# Measurement of Coalescence Frequency in an Agitated Tank

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A new method for measuring the frequency of coalescence of drops in an agitated tank is proposed. It makes use of the fact that the rate of establishment of a new steady state mean drop size following a reduction in agitation intensity is related to the coalescence frequency in the tank. This method allows independent examination of the effects of drop size and impeller speed on coalescence frequency, and has the advantage that, since the measurement is not dependent upon the addition of external substances, high degrees of purity can be maintained and the effect of trace additions to the dispersion observed. The results provide some support for the assumption of an inverse proportionality between coalescence frequency and drop size. For constant drop size, coalescence frequency was found to depend on impeller speed raised to the power of 1.3 to 1.65 and the volume fraction of dispersed phase to the power of 0.6. The magnitude of density difference between the phases and the operating temperature were found to affect coalescence frequency, although it is suspected that these two effects are interrelated. The addition of small quantities of simple electrolytes to the continuous phase was found to cause a marked reduction in coalescence frequency.

Methods of measuring coalescence rates in agitated tanks previously reported in the literature have relied mainly upon following the rate of spread of a tracer due to mixing in the dispersed phase. Madden and Damerell (7) followed the spread of sodium thiosulfate among water drops dispersed in toluene, by measuring the rate of reaction with iodine in solution in the continuous phase. Miller et al. (8) followed the spread of a dye in an organic phase dispersed in water, while Hillstead and Rushton (4) followed the course of the ferric chloride-potassium ferricyanide reaction in aqueous drops suspended in an organic phase, both authors using light transmission methods to measure the extent of mixing. On the other hand, Groothuis and Zuiderweg (3) measured coalescence rates by feeding two organic phases continuously, with densities greater and less than the continuous water phase, to an agitated tank, and measuring the amount of the light phase converted to heavy phase as a result of coalescence.

The present work is a description of a method for measuring coalescence frequency, developed with the aim of avoiding the necessity of introducing a tracer which may modify coalescence behavior to an unknown extent. The method has the added advantage that, unlike those previously used, drop size and power input per unit volume can be varied independently (although to a limited extent), allowing the effect of these variables to be isolated.

## BASIS OF PRESENT METHOD

Consider a stirred baffled tank containing two liquid phases under steady conditions of agitation, with fully developed turbulent flow. In the absence of specific factors preventing coalescence (protective colloids, surface active agents), it is assumed that coalescence and breakup of drops proceed simultaneously but independently. Eventually a mean drop size is established which remains constant in time and is determined by the opposing processes coalescence and breakup. If the impeller speed is changed, the mean drop size will also change until it reaches the steady state value associated with the new impeller speed. For example, a reduction in impeller speed is followed by an increase in the mean drop size to a new steady value. Under these circumstances the rate of coalescence must temporarily exceed the rate of breakup, although both processes would still be taking place. By the use of a simplified model for the system, this property of an agitated tank can be used to provide a *means of measuring* the rate of coalescence.

## BASIC ASSUMPTIONS

As a basis for further discussion, the turbulent flow field in an agitated tank is assumed to be homogeneous and

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isotropic, so that coalescence and breakup proceed at the same rate at all points in the tank and are not localized in any particular region. There are some bases for such an assumption. For example, it may be assumed that at high rates of stirring the Kolmogoroff theory of locally isotropic flow is applicable to the turbulent flow field in an agitated tank. This theory is reviewed by Hinze (*5*), and its application to dispersion and coalescence in an agitated tank is discussed by Shinnar (9). To summarize very briefly, it is suggested that at sufficiently high rates of energy input, the small-scale turbulent motions are isotropic. Their properties are determined by the energy dissipation rate and the kinematic viscosity of the fluid, and are independent of vessel geometry and the turbulence generating mechanism. According to Shinnar this condition applies to an agitated tank if the impeller Reynolds number ($D^2N\rho/\mu$) is greater than about $10^4$. Since for a Reynolds number of this magnitude the size of the dispersed liquid particles is likely to be small, it is assumed that their relative motions are determined by the fine scale structure of the turbulence. Homogeneity of the flow field, on the other hand, cannot be assured, but to assist in the establishment of a roughly homogeneous turbulence, advantage is taken of a suggestion by Gillespie (*1*) that the use of relatively large paddles results in a more homogeneous flow structure than would otherwise be expected. Intuitive reasoning suggests that this is likely to be the case, as the large pumping rates so obtained would result in a relatively uniform dissipation of turbulence energy over the whole volume of the tank. The impeller used in the experiments described below has been deliberately increased in size over that normally recommended for the design of agitated tanks (a six-bladed turbine with diameter equal to half that of the tank and with generous blade dimensions was used), and for impeller Reynolds numbers above $10^4$, it is taken as a reasonable approximation that the flow is homogeneous and isotropic.

In a dispersion in turbulent flow it is proposed that individual drops coalesce until the resultant reaches a size that is not stable under the conditions of turbulence prevailing, and is broken up. There is undoubtedly a maximum to the size of a dispersed fluid particle which could remain stable indefinitely in a particular turbulent flow field, although drops larger than the maximum stable size may exist for finite periods of time. Sleicher (*10*) has referred to the latter as marginally stable drops. The life expectancy of a marginally stable drop would be expected to approach zero as its size increases, and in a highly nonhomogeneous turbulent flow it might be expected that a marginally stable drop could exist for relatively long periods in regions of low turbulence intensity. On the other hand, in a homogeneous isotropic turbulence, it would not seem unreasonable to assume that the size of a marginally stable drop with life expectancy approaching zero would not be much different from the maximum stable drop size. Hence it is assumed here that drops grow by coalescence until they reach a maximum stable size, after which breakup occurs immediately. For convenience this will be referred to as the *maximum stable drop size postulate.*

## DETAILS OF METHOD

Now consider an agitated tank operating at constant impeller speed, in which the steady state mean drop size has been established, and imagine the impeller speed to be reduced suddenly to a new steady value. The intensity of turbulent fluctuations will decay rapidly to a lower level set by the new conditions of agitation. Assume for the moment that the turbulence intensity also changes in a stepwise fashion. Introducing the maximum stable drop size postulate, we see that the maximum stable size of a drop at the new turbulence level will be greater than the size of any of the drops present at the instant of reduction of the impeller speed. Therefore no breakup can occur until some drops grow to the new maximum stable size by coalescence. Hence the initial rate of increase of mean drop size is determined by coalescence alone. This is the principle which is to be used as a means of measuring coalescence frequencies.

The argument above is based on the supposition of instantaneous decay of turbulent properties following a stepwise reduction in impeller speed. Practically, the turbulence would decay at a finite rate. However, it is only required that the decay should be rapid with respect to the rate of coalescence, so that a negligibly small number of coalescences occur during the decay period. Whether this is likely cannot easily be deduced from the published literature, but on the other hand the results of direct measurement of initial rates of increase in drop size should give an indication as to whether the assumption of rapid decay is justified.

From previous measurements of coalescence frequency in stirred tanks (*3*, *7*, *8*), it is known that coalescence frequency increases with increase in impeller speed, implying that there is a strong effect of the intensity of turbulence. If the decay of turbulence is not sufficiently rapid following a sudden reduction in impeller speed, and a significant number of coalescences occur during the decay period, the apparent rate of coalescence deduced from the measurements of the initial rate of increase in drop size will be greater than that expected if the decay was virtually instantaneous. This effect would be expected to increase with the difference between the two levels of turbulence intensity. Therefore, if a significant effect of initial impeller speed is revealed during measurements of coalescence frequency at a fixed final impeller speed, an effect of turbulence decay is indicated. At the same time if there is no such effect, it can be taken as evidence that the decay is sufficiently rapid to meet requirements outlined above.

Summarizing to this stage, it has been shown that the initial rate of increase of drop size following a sudden reduction in impeller speed in an agitated tank can be taken as being a direct measure of coalescence frequency if the following assumptions hold;

1. The turbulent flow field is homogeneous and isotropic.
2. Drops grow by coalescence until they exceed a maximum stable size, after which breakup is immediate.
3. The decay of turbulence is virtually instantaneous.

Accepting these for the moment, it is necessary to relate the initial rate of change in drop size to coalescence frequency. Again it is necessary to make some assumptions in order to reduce the analysis of a complex phenomenon to a reasonably tractable level. Although it is known that the sizes of drops in a dispersion in an agitated tank cover a broad range, it is assumed here that little error is introduced by basing the following analysis on a system consisting initially of uniformly sized drops.

Consider a dispersion containing $n$ drops per unit volume of uniform diameter $\sigma_i$. Let the original surface area per drop be $s_i$, and the total surface area per unit volume S. Imagine that coalescence starts at time zero and proceeds at a uniform rate $u'$ per unit volume and time. Since the behavior of the system near time zero only is of interest, only coalescences between drops of diameter $\sigma_i$ are considered. When two drops coalesce, the surface area of the new drop is

$$s = 2^{2/3}s_i$$

The total surface area of such a dispersion after a small time $\theta$ is

$$S = s_i(n - 2u'\theta) + 2^{2/3} s_i u'\theta$$

$$dS/d\theta = -(2 - 2^{2/3}) s_i u'$$

If $\sigma_m$ is the surface-volume mean diameter of drops in the dispersion so formed, we have

$$S = 6F/\sigma_m$$

$$dS/d\theta = -(6F/\sigma_m^2)\, d\sigma_m/d\theta$$

$$d\sigma_m/d\theta = (2 - 2^{2/3})\, s_i u' \sigma_m^2/6F$$

At

$$\theta = 0 \qquad \sigma_m = \sigma_i$$

and

$$u' = 6F(d\sigma_m/d\theta)_0/(2 - 2^{2/3})\sigma_i^4 \tag{1}$$

It is more convenient to consider the coalescing frequency of a single drop, $u$ per unit time (more correctly, the reciprocal of the mean lifetime of a drop between coalescences).

$$u = u'/n \quad \text{and } n = 6F/\pi\sigma_i^3$$

whence

$$u = (d\sigma_m/d\theta)_0/(2 - 2^{2/3})\sigma_i \tag{2}$$

Equation (2) provides the necessary relationship between the initial slope of the mean drop size vs. time curve, and coalescence frequency, for initially monodispersed systems.

It is to be noted that the proposed method gives a measure of coalescence frequency between drops of a size determined by the initial impeller speed, at a turbulence level determined by the final or base speed. Since a number of different initial speeds can be used for a single base speed, there is in principle an opportunity of examining independently the effect of drop size and impeller speed on coalescence frequency. However, as discussed below, the range of initial impeller speeds that can be used is limited by practical consideration, and hence the range of drop sizes that can be covered is limited. Nevertheless the effect of other variables such as impeller speed, volume fraction of dispersed phase, and other external factors can be examined in detail by this method.

## EXPERIMENTAL EQUIPMENT

The agitated tank used was made from a 6-in. I.D. glass cylinder, 6 in. long with metal top and bottom plates. Four internal baffles, 1/10 vessel diameter, were used. The vessel was run full, and agitation provided by a 3-in. diameter, six-blade flat bladed turbine (blade dimensions 1 in. by 1⅛ in.), permitting impeller Reynolds numbers in excess of $10^4$ for speeds above 120 rev./min. All metallic components were

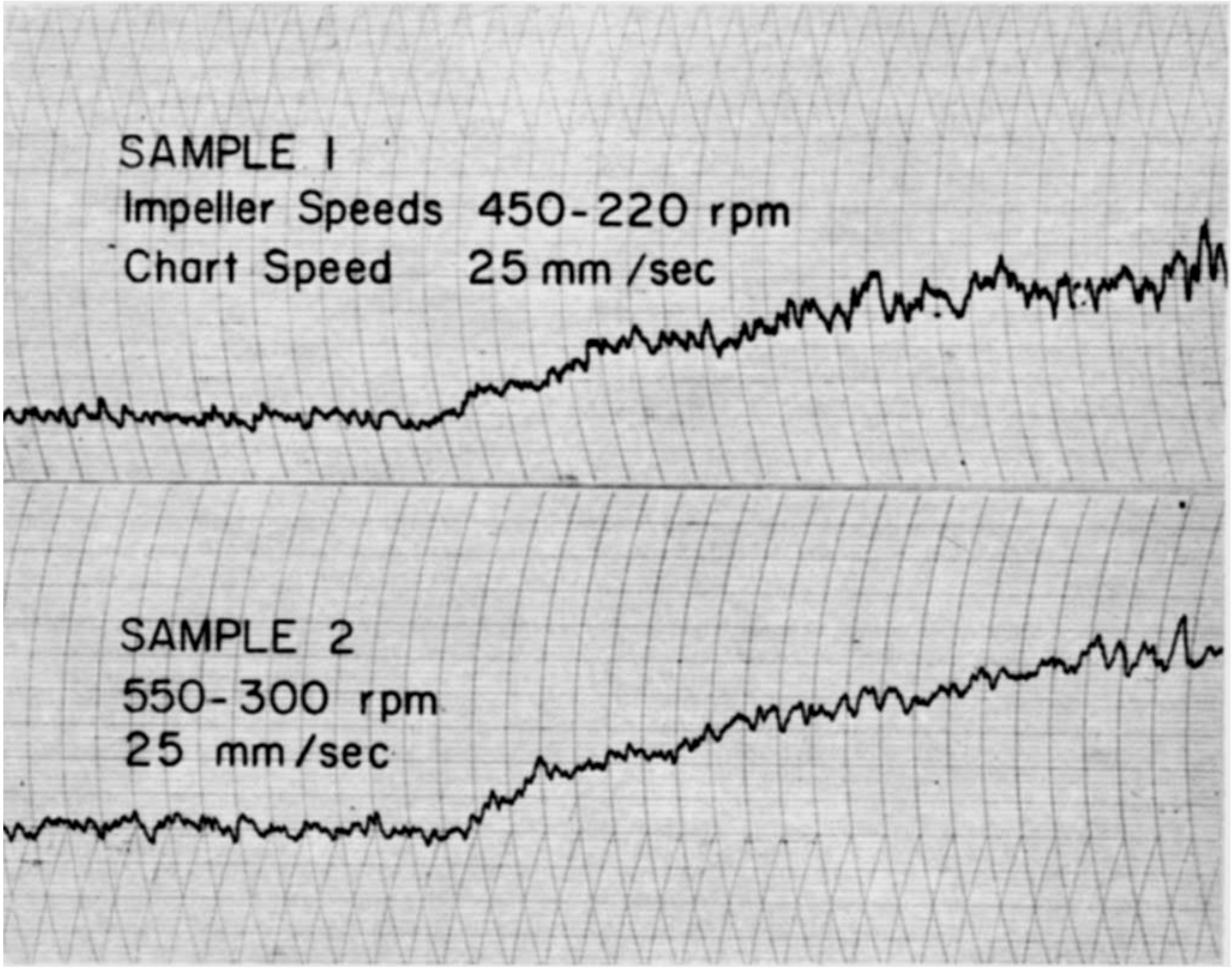

Fig. 1. Typical chart record of photocell output against time, following step change in impeller speed.

protected by a heavy nickel plating, and all gaskets and packings were of Teflon. The mixing vessel was provided with a small "cold finger" type of heat exchanger to permit control of temperature. This was in the form of a ⅜-in. O.D. cylinder 5 in. long, located vertically near the wall of the vessel. Impeller speed was adjusted by a mechanical speed varying device (Kopp Variator) selected for its ability to permit virtually instantaneous changes in impeller speed. The mass of rotating components after the speed variator was kept to a minimum to avoid inertial effects. The speed control arm of the variator was actuated by a small air cylinder, upper and lower impeller speeds being controlled by preset stops.

The mean drop size was measured by the light transmission method of Trice and Rodger (*11*). Their light transmission-interfacial area correlation was not found to be satisfactory, presumably due to slight differences in the construction of light probe, filter, and photocell used here. A separate correlation for 5, 10, and 25% by volume of dispersed phase was obtained for the particular system used, mean drop sizes being obtained photographically. The interfacial area-light extinction ratio curves so obtained were fitted by polynomials, which were thereafter used as a basis for calculating mean drop sizes.

The output from the photocell in the light probe was connected through a wide-band d.c. amplifier to a high-speed recorder. All static and transient measurements of light transmission were made with this system. The limiting factor to frequency response was the recorder, which was rated at 200 cycles/sec., and this was found more than adequate for the transients involved.

Mixtures of benzene and carbon tetrachloride, with composition adjusted to give densities close to those of the continuous phase, were dispersed in water. For convenience in separating the phases, the organic phase was in most cases made slightly heavier than the aqueous phase, with a density of about 1.01 g./cc. at 25°C. Since the coalescence properties of a dispersion are well known to be affected by traces of surface active contaminants, considerable care was exercised in the preparation and handling of the solutions, and during actual operation, to prevent chance contamination. With careful control of temperature, organic phase density, and solution concentration, reproducibility was found to be reasonable. Initially A.R. grade organic reagents and once distilled water were used. For later runs the organic reagents were redistilled and double distilled water was used.

## TREATMENT OF DATA

The measurements for a given set of operating conditions were the initial steady light transmission value, and a record of the change of light transmission with time following a stepwise reduction in impeller speed. The curves obtained were smoothed by eye, and the corresponding mean drop size vs. time curve obtained. The initial slope was determined graphically. Although the possibility of bias arises in the interpretation of the data, care was taken to avoid this by carrying out the calculations in random order, etc.

The recordings of steady and transient light transmission contained a considerable amount of noise. Reproductions of typical examples are shown in Figure 1. Noting that the light probe diameter of about 1 cm. is much larger than the drop sizes encountered, the noise is thought to originate, not from the passage of larger drops past the probe, but from regions of slightly different drop population density in the dispersion passing through the light beam.

The presence of noise of this nature made the interpretation of data for small changes in impeller speed difficult, as the noise-to-signal ratio was excessive when the difference in impeller speeds was less than 150 rev./min. (*the maximum stable drop size postulate is also less likely* to apply for small changes).

When the measurement of coalescence frequency was repeated a number of times for identical conditions, the results showed a degree of scatter. To obtain reasonably consistent average values, it was necessary to repeat measurements a number of times. All the experimental data points reported here represent the average of between ten and twenty separate measurements.

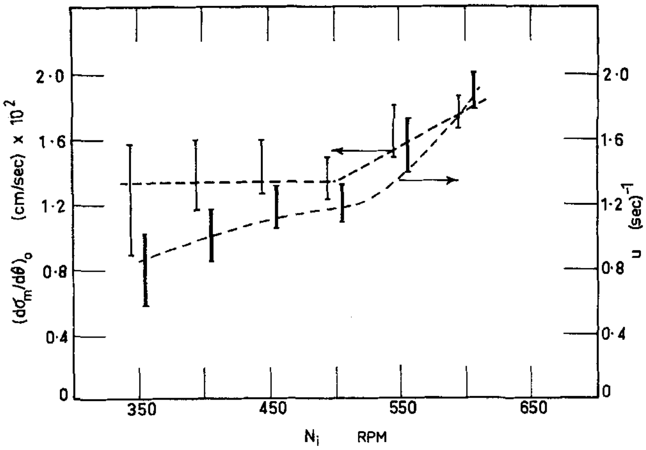

Fig. 2. **$(d\sigma/dt)$ and $u$ plotted as function of the change in impeller speed. Vertical lines represent 95% confidence limits of data.**

## EXPERIMENTAL RESULTS

It has to be established that the rate of decay of turbulence following a step change in impeller speed is sufficiently rapid, as compared to the coalescence rate, to justify the application of this method. It was proposed earlier that this may be tested by measuring coalescence frequency at a fixed final impeller speed for a range of initial impeller speeds. Another factor intrudes here, namely, that the initial impeller speed controls the initial size of drops which coalesce at a turbulence level determined by the final impeller speed, and coalescence frequency is expected to depend on the size of the drops. For a given volume fraction of dispersed phase it might be assumed that coalescence frequency would decrease with an increase in drop size. We can postulate an inverse relationship,

$$u \propto 1/\sigma \tag{3}$$

from which we expect $u \times \sigma_i$ to be constant for a given set of operating conditions. In view of Equation (2), this implies that $(d\sigma_m/d\theta)_0$ should be constant, rather than the coalescence frequency $u$, when initial drop size is varied.

A series of experimental runs was carried out with a constant final impeller speed of 210 rev./min. and with initial impeller speeds in the range of 350 to 600 rev./min. The results have been plotted in Figure 2 as vertical lines representing the 95% confidence limits of the data. Both the initial rate of change of the drop size and the absolute value of coalescence frequency as calculated from Equation (2) have been plotted in the same figure. It will be seen that the scatter of data at the lowest initial speed is large but decreases as the initial speed is increased. The initial rate of change of drop size does, in fact, appear to be constant over a range of initial impeller speeds. As the magnitude of the change in speed exceeds about 300 rev./min., the measured values of $(d\sigma_m/d\theta)_0$ start to rise, indicating that a significant amount of coalescence was taking place during the extended decay periods resulting from large changes in impeller speed. However, if the magnitude of the change is limited to a maximum of say 250 rev./min., it would seem reasonable to assume that the turbulence decay was virtually instantaneous. Therefore the magnitude of the step change in the im-

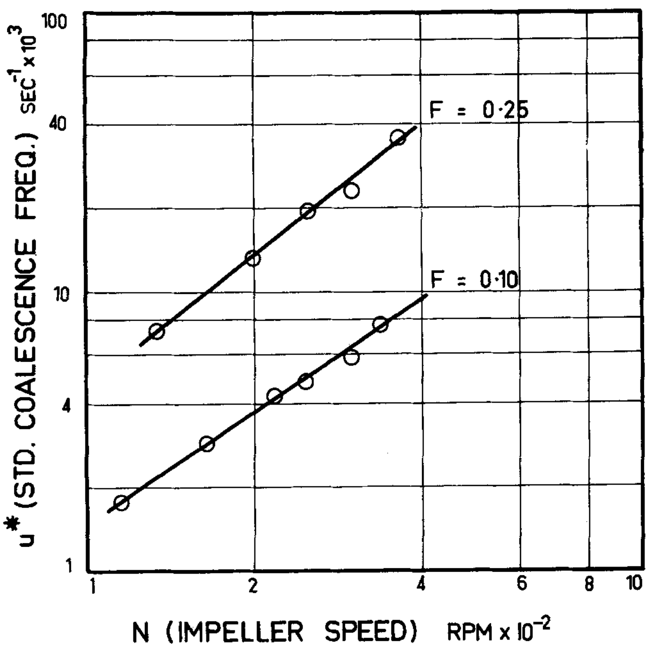

Fig. 3. Effect of impeller speed, with volume fraction dispersed phase as parameter.

peller speed was restricted by practical considerations to the range of 150 to 250 rev./min. Within these limits there should be no effect of the initial impeller speed, and the noise level was sufficiently low to permit reasonable accuracy in interpretation of the data. The results plotted in Figure 2 would appear to provide some evidence that coalescence frequency does in fact vary as the inverse of drop size. However, it is to be noted that the initial drop diameters investigated cover the limited range of 0.025 to 0.037 cm., and it was not possible to extend this range due to the limitation on the ranges of impeller speed discussed above. Hence practical difficulties prevent the examination of a larger range of initial drop sizes.

Since coalescence frequency is dependent upon initial drop size, and it was not possible to keep this factor constant for all determinations the question of how to report experimental data is raised. In view of the foregoing, it was considered logical to report $(d\sigma_m/d\theta)_0$ directly. This is in fact equivalent to reporting coalescence frequency for a standard sized drop, $1/(2 - 2^{2/3})$ cm. diameter (2.41 cm.). For convenience a new quantity, the standard coalescence frequency $u^*$, is introduced. This is defined as the frequency of coalescence of a standard sized drop, here 2.41 cm. diameter, and is numerically equal to $(d\sigma_m/d\theta)_0$, but has the dimensions sec.$^{-1}$. The standard coalescence frequency is used here as a means of indicating the effect of variables such as impeller speed, volume fraction dispersed phase, etc. Since the initial drop sizes were in the range of 0.01 to 0.04 cm., a rough measure of the absolute value of coalescence frequency is obtained if $u^*$ is multiplied by $10^2$.

Over the whole range of experiments, coalescence frequencies, as calculated from Equation (2), were found to lie in the range of 0.1 to 3.5/sec. As a basis for comparison with the results of previous workers, the power input per unit volume in these experiments was estimated to be in the range of 0.2 to 6 h.p./1,000 U.S. gal. Miller et al. (*8*) reported coalescence frequencies in the range of 0.03 to 0.6/sec. for power inputs of between 2 and 100 h.p./1,000 U.S. gal., for volume fractions of dispersed phase similar to those used here. Groothuis and Zuiderweg (*3*) found values of coalescence frequency in the range of 0.0008 to 0.04 for power inputs from 0.2 to 0.5 h.p./1,000 U.S. gal. If the data of Madden and Damerell (*7*) are extrapolated to the same volume fraction of dispersed phase as used here, coalescence frequencies in the range of 0.4 to 2.5 sec.$^{-1}$ are obtained, for power inputs in the range 1 to 7 h.p./1,000 U.S. gal.

A close comparison of experimental measurements would serve no purpose because of the marked effect of minute traces of contaminant on coalescence frequency. However, there is encouraging agreement, at least with regard to the orders of magnitude of values obtained.

Coalescence frequency is strongly dependent upon impeller speed. The effect of impeller speeds in the range of 110 to 360 rev./min. has been investigated for volume fractions of dispersed phase of 0.1 and 0.25. The results are shown in Figure 3. The effect of impeller speed for different temperatures of operation, and for dispersions with and without the addition of a small amount of electrolyte (0.05 g.-mole/liter of sodium chloride) to the continuous phase, has also been examined. These results are shown in Figure 4. The trend with impeller speeds is similar in each case, with $u^*$ proportional to $N^{1.3-1.65}$.

It has to be kept in mind that this variation is for constant initial drop size. Previous workers have reported a stronger effect of impeller speed on coalescence frequency [$u \propto N^{2.4}$ (*7*) and $u \propto N^{1.5-3.3}$ (*8*)], but their results contain the effect of impeller speed on drop size. In this work drop size was found to vary roughly as $N^{-0.6}$. This can be combined with the impeller speed dependence noted above, by accepting the inverse relationship between $u$ and $\sigma$ as suggested in Equation (3), to give

$$u \propto N^{1.9-2.25}$$

which is in good agreement with previous findings.

Miller et al. (*8*) indicated that they obtained greater reproducibility of measurement of coalescence frequency if a small amount of electrolyte was present in the aqueous phase. Such an effect might follow if variable amounts of ionic surface active agents were present, although they appeared to have taken care to avoid contamination of this nature. In this work the addition of 0.05 mole/liter of sodium chloride was found to reduce coalescence rates by a factor of about five (see Figure 4).

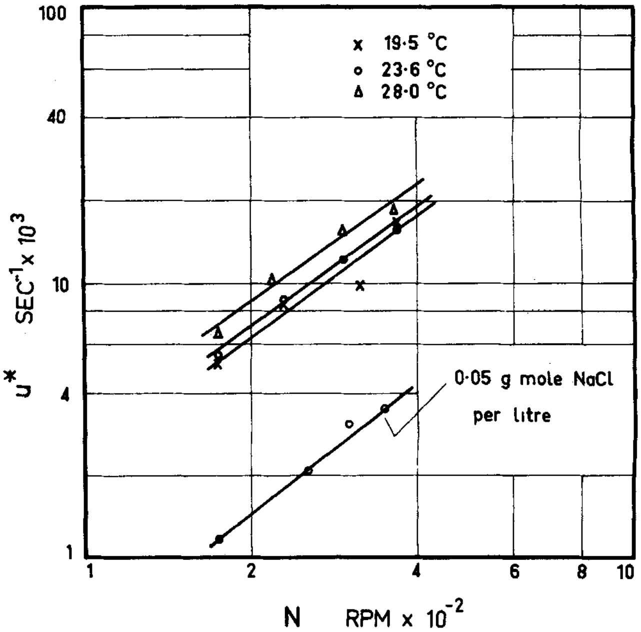

Fig. 4. Effect of impeller speed, with temperature and sodium chloride concentration as parameters. Volume fraction dispersed phase, 0.25.

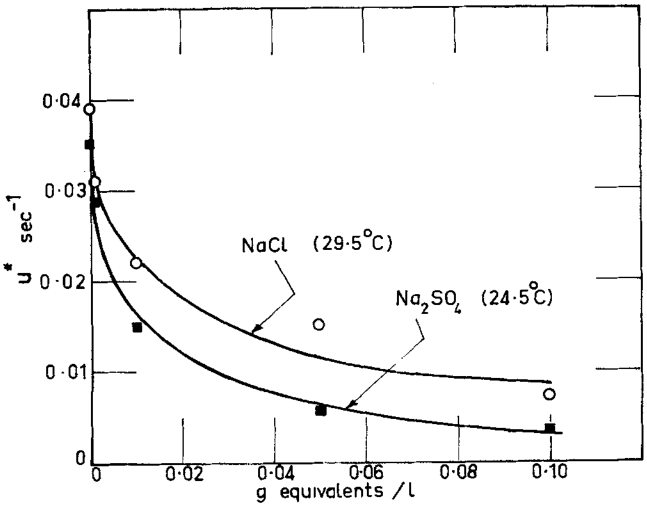

Fig. 5. Effect of electrolyte concentration. Impeller speed, 220 rev./min., volume fraction dispersed phase, 0.10.

This effect requires further investigation, since inorganic ions are considered to be surface inactive, but the addition of inorganic electrolytes to an aqueous phase produces a small increase in interfacial tension. If a dispersion were partially stabilized by the presence of an electrical double layer due to the adsorption of ionic surface active materials, the addition of 0.05 mole/liter of sodium chloride would be expected to cause an increase in coalescence frequency. Therefore by these arguments, it would be expected that the coalescence frequency would be unaltered or increased by the addition of sodium chloride.

The reduction in coalescence frequency described above was quite reproducible, but to provide further evidence, a series of experiments was conducted, starting with highly purified materials, in which sodium chloride concentration was systematically varied. Concentrations from 0 to 0.1 g. equiv./liter were examined, and the results are plotted in Figure 5. The effect of adding similar quantities of sodium sulfate is shown in the same figure. Because of the large decrease in standard coalescence frequency with very small electrolyte concentrations, the possibility of an effect through alteration of physical properties such as density or viscosity can be neglected, so that an explanation must be formulated in terms of the electrical properties of the solution. It should be noted that both electrolytes were ignited at the melting point before addition to the dispersion, to avoid the possibility of adding organic surface active contaminants.

Assuming that sodium or chloride ions are not adsorbed at the interface, there remain the possibilities:

1. that sodium or chloride ions are distributed nonuniformly between the organic and aqueous phases, giving rise to either positively or negatively charged droplets, and a consequent reduction in coalescence frequency, or
2. when a drop is broken up, the fragments might acquire electrostatic charges of different sign. This phenomenon has been observed in the formation of mists of nonpolar fluids (see for example reference *2*). The chance of coalescence of oppositely charged droplets is obviously greater than for droplets that are not charged, and it is possible that the overall rate of coalescence may be increased by a mechanism of this nature. The addition of an electrolyte would increase the rate of neutralization of charged particles, and hence cause a reduction in coalescence frequency.

The problem obviously requires further study before any real conclusions can be drawn as to the likelihood of (1) or (2), or some other mechanism not considered here, being the cause of the observed decrease in coalescence frequency.

Referring again to the work of Miller et al. (*8*) it now appears that in their work, the addition of 0.05 g.-mole of sodium chloride/liter could have "swamped out" the effect of small but variable quantities of ionic impurities, hence reducing the variability in measured coalescence frequencies.

Reference to Figure 4 will show an increase in coalescence frequency with an increase in temperature for the system under examination. Carbon tetrachloride and benzene have temperature coefficients of interfacial tension (*6*) of $-$ 0.098 and $-$ 0.058 dynes/(cm.)(°C.), respectively, which are approximately constant in the range of 10 to 40°C. Therefore, if interfacial tension was controlling, a decrease in coalescence frequency would be expected with an increase in temperature.

Since the agitation is in the constant Power number range, the variation of fluid viscosity would have no effect on the energy dissipation rate for a given impeller speed. Also, according to Kolmogoroff, for particles with diameter much greater than the length parameter $\eta$, where

$$\eta = (\nu^3/\epsilon)^{1/4}$$

(but much smaller than the scale of the energy containing eddies, taken to be of the same order of magnitude as the size of the turbulence generating mechanism), their behavior is determined by the dissipation rate per unit mass $\epsilon$ alone. Since this condition applies here, it appears that the effect of temperature is not due to a change in viscosity of the fluid.

The coefficients of thermal expansion of both carbon tetrachloride and benzene are greater than that of water. Therefore if an organic mixture has a density of about 1.01 g./cc. at 25°C. and the temperature is increased, the density of the mixture will decrease at a greater rate than that of water. It is suggested that the observed effect of

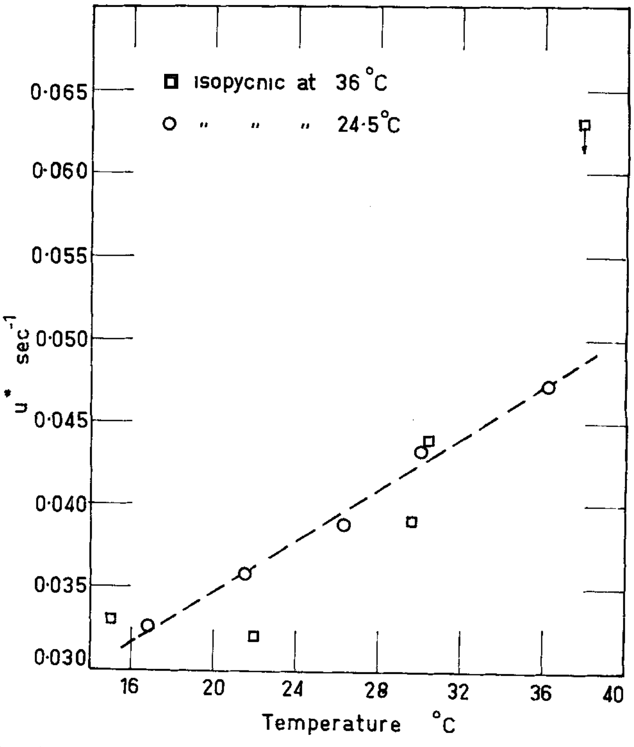

Fig. 6. Effect of temperature. Impeller speed, 220 rev./min.; volume fraction dispersed phase, 0.10.

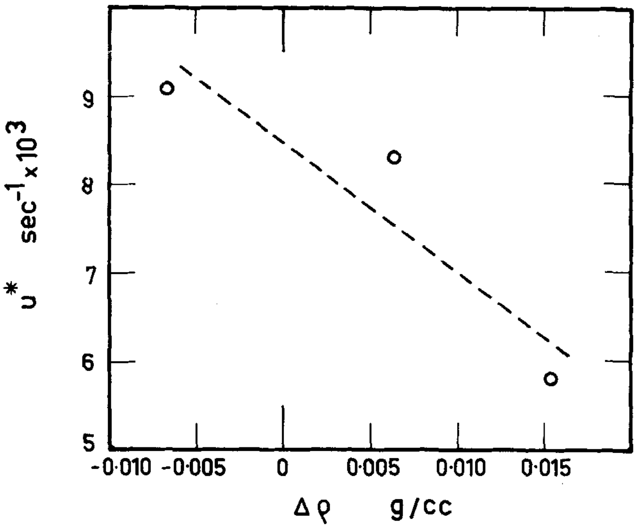

**Fig. 7. Effect of density difference ($\rho_d$ — $\rho_c$). Other conditions as for Figure 6.**

temperature is due to the changing difference in density between the two phases. Figure 6 gives a more extended coverage of temperature effects. Similar results were obtained for 10 and 25 volume % dispersions, and with 0.05 mole/liter of sodium chloride in the aqueous phase. Some limited data on the effect of changing organic phase density for constant temperature operation are given in Figure 7. This indicates a similar trend of coalescence frequency with density difference to that deduced from the temperature dependence of Figure 6.

It should be noted that density variation at constant temperature was achieved by replacing the dispersed phase with material of different composition. Such a procedure would always be accompanied by a risk of introducing variable amounts of contaminant, which could influence the coalescing properties of the dispersion and mask the effect of the variable under consideration. Although considerable care was exercised at all stages in the handling of materials, such factors have to be kept in mind when assessing the above results.

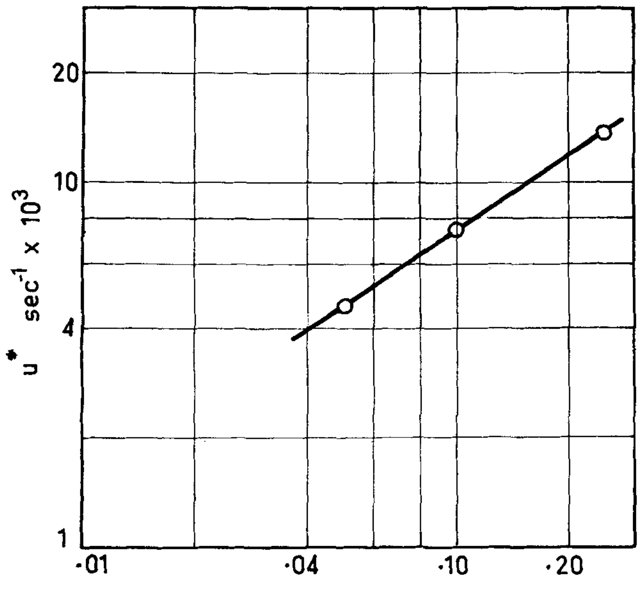

**Fig. 8. Effect of volume fraction dispersed phase. Impeller speed, 210 rev./min.**

Similar considerations apply to the measurement of the effect of volume fraction of dispersed phase. Standard coalescence frequency was measured as a function of volume fraction of dispersed phase, with the result shown in Figure 8. These data indicate $u^*$ to be proportional to $F^{0.6}$. This is in rough agreement with the data of Madden and Damerell (7) ($u \propto F^{0.5}$). Such a comparison is considered reasonable, since these authors used very dilute dispersions, and drop size would have been expected to remain constant with change in volume fraction of dispersed phase. A wider comparison is not feasible, since other workers using more concentrated dispersions did not report the variation of drop size with volume fraction of dispersed phase, and their measured coalescence frequencies would have contained an effect of drop size.

## CONCLUSION

The measured values of coalescence frequency and its dependence on impeller speed and volume fraction of dispersed phase appear to be in agreement with the results of previous workers. This is taken as justification for application of the method described here, in spite of the tenuous nature of some of the assumptions on which it is based.

## NOTATION

$D$ = impeller diameter, cm.
$F$ = volume fraction dispersed phase
$n$ = number of drops per unit volume, cc.$^{-1}$
$N$ = impeller speed, rev./min.
$s$ = surface area per drop, sq.cm.
$S$ = surface area per unit volume of dispersion, cm.$^{-1}$
$u$ = coalescence frequency, sec.$^{-1}$
$u'$ = coalescence frequency per unit volume, sec.$^{-1}$/cc.$^{-1}$
$u^*$ = standard coalescence frequency; the frequency of coalescence of a standard sized drop, sec.$^{-1}$

### Greek Letters

$\epsilon$ = power input per unit mass, sq.cm./sec.$^3$
$\eta$ = length parameter, scale of energy dissipating eddies, cm.
$\theta$ = time, sec.
$\nu$ = kinematic viscosity, sq.cm./sec.
$\rho$ = density, g./cc.
$\rho_c$ = continuous phase
$\rho_d$ = dispersed phase
$\sigma$ = drop diameter, cm.

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