug frequency, slug translational velocity, slug length, pressure gradient etc.

One of the earliest studies in two-phase air-water flow was conducted by [1]. Benzene, kerosene, water and various kinds of oils were used as the test liquids while air was used as the gas phase. Pipe diameter used in the study varied from 0.0586 – 1.017 inches. The authors classified two-phase flow observations into four main flow patterns: (a) liquid & gas both turbulent, tt; (b) liquid turbulent & gas viscous, tv; (c) liquid viscous & gas turbulent, vt; and (d) liquid & gas both viscous, vv. They determine the transition between each of the defined flow patterns as functions of single phase flow and correlated their experimental dataset. Lockhart and Martenelli [1] made two main assumptions; (1) the static pressure of the liquid phase and that of the gas phase are equal irrespective of the flow patterns, provided, an appreciable static pressure difference exists. (2) The volume of liquid and gas at any instance in the pipe was considered to be equal to the total volume of the pipe. Their postulations were based on the premise that flow patterns do not change along the pipeline. In effect, flow patterns with large fluctuations in pressure, such as slug and plug flows were eliminated as well as those with radial pressure gradients such as segregated and segregated wavy flows.

Lockhart and Martenelli [1] proposed a two-phase frictional pressure drop based on the volume occupied by liquid, the two-phase gas-liquid dimensionless pressure gradient and liquid holdup. The proposed correlation was related to a parameter, X called the Martinelli Parameter. X was defined as the square root of the ratio of the theoretical frictional pressure gradient of liquid to that of the gas assuming both phases were flowing as single phase fluids in the pipe. The two-phase frictional pressure gradient is proposed thus:

$$dP_{frict} = \Phi_L^2 \cdot dP_L \tag{1}$$

$$dP_{frict} = \Phi_G^2 \cdot dP_G \tag{2}$$

dP_L and dP_G are the frictional pressure gradient of the liquid and gas phase flowing alone in the pipeline respectively. ${\Phi^2}_L$ and ${\Phi^2}_G$ are the two-phase friction multipliers for liquid and gas respectively.

$dP_L$and dP_G are defined mathematically as:

$$dP_L = 2f_L\left(\frac{L}{D}\right)G^2(1-x)^2V_L \tag{3}$$

$$dP_G = 2f_G\left(\frac{L}{D}\right)G^2x^2V_G \tag{4}$$

f_L and f_G are the friction factors of the liquid and gas phase respectively while x and G are the quality of the liquid phase mass flux respectively. V_L and V_G are the specific volume of the gas and liquid phases respectively. A parameter known as the Martinelli and his co-workers discovered that the two-phase friction multipliers can be correlated by the Martinelli Parameter. They conducted series of experiment and correlated both the Martinelli parameter and the multipliers accounting for different flow patterns. Mathematically, the parameter (5) and subsequent correlations (6), (7), were proposed thus and the estimated C that fitted the curves were as shown in Table 1.

$$X^2 = \frac{dP_L}{dP_G} \tag{5}$$

$$\Phi_L^2 = 1 + \frac{C}{X} + \frac{1}{X^2} \tag{6}$$

$$\Phi_G^2 = 1 + CX + X^2 \tag{7}$$

Table 1: Empirical Constants based on Lockhart-Martinelli [1]

Liquid	Gas	Flow Pattern Notation	C
Turbulent	Turbulent	tt	20
Viscous	Turbulent	vt	12
Turbulent	Viscous	tv	10
Viscous	Viscous	vv	5

Hubbard [2] proposed a systematic identification of flow patterns in two-phase flow by using the spectral distribution of the pressure fluctuations at the walls of the conduits in which the two phase fluids, flow. They delineated flow patterns into three main types namely: separated, intermittent and distributed flows. Dukler and Hubbard [3] modelled steady state slug flow and subsequently obtained good estimations for slug flow parameters such as slug length, film length, slug velocities, film velocities and pressure drop.
Beggs & Brill [4] classified flow patterns into three main types: separated, intermittent and distributed. They grouped stratified, stratified wavy and annular flow as separated flow; plug and slug flow as intermittent flow and bubbly flow as distributed. In their flow pattern map, they generated an x-y plot with the x and y axes as Froude number and the input liquid content respectively. Their experimental results were obtained in a flow loop consisting of 90 ft long acrylic pipe (with gas flow rates ranging from 0 - 300 Mscf/day; liquid flow rates, 0 - 30 gal/min, average system pressure of 35 - 95 psia and inclination angles ranging from (-90° to +90°). Flow pattern transition lines were correlated as shown in Table 2 below. ε_L and ε_{L0} is the no slip liquid holdup while L_1, L_2, L_3 and L_4 and are the flow transition parameters. F_{rm} V_m V_{SL} are defined as the mixture Froude number, the mixture velocity and the liquid superficial velocity respectively. A typical [4] flow pattern map constructed by [5] is presented in Fig. 1 below.
Beggs & Brill [4] developed a phenomenological model for the prediction of pressure gradient. They considered an energy balance for the two fluids from one point to the other, for a steady-state mechanical energy balance, the total pressure gradient was considered to be the summation of the acceleration, static and frictional pressure losses given by:

$$-\frac{dP}{dx} = \left(\frac{\partial P}{\partial x}\right)_{ACN} + \left(\frac{\partial P}{\partial x}\right)_{ST} + \left(\frac{\partial P}{\partial x}\right)_{F} \quad (8)$$

where the first, second and third terms of (8) are the acceleration, static and frictional pressure gradients respectively.
The earliest postulation of theoretical modelling for two-phase liquid-gas flow was attempted by Taitel and Dukler [6]. The model assumed that the two phase oil-gas flow was Newtonian flow in horizontal and slightly horizontal pipelines with inclination angles ≤ ±10°. They considered an equilibrium liquid height in stratified smooth flow with a momentum balance for the gas and liquid phases thus:

$$-A_L\left(\frac{dP}{dx}\right) + \tau_i s_i - \tau_{wL} s_L + A_L \rho_L g \sin\alpha = 0 \quad (9)$$

$$-A_G\left(\frac{dP}{dx}\right) - \tau_i s_i - \tau_{wG} s_G + A_G \rho_G g \sin\alpha = 0 \quad (10)$$

Table 2: Beggs and Brill [4] flow pattern transition Criteria

Flow Transition Criteria	Flow Pattern	Parameter Definition
$\varepsilon_L < 0.01$ & $Fr_m < L1$ or $\varepsilon_L \geq 0.01$ & $Fr_m < L2$	Separated	$Fr_m = \frac{V_m^2}{gD}$
$0.01 < \varepsilon_L < 0.4$ & $L3 < Fr_m < L1$ or $\varepsilon_L \geq 0.4$ & $L3 < Fr_m \leq L4$	Intermittent	$\varepsilon_L = \frac{V_{SL}}{V_m}$ $L1 = 316\varepsilon_L^{0.302}$
$\varepsilon_L < 0.4$ & $Fr_m \geq L1$ or $\varepsilon_L \geq 0.4$ & $Fr_m > L4$	Distributed	$L2 = 0.0009252\varepsilon_L^{-2.4684}$
$\varepsilon_L \geq 0.01$ & $L2 < Fr_m < L3$	Transition	$L3 = 0.1\varepsilon_L^{-1.4516}$ $L4 = 0.5\varepsilon_L^{-1.4516}$

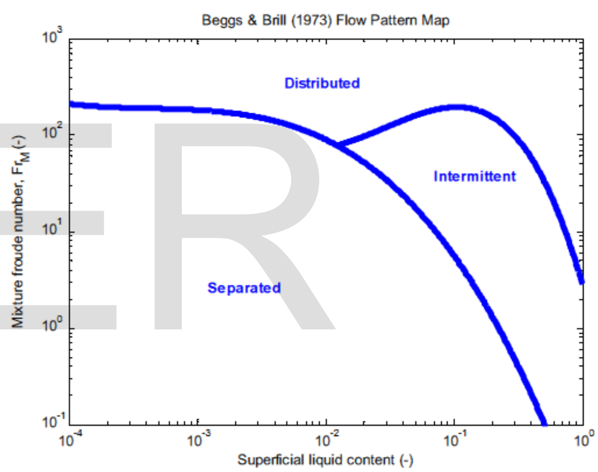


Fig.1: Beggs & Brill [4] flow pattern map for horizontal pipeline from [5]

An evaluation of (9) and (10) yielded the pressure gradient of the two phase flow. It is pertinent to note that the model however required some form of iterative solutions and several closure relationships some of which were geometrical considerations making its analysis relatively tedious.
Weisman and Kang [7] provide one of the most significant works on flow patterns for inclined pipelines. They conducted experiments on test facilities with pipe internal diameters of 12, 25 and 51 mm. They proposed a correlation for the transition to annular flow for all pipeline inclinations as:

$$(Fr_{sg})(KV_{sg}) = 25\left(\frac{V_{sg}}{V_{sl}}\right)^{0.625} \quad (11)$$

Kutateladze number, K_{sg} and Froude number, Fr_{sg} are functions of the superficial gas velocity and are given by:

$$KV_{sg}\left(= V_{sg}/[g(\rho_L - \rho_G)\sigma]^{0.25}\right) \quad (12)$$

$$Fr_{sg}\left(=V_{sg}{}^{2}/gD\right) \tag{13}$$

Transition to dispersed bubbly flow was given by:

$$\left[\frac{(-dP/dz)}{g(\rho_l-\rho_g)}\right]^{0.5}\left[\frac{[g(\rho_L-\rho_G)D^2]}{\sigma}\right]^{0.5} \geq 9.7 \tag{14}$$

$-dP/dz$ Is the frictional pressure gradient of the single phase liquid flow in the pipe and is the interfacial tension.
The transition to stratified-wavy flow was given by:

$$Fr_g{}^{0.5} = \left(V_{sg}/V_{sl}\right)^{1.1} \tag{15}$$

For the separated-intermittent transition, the correlation proposed was thus:

$$\left[\frac{\sigma}{gD^2(\rho_l-\rho_g)}\right]^{0.20}\left[\frac{[DG_G]}{\mu_G}\right]^{0.5} = 8\left[\frac{V_{sg}}{V_{sl}}\right]^{0.16} \tag{16}$$

Transition from bubbly to intermittent flow is given by:

$$\frac{V_{sg}{}^{2}}{gD} = 0.2\left[\frac{V_m}{gD}\right]^{1.56}(1-0.65\cos\theta)^2 \tag{17}$$

θ is the pieline inclinaton from the horizontal. Fig. 2 below shows the generalised flow pattern map constructed in the study.

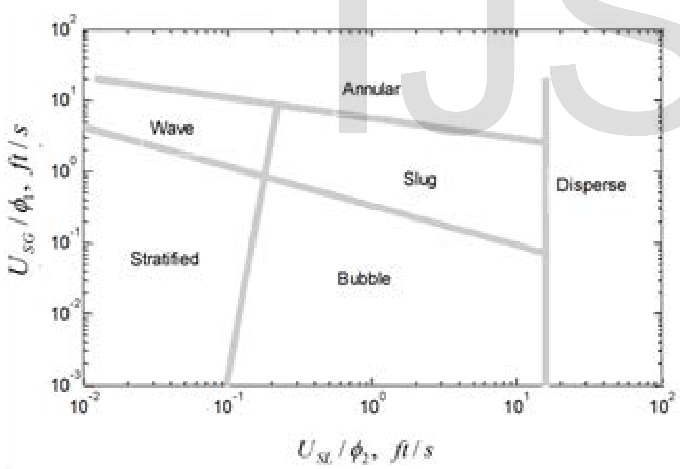


Figure 2: Weisman and Kang [7] generalised flow pattern map

Barnea et al. [8] studied Flow pattern transition for gas-liquid flow in horizontal and inclined pipes fabricated from 3m long plexiglass with two test sections having internal diameters (IDs) of 1.95 and 2.55 cm. They observed and characterized the multiphase gas-liquid flows into: Stratified (S) – In this flow pattern, density difference in the phases causes liquid to flow at the pipe's bottom with gas flowing on top. The interface between liquid and gas can either be smooth (SS) or wavy (SW). Intermittent (I) – Here the gas and liquid flow were non-uniformly distributed. Liquid slugs and plugs are separated by gas zones which contain a stratified liquid layer flowing along the pipe's bottom. An increase in gas flowrates results in enhanced turbulence between individual bubbles. Small bubbles are aerated in the liquid and concentrated towards the liquid slug front and the pipe's top. Intermittent flows are subdivided into Slug (SL) and elongated bubble (EB) flow patterns with the latter considered to be the limiting case of the former when its liquid slug is free of entrained gas bubbles [8].
Annular (A): Here, liquid flows as a film round the internal pipe walls with the film at the bottom noticeably thicker than that at the top. Liquid film surrounds a core of high velocity gas which may contain entrained liquid droplets. At relatively low gas flow rates in which the transition to annular from slug is first observed, most of the liquid flows at the pipe's bottom. Random wetting of the pipe's top by large aerated, unstable waves sweeping through the pipe was observed [8]. The regime observed wasn't slug which neither required a competent bridge of liquid nor was it fully developed annular flow which requires a stable film over the entire pipe perimeter, it was thus named wavy annular pattern (WA). Dispersed Bubble (DB): Here, a flow pattern with gas phase distributed as discrete bubbles within a continuous liquid phase was observed. The transition from AW to DB was initiated by the disintegration of bubbles which were first suspended in the liquid or elongated bubbles which disintegrate on colliding with the top of the pipe [8]. At this flow patterns inception, most of the bubbles are located near the top but at higher liquid rates the bubbles are more uniformly dispersed [8]. Fig. 3 shows flow patterns obtained in the study.

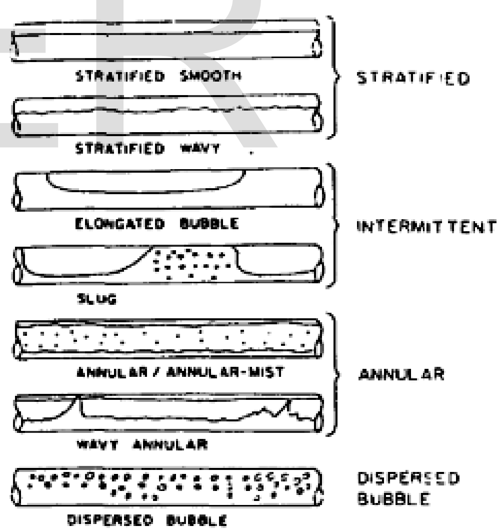


Figure 3: Flow Patterns in Air-Water Two-Phase Flow in a 19.5 & 25.5 mm ID Pipes (Barnea, et al. [8])

Even though several researches have been conducted in Air-Water two-phase flow, it is worth stating that comparisons with industrial software simulators are scarce in literature. Recently, a new multiphase flow toolkit was developed in OLGA (a multiphase flow simulator widely used in the industry and academia). A brief explanation of new multiphase flow toolkit (OLGAS Point Model) is given in Archibong-Eso et al. [9] while a detailed analysis of the model is presented in OLGA User Documentation Manual (2013) [10]. The model is a steady state multiphase flow simulator that assumes a fully developed flow in a short straight pipe. In this paper, we experimentally investigate two-phase air-water flow in horizontal a 0.0254 m pipe ID. Inclination effect on the two-phase flow is investigated by means of a 30° upward inclined pipe with the same ID. Multiphase Simulation of the experimental test matrix in OLGA using the OLGAS point model is also conducted. Finally, results obtained experimentally are compared with OLGA simulations.

2 Experimental Setup

Two multiphase flow test facility are used in this study. The 0.0254 m pipe ID in horizontal orientation, the 0.0254 pipe ID and 30° upward inclined orientation. The facilities are similar in design and operation. For brevity, the 0.0254 m pipe ID horizontal test section is described. The facility with schematics shown in Fig. 4 consists of a Perspex pipe with internal diameter of 0.0254 m and length of 5.5 m. The experimental observatory points and the pressure gradient transducers are located about 60 pipe diameters from the last injection point. Air, which is used as the gas phase in this facility, is supplied from an Atlas Copco screw compressor with maximum capacity and discharge pressure of 400 m³/hr and 10 barg and is fed into the main test line via a 1 inch flexible steel hose at 90° to the main line. Air is first delivered to a 2.5 m³ tank before delivery to the test facility to prevent pulsations. Air dryers are also used to prevent debris and moisture in the supply line of the compressors. Supplied air is metered with a 0.0125 m ID thermal mass flow meter with range of 0 – 2 m³/hr and a 0.0254 m ID vortex flowmeter with range 3 – 100 m³/hr. Water used in the study is obtained from Cranfield University water supply network Water is stored in a 0.15 m³ tank capacity made from plastic material and insulated with fibres on the periphery. A variable speed progressive cavity pump (PCP) with maximum capacity of 2.18 m³/hr and a maximum discharge pressure of 10 barg is used to pumped water into the test loop. Water flow is metered using an electromagnetic meter manufactured by Endress+Hauser, Promag 50P50 D50, with a range of 0 – 2.18 m³/hr. A 4 – 20mA HART output is connected from the meter to the data acquisition system (DAS).

Two GE Druck static pressure transducers, PMP 1400, with pressure range 0 – 4 barg and accuracy 0.04% over the full scale is used to obtain the static pressure in the test section, they are placed 2.17 m apart with the first of them 60D from the last injection point to ensure fully developed flows. A differential pressure transducer, Honeywell STD120, with minimum pressure drop measurement of 100 Pa and an accuracy of ±0.05% is used to measure the differential pressure. Temperature of the test fluids on the test section is measured by means of J-type thermal couples with an accuracy of ±0.1°C placed at different locations. Data acquired from the flowmeters, differential pressure transducers, pressure transducers and temperature sensors are saved to a Desktop Computer using a Labview® version 8.6.1 based system. The system consists of a National Instruments (NI) USB-6210 connector board interfaces that output signals from the instrumentation using BNC coaxial cables and the desktop computer.

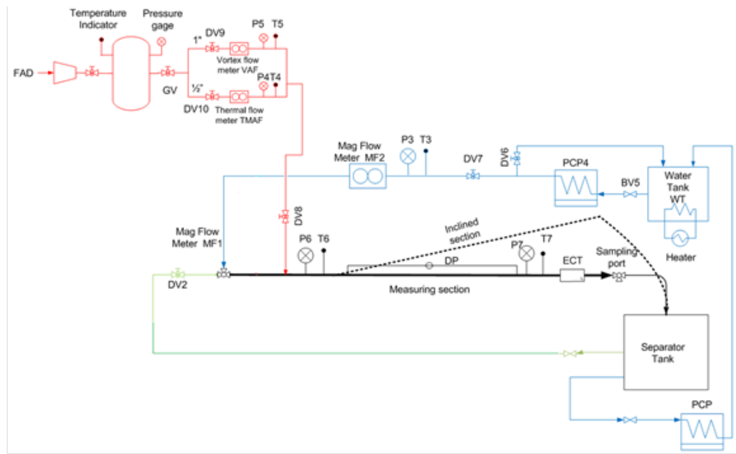


Fig 4: Schematic of the 0.0254 pipe ID test facility

3 Results and Discussions

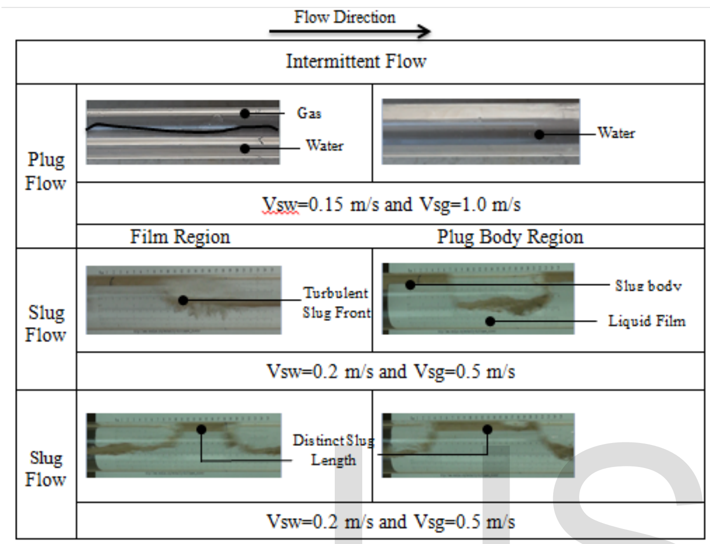
In this study, flow patterns and pressure gradient data are collected and analysed here by aid of instrumentations stated below. Visual analysis for the test was conducted on 750 Hz of video recordings obtained at each test point using two Sony HDR-CX 550 cameras while the differential pressure gradient data were obtained from the GE Druck differential pressure transducer and subsequently validated by the GE Druck static pressure transducers. Test matrix ranges from 0.18 – 1.0 m/s and 0.1 – 12.0 m/s Vsw and Vsg respectively. About 100 experimental test points with each consisting of 7,500 data points logged on the Labview DAQ were analysed for each test run.

3.1 Flow Pattern Visualization

At water superficial velocity, Vsw of 0.1 to 0.15 m/s and gas superficial velocity, Vsg, of 0.5, plug flow was observed. The flow consisted of two characteristic unit; a film region with the fluids flowing in strata with the denser phase (water) flowing at the lower layer (due to gravity) and the upper layer with the denser fluid (water) occupying the bottom of the pipe while the less dense air flow at the top. The second unit, the plug body was observed to intermittently fill the pipe section with water. Air entrainment wasn't observed in the plug body unit. Mechanism of formation of this flow pattern involves the gradual build-up of liquid level to more than 0.5 pipe diameters before it subsequently bridges the top of the pipe thus separating the air flow at the top section of the pipe. The build-up of water is attributed to the increase in Vsw which results in an increased liquid holdup in the flowing conduit.
For Vsw of 0.2 – 1.0 and Vsg of 0.3 and 10 m/s, slug flow was observed, it is similar to plug flow but with a higher momentum, a relatively shorter but faster liquid body. The enhanced turbulence decreases liquid body build-up time resulting in shorter slug lengths with increased gas entrainments in the slug body. Slug length was observably of dissimilar size, this may be as result of the stochastic nature of the flow pattern. The bits of distinction in the slug length may be attributed to

increase in turbulence in flow as water velocity is further increased. Slug frequency (defined as the mean number of slugs that travels through a reference point in a second) increased with increase in Vsw while an initial increase before a subsequent decreased was observed with increase in Vsg. Table 3 shows the pictorial images of slug and plug flows obtained in this study.

Table 3: Pictorial representation of flow patterns observed in 1in ID horizontal test facility



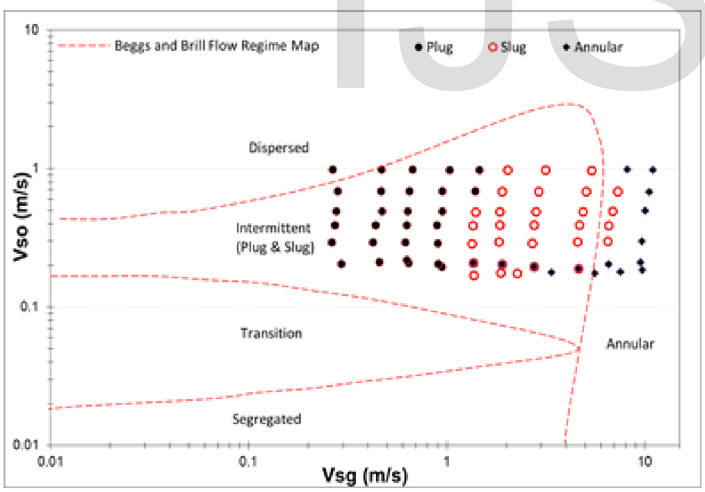


Fig. 8: Comparison of Flow Pattern Maps in this study with Beggs & Brill [4]

3.2 Flow Pattern Map

The horizontal flow patterns obtained in this study were used to construct a flow pattern map which was subsequently superimposed on the Beggs and Brill [4]. The choice of the map for comparison was influenced by the fact that the map was constructed over a wide range of experimental data, has wide industrial and academic acceptance, and are constructed on the basis of some phenomenological analysis. Their test facilities are also similar to the one used in this study. Flow patterns obtained in the horizontal water-air tests were correctly predicted by the Beggs and Brill [4] map as shown in Fig 8.

3.2.1 *Pipe Inclination Effects on Flow Patterns*

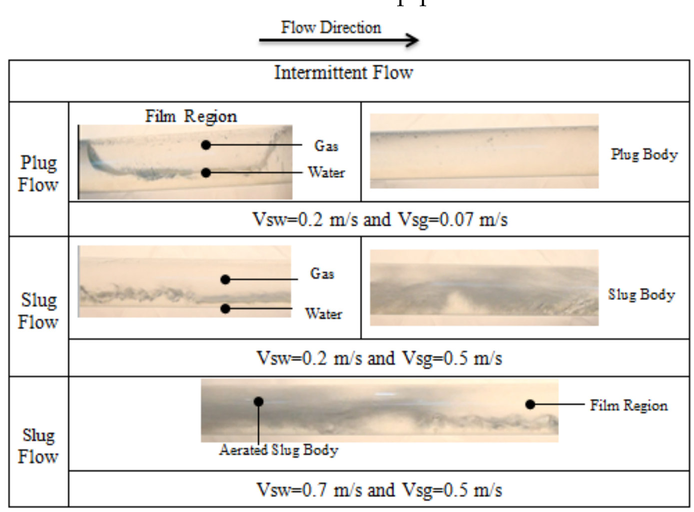
Flow patterns in the 0.0254 m pipe ID 30° inclined test rig were obtained in a similar fashion to that of the horizontal test facility. Table 4 shows a photographic representation of the flow patterns observed in this study which include the Plug and slug (both characterised as intermittent) and the annular flow patterns.

Flow patterns in the 0.0254 pipe ID, 30° inclined test section were similar to that in horizontal pipe, however for the slug flow pattern; it was observed that after the passage of some of the slug body, the liquid film in the film region flowed in reverse to the direction of flow. Slug flow pattern for inclined test facility were much more energetic with relatively shorter slug length compared to the horizontal pipeline flow. Slug front was very turbulent and increased gas entrainment in the slug liquid body is also noted. This is as a result of terrain slugging hitherto unavailable in the horizontal pipe configuration which only produced hydrodynamic slugging. Relative to the Weisman and Kang [7] flow pattern map, it shows that the present study is predicted very well as shown in Figure

Increased gas entrainment in the slug liquid body is also observed with the slug front being very turbulent.liquid film in the film region flowed in reverse to the direction of flow. Slug frequency were also dominant in the slug flow pattern

A comparison between the flow patterns obtained in the horizontal and 30° inclined test section is presented into in Fig. 9 below. Results indicate that inclining the test section by an angle 30° to the horizontal results in slight shift in flow patterns in favour of intermittent flow.

Table 4: Flow Patterns in 0.0254 m pipe ID with inclination



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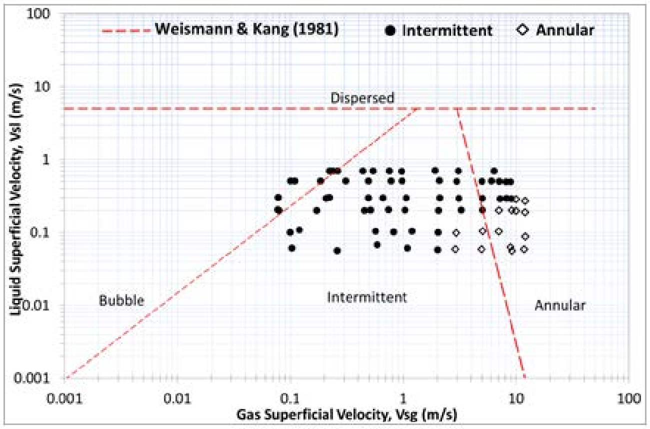

Fig. 9: Comparison of Experimental Results with the Flow Pattern Map of Weisman & Kang [12]

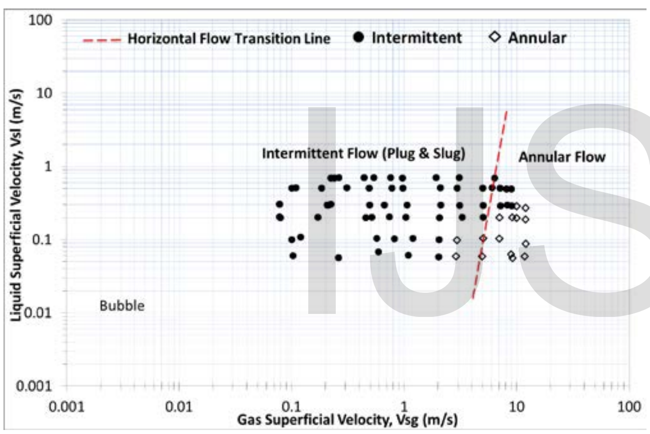

Fig. 10: Comparison of Horizontal and 30 deg. Upward clined Flow Patterns (0.0254 m pipe ID facilities)

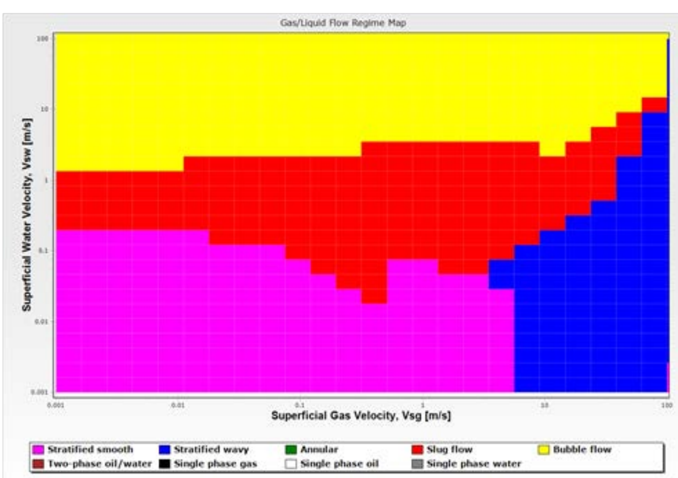

Fig. 11: Flow Patterns obtained from the OLGAS Point Model for Horizontal 0.0254 m pipe ID

3.2.2 *Comparison of Flow Patterns in OLGAS Point Model and Experimental Results*

OLGAS Point model in OLGA 7.3.3 was used to simulate the experimental results. The model accurately predicts the intermittent flow patterns. Allthough annular flow was used to describe the flow pattern in this work, it is noted that the flow was wavy and thus some researchers can chose to class this stratified wavy flow, it is our opinion that this is the classification that OLGA uses thus validating the OLGAS model as a good tool for steady state simulation of low viscous liquid and gas in a short pipe. Fig. 11 above shows the OLGAS Point model flow pattern map.

3.3 PRESSURE GRADIENT

Pressure gradient obtained for the horizontal water-air test are shown in Fig. 12 below. An increase in pressure gradient as superficial velocities of both fluids increases is generally observed. The increase in superficial velocities of gas results in a corresponding increase in mixture velocity and hence the pressure gradient (pressure gradient is proportional to the square of the velocity). Pressure gradient was also observed to be much steeper at higher water superficial velocities; this is as a result of the increased shear on the pipe walls with increase in liquid content. For a constant Vsg, pressure gradient increased with increase in Vsw, the increase is much higher at relatively high Vsg suggesting that flow patterns also have some effect.

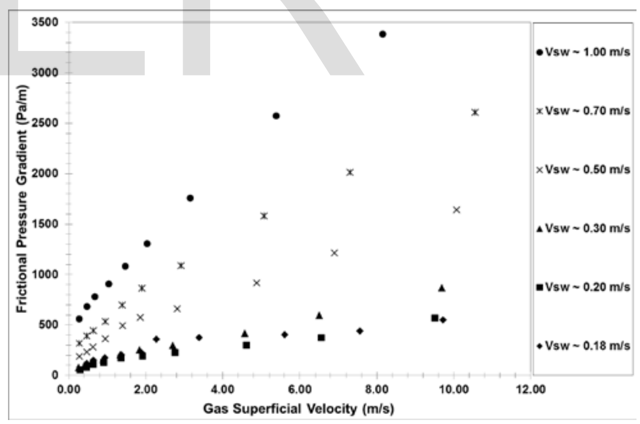

Fig 12: Frictional Pressure Gradient as a function of Gas Superficial Water Velocity

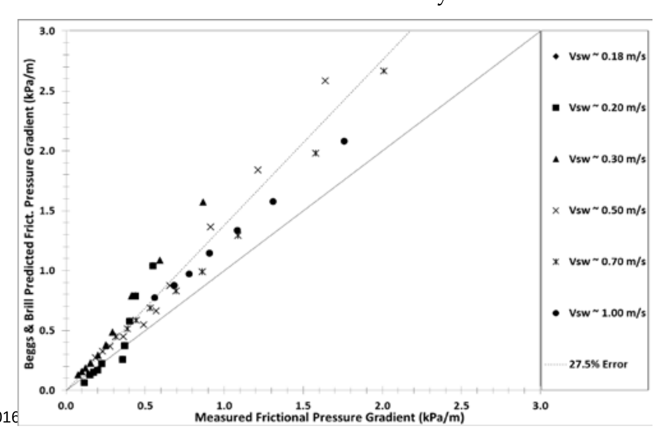

Fig. 13: Pressure Gradient Prediction by [4] as function of Measured Frictional Pressure Gradient

3.3.1 Comparison of Pressure Gradient Prediction by [4] with Experimental Results

Beggs & Brills [4] and Dukler & Hubbard [3] pressure gradient models were evaluated against the experimental measurements using the Average Error, (AE) and the Average Absolute Error (AAE) statistical analysis. Results obtained for both correlations shows an increase in prediction error with increase in Vsw. Overall, the Beggs & Brills model performed better with AE and AAE of 27.7% and 27.2% respectively compared to Dukler and Hubbard's model with 59.3% and 59.2% respectively. It is pertinent to note that measurement uncertainties contributed to measurement errors. A plot of the experimental pressure gradient against the Beggs & Brill prediction is shown in Fig. 13 above.

3.3.2 Pipe Inclination Effects on Pressure Gradient

As earlier stated, pressure is one of the key parameters in pipeline design and operation; it becomes even more important in inclined pipelines since the static pressure drop hitherto negligible in horizontal pipeline (due to zero elevation change) becomes dominant factor. For the whole range of test matrix considered, the pressure gradient characteristic behaviour is similar to the horizontal tests, however, the pressure gradient measured were significantly higher than the horizontal tests. As an example, it is seen that for Vsw 0.30 m/s and Vsg 2.0 m/s, pressure gradient obtained was about 2 kPa/m while the measurement for similar flow conditions in the horizontal test was about 0.6 kPa/m. This increases is as a result of the gravitational force which now acts to oppose flow. Fig. 13 below shows pressure gradient as a function of gas superficial velocity.

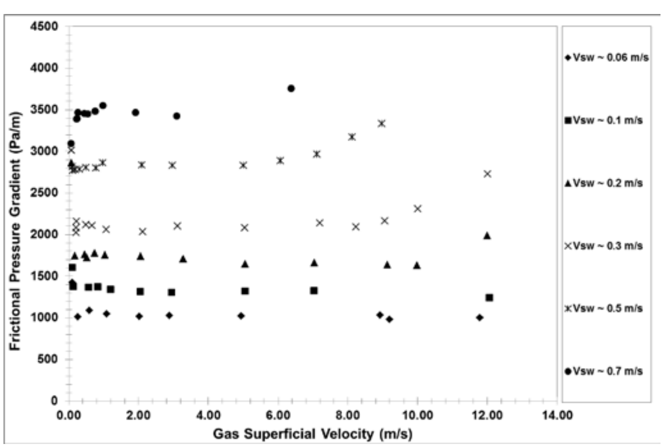

Fig. 13: Pressure gradient as function of Gas Superficial Velocity in the 30° Upward Inclined Pipeline

4 Conclusion

Flow patterns identified in the experimental studies for both the horizontal and inclined pipelines include; plug flow, slug flow and wavy annular flow. Comparatively, in the inclined pipeline, intermittent (plug and slug) flow was dominant than in the horizontal pipeline. This dominance was attributed to the increase effect of gravity forces in the inclined test section. Flow patterns from the horizontal and inclined test section were compared with the Beggs & Brill [4] and Weismann & Kang [7] maps respectively, results showed good agreement with experimental data. Additionally, experimental results were also compared with simulations conducted in OLGA 7.3.3 using the multiphase toolkit (OLGAS Point model). Results obtained showed that the toolkit accurately predicted the flow patterns in this experimental work.

Pressure gradient obtained in the air-water test was plotted as function of gas superficial velocity, results showed a gradual increase in pressure gradient with increase in gas superficial velocity at similar water superficial velocity. An increase in pressure gradient was also observed with increase in water superficial velocity at similar gas superficial velocity. Comparatively, pressure gradient in the inclined section was greater than that in the horizontal test section at similar flow condition.

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