CHAPTER IV
RESULTS AND DISCUSSION

4.1 Microemulsion Formation

As mentioned before, the objective of this study was to investigate the relationship between the efficiency of froth flotation and the ultra-low interfacial tension (IFT) of wastewater containing cutting oil. Alfoterra 145-5PO (Branch alcohol propoxylated sulfate, sodium salt) and AOT were used as surfactants to form the ultra-low IFT with cutting oil because Alfoterra and AOT have a proper HLB for the cutting oil-water system and is expected to form the middle phase microemulsion. The effect of surfactant concentration, NaCl concentration, and oil to water ratio on the ultra-low IFT of cutting oil were studied.

Pondstabodee *et. al.* (1998) concluded that the highest removal of ortho-dichlorobenzene (ODCB) of froth flotation corresponded to the formation of the Winsor Type III microemulsion. In addition, Chavadej e*t. al.* (2003) discovered that most of the oil removed came from the excess oil phase, not from the middle phase in the Winsor type III microemulsion. Therefore, in this study, it was also hypothesized that the ultra-low IFT, which is one of the unique characteristics of Winsor Type III microemulsion, can enhance the efficiency of froth flotation.

The microemulsion formation of cutting oil with Alfoterra shows only two obvious phases, which are the water and oil phases. The layer of the middle phase is very thin, and it could not be clearly observed visually. Consequently, the measurement of the phase transformation becomes difficult to identify whether the system has a middle phase or not. Hence, the phase diagram of the cutting oil with Alfoterra is shown here. The IFT of the system was measured by the spinning drop tensiometer to examine the existence of the Winsor Type III microemulsions. The diagrams of ultra-low IFT as a function of surfactant concentration, salinity, and oil to water ratio are illustrated here.

4.1.1 Effect of Single Surfactant Concentration on IFT

Figure 4.1 illustrates the effect of single surfactant concentration on the ultra-low IFT when salinity is 3 wt% and an oil to water initial volumetric ratio is 1:1.

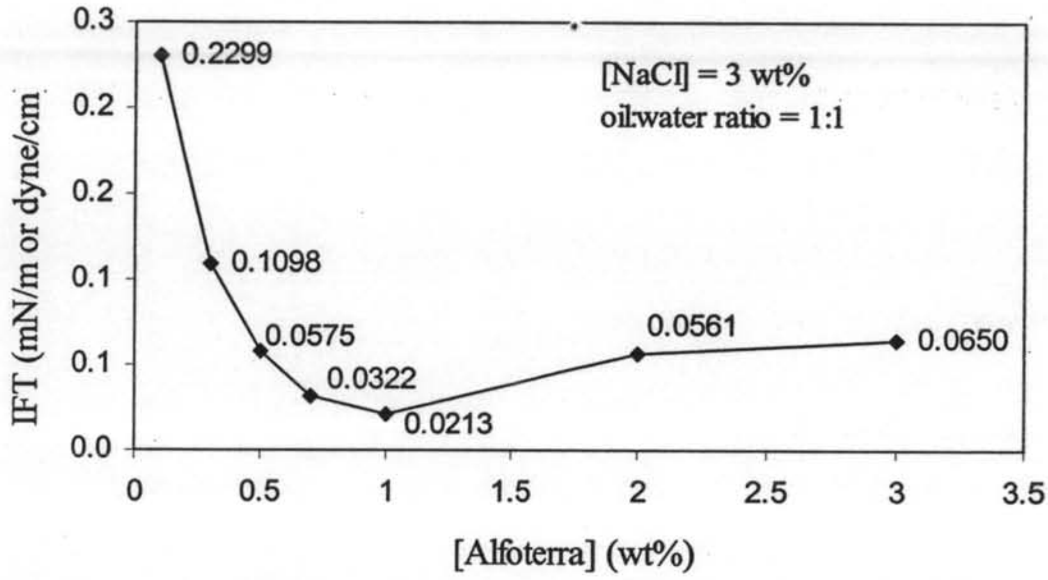

Figure 4.1 IFT as a function of Alfoterra concentration at 3 wt% of NaCl with oil to water ratio = 1:1 (v:v), and 30 °C.

From Figure 4.1, the IFT of the system decreases rapidly when Alfoterra concentration increases from 0.1 to 1 wt%. And then, it increases gradually with the increase in the Alfoterra concentration from 1 to 4 wt%. This is because the repulsive force between the anionic head groups of Alfoterra increases with the increase in the Alfoterra concentration. Therefore, micelle is difficult to form leading to lower oil solubilization, but higher IFT as shown by Equation (4.1), Chun-Huh's equation.

$$\gamma \;\alpha\; SP^{-2} \tag{4.1}$$

where; γ = interfacial tension, SP = solubilization parameter

Figure 4.2 illustrates the effect of single surfactant concentration on the ultra-low IFT when salinity is 3 wt% and an oil to water initial volumetric ratio is 1:1.

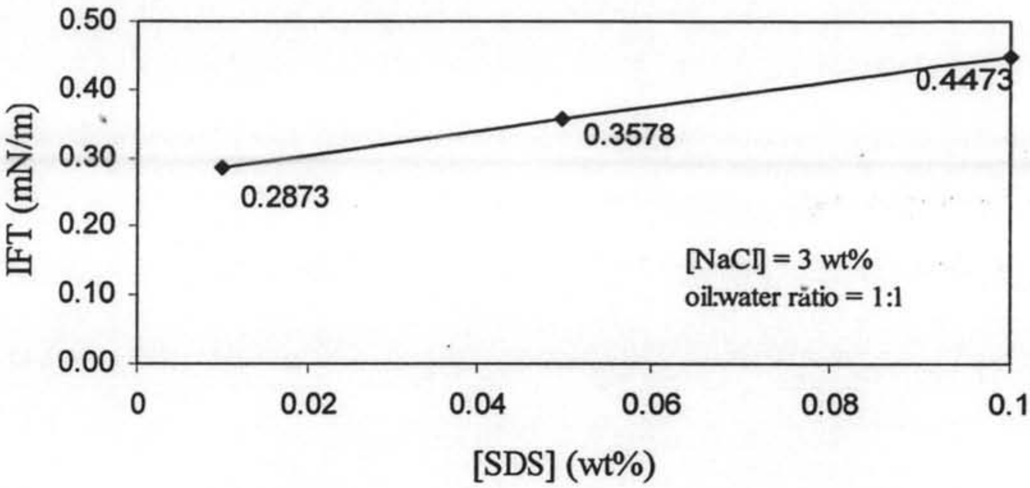

Figure 4.2 IFT as a function of SDS concentration at 3 wt% of NaCl with oil to water ratio = 1:1 (v:v), and 30 °C.

The minimum IFT around 2.87 x 10^{-1} mN/m was found at 0.01 wt% of SDS is not considered to be in the range of the ultra-low IFT (10^{-2}-10^{-3} dyne/cm) but it is provides good foamability and foam stability.

4.1.2 Effect of Mixed Surfactant Concentration on IFT

Figure 4.3 shows the effect of mixed surfactant concentration on the ultra-low IFT when salinity is 3 wt% and an oil to water initial volumetric ratio is 1:1.

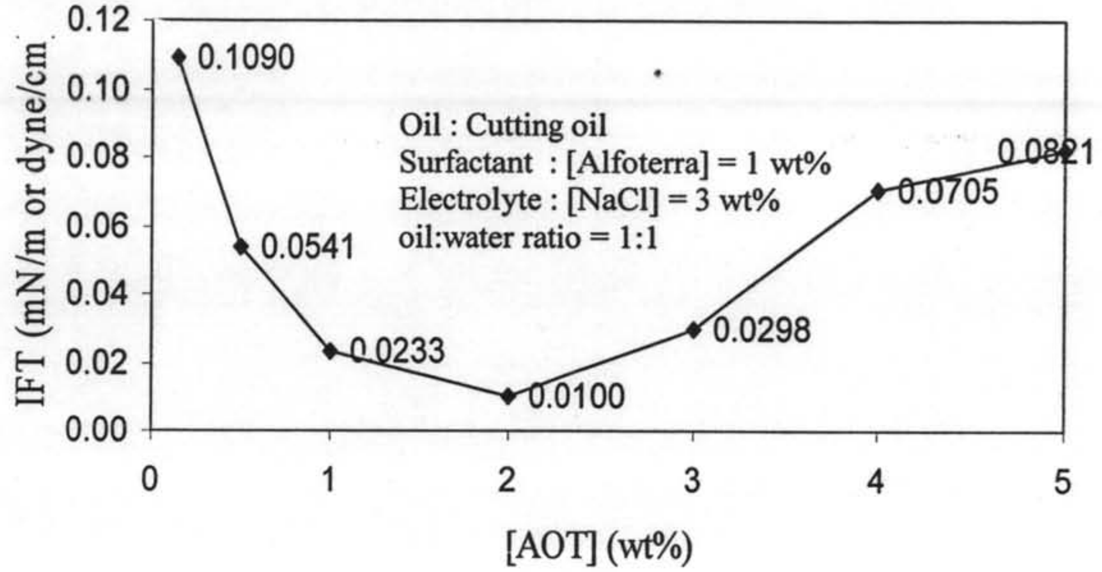

Figure 4.3 IFT as a function of AOT concentration at 1 wt% Alfoterra, 3 wt% NaCl, an oil to water ratio 1:1 (v:v), and 30 °C.

From Figure 4.3, the IFT of the system decreases rapidly when AOT concentration increases from 0.1 to 2 wt%. And then, it increases gradually with the increase in the AOT concentration from 2 to 5 wt%. This is because the repulsive force between the anionic head groups of AOT increases with the increase in the AOT concentration. Therefore, micelle is difficult to form leading to lower oil solubilization

The minimum IFT around 1.000 x 10^{-2} mN/m at 2 wt% of AOT is considered to be in the range of the ultra-low IFT (10^{-2}-10^{-3} dyne/cm) which is typically observed in a system with the middle phase microemulsion formation. Consequently, it can be concluded that the phase behavior study of the cutting oil system by using Alfoterra and AOT as surfactants can form the middle phase or Winsor Type III microemulsion.

Since the microemulsion systems of the cutting oil with mixed surfactants, Alfoterra and AOT, had very poor foam formation, it was not possible to run froth flotation experiments. Consequently, adding SDS as another frother to the solution is desirable because it provides good foamability and foam stability. The composition of Alfoterra and AOT were fixed at 1 wt% and 2 wt%, respectively, because it provides the minimum IFT. The SDS concentration was varied from 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09 and 1 wt% with 3 wt% NaCl and an oil to water initial volumetric ratio equal to 1:1. As shown in Figure 4.4, an increase in the SDS concentration increases the IFT and the minimum IFT appears at 0.04 wt% SDS (0.0024 mN/m). This is because SDS possesses a linear structure a high HLB value which is difficult to form Winsor Type III microemulsion with cutting oil, high hydrophobic oil, leading to high IFT. In contrast, Alfoterra possesses a hydrpphobic branch structure or a low HLB value which forms the Winsor Type III microemulsion easily with the cutting oil.

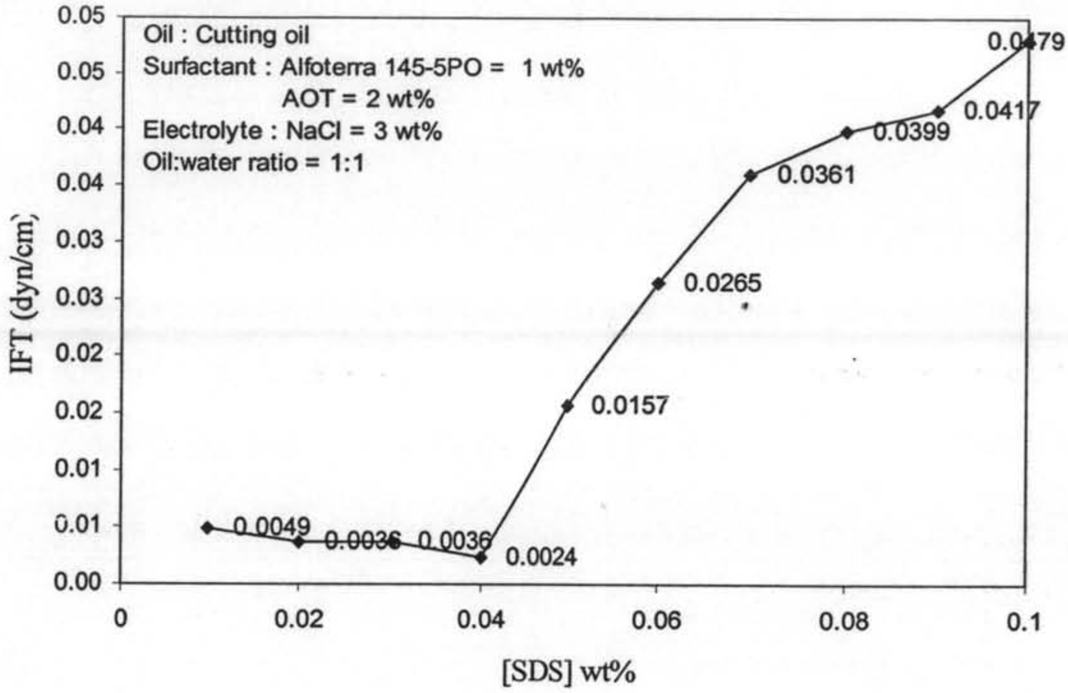

Figure 4.4 IFT as a function of SDS concentration at 1 wt% Alfoterra, 2 wt% AOT, 3 wt% NaCl, an oil to water ratio = 1:1, and 30 °C.

4.1.3 Effect of NaCl Concentration on IFT Mixed Surfactant Systems

The effect of adding salt on the IFT was studied in mixed surfactant (Alfoterra AOT and SDS) systems with salinity scan.

4.1.3.1 IFT with Mixed Surfactant System

The result from the effect of single surfactant concentration on IFT shows that 1 wt% of Alfoterra provides the minimum IFT. In addition, the result from the effect of AOT concentration in the mixed surfactant system on the performance of microemulsion shows that 2 wt% of AOT provides the best performance of the microemulsion. Consequently, the mixed surfactant system of 1 wt% of Alfoterra and 2 wt% of AOT was used for the IFT measurement with salinity scan in the range of 1 to 7 wt% of NaCl.

The IFT of the mixed surfactant system as a function of salinity with an initial oil to water ratio equal to 1:1 is illustrated in Figure 4.5. From the figure, as NaCl concentration increases from 1 to 7 wt%, the IFT of the system

system decreases rapidly when NaCl concentration increases from 1 to 3 wt%. And then, it increases almost linearly with the increase in the NaCl concentration from 3 to 7 wt%. This is because the repulsive force between the anionic head groups of both Alfoterra and AOT decreases when the NaCl concentration increases leading to an increase in the aggregation number as well as increasing solubilization of oil into the inner core of micelles but the decrease in the IFT. In other words, an increase in salinity enhance the phase transformation of a Winsor Type I microemulsion toward a Winsor Type III microemulsion.

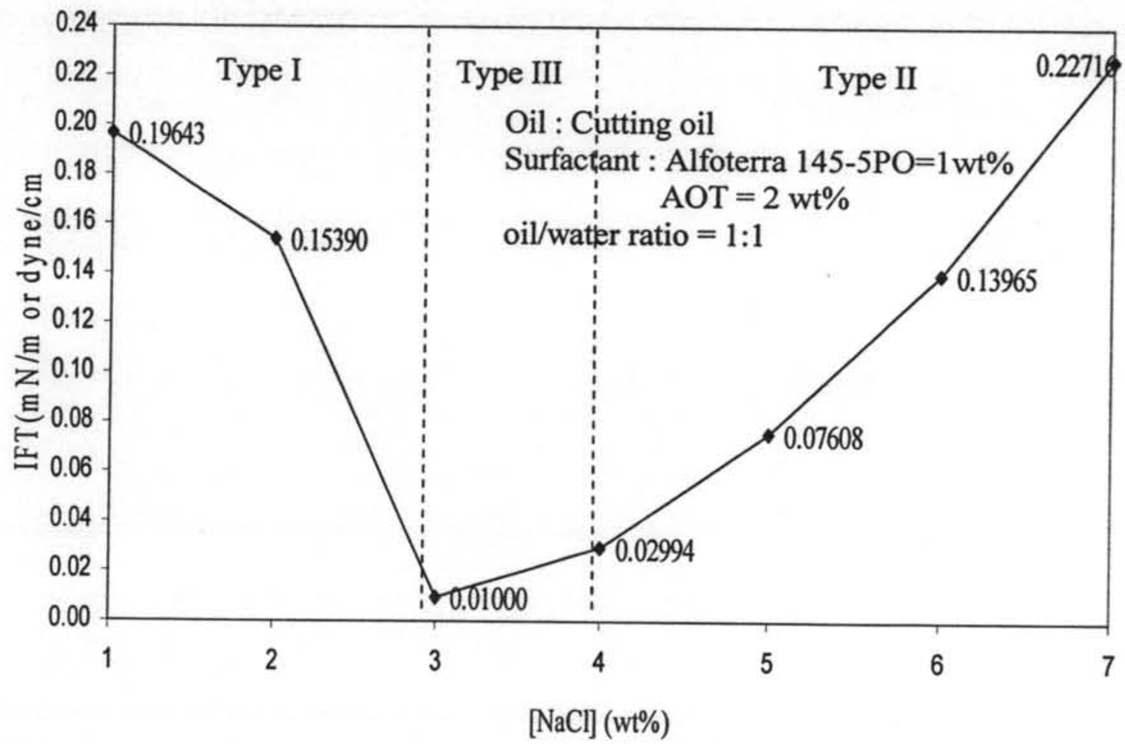

Figure 4.5 IFT of the mixed surfactant system as a function of salinity with an initial oil to water ratio = 1:1 (v:v).

4.1.4 Effect of Oil to Water Ratio on IFT

As mentioned before, the optimum NaCl concentration of 4 wt% provides a minimum IFT and reasonably high foamability and foam stability, and so 4 wt% NaCl was selected to study the effect of oil to water ratio on the IFT. Figure 4.7 illustrates IFT as a function of oil to water ratio with 0.1 wt% of Alfoterra, 0.5 wt% of SDS and 4 wt% of NaCl. It was found that the IFT seems to be independent on the oil to water ratio. This may be due to the same solubilization power of each system because it contains nearly the same Alfoterra and SDS concentration as well as NaCl concentration.

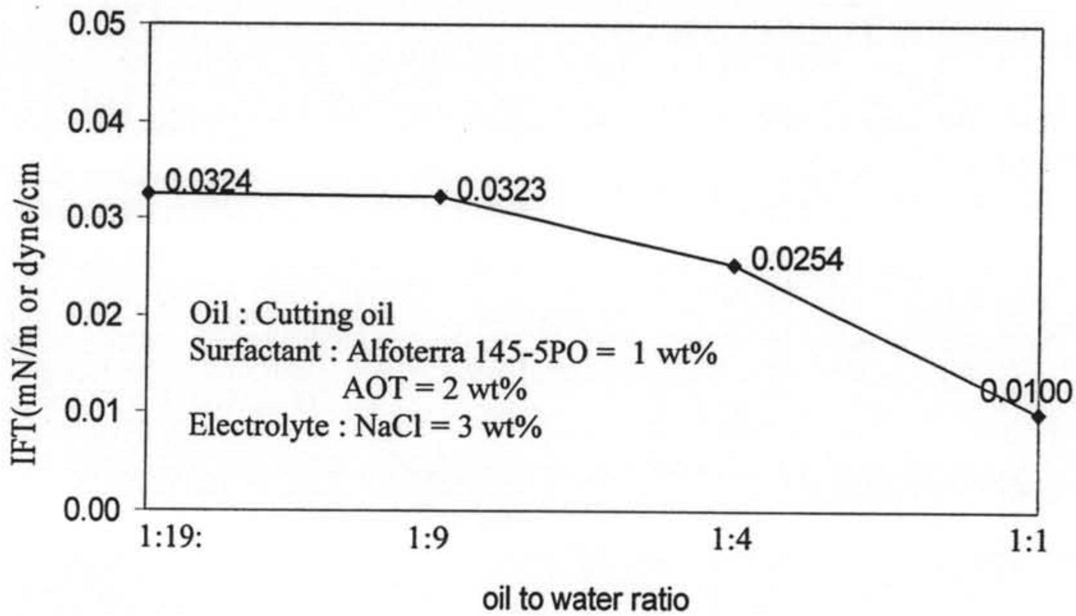

Figure 4.7 IFT as a function of oil to water ratio at 1 wt% Alfoterra, 2 wt% AOT, and 3 wt% NaCl.

The result from the effect of mixed surfactant concentration on IFT shows that 1 wt% of Alfoterra and 2 wt% of AOT provide the minimum IFT. The mixed surfactant system is not considered because foamability and foam stability of the system are very poor, so froth flotation cannot be achieved as illustrated in Figures 4.8 and 4.9.

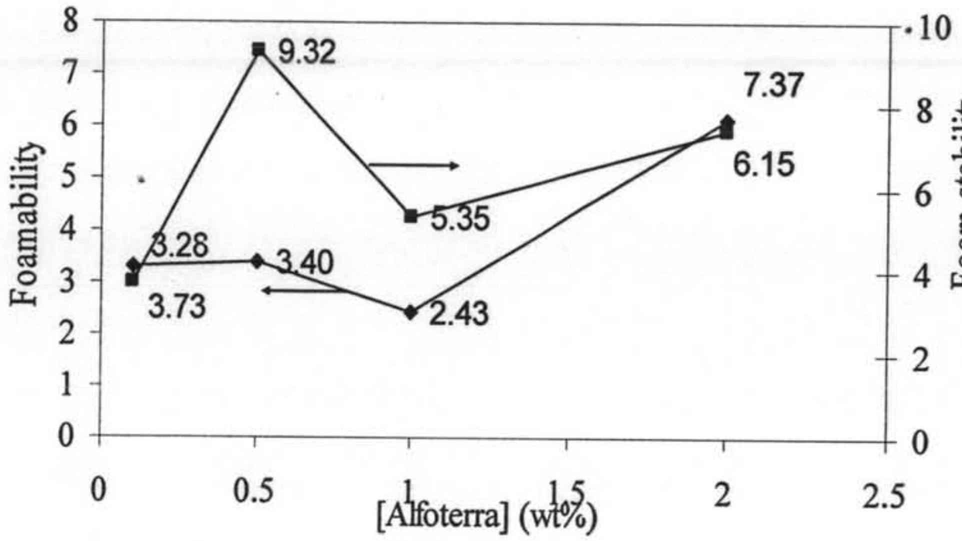

Figure 4.8 Foamability and Foam stability of single surfactant system at different Alfoterra concentration.

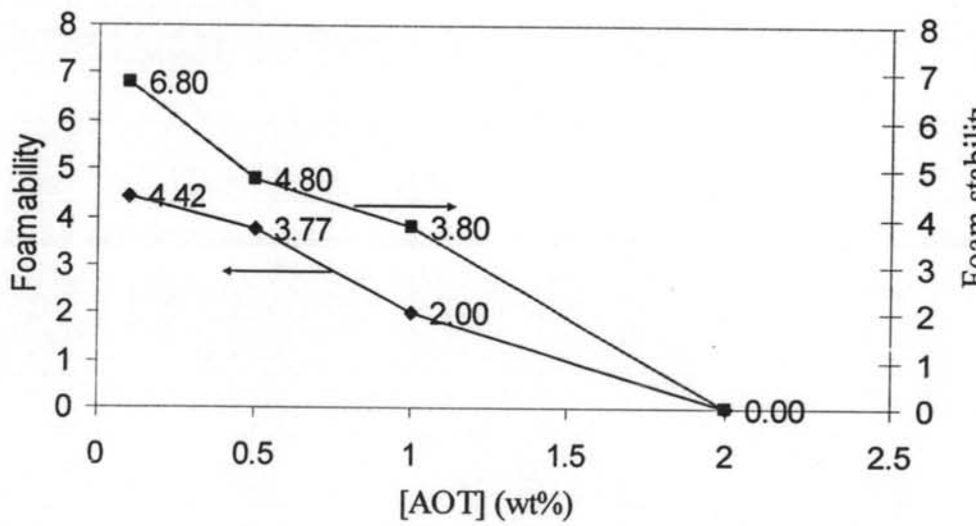

Figure 4.9 Foamability and Foam stability of mixed surfactant system at 1 wt% Alfoterra different AOT concentration.

In addition, the result from the effect of SDS concentration in the foamability and foam stability provides the best performance of the froth flotation illustrated in Figures 4.10.

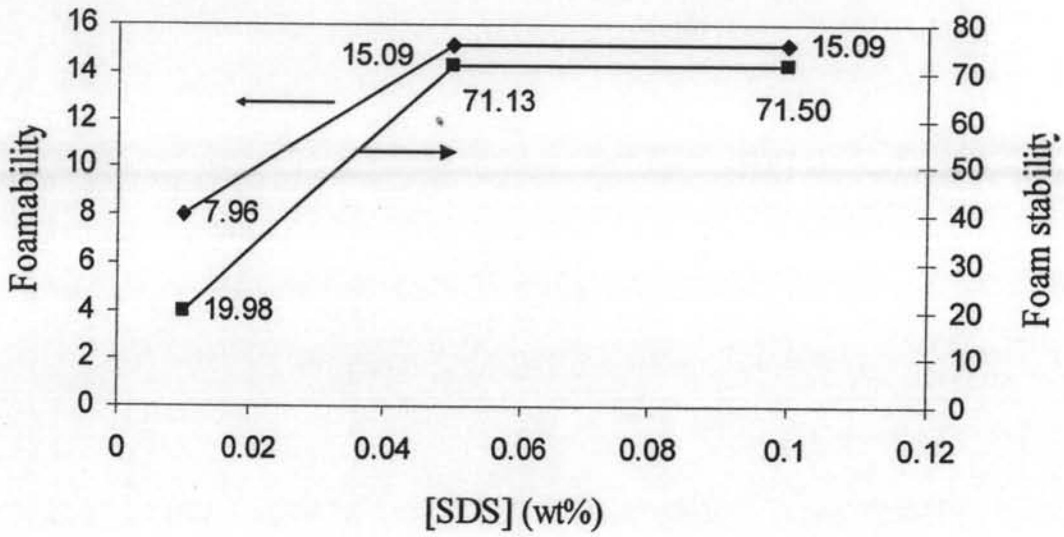

Figure 4.10 Foamability and Foam stability of single surfactant system at different SDS concentration.

As mentioned before, the optimum foamability and foam stability at 0.1 wt% of SDS provides the best performance of the froth flotation and so 3 wt% NaCl and 0.1 wt% SDS system was selected to study the effect of oil to water ratio on the IFT. Figure 4.11 illustrates IFT as a function of oil to water ratio. It was found that the IFT seems to be independent on the oil to water ratio. This may be due to the same solubilization power of each system because it contains nearly the same SDS concentration as well as NaCl concentration.

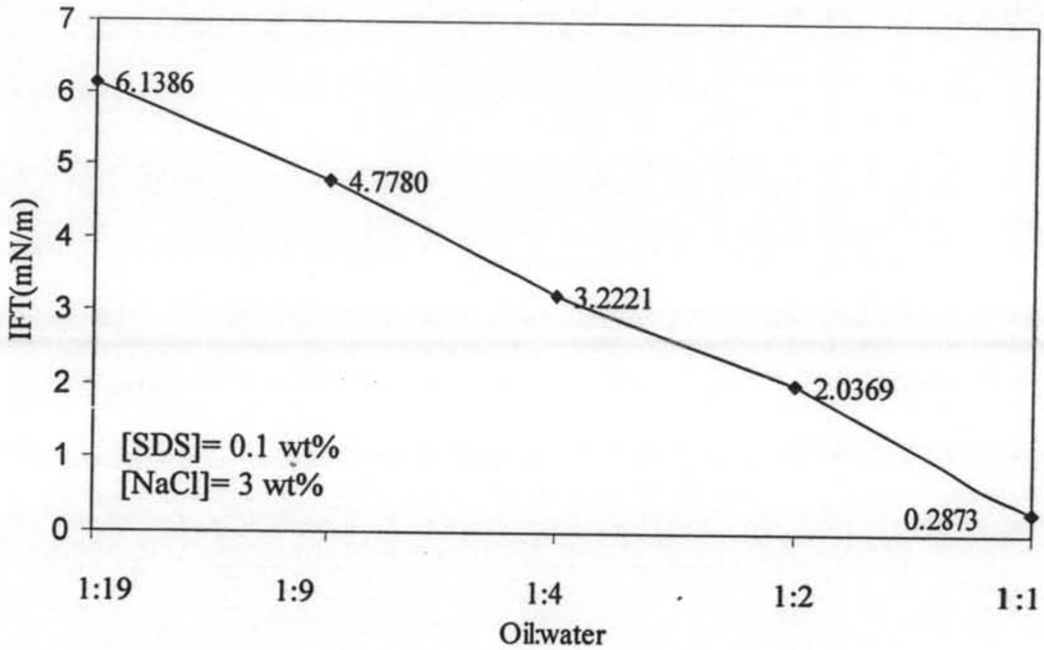

Figure 4.11 IFT as a function of oil to water ratio at 0.1wt% SDS and 3 wt% NaCl.

4.2 Froth Flotation Performance

Both oil removal and enrichment ratio are significant parameters to indicate the performance of froth flotation process. In addition, the surfactant removal, foam wetness, and foam flow rate should be determined and correlated with the froth flotation performance efficiency. Generally, high oil removal efficiency is a vital requirement for an effective froth flotation process but it is not the sole factor. If oil and water are present in the froth with the same proportion as in the influent, the selectivity and separation of oil from water do not occur. Hence, for effective separation, the concentration of oil in the overhead froth has to be much higher than that in the feed. Consequently, in this study, the separation efficiency is indicated by the enrichment ratio, which is defined as the ratio of concentration of oil in the overhead froth to that in the feed. In order to achieve the separation, the enrichment ratio must be greater than one. Moreover, the higher the enrichment ratio, the better the separation is. A total surfactant removal represents the amount of SDS that can remove from the solution.

4.2.1 Effect of Single Surfactant Concentration on Performance of Froth Flotation

For the pure SDS system as SDS concentration in the studied range, the oil removal increases as shown in Figure 4.12 because there are more foam to be produced with increasing SDS concentration and both surfactant and oil adsorb preferentially in the foam produced. The effect of SDS concentration on the oil removal is shown in Figure 4.12. Increasing SDS concentration from 0.01 to 0.1 wt% resulted in an increase in the oil removal. This is because the foam production rate increases with increasing SDS concentration as shown in Figure 4.13.

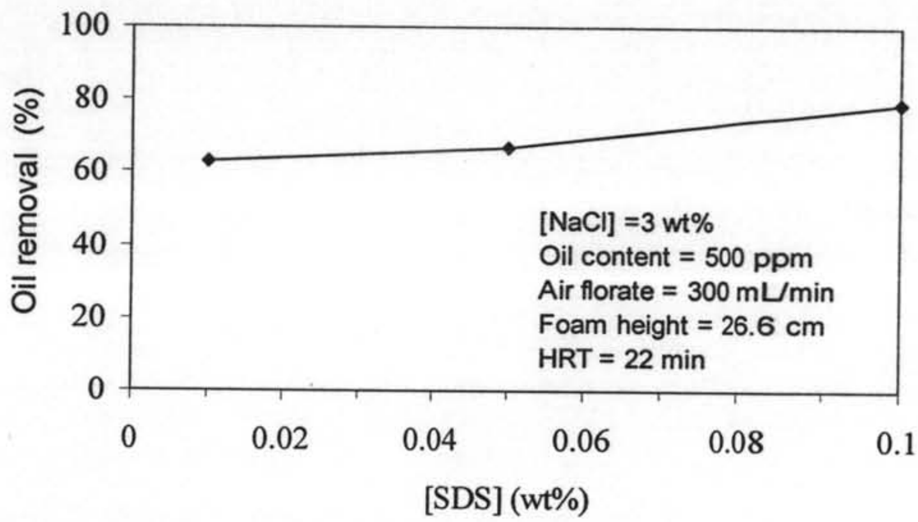

Figure 4.12 Oil removal efficiency of single surfactant system at different feed SDS concentrations.

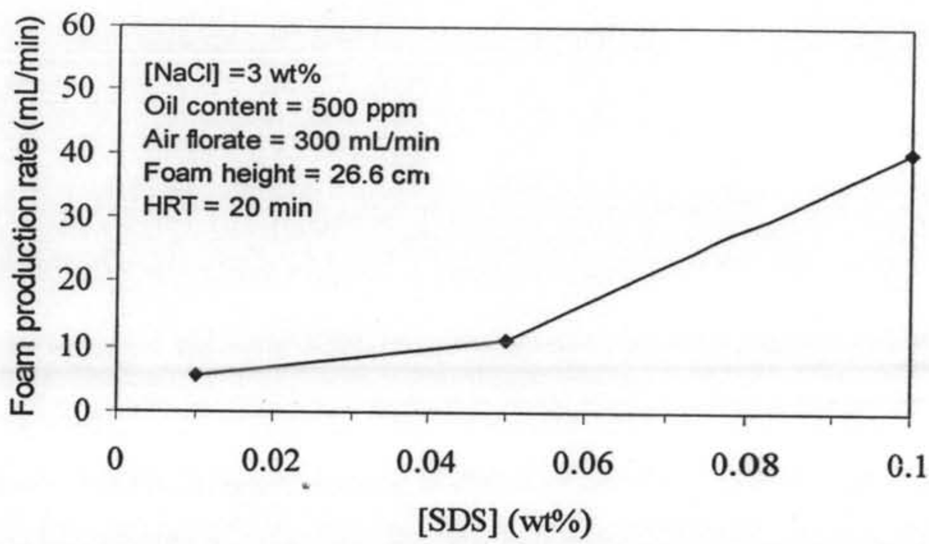

Figure 4.13 Foam production flow rate of single surfactant system.

As shown in Figure 4.14, an increase in SDS concentration from 0.01 to 0.1 wt%, the oil removal increases because there is more foam to be produced with increasing surfactant concentration (see Figure 4.13). Therefore, the surfactant can carry oil and remove it from the solution more efficiently.

The effect of SDS concentration on the enrichment ratio of cutting oil is shown in Figure 4.14. As the SDS concentration increases from 0.01 wt% to 0.1 wt%, the enrichment ratio slightly decreases because the concentration of surfactant at the foam decreases with increasing feed SDS concentration. Hence, the foam lamellae of a higher surfactant concentration becomes thicker than that with a lower surfactant concentration leading to a larger amount of water in the foam lamellae, so 0.1 wt% of SDBS results in the low enrichment ratio of cutting oil.

The effect of SDS concentration on the surfactant removal is shown in Figure 4.15. Increasing SDS concentration from 0.01 to 0.1 wt% results in an increase in the surfactant removal. This result relates to the effect of SDS concentration on the oil removal and the foam production rate as shown in Figures 4.12 and 4.13 because when foam production rate increase resulting in the increases of surfactant removal and when the foam production rate decreases leading to the decreases of the surfactant removal also as well as the effect of SDS concentration on the oil removal as described before.

As shown in Figure 4.16, the enrichment ratio of the surfactant decreases when the SDS concentration increases. This is related to the result of enrichment ratio of oil as shown in Figure 4.14. This reason can be explained as described in the effect of SDS concentration on the enrichment ratio of cutting oil.

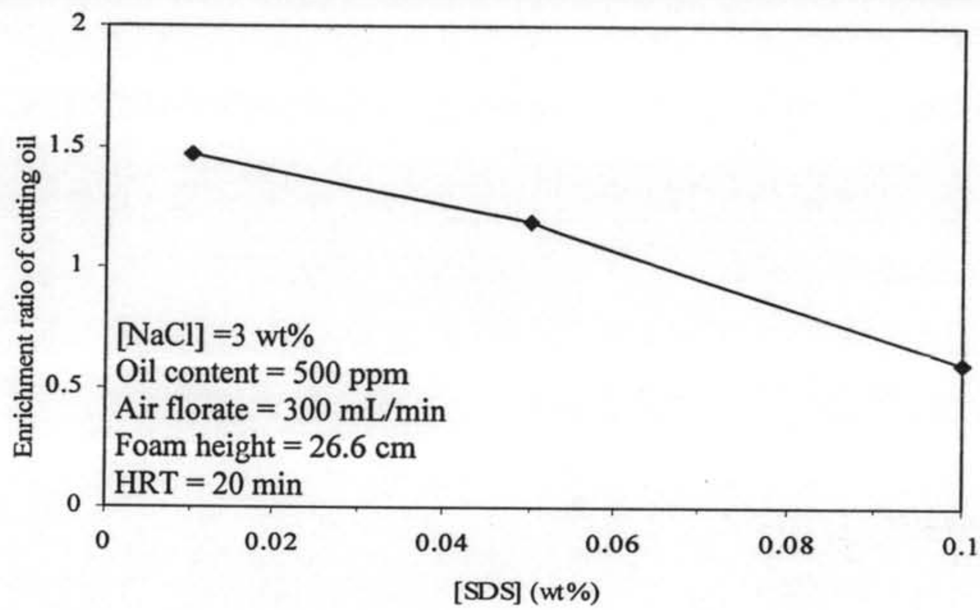

Figure 4.14 Enrichment ratio of single surfactant system at different feed SDS concentrations.

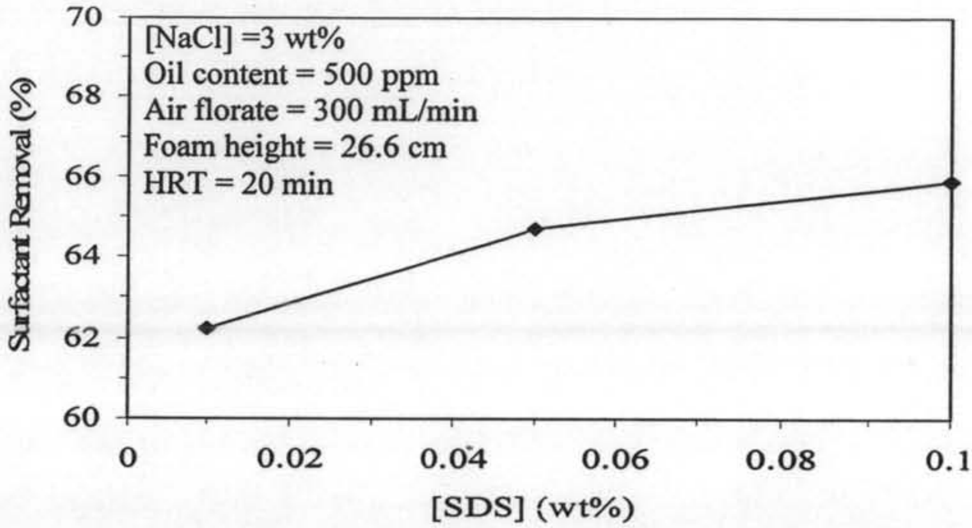

Figure 4.15 Surfactant removal of single surfactant system at different feed SDS concentrations.

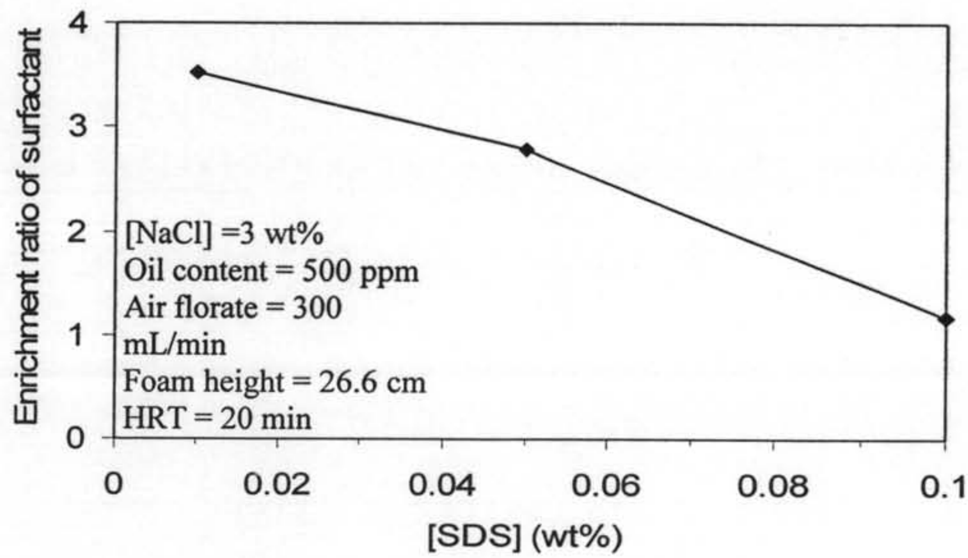

Figure 4.16 Enrichment ratio of surfactant of single surfactant system at different feed SDS concentrations.

An increase in SDBS concentration from 0.01 to 0.1 wt%, the oil removal increases (see Figure 4.17) because there are more foam to be produced with increasing surfactant concentration (see Figure 4.18). Therefore, the surfactant can carry oil and remove it from the solution more efficiently.

The effect of SDBS concentration on the surfactant removal is shown in Figure 4.20. Increasing SDBS concentration from 0.01 to 0.1 wt% results in an increase in the surfactant removal. This result relates to the effect of SDBS concentration on the oil removal and the foam production rate as shown in Figures 4.18 because when foam production rate increase resulting in the increases of surfactant removal and when the foam production rate decreases leading to the decreases of the surfactant removal also as well as the effect of SDBS concentration on the oil removal as described before.

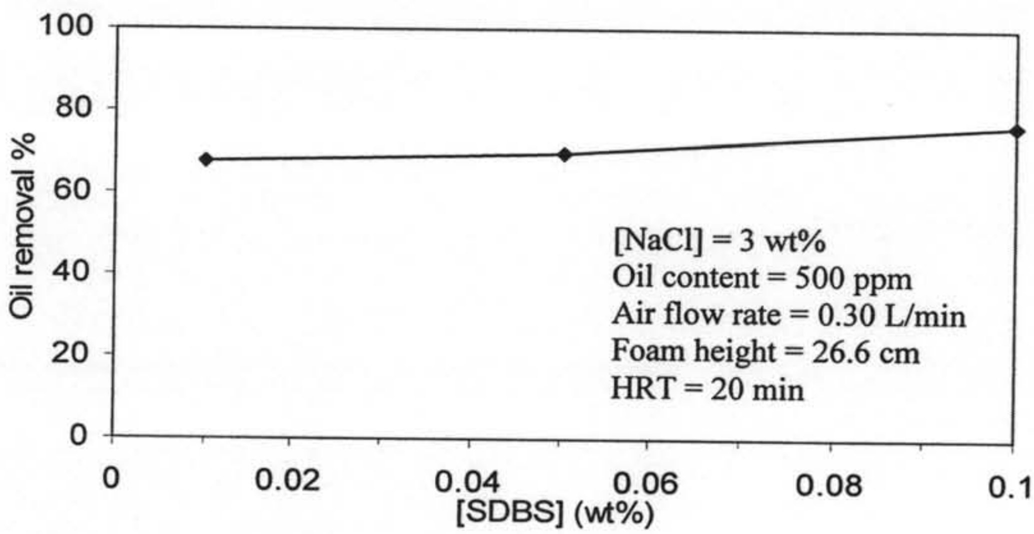

Figure 4.17 Oil removal efficiency of single surfactant system at different feed SDBS concentrations.

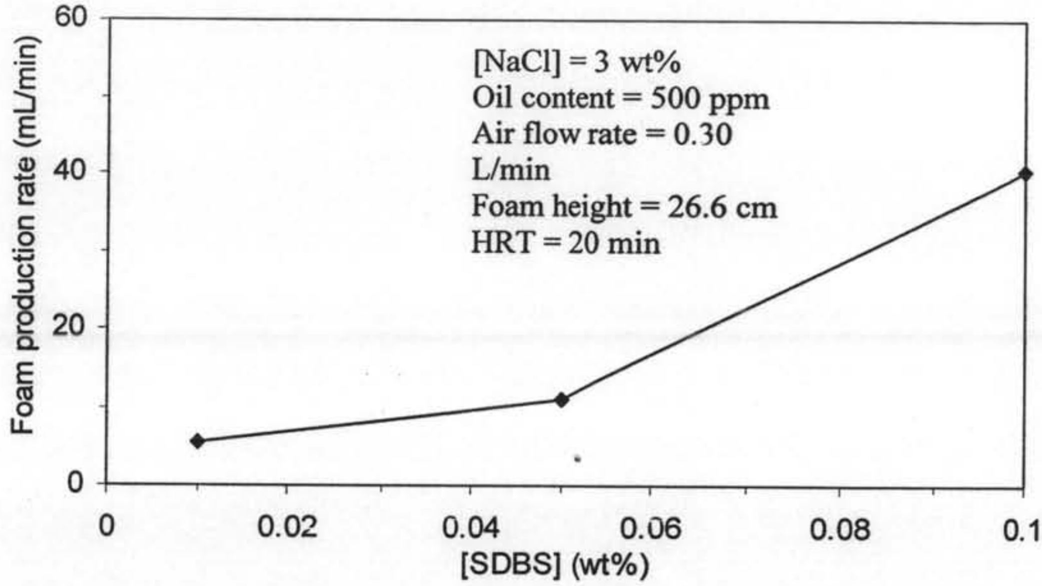

Figure 4.18 Foam production flow rate of mixed surfactant system at different feed SDBS concentrations.

The effect of SDBS concentration on the enrichment ratio of cutting oil is shown in Figure 4.19. As the SDBS concentration increases from 0.01 wt% to 0.1 wt%, the enrichment ratio slightly decreases because the concentration of surfactant at the foam decreases with increasing feed SDBS concentration. Hence, the foam lamellae of a higher surfactant concentration becomes thicker than that with a lower surfactant concentration leading to a larger amount of water in the foam lamellae, so 0.1 wt% of SDBS results in the low enrichment ratio of cutting oil.

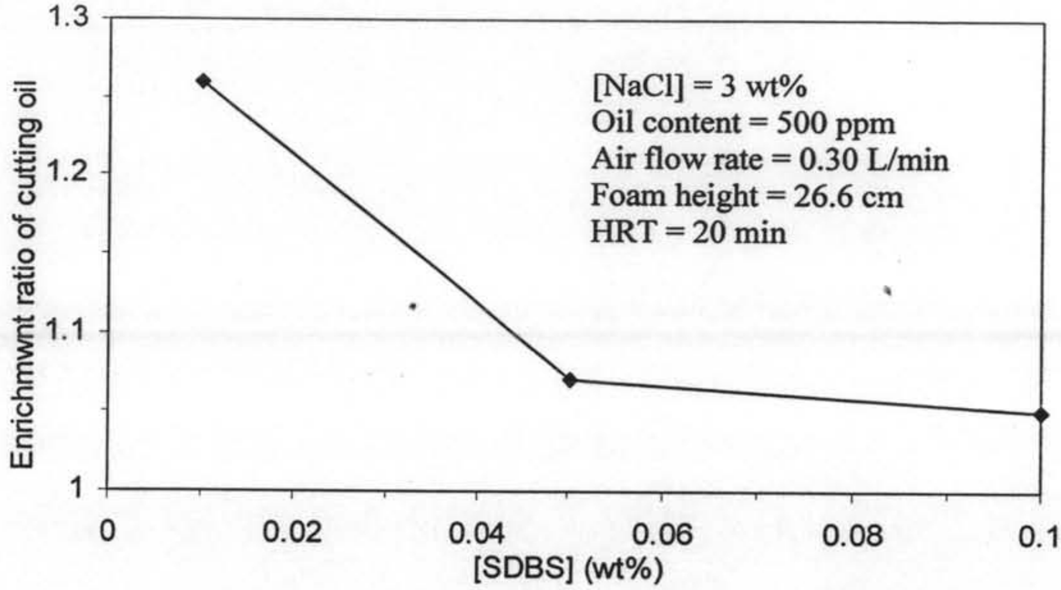

Figure 4.19 Enrichment ratio of single surfactant system at different feed SDBS concentrations.

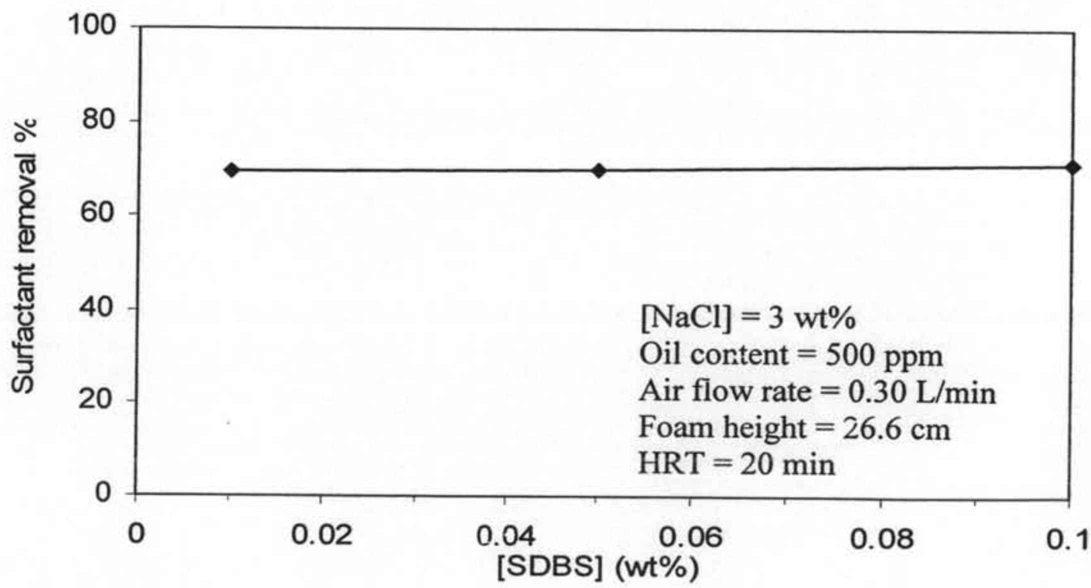

Figure 4.20 Surfactant removal of single surfactant system at different feed SDBS concentrations.

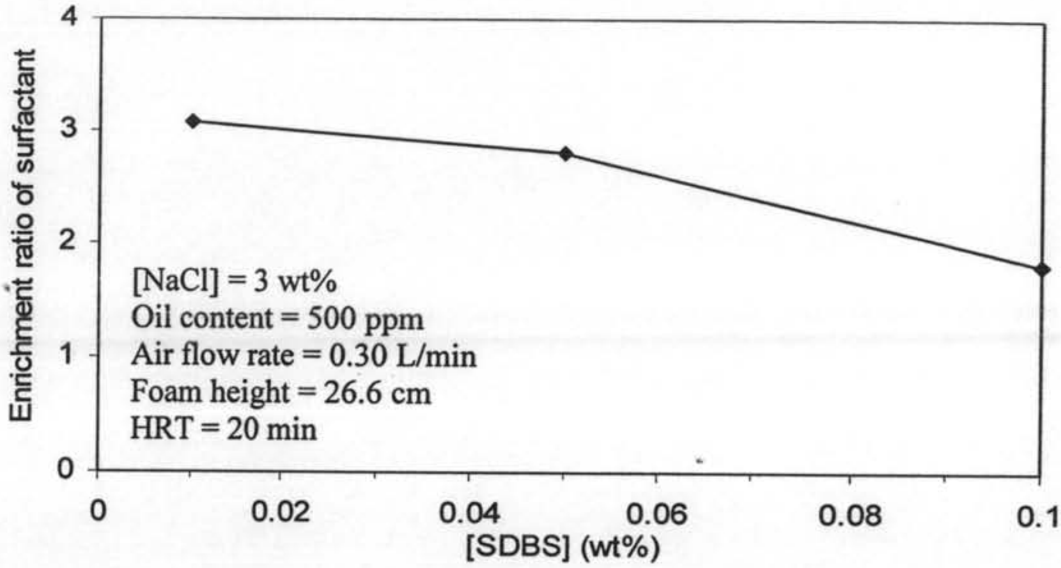

Figure 4.21 Enrichment of surfactant of single surfactant system at different feed SDBS concentrations.

4.22 Effect of NaCl Concentration on Performance of Froth Flotation

It has been known that salinity is one of operational parameters affecting froth flotation operation. The effect of NaCl concentration on the operation of froth flotation was carried out by varying NaCl concentration in the range of 3 to 7 wt% at 0.1 wt% SDS. Figure 4.22 shows the increase in the NaCl concentration from 3 to 7 wt% resulting in an increase in the oil removal. This is because the repulsive force between the anionic head groups decreases when the NaCl concentration increases. Consequently, the hydrophobic characteristics of the foam surface increase resulting in increasing amount of oil attached to the foam; hence, the oil removal increases.

For effective separation, the overhead froth should have a higher oil concentration than that in the feed. Here, the separation efficiency of the froth flotation is indicated by the enrichment ratio. Figure 4.23 illustrates the effect of NaCl concentration on the enrichment ratio. It shows that an increase in the NaCl concentration from 3 to 7 wt% increases the enrichment ratio of cutting oil. This is because NaCl reduces the repulsive force between the anionic head groups of the surfactant and so more oil can attach to the foam. Moreover, foam lamella becomes thinner leading to lower water content in the foam and higher oil content.

The effect of NaCl concentration on surfactant removal is shown in Figure 4.24. An increase in NaCl concentration from 3 to 7 wt% results in increasing surfactant removal because of the reduction of the repulsive force between the anionic head groups. Therefore, more surfactants can adsorb at the air-solution interface and then, the removal of surfactant increases. The surfactant removal decreases when the NaCl concentration is increased. This can be explained by the effect of salinity on the foam production flow rate as described previously.

Figure 4.25 shows that the enrichment ratio of surfactant increases with increasing NaCl concentration. When the NaCl conentration is further increased from 3 to 7 wt%, the enrichment ratio of surfactant decreases.

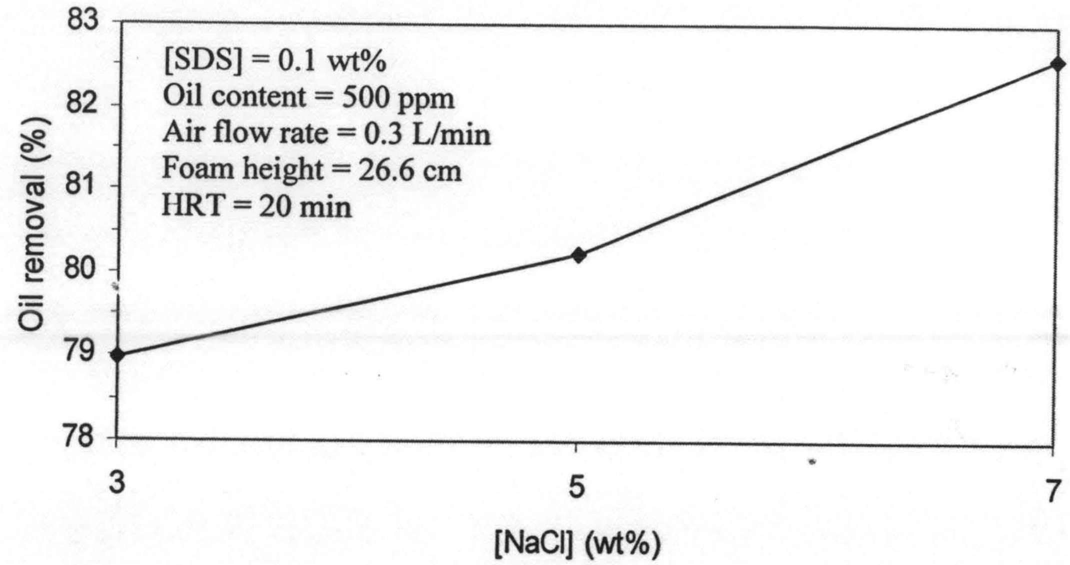

Figure 4.22 Removal efficiency of cutting oil at different feed NaCl concentration.

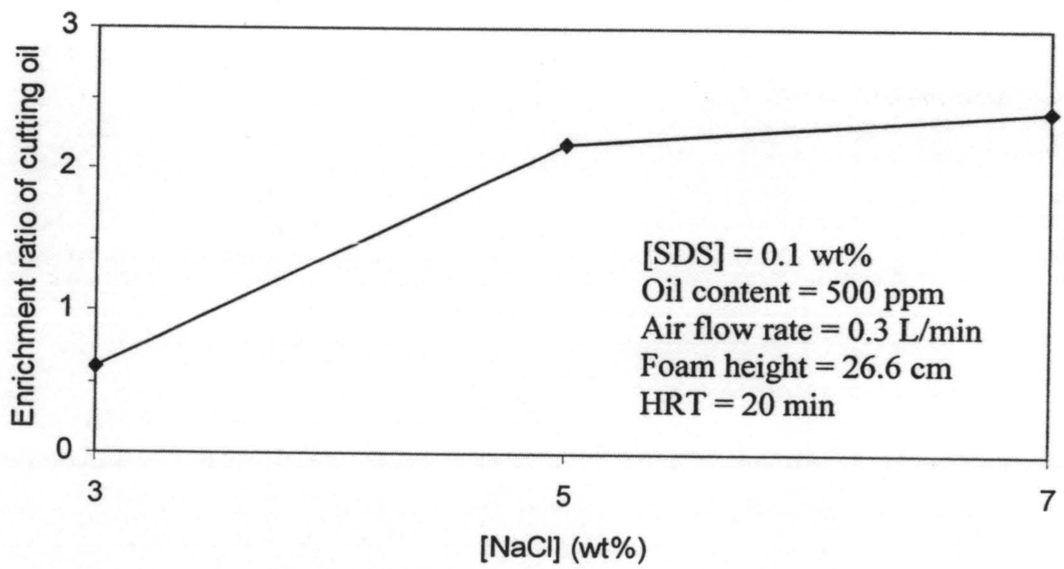

Figure 4.23 Enrichment ratio of cutting oil with different feed NaCl concentration.

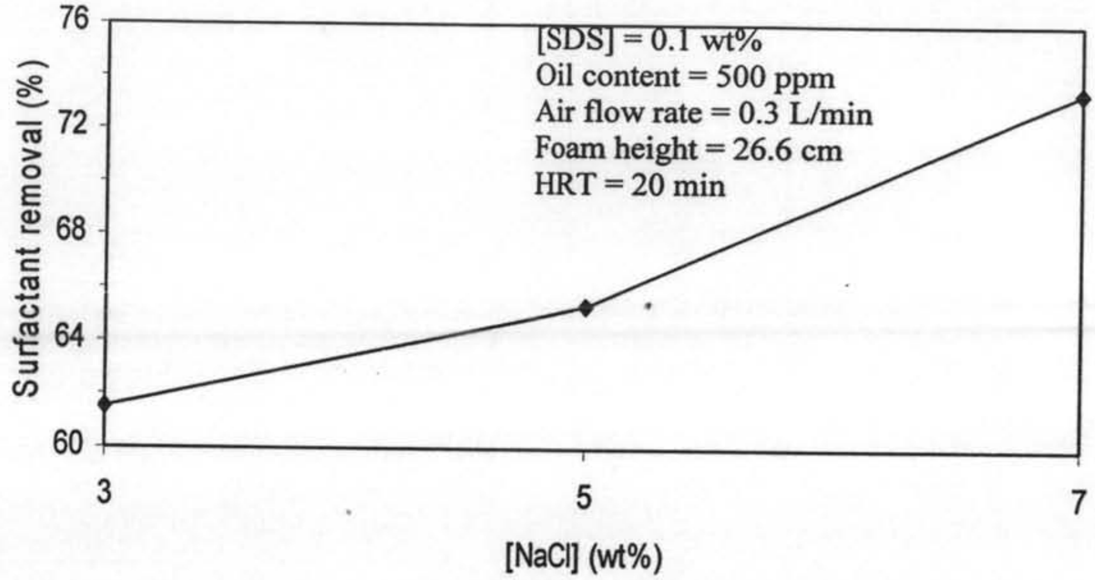

Figure 4.24 Surfactant removal with different feed NaCl concentration.

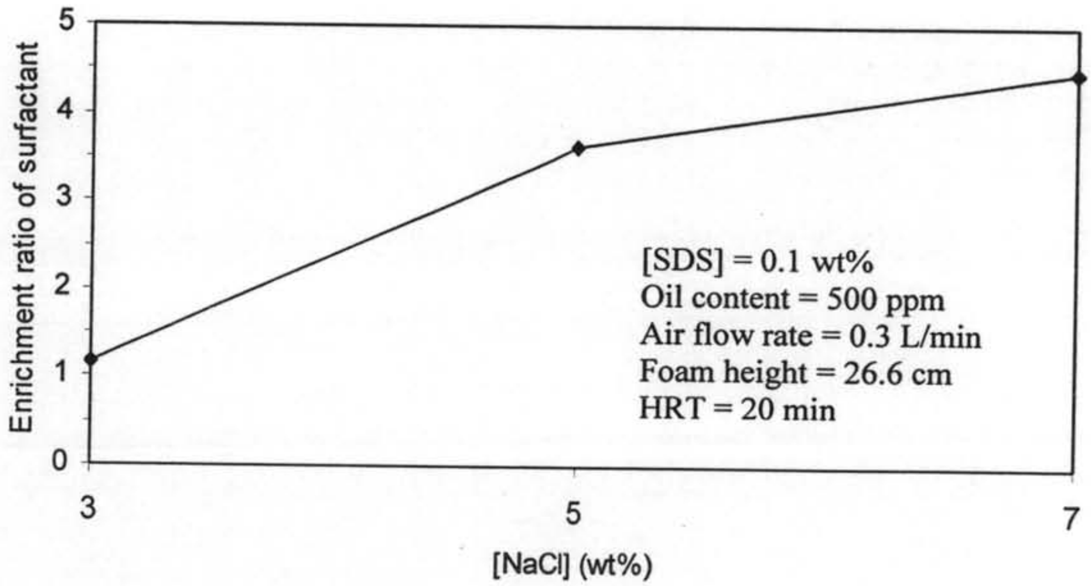

Figure 4.25 Enrichment ratio of surfactant with different feed NaCl concentration.

The effect of NaCl concentration of the system of SDBS 0.1 wt% on the froth flotation operation was carried out by varing NaCl concentration in the range of 3 to 7 wt%. Figure 4.26 shows the increase in the NaCl concentration from 3 to 7 wt% resulting in a decrease in the oil removal. This is because the repulsive force between the anionic head groups decreases when the NaCl concentration increases. Consequently, the hydrophobic characteristics of the foam surface increase resulting in increasing amount of oil attached to the foam; hence, the oil removal increases.

For effective separation, the overhead froth should have a higher oil concentration than that in the feed. Here, the separation efficiency of the froth flotation is indicated by the enrichment ratio. Figure 4.27 illustrates the effect of NaCl concentration on the enrichment ratio. It shows that an increase in the NaCl concentration from 3 to 7 wt% increases the enrichment ratio of cutting oil. This is because NaCl reduces the repulsive force between the anionic head groups of the surfactant and so more oil can attach to the foam. Moreover, foam lamella becomes thinner leading to lower water content in the foam and higher oil content.

The effect of NaCl concentration on surfactant removal is shown in Figure 4.28. An increase in NaCl concentration from 3 to 5 wt% results in increasing surfactant removal because of the reduction of the repulsive force between the anionic head groups. Therefore, more surfactants can adsorb at the air-solution interface and then, the removal of surfactant increases. The surfactant removal decreases when the NaCl concentration is increased from 5 to 7 wt%. This can be explained by the effect of salinity on the foam production flow rate as described previously.

Figure 4.29 shows that the enrichment ratio of surfactant increases with increasing NaCl concentration from 3 to 5 wt%. When the NaCl conentration is further increased from 5 to 7 wt%, the enrichment ratio of surfactant decreases. Again, this can be explained by the same reason for the effect of foam production rate.

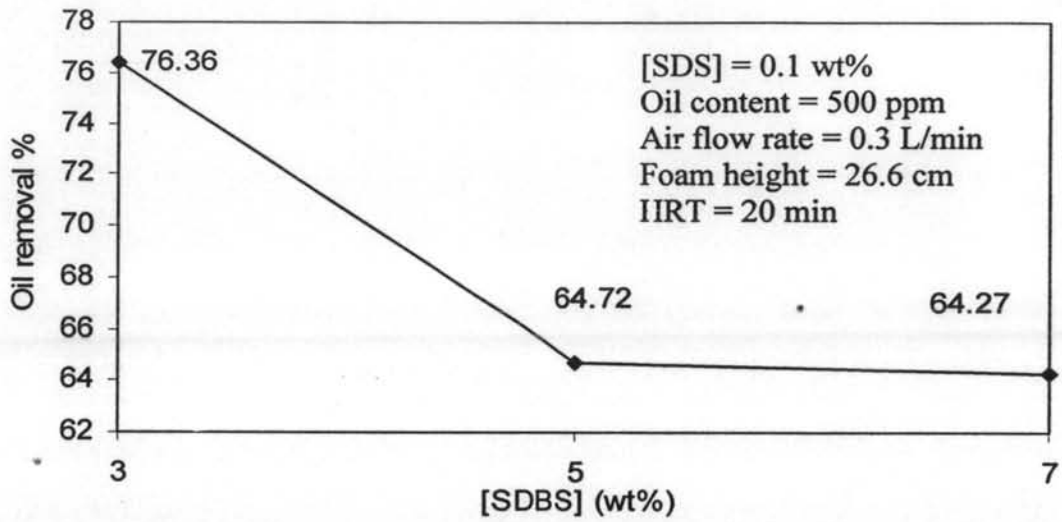

Figure 4.26 Removal efficiency of cutting oil at different feed NaCl concentration.

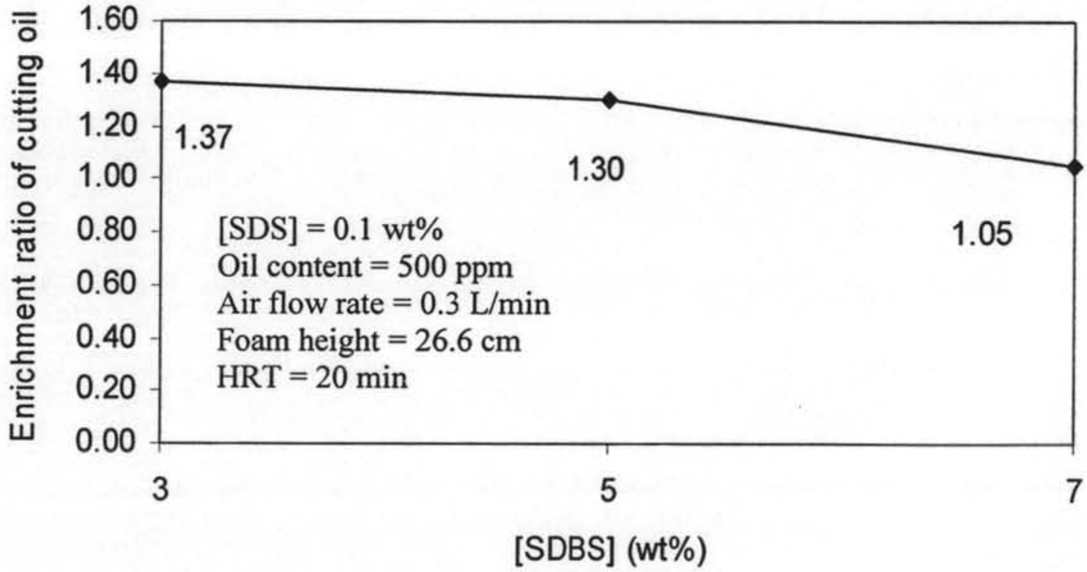

Figure 4.27 Enrichment ratio of cutting oil with different feed NaCl concentration.

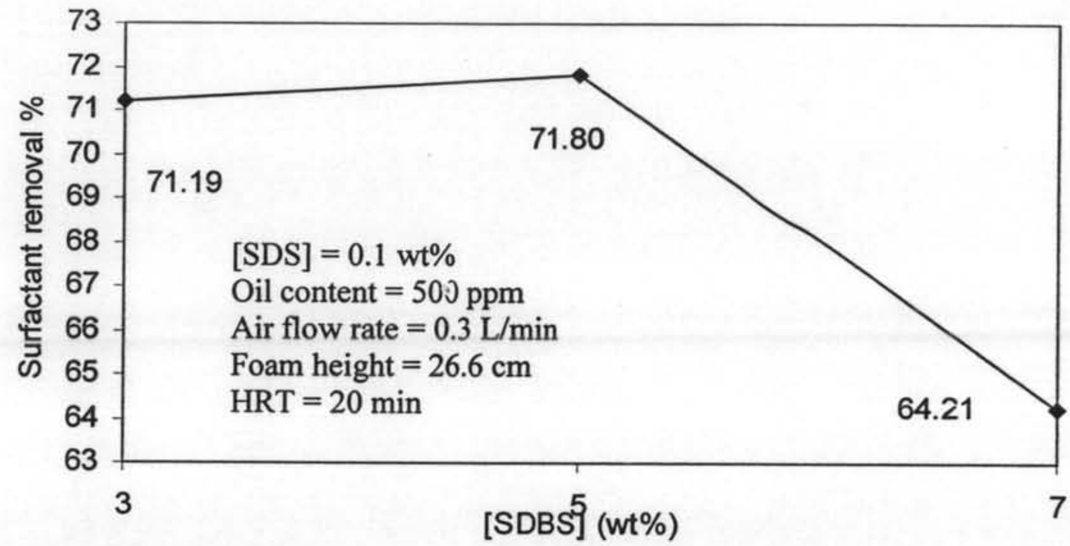

Figure 4.28 Surfactant removal with different feed NaCl concentration.

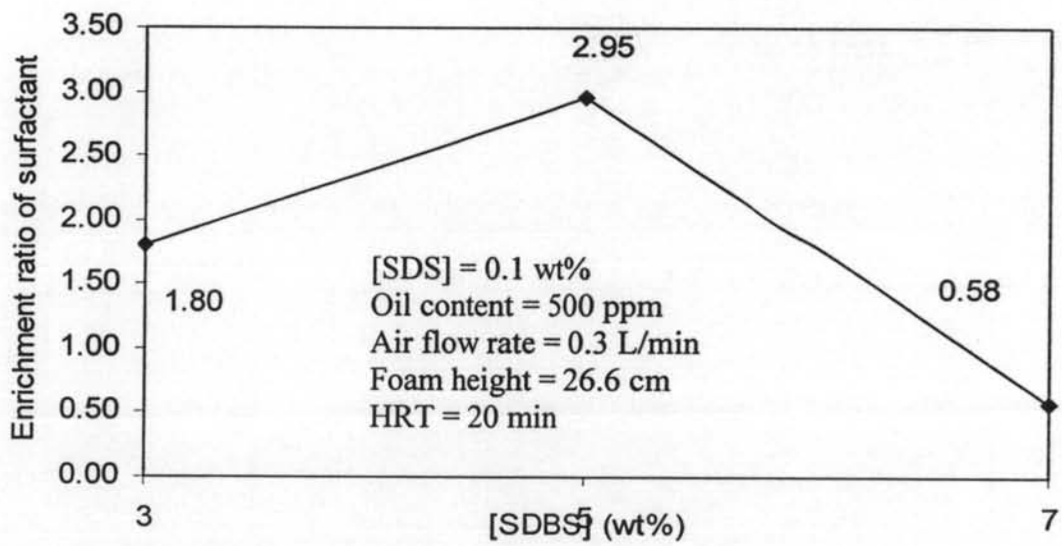

Figure 4.29 Enrichment ratio of surfactant with different feed NaCl concentration.

4.2.3 Effect of Air Flow Rate on Performance of Froth Flotation

Air flow rate is one of the vital parameters in forth flotation operation. SDS 0.1 wt% at 5 wt% of NaCl was selected to run froth flotation since the system could offer the highest oil removal.

As can be seen in Figure 4.30, oil removal efficiency is not affected significantly by the increasing air flow rate in range of 0.15 to 0.30 L/min. while the foamability of the system and foam production rate increase almost linearly as shown in Figures 4.31, 4.32 respectively. From Figure 4.40, increasing air flow rate affects insignificantly the foam stability of the system in the range from 0.15 to 0.30 L/min.

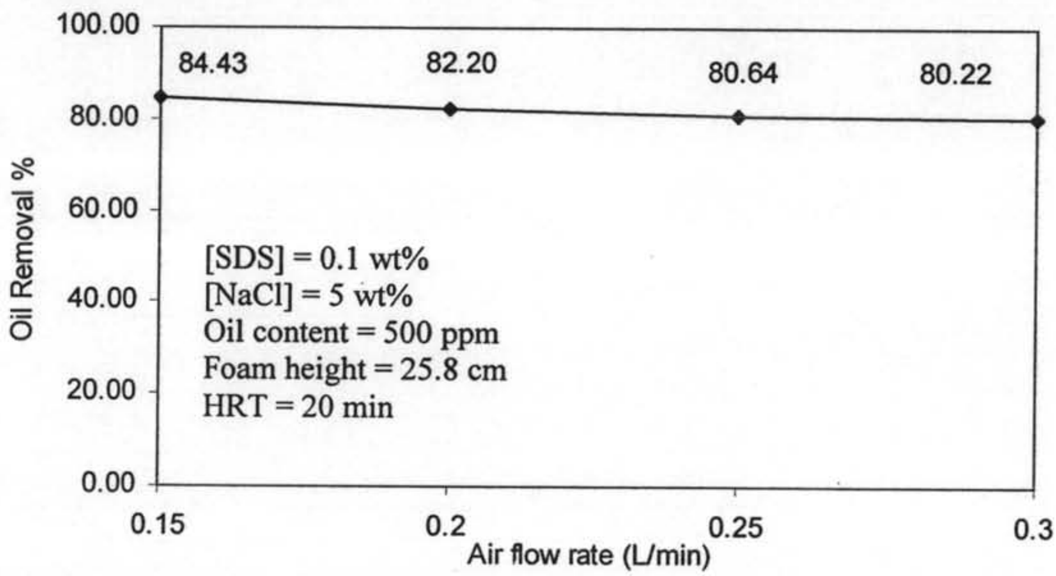

Figure 4.30 Oil removal of system at different air flow rates.

Figure 4.26 shows the effect of air flow rate on enrichment ratio of cutting oil. The higher air flow rate, the lower the enrichment ratio of cutting oil is obtained. This can be explained that a higher air flow rate simply produces more bubbles passing through the solution resulting in a higher foam production rate, with wetter foam as shown in Figure 4.32. As a result the enrichment ratio of diesel decreases.

Figure 4.35 shows the effect of air flow rate on the surfactant removal. Increasing the air flow rate from 0.15 to 0.30 L/min results in insignificant effect on the surfactant removal. This can be explained by using the combined effects of the foamability, the foam stability and the enrichment ratio of surfactant.

The enrichment ratio of surfactant decreases as the air flow rate increases as illustrated in Figure 4.36. This corresponds to the result of the foam flow rate. A high air flow rate results in a high foam flow rate leading to more difficulty for water drainage from the foam lamella and so there is a high amount of water in the collapsed foam as well as a low enrichment ratio of surfactant.

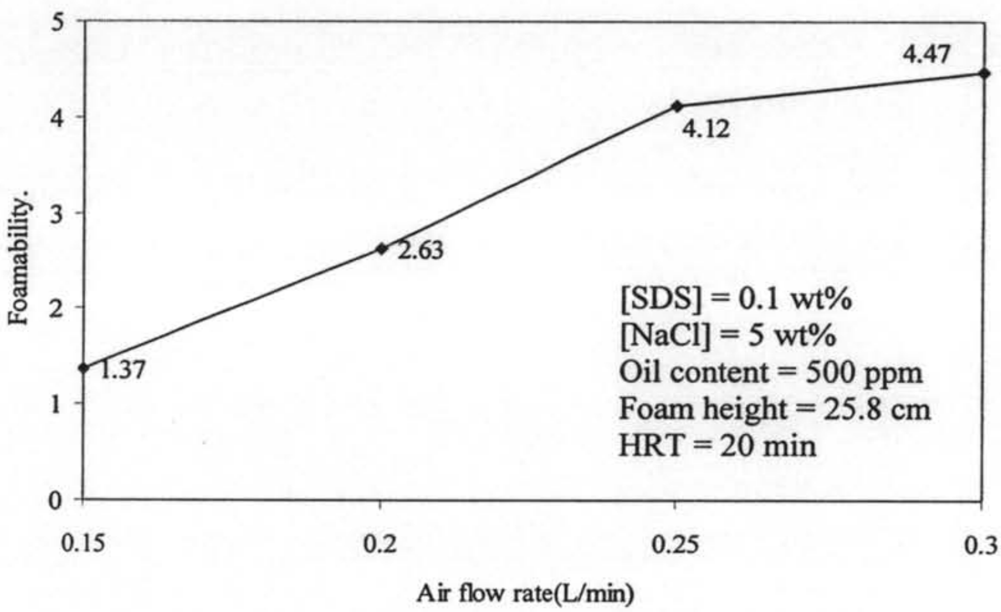

Figure 4.31 Foamability of cutting oil of system at different air flow rates.

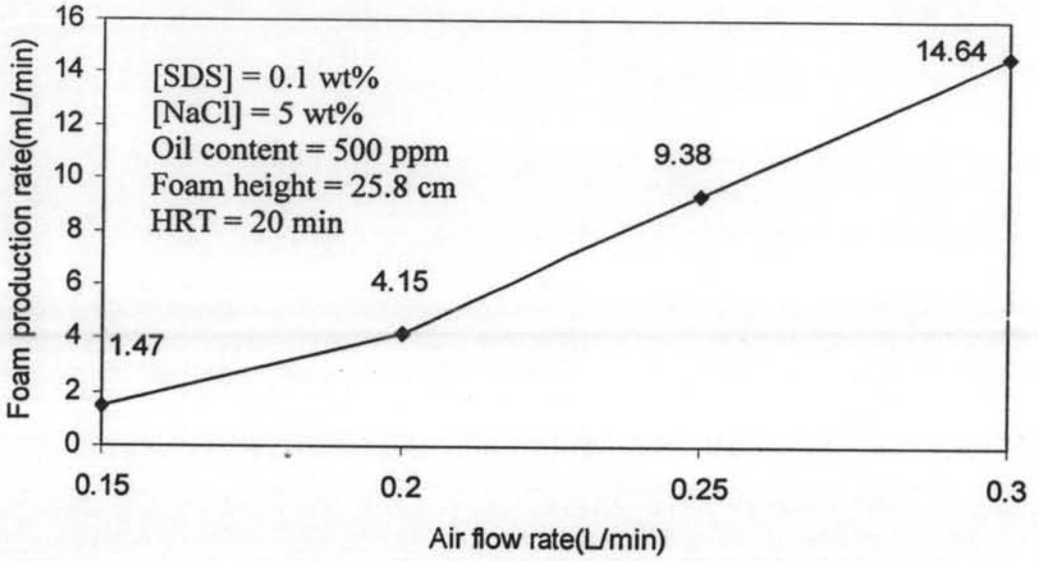

Figure 4.32 Foam production rate of system at different air flow rates.

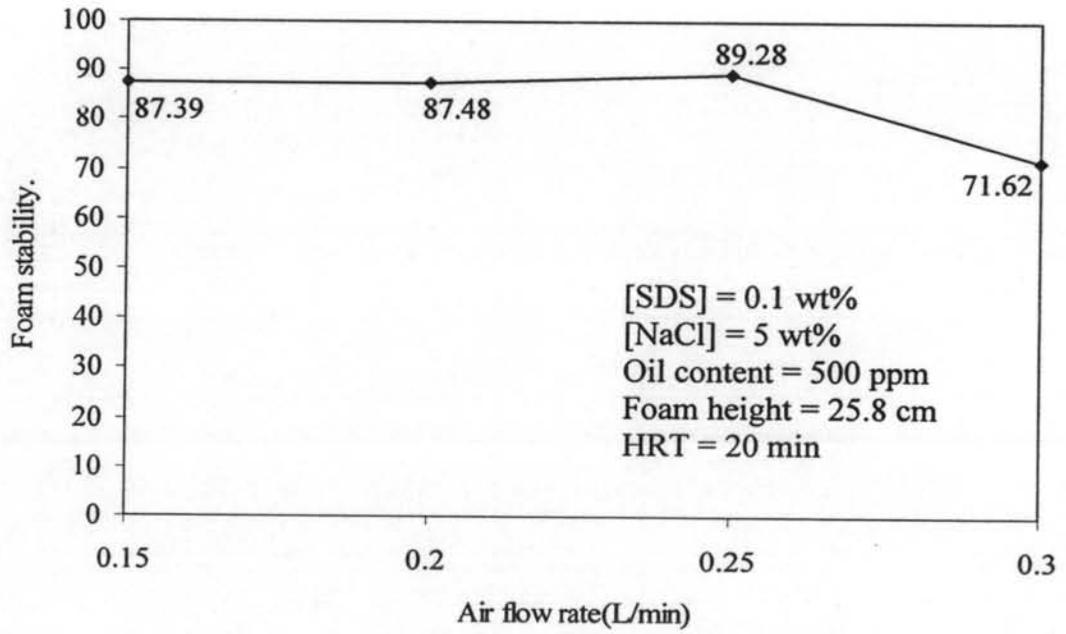

Figure 4.33 Foam stability of cutting oil of system at different air flow rates.

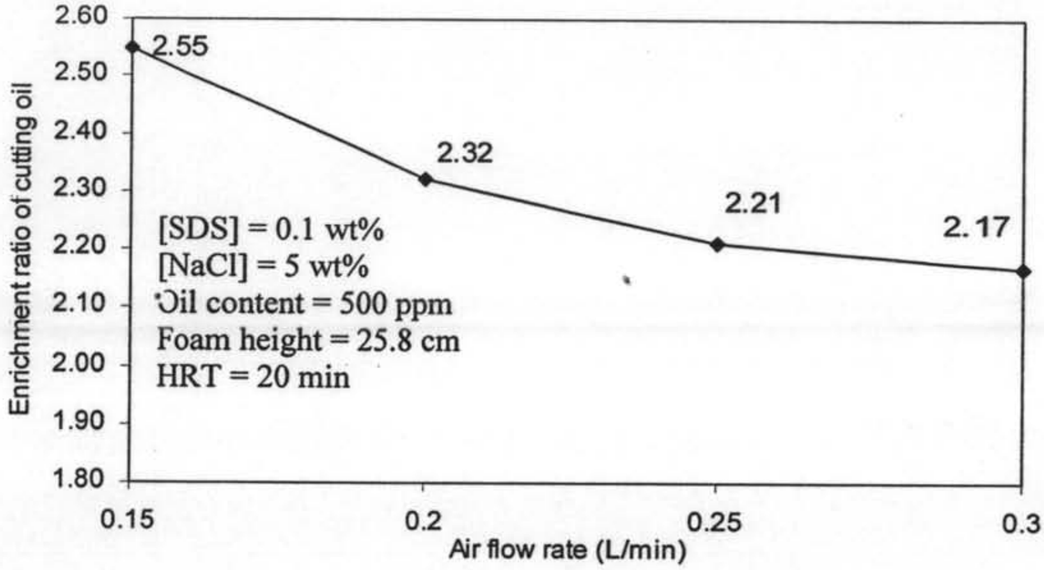

Figure 4.34 Enrichment ratio of cutting oil of system at different air flow rates.

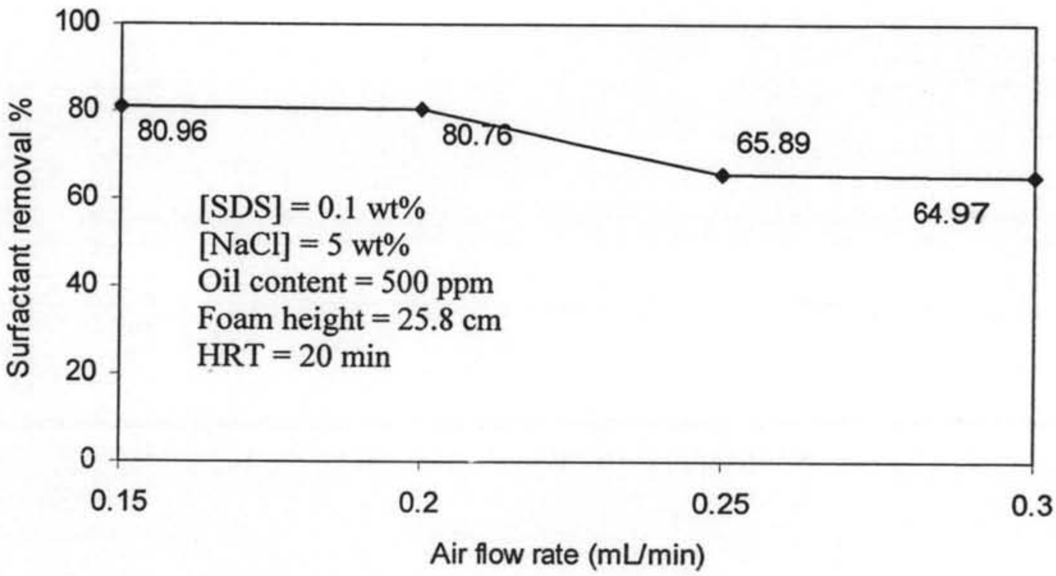

Figure 4.35 Surfactant removal of system at different air flow rates.

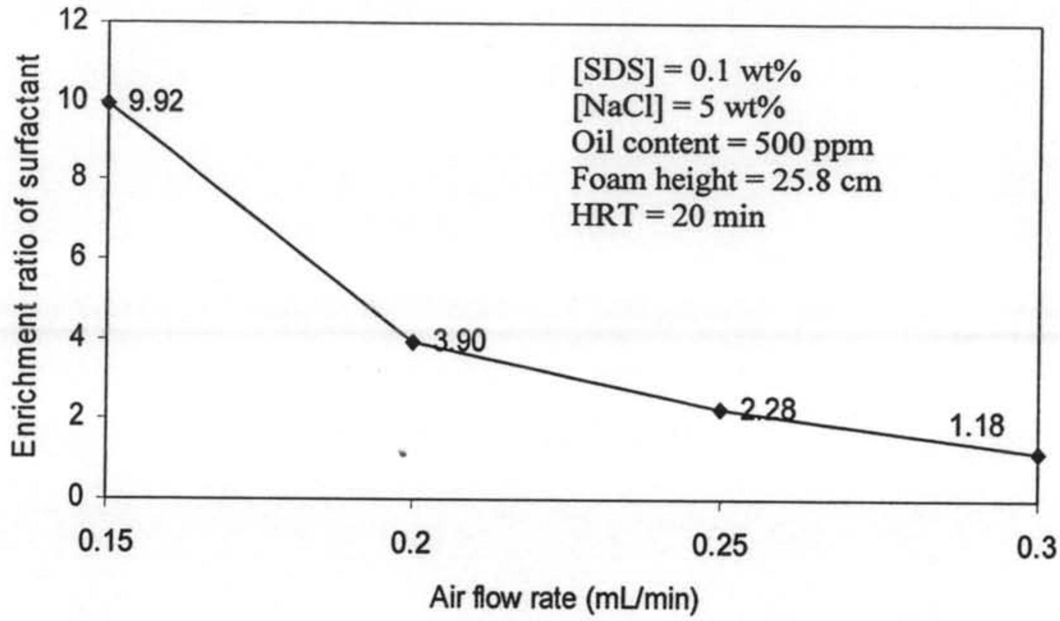

Figure 4.36 Enrichment ratio of surfactant of system at different air flow rates.

4.2.4 Effect of Hydraulic Retention Time (HRT) on Performance of Froth Flotation

From Figure 4.37, oil removal increases when HRT increases. This is because at a higher HRT represents a longer residence time for the solution to be contact with air bubbles. As a result, a higher amount of oil can be carried on to the top of the column and a higher oil removal is obtained.

As shown in Figure 4.38, the enrichment ratio of oil increases as HRT increases because a high HRT represents a lower feed flow rate resulting in more time of oil stay in the column as well as more time to be contacted and attached to the air bubbles and the froth at the top of the column. Therefore, in the collapsed froth contains a higher amount of oil and smaller water content with increasing HRT. As expected, increasing HRT resulting in decreasing foam wetness. This corresponds to the result of the enrichment ratio of oil because at a higher HRT, the system simply has a long time for allowing more water drainage for the foam produced. As a result, the foam wetness and the foam production rate decrease as shown in Figures 4.39.

Figure 4.40 and Figure 4.41 show the effects of HRT on surfactant removal and enrichment ratio of surfactant, respectively. With increasing HRT in the range 20 to 60 min, the effects of HRT on both surfactant removal and enrichment ratio of surfactant is insignificant but at the highest HRT, both removal and enrichment ratio of surfactant increase remarkably. The results indicate that at a low HRT, a proper balance between the foam production rate and the rate of water drainage from the foam attributes to relatively constant values of both removal and enrichment ratio of surfactant. However, at a very high HRT of 60 min, the rate of water drainage becomes prominent resulting in both higher values of the removal and enrichment ratio of surfactant.

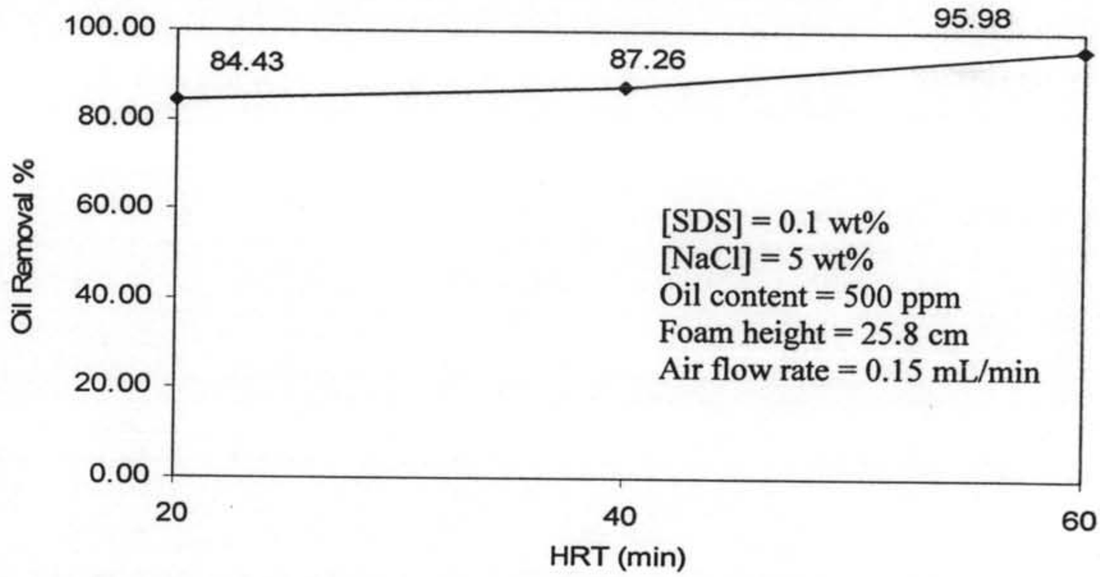

Figure 4.37 Oil removal of system at different HRTs.

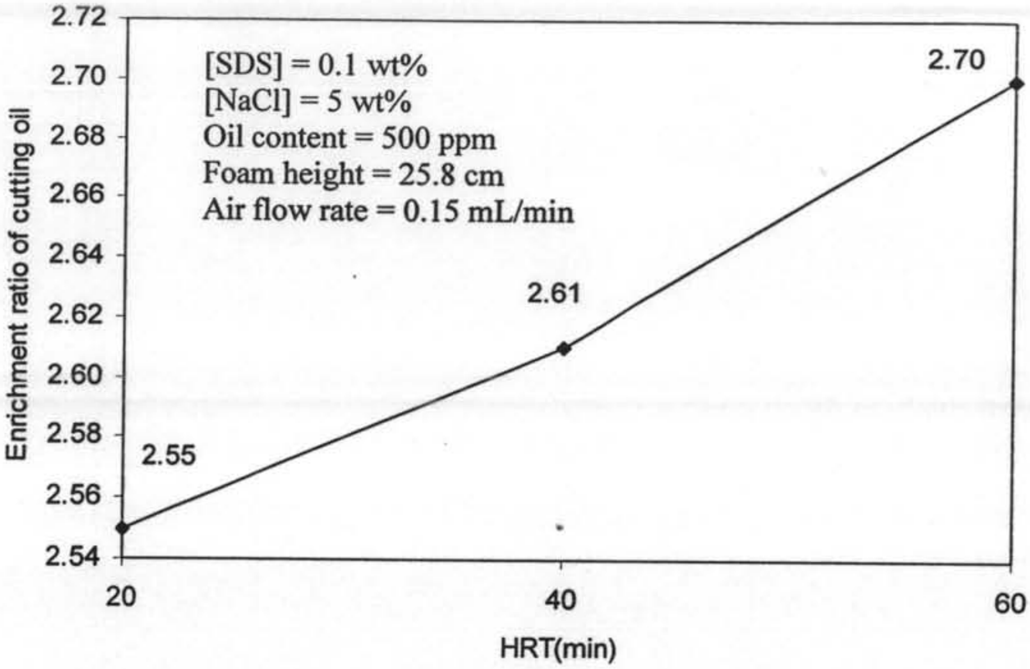

Figure 4.38 Enrichment ratio of cutting oil at different HRTs.

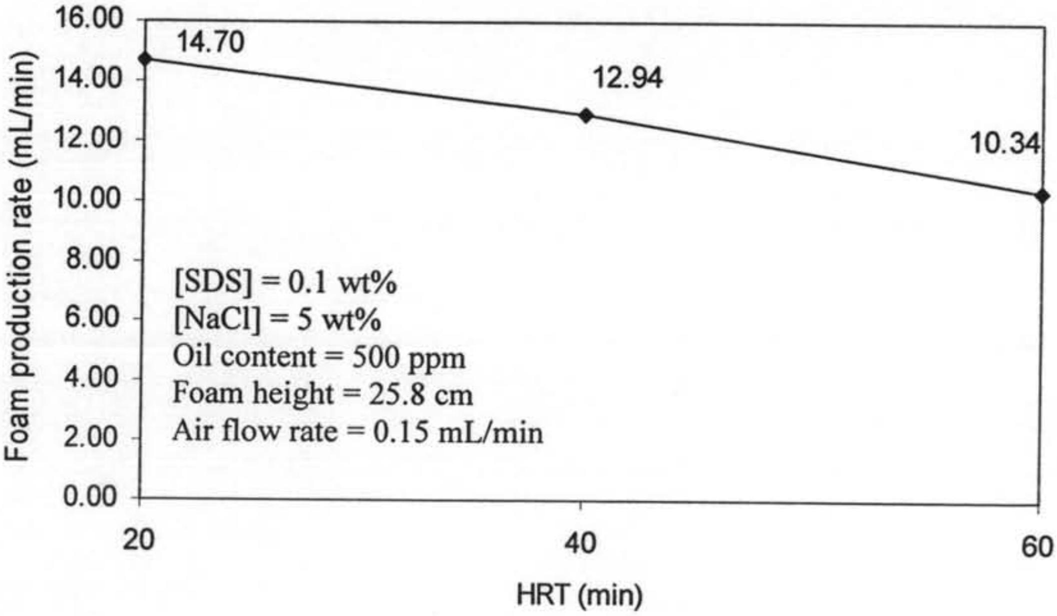

Figure 4.39 Foam production rate of system at different HRTs

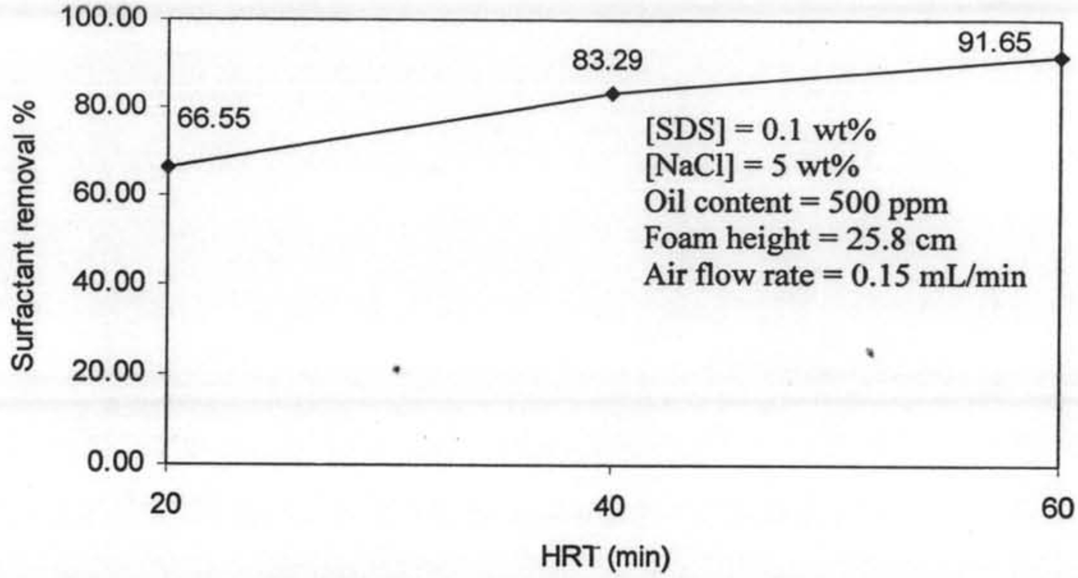

Figure 4.40 Surfactant removal of system at different HRTs.

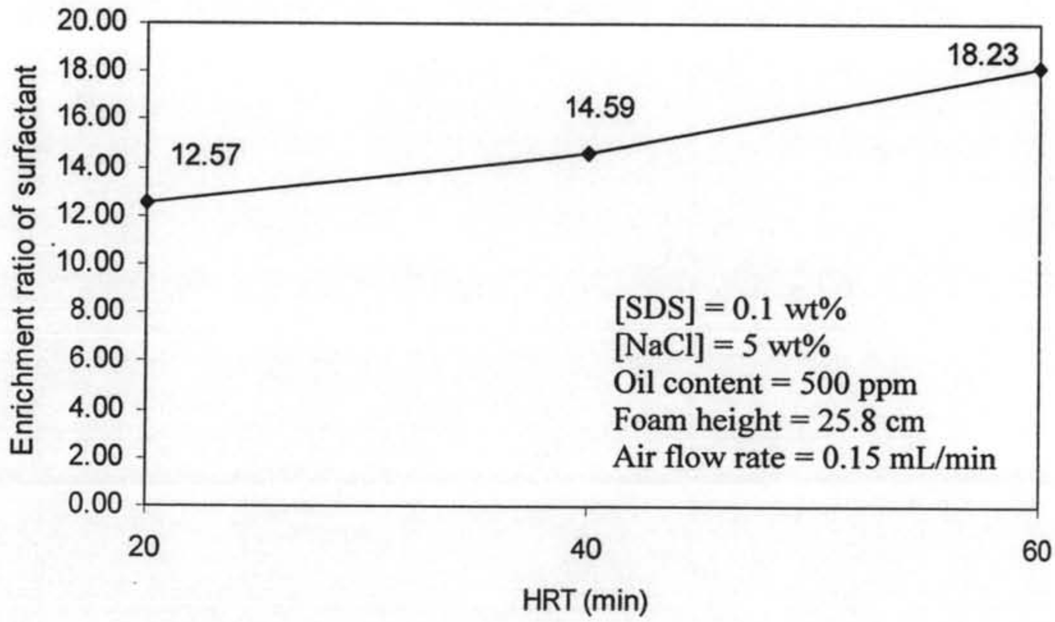

Figure 4.41 Enrichment ratio of surfactant of system at different HRTs.

4.2.5 Effect of Foam Height on the Performance of Froth Flotation

Foam height is also a parameter affecting the performance of froth flotation operation. Figure 4.42 shows an increase in foam height resulting in decreasesing oil removal efficiency. When a foam height increases, a foam production rate decreases as shown in Figure 4.43. This is because the foam produced tends to collapse more easily and so the possibility that more oil is entrained back into the solution causing a lower oil removal efficiency.

Moreover, a contrast trend of enrichment ratio of oil was found. As can be seen from Figure 4.44, the enrichment ratio of oil increases as the foam height increases because when the foam height increases leading to lower foam production rate as shown in Figure 4.43 resulting in a higher rate of the water back entrainment. Hence, the foam produced contains a lower amount of water or a higher enrichment ratio of oil.

As can be seen from Figure 4.45, the surfactant removal decreases as the foam height increases. This is because at high foam height leading to a low foam production rate as shown in Figure 4.43. As a result from having a high water back-entrainment into the solution in the column, there is a high possibility that surfactant is entrained back into the solution in the column. Hence, the surfactanrt removal efficiency decreases with increasing foam height.

Moreover, the enrichment ratio of surfactant increases when the foam height increases as illustrated in Figure 4.46. This is because when foam height increases leading to a low foam production rate as shown in Figure 4.43. Consequently, the rate of water back entrainment increases and, so foam contains a lower amount of water or high enrichment ratio of surfactant in the collapsed froth is obtained.

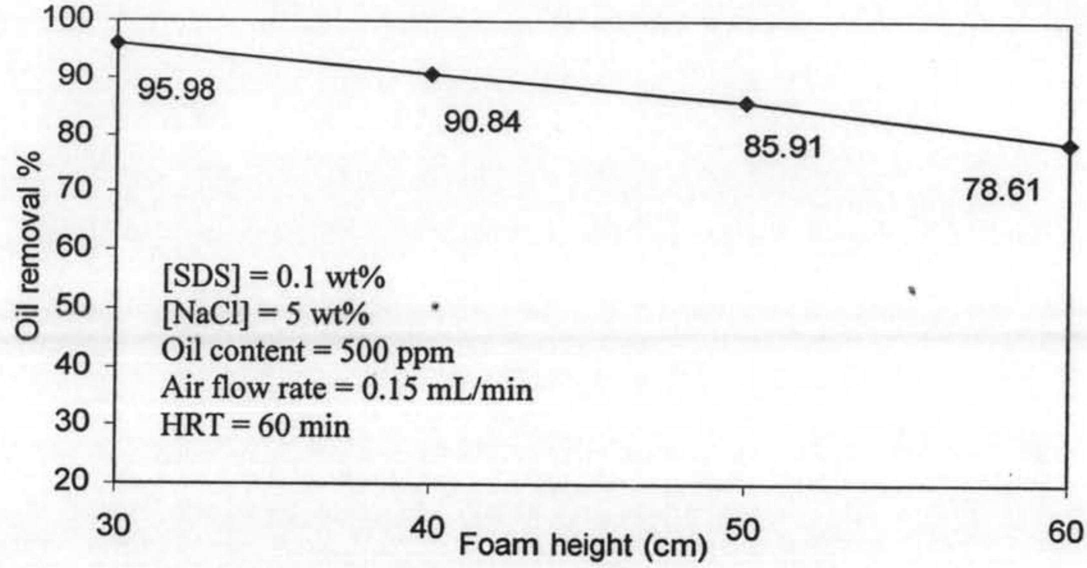

Figure 4.34 Oil removal of system at different foam heights.

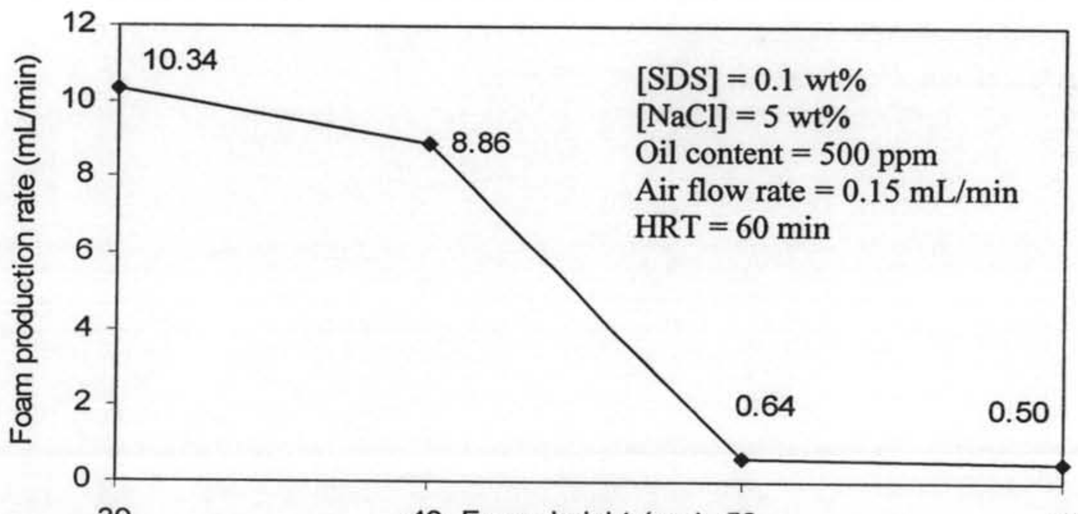

Figure 4.35 Foam production rate of system at different foam heights.

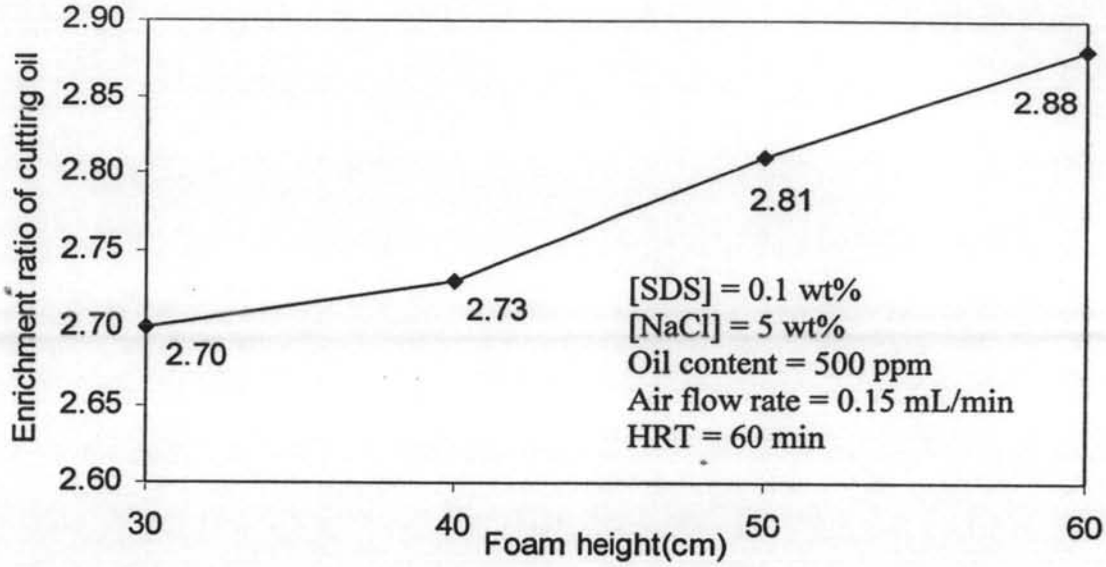

Figure 4.36 Enrichment ratio of cutting oil of system at different foam heights.

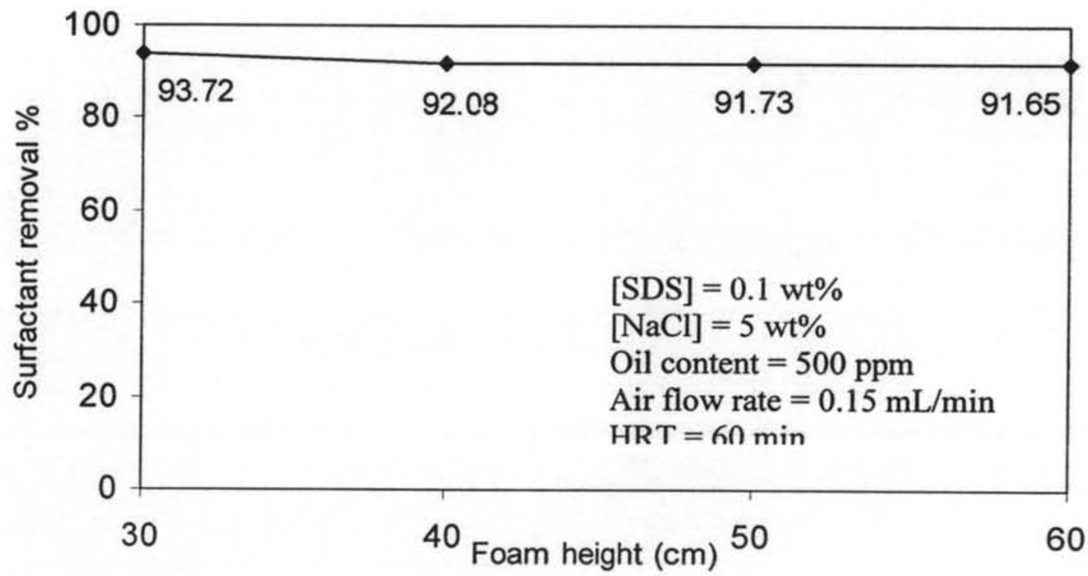

Figure 4.37 Surfactant removal of system at different foam heights.

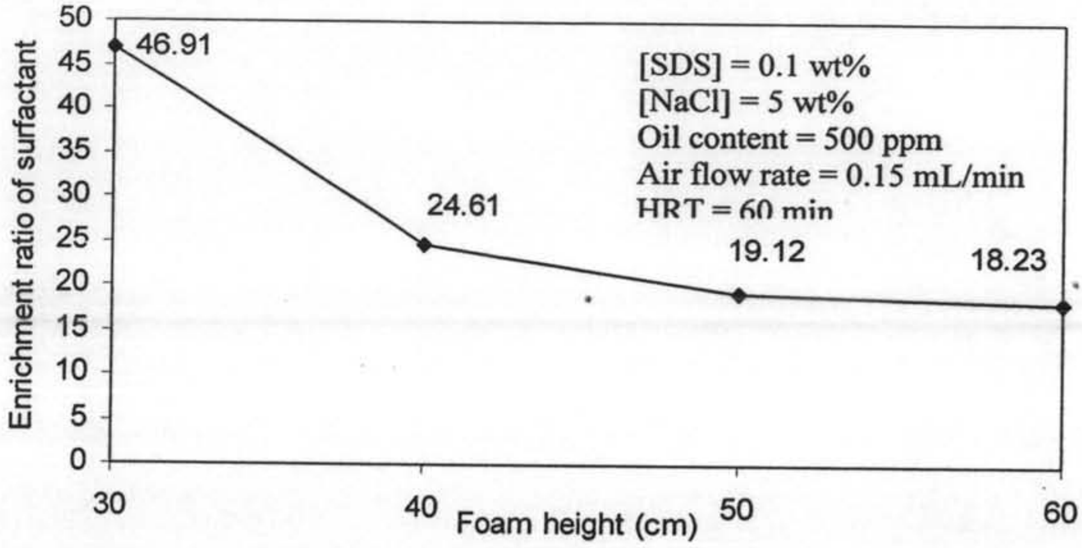

Figure 4.38 Enrichment ratio of surfactant of system at different foam heights.