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MODELING FLOW REGIME TRANSITIONS IN LARGE DIAMETER INCLINED PIPELINES

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ABSTRACT

Multiphase oil/water/gas flow regime transition studies are carried out in a 10-cm I.D., 18-m long Plexiglas pipe at inclinations of $\pm 2^0$ at system pressures up to 0.79 MPa.

The results are compared to those of other researchers, and the effects of pressure, inclination and liquid viscosity are shown.

The water cut of the liquid has some effects on the transitions from stratified to slug flow. Increasing the water cut results in the transition occurring at higher liquid velocity at the same gas velocity. Water cut has little effect on the slug/annular transition for the low viscosity oil used.

The system pressure has a small effect on the transition from stratified to slug and slug to annular. For the transition from stratified to slug, increasing the system pressure, requires higher liquid velocity. The transition from slug to annular occurs at lower liquid velocity with increasing system pressures. The inclination of the pipe has an effect on the transition from slug to annular flow. Increasing the inclination causes the transition to occur at lower gas velocity at the same liquid velocity.

NOMENCLATURE

T	Temperature, °C
P	System Pressure, MPa
V_{SG}	Superficial Gas Velocity, m/s
V_{SL}	Superficial liquid velocity, m/s

INTRODUCTION

Multiphase flow pattern prediction has many design applications. One of the most important is the oil and natural gas pipeline. Knowledge of the flow pattern is very important to understand the underlying fluid mechanics in multiphase flow. Given an exact set of conditions with fully developed flow and no terrian-induced flow effects, a particular flow pattern will occur. Many researchers have attempted to produce a way to report all of the necessary information to correlate the flow transitions.

To create a successful flow regime transition model, data is necessary for validation. The key parameters to observe are fluid properties, inclination, pipe diameter and system pressure. In the literature, there are many flow regime data for horizontal and vertical flows, but limited flow map data exist for inclined pipelines, especially for flow in large diameter pipes. This work reports more flow regime data, which includes the effects of inclination, pressure, and diameter and liquid viscosity on oil/water/gas three-phase flow in large diameter pipelines.

EXPERIMENTAL SETUP

Figure 1 shows the experimental setup of the flow loop. The entire system is made of 316 stainless steel and is designed to withstand a maximum pressure of 12 MPa. The volume of the tank is 1.44 m^3 and is filled with oil-water mixtures of specified water cuts. The fluid is pumped through a 7.62-cm ID stainless steel pipe and is metered using turbine flow meters; Carbon dioxide gas from high-pressure storage tanks is introduced into the system and the gas velocity is measured using in-line flow meters. The multiphase mixture then flows through a 10-cm I.D stainless steel test section when all the measurements are made. The gas-liquid mixture reenters the tank at the top through the 10cm pipeline. A de-entrainment plate is used to separate the gas and liquid. The gas is vented to the atmosphere and the liquid is recycled. When the system is inclined, measurements in both upward and downward flows can be made at the same time. A back pressure regulator is fitted on the top of the tank and is connected to the exhaust to control and maintain the required system pressure.

The flow patterns were determined with a technique using differential pressure fluctuations, the measurements were made with 0~35 KPa OMEGA PX-750 heavy-duty differential pressure transducers.

In this study, carbon dioxide was used for gas phase. Oil with a viscosity of 26 cp at 40°C and water were used for the liquid phases. The superficial gas velocity was varied from 0 ~ 17 m/s, while the superficial liquid velocity ranged from 0 ~ 2.5 m/s; The system temperature remained constant at 25 °C, and the system pressure varied up to 0.79 MPa.

FLOW PATTERN TRANSITION MODELING

Wilkens (1997) [2] developed a mechanistic model for predicting the transition from stratified to slug flow in three-phase large diameter pipelines. The model includes the effect of inclination and pressure. The basis for the stratified to slug transition model is the coexistence of stratified flow and slug flow. This approach stems from the ideas expressed by Jepson (1989) [7].

Wilkens [2] also developed ideas for predicting the transition from slug to annular flow. Previous researchers have demonstrated the presence of secondary flows, wave spreading, droplet deposition, etc. in describing annular flow. The basis for this slug to annular transition model is the coexistence of annular and slug flows. The model also incorporated other criteria such as a maximum film Froude number, maximum slug body void fraction, and the liquid hold up in the slug becoming equal to the liquid area in the film region. In addition these, a criteria was developed based on the minimization of pressure drop.

Lee (1993) [5] noted that in both annular flow and slug flow, the oil and water are completely mixed. For this reason, the equation for two-phase flow can be used here as well. Lin (1985) [3] suggested that annular flow can be reached when the film was spread completely around the pipe. In this case, the gas-liquid interface is quite rough and liquid has spread completely around the pipe, although the thickness may be only 1 to 2 mm at the top. For this model, the annular film is considered to spread just enough that it meets at the top of the pipe.

RESULTS AND DISCUSSION

Downward Flow

Figure2, 3 and 4 are flow regime maps for water cuts of 100%, 50% and 0%, in -2^0 downflow at 0.13Mpa, respectively. It is noted that the transitions are similar at each water cut. The results are similar to the Mantripragada (1998). Comparing the flow regime maps, it is seen that water cut has an effect on the stratified to slug transition. Figure 5 is a plot of the stratified-slug transition at different water cuts. It shows seen that as the water cut is increased, the transition occurs at higher superficial liquid velocities at the same superficial gas velocity. This is due to the decrease in liquid viscosity and these results are similar to those of Hanratty (1987) [7].

Figure 6 illustrates the transitions from slug to annular flow at different water cuts at 0.13 MPa, at an inclination of -2^0. It is seen that there is little effect of water cut in the slug-annular transition. The results are similar to those observed by Maley (1997) [4].

Upward Flow

Figures 7,8,9 are flow regime maps for water cut 100%, 50%, 0%, +2^0 upflow at 0.13 MPa. Slug flow is the main flow pattern, and no stratified flow occurs at the conditions tested. The results are similar to those of other researchers. At low liquid and gas superficial velocities, plug flow occurs. Upon increasing the gas velocity, the slug flow regime is reached. At even higher gas flow rates, pseudo-slug flow will occur. Annular flow occurs when the less dense fluid flows as an annular ring around the pipe wall.

Figure 10 shows the transition from slug to annular at different water cuts at the conditions of system pressure 0.13MPa, an inclination of +2^0. Water cuts have little effect on the transition.

Effect of System Pressure

Now consider the effect of system pressure on the transition from stratified to slug flow. Figure 11 shows the transition for different system pressures, at a water cut of 100%, at an inclination of -2^0. Increasing the system pressure causes the transition to occur at higher liquid superficial velocity at the same superficial gas velocity. This is because at a higher pressure, the gas wall friction factor is increased. This caused more momentum to be lost to the wall and a higher liquid velocity is sustained. This results in increasing the liquid velocity for the transition to occur.

Figure 12 shows that the transition from slug to annular flow at the conditions of different system pressures, water cut 100%, at an inclination of -2^0. Increasing the system pressure causes the transition to occur at a lower liquid velocity at the same superficial gas velocity. This is due to increased gas-liquid shear due to higher gas density. So, the system pressure has some effects on the transitions from stratified to slug and slug to annular flow.

Effect Of Inclination

Figure 13 illustrates the transition from slug to annular flow for upward and downward flows at 2^0 inclinations, for a water cut of 100%, pressure 0.13 MPa. Increasing the inclination of the pipe results in the transition occurring at lower gas velocity at the same liquid superficial velocity. This is because the effect of gravity becomes more uniform across the cross-section of the pipe with increasing inclinations and thus moderate effect on the transition from slug to annular flow.

Comparison with Models

Figure 14 illustrates the stratified to slug flow transition for a water cut of 100% at 0.13 MPa, at an inclination of -2^0. The experimental results are compared with the models developed by Taitel & Dukler (1976) [1] and Wilkens (1997) [2]. At low gas flow rates (less than 3 m/s), both models predict the transition reasonably well. Above a superficial gas velocity of 3 m/s, the Taitel & Dukler [1] model significantly underpredicts the transition line. For example, the transition to slug flow is predicted at a superficial liquid velocity as low as 0.25 m/s at a superficial gas velocity of 7 m/s. Slug flow would clearly not occur at a lower liquid flow rate than it did in horizontal flow. The Wilkens [2] model however adequately predicts the transition line in all cases.

Figure 15 shows the comparison for 50% water cut, 0.13 MPa, -2^0 inclination. The experiments compare with the results predicted by both models at low gas rates. Above a gas flow rate 3 m/s; the experiments deviate from the results predicted by the Taitel [1] model. For example, stratified-slug transition is predicted at a superficial liquid velocity as low as 0.23 m/s at a superficial velocity of 7 m/s. The Wilkens [2] model however predicts the transition adequately.

Figure 16 compares the experiments of the transition from slug to annular flow with the results predicted by both models for 100% water cut at 0.13 MPa and inclination of -2^0. The Taitel & Dukler [1] model poorly predicts this transition. This is a well known limitation of the Taitel & Dukler [1]model. The Wilkens [2] model compares with the experimental results very well. Figure 17 illustrates the comparison between the experiments and the results predicted by both the models for the transition from slug to annular at 50 % water cut, 0.13 MPa. They show that the experiments compare with the results predicted by the Wilkens [2] model well and deviate from that predicted by Taitel model [1].

CONCLUSION

Stratified flow was eliminated in upward flow while slug flow was found to dominate. In downward flow stratified flow was dominant while the area of slug flow was reduced.

The water cut of the liquid has some effects on the transitions from stratified to slug. For the transition from stratified to slug, increasing the water cut, causes the transition to occur at higher liquid velocity at the same gas velocity. However, water cut has little effect on the slug-annular transition for this oil/water mixture.

The system pressure has a moderate effect on the transition from stratified to slug and slug to annular. For the transition from stratified to slug, increasing the system pressure, causes the transition to occur at higher liquid velocity. The transition from slug to annular flow, occurs at lower gas velocity. The inclination of pipe has strong effect on the transition from slug to annular flow. Increasing the inclination, causes the transition to occur at lower gas velocity at the same liquid velocity.

The Wilkens models compare with the experimental results very well. The Taitel & Dukler [1] model predicts the transition from stratified to slug well at low gas and liquid velocities, but not well for higher gas and liquid velocities, and it poorly predicts the transition of slug to annular flow.

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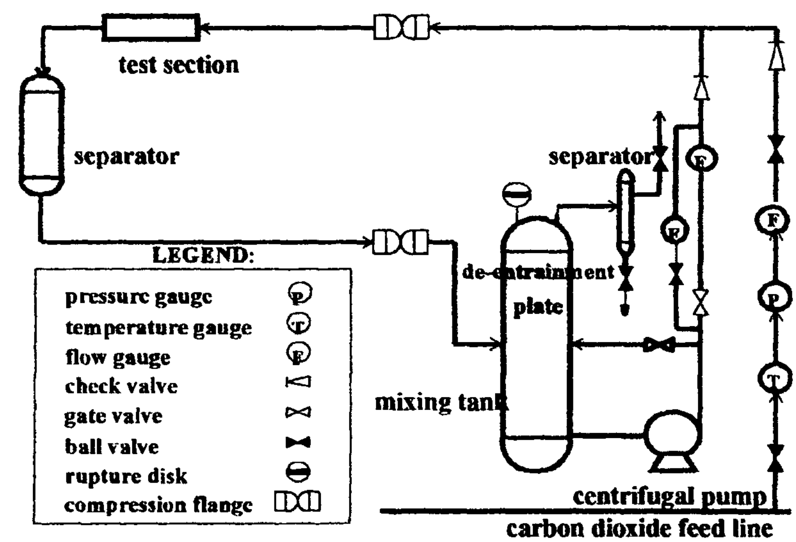

Figure 1: High-pressure, inclinable flow system process flowsheet.

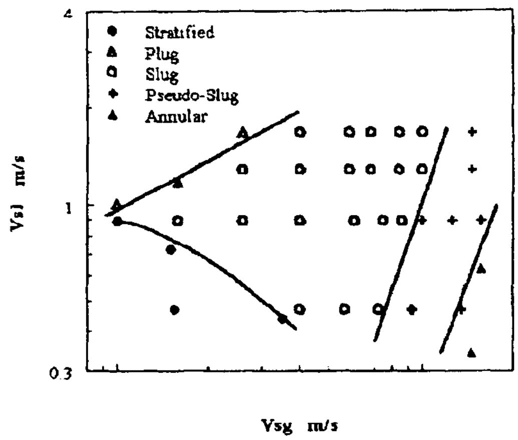

Figure 2 Flow regime at 100% water cut, -2 degree, 0.13MPa

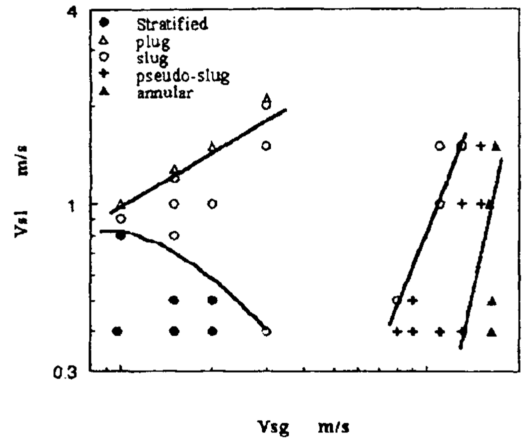

Figure 3 Flow regime at 50% water cut, -2 degree, 0.13MPa

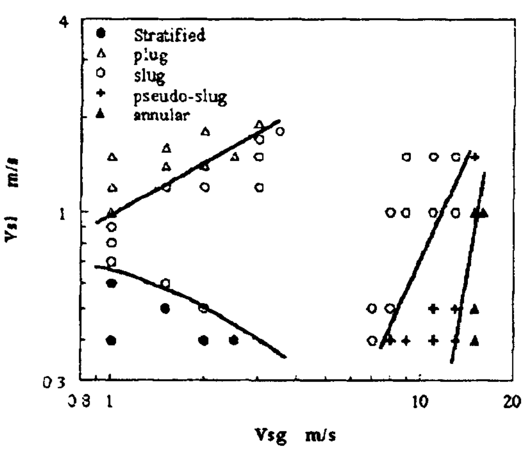

Figure 4 Flow regime at 0% water cut, -2 degree, 0.13MPa

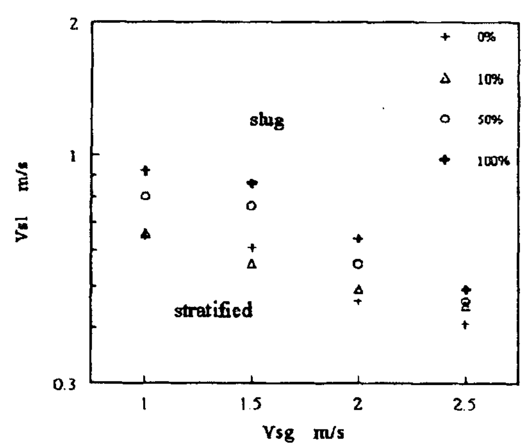

Figure 5 Transition from stratified to slug at different water cuts, -2 degree, 0.13MPa

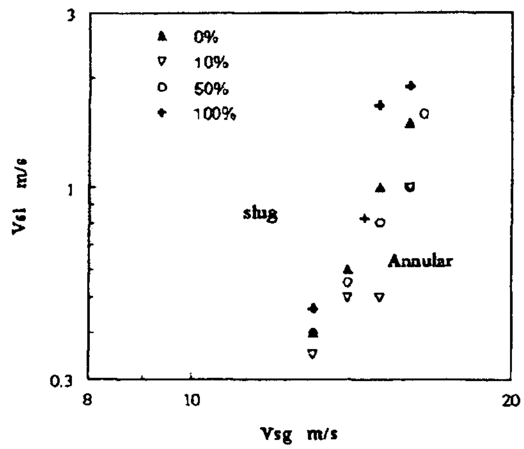

Figure 6 Transition from slug to annular at different water cuts, -2 degree, 0.13MPa

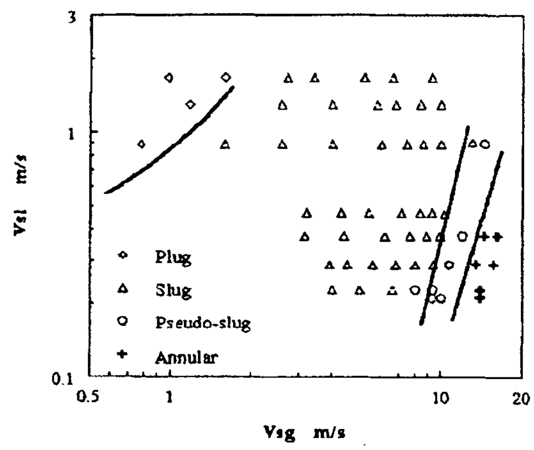

Figure 7 Flow regime at 100% water cut +2 degree, 0.13MPa

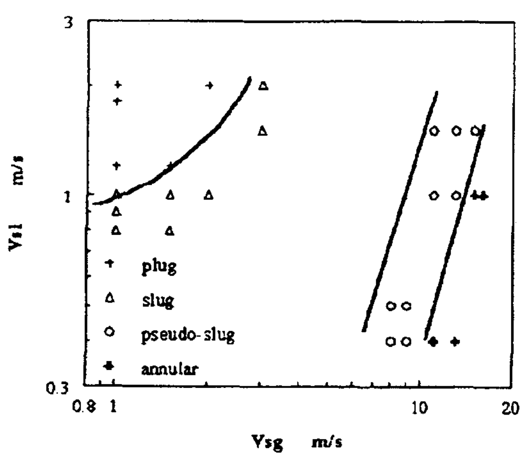

Figure 8 Flow regime at 50% water cut +2 degree, 0.13MPa

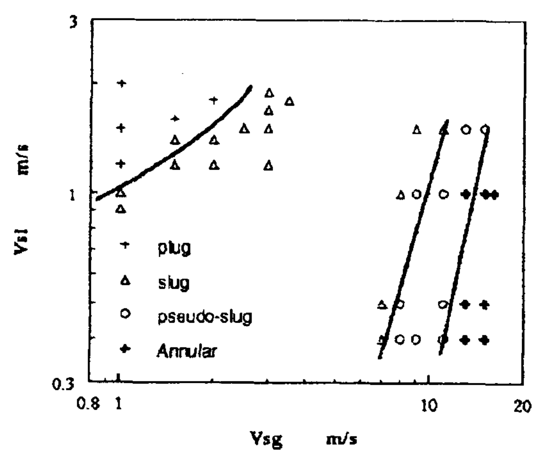

Figure 9 Flow regime at 0% water cut +2 degree, 0.13 MPa

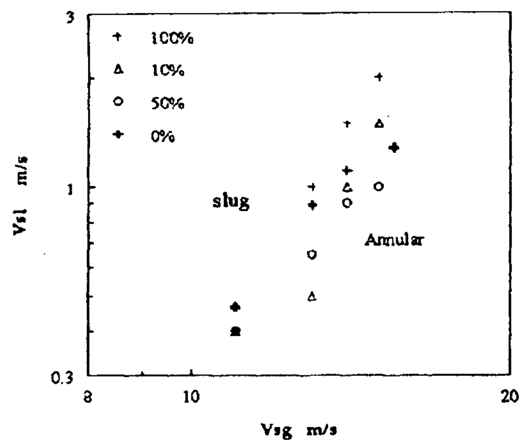

Figure 10 Transition from slug to annular at different water cuts,+2 degree,0.13MPa

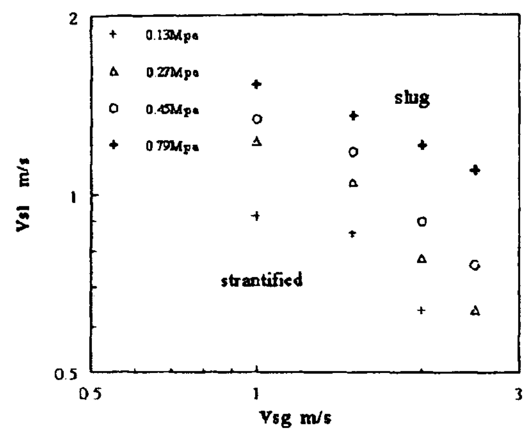

Figure 11 Transition from stratified to slug at different ppressure, -2 degree, 100% water cut

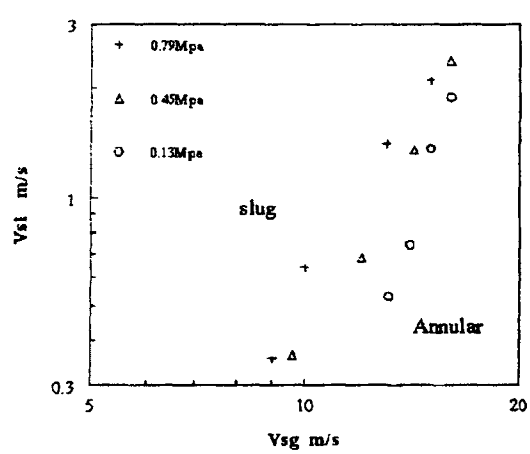

Figure 12 Transition from slug to annular flow at different pressure, -2 degree, 100% water cut

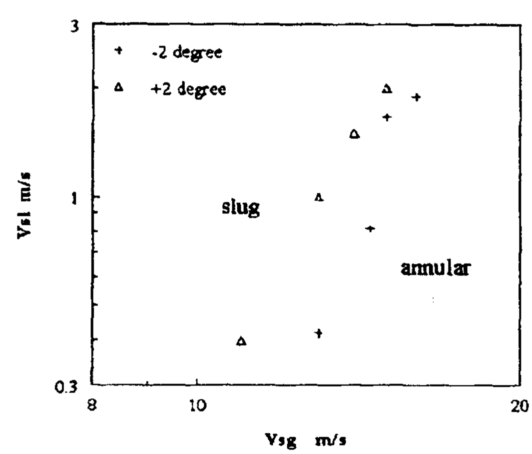

Figure 13 Transition from slug to annular at different inclinations, 100% water cut, 0.13MPa

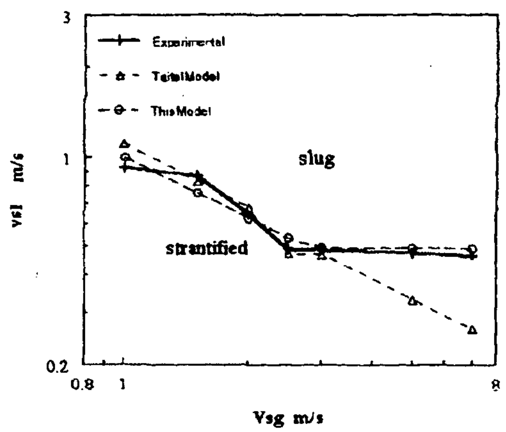

Figure 14 Comparison of experimental results with the predicted models for transition from stratified to slug at 100% water cut, -2 degree, 0.13MPa

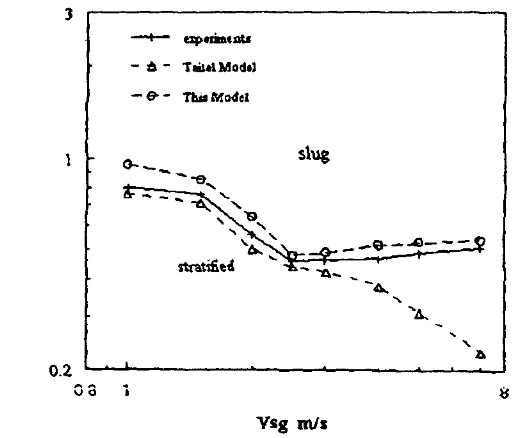

Figure 15 Comparison of experimental results with the predicted models for transition from stratified to slug at 50% water cut, -2 degree, 0.13MPa

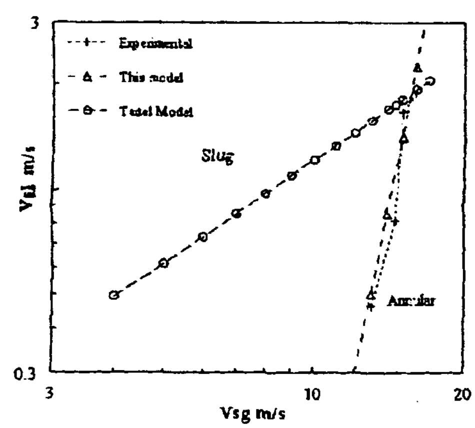

Figure 16 Comparison of experimental results with the predicted models for transition from slug to annular at 100 % water cut, 0.13 Mpa, -2 degree

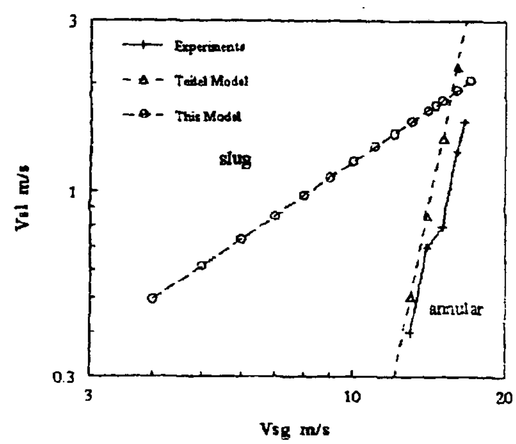

Figure 17 Comparison of experimental results with the predicted models for transition from slug to annular at 50 % water cut, 0.13 Mpa, -2 degree