

The effect of surfactants on flow characteristics in oil/water flows in large diameter horizontal pipelines

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ABSTRACT

Experiments studying oil/water flows have been conducted in a 10 cm diameter, 40 m long, horizontal pipeline. Oil with a viscosity 3 cP at 25° and ASTM standard seawater were used for the liquid phases at superficial liquid velocities ranging from 0.4 to 3.0 m/s for each phase. The temperature and pressure are maintained at 25° and 0.136 MPa. Flow regimes, hold-up, velocity distribution, and pressure drop were determined at input water cuts of 20, 40, 60, and 80%. The changes in flow characteristics have also been studied by adding surfactant which reduced the interfacial tension from 33 to almost zero dyne/cm.

For superficial mixture velocities lower than 1.2 m/s, only small amounts of water are encountered above a height to diameter ratio of 0.8, i.e. near the top of the pipe and water alone existed at the bottom of the pipe. For the mixture velocity range of 1.6 ~ 2.2 m/s, the degree of mixing was seen to increase considerably. For mixture velocities above 2.6 m/s, the *in situ* water percentage was almost same as the input value indicating that the oil and water mixture is well mixed and virtually homogeneous in nature.

The addition of surfactant enhances the degree of mixing of oil water flow and homogenous flow can be obtained at 2.2 m/s and 2.0 m/s for 5 ppm and 10 ppm surfactant concentrations respectively at each water cut.

The velocity profile is a function of input water cut and mixture velocity and surfactant concentration. Without surfactant and mixture velocities below 1.6 m/s, at low water cuts, the water layer moves at velocities lower than the mixture velocity. At 40% and above, the water layers move faster.

The pressure gradient increases, with increase in input water cut until it reaches a maximum at about 40% water cut. It then decreases with increase in water cut. The addition of the surfactant does not have much effect at the 5 ppm concentration but at 10 ppm significant increases occur especially at the high mixture velocities.

1. INTRODUCTION

With the more and more sea water has been produced by maturing oil wells, oil-water flow is drawing much more attention in the petroleum industry. Most research on oil-water flows has focused on the pressure gradient. Ariachakaran et al. (1989) developed pressure gradient models for stratified and homogeneous flows. Sarica et al. (1997) studied the oil-water flows in vertical and deviated wells. The pressure drop and holdup were found to be strongly affected by oil-water flow patterns, water cut, and inclination angle.

However, corrosion is a serious problem in multiphase pipelines and the corrosion mechanisms are dependent on the phase in contact with the pipe wall. The presence of water layers at the pipe wall can cause extensive levels of corrosion. It is therefore extremely important to be able to predict oil-water flow patterns and the presence of free water.

Flow patterns change with increases in the input concentrations and the superficial velocities of the two phases. Figure 1 shows the oil-water flow patterns observed by Oglesby (1979). The segregated flow regime is defined as the flow of the liquids in two distinct layers, with no mixing at the interface. As the mixture velocity is increased, some mixing occurs at the interface giving rise to semi-segregated flow. The flow is said to be semi-mixed when there is a segregated flow of a dispersion and a 'free' phase and the dispersion volume is less than half the total pipe volume. Malhotra (1995) observed a semi-mixed flow pattern in his studies on oil-water flows in 10 cm diameter pipelines. Mixed flow occurs when the oil-water dispersion occupies more than half the pipe volume. When some steep gradients of fluid concentrations in the mixture are incurred, the flow pattern is termed as semi-dispersed. The homogeneous flow is that flow regime becomes fully dispersed when the mixture flows as a homogeneous phase, with no appreciable changes in concentration in the pipeline.

Brauner and Maron (1992) formed a basis for constructing a general two-fluid flow pattern. Mechanistic models were proposed for the transitional boundaries between flow patterns in liquid-liquid flow. A parametric study was made for a wide range of geometry and physical as encountered in liquid-liquid systems.

In oil-water flows, increasing the concentration of the "dispersed" phase beyond a certain critical point, causes it to become the "continuous" phase and the other phase, which no longer coats the walls of the pipeline, is seen to become the "dispersed" phase. This phenomenon is called phase inversion. Guzhov (1976), Oglesby (1976) and Ariachakaran (1983) observed the phase inversion in their studies on oil-water flows in horizontal pipelines. The phase inversion phenomenon is also important for the onset of corrosion and the subsequent use of corrosion inhibitor chemicals. Inhibitors are usually oil or water soluble and need that phase to be continuous phase for the inhibitor to work effectively.

Prediction of corrosion rates in oil-water full pipe flow requires knowledge of the in situ holdup and velocity of the water layer. Studies on hold up in horizontal and inclined pipelines have been done by Vigneaux et al. (1988), Malhotra (1995), Sarica et al. (1997) and Vedapuri (1997). Vigneaux et al. studied the effect of inclination, mixture velocity, and input water cut on the oil and water volume fraction gradients along the diameter in 10 cm and 20 cm diameter pipelines. Vedapuri proposed a mechanistic model to predict the hold up and pressure drop in semi-stratified and semi-mixed flows.

Addition of surfactants to the corrosion inhibitor formulations can increase the dispersibility of the inhibitor and help increase its effectiveness. It is also possible that the surfactant will change the surface and interfacial tensions of the fluids and enhance the oil-water mixing and maybe the formation of emulsions.

This work examines the effect of addition of surfactant on the flow characteristics.

2. EXPERIMENT SETUP AND PROCEDURE

The experimental layout of the flow loop is shown in Figure 2. The oil-water mixture with specified composition is placed in a 1.2 m³ stainless storage tank (A). The tank is equipped with two 3kW heaters (B). The oil-water mixture is pumped into a 7.5 cm ID PVDF pipeline using a 5hp centrifugal pump (C). The flow rate is controlled using a by-pass system (D), which also serves to agitate the oil-water mixture in the tank. An orifice plate is used to measure flow rate. A T-junction fitted with a ball valve is present at the exit of the pump. Liquid samples are withdrawn at regular intervals from this junction, before the start of the experiments and while the experiment is in progress, to ensure the flowing water percentage maintained.

The oil-water mixture then passes through a 10.16 cm ID, 2 m long flexible hose and enters the 36m long and 10.16 cm I.D Plexi-glass section and is then returned to the tank. The system pressure can be maintained using carbon dioxide from compressed cylinders

A 2 m long Plexi-glass test section is installed in the pipeline and is shown in Figure 3. A sampling tube is used to withdraw isokinetic liquid samples from different locations along the vertical diameter. From the liquid sample, the local volumes of oil and water then are measured and the local holdup calculated.

The *in situ* velocity profile across the vertical diameter is determined using a Pitot tube. The pressure drop between the static and dynamic heads was measured using a manometer. Velocity profiles were calculated based on the *in situ* water percentage.

The pressure gradient is measured using a manometer. Red oil soluble dye is added to the oil to help the observation and a VHS video camera was also used to make visual observations of the flow.

The test matrix is described in Table 1.

Table 1 Experimental Test Matrix

• Inclination	0°
• Liquid phase	Oil (3 cP at 25 C), Standard ASTM salt water
• Surfactant Concentration	0ppm, 5ppm, 10ppm
• Temperature	25 C
• Liquid Velocities	0.4 – 3.0 m/s
• Water Cut	0%, 20%, 40%, 60%, 80%, 100%

At higher input water cuts of 40% and 60%, there appears to be more mixing at the oil/water interface. For example, at an input water cut of 60%, there is an oil layer above an h/d of 0.8 and a water layer below 0.3. In between, the oil/water composition changes almost linearly with vertical position. The mixed oil/water layer is present here.

As the surfactant concentration is increased to 5ppm, Figure 5 gives the corresponding results. Similar results are observed for 20% water cut. However, for input water cut of 40, 60 and 80%, it is noted that more water is present at the top of the pipe. For example, at an h/d of 0.9, the amount of water present is 10, 15, and 27% for input water cuts of 40, 60, and 80% respectively. Similarly, near the bottom of the pipe, some oil has been entrained especially for the 40 and 60% water cuts. For the 40% water cut, 11% oil is present at the bottom of the pipe. The variation of the oil/water composition in the middle sections of the pipe increases with the addition of surfactant. This indicates more mixing is taking place here.

Figure 6 shows the effect of increasing the surfactant concentration to 10 ppm. Again there seems little change for the 20% input water cut. However, the water distribution curve changes drastically for remaining three input water cuts. There is a small amount of oil reaching the bottom of the pipe for an input water cut of 20%. For the other three input cuts oil and water are relatively well mixed along across the pipe diameter. The most conspicuous change happens to 80% water cut. Here, about 40% water reaches the top of the pipe and 5% oil goes toward the bottom of the pipe.

For the 1.4 m/s, Figure 7, 8 and 9 show the similar trends. It is seen that, in each case, the thickness of the mixed oil/water layer increases with increase in the mixture velocity. More water is present at the top of the pipe and some oil is finding its way to the bottom. It can also be seen that the variation of the composition of the oil-water mixture has changed. For the 40 and 60% water cuts, the variation in the composition does not change much with vertical position. For example, at 80% water cut, as the height is changed from 0.2 to 0.8, the composition of the mixed layer changes from 12 to 6% water. This gives the appearance of a well mixed, almost homogeneous, oil/water layer between these heights.

When surfactant is added at a mixture velocity of 1.4 m/s, Figure 9 indicates that the surfactant does have a greater effect than that for the velocity of 1 m/s. The profiles for the 40, 60, and 80% water cuts show a trend to become almost uniform across the pipe.

This is more readily seen at a higher mixture velocity of 1.8 m/s. Figure 10 shows the water distribution for 40% input cut at three different surfactant concentration. It clearly displays that the water distribution curves are tending to be uniform with increase in the surfactant concentration.

It is observed that for the mixture velocity range of 1.6 m/s and 2.2 m/s, the degree of mixing increased considerably. The oil-water mixture is seen to be homogeneous at the mixture velocity of 2.6 m/s and 3.0 m/s for each water cut without surfactant in system. With 5 ppm surfactant, the velocity for oil/water flow to be homogeneous is about 2.2 m/s, and it is 2.0 m/s for 10 ppm surfactant concentration.

thicker and more and more well mixed with increase in surfactant concentration. This especially noticed at the mixture velocities of 1.6 and 2 m/s.

3.4 PRESSURE GRADIENT

The variation of pressure gradient at input water cut of 20, 40 60 80% for three different surfactant concentration are shown in Figure 17, 18 and 19. The experimental error is about 5%.

From these three figures, it is seen that for velocity of 1.0 m/s, there are no large changes in the pressure gradient with an increase in the input water cut.

In Figure 17, at a superficial mixture velocity of 1.4 m/s, as the input concentration of water is increased to 20%, the pressure gradient increase from 136 N/m^3 to 210 N/m^3 . There is a dramatic increase in the pressure gradient between the input water concentrations of 20% and 40%. The pressure gradient reaches 317 N/m^3 at 40% then drops down to 260 N/m^3 at 60%. It then decreases to 220 N/m^3 when the water cut is increased to 80%. Further increase in the water percentage to 100% results in a pressure gradient of 157 N/m^3 which is in agreement with the calculated value of 164 N/m^3 for water alone.

When 5 ppm surfactant is added Figure 18 indicates that there is little effect on the pressure gradient. There are small differences at the higher mixture velocities of 1.8 and 2 m/s. However, when 10 ppm surfactant was added, Figure 19 shows the pressure gradient is affected. For example, at a mixture velocity of 2.2 m/s at an input water cut of 40%, the pressure gradient increases from 580 to 630 and then to 700 N/m^3 when 5 and 10 ppm of surfactant are added. This is illustrated in Figure 20.

Lafin and Oglesby (1976) showed a similar variation in the pressure gradients for oil water dispersions. The pressure gradient peaked at around 38% water cut. During the experiment, a relatively well mixed flow was observed for 40% compared to the other input water cuts at the same velocity. This leads to a much higher value of the apparent viscosity for 40% than for other water cuts, then results in a higher pressure gradient.

4. CONCLUSIONS

- The flow regimes namely segregated, semi-segregated, mixed, semi-dispersed and homogeneous are observed for the 3 cP oil and water mixtures for mixture velocities in the range of 0.4 to 3.0 m/s without surfactant. Homogeneous flow was noted above 2.6 m/s.
- Addition of surfactant enhances the degree of mixing of oil water flow. The homogeneous flow can be obtained at 2.2 m/s and 2.0 m/s for 5 ppm and 10 ppm surfactant concentrations respectively at each water cut.

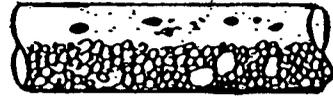
Segregated – no mixing at the interface



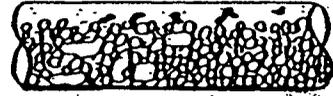
Semi-segregated – some mixing at the interface



Semi – mixed – segregated flow of a dispersion and “free” phase. Bubbly interface, Dispersion volume less than half of the total pipe volume.



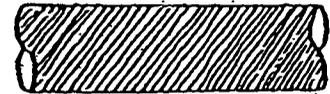
Mixed – same as the above coding but with the dispersion occupying more than half the total pipe volume



Semi – dispersed – some vertical gradient of fluid concentration in the mixture



Fully dispersed homogenous flow



Flow Direction →

Figure 1 Description of Flow Pattern Classification for Oil – Water Flow (Oglesby, 19

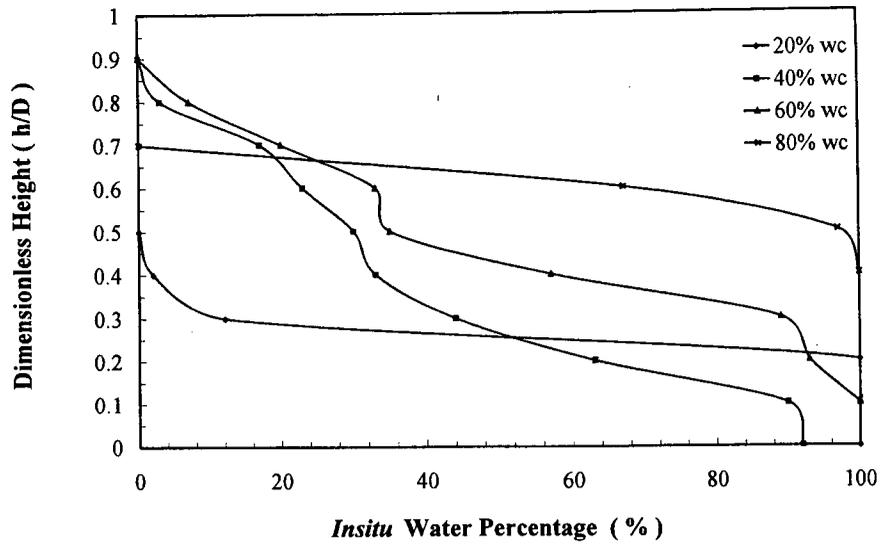


Figure 4 Variation of Water Percentage with Vertical Position
(1.0 m/s)

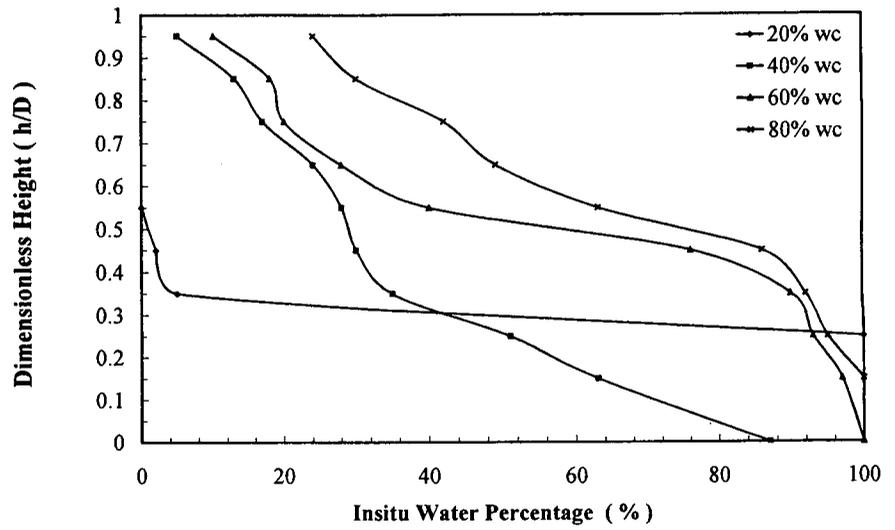


Figure 5 Variation of Water Percentage with Vertical Position
(1.0 m/s, 5 ppm)

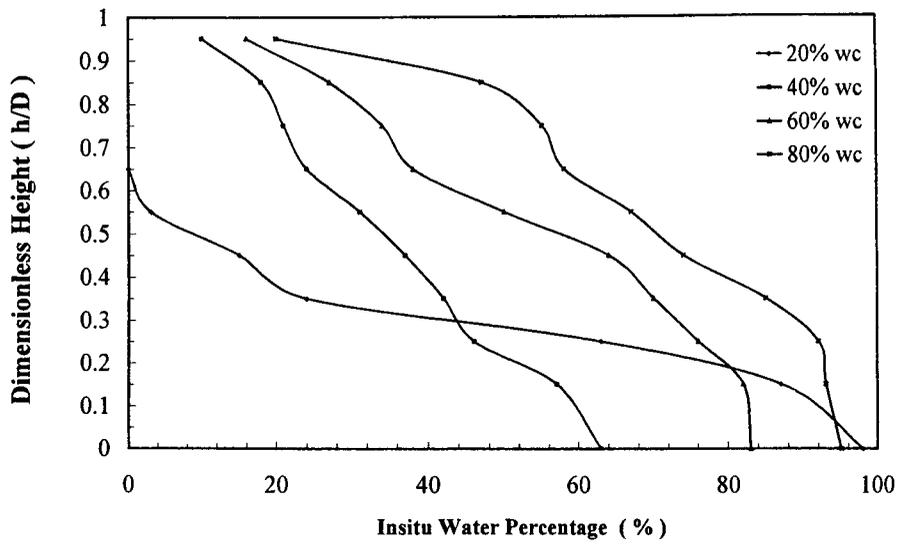


Figure 8 Variation of Water Percentage with Vertical Position
(1.4 m/s, 5 ppm)

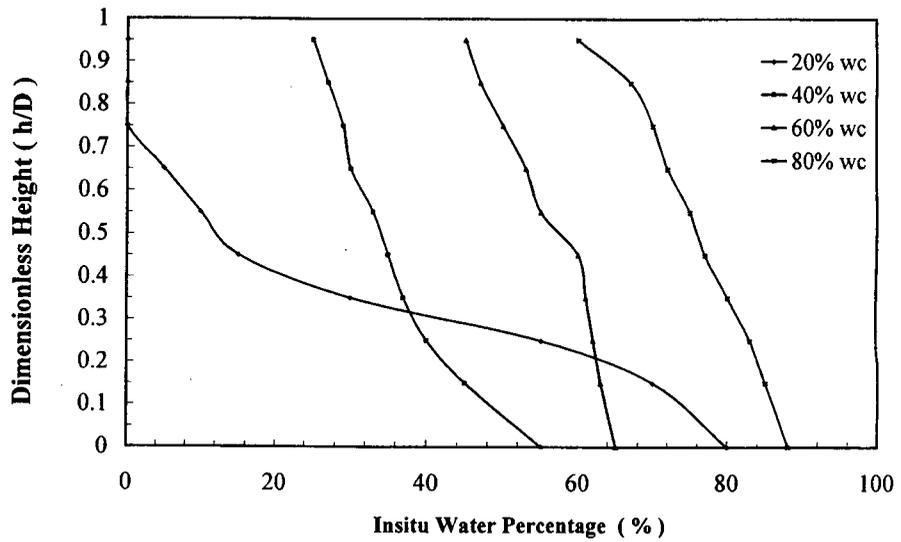


Figure 9 Variation of Water Percentage with Vertical Position
(1.4 m/s, 10 ppm)

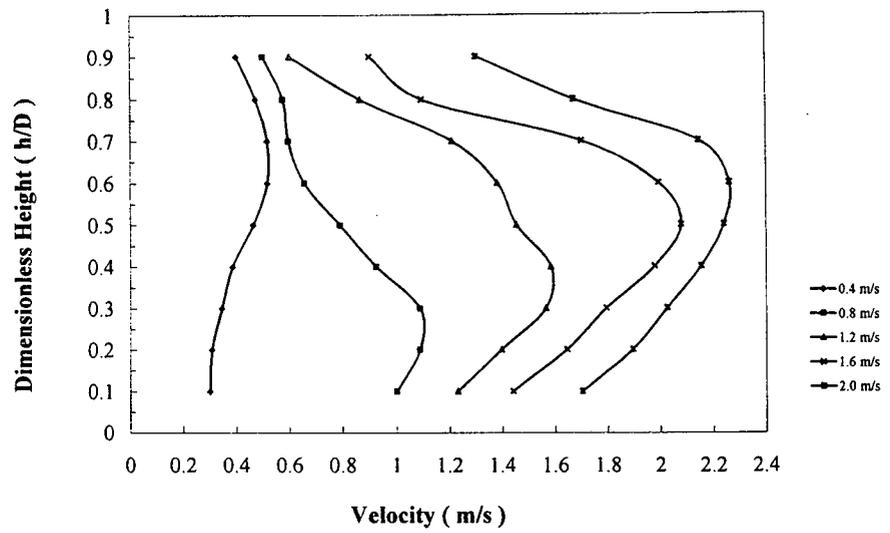


Figure 12 Insitu Velocity Profile for Different Mixture Velocities (40% water cut)

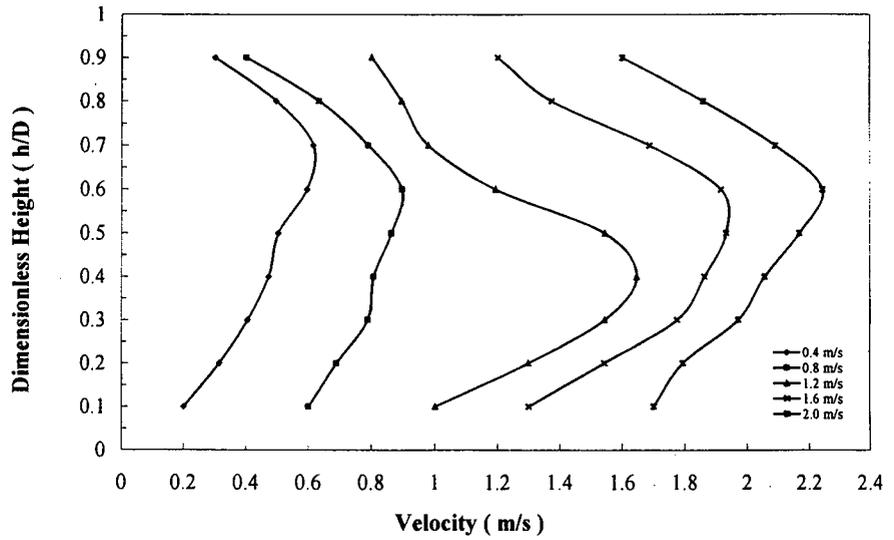


Figure 13 Insitu Velocity Profile for Different Mixture Velocities (60% water cut)

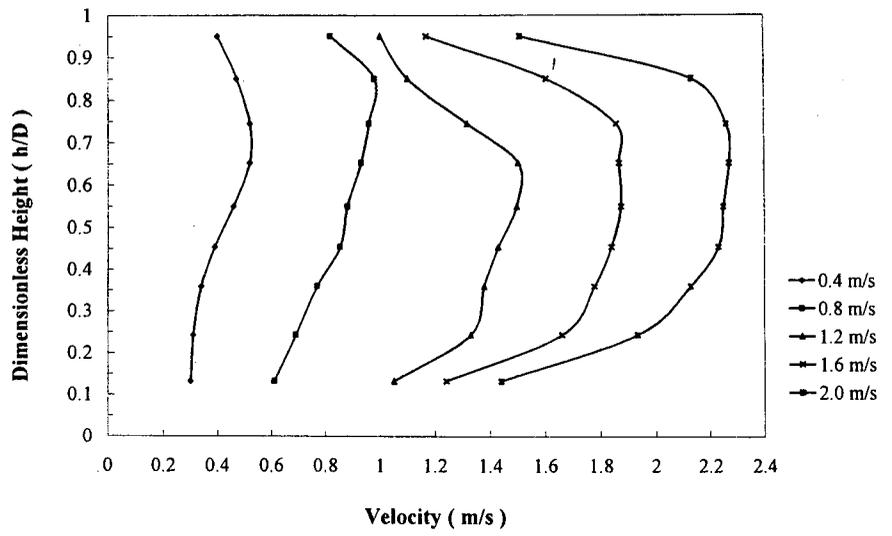


Figure 16 Insitu Velocity Profile for Different Input Mixture Velocities (40% water cut, 10 ppm)

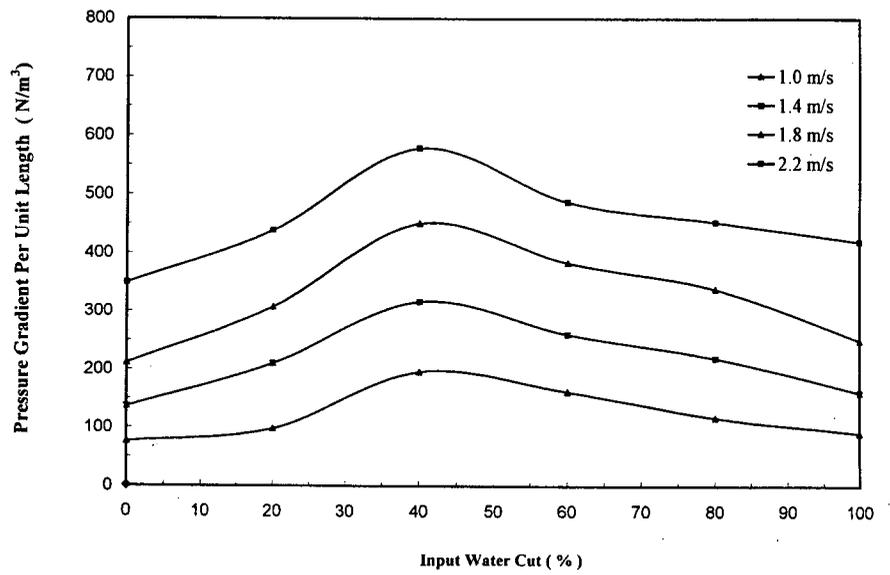


Figure 17 Variation of Pressure Gradient with Input Water Cut (0ppm)

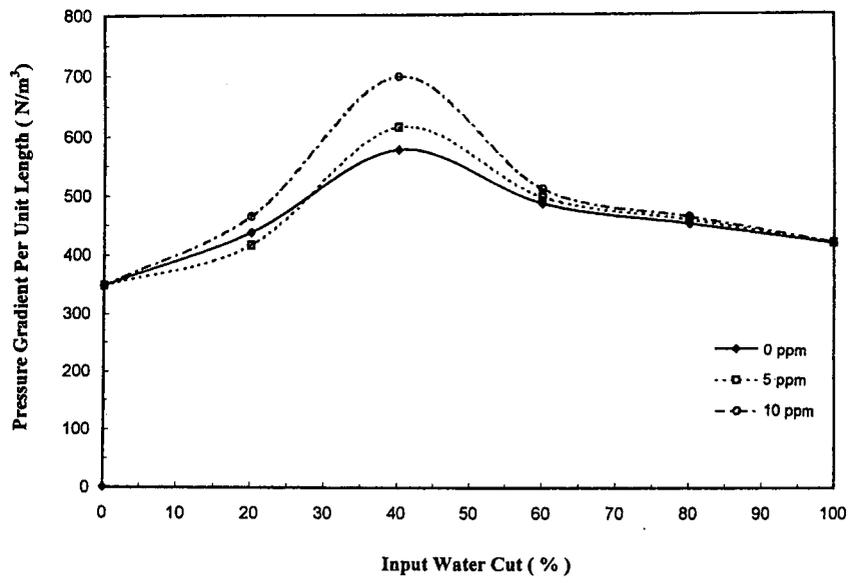


Figure 20 Effect of Surfactant Concentration on Pressure Gradient (2.2m/s)