CHAPTER IV
RESULTS AND DISCUSSION

4.1 Microemulsion Formation Study

Winsor Type III microemulsion exhibits the excellent detergency performance (Tongcumpou *et al.,* 2003); therefore, to seek the suitable surfactant formulation had to be concerned first. In this study, the microemulsion formation of monoglyceride was studied by using mixed surfactants containing an extended surfactant— $C_{12,13}$–4PO–SO_4Na as main surfactant, 1-dodecanol as lipophilic linker, and SMDNS as hydrophilic linker. Both lipophilic and hydrophilic linkers were employed because the linker molecules can enhance the interaction between surfactant and oil; hydrophilic linker increase the water solubility of the surfactant and lipophilic linker causes the enhancement of the interaction between surfactant and oil phase and also causes the reduction of the used salinity for phase transformation as well (Acosta *et al.*, 2002).

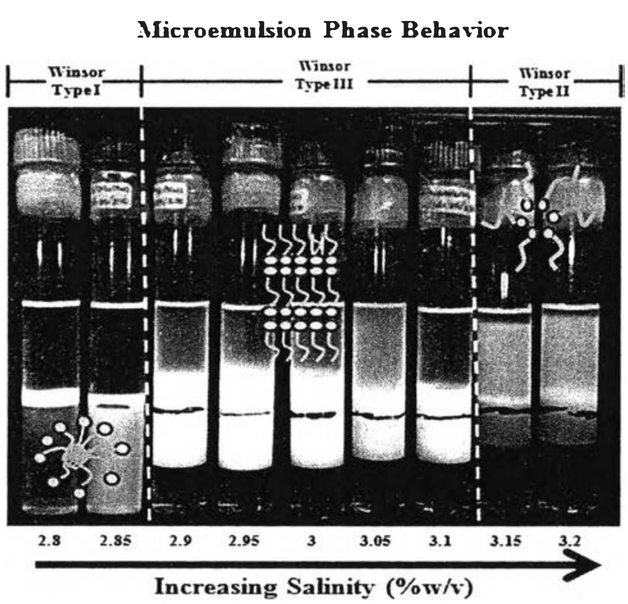

Figure 4.1 The phase behaviors of microemulsions of methyl palmitate with mixed surfactants (55 part of $C_{12,13}$–4PO–SO_4Na, 41 part of 1–dodecanol, and 4 part of SMDNS) as a function of salinity at 40 °C.

To investigate the effect of salinity on the microemulsion formation, microemulsions phase behaviors of monoglyceride (methyl palmitate) with the selected formulation (55 part of $C_{12,13}$–4PO–SO_4Na, 41 part of 1–dodecanol, and 4 part of SMDNS) as a function of salinity was performed at a surfactant solution–to–monoglyceride ratio of 1:1 at 40 °C. The results were obviously observed that the types of microemulsion were transformed from Winsor Type I to Type III and Type II with increasing salinity. The system revealed that at 3 %w/v NaCl concentration, Winsor Type III microemulsion was obtained as shown by the highest volume of the middle phase, which has high solubilization capacity and low interfacial tension (IFT) (Solans *et al.,* 1992). The result suggests that increasing salinity causes the system become more hydrophobicity or more surfactant moving out from the water phase to the oil phase (Komesvarakul *et al.,* 2006). In addition, the addition of NaCl helps to reduce IFT since NaCl reduces the repulsive force between the charged ionic surfactant head groups which can lead to decreasing the CMC and increasing the aggregation number (Rosen, 2004). Therefore, 3 %w/v NaCl concentration was selected as the optimum salinity to further study the detergency experiment.

4.2 Detergency Performance Study

4.2.1 Correlation of Microemulsion Formation and Detergency Performance

The correlation of the phase behavior of microemulsion systems and detergency performance has reported that the maximum detergency corresponds to the optimum condition in a Winsor Type III system. (Tongcumpou *et al.,* 2005).

4.2.1.1 Effect of total surfactant concentration

As mentioned before the results of microemulsion formation study, a formulation of 55 part of $C_{12,13}$–4PO–SO_4Na, 41 part of 1–dodecanol, and 4 part of SMDNS at 3%w/v NaCl, was selected for detergency experiment. The study for optimum total surfactant concentration of the selected formulations was considered. Figure 4.2 shows the percentage of detergency as a function of surfactant concentration. From this result, the percentage of detergency increased with an increasing in surfactant concentration until it reached a maximum monoglyceride removal at 0.3 %w/v total surfactant concentration. At this concentration, the maximum detergency of monoglyceride removal was obtained at 26.75 %.

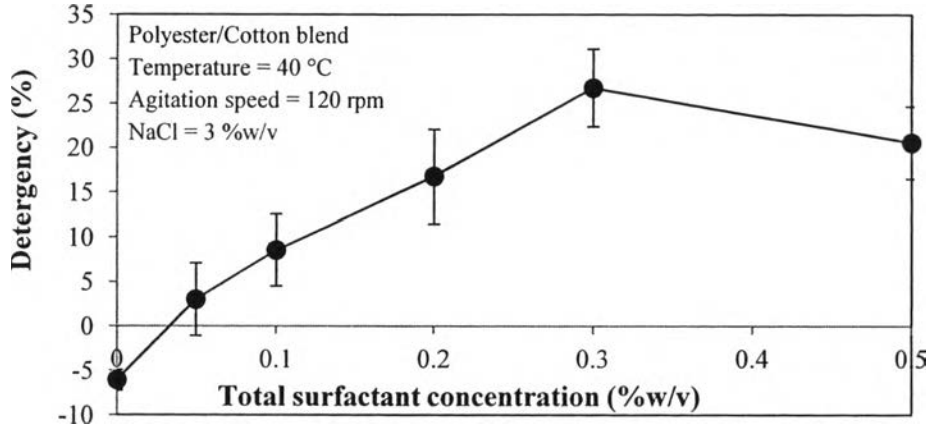

Figure 4.2 Detergency performance of monoglyceride as a function of total surfactant concentration under Winsor Type III microemulsion.

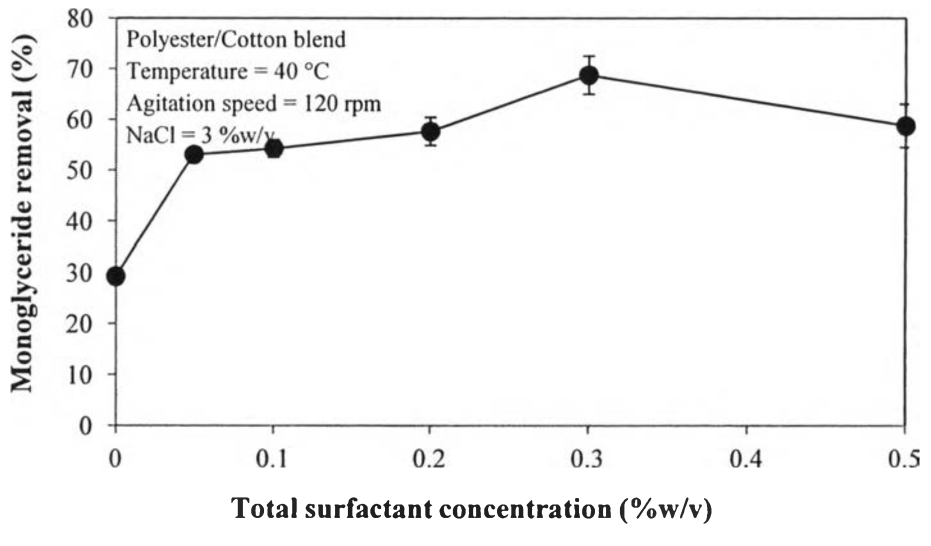

Figure 4.3 Monoglyceride removal as a function of total surfactant concentration under Winsor Type III microemulsion.

Moreover, the cleaning efficiency of monoglyceride oily soil can also be determined from the amount of attached monoglyceride oily soil residue on the fabric in order to calculate the amount of monoglyceride oily soil removal in terms of the percentage of monoglyceride removal as shown in Figure 4.3. The result showed the similar trend as determining by the change in reflectance (the percentage of detergency). The percentage of monoglyceride removal increased with increasing total surfactant concentration and reached the maximum monoglyceride removal at 0.3 %w/v total surfactant concentration which given 65.8% of monoglyceride removal. Beyond the 0.3 %w/v total surfactant concentration, the monoglyceride removal decreased slightly with increasing total surfactant concentration. The results can be described that the increase in surfactant concentration caused increasing in micelle concentration, which resulting in higher oil solubilization. In addition, the monoglyceride re-deposition on the fabrics decreased with increasing total surfactant concentration up to 0.3 %w/v. However, with further increasing total surfactant concentration above 0.3 %w/v, the monoglyceride re-deposition slightly increased.

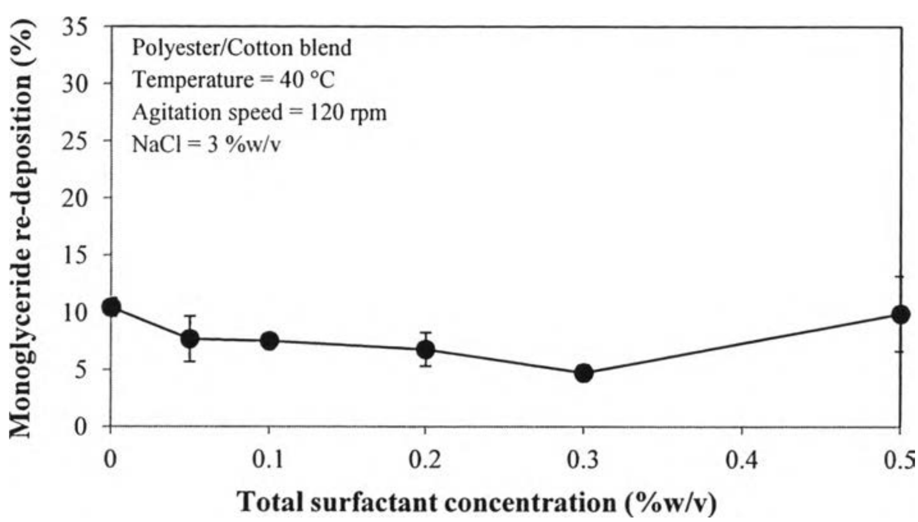

Figure 4.4 Monoglyceride re-deposition as a function of total surfactant concentration under Winsor Type III microemulsion.

4.2.1.2 Effect of salinity

To investigate the effect of salinity on the detergency performance, in order to confirm that the optimum salinity of microemulsion formation is a maximum detergency performance. Figure 4.5 shows the percentage of detergency as a function of salinity at 0.3 %w/v total surfactant concentration. The results showed that at salinity lower than 3 %w/v, the percentage of detergency increased with increasing salinity. Once the salinity exceeded 3 %w/v, the detergency performance slightly decreased. The percentage of detergency showed the negative results at very low sodium chloride concentration, because the soiled fabric exhibited the darker color after washing due to the lower of monoglyceride removal.

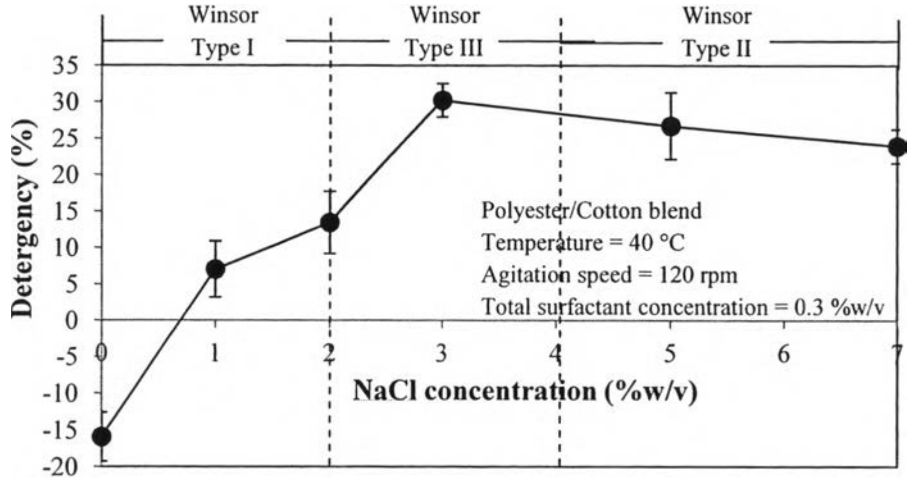

Figure 4.5 Detergency performance of monoglyceride as a function of salinity with 0.30 %w/v total surfactant concentration under 40 °C of washing temperature.

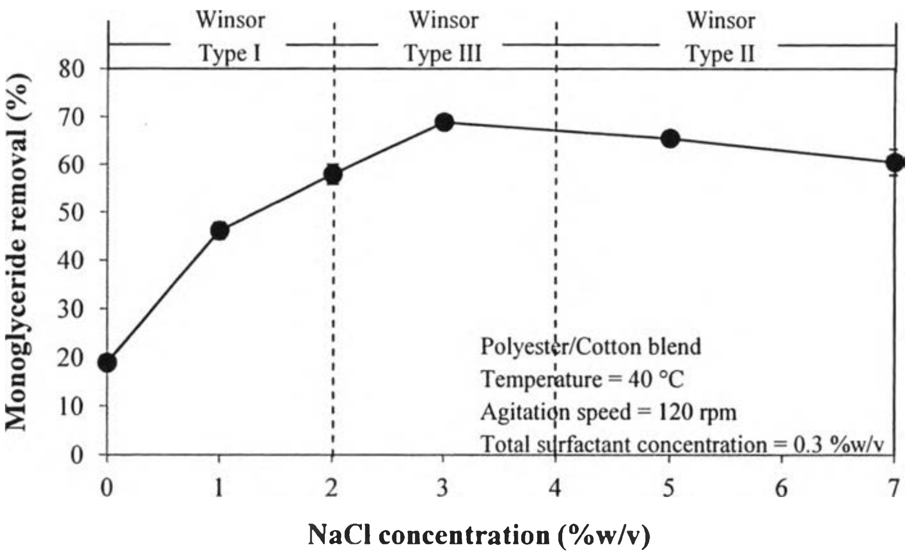

Figure 4.6 Monoglyceride removal as a function of salinity with 0.30 %w/v total surfactant concentration under 40 °C of washing temperature.

Figure 4.6 shows the percentage of monoglyceride removal increased with increasing salinity and reached a maximum at 3 %w/v NaCl. The results can be explained by the fact that the presence of counterion from the added salt is responsible for the reduction of repulsive force between head group of anionic surfactant molecules. As a result, there is a higher adsorption density of surfactant at the interface between washing solution and dispersed soil, leading to the reduction in the free energy at the interface (Tongcumpou *et al.*, 2003). Beyond the 3 %w/v NaCl, the oil removal decreased slightly with further increasing salinity. The result can explained that at high salinity, can increase in repulsion force between the head group of surfactant, leading to increasing CMC and negative effect on micellization (Butt *et al.*, 2006). Figure 4.6 shows the effect of salinity on monoglyceride re-deposition at 40 °C. The amount of monoglyceride re-deposition on the fabric decreased with increasing salinity up to 3 %w/v. Beyond 3 %w/v NaCl, the oil re-deposition increased with further increasing NaCl concentration. The results confirm that the maximum monoglyceride removal was found at Winsor Type III microemulsion corresponding to the optimum salinity. Therefore, the condition of 3 %w/v of NaCl and 0.3 %w/v of total surfactant concentration were selected as the optimum formulation.

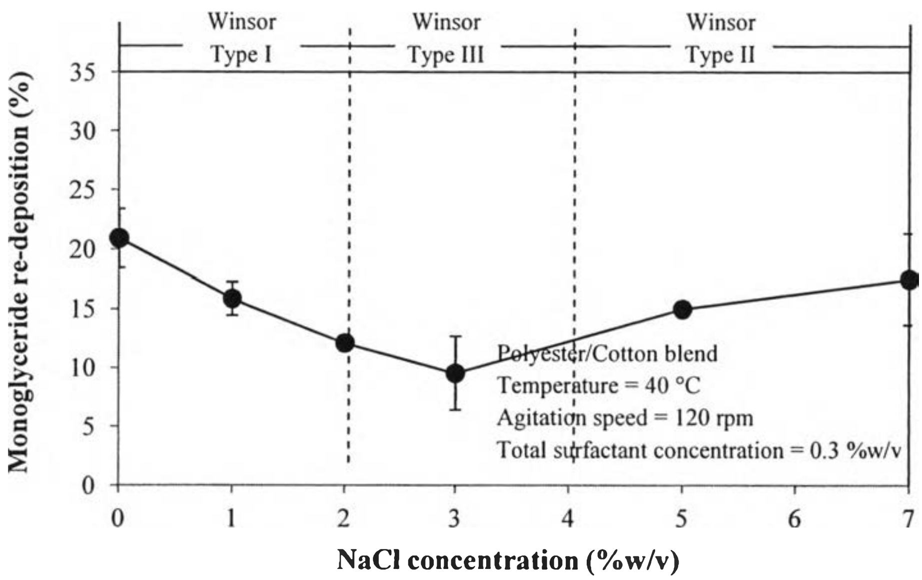

Figure 4.7 Monoglyceride re-deposition as a function of salinity with 0.30 %w/v total surfactant concentration under 40 °C of washing temperature.

4.2.1.3 Effect of washing temperature

On the effect of temperature on the detergency performance, it was focused on the selected formulation at 0.3 %w/v total surfactant concentration and 3 %w/v

NaCl, as a function of washing temperature. Figure 4.8 shows the percentage of monoglyceride removal increased with increasing washing temperature since an increase in temperature directly enhance oil mobilization due to the reduction of oil viscosity (Tanthakit *et al.*, 2010). This may be another reason for the slightly better detergency performance of the selected formulation. Figure 4.9 shows the percentage of oil re-deposition decreases slightly with increasing washing temperature.

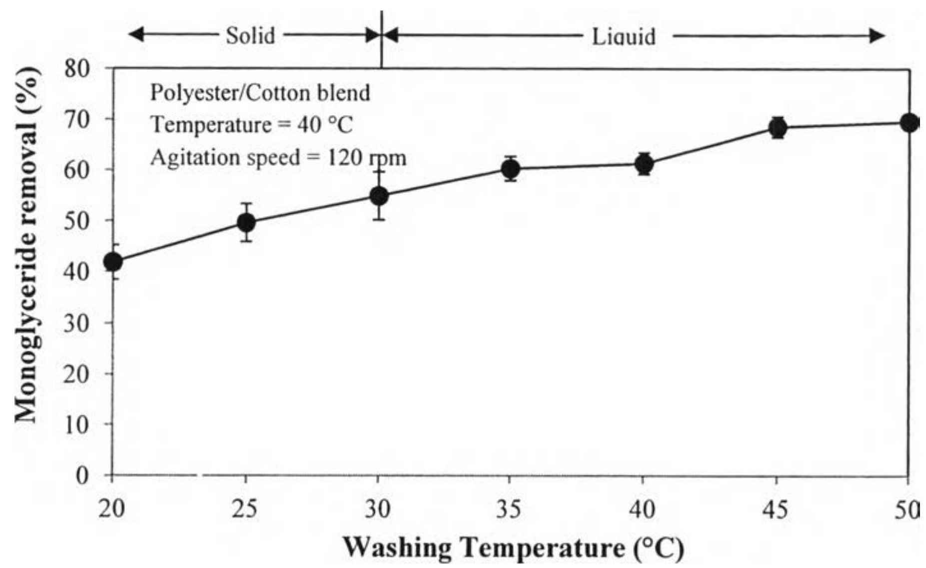

Figure 4.8 Monoglyceride removal as a function of washing temperature using the selected formulation (0.3 %w/v total surfactant concentration and 3 %w/v NaCl).

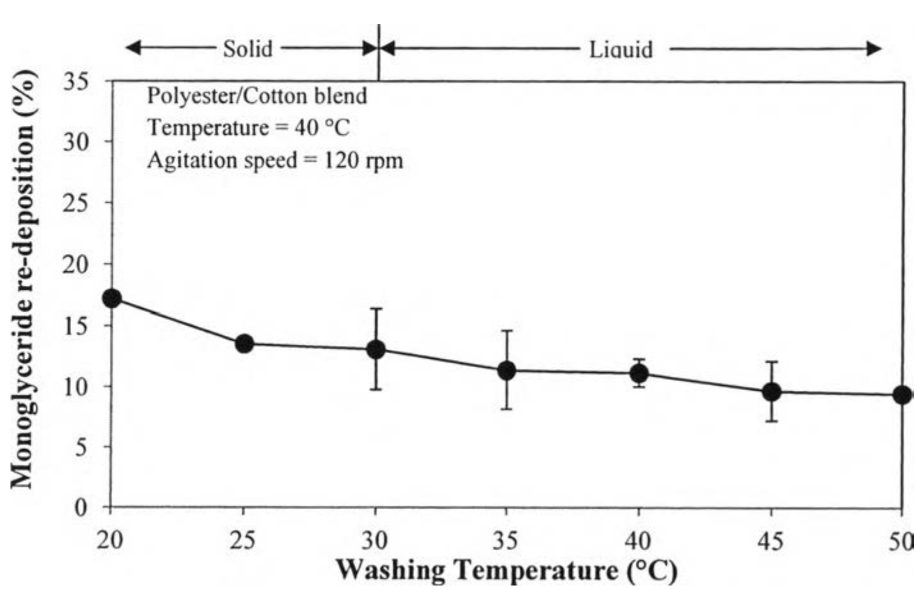

Figure 4.9 Monoglyceride re-deposition as a function of washing temperature using the selected formulation (0.3 %w/v total surfactant concentration and 3 %w/v NaCl).

4.2.2 Effect of Type of fabrics on detergency performance

The effect of fabric types was also study on detergency performance which are polyester/cotton blend and pure polyester Figure 4.10 shows the monoglyceride removal at different washing temperature for the polyester/cotton blend and pure polyester using the selected formulation at 0.3 %w/v total surfactant concentration and 3 %w/v NaCl. For any given fabric types, the percentage of monoglyceride removal increased with increasing washing temperature. This result can be explained that increasing of temperature direct to enhance oil mobilization since the reduction of oil viscosity (Tanthakit *et al.*, 2010). Among the studied fabrics, the polyester/cotton blend fabric showed the higher removal efficiency when compare with pure polyester. The results can be explained by the fact that the polyester/cotton blend fabric is a mix of pure polyester fabric and pure cotton fabric. In addition, the structure of cotton contains hydroxyl groups which highly polar and so it is easy to swell in water, resulting in lowering the oil-cotton surface interaction, and the amount of surfactant adsorbing the cotton surface was higher than that on the polyester surface. In the case of the polyester fabric, the interaction between the oil and polyester fabric is much higher than that of oil and cotton. Thus, the polyester/cotton blend fabric was affected from the structure of cotton. So, the polyester/cotton blend show higher detergency efficiency. The results of monoglyceride re-deposition show a similar trend for both types of fabric in surfactant solution, as shown in Figures 4.11. For any given fabric types, the percentage of monoglyceride re-deposition decreased with increasing washing temperature.

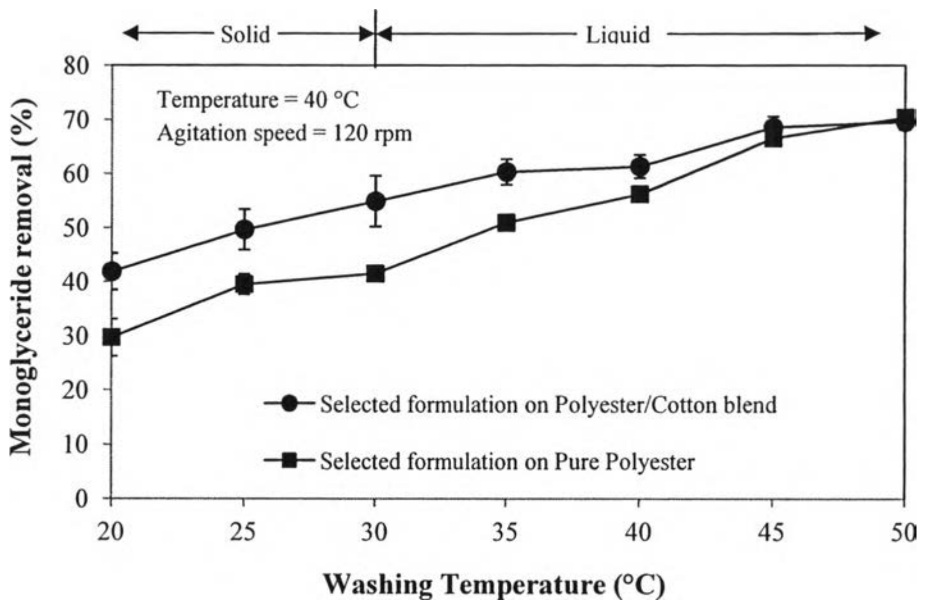

Figure 4.10 The correlation of monoglyceride removal (%) with various types of fabrics as a function of washing temperature using the selected formulation (0.3 %w/v total surfactant concentration and 3 %w/v NaCl).

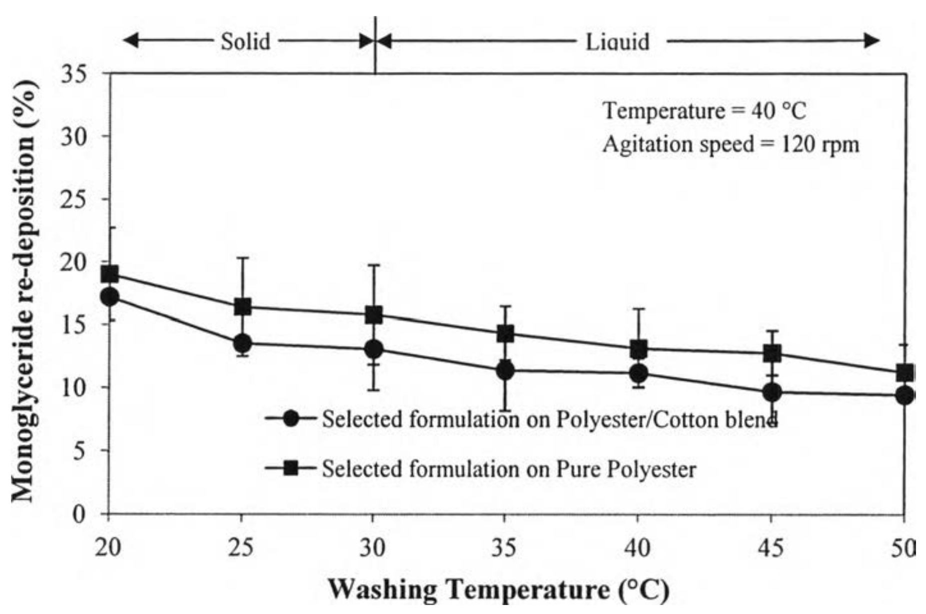

Figure 4.11 The correlation of monoglyceride re-deposition (%) with various types of as a function of washing temperature using the selected formulation (0.3 %w/v total surfactant concentration and 3 %w/v NaCl).

4.2.3 Comparison of selected formulation and commercial detergent

The detergency performance of the selected formulation was compared with the commercial liquid detergent, which name is Breeze Excel Liquid, as a function of surfactant concentration. Figure 4.12 shows the detergency performance of the commercial was lower than the selected formulation at the same total surfactant concentration. In addition, the monoglyceride re-deposition of the commercial was higher than the selected formulation at the same total surfactant concentration. This result can be confirmed that the selected formulation can improve the detergency performance.

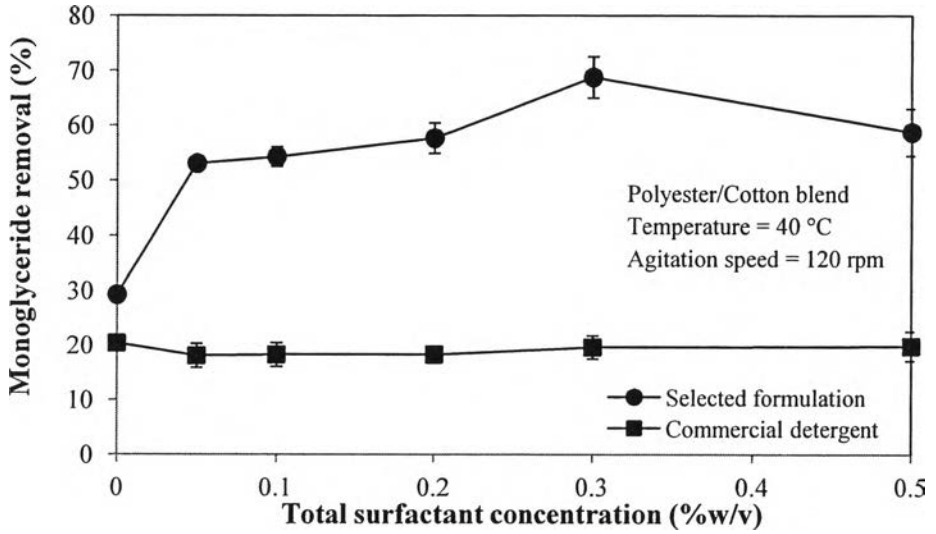

Figure 4.12 Monoglyceride removal as a function of total surfactant concentration of selected formulation and commercial detergent.

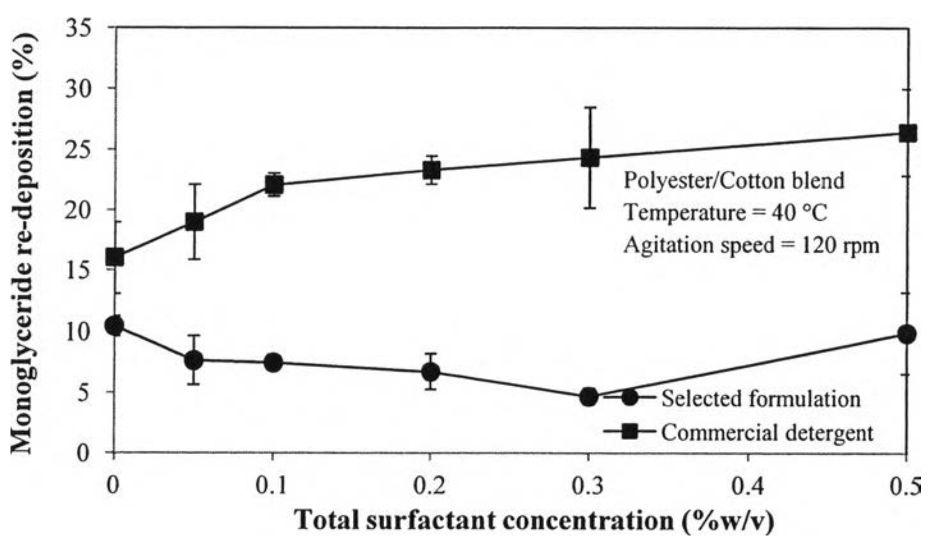

Figure 4.13 Monoglyceride re-deposition as a function of total surfactant concentration of selected formulation and commercial detergent.

4.3 Correlation of dynamic interfacial tension (IFT) and monoglyceride removal

The dynamic IFT values between the washing solution and the oil (methyl palmitate) at different salinities and temperatures were also studied. Figure 4.14 shows the correlation of dynamic IFT and oil removal efficiency on both test fabrics using a $C_{12,13}$-4PO-SO_4Na concentration of 0.3 wt% and 40°C. For any given type of fabrics, the maximum oil removal was found to at the optimum NaCl concentration of 3 wt% which corresponded to the lowest dynamic IFT. Figure 4.15 shows the correlation of oil removal and dynamic IFT at different washing temperature. The results showed that at a temperature lower the melting point (30 °C), the detergency efficiency decreased because the oil was in a solid state. When increasing the temperature, the detergency efficiency was increased because the dynamic IFT at this region are ultralow interfacial tension.

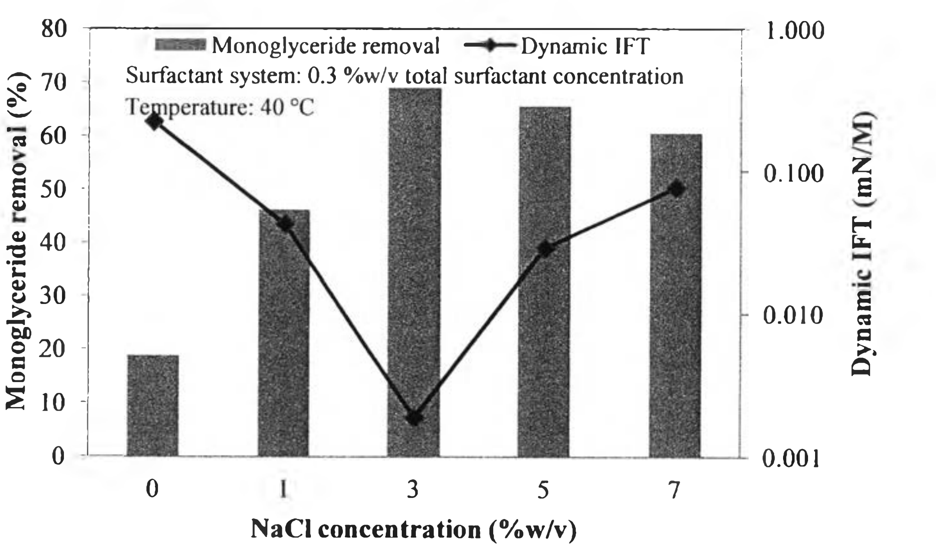

Figure 4.14 The monoglyceride removal and dynamic IFT at different salinities above melting point.

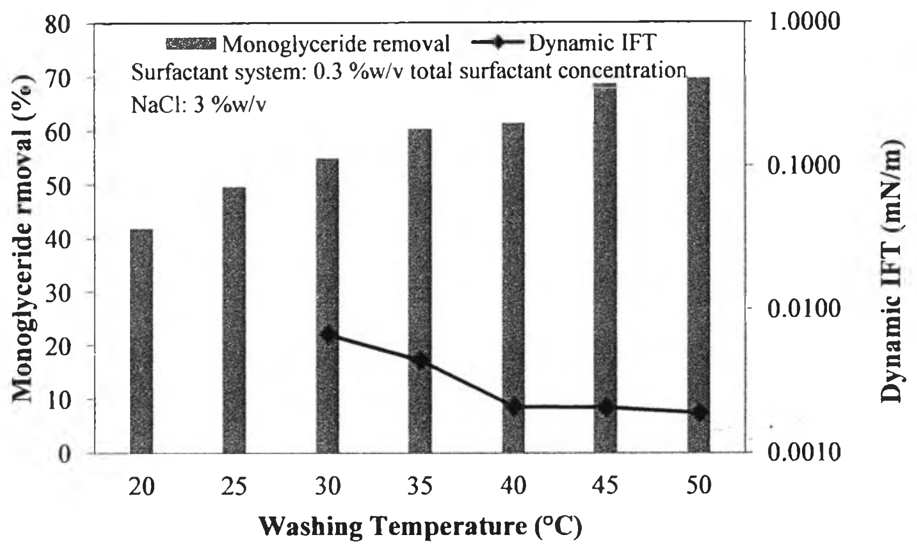

Figure 4.15 The monoglyceride removal and dynamic IFT at different temperatures above the melting point.

4.4 The critical micelle concentration (CMC) value

Figure 4.16 shows the surface tension and log surfactant concentration for selected formulation at 25 °C and 40 °C, respectively. When added salt into surfactant solution, the CMC value was lower than that without salt at 25 °C (1000 µM for selected formulation added 3 %w/v NaCl and 1200 µM for selected formulation without salt). When increasing the temperature to 40 °C, the CMC value insignificant as shown in Figure 4.17. In 2006, Witthayapanyanon *et al.*, studied the CMC values at various extended surfactants and they found that all extended surfactants had the CMC values much lower than conventional surfactants. Moreover, they also observed the CMC values of extended surfactants with added salt, and they reported that the CMC values decreased for all surfactant systems with added salt.

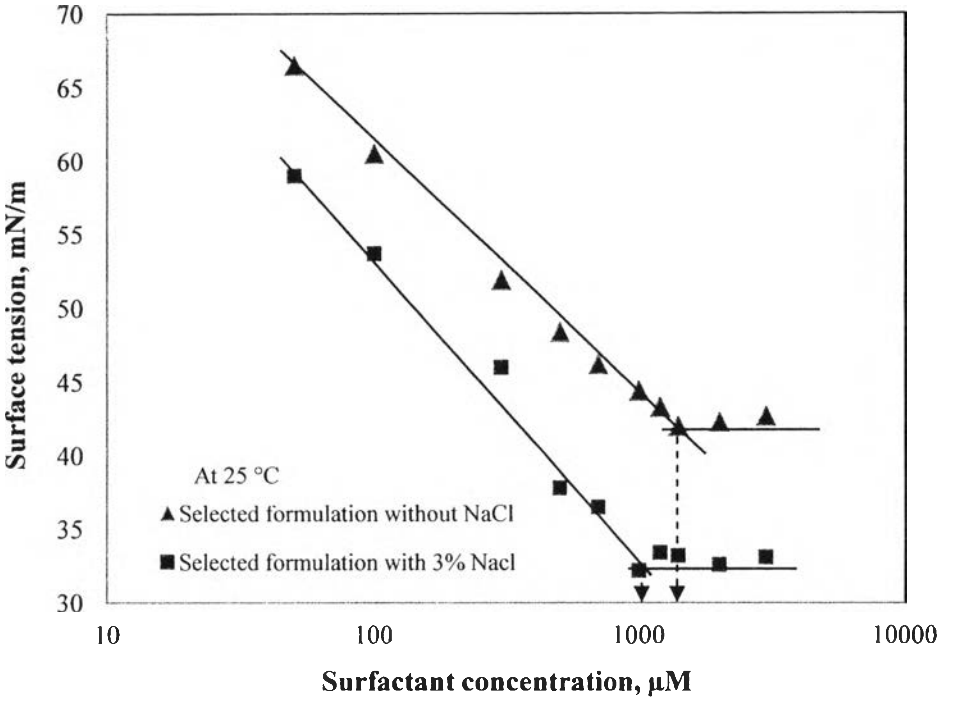

Figure 4.16 Surface tension of selected formulation without salt and with 3 %w/v NaCl at 25 °C.

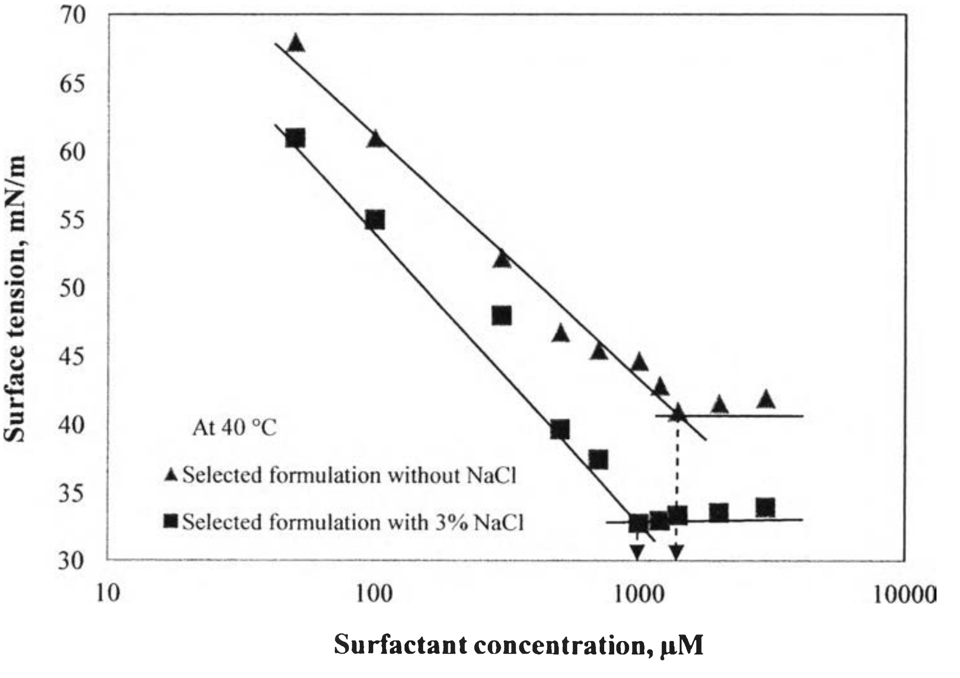

Figure 4.17 Surface tension of selected formulation without salt and with 3 %w/v NaCl at 40 °C.

4.5 pH Results

Effect of pH to mixed surfactant system was showed in Table 4.1. The result showed that pH values is insignificant system because before and after the washing experiments of mixed system did not change.

Table 4.1 pH values of mixed surfactant solutions at various concentration

Total surfactant concentration (%w/v)		Wash	Rinse 1	Rinse 2
0.00	Prewash	6.08	6.08	6.08
	Postwash	5.95	5.88	5.88
0.05	Prewash	6.30	6.08	6.08
	Postwash	6.18	5.97	6.10
0.10	Prewash	6.09	6.08	6.08
	Postwash	6.00	6.31	6.38
0.20	Prewash	5.56	6.08	6.08
	Postwash	5.53	6.09	6.28
0.30	Prewash	5.07	6.08	6.08
	Postwash	5.07	6.19	6.26
0.50	Prewash	4.62	6.08	6.08
	Postwash	4.62	6.02	6.21