

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Determination of Cloud Point

The cloud points of NP(EO)₈, NP(EO)₉, and NP(EO)₁₀ at the concentration of 0.02 M are shown in Table 4.1. The cloud point increases with the increase in the number of ethylene oxide in the surfactant molecule. This is because the increase in the number of ethylene oxide increases the surfactant solubility (Michael and Irene, 1993).

Table 4.1 Cloud points of the surfactants used.

Concentration (M)	Cloud point of nonionic surfactants (°C)		
	NP(EO) ₈	NP(EO) ₉	NP(EO) ₁₀
0.02	23	54	66

From the technical data published by Rhone-Poulenc, the cloud points of 1 wt% solutions of NP(EO)₈, NP(EO)₉, and NP(EO)₁₀ are given at 22-28°C, 52-53°C, and 60-65°C respectively. Since the 0.02 M of the three surfactant solutions are higher than the concentration of 1 wt%(See Appendix E for equivalent concentration in wt% and M), it can be said that the cloud points obtained in this work are in the same range as the ones quoted by the manufacturer.

4.2 Effect of Temperature on Foamability Below and Above the Cloud

Point

The effect of temperature on foamability of NP(EO)₈, NP(EO)₉, and NP(EO)₁₀ is shown in Figures 4.1-4.3.

The foam height at 0 minute represents the foamability of the solution. In the case of NP(EO)₈, foam height is high at the temperature below the cloud point and decreases dramatically at the temperature above the cloud point. In the case of NP(EO)₉ and NP(EO)₁₀, foam height is high and slightly decreases with the increase in temperature below the cloud point and then reduces dramatically above the cloud point. There is however a sharp increase of foam height at the cloud point. The results show that the cloud point plays an important role in the foamability of nonionic surfactants. At the cloud point, there is enough energy to break hydrogen bonding between the oxy groups in the ethylene oxide chains and water molecules which are responsible for the prevention of the surfactant molecule comes together. This lead to the closer packing of surfactant molecule on the surface resulting in the sharp increase in foamability at the cloud point of NP(EO)₉ and NP(EO)₁₀. This is because when more molecules of the surfactant adsorb on the surface causing the higher the Gibbs-Marangoni effects. It is confirmed by the surfactant concentration in foam and the surface tension. The effect of temperature on surfactant concentration in foam and its surface tension are shown in Figures 4.4-4.6.

The results show that the surfactant concentration in foam reaches the maximum at the cloud point, in contrast, the surface tension has the lowest value at the cloud point. The same results are obtained for NP(EO)₉ and NP(EO)₁₀. However, for NP(EO)₈, which is the absence of the sharp increase in the foamability at the cloud point, there is also the absence of the sharp

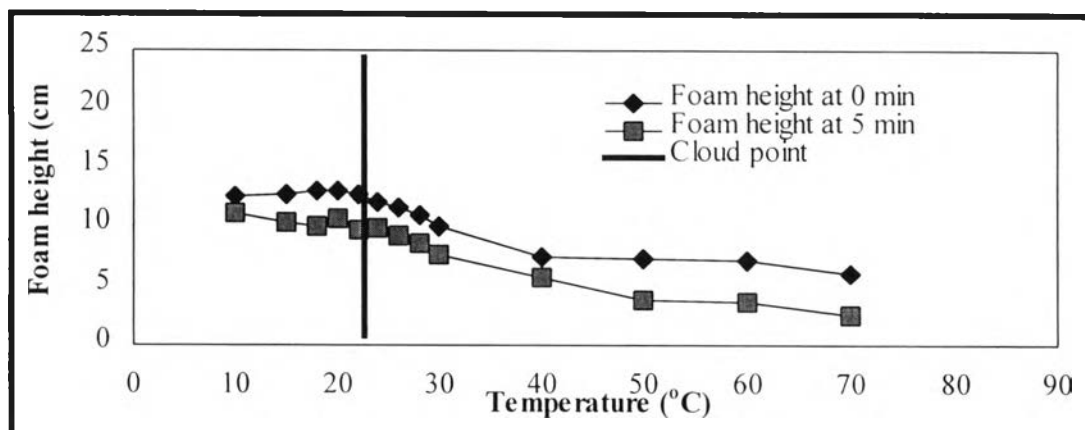


Figure 4.1 Effect of temperature on foamability and foam stability below and above the cloud point of 0.02 M NP(EO)₈.

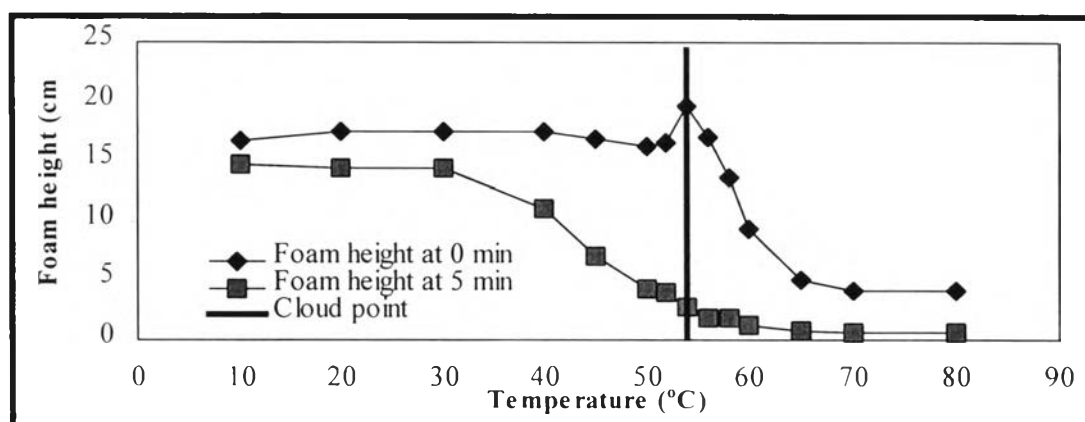


Figure 4.2 Effect of temperature on foamability and foam stability below and above the cloud point of 0.02 M NP(EO)₉.

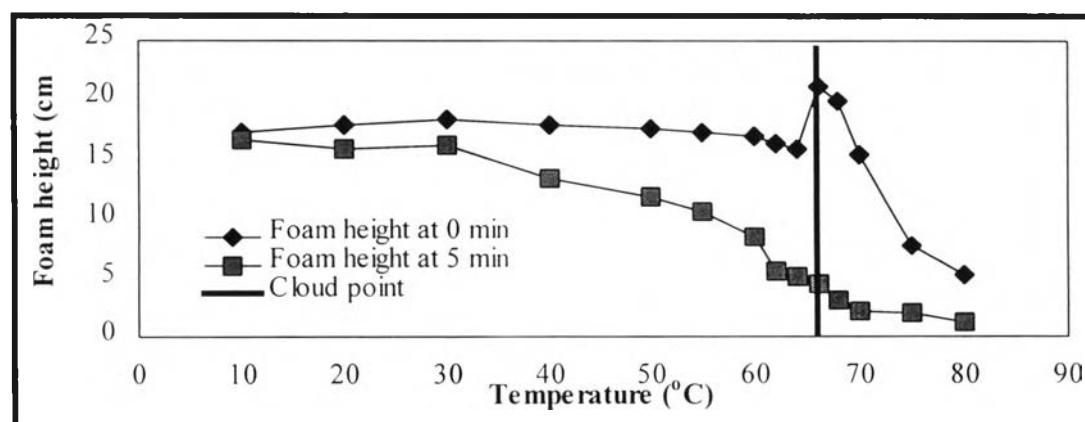


Figure 4.3 Effect of temperature on foamability and foam stability below and above the cloud point of 0.02 M NP(EO)₁₀.

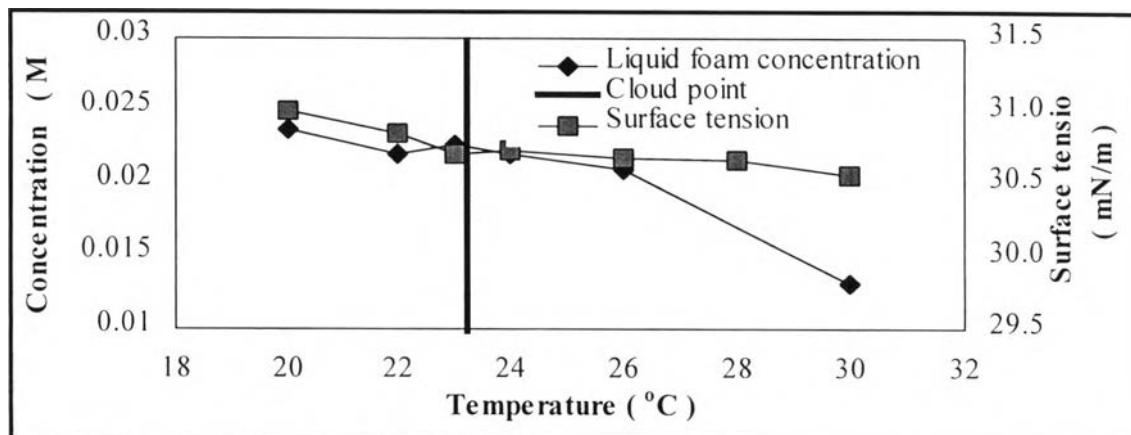


Figure 4.4 Effect of temperature on surfactant concentration in foam and surface tension of NP(EO)₈.

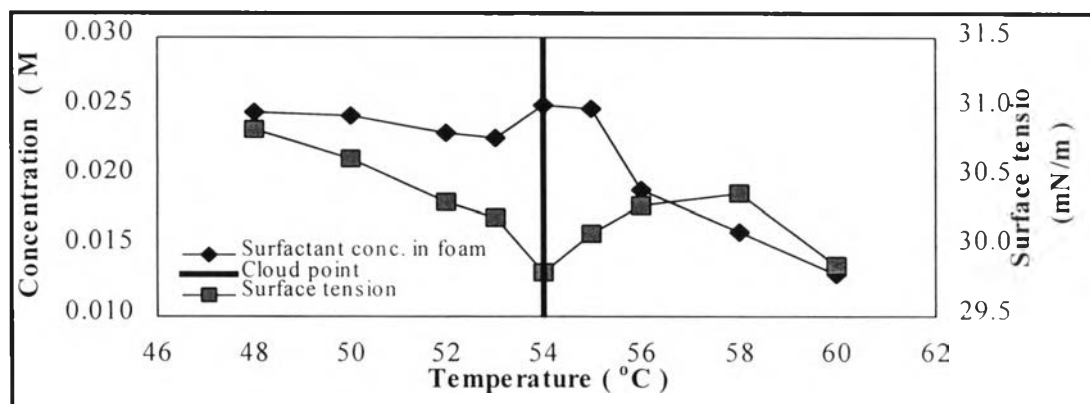


Figure 4.5 Effect of temperature on surfactant concentration in foam and surface tension of NP(EO)₉.

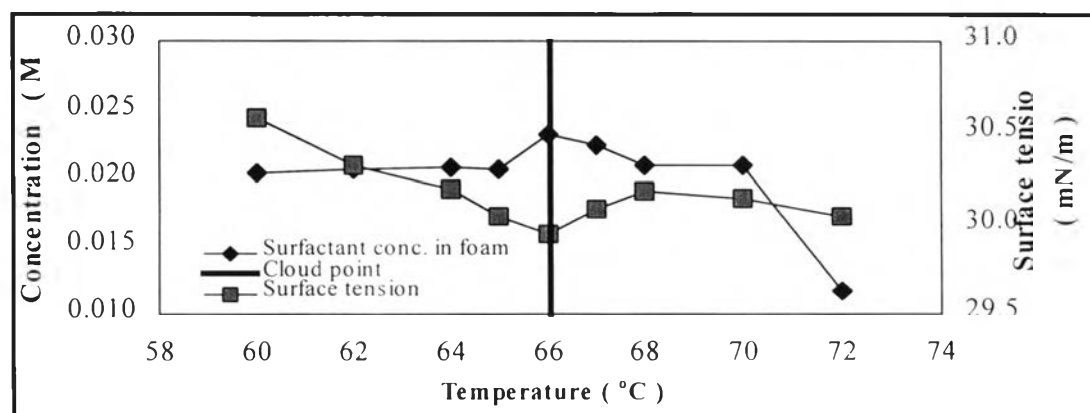


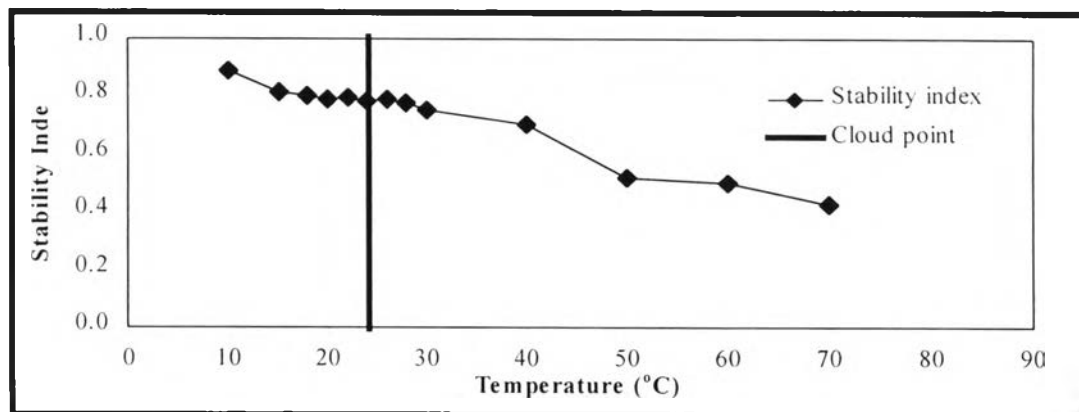
Figure 4.6 Effect of temperature on surfactant concentration in foam and surface tension of NP(EO)₁₀.

increase of the surfactant concentration even though the surface tension has the lowest value at the cloud point. This is because there is already well packing of the surfactant molecules on the surface because the ethylene oxide groups in this surfactant are short resulting in the less water molecules around the ethylene oxide groups. In general, the surface tension decreases with the increase in temperature. At above the cloud point, the nonionic surfactant is separated into two phases, which are a micellar-rich phase and a micellar-poor phase. The micellar-rich phase which is immiscible with the micellar poor phase is believed to act as an antifoam causing a dramatic decrease in foamability above the cloud point (Bonfillon *et al.*, 1997).

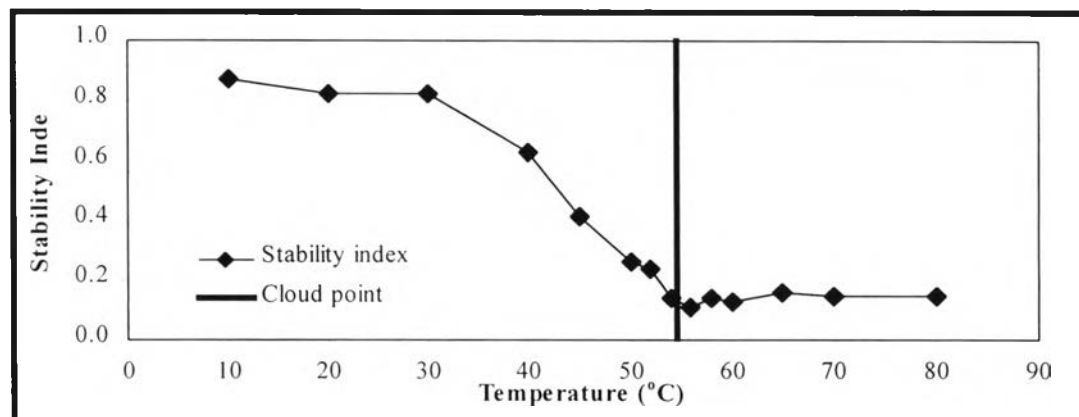
4.3 Effect of Temperature on Foam Stability Below and Above the Cloud Point.

The effect of temperature on foam stability of NP(EO)₈, NP(EO)₉, and NP(EO)₁₀ is shown in Figures 4.7-4.9 where the stability index was plotted against temperature.

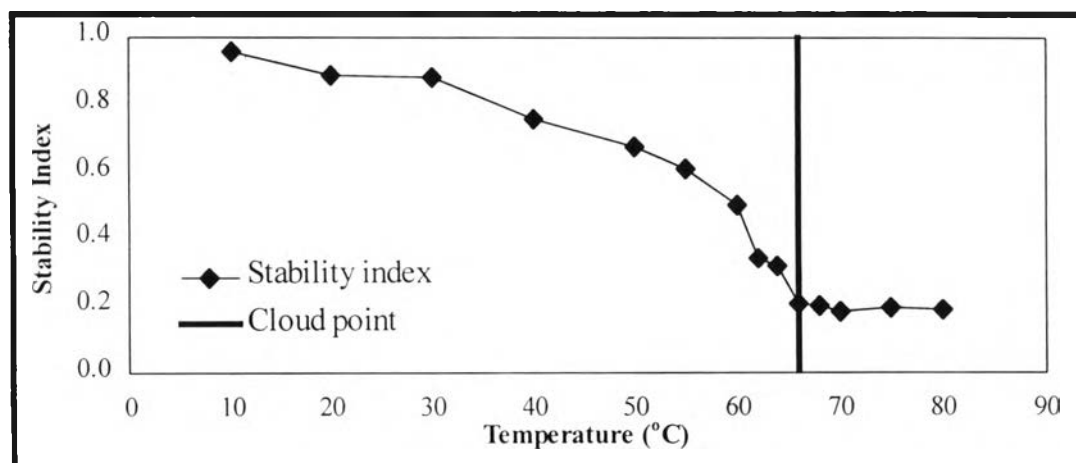
The stability index is defined as the foam height at 5 minutes divided by the foam height at 0 minute. In the case of NP(EO)₈, foam stability is relatively high throughout the whole temperature range, however, the stability index starts to decline at above 30°C from 0.8 to 0.4. As the temperature is increased, in the case of NP(EO)₉ and NP(EO)₁₀, the foam stability index starts to decline at above 30°C from above 0.8 to below 0.2 over the temperature range. The results show that the foam stability of all three surfactants has no particular relation to the cloud point. In this case, the foam stability only depends on the temperature.



Figures 4.7 Effect of temperature on foam stability of NP(EO)₈.



Figures 4.8 Effect of temperature on foam stability of NP(EO)₉.



Figures 4.9 Effect of temperature on foam stability of NP(EO)₁₀.

4.4 Effect of Concentration on Foamability Below and Above the Cloud Point

The effect of surfactant concentration on foamability of NP(EO)₉, is shown in Figures 4.10. It can be seen that, below the cloud point temperature, the foam height increases with the increase in the surfactant concentration over the concentration range. Above the cloud point temperature, the foam height of the solutions increases with the increase in the concentration, then sharply decreases at the concentration with co-exit with the solution becomes cloudy and after that the foam height also increases with the increase in concentration. Although, the foam height at above the cloud point temperature starts to increase with the increase in concentration again from the first concentration at which the solution becomes cloudy, the foam height at this temperature is not high as the foam height below the cloud point at the same concentration. This is because of the presence of the micellar-rich phase in the surfactant solution.

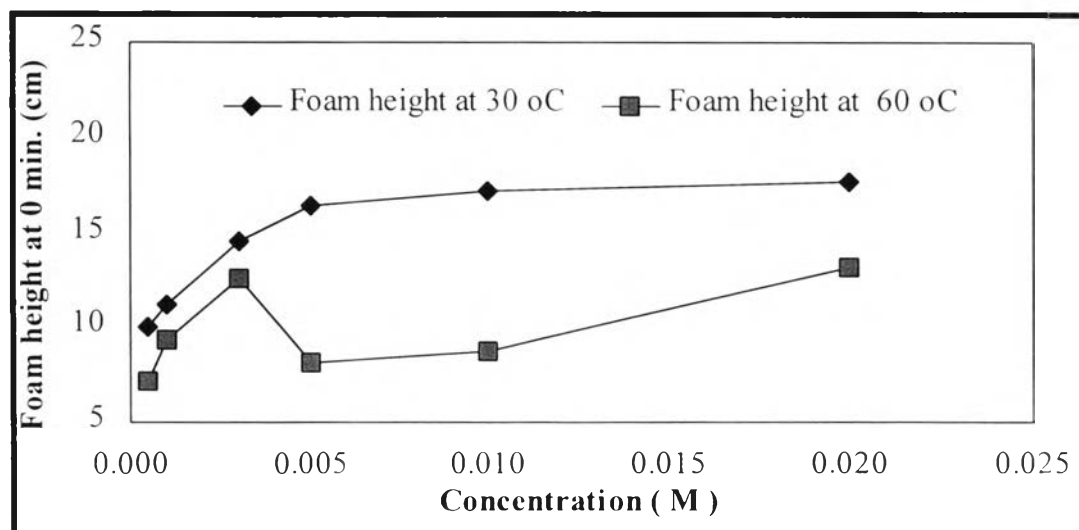


Figure 4.10 Effect of concentration on foamability at temperature below and above cloud point of NP(EO)₉.

4.5 Effect of Temperature on Foamability of the Dilute Phase

The dilute phase of the three surfactants was obtained from the phase separation experiments as described in 3.3.3. Results of the phase separation are shown in Table 4.2.

The results show that the higher the phase separation temperature, the greater the concentration of the coacervate phase and the lower its volume fraction.

Table 4.2 Fractional volume and concentration of dilute phase and coacervate phase.

Surfactants	Temp (°C)	Fractional volume		Concentration (M)	
		Coac. phase	Dilute phase	Coac. Phase	Dilute phase
NP(EO) ₈	25	0.0822	0.9178	0.1075	0.0125
	35	0.0762	0.9238	0.2447	0.0016
	45	0.0520	0.9480	0.3432	0.0020
NP(EO) ₉	55	0.0800	0.9200	0.1638	0.0075
	70	0.0310	0.9690	0.4943	0.0045
NP(EO) ₁₀	70	0.0520	0.9480	0.3105	0.0040

The effect of temperature on foamability of the dilute phase of NP(EO)₈, NP(EO)₉, and NP(EO)₁₀ is shown in Figure 4.11-4.13.

At below the phase separation temperature up to the phase separation temperature, the foam height of the dilute phase is high even though the dilute phase has a very low concentration. This is because the concentration of the dilute phase is higher than the CMC of the surfactant (See Appendix E). The foam height of surfactant solutions usually reaches the maximum at the CMC. At the temperature around the cloud point of the original solution, there is no sharp decrease in the foamability of the dilute phase. The results show that in the absence of the coacervate phase, no foam reduction around the cloud point

occurs. However, at above the phase separation temperature, the foam height of the dilute phase decreases dramatically. This is because the dilute phase again becomes cloudy resulting in the presence of the micellar-rich phase in the solution. The same results are observed for all the three types of nonionic surfactant studied. These results further confirm that the presence of the micellar-rich phase in the solution causes the dramatic reduction of foam above the cloud point.

4.6 Effect of Temperature on Foamability of the Coacervate Phase

The effect of temperature on foamability of the coacervate phase of NP(EO)₈, NP(EO)₉, and NP(EO)₁₀ is shown in Figure 4.14-4.16. The foam height of the coacervate phase increases with the increase in temperature over the temperature range under studied even though the temperature is above the phase separation temperature. The two effects on foamability of the coacervate phase are the new phase separation at above the phase separation temperature (the solution again becomes cloudy) and the viscosity of the coacervate phase. The results show that the foamability of the coacervate does not depend much on the new phase separation, but rather on the viscosity of the coacervate phase. As the temperature increases, the viscosity of the solution decreases resulting in higher foamability. This is because when the viscosity is reduced, the new created surface area can be formed easier than at high viscosity. Consequently, the surfactant molecules in the bulk solution can move to the surface easier. The same results are observed for all the three types of nonionic surfactant studied. The results show that the coacervate phase does not act as as antifoam by itself. The coacervate phase will act as an antifoam only when it is present in the solution mixed with the micellar-poor phase.

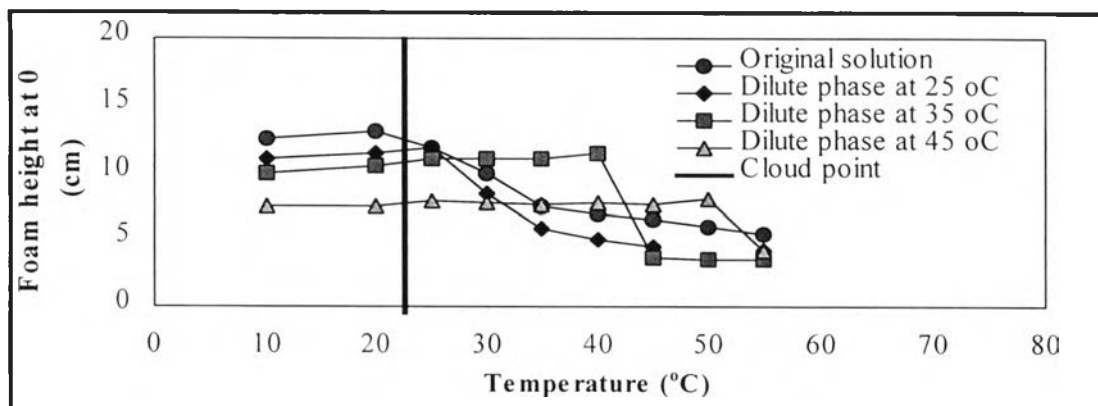


Figure 4.11 Foamability of dilute phase of NP(EO)₈ at the phase separation temperature of 25 °C, 35 °C, and 45 °C.

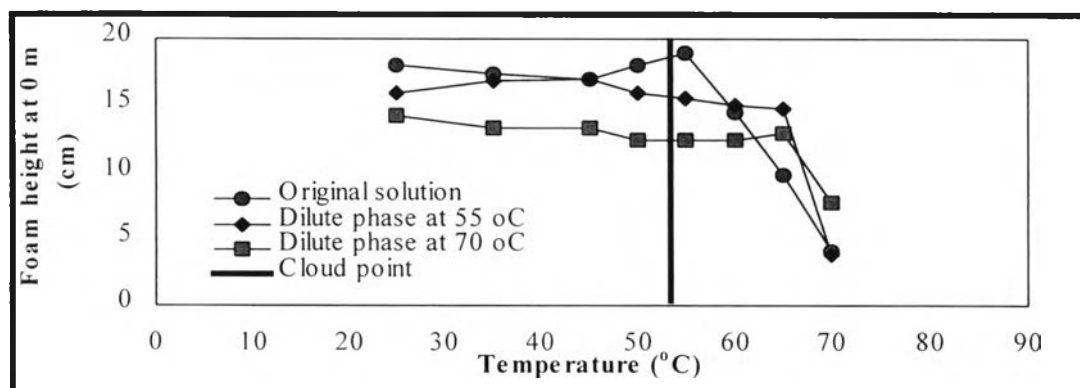


Figure 4.12 Foamability of dilute phase of NP(EO)₉ at the phase separation temperature of 55 °C and 70 °C.

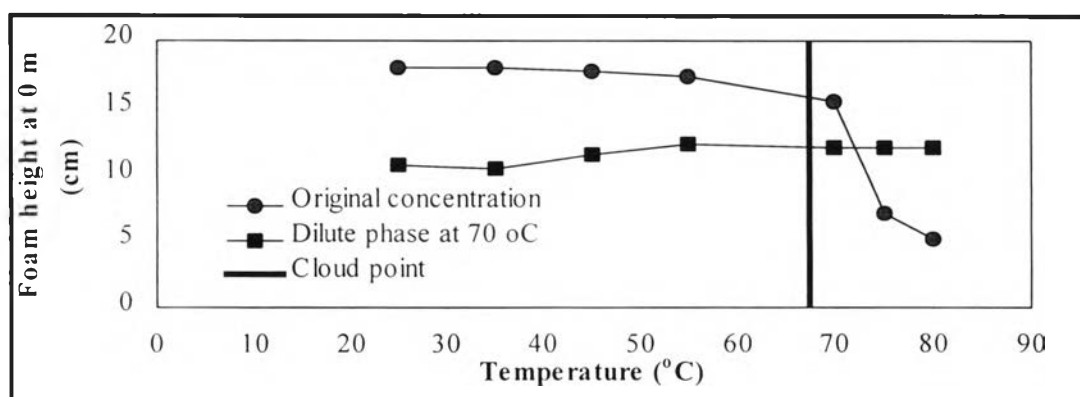


Figure 4.13 Foamability of dilute phase of NP(EO)₁₀ at the phase separation temperature of 70 °C.

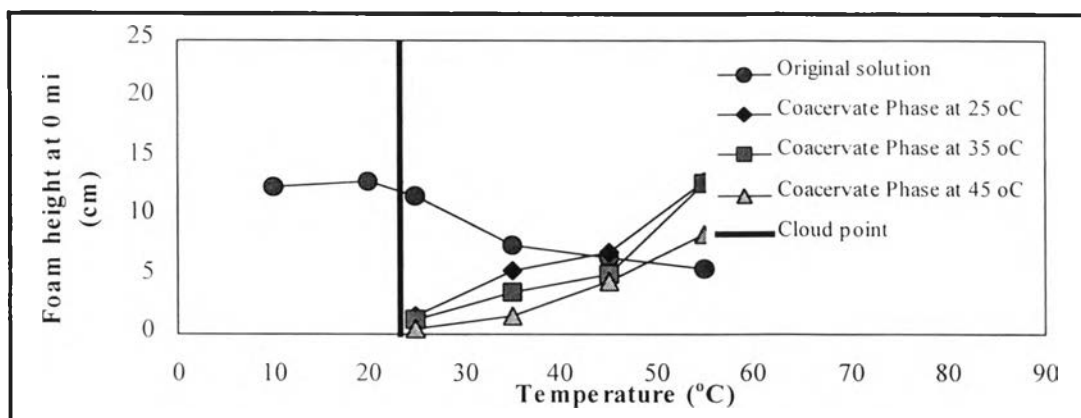
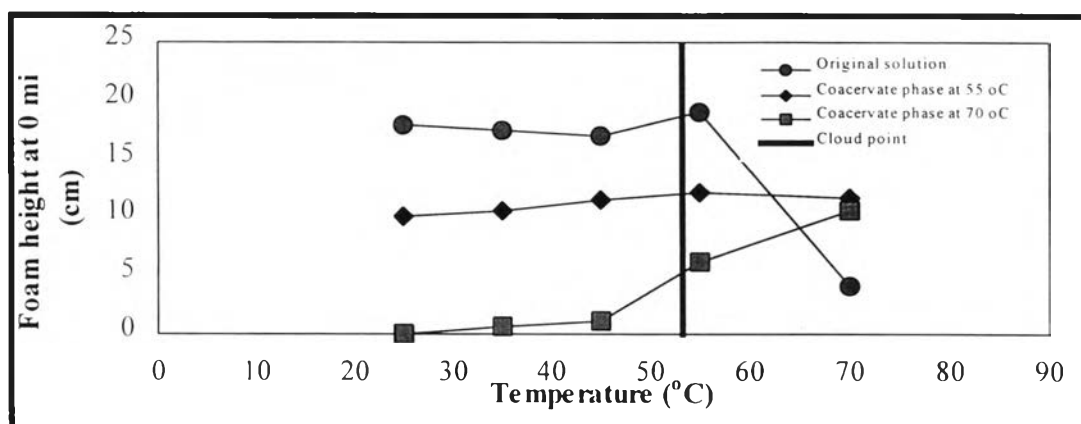


Figure 4.14 Foamability of coacervate phase of NP(EO)₈ at the phase separation temperature of 25 °C, 35 °C, and 45 °C.



Figures 4.15 Foamability of coacervate phase of NP(EO)₉ at the phase separation temperature of 55 °C and 70 °C

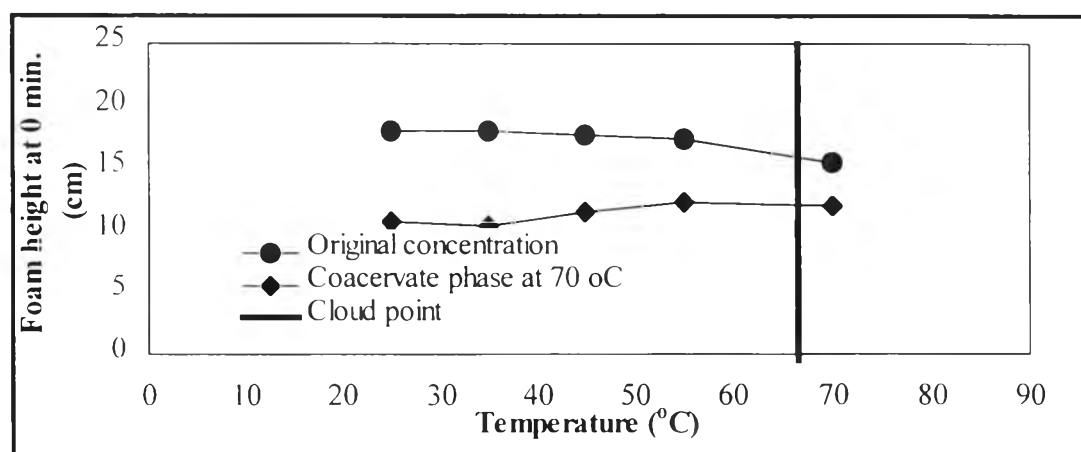


Figure 4.16 Foamability of coacervate phase of NP(EO)₁₀ at the phase separation temperature of 70 °C.

4.7 Determination of the Antifoam Coefficients

The surface tension of the dilute phase, the coacervate phase, the interface between the dilute phase and the coacervate phase (interfacial tension), and the antifoam coefficients at the phase separation temperature is shown in Table 4.3.

Tables 4.3 Surface tension of dilute phase, coacervate phase, interfacial tension, and the antifoam coefficients at the phase separation temperature of the surfactants used.

	NP(EO) ₈			NP(EO) ₉		NP(EO) ₁₀
	25 °C	35 °C	45 °C	55°C	70°C	70°C
Dilute phase	30.5	30.1	30.0	30.34	29.4	29.93
Coacervate phase	29.9	29.6	29.3	30.12	28.9	29.87
Interfacial tension	0.3	0.2	0.3	0.35	0.1	0.1
Spreading coefficient(S)	0.3	0.3	0.4	-0.1	0.4	0.0
Bridging coefficient (B)	36.3	30.8	42.5	13.4	25.8	4.0

The surface tension of the dilute phase and the coacervate phase of the same surfactant types decreases with the increase in temperature. The results show that the coacervate phase of all three surfactant types plays the role of an antifoam by the bridging mechanism. This is because the bridging coefficients give a much higher positive value than the spreading coefficients which have low positive values.