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# Investigation of the effects of ultrasound processing on the characteristics of lubricating emulsions

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**Abstract:** This study examines the potential application of used vegetable oil for the production of lubricating emulsions. It has been determined that for the bleaching of used vegetable oil with an acid value (AV) of 4.0 mg KOH/g, a 4% clay-based adsorbent is sufficient. The maximum emulsion stability, achieved after 8 minutes of ultrasonic treatment, corresponds to a formulation containing 20% vegetable oil, 3% emulsifier, and 0.2% $NaHCO_3$. Further increasing the amount of vegetable oil improves the emulsion quality; however, it also raises production costs.

**Keywords:** Vegetable oils, emulsions, droplet size, ultrasonic treatment, used oils, emulsion stability.

**Introduction:** Emulsions are microheterogeneous systems formed from two immiscible liquids. The size of the globules ranges from 0.1 to 50 µm. Emulsions are classified into direct emulsions, i.e., "oil-in-water" (O/W), where the dispersion medium is water, and inverse emulsions, "water-in-oil" (W/O), where the dispersion medium is oil, a non-polar liquid. Emulsions are further categorized into three types based on the relative content of the dispersed phase: dilute emulsions (where the dispersed phase constitutes up to 0.1%), concentrated emulsions (0.1%–74%), and highly concentrated emulsions (above 74%) [1-3].

When two liquids of different polarities are vigorously mixed, an emulsion forms due to an increase in interfacial surface area, leading to enhanced excess surface energy (σS). This excess energy causes the coalescence of dispersed phase droplets (globules), resulting in rapid emulsion breakdown. Therefore, stabilizers or emulsifiers are commonly used in practical applications to produce stable emulsions, chosen based on the type of emulsion being formed [4-6].

According to Bancroft's rule, the dispersion medium is the liquid in which the emulsifier dissolves or is better wetted. To enhance emulsion stability, emulsifiers and stabilizers are frequently employed. Emulsifiers often include surface-active agents (surfactants), colloidal electrolytes, high-molecular-weight compounds (HMWCs), and highly dispersed powders. In O/W emulsions, hydrophilic substances such as alkali metal soaps, gelatin, albumin, tannin, protein, chalk, gypsum, and clay are used, whereas for W/O emulsions, hydrophobic substances such as multivalent metal soaps, lanolin, rubber, ceresin, paraffin, and carbon black are utilized [7,8].

The emulsifying mechanism of surfactants is based on the adsorption of molecules at the phase boundary, forming solvation shells around the droplets. Figure 1a illustrates an O/W emulsion globule obtained by intensive mixing of toluene and water with the addition of the emulsifier sodium oleate. In this case, emulsion stability is ensured by the reduction of interfacial surface tension and the formation of a hydration shell. The electric charge of the droplet is induced by the ionic dissociation of the polar -COONa group, which enhances emulsion stability. Figure 1b presents a W/O emulsion globule obtained in the presence of calcium oleate [9].

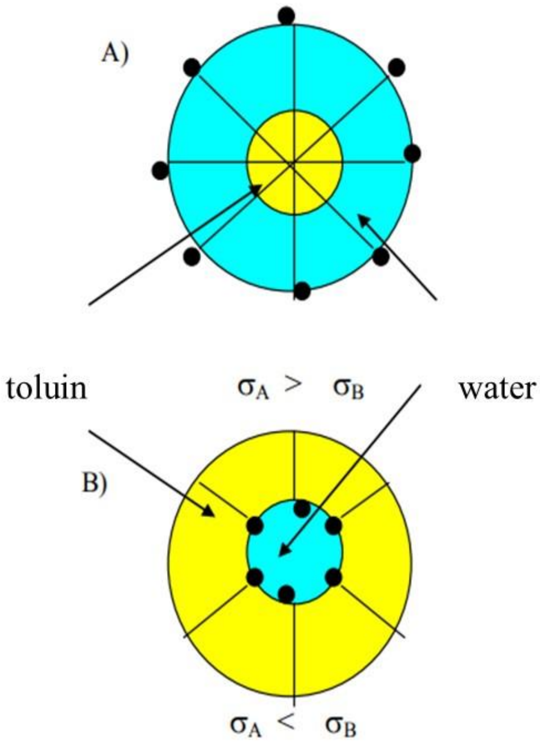



***Figure 1. Orientation of Emulsifier Molecules at the Phase Interface***

The structure of the stabilizing interfacial layer is complex. The polar groups in the colloidal electrolyte are oriented toward the aqueous phase, while the non-polar groups are directed toward the non-polar phase.

As a result, two surfaces are formed with different surface tensions (σA) and (σB). The emulsifier wraps around the droplets to prevent coalescence. When the surface tension between the emulsifier and oil (σA) is greater than that between the emulsifier and water (σB), an O/W emulsion is formed. In this case, for the oil phase with a high (σA) value, the formation of a minimal spherical surface is more likely compared to the aqueous phase. However, if (σA) is lower than (σB), a W/O emulsion is formed (see Figure 1b). The ratio between the hydrophilic and lipophilic (hydrophobic) parts of the emulsifier molecule plays a key role in its emulsifying ability. This ratio is commonly referred to as the hydrophilic-lipophilic balance (HLB) [10].

Food-grade lubricating emulsions for coating molds and sheets are among the imported products in the republic. Analyzing the composition of these emulsions has shown that they consist of vegetable oil, water, emulsifiers, and other components. Currently, the main vegetable oils produced in the republic include cottonseed, soybean, and sunflower oil. However, due to the insufficient production of these oils, they are still being imported. Therefore, for the production of lubricating materials, it is necessary to find an alternative to vegetable oils or explore other less commonly consumed vegetable oils. One such alternative is used cooking oils from public catering services.

This study investigates the feasibility of using used vegetable oils collected from public catering services to produce food-grade lubricating emulsions.

## METHODS

Used vegetable oils exhibit a color index of 18 red units, 6 blue units at 35 yellow, with an acid value (AV) of 3.8 mg KOH/g, and a peroxide value (PV) measured in mmol of active oxygen per kg.

To analyze the composition of used oil, the bleaching of used cottonseed oil was carried out. The adsorption purification was conducted using a traditional method with up to 5% Pakistani clay adsorbent.

## RESULTS AND DISCUSSION

***Figure 1. Photographs Before and After Adsorptive Bleaching of Used Cottonseed Oils***

The degree of purification of used cottonseed oil with clay adsorbents was evaluated based on the acid value (AV).

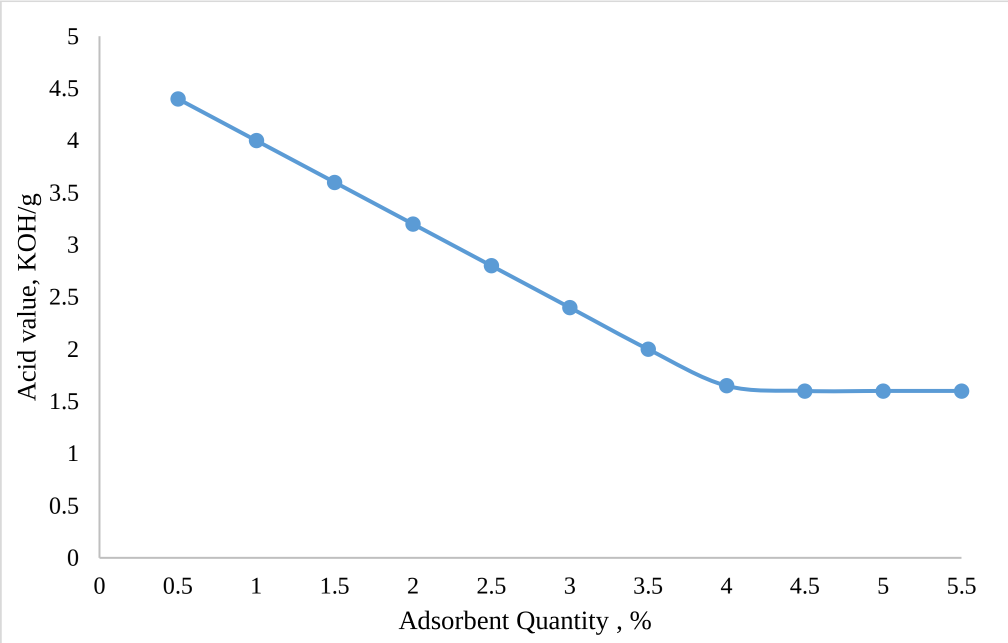



***Figure 2. Effect of adsorbent quantity on acid value during adsorptive purification of used cottonseed oil***

As shown in Figure 2, an increase in the amount of adsorbent reduces the acid value from 4.5 to 1.6 mg KOH/g. However, when the adsorbent quantity reaches 4%, the acid value (AV) remains practically unchanged. Therefore, for bleaching used vegetable oil with an acid value of 4.0 mg KOH/g, a 4% clay-based adsorbent is sufficient.

The resulting bleached vegetable oil was used as a base for the production of food-grade lubricating

emulsions. The emulsifiers and stabilizers used in the formulation are primarily imported. In this case, food-grade lecithin (Russia) was employed as the emulsifier.

Food emulsions are produced using mechanical dispersion, spontaneous emulsification, and electro-physical emulsification methods. The properties of emulsions are evaluated based on several characteristics, including emulsion dispersity, stability over time, and the concentration of the dispersed phase.

Ultrasonic treatment allows for the production of more stable emulsions compared to mechanical methods. Frequency oscillations facilitate the formation of ultra-dispersed emulsions with a wide range of dispersity, even from complex substances. Therefore, ultrasonic treatment enhances storage stability, as the particle size distribution ranges from 1 to 0.5 µm.

During ultrasonic treatment of heterogeneous systems, two simultaneous processes occur: emulsion formation at the phase interface and bulk coagulation. To obtain particles of uniform size, it is crucial to establish a balance between dispersion and particle

aggregation by determining the threshold value.

Food-grade lubricating emulsions were obtained using ultrasonic (US) treatment under various conditions. The characteristics of the resulting emulsions are presented in Table 1.

**Table 1. Dependence of Emulsion Stability on US Treatment Time**

| Composition of Lubricating Food Emulsions | Stability* (%) of Lubricating Food Emulsions Derived from Refined Cottonseed Oil Over Time (min) | Stability* (%) of Lubricating Food Emulsions Derived from Bleached Waste Oils Over Time (min) |
|---|---|---|

| | 4 | 6 | 8 | 10 | 4 | 6 | 8 | 10 |
|---|---|---|---|---|---|---|---|---|
| 15% Vegetable Oil + 5% Emulsifier + 0.2% $NaHCO_3$ | 72 | 81 | 85 | 87 | 68 | 74 | 80 | 82 |
| 20% - Vegetable Oil +3% эмульгатор+0,2%$NaHCO_3$ | 75 | 79 | 86 | 87 | 70 | 75 | 78 | 81 |
| 25% - Vegetable Oil +2% Emulsifier +0,2%$NaHCO_3$ | 77 | 82 | 90 | 92 | 72 | 76 | 82 | 85 |

*-Stability was determined by centrifugation.

As shown in Table 1, increasing the duration of ultrasonic (US) treatment enhances the stability of lubricating emulsions. However, the stability parameters of emulsions derived from used oils are lower than those obtained from fresh oils. Additionally, increasing the oil content in the emulsion composition improves its stability. In this formulation, the addition of NaHCO3 helps neutralize free fatty acids present in vegetable oil, resulting in the formation of saponified fatty acids that act as emulsifiers, thereby increasing emulsion stability.

The maximum emulsion stability was achieved with 8 minutes of ultrasonic treatment using a formulation consisting of 20% vegetable oil, 3% emulsifier, and 0.2% NaHCO3. Further increasing the vegetable oil content enhances the emulsion quality but also raises production costs. Based on these findings, the addition of 20% vegetable oil is sufficient to obtain a stable lubricating emulsion.

With increasing US treatment time, the probability of droplet coalescence decreases, while the cavitation effect ensures uniform distribution of the dispersed phase droplets. Dispersing the oil phase into the aqueous phase requires energy to break the interface between oil and water. During cavitation, ultrasonic shear forces break large droplets into smaller ones. To determine the effect of power in the range of 40% to 60% on the size distribution of the dispersed phase, an investigation was conducted, with the results presented in Table 2.

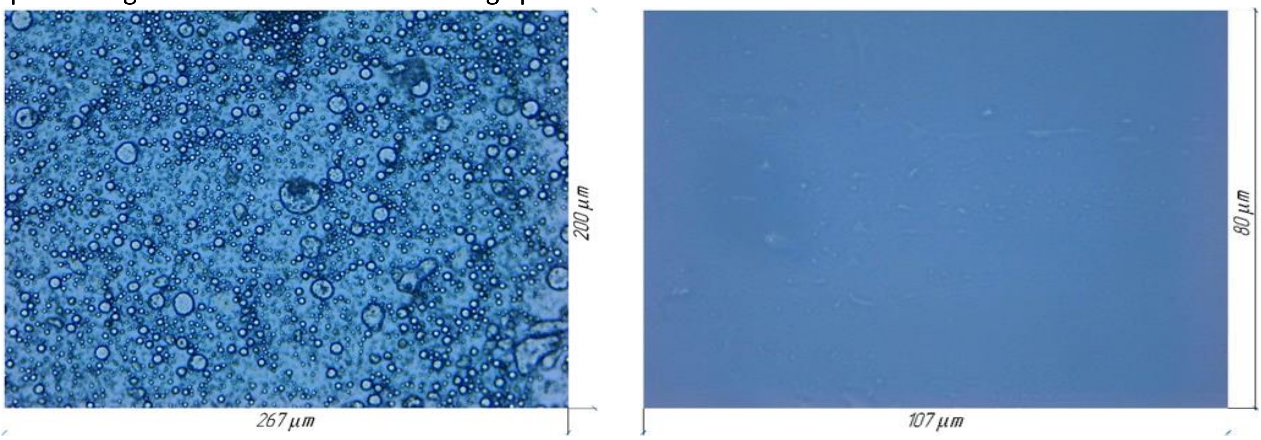
**Table 2. Dependence Between Ultrasonic Power and Particle Size During US Treatment**

| Emulsion obtained from: | Ultrasonic Treatment Power (%) | Duration of Homogenization (min) | | | | |
|---|---|---|---|---|---|---|
| | | 2 | 4 | 6 | 8 | 10 |
| | | Particle Size of Dispersed Phase (μm): | | | | |
| -From refined cottonseed oil | 40 | 3 | 15 | 25 | 43 | 50 |
| | 50 | 5 | 22 | 35 | 48 | 55 |
| | 60 | 8 | 22 | 41 | 53 | 55 |
| - From bleached waste oils | 40 | 1 | 11 | 23 | 40 | 45 |
| | 50 | 3 | 18 | 32 | 43 | 52 |
| | 60 | 5 | 20 | 38 | 50 | 52 |

As shown in Table 2, increasing the duration of ultrasonic (US) treatment reduces the likelihood of droplet coalescence in the dispersed phase. During cavitation, dispersed phase droplets are evenly

distributed in size. With increasing treatment time, particle size decreases. However, to achieve a highly dispersed emulsion, sufficient energy is required to break the oil-water interface. As power increases, particle size decreases, with the smallest particle size obtained at 50% power after 8 minutes of treatment. US processing leads to the breakdown of large particles due to shear forces generated during cavitation. Additionally, emulsion stability improves due to significant energy dissipation at the specified amplitude.

The effect of US treatment on dispersion was further examined through microscopic imaging. The images indicate that oil droplets subjected to US treatment are nearly homogenized. This further confirms the stability of these emulsions.




(a) (b)

**Figure 3. Photographs of Emulsion Samples Obtained Using: (a) Conventional Homogenizer, (b) Ultrasonic Treatment**

Thus, with increasing US treatment time, the probability of droplet coalescence decreases, while the cavitation effect ensures uniform distribution of the dispersed phase droplets, enhancing long-term stability.

## CONCLUSION

It was established that the maximum emulsion stability was achieved after 8 minutes of ultrasonic treatment with a formulation containing 20% vegetable oil, 3% emulsifier, and 0.2% NaHCO3. Further increasing the vegetable oil content improves emulsion quality but also raises production costs. Based on this, the addition of 20% vegetable oil is sufficient for obtaining a stable lubricating emulsion.

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