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EFFECTS OF PIPELINE INCLINATION ON TWO PHASE FLOW PATTERNS

Adela M. Syikilili[1*], Cuthbert Z. Kimambo[1], Joseph H. Kihedu[1], Ole J Nydal[2]

1 University of Dar es Salaam (*Corresponding Author)

2 Norwegian University of Science and Technology

ABSTRACT

Production and transport of petroleum fluids involves multiphase flow in pipelines. Handling of these fluids require knowledge on flow behavior whereby, experimental works is a key contributor. Many experimental works done were dedicated to horizontal and vertical pipelines while scarce works on inclined pipelines. The aim of this work was to present an experimental study on analysis of the effect of inclinations on gas-liquid flow patterns. In this study air and water was used in a 60 mm internal diameter pipe with 6 m length. The coverage is upward inclinations of 0^o to 90^o. Flow patterns were recognized using high speed camera and conductance probes. Results shows that inclination has a significant effect on flow patterns distribution.

Keywords: Two phase flow, inclined pipelines, flow patterns and flow regimes.

1 Introduction

Flow pattern is distribution geometry of fluid phases within a pipeline during multiphase flow. Knowledge of flow patterns is vital important in oil and gas industry [2]. Prediction of pressure drop and liquid fraction in pipelines and wells during design of production systems relies on the understanding of flow patterns [4]. Together with its effect on design parameters, flow patterns affect corrosion of pipes, formation of hydrates and deposition of wax and asphalting [3].

Several researchers worked to enable prediction of these flow patterns using mathematical models [1, 5, 7, 8]. Experimental works have been a key ingredient to the establishment and verification of these models. Generally, there are scarce works on flow patterns investigation in inclined pipes especially in high inclination [4, 6]. Therefore, more work is required to clarify the effect of inclination on flow patterns and its transitions in wide range of pipe inclination angles. This work aims to analyse the effect of inclination on flow patterns considering a wide range of inclination angles.

2 Experiment Description

2.1 Experimental setup

Experiments were conducted using multiphase flow rig having air and water loops. Compressed air flows from 8-bar vessels through pressure reduction valve to a 4-bar vessel before entering the test section. Flow meters and pressure gauge are attached to airline. Water is pumped by centrifugal pumps from main separator to the test section. Volumetric flow meter measures the water flow rate before the test section. The test section is made of transparent pipe having 6 m long with internal diameter of 60 mm. Air and water are mixed at the beginning of test section as shown in the Figure 1. At the end, water and air separated in a small separator attached. The air was released to the atmosphere though a flexible pipe while water is taken to first separator and then main separator where it is recycled back to the test section. Two pairs of conductance probe rings are installed closer to the end of the test section while a GOPRO HERO 6 high speed camera installed at the middle of test section. There are three absolute pressure and two differential pressure gauges along. The instrumentation signals are recorded in LabVIEW data base.

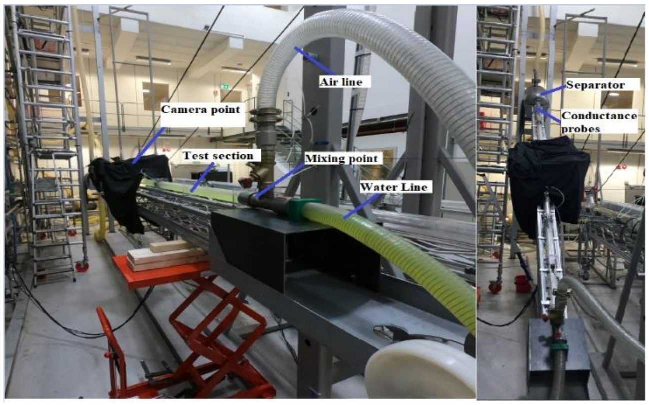

Fig 1: Test section (horizontal and inclined)

2.2 Patterns Identification

Flow patterns were identified by observation with the aid of high-speed camera and conductance probes. Various types of flow were observed from the camera and probes as shown in Figure 2 and Figure 3. Stratified flow is clear separation between air and water. The conductance signal is a straight line. While, stratified wavy flow shows a wavy interface between water and air and its conductance signal is a line with vibrations. Elongated bubble is alternating fractional fill and full water slugs. The slug is not highly aerated and is in one forward direction. Probes signal shows maximum conductance during the full water slug and minimum value indicating the fractional fill of water in the pipe. Cap bubbles are bubbles or air with a cap like structure flowing at the upper most part of the pipe. The probes signal for cap bubble are similar to elongated bubble except that maximum signals are very close. Slug flow is similar to elongated bubble except that the slugs are highly aerated and hence probes signals do not reach maximum value. Annular flow happens at high gas flow rate making the liquid phase surrounds the pipe perimeter.

2.3 Experimental matrix

A total of 434 experimental points considered in this study. Liquid flow rates were 0.02, 0.05, 0.1, 0.5, 1.0 and 2.0 m/s. Gas flow rate was in a range of 0.2 to 6.5 m/s at atmospheric pressure and 20°C except for 15° experiments whereby, gas flow rate reached to 50 m/s. Pipeline inclination covered are 0°, 5°, 10°, 15°, 20°, 30°, 40°, 40°, 60°, 70° and 90°.

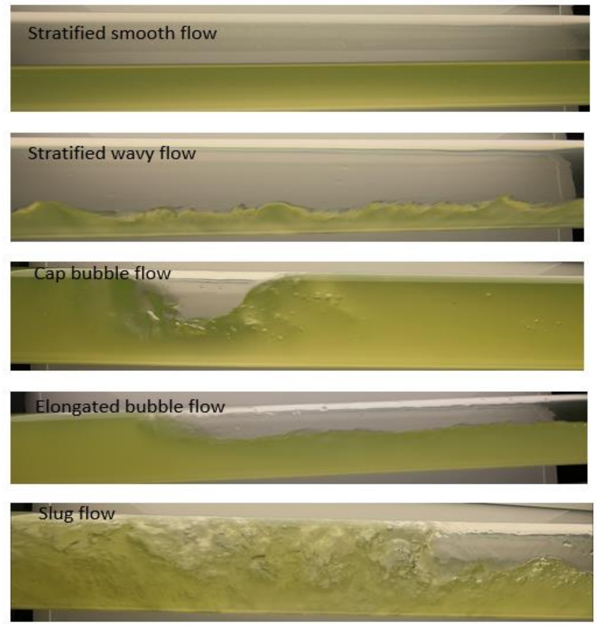

Fig 2: Observed flow patterns definition with pictures

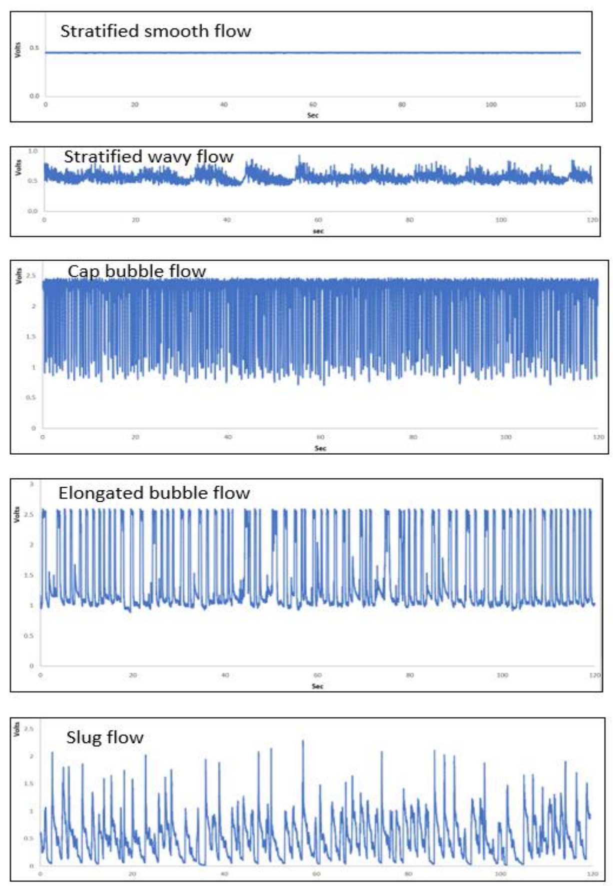

Fig 3: Flow patters definition with conductance probes signals

3 Results and Discussion

The flow patterns behaviour is highly affected by inclination. Observations are summarized in the Figure 4-9 and Table 1. Slug flow dominates all inclinations except for horizontal flow. Its implication in oil and gas industry is on loading of wells and flowlines. Annular flow is preferred during production of petroleum fluids. When production pressure decreases gas flow decreases causing beginning of slug flow which results to loading problems. Therefore, another source of energy is required to keep the flow at annular flow conditions.

3.1 Stratified smooth and stratified wavy flow

Smooth interface between liquid and gas was observed only at horizontal flow (0^o) and at low liquid and gas flow rates as shown in Figure 7. This is similar to other researchers' findings who documented that stratified smooth flow is only found at horizontal and small inclinations of less than 0.25 degrees [4, 6]. Stratified wavy flow was resulted at an increase of gas flow rates while maintaining low liquid flow rates at horizontal flow. At inclined pipe (5^o to 25^o), stratified wavy flow occurred at a transition from slug flow to annular flow.

3.2 Dispersed Bubble flow

For a range of the fluid flow rate tested, the dispersed bubble or bubble flow was observed more at 70^o and 90^o inclinations. It was observed when the gas was flowing with low gas rates and liquid was flowing continuously upwards at low flow rate. Single points with bubble flow were observed at maximum liquid flowrate (2 m/s) and inclination of 15^o, 30^o and 60^o. These points are close to dispersed bubble transition [1].

3.3 Cap bubble, Elongated bubble and Slug flow

These are types of flow which dominate in many inclinations. Cap bubbles are seen at very low superficial gas velocity and high superficial liquid velocity for horizontal and small inclinations. As inclination increases, cap bubble was seen at lower superficial liquid velocity (see Figure 4). When gas velocity increases, elongated bubble appears. It appears either at low gas flow rates and low liquid flow rates or at high gas flow rates and high liquid flow rates at inclination less than 60^o as shown in Figure 5. In horizontal flow they were observed only at high liquid flow rate. Liquid back flow is not a case during both cap and elongated bubble flow.

Slug flow was observed in all inclination angles above 0.4 m/s gas flow rates and at all liquid flow rate except for horizontal flow which happens at high gas and liquid flow rate (Figure 6). Formation of slug flow at inclined pipe is highly affected by flow back of liquid layer present at the bottom of gas layer after the passage of liquid slug.

3.5 Annular, annular wavy flow and churn flow

Most of the data tested was limited to annular flow ranges except for 15^o only. Annular wavy is quite similar to stratified wavy except that the upper part of pipe is somehow wetted than at stratified wavy flow. It was observed between slug and annular flow for 30^o to 60^o inclinations as shown in Figure 8. For 90^o inclinations annular wavy flow is replaced by churn flow region (Figure 9).

Table 1: Results Summary

Regime	Inclination (degrees)	Gas rate (m/s)	Liquid rate (m/s)
Stratified smooth	0	0.1 to 0.3	≤ 0.1
Stratified wavy	0 to 25	≥1.5	≤ 0.1
Bubble flow	70 to 90	≤ 0.5	All
Cap bubble	0 to 90	≤ 2	≥0.05
Elongated Bubble	0 to 60	All	All
Slug	0 to 90	≥0.4	All
Churn	70 to 90	2 to7	≤ 0.1
Annular wavy	15 to 60	3 to 11	All
Annular	15	≥11	≤ 1

4 Conclusion

This study described the effect of pipeline inclination on flow patterns in two-phase flow. Flow regime classification was done using high speed camera together with high speed conductance probes. It was observed that, pipe inclination has a considerable effect on the flow regime mapping. Stratified smooth flow was observed only in horizontal pipe. Slug flow dominates in

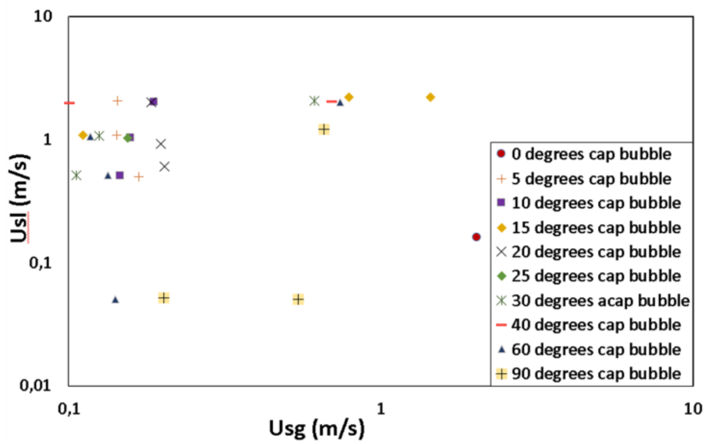

Fig 4: Cap bubble flow

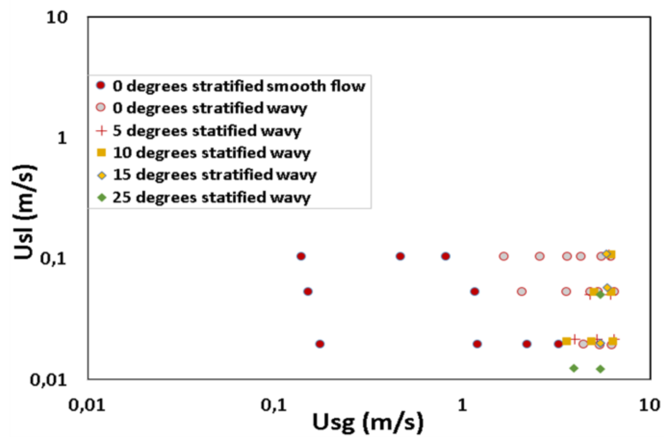

Fig 7: Stratified smooth and stratified wavy flow

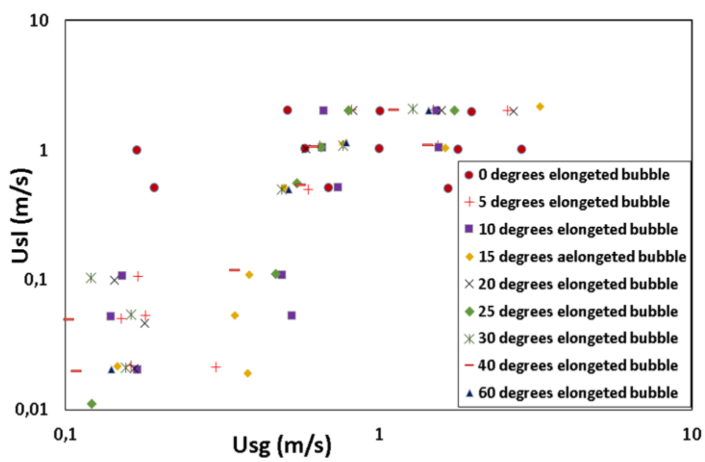

Fig 5: Elongeted bubble flow

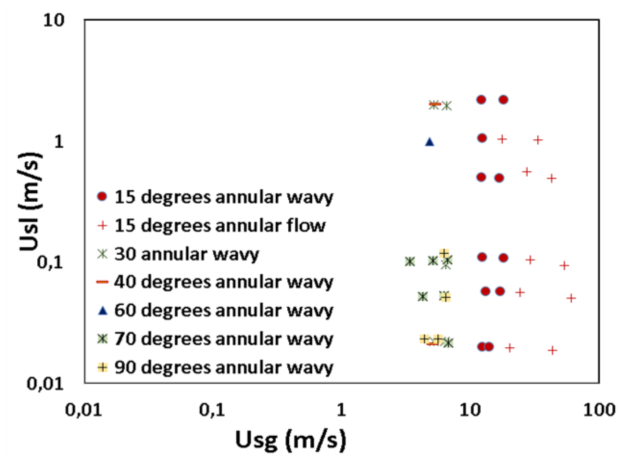

Fig 8: Annular and annular wavy flow

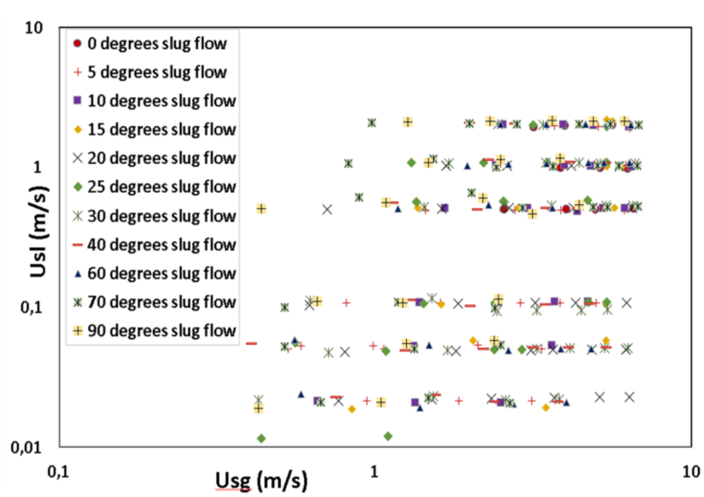

Fig 6: Slug flow

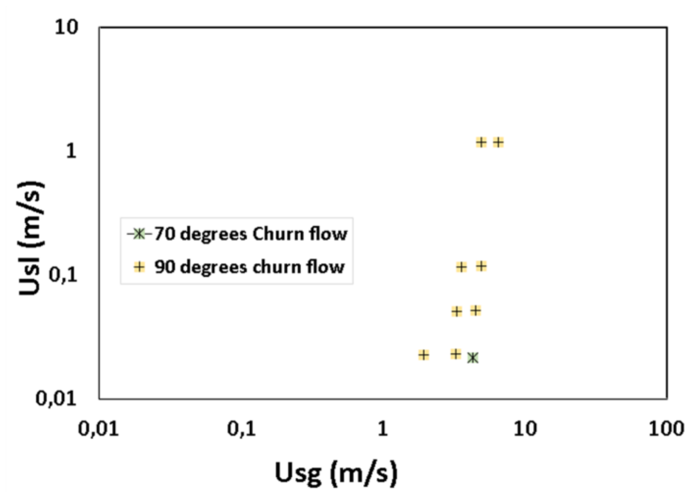

Fig 9: Churn flow

all inclinations. Liquid flow back has major contribution to slug flow initiation. A stratified wavy was observed at low inclinations and annular wavy at higher inclinations. Churn flow was observed most at 90°. As the angle of inclination increases the initiation of intermittent flow (slug and churn flow) appear at decreased gas flow rates. This causes earlier application of backup energy during production of petroleum fluids. When comparing this study to other experimental works, there is highly results resemblance with minor differences which can be caused by patterns definitions and experiment conditions.

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