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CFD MODELLING OF PRESSURE DROP ALONG AN INCLINED OIL-WATER FLOW SYSTEM

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*Abstract-***With the increasing need to ensure an optimized production in various processes, especially transportation in the oil and gas industry, the accurate understanding of the dynamics of multiphase flow and its effect on the pressure drop along a flow string is becoming pertinent. The achievement of efficient equipment design such as pumps, separators, flow lines and other production equipment depends on a good prediction of the pressure drop alongtheflowsystem. It is also crucial to understand how changes in fluid properties, flow conditions and pipe geometric properties affect pressure which is an important parameter that is often encountered in the oil and gas industry. Extensive works on oil-water flow mixture have been carried out by numerous investigators considering the horizontal and vertical orientations. Reliance on the empirical correlations and models developed by these investigators to model in pipeline design can be somewhat found wanting because of limitations imposed by the reality of hilly terrains encountered during transportation of oil-water mixture. In this work, experimental data from studies carried out by Hanafizadehet al. [1] was used as the data source. The pipe geometric properties, mixture velocity, oil and water properties and conditions from the above-mentioned studies were used as inputs to the ANSYS FLUENT software to develop a model for pressure drop along with an inclined oil-water flow system. Results obtained from the CFD modelling were in close agreement with the experimental result of Hanafizadehet al.[1]**

Keywords: **CFD, Simulations, Contours, Pressure drop, Phase.**

I. INTRODUCTION

Two-phase (liquid-liquid) flow occurs frequently in the oil and gas, and many petrochemical industries. For instance, in the extraction of oil from oil wells, water is sometimes injected into the oil sources to make the oil extraction performance more convenient. Therefore, oil production leads to the transportation of a mixture of water and oil over a long distance to refineries or facilities where they will be separated from each other. The terrain through which the mixture flows is usually not flat, it has to flow through undulating and hilly terrains. These inclinations may lead to a higher mixing of the oil and water mixture thus affecting the flow patterns, phase distribution and the pressure drop along the flow system is also affected.[2]

Along the pipeline, different flow patterns occur at some critical points (such as valves, Tees, equipment etc.), hence it is important to find out about the flow patterns to avoid damage to the critical points due to uncontrolled impulse or cavitation.In an oil-water flow system, the main flow patterns encountered are the bubble, slug, dual continuous, stratified, churn and annular flow. The dynamic flow characteristics, as well as the flow parameters such as phase hold-up, pressure gradient and the flow pattern in liquid-liquid flow, are important in applications such as design and optimization of oil production wells, wellbore modelling, artificial airlift method and the crude oil pipeline transportation network[3].

In the transfer of oil-water mixture, the reduction of pressure loss is very importantand to achieve this, the condition that gives the flow pattern with the lowestpressure drop is considered the best [1]. However,asignificant factor that affects the pressure drop along an oil-water flow system in apipeline is the inclination angle of the pipe. The occurrence of a small inclinationand its size affects the interface that exists betweenthe flow patterns in horizontalflow. The declination in a pipe increases the water velocity when compared tothat in a horizontal pipe. The difference in flow patterns, velocity and phase hold-up due to the inclination will alter the pressure drop measured in an inclined pipecompared to horizontal ones[2].

1.1 Background of the study

The co-current flow of an immiscible mixture of oil and water is encountered in various types of operations, such as those carried out in the oilfield[4]. In multiphase flow studies, the liquid-liquid flow has received lesser attention compared to other types of flow[4]. The behaviour of an oil-water mixture is different from that of a single flow of either oil or water [5] hence,An accurate prediction and control of two-phase flow behaviour and its characteristics such as flow pattern, liquid hold-up and pressure differential are crucial in many Engineering applications and this requires a good understanding of the hydrodynamics of the flow system.

Atmacaet al [6]defined a two-phase liquid-liquid flow as the flow of two immiscible liquids co-currently in a pipe. The behaviour of two-phase liquid-liquid flow has been studied in several experimental and theoretical studies. The vast majority of the studies reported on prediction and characteristics associated with either vertical or horizontal pipes with limited reports for inclined pipes.However, the study titled “Horizontal flow of the mixture of oil and water” by Russell et al [8]represents the earliest work of an oil-water flow system[5].Several experimental pieces of research carried out on flow pattern identification byRussellet al[8] and Charles et al[9] became a reference for the basic knowledge andunderstanding of the behaviour displayed by the flow that involves two immiscibleliquids. In their work, they correlated the experimental pressure data obtainedusing a modified fanning factor with superficial water velocity to obtainvariousacetate-butyrate tubing of 1.038-in inside diameter at different water velocities.They observed that drops of oil in water, slugs of oil in water, froth and drops of water in oil where the flow pattern occurs at a constant superficial water velocity with increasing oil-water ratio.

Beggs and Brill [10] experimentally studied a two-phase system in an inclinedplane and developed correlations for liquid hold-up and friction-factor that can beused to forecast pressure differential for two-phase (oil/water) flow in pipesat different angles for different flow conditions in a 1.5-in diameter pipe. Furthermore, In anexperimental study by Zavarehet al. [11], the work done by Charleset al.[9] was improved upon, taking into cognisance the effects of inclination and vertical angles in an oil-water flow system. Their main focus was on predicting the thebehaviour of the flow regimes that were developed by the earlier researcher. Hagedorn and Brown[11] experimentally studied pressure differential that occurs as a result of continuous two-phase flow. Using three different vertical conduits with small diameters of 1, 1.25 and 1.5-in nominal sizes, they developed correlations and equations which satisfy necessary conditions that reduce a two-phase to a single-phase flow when the flow rate of either of the phases is zero.

Brauner[12] presented a simple tool to forecast and analyse the annular-core flow of two immiscible liquids. In his work, he developed a model which put various rheological behaviours of fluids (laminar-laminar, turbulent-turbulent or mixed flow regimes) in a two-phase system, considering the disparity between viscosity and density ratio under a unified framework. A satisfactory agreement was established when a comparison was made with available and previous experimental data of pressure drop and in-situ hold-up.Going forward,Lovick and Angeli[13] carried out an experiment to study dual continuous flow patterns in oil-water flows. Using a 38-mm diameter, horizontal stainless steel pipe they found out that dual continuous flow occurs at intermediate mixture velocities between stratified and dispersed flows and leads to a pressure differential that is less than those of single-phase oil flow. They also observed that the velocity ratio increased with increasing input oil fraction and it was above 1 at high oil fractions apart from at the highest mixture velocity where it dropped to values less than 1. They concluded the standard two-fluid model was unable to forecast the pressure differential and liquid hold-up during dual continuous flow and as a result, they proposed a modified model which takes into account the entrainment interface shape and entrainment of one phase in another needed to be developed.

Rodriguez and Oliemans[14] performed an experimental study in a 15-m long, 8.28-cm diameter inclinable steel pipe. Using mineral oil and brine as fluids at mixture velocities of 0.04 m/s and 5.55 m/s. Their findings with regards to flow pattern were in a reasonable agreement with the flow patterns that were proposedearlier by Tralleroet al.[15] They were also able to validate their measured results of pressure drop by comparing with results obtained from simple model, the two-fluid model and the homogeneous model. The comparison was able to provide valuable course of action on the applicability and also accuracies of predictions when using the models for intermediate flow configuration. The study culminated in a conclusion that the accuracy in the prediction with the simple model is dependent on the flow pattern as well as the pipe inclination.

Lum and Angeli[2] experimentally investigated the effect of inclinations on the flow pattern, pressure gradient and liquid hold-up of a liquid-liquid phase flow. The investigation was carried out in a 38-mm ID stainless steel pipe with water and oil as the test fluids. They observed a new flow pattern appeared at inclinations of $+5^0$ and $+10^0$ and the termed it “oil plug flow” while they observed that stratified wavy pattern occurred at -5^0 inclination. Although it was expected that the velocity of the oil phase will increase with increase inclinations, it was however found that the oil flows faster than the water at most composition and mixture velocities. The researchers made a generalization that for all pipe inclinations at low mixture velocities, the oil to water velocity ratio increased with oil fraction from below to above 1. The increase is more noticeable in the upwards inclinations while it was moderate in the downward inclinations. The study also established that frictional pressure gradient in horizontal flow were lower than both upward and downward inclined flows even though the flow patterns were similar.Going forward, Grassi, Strazza and Poesio[16] carried out experiments with the aim of validating theoretical models of high viscosity ratio liquid-liquid flow in a horizontal pipe and slightly inclined pipe. In their work with water to oil viscosity ratio of 800 at 20^0C, they investigated pressure drop and flow pattern that are associated with oil-water flow in horizontal and slightly inclined pipes. The result was compared with theoretical predictions and they found a reasonable agreement with their experimental data. For the predicted transition boundaries superimposed on main flow pattern, the experimental results were used as a base to fit the free parameters, and a good prediction was observed for both the core annular flowregime and the transition to oil in water dispersion. However, they could not ascertain a transition criterion that involved the stratified flow, due to small number of stratified flow experiment points observed. They also observed that contrary to their expectation, the choice of effective viscosity expression in the implementation of the homogeneous oil in water dispersion does not have any significance with the final prediction.

Rodriguez, Bannwart and Carvalho [17]experimentally investigated pressure loss in core annular flow and also went further to develop a model that will predict pressure loss for the core annular flow and also take into account a slip ratio term that will account for the buoyancy that is at the oil core. The experimental data from the investigation was used to validate the propped model. In their study, they conducted an on-shore field experiment in a 274-m long, 7.7-cm ID steel pipeline considering a single oil phase and a two phase oil water pressure gradient. They observed that the addition of water to the oil resulted in oil flow rates becoming seven times faster while the pressure loss is four times lower than the single phase oil. The study also proposed a “Frictional Pressure Gradient Factor” which corresponds to the ratio of single phase oil to oil/water two phase frictional pressure gradient and it was found to be about 150 when the same amount of oil is transported.Strazzaet al[18]carried out an analysis on core annular flow in horizontal pipe and also extending their study to include slightly inclined pipe using high viscous oil. They focused mainly on the pressure drop and oil hold-up measurements that are related with core annular flow boundary. They observed that the flow maps obtained showed only slight difference with respect to other works such as Lum et al[2] and Rodriguez and Oliemanns[14]. They attributed the difference to be most likely due to the substantial balance that existed between the superficial surface tension force and the buoyancy as highlighted by the Eotvo’s number. However they emphasized on the advantage of core annular flow by presenting the pressure gradients in terms of reduction factor similar to Frictional pressure gradient proposed by Rodriguez et al[17]. Sharma et al[19] also developed a new model that will predict flow behaviour for oil-water in horizontal and slightly inclined pipes based on a universal principle that a system becomes stable when its energy is at a minimum. The continuity and combined momentum balance equations were solved for the segregated flow pattern, while for the full dispersion conditions, only the total energy is minimized and the solution was obtained for the continuity equation. They observed that the developed model provided extensive information about flow behaviour and it was able to represent the gradual changes that occurred and thus gives a better prediction of the design parameters. Experimental data from the likes of Tallero [20] was used to validate the developed model and it gave a very good estimate of pressure gradient, water hold-up and flow pattern. However, they stated that the model was sensitive to closure relationships such as droplet size, mixture viscosity and onset of entrainment and as such suggested that it could be improved if better closure relationships are developed.

Shamsul et al[21] performed an experimental investigation using light Malaysian waxy crude oil and synthetic formation water of oil/water flow in horizontal pipes and also carried out studies for nine different flow rates in a 5.08-cm core bore horizontal flow loop that has a length of 1311. They argued that with the advancement of instruments and techniques since the early 90’s the investigation of different flow parameters could be done with a higher level of accuracy and the flow pattern of the oil-water flow could be analysed objectively. Using the static image capturing and video recording at different mixture velocities and water cut they were able to identify five different flow patterns were formed when waxy crude oil/water system is used. Prominent researchers such as Tallero [15],Angeli and Hewitt [22] and Lovick and Angeli[13] have discussed flow pattern with reference to mineral oil or refined oil as one of the test fluids. The investigators in this study were able to observe the basic flow patterns, however a new flow pattern was revealed by their research. They associated the discovered flow pattern to the complex characteristics of the Malaysian waxy crude oil and hence observed that different types of fluid exhibit different types of behaviour in a liquid-liquid flow system and thus suggested that the issue begiven serious consideration.

Hanafizadehet al[1]experimentally investigated the oil-water flow regime in a 20mm diameter pipe with a length of 6m in an inclined position. A high speed digital camera was equipped for visualization, flow regime identification and recording flow was used. The investigation was carried out in three different stages with the horizontal being the first stage, followed by an inclined upward flow and finally the inclined downward flow. They made comparison with the earlier works of Angeli and Hewitt [22] and they observed that there was a difference in transition boundary of bubbly to slug flow. They also observed that increasing the inclination angle of a pipe created a two phase upward flow and at high inclination angles the upper part of the flow pattern map was approximately occupied by bubbly flow and slug flow. On the other hand they observed that by decreasing the inclination angle a downward two phase flow was created and anew phenomena of wavy stratified flow filling the region between slug flow and annular flow. The dominant flow patterns at high downward inclination were noted to be smooth stratified and wavy stratified.Finally, Pan et al[23] carried out an experimental investigation to characterize the effect of pipe inclination, flow rate and inlet water cut considering annular flow pattern in a pipe with diameter of 20mm. they went further to use a modified VOF model based on the CFD software package fluent to predict the in-situ oil fraction and pressure drop. They observed that the pressure drop is strongly dependent on the flow rate, it has a positive proportional relationship such that an increase in the flow rate leads to a rapid increase in pressure drop. They also observed that the slip ratio also positive relationship with the flow rates at all inclinations. At $\theta = 0^0$, 1^0 and $+3^0$ inclinations the slip ratio rapidly decreases with increasing water cut, however it was noted that at $\theta = +5^0$, the slip ratio was dependent on the inlet flow rate and the water cut. The VOF model that was proposed by the investigators was able to give a forecast of the characteristics of annular flow in the horizontal and slightly inclined pipes successfully. It was also in good agreement with the experimental data that was obtained during the investigation.

1.2 Pressure Drop Prediction in Two Phase Inclined Pipes

The ultimate goal in two phase flow models is to calculate the pressure drop that occurs in the flow system. The knowledge of pressure drop in a two phase flow system is very crucial to its design. It enables the design engineer to design the pump that is required for the operation of the flow system and also determine the location of the pump along the pipeline. The total pressure drop calculations along the horizontal pipe consists of two components; the acceleration pressure drop in the mixing zone and the frictional pressure drop in the slug body.

Early researchers made various attempts to use gas-liquid empirical correlations to forecast the pressure drop of liquid-liquid flow system. Table 1 below shows some pressure drop correlations from earlier researches.

1.Pressure Drop Correlations from Earlier Researches.

Author	**Correlations**
Arirachakaranet al	$$\frac{dP}{dz} = \frac{P_0}{P_C}\left[\frac{dP}{dz}\right]_{f_0} + \frac{P_0}{P_C}\left[\frac{dP}{dz}\right]_{f_w}$$ (stratifiedflow) Where $\left[\frac{dP}{dz}\right]_f = \frac{f\rho J^2}{2g_c d}$ Laminar flow ($NR_{em} < 1500$) $$f_m = 1.74 - 2.0\log\left(\frac{2\varepsilon_T}{d} + \frac{18.7}{NR_{em}\sqrt{f_m}}\right)$$
Russel and Charles	$$\frac{\Delta P_{ow}}{\Delta P_{so}} = \frac{{\mu_1}^2}{(2(\mu_1 - \mu_2)\mu_2)}$$ Where μ_1 is viscosity of water and μ_2 is viscosity of oil
Brauner	$$\frac{dP}{dz} = 2f_m\frac{\rho_m {J_m}^2}{D} - \rho_m g\sin\beta$$ (dispersedflow) $$X = \left[\frac{-\frac{dP}{dx}}{\left(\frac{4C}{D}\right)\left(\frac{J_0 D}{V_0}\right)^{n_w}\frac{\rho_0 {J_0}^2}{2}}\right]\left[{Re_{os}}^{-0.8}\left(1+\frac{J_w}{J_0}\right)^{-1.8}\right]$$ Core annular flow-laminar annulus $$X = \left[\frac{-\frac{dP}{dx}}{\left(\frac{4C}{D}\right)\left(\frac{J_0 D}{V_0}\right)^{n_w}\frac{\rho_0 {J_0}^2}{2}}\right]\left[\left(1+\frac{J_w}{J_0}\right)^{-1.8}\right]$$ Core annular flow- turbulent annulus

Hanafizadehet al	$\frac{dP}{dz} = \frac{-f_m \rho_m {U_m}^2}{2D} - \rho_m g \sin\theta$ $f_m = 0.312 \left(\frac{\rho_{m U_m D}}{U_m}\right)^{-0.25}$ $U_m = U_{so} + U_{sw}$ $\rho_m = \alpha\rho_0 + (1-\alpha)\rho_w$

This work aims to model oil-water two phase-flow in pipes with different angles of inclination using Computational Fluid Dynamics (the Volume of Fluid method in ANSYS v16.0). The two phase flow was investigated in an inclined pipe of 0.02m inner diameter and 6m long with a velocity of 1.5m/s and water cut of 0.3. Different angles of inclination were also scrutinized. Furthermore, the effect of the inclination on the pressure drop was examined in the simulation carried out using ANSYS v16.0. The model considered an inclined oil-water flow system at various angles of inclination and the result that was gotten from the ANSYS v16.0 model using Volume of fluid method, was compared with experimental results from the work of Hanafizadehetal[1].

II. METHODOLOGY

The main objective of this study was to use Computational Fluid Dynamics to determine the pressure profile along an inclined oil-water flow system, hence the need to obtain or source for input data. Therefore, the two-phase flow experiment carried out by Hanafizadehet al[1]in a multiphase flow facility was used as the source of data. The experiment was carried out in a pipe that can have different inclination angles regarding the horizontal. Figure 1 below is a schematic sketch of the test facility.

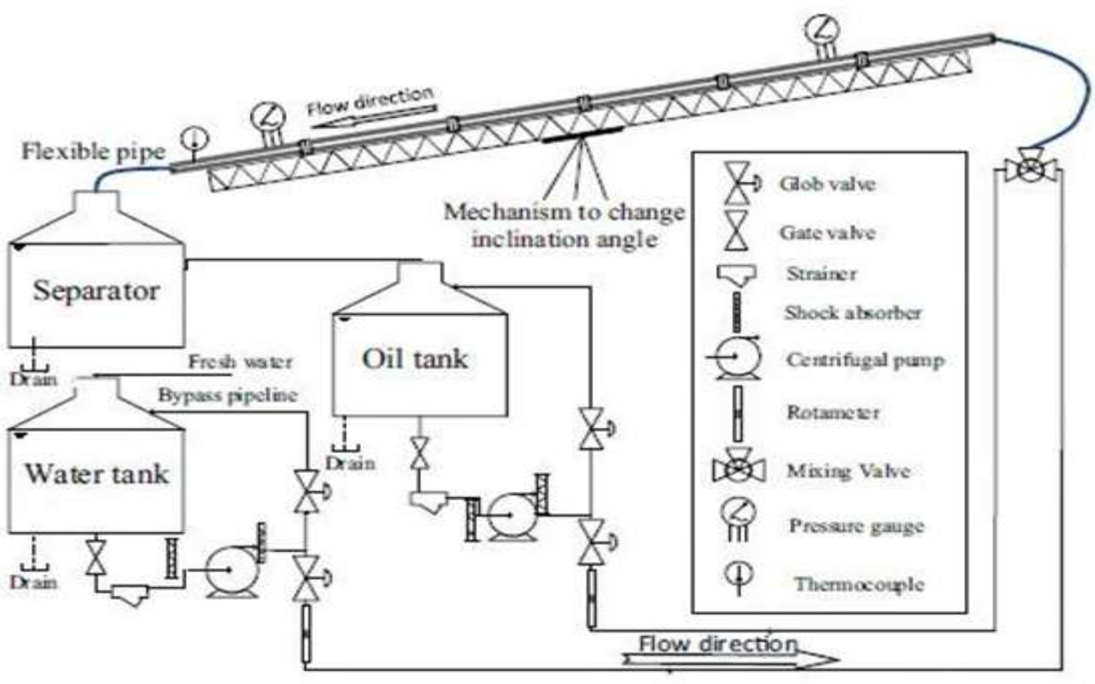

Figure 1. Schematic Sketch of the test facility

The test section has a 6m acrylic pipe with an internal diameter of 20mm and an outer diameter of 30mm with water and oil as working fluids for the experiment stored in two separate storage tanks. A positive displacement pump was used to pump the oil and water mixture to the test line and stored in a gravity separator tank in which water and oil separate due to density differences. The separated oil wasthen returned to its respective storage tank, the separated water was discharged to sewage and fresh water was used for the next set of analyses. Table 1 shows the fluid properties at 20^0C.

Table 2. Fluid Properties at 20^{0}C.

Parameter	Oil	Water
Density	830 kg/m^3	980 kg/m^3
Viscosity	3 mPas	1 mPas

Source: Hanafizadehet al[1]

PTF106 pressure transmitter, with an accuracy of 0.3% full scale was placed along the pipe to measure the pressure drop across the pipe.For the experiment, the superficial velocity of the oil rangedbetween0.29 m/s to 2.35 m/s, and between 0.5 m/s to 3.2 m/sfor the water. The pressure gradients were measured in the pipe for inclination angles of +0, +15, +30 and +45. An average value of pressure drop from the threeseparatemeasurements was considered as the final pressure drop.

2.1CFD Modelling

2.1.1Modelling Strategy

The inclined pipe two-phase flow was modelled using Fluent in ANSYS Workbench V16.0. The Volume of Fluid (VOF) transient,multiphase model was used to model the flow of oil and water in the inclined pipe.The following assumptions were made in investigating the oil-water multiphase pipe flow for all the inclination angles that were considered, and these were 15°, 30°, 45°, and 60°:

1. No-slip boundary condition at the wall of the pipe.
2. The flow within the inclined pipe was isothermal.
3. The two phases flowing within the pipe were in their pure states.
4. No vaporization of liquid during the flow (the flow occurred at 20^{0}C).The two liquids were immiscible.

The two-phase flow in the inclined pipe was carried out in ANSYS Workbench according to the following steps:

1. ANSYS Workbench was launched.
2. The fluent Fluid Flow Analysis system was selected from the Analysis Systems (Toolbox) in Workbench.
3. The 3D geometry of the inclined pipe was created in Design Modeller for the first angle of inclination (15°).
4. The geometric model was meshed in ANSYS Mechanica.
5. Thereafter, the meshed model was set up and solved in Fluent.
6. The model results were visualized in ANSYS CFD Post. The model results were displayed as contour plots and line graphs of static pressure distribution, velocity magnitude, oil-phase and water-phase volume fractions along the pipe.
7. Steps 2 to 6 were repeated for the remaining angles of inclination.

Figure 2 shows the sequence of work for the simulation of the oil-water flow in the inclined pipe.

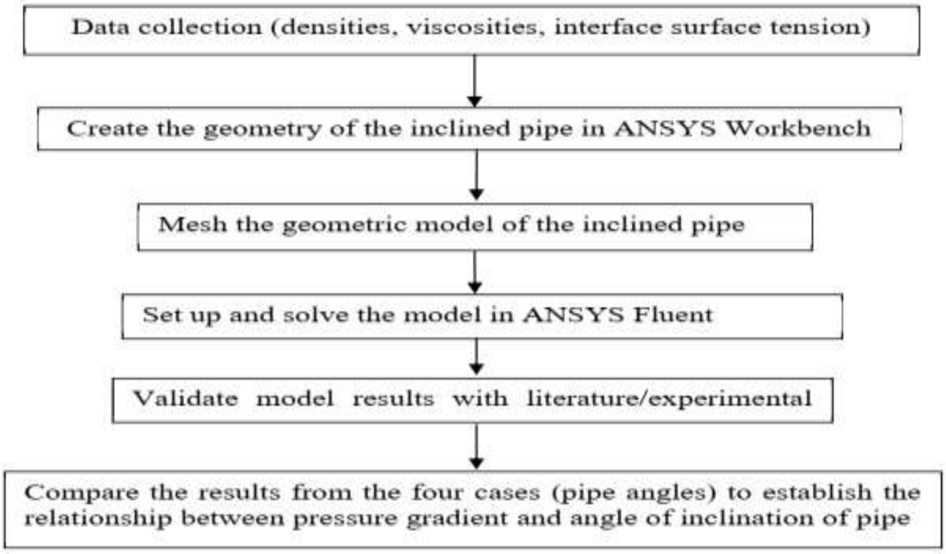

Figure 2. Sequence of work

2.2. Model Data

Table 3 gives the specification of the pipe (pipe geometry). The properties of the oil and water phases are presented in Table 4

Table 3. Specification of the pipe

S/n	Geometric feature	Magnitude/Size
1.	Height, H	6m
2.	Internal diameter, I.D	20mm

Table 4. Phase properties

S/n	Property	Oil	Water
1.	Density (kg/m^3)	990	830
2.	Dynamic viscosity (Pa.s)	0.001	0.003
3.	Interfacial surface tension (N/m)	0.032	

The model data are given in Table 5

Table 5.Model data

S/n	Property	Oil	Water
1.	Volume fraction at inlet	0.7	0.3
2.	Mixture inlet velocity (m/s)	1.5	
3.	Simulation time (s)	1	

III. RESULTS AND DISCUSSION

The CFD simulation was carried out at a mixture velocity and water cut of 1.5m/s and 0.3 respectively. The Volume of fluid (VOF) method was used for simulating the two phase oil-water flow in an inclined pipe at different inclination angles. The different inclination angles used were 15^0, 30^0, 45^0 and 60^0.Various contours and plots were obtained from the simulation for the static pressure for the different inclination angles considered.

Figs 2-5 show the contour of static pressure at inclination angles 15^0, 30^0, 45^0 and 60^0 respectively. It is observed that the pressure reduces as we move along the pipe length with the red colour indicating the maximum static pressure value (which naturally occurs at the pipe inlet) while the blue colour corresponds to the lowest static pressure value (this occurs at the pipe outlet).

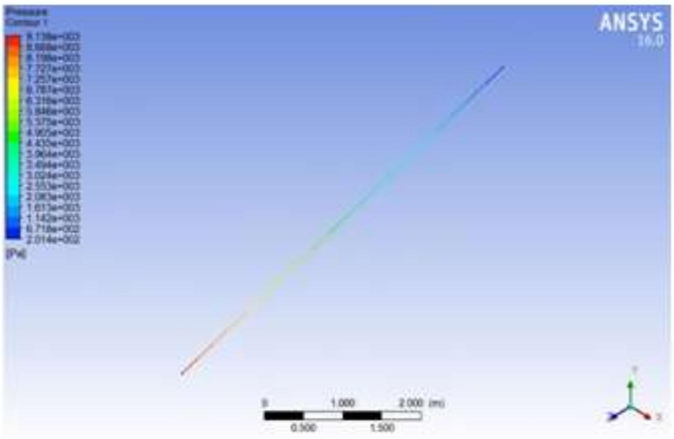

Figure 2. Pressure contour at an inclination of 15^0

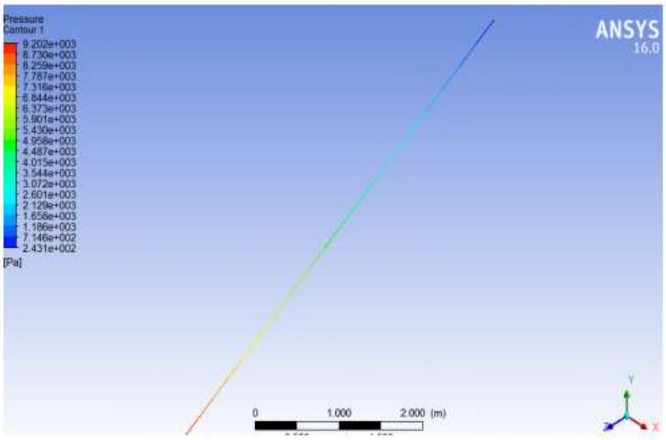

Figure 3. Pressure contour at an inclination of 30^0

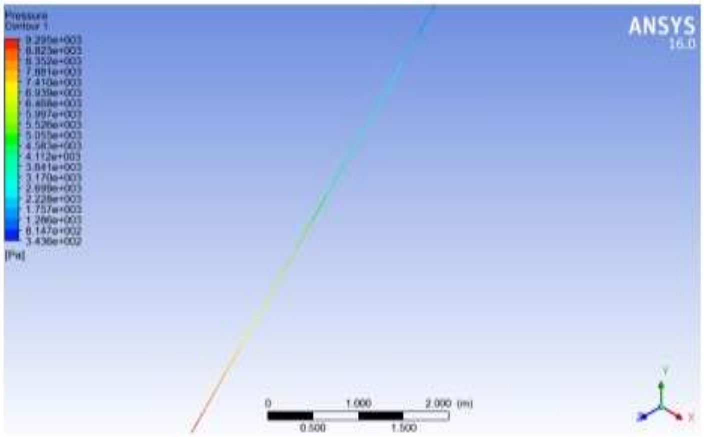

Figure 4. Pressure contour at an inclination of 45^0

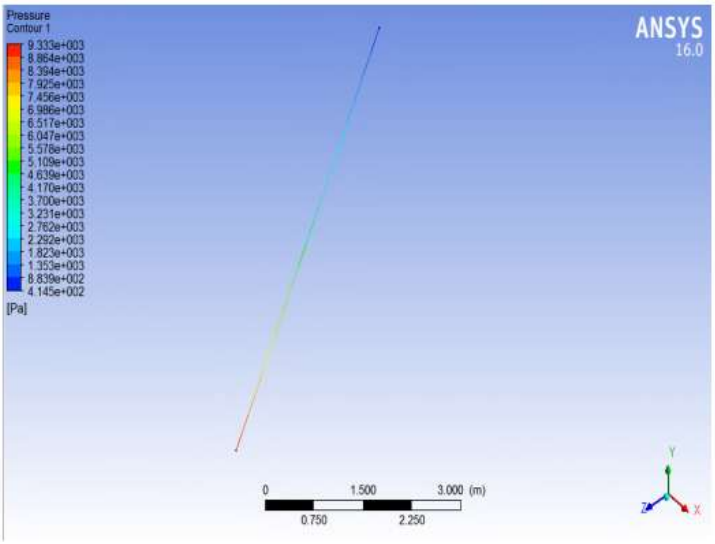

Figure 5. Pressure contour at an inclination of 60

Figs. 6-9 give the plots of the pressure drop in 2D y-z plane for 15^0, 30^0, 45^0 and 60^0 respectively with the y axis indicating the pressure and the z-axis representing the length of the pipe. It is observed that the pressure drops as we move along the length of the pipe from the inlet to the outlet. As the angle of inclination is increased, it is observed that the pressure drops more rapidly and thus the slope can be said to be steeper (that is, the pressure gradient rises as the angle of inclination of the pipe increases). This indicates that more energy will be needed to move the fluid along the pipe as the inclination angle is increased.

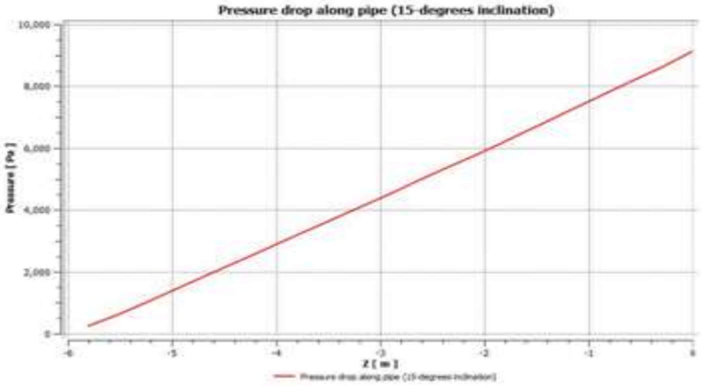

Figure 6. Pressure drop along pipe length at 15^{0}inclination

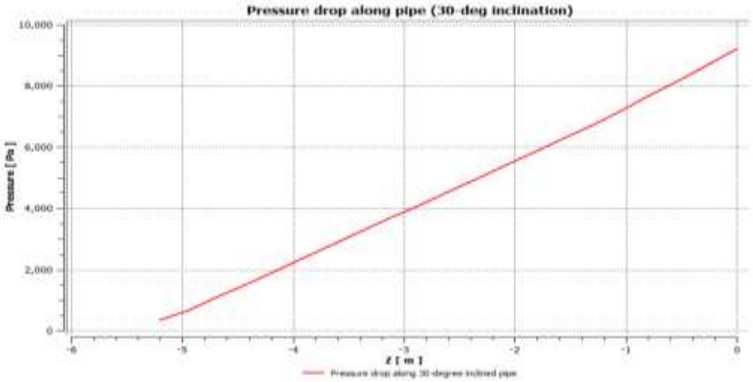

Figure 7. Pressure drop along pipe length at 30^0 inclination

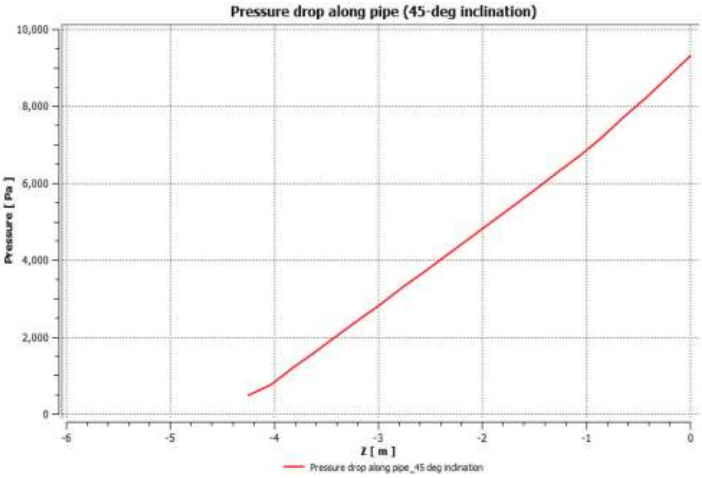

Figure 8. Pressure drop along pipe length at 45^0 inclination

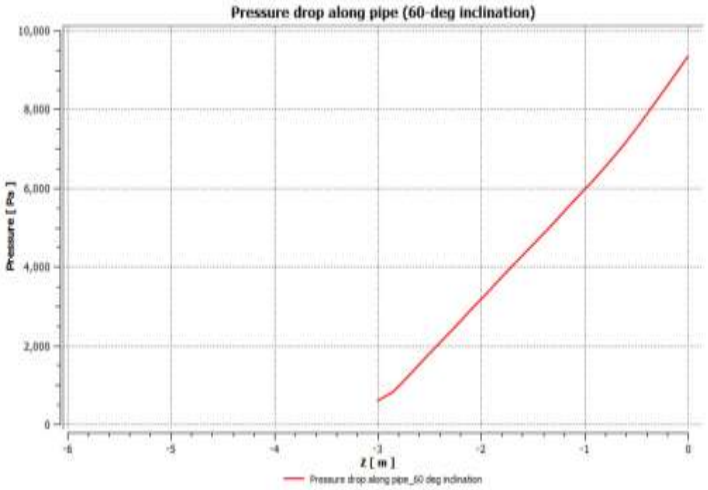

Figure 9. Pressure drop along pipe length at 60^0 inclination

From the various static pressure plots represented in Figs 6-9 above, the pressure drop per unit length were obtained for the inclination angles 15^0, 30^0, 45^0 and 60^0. The effect of the inclination angle on the pressure drop per unit length of the pipe at mixture velocity of 1.5m/s and water cut of 0.3 is depicted in figure 10.

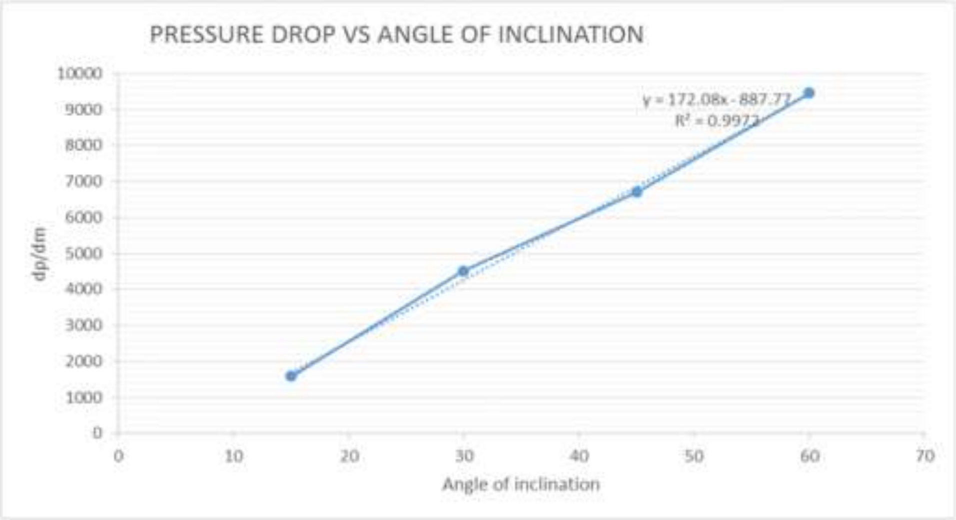

Figure 10. Plot of pressure drop against the angle of inclination.

Figure 10 reveals that as the angle of inclination increases the pressure drop increases. This is as predicted in previous works by Pan et al (2016)[24]. The values obtained as pressure drop per unit length from the CFD modelling were compared with the values reported by Hanafizadehet al (2016)[1]. This is depicted in Figure11 and it can beobserved that the values obtained from the simulation are in close agreement with the experimentalvalueobtained.

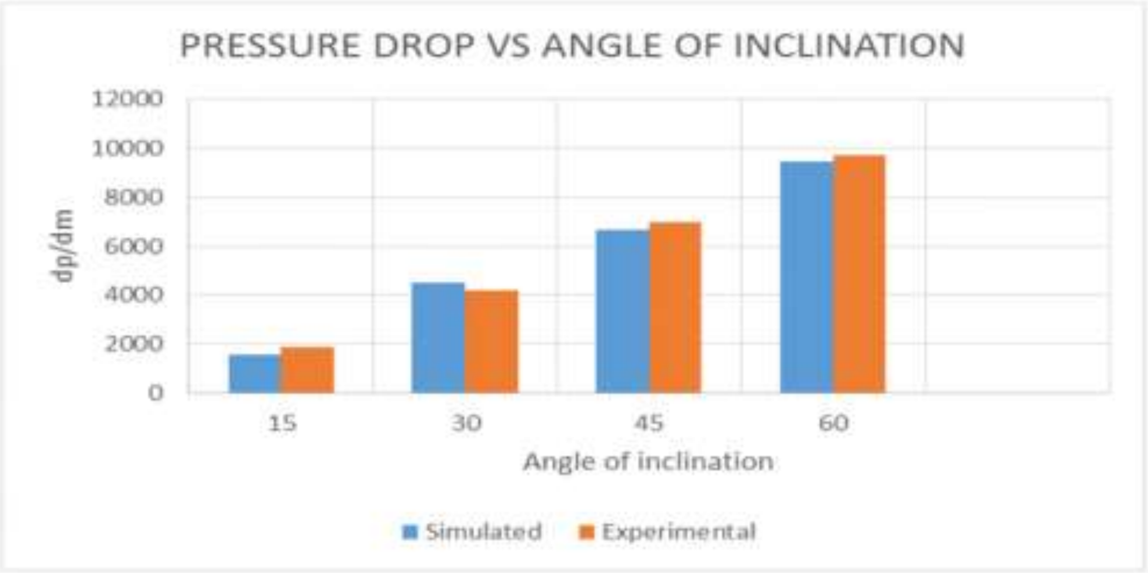

Figure 11. Comparison of pressure drop at various angles of inclination between simulated values and Experimental values.

IV CONCLUSION

Herein, oil-water two phase flow in pipes with different angles of inclination were modelled using the Volume of Fluid method in ANSYS v16.0 successfully. The two phase flow was examined in an inclined pipe of 0.02m inner diameter and 6m long with a velocity of 1.5m/s and water cut of 0.3. Different angles of inclination were considered and it was observed that clear layers of water and oil exist in the pipe. This suggested a stratified flow pattern in the pipe.

The effect of the inclination on the pressure drop was examined in the simulation carried out using ANSYS v16.0. Furthermore, the model considered an inclined oil-water flow system at various angles of inclination, and it was depicted that as the angle of inclination increases the pressure drop that occurs along the pipe also increases. Hence it can be inferred that as angle of inclination increases more energy is needed to move the fluid along the pipe.

Finally, the result that was gotten from the ANSYS v16.0 model using Volume of fluid method was compared with experimental results from the work of Hanafizdehet al (2016) and it was observed that there was a fair agreement between the two; as such the ANSYS model provides a very fair way to validate experimental results.

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