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Effect of Surfactant Concentration and Operating Temperature on the Drop Size Distribution of Silicon Oil Water Dispersion

Amer El-Hamouz
School of Chemical Engineering and Analytical Science, The University of Manchester, Manchester, United Kingdom

The effect of sodium lauryl sulphate (SLES) surfactant and the operating temperature on the drop size distribution of a 350 cSt Dow Corning 200 series oil water dispersion was successfully studied. The dispersion was prepared in a standard 6 litres mixing tank at different impeller speeds. A measurement of the SLES critical micelle concentration (CMC) at 25°C was carried out. The interfacial tension of silicon oil water under various SLES concentration at a temperature range of 25 to 80°C was accomplished. Results showed that the interfacial tension of the silicon oil water decreased as the operating temperature increased and as the surfactant concentration increased. When the operating temperature was increased at the highest SLES concentration tested, a decrease of d_{32} was observed. This was attributed to the possibility of hydration of the surfactant at high temperature. Same behavior was observed when measuring the drop size distribution at constant temperature but different SLES concentration. It was found that the mean drop size decreases with mixing time. Different slopes of the change of the median drop size with time were obtained for different SLES concentration. For the same concentration, the slope changes after 1 hour. The degree change of the slope is due to the change of interfacial area of the oil water as mixing time elapsed and the depletion of the surfactant concentration.

Keywords SLES, silicon oil, dispersion, agitated vessel

INTRODUCTION

The size of the droplets in a detergent emulsion is very important with respect to their properties. Therefore, understanding the effect of the physical properties of the system and the process conditions are of paramount importance. It is well known that the drop size distribution in an agitated dispersion is a result of the dynamic equilibrium that exists between the breaking and coalescing drops. Drop breakage is due to the turbulent field while drops coalescence is due the collision between drops. Several workers modelled this mathematically using the population balances equations. This allowed them to predict and control the drop size distribution of drops.[1,2] However, since both rate processes occur simultaneously, it is extremely difficult to elucidate how the physical properties of the system and the operating variable affect each, unless the experimental conditions are chosen carefully to minimize or completely eliminate one of the two processes. Two methods have been widely used to eliminate coalescence between drops: (1) the use of low dispersed phase fractions[3,4] and (2) the addition of surfactants substances to the system.[5–7]

Large amount of theoretical and experimental works can be found in the literature concerning the prediction of the drop size distribution in turbulent dispersions, and most of them refer to the theory of Hinze-Kolmogorov (to name a few[4,8–13]). Most of the published works except Zhou and Kresta[8] and Wang and Calabrese[3] are for low viscosity dispersed phase. However, most investigations refer to surfactant free systems and ambient operating temperature.

The objectives of this article are of two-fold. The first is to determine the effect of sodium lauryl sulphate (SLES) surfactant concentrations on the drop size distribution of silicon oil water dispersion under various mixing condition. The second is to study the effect of temperature on the drop size distribution under high concentration of surfactant.

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On leave from Department of Chemical Engineering, An-Najah National University, Nablus, Palestine.

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Address correspondence to Amer El-Hamouz, Department of Chemical Engineering, An-Najah National University, P. O. Box 7, Nablus, Palestine. E-mail: elhamouz@yahoo.com

THEORY

The basic theoretical concept of Hinze and Shinner is commonly applied to calculate the Sauter mean diameter, d_{32}, in stirred liquid-liquid dispersions. Dispersions produced by mechanical energy usually are stable only over a short period of time. Breakage of an isolated droplet is determined mainly by the ratio of external and internal stresses acting on such a drop to exceed a critical value. The external deforming forces are the result of turbulent fluctuations and the viscous stress due to the velocity gradients in the surrounding field. The restoring forces are the result of the interfacial tension and/or the internal viscous stress. An understanding of factors that affect drop size distribution and its evolution enable the process engineer to control the drop size and uniformity of the size distribution of the product.[14]

Based on Hinze's theory of isotropic turbulence, and for a non coalescing low viscosity drops, the maximum stable drop size can be predicted by

$$\frac{d_{\max}}{D} = c(W_e)^{-0.6} \quad [1]$$

where W_e is the Weber number which represents the effects of turbulence intensity and the physicochemical properties of the system and can be presented by

$$W_e = \frac{\rho_c N^2 L^3}{\sigma} \quad [2]$$

where σ is the interfacial tension of the system, ρ_c is the continuous phase density, N is the rotational speed and L is the impeller diameter. Reported values of the constant "c" vary and fall in the range 0.12 to 0.15.

The value σ is strongly affected by the presence of surfactant. Adsorption of surfactant at the oil/water interface resulted in lowering surface free energy between the oil water phases (lowering σ) and, thus, increasing W_e number which in turn results in decreasing the droplet size. The smaller the droplet size, the more stable is the dispersion. In a free surfactant system, there is equilibrium between drop breakage and drop coalescence. The presence of surfactant minimizes or prevents drops coalescence and therefore the drop size will be dominated by breakage process only. The further breakage of drops in a stirred dispersion due to the presence of surfactant is not only through the reduction of the interfacial tension, but also by the generation of an interfacial tension gradient across the drop. This results in an extra stress which adds to the turbulent stress and hence results in the formation of smaller drops.[15]

Almost from the very beginning of the study of surfactant solutions, it was recognized that the physical properties of surfactant solutions, such as surface tension, detergency, osmotic pressure, electrical conductivity, etc, show an abrupt change in the neighbourhood of CMC. The CMC is the concentration of surfactants at which the saturation adsorption of surfactants on the surface of the solution is reached and the micelles first appear in the solution. Surfactant molecules reside in three environments in a surfactant solution above the CMC. Surfactant molecules disperse as monomers in the aqueous phase, form aggregates (micelles), or adsorb as a film at the air water interface. Micelles are often drawn as static structures of spherical aggregates of oriented surfactant molecules. The surfactant is in dynamic equilibrium among all these compartments. Thus at a given temperature, pressure, and concentration, the number of monomers, micelles, and monomers adsorbed at the air/water interface is fixed under equilibrium conditions.

Additionally, the micelles themselves are continuously disintegrating and reforming. At equilibrium, the number of micelles formed in a given time is equal to the number of micelles disintegrated in the same time period; this was confirmed by Patist et al.[16] The effect of micelles lifetime on the droplet size in emulsions was studied by OH et al.[17]

TABLE 1
Published work related to silicon oil surfactant solution

	System used					Interfacial tension (IFT) and surfactant used if any	
Ref.	Concentration	Temp, °C	ρ_c (kg m^{-3})	ρ_d (kg m^{-3})	μ_d mPa · s	IFT, mN/m	
[8]	0.03% Silicon oil water	25	998	1050	173.2	45	No surfactant
[1]	0.3% Silicon oil water	25	1000	900–975	10–1000	45–50	No surfactant
[4]	0.038% Silicon oil-aqueous mathanol water	25	997–792	834–968	1–1000 mP · s	1–45 (100–0% methanol)	No surfactant
[3]	Less than 0.3% silicon oil–water	25	997	960–975	100–10,000	37.8	No surfactant
[5]	Mixture of silicon oil (less than 0.3%) in glycerol-water mixture	25	—	—	Mixture of 20 and 350 cp	12.6–18.8	0.3% Tween-60 surfactant in solution

Lee and Soong[18] studied the effect five surfactants on the mean droplet size of nine liquid-liquid systems in agitated vessels. Goloub and Pugh[7] studied the effect of the surfactant head group on the emulsification processes for dilute dodecane in water emulsion. Three different surfactant types were used: nonionic, an anionic, and cationic.

SLES and sodium dodecyl sulphate (SDS) are both anionic surfactants having similar molecular structure with a unique structural difference in the SLES due to the presence of ethylene oxide (EO) units. Very little research can be found in the open literature on SLES[19] and on silicone oil water dispersion under the presence of surfactant. This can be seen in Table 1.

In the work presented herein, the CMC of SLES and the interfacial tensions of silicon SLES water solution were measured to enrich the literature. These are essential inputs needed to supplement the achievement of the objectives of this study.

2 MATERIALS AND PROCEDURE

2.1 Materials

Experiments were carried out in an ESCO mixing rig shown in Figure 1. The vessel has a working volume of 6 litres with a 20 cm internal diameter with a standard geometry anchor blade inside. A 5 cm diameter high shear Sawtooth impeller, Figure 2 is fitted and could be in operation simultaneously or separately to the anchor.

FIG. 1. ESCO 6 litre mixing tank.

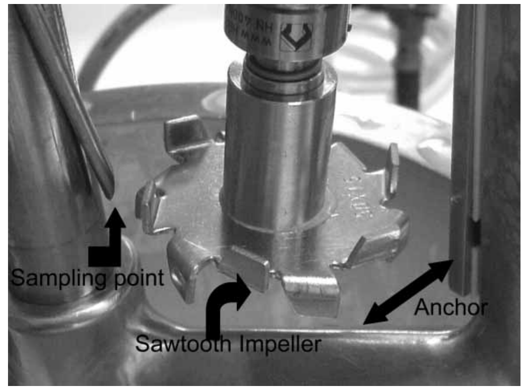

FIG. 2. Sawtooth impeller and the injection-sampling point.

A model system of Dow Corning Oil 200 Fluid in SLES water was chosen for the experimental work. This system is of industrial interest. SLES (supplied by Cognis UK Ltd., Hertfordshire, UK) is a mixed alkyl ether sulphate (C12-14) with 2EO and sodium salt. It is a yellow viscous liquid to paste. According to the supplier information, SLES has a sodium chloride content of 0.5% max/1% max and its sodium sulphate content is also 0.5% max/1% max.

SLES has a specific gravity of 1.03–1.04. It is a widely used surfactant in many household and personal care products because it gives good drop size stability. The use of an impure surfactant system was intentional–such systems are widely used industrially; while desirable for "academic" reasons the high cost of pure systems restrict their use in industry.

2.2 Experimental Procedure

The ranges of the parameters used in the experimentation are listed in Table 2.

The following experimental procedure was used in all the experiments.

1. Deionized water was charged into the vessel with the required amount of SLES.

TABLE 2
Experimental parameters used

Parameter	Value
Dispersed oil viscosity, cSt	350
Impeller type	High shear Sawtooth
Impeller diameter	0.05 m
Impeller speed, rpm	1100, 1500, and 2000
Injection position	Impeller
Reynolds number	38, 250 to 124,000
Operating temperature, °C	25–80
SLES concentration (ppm)	83, 392, and 7090

2. The solution was heated to the required temperature while the contents were mixed using the anchor at 50 rpm; mixing was continued for at least 5 minutes after the set temperature was achieved and then the anchor was switched off.
3. The high shear impeller speed was set to the required value.
4. An amount equivalent to 1%w/w (Dow Corning 200 fluid) the oil was injected gently at 1 cm from the impeller at the impeller centreline using a syringe (Figure 1). The stopwatch was started as soon as all the oil had been added. The refractive index of the oil was measured before the test. In case of impeller injection, the oil is injected gently using a syringe.
5. The stopwatch was started as soon as all the oil had been added.
6. A sample of 20 ml of the suspension was taken through the sampling point and diluted it into an equal amount of deionized water. The sampling point was set at 1 cm from the impeller at the impeller centreline (shown in Figure 2). The sample was then taken to the Malvern Mastersizer laser diffraction particle sizer 2000 to measure the drop size distribution. It was found experimentally that samples measured directly after withdrawal gave the same results as samples measured after 1 day. This was because of the presence of the SLES surfactant. Sampling was repeated at fixed time intervals until the measured Sauter mean diameter did not change with time.

The impeller speed ranges were chosen so that at the lowest impeller speed gives a Reynolds number above 20,000 (fully turbulent region). The maximum impeller speed is measured so that there will be no surface aeration. This was investigated experimentally using a Perspex 6 litres vessel with dimensions and internals specifications same as the 6 litres ESCO mixing vessel.

2.3 Drop Size Measurement by Laser Diffraction

A Malvern Masterziser 2000 laser light scattering instrument and the HyfroSM small volume recirculating cell were used for sample analysis. A lens with focal length of 200 mm was attached to the optical measurement unit. The analyser was capable of detecting droplets in the size range of 0.02 to 2000 μm with an accuracy of $\pm 1\%$ on volume median diameter. The primary output of the instrument is the relative volume size distribution stored in 32 size classes uniformly spaced on a logarithmic scale. Determination of the droplet size distribution by Malvern is based on the measurement and interpretation of the angular distribution of the light diffracted by the droplet using the Mie theory. It is an extremely flexible measurement technique that does not require calibration, but it needs information on the refractive index of the dispersed phase. It has been used successfully by several workers for long time and recently by Sis et al.[2] and Angle and Hamza.[12,13] The calibration of the instrument, however, always was checked using standard particles. Mixing was not interrupted during sampling. Samples were aspirated using a syringe attached to a Teflon capillary. Both sampling and size distribution measurements were completed typically within 20 seconds. Refractive index was measured to be 1.401 and 1.403 for the 50 and 350 cSt silicon oil, respectively.

TABLE 3
Measured viscosities and specific gravity of Dow Corning Oil

Operating temperature, °C	Measured viscosity, cSt	Specific gravity
25	350	0.970
40	250	0.958
60	170	0.937
80	127	0.918

3 RESULTS AND DISCUSSIONS

3.1 Viscosity Measurement

As experiments were planned to be carried out at elevated temperatures, there was a need to measure the viscosities of Dow Corning oil at different temperatures. A Haake RV20 viscometer fitted with a MV2 rotor was used for measuring the viscosity. Viscosity results are shown in Table 3.

3.2 Interfacial Tension Measurement

All interfacial tension measurements were made with a Kruss drop volume tensiometer, Model DVT-10. A schematic representation of this apparatus is presented in Figure 3. The first liquid is placed in the glass tube. The second liquid is introduced into the tube through a 254 μm diameter capillary

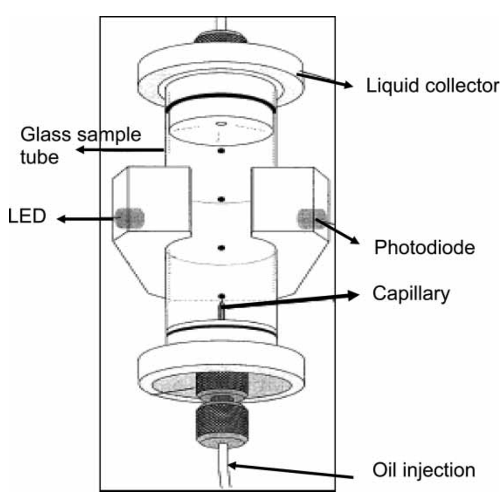

FIG. 3. Configuration of the introduction of the light phase into the sample cell of the Kruss DVT-10 tensiometer.

using a syringe pump. The capillary can be attached to the tube either at the top or at the bottom. This allows two possible capillary orientations: vertically upward, thus, allowing the introduction of the light phase into the heavy phase; or vertically downward, thus, allowing the introduction of the heavy phase into the light phase. An infrared light emitting diode and photodiode are positioned halfway along the glass tube in order to detect the drops as they detach from the capillary. A timer is started when the first drop is detected. Elapsed times between subsequent drops are then measured. Since the flow is kept constant by the syringe pump, the time between drops can be used to calculate the volume of each drop. A few drops (4–10) usually are measured to allow some statistics on quality of the data to be gathered. The relative standard deviation of the data is usually about 1%.

When a droplet forms, a balance of forces exists at the orifice until the drop grows large enough to detach. At this instant, the volume of the drop is directly proportional to interfacial tension between two phases. A force balance on a drop ready to detach at the tip of the capillary orifice results in the following equation for interfacial tension:

$$\gamma = \frac{V(\rho_H - \rho_L)}{\pi d} g \qquad [3]$$

In the above equation, V is the volume of the drop, ρ_H and ρ_L are the densities of the heavy phase and light phase, respectively, d is the orifice diameter of the capillary. The thickness of the orifice wall at the tip is only a few μm to ensure valid results which require no corrections. In general at flow rates above 2.0 ml/hour, acceleration of low viscosity fluid begins to contribute more than 1% of the detachment force and the data then needs to be corrected. However, syringe pumps are less accurate at low flow rates since under these conditions they must push the syringe piston forward more slowly, requiring fewer counts to the starter motors used for this purpose.

3.3 Measurement of the CMC

Surface tension and dye solubilisation are two techniques commonly used for the determination of the CMC in micellar solutions. In this work, the surface tension of the SLES deionised water solution at room temperature using Wilhelmy plate method (Kruss K-12 Processor Tensiometer) was carried out. The measured values determine directly the real surface tension values at equilibrium. The change of the surface tension of SLES with concentration was measured and plotted in Figure 4.

It was found that the surface tension of SLES solution decreases (and the corresponding surface pressure increases) with increasing surfactant concentration, reflecting an increase in the activity of the SLES in the solution under constant coverage of the air-water interface with the SLES; the surface tension reached a constant value that does not change with a further increase in the bulk SLES concentration at the CMC (after which the SLES activity at the solution remained constant). The surfactant CMC of SLES was determined from the abrupt change in the slope of the surface tension values versus surfactant concentration. The accuracy of the equipment is 0.2 mN/m. Surface tension measurement results for silicon fluid water at interface at 25°C are shown in Figure 4.

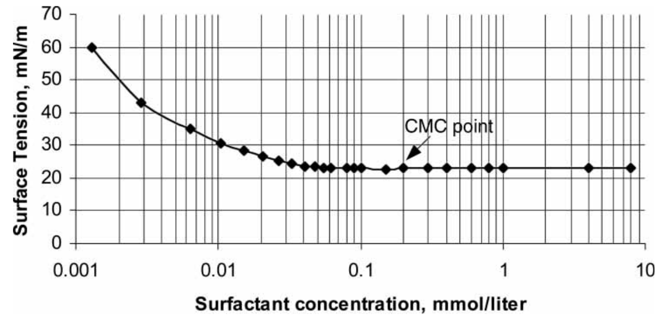

FIG. 4. Surface tension data for SLES solution at 25°C.

From the plot, it can be seen that the CMC value of SLES is between 0.1 and 0.20 mmol dm^{-3}. A clear abrupt in the surface tension of SLES is not observed due to unknown reasons. A value of 0.2 is taken for the CMC. This value is higher than 0.12 as measured by Cocera et al.[19] but both are still lower than 0.7 mmol dm^{-3}, which is the lowest reported value of CMC for SDS surfactant. This could be related to the presence of sodium salt.

SLES is expected to have lower CMC value than SDS because of the presence of EO units. Assuming an SLES molecular weight of 420 then the CMC concentration will be the equivalent to 0.084 g l^{-1} (84 ppm). With this value, then the lowest concentration of SLES used in our experimental work equals to the CMC value. Other chosen SLES concentration values were 392 and 7092 ppm. These values are equivalent to around 4 and 84 times the CMC, respectively.

3.4 Interfacial Tension Measurement at Different Temperatures

The Kruss DV 10 tensiometer was cleaned thoroughly prior to the start of each experiment. The surfactant water (light phase) was introduced into the glass tube and the silicon oil (heavy phase) was introduced by the syringe pump. The light and heavy phases were preheated to the required temperature before introduced to the glass tube or the syringe. To minimize heat loss, the glass tube was inserted into a heating bath where the temperature was kept constant. Any air bubbles present in the tubing were removed by operating the pump. The capillary was then attached to the glass. All experiments reported were carried out at a constant syringe pump flow of 2 ml/hour. The volumes of at least five drops were calculated. Results of the interfacial tension measurements with

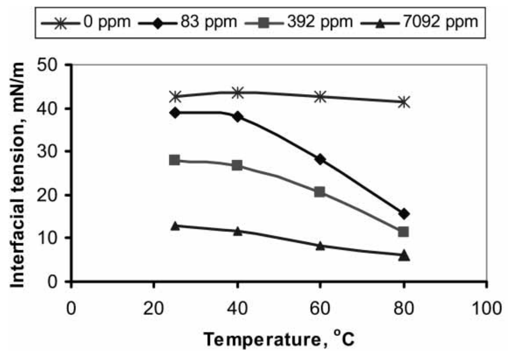

FIG. 5. Variation of the interfacial tension of silicon oil water at different temperature and surfactant concentration.

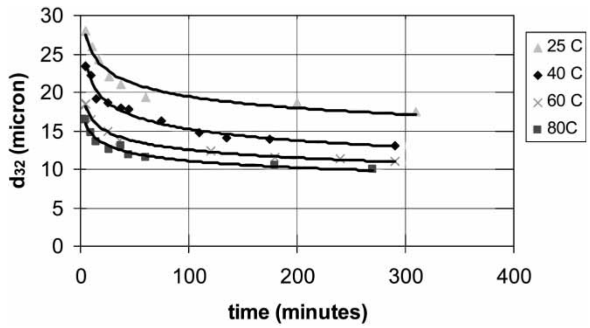

FIG. 6. Effect of temperature on the Sauter mean diameter at 2000 rpm using the 350 cSt silicon oil.

and without the presence of surfactant at a temperature range of 25 to 80°C are shown in Figure 5.

Interfacial tension results of a surfactant free silicon oil water system were found not to be significantly affected by varying the operating temperature. At 25°C the interfacial tension of 350 cSt oil was measured to be 42.5 mNm^{-1} and at 80°C, it was measured to be 41.5 mNm^{-1}. Zhou and Kresta[8] reported an interfacial tension value of 45 mNm^{-1}; whereas Kanellopoulos and Owen[20] showed that the interfacial tension for 0.65–5 cSt silicon oil varies from 42.8 to 44 $mN\,m^{-1}$, respectively. Based on these measurements and the work by Wang and Calabrese,[4] the interfacial tension values of silicon oil of different viscosities are nearly independent on viscosity values. Therefore, the presented results of the interfacial tension of the surfactant free silicon oil water system at 25°C are in line with published results at same temperature.

The effect of surfactant concentration and temperature on the interfacial tension can be clearly seen in Figure 5. An increase of the surfactant concentration at a constant temperature value results in a decrease in the interfacial tension. Also, at constant surfactant concentration the increase in the solution temperature in the range of 25 to 80°C shows a dramatic decrease in the interfacial tension values. This is due to the expansion of monolayer (higher surface area per molecule) spread at the air water surface. Unfortunately no data are reported in the literature to compare the present results.

3.5 Temperature Effect on Sauter Mean Diameter, d_{32}

Set of experiments at various temperature values ranging from 25 to 80°C were carried out using the 350 cSt oil at 2000 rpm. In each experiment, the temperature was kept constant by the aid of the heat exchanger attached to the ESCO rig; also the concentration of SLES used was 7090 ppm. Drop size distribution was carried out and the variation of the Sauter mean diameter with time was recorded and plotted in Figure 6. The qualitative changes of d_{32} with time for all the temperature curves were very similar in shape with approximately same overall change of the value of the Sauter mean diameter during the same time interval. The time took to reach the equilibrium d_{32} decreased by increasing the temperature. An explanation of the smaller Sauter mean diameter obtained at high temperature can be explained not only by the fact that as the temperature increased, the interfacial tension decreased but also due to the decrease in the area per surfactant molecule. This can be attributed to either hydration water at higher temperature or an increase in the hydrophobicity of the surfactant or both.

The lower the value of the interfacial tension results in a reduction in the surface resistance to breakage and, therefore, smaller drop size. At the highest SLES concentration, 7090 ppm, the interfacial tension decreased from 13 to 6 mN/m as the temperature increases from 25 to 80°C. This reduction in the interfacial tension, resulted in reducing the Sauter mean diameter from 17.5 to 10 μm.

3.6 Effect of SLES Concentration on Drop Size Distribution

Measurements of the drop size distributions and the median drop size were carried out at three SLES concentration values, 84, 392, and 7090 ppm. All experiments were carried out at 40°C and under 2000 rpm mixing condition. A plot of the d_{32} versus the agitation time for the lowest surfactant concentration at 2000 rpm is shown in Figure 7. The evolution of the droplet size distribution after 3, 18, 35, and 180 minutes are presented. As the time goes one, the largest drop size decreased. A small secondary peak of finer particles appears in the diagram reflecting the step change in average droplet size. Secondary droplet size are not unusual in industrial process and this is related to the phenomena of the breakage of one drop into two daughter drops and "satellite" droplets as result of stretching of liquid filament just before daughter drops separate. Since the distribution maintains self-preserving property in the presence of the surfactant, the median droplet size can represent the variation of droplet size with mixing time. To demonstrate the effect of the SLES concentrations on the drop size distribution, Figure 8 shows the size distribution of

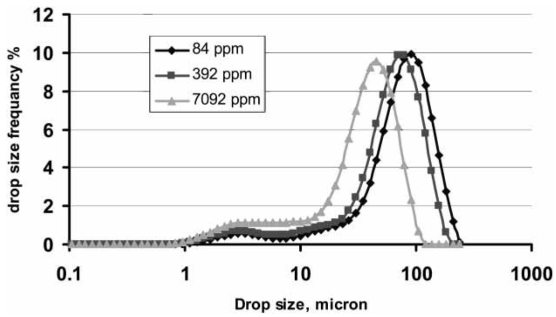

FIG. 7. Evolution of the droplet size distribution with time at 84 ppm surfactant solution and 2000 rpm mixing speed.

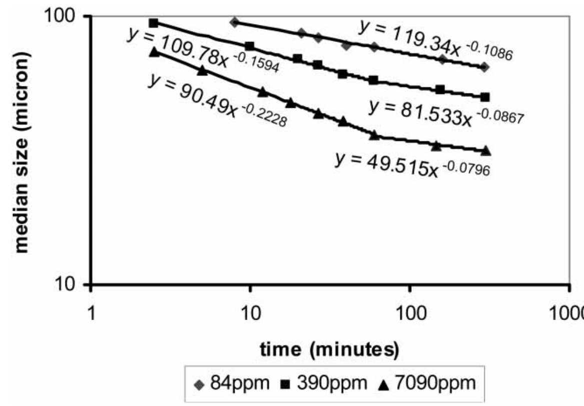

FIG. 9. Variation of median droplet size of 350 cSt silicon oil with mixing time at 40°C and 2000 rpm under different surfactant concentrations.

droplets obtained after an arbitrary mixing time of 35 minutes under a mixing speed of 2000 rpm.

A plot of the change of median drop size with time for the three SLES concentrations is shown in Figure 9. There is a clear decrease in the median droplet diameter as the SLES concentration increase although the SLES concentration values were at or above the CMC value. The figure shows that for the highest two SLES concentration, the slope of the median drop size with time changes after 60 minutes due to the way the interfacial area, and work introduced into the system changes with time. The regression values of all lines are acceptable as they are above 0.99. The energy supplied during the dispersion is consumed by mechanical work for moving the liquids and producing shear as well as in expanding the total interfacial area. The first part of the work remains constant although the SLES concentration is increased. However, the second part of the work, which is equal to the interfacial tension times the increase in interfacial area does changes. The interfacial tension at the oil/water interface changes with concentration as follows; when the SLES concentration is very near the CMC, then as the interfacial area increases, the interfacial tension will increase because the surface concentration at the oil/water interface decreases with time. In other words, the interfacial tension increases as we increase the total interfacial area. Therefore, when a SLES concentration is very higher than the CMC, the decrease in surface concentration will be delayed until all the excess surfactant is utilized in the adsorption at the newly created interface. Thus, a smaller droplet size or large interfacial area will be produced as the initial SLES concentration is increased.

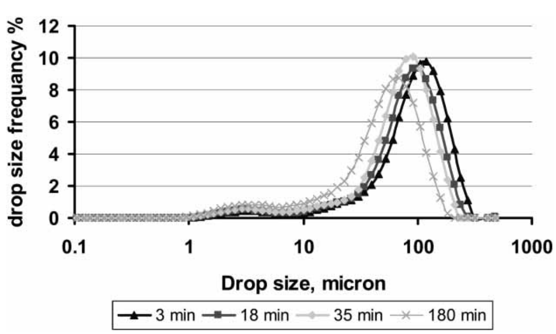

FIG. 8. Decrease in the silicon oil droplet as a function of SLES concentration after 35 minutes mixing time.

The effect of time in decreasing droplet size is obvious. As time goes on, the interfacial area increases because of the more work input and hence smaller droplet size are produced.

The reason behind the change in slope of the change of median drop size with time is due to the fact that the interfacial area at the oil/water interface increases with time and also with depletion of surfactant in the bulk which result in an increase of the interfacial tension the oil droplet interface. This increase in the interfacial tension could result in more coalescence of droplets but it is not that high and balanced by droplet breakage.

4 CONCLUSIONS

This study was carried out to investigate the effect of the concentration of commercial surfactant, SLES, and operating temperature on the drop size distribution of 1%w/w 350 cSt silicon oil water dispersion. The following conclusions were drawn:

- The interfacial tension of silicon oil water system decreased as the operating temperature increased in the presence of SLES surfactant. The higher the concentration of the surfactant at constant temperature, the more reduction in the interfacial tension value.
- There was a successful measurement of the CMC value of SLES. No precise value for the CMC was found in the open literature due to the shortage of research carried out on such surfactant.
- At a very high SLES concentration, increasing the operating temperature resulted in a decrease in the d_{32}. This decrease might be due to whether hydration of water at high temperature occurred or surfactant hydrophobicity was increased or both.

This result could be an open window for further work in this area.

- There was an effect of the SLES concentration on the mean drop size even at concentrations 84 times the measured CMC. This effect was related to the increase of the interfacial area at the oil/water interface with time and also with depletion of surfactant in the bulk. Two different slopes of the change of the droplet median with time were found as a result.

REFERENCES

[1] Podgorska, W. (2006) Modelling of high viscosity oil drop breakage process in intermittent turbulent. *Chem. Eng. Sci.*, 61: 2986–2993.

[2] Sis, H., Kelbaliyev, G., and Chander, S. (2005) Kinetics of drop breakage in stirred vessel under turbulent conditions. *J. Dispersion Sci. Technol.*, 26: 565–573.

[3] Calbrese, R.V., Chang, T.P.K., and Dang, P.T. (1986) Drop breakup in turbulnt stirred contactors: Part 1: Effect of dispersed phase viscosity. *AIChE J.*, 32: 657–666.

[4] Wang, C.Y. and Calabrese, R.V. (1986) Drop breakup in turbulent stirred—Tank contactors part II: Relative influence of viscosity and interfacial tension. *AIChE J.*, 32: 667–676.

[5] Kumar, S., Ganvir, V., Satyanand, C., and Kumar, R. (1989) Alternative mechanism of drop breakup in stirred vessels. *Chem. Eng. Sci.*, 18: 3269–3280.

[6] Sis, H. and Chander, S. (2004) Kinetics of emulsification of dodecane in the absence and presence of non-ionic surfactant. *Colloids Surfaces A*, 235: 113–120.

[7] Goloub, T. and Pugh, R.J. (2003) The role of the surfactant head group in the emulsification process: single surfactant systems. *J. Colloid Interface Sci.*, 257: 337–343.

[8] Zhou, G. and Kresta, S.M. (1998) Evolution of drop size distribution in liquid-liquid dispersions for various impellers. *Chem. Eng. Sci.*, 53: 2099–2113.

[9] Pacek, A.W., Mann, C.C., and Nienow, A.W. (1998) On the Sauter mean diameter and size distributions in turbulent liquid/liquid dispersions in a stirred vessel. *Chem. Eng. Sci.*, 53: 2005–2011.

[10] Lashaeras, J.C., Eastwood, C., Martinez-Bazan, C., and Montanes, J.L. (2002) A review of statistical models for the break-up of an immiscible fluid immersed into fully turbulent flow. *Int. J. Multiphase Flow*, 28: 247–278.

[11] Ceylan, S., Kelbaliyev, G., and Ceylan, K. (2003) Estimation of the maximum stable drop sizes, coalescence frequancies and the size distribution in isontropic turbulent dispersions. *Colloids Surf. A*, 212: 285–295.

[12] Angle, C.W. and Hamza, H.A. (2006) Predicting the sizes of toluene-diluted heavy oil emulsions in turbulent flow part 2: Hinxe-Kolmogorov based model adapted for increased oil fractions and energy dissipation in a stirred tank. *Chem. Eng. Sci.*, 61: 7325–7335.

[13] Angle, C.W. and Hamza, H.A. (2006) Drop sizes during turbulent mixing of toluene-heavy oil fractions in water. *AIChE J.*, 52: 2639–2650.

[14] Sechremeli, D., Stampouli, A., and Stamatoudis, M. (2006) Comparison of mean drop sizes and drop size distribution in agitated liquid-liquid dispersions produced by disk an open type impellers. *Chem. Eng. J.*, 117: 117–122.

[15] Koshy, A., Das, T.R., and Kumar, R. (1988) Effect of surfactants on drop breakage in turbulent liquid dispersions. *Chem. Eng. Sci.*, 43: 649–654.

[16] Patist, A., Oh, S.G., Leung, R., and Shah, D.O. (2001) Kinetics of micellization: its significance to technological process. *Colloid Surfaces A*, 176: 3–16.

[17] OH, S.G., Jobalia, M., and Shah, D.O. (1993) The effect of micellar lifetime on the droplet sizes in emulsions. *J. Colloid Interface Sci.*, 155: 511–514.

[18] Lee, J.M. and Soong, Y. (1985) Effects of surfactants on the liquid–liquid dispersions in agitated vessels. *Ind. Eng. Chem. Process Des. Dev.*, 24: 118–121.

[19] Cocera, M., Lopez, O., Estelrich, J., Parra, J.L., and de la Maza, A. (2002) Adsoprption of sodium laurel ether sulfate on liposomes by jeans of a fluorescent probe: effect of the ethylene oxide group. *Langmuir*, 18: 8250–8254.

[20] Kanellopoulos, A.G. and Owen, M.J. (1971) Adsorption of sodium dodecyl sulphate at the silicone fluid-water interface. *Trans. Faraday Soc.*, 67: 3127–3138.