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The effect of inclination on slug characteristics in three phase, oil/water/gas flow in large diameter pipes

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ABSTRACT

Multiphase experiments have been carried out in a 10-cm ID, 36 m long multiphase pipeline to examine the effect of inclination on slug characteristics such as slug frequency, slug velocity, liquid film velocity, height of the liquid film, and Froude number. Studies were performed for superficial liquid velocities of 0.5 and 1.0 *mls* and superficial gas velocities between 2 and 6 *mls* in horizontal, +2 degree and +5 degree pipes. Mixtures of oil and ASTM Substitute Seawater were used in the liquid phase and carbon dioxide was used in the gas phase. Oil with a viscosity of 2.5 cP was used for the study. The water cut was maintained at 40%. The system was maintained at a pressure of 0.13 MPa and

Subscripts

sL	superficial liquid
m	mixture of gas and liquid
t	translational
LF	liquid film
eff	effective

Greek Letters

v	slug frequency, sec"
e	inclination of the pipeline, degrees

1. INTRODUCTION

The simultaneous flow of oil/water/gas mixtures in the pipeline is encounted frequently in the petroleum industry since water and carbon dioxide gas are injected into the well to enhance the oil recovery as the well gets depleted. Many oil fields are located in remote places such as subsea and Alaska. It is not practical to have a separation facility at the well site in this area. Therefore, the multiphase mixture is combined from several wells and transported in a single pipeline to a central gathering station. Numerous changes in pipeline inclination are always encountered since the distance from the well to central gathering stations is often many miles. These changes in inclinations affect the flow pattern and flow characteristics.

Slug flow is the dominant flow. regime found in oil and condensate flowlines and the existence of slug flow can cause serious problems to the pipeline. Corrosion rate and pressure drop are very high in the slug flow regime since the front of the slug creates a highly turbulent mixing zone. Sun and Jepson (1992) showed that slug flow has regions with high shearing forces and flow turbulence that destroy the liquid boundary layer close to the wall. These regions can remove corrosion products and protective corrosion inhibitor films from the pipe wall. It has been noted by Kang et al. (1998, 1999) that the corrosion rate and pressure drop in the slug flow regime can

The study of flow regime transitions ...

diameter pipeline has been carried out by Jepson and Taylor (1993). It was shown that the transitions from stratified to slug flow and from slug to annular flow differ substantially compared to the results from small diameter ...

Table 1. Test Matrix

Oil	2.5 cP at 25°C
Input Water Cut	40%
Pressure	0.13 MPa
Temperature	25 VC
Inclination	0, +2 and +5 Degrees
Superficial Liquid Velocity	0.5 and 1.0 mls
Superficial Gas Velocity	2, 4 and 6 mls

3. RESULTS AND DISCUSSIONS

3.1 Height of the Liquid Film

Figures 2 and 3 show the effect of inclination on the height of the liquid film at superficial liquid velocities of 0.5 and 1.0 mls respectively. It was observed from both Figures that the height of the liquid film decreased wi,th the increase in superficial gas velocity and increased with the increase in superficial liquid velocity at ali inclinations. For example, for horizontal pipes at a superficial liquid velocity of 0.5 *mis*, the height of the liquid film decreased from 4.2 cm to 3.7 cm with the increase in superficial gas velocity from 2 to 6 *mls.* At a superficial gas velocity of 4 *mis*, the height of the liquid film increased from 4.0 cm to 4.3 cm with the increase in superficial liquid velocity from 0.5 to 1.0 *mls.*

It can be seen from both Figures that the height of the liquid film increased with the increase in- inclination at the same superficial liquid and gas velocities. At superficial liquid and gas velocities of 0.5 and 4 *mis*, the height of the liquid film increased from 4.0 cm to 4.2 cm and from 4.0 cm to 4.4 cm with the inclination from 0 to +2 degrees and from 0 to +5 degrees respectively. At a superficial liquid velocity of 1.0 *mis*, the height of the liquid film increased from 4.5 cm to 4.9 cm with the increase in inclination from 0'10 +5 degrees.

3.2 Liquid Film Velocity

At superficial liquid velocities of 0.5 and 1.0 *mis*, the effect of inclination on liquid film velocity is shown in Figures 4 and 5 respectively. It can be seen from both Figures that the liquid film velocity increased with the increase in both superficial liquid and gas velocities. At a superficial gas velocity of 4 mls and 2 degrees inclination, the liquid film velocity increased from 0.77 to 1.43 mls with the increase in superficial liquid velocity from 0.5to 1.0 *mls.*

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It is seen that the liquid film velocity decreased with the increase in inclination in all cases since gravity forces decelerate the liquid film. At superficial liquid and gas velocities of 0.5 and 2 *mis*, the liquid film velocity decreased from 0.66 to 0.53 mls and then from 0.53 to 0.21 mls with the increase in inclination from 0 to 2 degrees and 2 to 5 degrees respectively. At 5 degree inclination a fluid fall back effect was observed. The liquid film rolls back due to the influence of gravity. It was observed that at higher superficial gas velocity, the effect of inclination on the liquid film velocity was reduced. This is because TcTwt0.5MwPC2wPc2cWTcTwth°ecause

3.3 Slug Translational Velocity and Froude Number

Figure 6 presents the effect of inclination on slug translational velocity at a superficial liquid velocity of 0.5 m/s. It can be seen that the slug translational velocity increased with the increase in superficial gas velocity. It is also seen that the slug translational velocity did not change significantly with inclination.

The Froude number determines the turbulent intensity of the slug. The Froude number generally increases with the increase in gas velocity at the same liquid velocity and slightly decreases with the increase in liquid velocity at the constant gas velocity. The Froude number increased from 4.6 to 13.7 with the increase in superficial gas velocity from 2 to 6 m/s in horizontal flow as shown in Figure 7. Figure 7 shows the effect of inclination on the Froude

4. CONCLUSIONS

Experiments have been carried out to examine the effect of inclination on slug characteristics such as slug translational velocity, the height of the liquid film, slug frequency, and Froude number.

The height of the liquid film increased with the increase in inclination at the same superficial liquid and gas velocities.

The liquid film velocity decreased with the increase in inclination in all cases since gravitational forces decelerate the liquid film.

The slug translational velocity did not change significantly with inclinations of up to +5 degrees.

The Froude number had the almost same value with inclination since the liquid film velocity decreased and the height of the liquid film increased with the increase in inclination.

The slug frequency increased with the increase in inclination for given superficial liquid and gas velocities. The reason is that as inclination increases, the height of the liquid film increases, which leads to allowing more waves bridging the pipe for the same superficial liquid and gas velocities.

The correlation for slug frequency between -15 to + 15 degrees inclination has been developed based on experimental data. This correlation has a good agreement with experimental data for low viscosity oil and for gas flow rates of up to 6 *mls.*

5. ACKNOWLEDGEMENT

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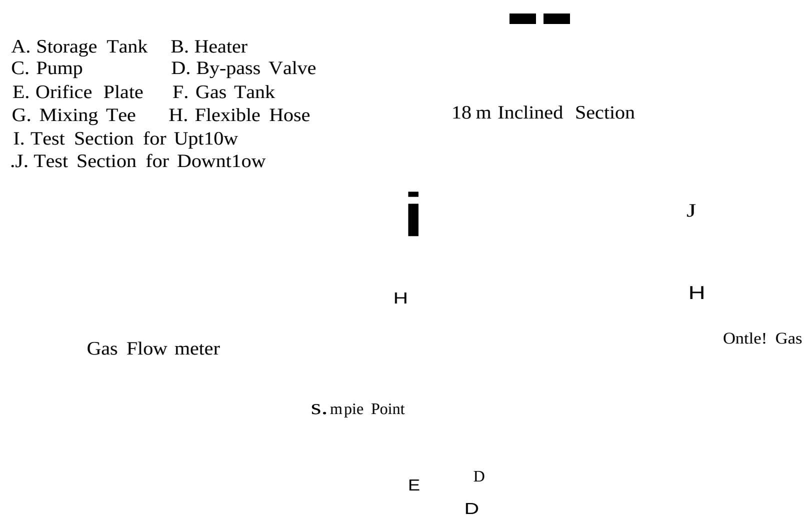
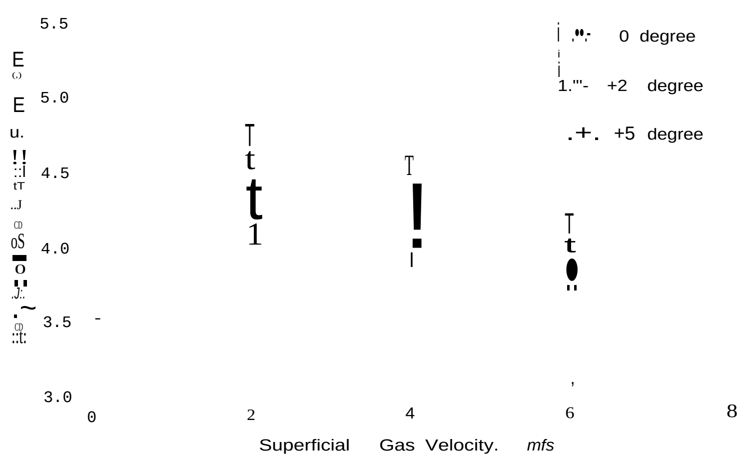
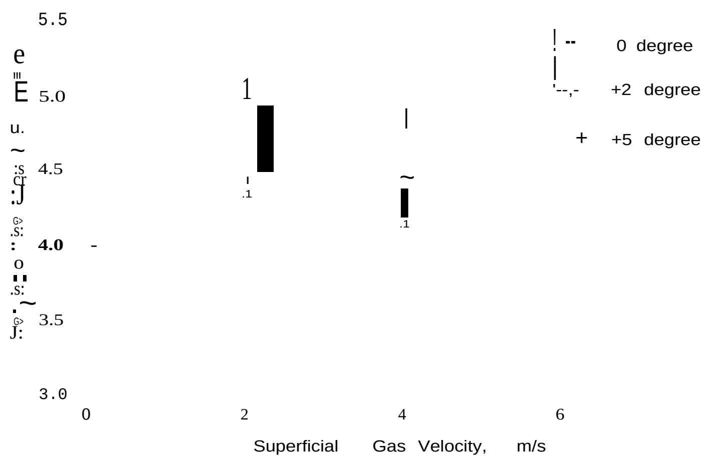


Figure 1. Experimental Layout of Flow Loop



Figur e 2. Effect of Inclination on H eight of the Uquid Film
V sl


5.5
5.0
4.5
4.0
3.5
3.0
0
2
4
6
8
Superficial Gas Velocity, m/s
0 degree
+2 degree
+5 degree

Figure
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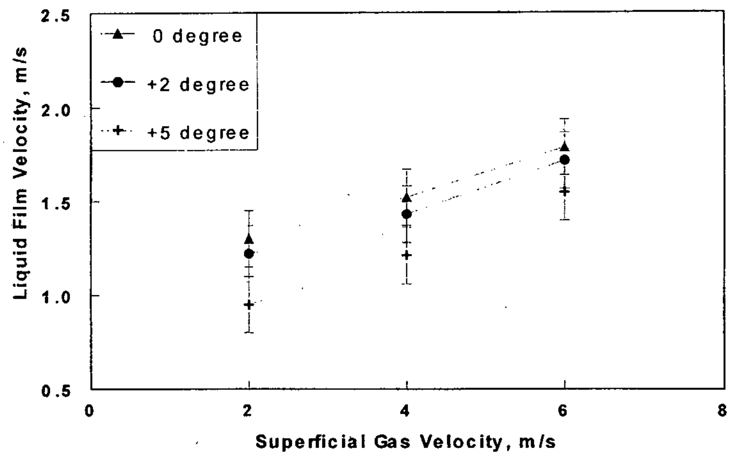


Figure 5. Effect of Inclination on Liquid Film Velocity
Vsl = 1.0 m/s, 40% Salt Water Cut, P = 0.13 MPa

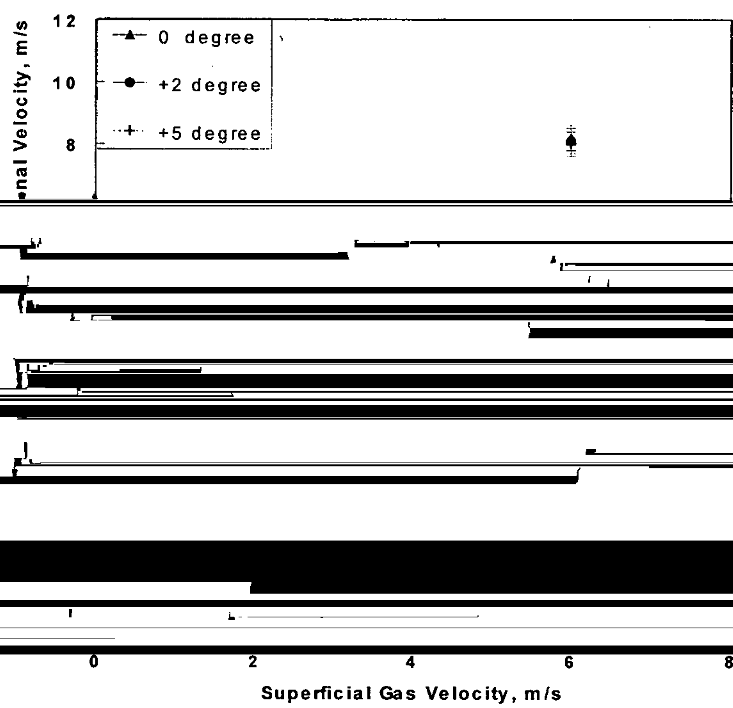


Figure 6. Effect of Inclination on Slug Translational Velocity
Vsl = 0.5 m/s, 40% Salt Water Cut, P = 0.13 MPa

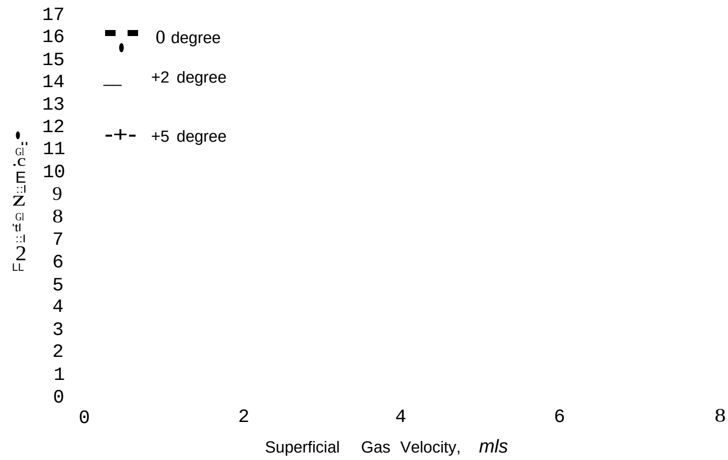
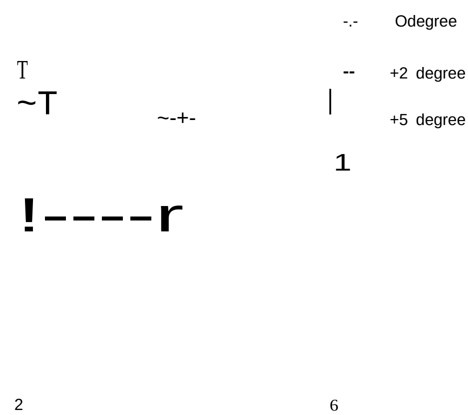


Figure 7. Effect of Inclination on Froude number
Vsl = 0.5 mls, 40% Salt Water Cut, P = 0.13 MPa



+2 degree

+5 degree

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