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The Effect of Composition, Temperature, and Mole Fraction on Solubility in Ternary Diagram of Oil, Water, Soapnuts (*Sapindus Rarak* DC.)

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ABSTRACT

This study analyzed the effect of composition, temperature, and mole fraction on solubility in a three-component equilibrium system consisting of oil, water, and soapnuts (Sapindus rarak DC.) as a natural surfactant. The study was conducted by extracting soapberry through boiling and titrating at temperatures of 30°C, 50°C, and 70°C with oil-surfactant ratios (1:5, 2:4, 3:3, 4:2, and 5:1). The volume of water to the turbidity point was measured to observe solubility. The results showed that the composition ratio and temperature affected solubility. Increasing the oil ratio required more water for the emulsion, while a higher surfactant ratio stabilized the emulsion. Higher temperatures increased solubility, but extreme temperatures caused phase separation. The optimal ratio for a stable emulsion was 3:3 at 70°C with the lowest water volume (1.3 mL). This study produced a ternary diagram depicting the solubility region.

Keywords: ternary diagram, soapnuts, solubility, phase equilibrium, natural surfactants

1. INTRODUCTION

Solubility in chemistry refers to the ability of a substance to dissolve in a solvent and form a homogeneous mixture. A ternary system, consisting of three components, can exist in a single phase or multiple phases. To understand the equilibrium relationships in this system, an equilateral triangle-shaped ternary diagram is used, where each point represents a unique composition of the three components.[1] This diagram is important in identifying regions of single-phase (homogeneous) stability and phase separation.[2]

One of the natural surfactants that has attracted attention is soapnut (*Sapindus rarak* DC.), a plant native to Asia that is rich in saponins. Saponins are amphiphilic compounds that have hydrophilic (water-attracting)

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and lipophilic (oil-attracting) properties, allowing soapnut to function as an effective natural emulsifier.[2] Compared to synthetic surfactants, soapnut is environmentally friendly, biodegradable, and safe for the ecosystem.[3]

Solubility in ternary systems is influenced by composition, polarity, temperature, and mole fraction. Composition determines whether the system forms a homogeneous solution or undergoes phase separation.[4] Polarity plays a role according to the principle of "like dissolves like", where polar substances dissolve in polar solvents, while surfactants such as saponins can facilitate the mixing of polar and nonpolar substances.[5] Temperature affects solubility by increasing molecular motion, while mole fraction determines the stability of the emulsion in the system.[6]

Since its introduction by Riley (1951), Shepard (1954), and Winkler (1954), the ternary diagram has become an important tool in analyzing the behavior of multicomponent systems in various fields.[7] This study aims to analyze the effect of composition, temperature, and mole fraction on solubility in ternary systems of oil, water, and soapnut, as well as to provide a deeper understanding of phase interactions and equilibrium conditions.

2. EXPERIMENTAL

2.1. Chemicals, Equipment and Instrumentation

The chemicals used in this study include oil, soapnut (*Sapindus rarak DC.*) as natural surfactant, and H_2O. The equipment involved in this experiment includes burette with stative and clamp, water bath, erlenmeyers 100 mL, measuring cups 100mL, beaker 100 mL, thermometer 100°C, and glass funnel.

2.2. Research Procedure

To analyze the effect of composition and temperature on solubility in the three-component equilibrium system of oil, water, and soapnuts, the first step is to prepare soap nut extract. A total of 10 to 15 soap nuts are boiled in 500 mL of water for 15 to 20 minutes. After boiling, the soap nut extract is filtered and cooled before being used in the experiment.

Next, a titration process is carried out to observe changes in solubility. Five erlenmeyer flasks are prepared with variations in the ratio of oil and soapnut surfactant, namely 1:5, 2:4, 3:3, 4:2, and 5:1. Each erlenmeyer flask is then placed in a water bath that has been set at 30°C and left for five minutes to reach thermal equilibrium. After that, titration is carried out by adding mineral water little by little while stirring until the mixture dissolves optimally. The volume of water used in each titration is carefully recorded. After the measurement at 30°C was completed, the same procedure was repeated for 50°C and 70°C. Before titration was carried out at each temperature, each erlenmeyer flask was placed back in the water bath for five minutes to ensure that thermal equilibrium was achieved. The volume of water required to achieve turbidity at each temperature was then recorded as experimental data.

3. RESULTS AND DISCUSSION

The volume of water required to reach the turbidity point in the titration of oil with surfactants varied depending on the ratio of oil to water and the temperature of the solution. At a temperature of 30°C, the volume

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of water used ranged from 1.5 mL to 5.5 mL, with the highest requirement at a ratio of 5:1 of 5.5 mL and the lowest at a ratio of 2:4 of 1.5 mL. When the temperature increased to 50°C, at a ratio of 1:5, the volume of water used was 1.9 mL, while for a ratio of 5:1, the volume of water increased to 6.4 mL, indicating that higher oil ratios tend to require more water to reach turbidity. At a temperature of 70°C, the volume of water required for titration changed significantly. Some ratios such as 3:3 remained stable with a water requirement of 1.3 mL, while the 5:1 ratio that previously required 6.4 mL at 50°C decreased drastically to 2.9 mL. Overall, this shows that temperature and the oil-surfactant ratio have a direct effect on the solubility in this three-component system.

During the titration process, the mixture of oil and surfactant underwent a visual change, where the solution became cloudy after reaching its saturation point. This indicates that the oil and water phases are starting to separate, with the surfactant acting as a stabilizer but having limited ability to maintain the homogeneity of the system.

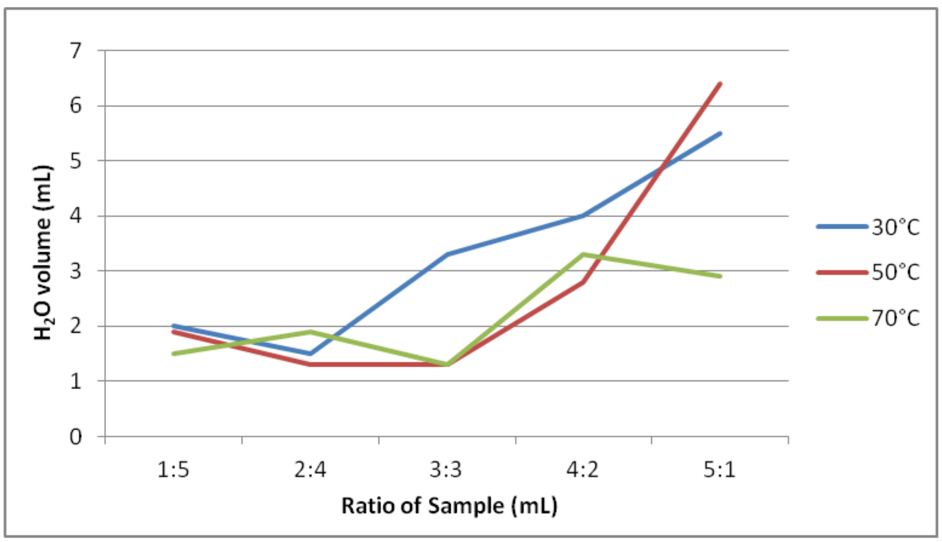

Figure 1. Volume of water required during titration

3.1. Analysis Composition Variations of Oil, Water, and Soapnuts in Solubility

The ratio of oil to surfactant greatly affects the solubility and volume of water required in titration. This is due to the amphiphilic nature of surfactants such as candlenut soap, which has hydrophilic (water-soluble) and hydrophobic (oil-soluble) parts.[8] These amphiphilic molecules help form micelles that can reduce the interfacial tension between oil and water, thus facilitating the formation of emulsions.[9]

The results found that at a greater oil ratio than surfactant (5:1), the volume of water needed to reach the turbidity point was greater. This states that the limited amount of surfactant is not enough to form micelles effectively, causing the phase separation between oil and water to remain dominant.[10] Conversely, at a greater surfactant ratio than oil (1:5), the system becomes more stable as an emulsion, so that the volume of water needed to reach the turbidity point is less because the solubility increases significantly. At a balanced ratio (3:3), the volume of water required reaches an optimum point because the system is in an ideal condition to

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form stable micelles. After this optimum point, the addition of excess surfactant no longer significantly increases the solubility because most of the oil is already dispersed in the form of micelles.

3.2. Effect of Temperature on Solubility in Three-Component Systems

The results showed a decrease in the volume of water required to reach the turbidity point with increasing temperature, especially at higher surfactant ratios. At 30°C, the volume of water ranged from 1.5 mL to 5.5 mL, where the 5:1 ratio required the largest volume of water (5.5 mL) because the interfacial tension between oil and water was still high. This shows that at low temperatures, the kinetic energy of the molecules is lower, so the interaction between oil and water is still difficult to overcome by surfactants.[11]

When the temperature increased to 50°C, the volume of water required decreased, especially at higher surfactant ratios. This is show that increasing temperature increases the kinetic energy of molecules, decreases interfacial tension, and facilitates emulsion formation.[12] However, at a high oil ratio (5:1), the volume of water actually increased to 6.4 mL at 50 °C. This shows that the insufficient amount of surfactant is compensated by increasing the temperature to help disperse the oil.

At 70 °C, there is a drastic decrease in the volume of water required to reach the turbidity point, for example at a ratio of 5:1 from 6.4 mL at 50 °C to 2.9 mL. This shows that further increasing the temperature increases the solubility to the optimum point. However, if the temperature is too high, the stability of the micelle can be disrupted due to the decrease in hydrogen bonds in the surfactant, which can potentially cause re-separation between the oil and water phases.[11] The results of the experiment showed that the balanced ratio (3:3) remained stable at 1.3 mL at 70°C, indicating an optimum point for the formation of stable micelles.

3.3. The Role of Mole Fraction in Determining the Equilibrium

The mole fraction in a three-component system greatly affects the solubility and phase distribution. At low surfactant mole fractions, phase separation occurs because oil and water have limited solubility in each other.[13] Conversely, with increasing surfactant mole fractions, micelles or microemulsions are formed which allow oil to be dispersed more effectively in water.[14]

The results show that at a higher oil ratio to surfactant (5:1), the volume of water required is greater because the mole fraction of surfactant is low, causing dominant phase separation. At a higher surfactant ratio (1:5), the volume of water required is reduced because the high mole fraction of surfactant facilitates the formation of stable micelles. At a balanced ratio (3:3), the system reaches optimal equilibrium, where the surfactant is sufficient to disperse the oil without causing excess emulsion. This shows that at the optimal surfactant mole fraction, the solubility and stability of the system increase significantly.[15]

3.4. Relationship with Ternary Diagram and Equilibrium Region

The ternary diagram is used to visualize the relationship between the three components in this system.[16] In the experiment, the shift in the position of the mixture in the diagram depends on the ratio of oil, water, and surfactant. For example, a mixture with more oil tends to be near the oil corner, while a mixture with more surfactant approaches the surfactant corner.

When the mixture is stirred, a transition from one region to another is observed through the appearance of turbidity. This is in accordance with the theory that turbidity is caused by the microscopic dispersion of

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small oil droplets in the water phase, indicating that the system has reached the two-phase boundary.[17] The results of the experiment support that at a high ratio of oil to surfactant, the system tends to be in the phase separation region, while at a high ratio of surfactant, the system is more stable in the homogeneous solution region.

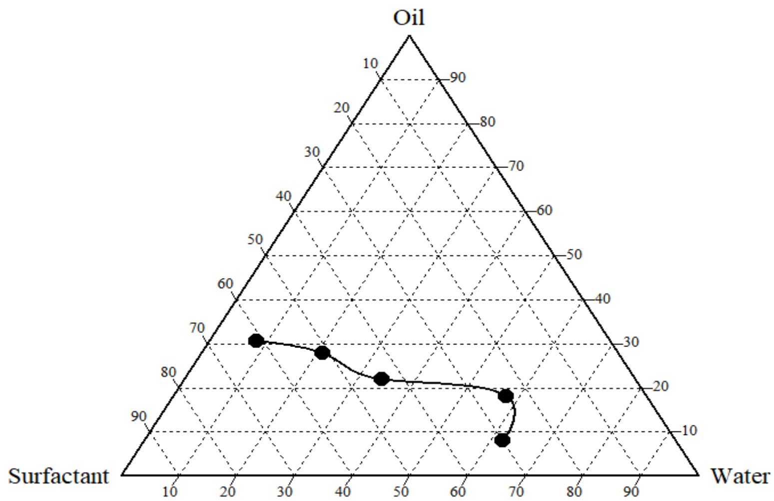

Figure 2. Ternary diagram of oil, surfactant, and water at 30°C

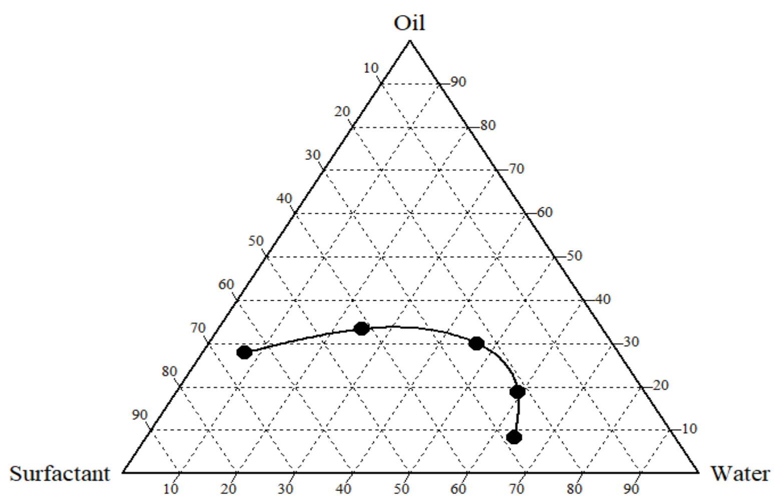

Figure 3. Ternary diagram of oil, surfactant, and water at 50°C

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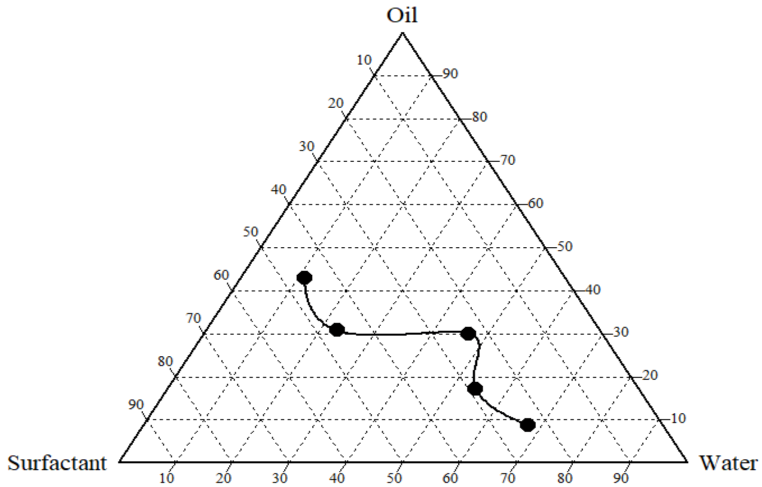

Figure 4. Ternary diagram of oil, surfactant, and water at 70°C

4. CONCLUSION

The solubility of a three-component system (oil, water, soapnuts) is highly dependent on the component ratio. The larger the volume of surfactant, the more stable the emulsion formed and the smaller the volume of water required to reach the turbidity point. Temperature has a major effect on the solubility and volume of titration water. Increasing the temperature to 70°C increases the solubility due to decreased interfacial tension and increased kinetic energy, but too high a temperature can cause micelle destabilization. The mole fraction of the surfactant affects the boundary of the equilibrium region in the ternary diagram. At low mole fractions, the system tends to experience phase separation and requires more titration water, while high mole fractions produce more homogeneous solutions with lower titration water requirements.

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