

CHAPTER II

BACKGROUND AND LITERATURE SURVEY

2.1. Surfactants

Surfactants, a contraction of the terms SURFace ACTIVE AgeNT, are materials that tend not only to accumulate at surface but change the properties of those surfaces (Clint, 1992). Surfactant has a characteristic molecular structure consisting of structural group that has very little attraction for solvent, known as a lyophobic group (hydrophobic group for the water or tail group), together with a group that has strong attraction for the solvent, called the lyophilic group (hydrophilic group for the water or head group). The hydrophobic group is usually a long-chain hydrocarbon residue, and less often a halogenated or oxygenated hydrocarbon or siloxane chain; the hydrophilic group is an ionic or highly polar group. Depending on the nature of the hydrophilic group (head group) (Rosen, 1988), surfactants are divided into four classes: anionic, cationic, nonionic, and zwitterionic.

2.2 Foam

2.2.1 Foam Formation

Foam is produced when air or some other gas is introduced beneath the surface of a liquid that expands to enclose the gas with a film of liquid. So foam is a gas dispersed in a liquid.

The formation of foam from a bulk involves the expansion of the surface area due to the work action upon the system. As surface tension is the work involved in creating a new system, the amount of new area formed will be greater the lower surface tension. Therefore, the surfactant is required for foam formation because it can reduce the surface tension of the new surface area as shown in Figure 2.1.

2.2.2 Structure of Foam

The structure of foam is quite complicated. Foam consists of a thermodynamically unstable two-phase system of gas bubbles in a liquid. The structure of gas cell consists of thin liquid film with approximately plane parallel sides and there are two sides film which are called the lamellae of the foam. The junction between three or more gas bubbles is called the Plateau border or Gibbs triangles as seen as in Figure 2 (Rosen, 1988).

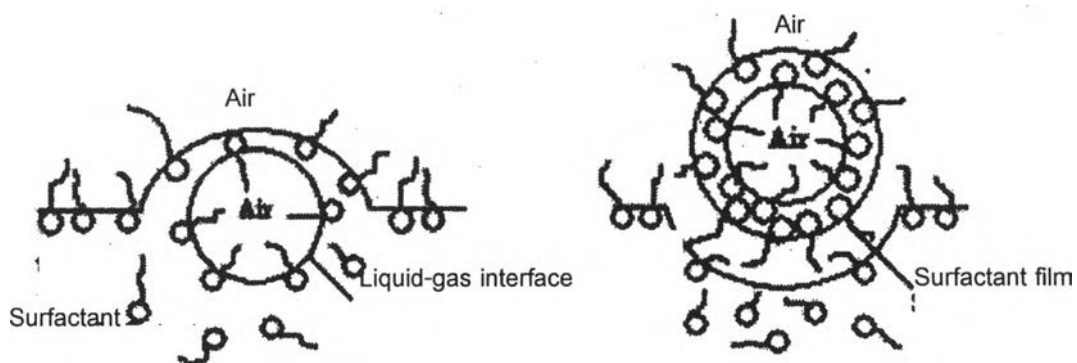


Figure 2.1 Formation of foam.

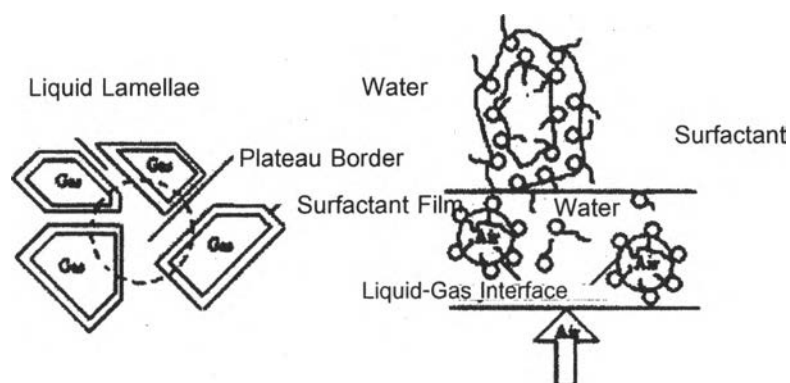


Figure 2.2 The structure of foam.

2.2.3 Foam Stability

The stability of foam can be split into two factors, film elasticity and film drainage (Rosen, 1988). Film elasticity can be explained by two theories, Gibbs surface elasticity and the Marangoni effect. Both effects postulate that film elasticity is due to the local increase in surface tension when the new surface area is created. The increasing in surface tension causes liquid to flow from the thick section to the thinner section, which is called healing. Both theories can be explained the foam formation because gravity causes liquid to drain out of the thin lamellae, and hence the surface tension increases in the thin lamellae. There is now a restoring force from the Gibbs elasticity and the Marangoni effect bringing surfactant molecules back into the region of high surface tension (Porter, 1994), as shown in Figure 2.3.

The film drainage is the second factor that shows the stability of foam. Drainage of the film occurs under two influences: gravity and surface tension. Drainage by gravity is an important effect on the thickness of lamellae. The bulk viscosity of the foaming solution is a major factor in determining the rate of drainage by gravity in thick lamellae. At high concentration of surfactant the viscosity of the bulk solution also high therefore the drainage rate in the lamellae decreased with the amount of surfactant in the lamellae increased.

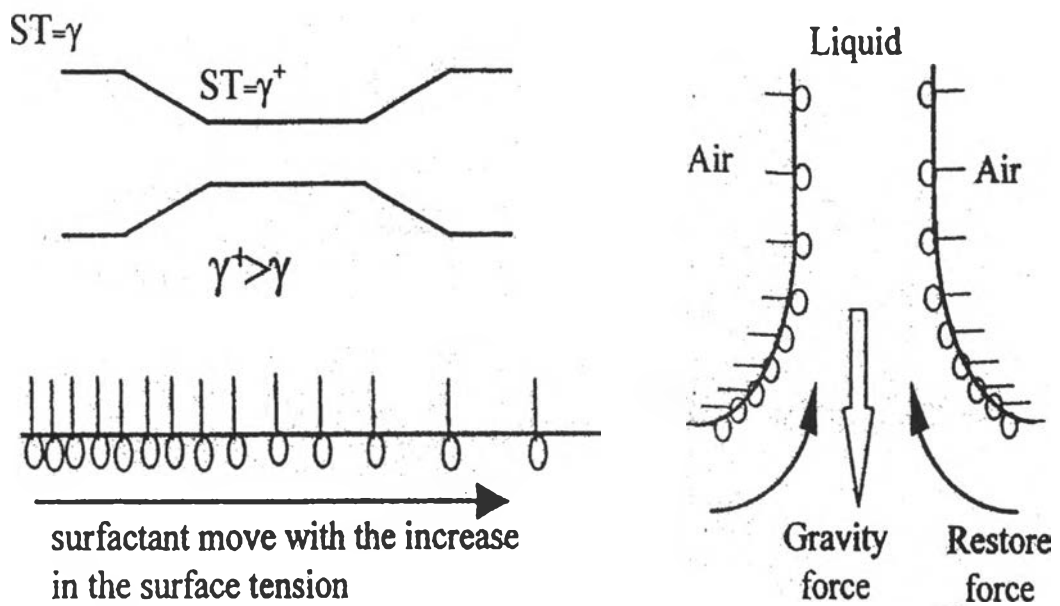
Drainage by surface tension difference depends on the existence of pressure difference at the various differences at the various points in the lamellae because of the difference in curvature at the surface of the lamellae. The pressure difference (dP) quantified by Laplace as follows :

$$dP = ST(1/R_1+1/R_2) \quad (1)$$

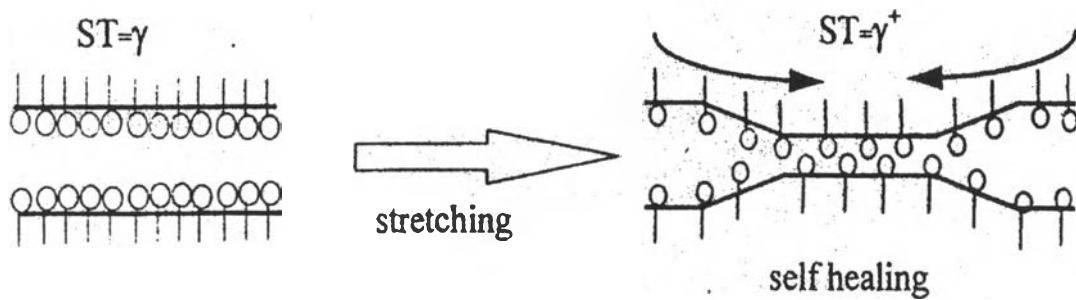
where ST is surface tension and, R_1 and R_2 are the radii of the curvature of the liquid surface.

The pressure difference causing drainage of liquid into the Plateau border at point A from point B as shown in Figure 2.4. The greater surface tension the greater liquid drainage, the lower stability of foam. Foam is destroyed when the liquid drains out between the two parallel surfaces of the lamellae causing

it to become thinner. At a certain critical thickness the film collapses and the bubble will burst. So that the stability of the film will depend on many factor that have effect on the film drainage such as type of surfactant, concentration of surfactant, temperature, etc. (Rosen, 1988; Porter, 1994).



a) Marangoni effect



b) Gibbs film elasticity

Figure 2.3 The Marangoni effect and gibbs film elasticity.

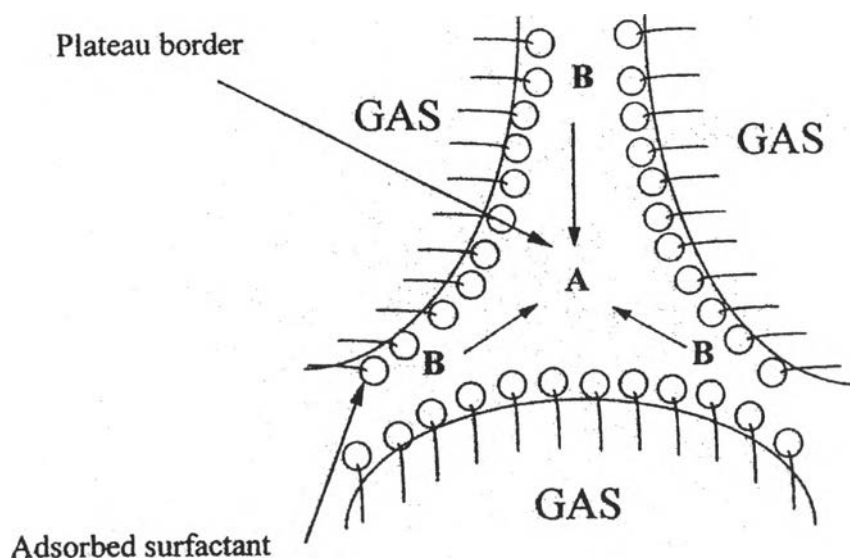


Figure 2.4 Gas bubble.

2.3 Foam Fractionation

The foam separation process is an adsorptive bubble separation technique that selectively separates surface-active compound in a solution, collects surfactant at the interface between the liquid and gas (Carrleson, 1992). This process is effective especially for separation of materials at low concentration. Surface-inactive compounds (colligens) can be removed from solution of an appropriate surface-active material (surfactant) is added to the system (Elving, 1982). The foam separation process can be divided into two types, foam fractionation and froth flotation. Foam fractionation separates dissolved material, while froth flotation separates insoluble material (Okamoto, 1979).

In foam fractionation, air is sparged to produce bubbles which rise to the top of liquid column producing foam. As the bubbles travel through the liquid phase, surfactant adsorbs at the air-liquid interface. When the air bubble emerges from a cell in the foam honeycomb, the thin liquid film in the foam (lamellae) is stabilized by the adsorbed surfactant (Sebba, 1987). Drainage of liquid in the lamellae due to the gravity, and surface tension difference cause the foam to eventually break or

collapse (Rosen, 1988). The collapsed foamate solution that is collected from the top of column has higher concentration of the surfactant than the initial solution. There are two modes of foam fractionation, simple mode (batch wise or continuous), and higher mode with enriching and/or stripping.

A number of researchers have been conducted on the different modes of operation of foam fractionation unit. Some of the relevant works on surfactant recovery using foam fractionation are described with here.

2.3.1 The Simple Mode

For the simple mode, Konduru (1992a) studied the correct way of operating a foam-fractionating column strictly in simple mode. The system chosen was zinc and sodium lauryl sulphate. After thorough examination it was determined that the height of foam-liquid interface, air flow rate and bubble diameter must be mutually adjusted in order to bring the column close to its simple-mode operation. The simple mode unit means one theoretical (perfect) stage, which requires careful operation for avoiding bubble coalescence in the rising foam. Such coalescence unwillingly releases adsorbed solute back down through the rising foam, causing internal reflux-thereby establishing an erroneous separation beyond that of a single stage. Moreover, there should be no concentration gradient in the liquid pool. Grieves and Wood (1964) and Grieves and Bhattacharyya (1965) studied the effect of temperature and found that temperature has subtle effect on the foam separation process. Wood and Tran (1966) studied the effect of column diameter. The column diameter was optimized in the suitable operating zone by the wall effect. The mass transfer coefficients generally increased and it did not appear to be any cut-off point (i.e., the trend continues beyond column diameter-to-packing size ratio of 12:1). This trend is attributed to a so-called wall effect, which would be more pronounced in a small diameter column. The use of foam fractionation to recover surfactant from water in continuous mode was studied by Tharapiwattananon (1995). The results showed that the effectiveness of foam fractionation process in recovering cationic surfactant (CPC) is better than for nonionic (DADS) or anionic (SDS) surfactant. Increasing in the air flow rate and surfactant concentration results in a decrease in the enrichment ratio and an increase in the surfactant recovery rate. In contrast,

decreasing the pore size and foam height results in a decrease in the enrichment ratio and increase in the surfactant recovery rate. Kumpabooth (1997) continued the work by studying the effect of temperature on foam fractionation and showed that increasing temperature has a generally positive impact on the foam fractionation as more concentrated foam liquid is recovered overhead while increasing salinity, the foam wetness increases as enrichment ratio decreases, so generally a higher volume of a less concentrated solution is formed overhead for a slightly increased foam recovery rate.

2.3.2 The Higher Mode (Multi-stage Mode)

Morgan and Wiesmann (2001) studied the recovery of alkyl ethoxylate surfactant using a multistage foam fractionator. In this multistage operation, the removal degree and the enrichment factor were maximum when the number of stages was equal to 3. The effect of several variables such as air flow rates, foam height, liquid height, number of tray and surfactant concentration using a cationic surfactant with multistage foam fractionation were studied by Boonyasuwat *et al.* (2002). They found that increasing the air flow rates and surfactant concentration results in a decrease in the enrichment ratio and an increase in the surfactant recovery. Increasing foam height yields higher enrichment ratio and lower surfactant recovery rate. Liquid height in the trays has a little effect on the multi-stage separation process and an increase in the number of tray results in an increase in the enrichment ratio.