ARGONNE NATIONAL LABORATORY
P. O. Box 299
Lemont, Illinois

INTERFACIAL AREA IN LIQUID-LIQUID
DISPERSIONS RELATED TO
FLUID MOTION IN MIXING VESSELS

by

Walton A. Rodger

Chemical Engineering Division

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LIST OF NOMENCLATURE

Roman Capital Letters

A	Area through which jet flow of impeller is operative
D	Impeller diameter
H	Head produced by impeller
I	Emergent light intensity
I_0	Incident light intensity
K	Proportionality constant
K_s	Scattering area coefficient
L	Optical path length
M	Relative specific refraction of drop (Lorentz Coefficient)
N	Impeller speed
N_i	Number of drops in interval
O/W	Oil-in-water
Q	Volumetric flow produced by impeller
S	Scattering cross section
T	Tank diameter
T_0	Reference tank diameter (6 inches)
W	Width of impeller blade
W/O	Water-in-oil

LIST OF NOMENCLATURE (Continued)

Roman Lower Case letters

a	Interfacial area per unit volume
d	Drop diameter
d_i	Drop diameter in interval, i
d_{sv}	Mean surface-volume or Sauter drop diameter
f	Volume fraction dispersed phase
g	Acceleration due to gravity
k	Exponent on D/T ratio, a function of the Weber number
m	Relative refractive index of drop to field phase
n	Number of drops per unit volume of total mixed phase
t	Settling time
t_0	Reference settling time (1 minute)
u	Linear velocity of flow produced by impeller

LIST OF NOMENCLATURE (Continued)

Greek Letters

α, β	Optical parameters
$\Delta\rho$	Density difference of phases
μ_D	Viscosity of dispersed phase
μ_F	Viscosity of continuous or field phase
ν_D	Kinematic viscosity of dispersed phase
ν_F	Kinematic viscosity of field phase
π_i	Dimensionless group
ρ_D	Density of dispersed phase
ρ_F	Density of field phase
σ_i	Interfacial tension
ϕ	Scale-up function

ABSTRACT

In this investigation a study was made of interfacial area produced in liquid-liquid systems in baffled cylindrical mixing vessels by the action of turbine impellers.

The study was limited to consideration of O/W dispersions. In all cases the liquid height was set equal to the vessel diameter and equal volumes of the two phases were used. The impellers used were six-blade flat-blade turbines.

Two methods of measuring interfacial area of O/W dispersions are presented -- one photographic and the other making use of a correlation between light transmittance and interfacial area. The interfacial area-light transmittance method is described and its precision and accuracy established. This correlation was used to make interfacial area determinations on 17 systems the physical properties of which covered a wide range. Data were obtained for all systems in a 6-inch vessel and for four systems in 12- and 18-inch vessels also. A variety of impeller sizes and speeds were employed.

The data obtained were correlated empirically as a complex function of the Weber number. The average deviation of the correlation is shown to be equivalent to that of the light transmittance-area correlation. The predicted effects of geometric and physical variables are shown to be logical.

Observations on the inversion of O/W to W/O dispersions are made and the effect of this inversion on dispersion settling time noted.

CHAPTER I INTRODUCTION

HNL-500

Statement of Problem

It is the object of this investigation to obtain a measure of the amount of interfacial area created between two immiscible liquids when they are brought into contact with one another by the action of an impeller in a mixing vessel. The problem is the outgrowth of an abortive attempt some three years ago to make a choice between possible solvents for a mixer-settler solvent extraction system based upon the settling time of dispersions. The simple experiments set up at that time served only to indicate the complexity of the problem and to kindle an interest in a more definitive approach to the problems of creation and destruction of interfacial area in liquid-liquid systems.

Accordingly there was set up at Argonne National Laboratory a three-part program:

- 1) to obtain accurate measurements of interfacial area,
- 2) to attempt to find a correlation of interfacial area and/or settling time with the physical properties of the system and with the size of the system and the input of energy into it, and
- 3) to use the information obtained in (1) and (2) to study mass transfer, separating the effects of film resistance and transfer area.

The first of these objectives has been met and a portion of the results published.^{(35,36)*} This report deals with the first two phases of

*Superscript numbers refer to bibliography at end of thesis.

the problem. Work is well under way in the Chemical Engineering Division of Argonne National Laboratory on the third.

It became evident early in the study of this problem that there were so many possible variables that some simplification would be necessary if any degree of order were to be obtained in finite time. Consequently the second phase of the work has been confined to the following:

- 1) Dispersions were created in cylindrical mixing vessels and the liquid height was set equal to the vessel diameter.
- 2) The vessels had "standard baffles" and the impellers used were six-blade flat-blade turbines the dimensional ratios of which were those suggested by Rushton, et al.⁽²⁸⁾ Principles of dimensional similarity were observed through the investigation.
- 3) Equal volumes of each phase were used and the impeller was located centrally and at the interface of the two liquids.
- 4) All dispersions studied were oil-in-water (O/W).

Importance of the Investigation

Solvent extraction is a diffusional process and the amount of mass transferred per unit time is dependent upon the driving force, the resistance to transfer, and the effective interfacial area, a . The study of mass transfer in solvent extraction has been greatly hampered by the inability to measure the effective interfacial area except in a few very special cases (e.g. wetted wall columns, single drop experiments, two immiscible phases stirred gently so as not to disturb the interface).

It has been customary, therefore, to lump together the effects of film resistance and interfacial area into a single term generally referred to as ka where a is the area per unit volume. The interaction of a multiplicity of variables upon this combined group is so complex that little headway has been made in obtaining generalized correlations of mass transfer based upon physical properties. The ability to measure interfacial areas under conditions of practical process significance is of importance because it will permit the independent study of the effects of area and resistance.

Direct measurement of area requires that equipment be built specifically to allow the measurements to be made. In many cases this is difficult or impossible. The work reported herein permits the direct estimation of interfacial area for one important process configuration over a wide range of physical properties and the useful range of energy inputs.

Previous Work

While there exists in the literature much information concerning stable or relatively stable emulsions, very little work has been done on temporary liquid-liquid dispersions of the type of interest in solvent extraction processes. Stable emulsions generally are characterized by a low volume fraction of dispersed phase and drop sizes of the order of 1μ .⁽⁸⁾ In these sizes the effect of electric charge on the particle or "zeta potential" is of importance.^(21,37) The effect of the zeta potential falls off rapidly with increasing size and it has been shown⁽²⁵⁾ that at

droplet sizes of 50μ it is negligible. Since no drops less than 50μ were found in this investigation, the effect of zeta potential has been neglected and, in fact, data obtained on stable emulsions of small particle size are not considered pertinent in this work.

A recent publication by Langlois et al.⁽¹⁹⁾ reports on work similar to that reported herein which has been going on independently at the University of California. The results of Langlois' work are compared with these in the Discussion of Data section. It is felt that Langlois' data are questionable for several reasons. The light probe used to measure interfacial area interfered too much with the mixing pattern in the tank and permitted local coalescence in the area where light transmission readings were taken. The photographs upon which the correlation was based are very poor and could not have yielded accurate data. The light transmission correlation used was of the form

$$\frac{I_0}{I} = 1 + \beta a.$$

This form cannot be supported upon any theoretical grounds. Rather some form of the Beer-Lambert relationship

$$\ln \frac{I_0}{I} = \alpha a$$

would be expected and is, in fact, found in the work reported herein.

Finally Langlois' light data had an average deviation of about 20 per cent.

His attempts to correlate mixing data in a general form resulted in maximum deviations of as much as 300 per cent.

Kessie,⁽¹⁵⁾ in an investigation of dispersions caused by turbulence in pipes, showed a correlation of light transmission with interfacial area as an exponential function. The dispersions studied were about 2 per cent by volume oil in water. Dyes were added to the oil in quantity sufficient to make the oil droplets nearly completely opaque.

A number of investigators^(6,31,33,34) have studied the breakup of liquid drops under defined conditions of flow. Much of this work has been in laminar flow and in all cases the effect of coalescence has been eliminated or at least minimized. Hinze⁽¹⁴⁾ has presented an excellent analytical analysis of the hydrodynamic mechanisms of the splitting of liquid drops under a number of assumed flow fields.

Attempts to study the settling time or "break time" of liquid-liquid dispersions were made by Bernstein,⁽²⁾ Hernandez-Fragoso,⁽¹³⁾ Flynn,⁽⁷⁾ Oldshue,⁽²²⁾ and Christian.⁽⁴⁾ Each of these studied the separation time of immiscible liquids in systems similar to that reported herein. All reported a phenomenon called "critical speed" being an impeller speed above which the break or separation time decreased markedly. Hernandez-Fragoso suggested the zeta potential as an explanation. Only Christian noted a phase inversion and he states that the phase inversion and break time were not coincident. His data appear to indicate otherwise, however. The phenomenon of "critical speed" was noted many times in the work reported herein and it was uniformly accompanied by an inversion of phases.

CHAPTER II EXPERIMENTAL EQUIPMENT

The experimental equipment used in this investigation consisted of:

- 1) three mixing vessels, 6-, 12-, and 18-inches nominal diameter fitted with baffles and a variety of 6-blade, flat-blade turbine impellers,
- 2) a controlled variable-speed drive for the impellers,
- 3) a light source and detector unit for the indirect measurement of interfacial area.

Mixing Vessels

The three mixing vessels were made of glass. An assembly drawing of the 6-inch vessel is shown in Figure 1. Brass flanges, teflon gaskets, and several tie rods were used to assemble the units. The 12- and 18-inch vessels were similarly made.

The three vessels had inside diameters of $5\frac{9}{16}$, $11\frac{3}{8}$, and $17\frac{3}{8}$ inches respectively. Each had a set of four removable stainless steel baffles which extended above the expected liquid surface and were one-tenth the diameter of the vessel in width. Each vessel could be fitted with 6-blade, flat-blade turbines of various diameters, made of stainless steel. The relative dimensions of these impellers which follow the suggestions of Rushton et al.,⁽²⁸⁾ are shown in Figure 2. These dimensions were chosen so that existing mixing power data could be used in conjunction with this work if desired. A picture of the assembled 6-inch vessel is shown in Figure 3.

Fig. 1. Assembly Drawing of 6-inch Mixing Vessel

$$D:S:L:W=20:15:5:4$$

Fig. 2. Turbine Dimensions

Light Source (not shown) is located below the vessel

Fig 3 Experimental Mixing Vessel

The desired vessel was mounted on a platform affixed to the movable bed of a drill press. This permitted easy interchange and positioning of the impellers.

Impeller Drive

Mounted on a balcony above the mixing vessel was a $1/3$ HP motor with a drive shaft extending down into the vessel. The shaft speed was controlled by a General Electric Thy-Mo-Trol unit model number GEI-27470. The variable control resistance with which the unit was fitted was replaced with a set of fixed resistances and a decade selector switch. This permitted the reproduction of eleven impeller speeds from 0.5 to 18 rps.

Light Source and Detector

The equipment required for light transmittance measurements consisted of three major components: a light source to provide a uniform, collimated beam; a sensitive light detector unit; and an electronic circuit to measure the amplified output of the detector unit. In the design of the equipment, ruggedness and reproducibility were of prime importance. Also of concern was the desire to mount as much of the equipment as possible external to the mixing vessel to minimize contamination of the liquids and interference of the normal flow pattern.

Both the light source and detector were externally located. The light source was located below and the detector above the mixing vessel. A light pipe or probe extended down from the detector into the dispersion. The distance from the bottom of the vessel to the end of the light pipe determined the optical path.

The light source used was a Universal Microscope Illuminator, No. 353, made by the American Optical Company and fitted with a six-volt automobile bulb. During the course of the work improvements were made in the light source and detector. Therefore two correlations were required which are presented in the next chapter. For the first of these, Correlation D, the light leaving the microscope lamp was collimated by the use of an 18-mm aperture. The light was filtered through a red filter, Corning # 2404. The emergent light was transmitted to a photocell by a glass sensing probe extending into the dispersion. The probe was a 30-cm, 3/8-inch diameter Pyrex 7740 platinum-coated glass rod polished on both ends. The liquid gap between the glass bottom of the vessel and the lower end of the probe (i.e. the light path, L) was adjustable. Data used in determining the light correlations were taken at values of L of 1.0, 1.5, and 2.0 cm. The data used in this work were taken at a light path of 1.5 cm.

Later a collimating lens was added to the light source (see Figure 4) and an optical seal was made between the upper end of the glass sensing probe and the photocell using Dow Corning No. 200 silicone oil and a short section of black, 3/8-inch rubber tubing to cover the joint. This arrangement resulted in a somewhat more satisfactory correlation referred to herein as Correlation B (also see next chapter).

The detector unit is shown in Figure 5. It was found that more reproducible readings were obtained if the sides of the probe were protected from stray light by a platinum mirror finish. The mirror finish

Fig. 4 Schematic Diagram of Light Source

Fig. 5. Light Detector Unit

was obtained by painting the cleaned rod with a thin coat of "Liquid Bright Platinum No. 05," Hanovia Chemical and Manufacturing Company, then heating to dull cherry red to produce the bright finish. The several probes made in this manner gave reproducible results. Overheating resulted in a dull finish which gave inconsistent readings.

An end-type photoelectric cell, RCA IP41, was used to give a better optical seal than that obtainable from side entry types. A vacuum tube was used in preference to a gas type, as the linearity of response was better. The IP41 tube, together with the red filter, responded in the near infra-red range as shown in Figure 6.

The output of the photocell was amplified and measured by balancing against a constant voltage with a calibrated helipot resistance. Since the photocell had a linear response, the resistance required was a measure of the light energy reaching the photocell and was used in calculations without conversion since ratios of light energy are involved. The circuit used is shown in Figure 7.

A photograph of the entire equipment set up is shown in Figure 8.

Fig. 6. Wavelength Distribution of Filtered Light and Phototube Response

Fig. 7. Circuit Diagram of Equipment Used to Measure Photocell Response

Fig. 8. Photograph of Experimental Equipment

CHAPTER III MEASUREMENT OF INTERFACIAL AREA

The interfacial area measurements herein reported were obtained in two ways: photographically and by the use of a correlation developed between interfacial area and light transmission. The results of this portion of the work have been published separately^(35,36) in detailed form. A summary of this work is given here.

Previous Work

Most of the interest in light scattering has been restricted to very dilute monodisperse* systems of small particles generally less than one micron in diameter. Mathematical treatments of concentrated polydisperse** systems are not available. In addition, there are few quantitative data available relative to liquid-liquid or gas-liquid dispersions.

In 1925 Stamm and Svedberg⁽³⁰⁾ were interested in the relationship between the right-angle scattering of light and the size distribution of soap-stabilized benzene-water emulsions. They suggested a linear relationship between light transmittance and concentration for a given particle size. Clark and Blackman⁽⁵⁾ investigated light transmittance as a measure of the interfacial area of foams. On the basis of admittedly qualitative data, a linear relationship between light transmittance and volumetric area was suggested.

*Monodisperse in the sense that all particles in the dispersion are the same size.

** Polydisperse in the sense that a distribution of particle size is present.

Recently, Langlois and co-workers^(19,20) published a correlation of light transmission with interfacial area for liquid-liquid systems. Their results were correlated empirically by a linear equation in the following form:

$$\frac{I_0}{I} = 1 + \beta a \quad (1)$$

where

$\frac{I_0}{I}$ = the ratio of incident to emergent light intensity

a = interfacial area per unit volume total mixed phases
(volumetric area)

β = a constant characterizing a specific liquid pair.

This relationship was considered to be independent of the volume fraction dispersed phase. The constant, β , was given as a function of the relative refractive index of the dispersed phase.

The papers by Langlois et al. are of particular interest because they represent the first successful attempt to establish a quantitative relationship between light transmission and volumetric area. However, the reproducibility of results obtained with a given probe was poor and each probe required individual calibration.⁽¹⁸⁾ Duplication of this work would be difficult.

It is apparent from the literature that the quantitative equations relating particle size and concentration to light transmittance are limited and cannot be applied to polydisperse systems of large spherical particles. The available empirical relationships for polydisperse

systems do not demonstrate satisfactory accuracy and precision. In addition, it is difficult to reproduce the equipment design and each detector unit requires individual calibration.

Theory

The light transmitted through a polydisperse system of transparent isotropic spherical particles provides a measure of the interfacial area if it can be demonstrated that light transmission is a function of the total projected area. This means that it must be shown that the light transmission is a function of the mean surface-volume diameter or Sauter, d_{sv} . Conversely, a correlation is not possible if the scattered light energy is sensitive to the particle size distribution. For a polydisperse system consisting of N_i particles of diameter d_i in a given size interval:

$$d_{sv} = \frac{\sum N_i d_i^3}{\sum N_i d_i^2} \quad (2)$$

For a volume fraction of dispersed phase of f , the volumetric area is defined as follows:

$$a = \frac{6f}{d_{sv}} \quad (3)$$

The factors which control light transmittance are embodied in the familiar extinction or Beer-Lambert relationship:

$$SndL = \frac{dI}{I} \quad (4)$$

The scattering cross section, S , is the ratio of the light energy lost by scattering to the incident light energy per unit area and n is the number

of particles per unit volume. Integrating over the distance between light source and detector, L , as the incident light diminishes from I_0 to I , the conventional extinction equation is obtained:

$$\ln \frac{I_0}{I} = S_n L = K_s \frac{d^2 \pi}{4} n L \quad (5)$$

where

$$K_s = \frac{4S}{d^2 \pi} \quad (6)$$

d = particle diameter.

Calculations by several investigators^(3,9,11,16,29) indicate that the scattering area coefficient, K_s , is extremely sensitive to particle size near the wavelength of the incident light. However, the effect of particle diameter decreases with increasing particle size and K_s is found to be relatively constant for particles larger than 50 microns. Other investigators, Bailey⁽¹⁾ and Rose and French⁽²⁴⁾ have verified this observation by purely experimental methods.

In this investigation the observed particle size distribution has generally been between 50 and 1000 microns and the scattering area coefficient may be considered as a constant with respect to particle diameter. Therefore, the drop diameter, d , may be defined as the mean surface-volume diameter, d_{sv} , and equation (5) may be written in terms of the interfacial area per unit volume of total mixed phases, a , and a scattering factor, α .

$$\ln \frac{I_0}{I} = \frac{K_s}{4} La = \alpha La \quad (7)$$

For a given incident light wavelength the scattering factor, α , should be a unique function of the relative refractive index of the liquid pair.

In the basic relationship, equation (4), it is assumed that light once scattered from the path of the primary beam is lost. This is true only for very dilute dispersions. However, for the systems studied, light scattered from the primary beam may be returned to the original path by secondary scattering. Hence, multiple scattering is an important factor which must be considered. The effect of multiple scattering is a function of both the relative refractive index and the incident light beam diameter.

Other factors which may be considered to have a significant effect on the transmittance relationship are functions of the light source and detector geometry. For example, consider the problem of measuring the emergent light intensity, I . The incident light, I_0 , is a collimated beam. The emergent light, I , is defined as that portion of I_0 which passes unimpaired through L cm of dispersion. This means that the emergent light is that portion of the incident light scattered in the forward direction parallel to the path of the primary beam. Gumprecht and Sliepcevich⁽¹⁰⁾ point out that it is technically impossible to obtain an exact measure of the emergent light. Any detector design will measure, in addition to light scattered in the forward direction, some of the light scattered at small angles from the path of the primary beam.

The basic transmission relationship (equation 7) may be modified to conform with these practical considerations:

$$\ln \frac{I_0}{I} = f(\alpha, a, L) \quad . \quad (8)$$

Equation (8) shows that an exponential relationship exists between the light transmittance and some function of α , a , and L . The exact nature of the function must be determined experimentally.

Experimental

Experimental techniques and equipment were developed to measure the interfacial area per unit volume of total mixed phases (volumetric area), and the light transmittance of the dispersion at a specified optical path. The volumetric area was determined photographically, and the light transmittance by photoelectric measurements.

Dispersions were created in the 5-9/16 inch diameter mixing vessel already described (see Figure 3).

The volumetric area which exists in a liquid-liquid system during mixing was determined from photographs of the dispersion. Photographs were taken through the base of the mixing vessel with a 35-mm Leica camera fitted with an Ektar 5-cm lens, reflex prism, and close range bellows using Kodak Plus-X film. Illumination was provided by a 0.0002-second Comet 100-watt-second strobe light mounted beside the vessel. Light from the droplets reached the camera by reflection. Pictures with good drop resolution were obtained by over-exposing the film by one stop and double-developing the negative. Resolution was improved by photographing through a G filter. A typical photograph is shown in Figure 9.

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Fig. 9. Typical Photograph of Dispersion

Preliminary runs were made to establish techniques for area measurements in a rectangular cross section mixing vessel specially designed to facilitate photographic study. An assortment of glass beads dispersed in a mixture of carbon tetrachloride and tetrabromomethane was photographed. These beads ranged in diameter from 210 to 710 microns. Several observers working independently determined the interfacial area from photographs by tracing the droplets in the plane of focus and by classifying the diameters.

The precision of the technique is shown by the data of Table 1. The accuracy of the technique is apparent from a size frequency plot, Figure 10, which compares the experimentally determined size distribution with the distribution determined by classification of the beads into sieve sizes. Both the accuracy and precision of the photographic method, based on measurements by several independent observers, are shown to be better than plus or minus five per cent.

In determining the correlation, equal volume portions (1080 ml) of each phase were placed in the mixing vessel and equilibrated from two to four hours to saturate the liquid pair mutually. Commercial or reagent grade organic liquids, pretreated by distillation, were used. The aqueous phase was distilled water or glycerin-water mixtures. Runs were made at 25 ± 1 C and refractive indices were determined at 25.0 C.

For each system a series of transmittance measurements was obtained. Simultaneously, photographs of the dispersion were taken to

Table 1. Glass Bead Test for Accuracy and Precision of
Photographic Method for Measuring Interfacial Area

A. Photographically Determined Interfacial Area

<u>Observer</u>	<u>sq cm</u> <u>cu cm</u>
A	123
B	121
C	125
D	122
E	122

B. Interfacial Area Determined by Classification

	<u>sq cm</u> <u>cu cm</u>
Maximum Value	129
Minimum Value	107
Average Value	117
Average Value Determined Photographically	123

C. Size Distribution of Beads Used in Test

<u>Diameter (Micron)</u>	<u>Wt Per Cent</u>
210-297	4.1
420-500	35.1
500-590	29.6
590-710	31.2

Fig. 10. Comparison of Calculated Size Frequency of Dispersed Glass Beads with Measured Values Obtained by Several Observers

provide a measure of the volumetric area. The specific volumetric area under a given set of conditions was found to be reproducible if surface active contamination were absent. To minimize contamination, the equipment was thoroughly cleaned with acetone, water, acid-dichromate cleaning solution, water, and distilled water in that order.

The incident light, I_0 , was defined as the light energy per unit area measured through the clear field phase before emulsification, while the emergent light, I , was defined as that portion of the incident light which reached the detector probe after emulsification.

The reading of the incident light was arbitrarily controlled by the voltage applied to the light source. Mixing was begun and emergent light readings taken when steady state conditions were reached (from 2 to 45 min) as indicated by a constant transmittance reading. Immediately after each emergent light reading, a measurement was taken to establish the reading for zero transmittance, as small changes in this quantity have considerable effect on the value obtained for the emergent light.

Correlation of Transmittance Data

The experimental data were correlated empirically as shown in Figures 11 and 12 corresponding to the two light sources and detectors described in Chapter II. Figure 12 represents the more refined equipment (Correlation B) and was used for most of the data reported herein.

The scattering factor, α , is a complex function of the scattering cross section, S . Where the particle diameter is small with respect to

Fig. 11. Correlation (D) of Light Transmittance with Volumetric Area

Fig. 12. Correlation (B) of Light Transmittance with Volumetric Area

the wavelength of the incident light, the scattering cross section is a simple function of the specific refraction, M ,⁽²³⁾ sometimes referred to as the Lorentz coefficient:

$$M = \left| \frac{m^2 - 1}{m^2 + 2} \right|$$

where

m = refractive index of drop/refractive index of field phase.

For large spherical particles the scattering cross section is a complex function of the Lorentz coefficient. Bailey⁽¹⁾ and Rose and French⁽²⁴⁾ used the Lorentz coefficient as the refractive index parameter in their work with particle sizes up to about ten microns. In the present work the Lorentz coefficient proved to be a satisfactory correlating optical parameter for polydisperse systems consisting of particles from 50 to 1500 microns in diameter as evidenced by Figures 13 and 14. The Lorentz coefficient should be evaluated at the wavelength of the incident light. However, a satisfactory correlation was obtained with the refractive index measured at the more convenient sodium D line. The generalized correlations (Figures 11 and 12), which show light transmittance as a function of interfacial area, optical path, and an optical parameter, are valid only for the conditions of this investigation. These conditions are: the light source and detector geometry as shown in Figures 4 and 5, the incident light spectrum as shown in Figure 6, transparent liquids, and a volume fraction of the dispersed phase of 0.50.

Fig. 13. Scattering Factor, α , as a Function of the Relative Specific Refraction, M . Correlation D.

Fig. 14. Scattering Factor, α , as a Function of the Relative Specific Refraction, M . Correlation B.

Reproducibility of Data

Consecutive transmittance readings were reproducible to within three per cent and in most cases one per cent. In the case of duplicate runs, with the same supply of the liquid pair, the introduction of additional variables such as substitution of probes and readjustment of the optical path length caused some loss in reproducibility. However, transmittance measurements for these duplicate runs were usually within three per cent and rarely varied by as much as five per cent.

Both area and transmittance data used in the correlation were obtained from measurements at the bottom of the mixing vessel. For that reason, there can be little doubt that the photographically determined areas represented the area at the point where the transmittance measurements were obtained. However, even considering the extreme degree of turbulence in these agitated systems, there might be some question concerning the homogeneity of the bulk of the dispersion, particularly near the agitator. To resolve this question a simple test was devised which showed the dispersions to be essentially homogeneous. A portable one-piece detector-source unit consisting of phototube and flash light bulb was placed in several different locations in the mixing vessel. Within the limits of experimental precision, no variation in light transmittance was observed indicating essentially complete homogeneity of the dispersion.

CHAPTER IV EXPERIMENTAL PROCEDURES

In each series of runs the following procedure was followed:

- 1) The liquids to be used were carefully purified and all equipment which would come in contact with the liquids was cleaned.
- 2) The vessel was filled with a 50 per cent (by volume) mixture of the system under study to a height equal to the diameter of the vessel. The liquids were then equilibrated for several hours and the temperature brought to 25 C.
- 3) With each of the impellers, data were taken at several impeller speeds. These consisted of a reading of light transmission and the taking of one or more photographs for the determination of interfacial area. Following this the time necessary for the dispersion to settle to the appearance of the first clear interface was measured.
- 4) At the conclusion of the run samples were taken of each phase and the density, viscosity and refractive index of each and the interfacial tension between the two were measured.

Control of Contamination

It became evident very early in this investigation that small amounts of contamination were capable of significantly affecting the properties under study -- particularly the settling time of the dispersions. Consequently, except in those cases where contamination was deliberately courted or introduced, efforts were made to keep the liquids and the equipment scrupulously clean.

The equipment was located in a small isolated room and unnecessary traffic was discouraged. The entire room, walls and ceiling included, was regularly vacuumed to reduce dust loading in the air. The air supply to the room was filtered and air conditioned. Smoking was prohibited.

One of the liquids used was always water. Since there appeared to be little or no difference between the behavior of the regularly supplied building distilled water and double distilled water, the former was used throughout. The organic liquid was distilled prior to use. The distillation scheme used depended upon the particular liquid. Vacuum, atmospheric, and steam distillations were employed.

The glass mixing vessel was first cleaned with cleaning solution, thoroughly rinsed with distilled water then with acetone and finally with more distilled water. The impellers and baffles were dipped into nitric acid, rinsed with water, acetone and then water. The cleaned equipment was handled as little as possible and only with clean hands. The equipment was kept covered as much as possible. From time to time the temperature of the dispersion was taken with a glass thermometer. This was cleaned with acetone each time before use.

Equilibration

The purified liquids were measured into the cleaned mixing vessel such that the volume fraction was 50 per cent and the total height of the liquid equalled the inside diameter of the tank. One of the intermediate sized impellers to be used was then inserted into the

vessel and the mixture stirred just rapidly enough to produce a complete dispersion. The equilibration was continued for several hours to insure the mutual saturation of the phases. During this time the temperature was brought to 25 C. This was generally not difficult since except on the hottest days in summer, the room temperature was just about 25 C. The temperature of the vessel and contents was raised by shining a heat lamp on it and lowered by inserting a cleaned stainless steel cooling coil.

All runs were made at 25 ± 0.5 C. Generally the temperature was within 0.1C of the reference temperature.

Method of Obtaining Data

After equilibration was adjudged complete, runs were made to obtain interfacial area and settling time for each of several impellers at several impeller speeds.

In the 6-inch tank, the impeller speed was determined by using the no-load calibration speed of the stirrer which had been determined for each position on the selector switch by the use of a revolution counter and stop watch. In the 12- and 18-inch tanks with impeller diameters of 6 inches or more, sufficient power was drawn that the Thy-Mo-Trol unit did not maintain an adequately constant speed between no- and full-load. Therefore in these cases higher speeds were determined by the use of a Strobotac and low ones by tactilely counting the rpm.

For each impeller it was necessary to use a speed sufficiently great to produce a complete emulsion. This could be determined visually but was even more evident from observation of the sensing galvanometer in the light transmission circuit. Steady probe readings could not be obtained below the speed of complete dispersion. The highest impeller speed used was that which just began to beat air into the system. It was usually possible to obtain four or five points for each impeller. In the 6-inch tank, the 2-, 3-, and 4-inch impellers were used. In the 12-inch tank data were obtained using the 2-, 3-, 4-, 6-, and 8-inch turbines; while in the 18-inch tank it was possible to use the 3-, 4-, 6-, 8-, 9-, and 12-inch impellers.

The most important determination made was that of interfacial area. This was done in two ways: photographically and by means of a light transmission correlation. The photographic method is tedious and was used only as an occasional check once the light transmission method was worked out (see Chapter III).

After the light readings and photographs were taken, the impeller was stopped and the time for the dispersion to settle to the first appearance of clear interface was noted with a stop watch. For any given supply of liquid this value was reasonably reproducible. It was in this quantity, however, that the effect of contamination was most apparent. It was observed that for a given system, settling times differing by several hundred per cent were quite possible. The longer settling times were characterized by the appearance at the interface

of a pearly gray film. Seldom could any significant difference be found in any of the physical properties - even interfacial tension - when this phenomenon was observed.

During the settling a visual observation was made of the type of dispersion which had been created. A settling system has the appearance of a three-phase system consisting of a relatively clear volume both above and below the band of uncoalesced emulsion. At one of the interfaces the rate of travel toward the eventual interface takes place due to the settling alone. This is a relatively quiescent interface. At the other the droplets grow rapidly in size by combining with one another and with the bulk clear phase with which they are in contact. This coalescing interface is a very active one. The clear phase above (or below) the coalescing interface is the continuous phase. This is illustrated schematically in Figure 15.

Measurement of Physical Properties

At the conclusion of each series of runs, samples were taken of each of the settled phases. The following physical properties were obtained:

- 1) density
- 2) viscosity
- 3) refractive index
- 4) interfacial tension.

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Fig. 15. Illustration of Types of Coalescence.

Density was obtained using pycnometers thermostated to 25 C. Viscosity was obtained at the same temperature using Ostwald viscometers and the refractive index was obtained using a standard refractometer.

Interfacial tension was obtained by use of the Harkins drop-weight method⁽¹²⁾ in the equipment illustrated in Figure 16.

A. For Use with Organic Phase
Lighter than Water

B. For Use with Organic Phase
Heavier than Water

Fig. 16. Tensiometers for Measurement of Interfacial Tension

CHAPTER V EXPERIMENTAL RESULTS

Systems Studied and Results

Data were obtained on a total of 17 systems. These systems are listed in Table 2 together with the density, viscosity and refractive index of the mutually saturated (at 25 C) liquids and the interfacial tension between them. The systems were selected to give as wide a range of physical properties as possible within the limitations of the area-light transmittance correlation.

All 17 systems were run in the 6-inch vessel using 2-, 3-, and 4-inch impellers at a variety of speeds. The interfacial areas and settling times observed are given in detail in the Appendix (Table 4). The supporting light transmittance data are shown in Table 7 also in the Appendix.

Four of the systems [Amsco (kerosene), Hexone (methyl isobutyl ketone), xylene, and isobutanol] were also run in the 12- and 18-inch tanks. These data are shown in Tables 5, 6, 8, and 9 in the Appendix.

The treatment of these data is discussed in the following subsection.

Correlation of Data

It was originally felt that the following variables would be of importance in this investigation:

Table 2. Physical Properties of Systems Studied^a

Run	System ^b	Density Field Drop		Viscosity Field Drop		Inter- facial Tension σ_i dynes/cm	Refractive Index Field Drop	
		ρ_F g/cu cm	ρ_D	μ_F cp	μ_D		η_F	η_D
922	Cyclohexane	0.997	0.761	0.894	0.762	49	1.3329	1.4181
31	Amsco ^c	0.994	0.774	0.884	1.081	44.1	1.3330	1.4330
628	Amsco ^d	0.997	0.771	0.889	1.020	44.1	1.3332	1.4326
1028 113	Amsco ^d	0.997	0.774	0.883	1.086	44.2	1.3330	1.4348
119 1111	Xylene	0.997	0.860	0.903	0.615	38.1	1.3329	1.4940
23	Xylene	0.997	0.860	0.889	0.605	37.2	1.3330	1.4944
29	5% White Oil in Xylene	0.997	0.860	0.890	0.677	37.6	1.3331	1.4919
214	28% White Oil in Xylene	0.997	0.864	0.892	1.202	38.0	1.3330	1.4889
224	61% White Oil in Xylene	0.997	0.871	0.889	7.416	45.1	1.3330	1.4829
314	Benzene	0.997	0.873	0.896	0.607	40.2	1.3332	1.4975
216	Hexone ^e	0.995	0.800	0.925	0.578	10.8	1.3346	1.3940
1121 1123	Hexone ^e	0.995	0.800	0.931	0.591	10.6	1.3347	1.3943
75	20% CCl ₄ in Benzene	0.9970	1.0144	0.894	0.661	35.8	1.3332	1.4901
727	11% CCl ₄ in Benzene	0.9968	0.9574	0.918	0.656	30.6	1.3330	1.4985
728	25% CCl ₄ in Benzene	0.997	1.038	0.890	0.680	35.0	1.3330	1.4896
28	28% CCl ₄ in Benzene	0.9970	1.0749	0.893	0.689	34.7	1.3339	1.4867
927	Chlorobenzene	0.997	1.101	0.890	0.766	37.7	1.3329	1.5218
730	Isobutanol	0.987	0.839	1.157	2.022	3.0	1.3398	1.3884
1128 1130	Isobutanol	0.986	0.834	1.22	2.92	2.1	1.3411	1.3887
810	Isoamyl Alcohol	0.993	0.825	0.982	3.48	4.8	1.3362	1.4009
128	Tributyl Phosphate	0.9967	0.9785	0.894	3.91	7.1	1.3332	1.4169

a Properties given are for mutually saturated phases at 25C and were obtained after completion of a run.

b In all cases the dispersed phase is indicated - the continuous phase was distilled water.

c A kerosene as received from Central Solvents and Chemicals Co., Chicago, Ill.

d Same kerosene prewashed with caustic and water and then distilled.

e Methyl isobutyl ketone.

Impeller Diameter	D	ft
Tank Diameter	T	ft
Reference Tank Diameter (6-inch)	T_0	ft
Impeller Speed	N	rpm
Density		
Field or Continuous Phase	ρ_F	lb/cu ft
Drop or Discontinuous Phase	ρ_D	lb/cu ft
Phase Density Difference	$\Delta\rho$	lb/cu ft
Viscosity		
Field Phase	μ_F	centipoise (lb/ft sec)
Drop Phase	μ_D	centipoise (lb/ft sec)
Interfacial Tension	σ_i	dynes/cm (lb/sec ²)

And the two properties under investigation:

Interfacial Area	a	sq cm/cu cm (ft ⁻¹)
Settling Time	t	minutes (sec)
Reference Settling Time (1 minute)	t_0	minutes (sec)

In the original analysis it was considered that interfacial area, a, and settling time, t, could be correlated independently of one another. Consequently a conventional dimensional analysis⁽¹⁷⁾ was made using the first ten of the foregoing quantities and the interfacial area, a. The complete set of dimensionless groups chosen was:

$$\begin{aligned}
 \pi_1 &= Da & \pi_5 &= \frac{D^2 N \rho_F}{\mu_D} \\
 \pi_2 &= D/T & \pi_6 &= \rho_F / \rho_D \\
 \pi_3 &= \frac{D^3 N^2 \rho_F}{\sigma_i} & \pi_7 &= \Delta \rho / \rho_F \\
 \pi_4 &= \frac{D^2 N \rho_F}{\mu_F} & \pi_8 &= \frac{T}{T_0}
 \end{aligned}$$

For convenience as a first simplification, groups π_4 , π_5 , and π_6 were combined:

$$\frac{\pi_4 \times \pi_6}{\pi_5} = \nu_D / \nu_F$$

This combination presupposes that the experimental data will be fitted by exponents on π_4 , π_5 , and π_6 in the ratio 1:-1:1. The simplification can only be justified if the data can be fitted to a correlation by its use. An attempt was then made to correlate the data obtained using as parameters:

Da	A dimensionless measure of the inter-facial area
D/T	The impeller to tank diameter ratio
$\frac{D^3 N^2 \rho_F}{\sigma_i}$	The Weber number - a characterization of the ratio of shear stresses produced by the impeller to the surface forces on the drops produced
$\Delta \rho / \rho_F$	A measure of buoyancy
ν_D / ν_F	The kinematic viscosity ratio
T/T_0	A scale-up ratio

The data for each system studied were first plotted on logarithmic paper in the form of Da against Weber number as illustrated for the system xylene-water in Figure 17. This plot is typical of every system studied. Each system was consistent within itself in that data for different impellers fell on parallel lines and there was a definite dependence on the D/T ratio which would result in a single correlating line for the system. However, between systems the dependence on the D/T ratio, k , necessary to bring points for all impellers into a single line varied from 0.75 to 1.4 and the slopes of the lines varied from 0.25 to 0.48.

It was apparent that the dependence on the D/T ratio increased with increasing Weber number. Consequently for each system the D/T dependence, k , was plotted against the average Weber number as shown in Figure 18. Thereafter the data for each system were expressed as a single line by dividing the observed value, Da , by the function $(D/T)^k$ wherein the value of k is determined for each point from Figure 18.

Next for each system in the 6-inch tank the value of $Da/(D/T)^k$ was determined at a Weber number of 500 and these values were cross-plotted on logarithmic paper against the kinematic viscosity ratio, ν_D/ν_F . A straight line with a slope of $1/5$ was obtained. Similarly cross plotting against the value of $\Delta\rho/\rho_F$ on semi-logarithmic paper, gave a straight line with the equation:

$$\frac{Da}{(D/T)^k} = K \exp (3.6 \Delta\rho/\rho_F) \quad .$$

Fig. 17. Illustrative Presentation of Data
Da vs Weber Number

System: Xylene-water Run No. 23
Dispersion: 50% O/W in 6-inch tank

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Fig. 18. Variation of D/T Dependence with Mean Weber Number

All of the data obtained in the 6-inch vessel were then expressed in the form

$$\frac{Da}{(D/T)^k (\nu_D/\nu_F)^{1/5} \exp [3.6 \Delta\rho / \rho_F]}$$

plotted against the Weber number on logarithmic paper. At this point some considerable scatter remained in the data. It was then noted that all those points which were significantly high had long settling times while those significantly low settled very rapidly. An examination of the data for a number of systems in which contamination had either deliberately or inadvertently been encountered indicated that the interfacial area found increased about as the 1/6th power of the settling time. The data were therefore normalized to a standard settling time, t_0 (taken arbitrarily as 1 minute), by dividing the previous quantity by the settling time ratio, t/t_0 , to the 1/6th power. This procedure brought all of the 6-inch data into a single correlation with an average deviation equivalent to that of the basic light transmittance correlation.

There remained the determination of the effect of scale up into the larger tanks. For each of the four systems studied in the larger tanks, the quantity

$$\frac{Da}{(D/T)^k (\nu_D/\nu_F)^{1/5} \exp (3.6 \Delta\rho / \rho_F) (t/t_0)^{1/6}}$$

was plotted against the Weber number on logarithmic paper. The value for the settling time in the larger tanks was corrected to an equivalent 6-inch settling time. A typical result for the system Amsco-water is shown in Figure 19. The value of this quantity at a Weber number of

Fig. 19. Illustrative Scale Up Data

1000 (extrapolated if necessary) was then plotted for each of the four systems against the scale-up ratio, T/T_0 . This is shown in Figure 20. Since these data give a reasonably straight line on semi-logarithmic paper, the scale-up dependence is also exponential and has the equation:

$$\phi = 0.71 \exp (0.35 T/T_0)$$

The scale-up factor, ϕ , equals 1.46 for the 12-inch tank and 2.15 for the 18-inch tank.

All of the data correlated in this way are shown in Figure 21 as a logarithmic plot of

$$\frac{Da}{(D/T)^k (\nu_D/\nu_F)^{1/5} \exp (3.6 \Delta\rho/\rho_F) (t/t_0)^{1/6} \phi}$$

against the Weber number. The data for 17 systems in three sizes of tanks, a total of 244 determinations, are expressed as a straight line with a slope of 0.36. The average deviation based on interfacial area is 6.3 per cent, equivalent to the average deviation of the light transmittance correlation. The maximum deviation (one point) is 28 per cent; all except three points are within 20 per cent.

The necessity for including the settling time in this correlation is regrettable since this requires the knowledge of a property which can only be measured in the experimental apparatus. It may be estimated, but only approximately, by a bottle shake test. About 80 per cent of the data (those settling between 0.2 and 3 minutes) are shown in Figure 22 with the settling time term omitted. Since this results in a considerable increase in the scatter of the data the correlation

Fig. 20. Scale Up Data

Fig. 21. Generalized Correlation of Interfacial Area with Weber Number

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Fig. 22. Simplified Correlation of Interfacial Area with Weber Number

is further simplified by the use of an average value for k (1.0). In this case the average deviation is 12 per cent and the maximum deviation (same poor point) is 55 per cent. All but seven of the points are within 30 per cent.

CHAPTER VI DISCUSSION OF DATA

The correlations presented in Figures 21 and 22 were arrived at by the methods of dimensional analysis and cross plotting and are empirical representations of the data. The data have been obtained carefully and are believed to be accurate to within 10 per cent. Sufficient data have been taken over wide enough ranges of variables that the correlations are felt to be real and not fortuitous. The correlations were originally worked out for a dozen systems and the remaining ones, including some farthest from the norm (e.g. the benzene-carbon tetrachloride mixtures with low $\frac{\Delta\rho}{\rho_F}$ and isobutanol in the 18-inch tank--with the highest Weber numbers), were taken later.

The data cover the following ranges:

Weber No., $\frac{D^3 N^2 \rho}{\sigma_i} F$		90 -- 200,000
Kinematic Viscosity Ratio, $\frac{\nu_D}{\nu_F}$		0.75 -- 9.5
Density Difference Factor, $\frac{\Delta\rho}{\rho_F}$		0.018 -- 0.22
Impeller Diameter	D	2 -- 12 inches
Impeller Speed	N	1 -- 20 rps
Tank Diameter	T	6 -- 18 inches

The greatest weakness of the general correlation (Figure 21) lies in the fact that it was necessary to include the settling time. The correlation shown in Figure 22 can be used, omitting the settling time factor, for systems which settle in between 0.2 and 3 minutes but the

average deviation is almost twice as large. An effort was made to develop a simple bottle shake test which would serve as a means of predicting the settling time in the tank. This effort was not completely successful. A few systems, in particular Amsco, could not be made to fit such a correlation.

The settling time is believed to represent a measure of the amount of surface active contamination present. Although stringent efforts (described previously) were taken to keep the systems clean, some systems could not be purified in the first place, and in other cases contamination was inadvertently introduced during the course of a run. The presence of contamination was easily noted visually. It was always accompanied by a dull grey film at the interface. Clean systems give interfaces which are highly reflective. At no time was there sufficient change in any physical property, except settling time, to account for the observed change in interfacial area. The settling time is used, therefore, as the only measure so far discovered to characterize the effect of surface active contamination. The exponent (1/6) for the settling time ratio was determined in a series of experiments in which contamination was deliberately courted. The results of these tests are presented in the Appendix, Table 11.

Since this is an empirical correlation, it is unwise and unwarranted to draw firm theoretical conclusions from it. It is interesting, however, to consider the predicted changes in interfacial area with changes in the various controllable geometric and physical factors studied. These effects are summarized in Table 3.

Table 3. Summary of Effects Predicted by
Generalized Correlation (Figure 21)

Relationship:

$$a = \frac{K}{D} \left[\frac{D^3 N^2 \rho_F}{\sigma_i} \right]^{0.36} \left(\frac{D}{T} \right)^k \left(\frac{\nu_D}{\nu_F} \right)^{1/5} \left(\frac{t}{t_0} \right)^{1/6} \exp \left[3.6 \frac{\Delta \rho}{\rho_F} \right] \phi$$

See Figure 18 for values of k

See Figure 20 for values of ϕ

Increase	Relationship	Effect on a
Weber Number	$a \sim We^{0.36}$	increases
a) by increasing N		increases with $N^{0.72}$
b) by decreasing σ_i		increases as $\sigma_i^{-0.36}$
c) by increasing D	$a \sim D^{k+0.08}$	increases nearly directly with D and effect is larger with increasing Weber Number.
Kinematic Viscosity Ratio	$a \sim \left(\frac{\nu_D}{\nu_F} \right)^{1/5}$	increases slowly
$\Delta \rho / \rho_F$	$a \sim \exp \left[3.6 \frac{\Delta \rho}{\rho_F} \right]$	increases exponentially
Settling Time	$a \sim \left(\frac{t}{t_0} \right)^{1/6}$	increases slowly
D/T (At Const We)		
a) by increasing D	$a \sim D^{k-1}$	decreases below $We = 500$ increases above $We = 500$ effect is small
b) by decreasing T	$a \sim \frac{\phi}{T^k}$	increases

Under the conditions of study, a state of dynamic equilibrium between the formation and coalescence of drops is attained. Drop attrition occurs in some manner due to the energy introduced into the system by the impeller. Meanwhile coalescence is taking place throughout the system. If it is assumed that for coalescence of two drops to take place, the drops must approach each other more closely than the scale of turbulent eddys in the system, then as a first approximation it may be considered that the coalescence is independent of the energy input and takes place continually throughout the system,⁽⁶⁾ even in the "jet flow" off the blades of the impeller. The system may then be analyzed in terms of those factors which tend to promote turbulence or flow and those which affect the surface forces.

Effect of Weber Number

In the first place it is indicated that the area should increase approximately as the $1/3$ power of the Weber number. The Weber number may be considered as a characterization of the ratio of the shear to surface forces in a system. Since the turbulence introduced into the system may reasonably be expected to increase the breakup of the drops, and the surface force represents the major restoring force promoting coalescence, it is reasonable to expect that the area will increase with the Weber number. It is of more interest to examine the method whereby the Weber number is changed. The area increases approximately as the $3/4$ power of impeller speed and as the $-1/3$ power of interfacial tension. If the change is brought about by changing

the impeller diameter, two other groups must be considered and the area is found to increase nearly directly with D , the effect being somewhat larger at higher Weber numbers due to the effect of the increasing exponent, k , on the D/T ratio.

Langlois, et al.⁽²⁰⁾ found, in a very similar study of temporary liquid-liquid emulsions which were 20 and 40 per cent dispersed phase and some gas-liquid systems of much lower dispersed phase fraction, that interfacial area increased as the 0.6 power of the Weber number and as the 1.2 power of impeller speed. They also showed that the area was dependent upon the volume fraction of the dispersed phase and became relatively smaller as the fraction of dispersed phase was increased. Furthermore the effect appears to become sharply exponential at the upper limit of their data (40 per cent). It would not appear unreasonable in comparison of the two sets of data to expect that for the more concentrated dispersions (50 per cent) the effect of coalescence would become more pronounced and the dependence upon the Weber number might well be less than that found for more dilute dispersions. Similarly Hinze,⁽¹⁴⁾ using data of Clay⁽⁶⁾ obtained on 5 per cent dispersions in the annular space between a stationary and a rotating cylinder, also found that area increased with the 1.2 power of N and the -0.6 power of σ . On the other hand Roy and Rushton,⁽²⁶⁾ working with a 2 per cent, non-coalescing system in a 2-inch pipe, found that the area increased with the $1/3$ power of the Weber number. In this case the range of Weber number covered was small and nearly all the change was produced by changing the velocity of flow.

Consider that the breakup of drops will take place largely in the volume of the jet flow off the tip of the impeller. The flow produced by an impeller has been found by Rushton⁽²⁷⁾ to be proportional to the cube of the diameter.

$$Q \sim ND^3 \text{ ft}^3/\text{sec}$$

On the other hand the area of flow increases with the square of the diameter since the width of the blade is scaled up with the diameter.

Therefore

$$u \sim \frac{Q}{A} \sim \frac{ND^3}{DW} \text{ ND ft/sec}$$

and the velocity head is proportional to $(ND)^2$.

$$H \sim \frac{(ND)^2}{2g} \quad .$$

If it is assumed that the velocity of the jet flow alone is responsible for the breakup of drops it might be expected that the effect of D and N should be the same. The effect of D is found to be somewhat larger than that of N, however. It would appear reasonable, then, to assume that a good share of the drop breakup occurs at or near the wall of the vessel where the net flow requires a 90° change in direction toward the top or bottom of the vessel. If this is the case, the controlling factor is the linear velocity near the wall. It has been shown⁽³²⁾ that velocities in a freely expanding jet fall off exponentially with distance from the jet and an analogous situation is expected in this case. Then if the velocity at the impeller tip is doubled by doubling the impeller speed, the velocity at the wall will

also be doubled. On the other hand, if the tip velocity is doubled by doubling impeller diameter (at constant N) the velocity at the wall will be considerably more than doubled as the distance from impeller to wall is less. This hypothesis that a considerable portion of the break-up of drops takes place near the wall where the flow changes direction is, then, consistent with the observed data.

Effect of Kinematic Viscosity Ratio

The predicted effect of viscosity ratio is small. It is in the direction of increasing interfacial area with increasing viscosity ratio. It should be noted that since the continuous phase was in all cases water, the change in viscosity ratio presented is actually a change in dispersed phase viscosity.

Several investigators^(6,31,33,34) have studied the effect of viscosity and viscosity ratio on the breakup of drops. This work has been done with definable flow fields, often laminar, under non-coalescing conditions or at least under conditions in which the effect of coalescence is small. All agree that, in the range of viscosity ratios considered in this work, the viscosity effect is small but all indicate that it should be in the direction of smaller interfacial area with increasing drop to field phase viscosity. That this study indicates the reverse implies that increasing the dispersed phase viscosity hinders the coalescence of the drops.

Effect of $\Delta\rho/\rho_F$

The effect of increasing the density difference between the phases is to increase the interfacial area exponentially. An exponential form for this group is to be expected mathematically since it is the only group considered which can go in the limit to zero. It is evident that the relative velocity between the dispersed drops and the field phase will be greater the larger the density difference is. Presumably the effective velocity in producing shear stress and drop bursting is the net velocity difference between phases--not the gross flow of fluid in the impeller jet.

Of course, settling out of the phases would be expected to increase with increasing $\Delta\rho$ and it might appear that this should work for a smaller rather than larger interfacial area. In no case studied, however, even at the lowest values of $\Delta\rho$, was the separation of phases slower than the coalescence. Since all data were taken with sufficient energy input to produce complete dispersions, the buoyant forces were small in comparison to the shear stresses. The net expected result is an increase in area with density difference.

Effect of Settling Time

As indicated previously, it was necessary to include the dispersion settling time in order to correlate all of the data obtained. The only explanation for this so far advanced is that settling time represents the most sensitive quantity available to measure the effect of surface contamination. It has been observed by many investigators

that the addition of surface active agents promotes emulsification. In fact stable emulsions are seldom possible without the deliberate addition of "emulsifying agents" which are surface active materials. In this study every effort was made to keep surface active materials out of the system. Since very minute quantities of many substances will cause surface contamination, the degree of cleanliness required is most difficult to obtain experimentally. Despite the use of "aseptic" techniques, contamination was sometimes present. Gross contamination was recognized visually by a large increase in settling time and the appearance at the settled interface of a dull gray film. Small amounts of contamination were characterized by a slight increase in settling time and a dulling of the interface. Clean systems exhibited a highly reflective settled interface.

At the beginning of the work it was expected that contamination would produce some change in the physical properties, particularly in the interfacial tension. It was somewhat surprising to find that in no case was sufficient change found even in interfacial tension to account for the observed change in interfacial area. The use of settling time as a measure of this contamination was therefore forced. The factor, t/t_0 , used is dimensionless only in that it represents the normalization of all data to a standard settling time of one minute.

If increased settling time is accepted as a measure of increased contamination, the indicated increase in interfacial area is to be expected from the stabilization of drops and the hinderance of coalescence.

Effect of D/T Ratio and Scale-up Ratio

The effect of a change in the D/T ratio depends upon the way in which the change is made. If it is brought about by increasing D, the effect is that discussed earlier in the section dealing with changes in the Weber number. If the Weber number is maintained constant (say by decreasing N) as D is increased, the effect is small. The interfacial area will decrease a little below a Weber number of 500 and increase somewhat above that point. If on the other hand T, the tank diameter, is increased, the interfacial area will decrease. This observed fact also supports the hypothesis that a large part of the breakup of drops occurs at the points near the wall where the flow direction abruptly changes. Here, again, the velocity at which the directional change takes place will be reduced by increasing T.

Qualitative Observations

In the course of this work a number of qualitative observations were made which are interesting and perhaps worthy of additional study at a later date. The most interesting of these is the phenomenon of phase inversion.

It was noted that with most systems the stable dispersion at low energy input was O/W but as the energy input was increased the system would invert to W/O. This inversion could be detected by a sudden change in reading on the light probe and by observation of the mode of settling when the impeller was stopped (cf. Figure 15). The change to W/O was always accompanied by a change in settling time

(often large and almost always in the direction of more rapid settling) and by reversal of the phase which was clearer immediately after settling. This phenomenon of change in settling time has been noted previously by Hernandez-Fragoso,⁽¹³⁾ Christian,⁽⁴⁾ and Oldshue.⁽²²⁾ They referred to this as "critical speed". Only Christian notes the phase inversion and he does not correlate it with the break time.

As the value of $\Delta\rho/\rho_F$ was made larger, it became easier to cause the inversion. Systems with $\Delta\rho/\rho_F$ values of the order of 0.6 could not be made to produce O/W dispersions unless the position of the impeller was changed. The desired dispersion can generally be forced by locating the impeller completely in the phase which is desired to be continuous.

This phenomenon merits further study. It was not pursued in this investigation because as yet a satisfactory light correlation for interfacial area in W/O systems has not been worked out. This is in turn due to the fact that photographs of W/O dispersions have always shown drops within drops and a proper definition of the interfacial area would be difficult. A photograph of a W/O dispersion exhibiting this effect is shown in Figure 23. This effect is believed to be due to the fact that the W/O dispersions were formed by inverting O/W dispersions and in the inversion process some of the smaller oil drops are trapped inside the newly formed water drops. Some extremely scant photographic evidence for this explanation has been obtained.

Fig 23. Photograph of W/O Dispersion

It may be possible to force virgin W/O dispersions by proper location of the impeller. Then if the light-transmission correlation can be extended, this work could also be extended to include W/O dispersions and the point of inversion. Such a study will be difficult to carry out experimentally as the inversion point is hard to reproduce. It appears to be extremely sensitive to the position of the impeller.

Since W/O dispersions nearly always settle considerably faster than the O/W dispersions, they would be of considerable commercial interest in the field of solvent extraction since the throughput capacity of contacting equipment should be greater if the oil phase is made the continuous one.

Another factor of interest is the minimum energy required just to produce a complete dispersion. In this work the impeller speed was controlled in increments. The first data were taken at the first increment at which a complete dispersion had been obtained. Thus the data obtained on this point are not sufficiently accurate to correlate the minimum energy requirements. Such a study would be of practical and perhaps theoretical interest.

CHAPTER VII CONCLUSIONS

(1) A study has been made of interfacial area in immiscible liquid-liquid systems as a function of physical properties and energy input into the system and two methods of measuring interfacial area are presented--one photographic and one making use of light transmittance.

(2) Data are presented for 17 O/W systems in three sizes of tanks using a variety of impeller sizes. The data are correlated empirically (see Figure 21) with an average deviation of 6.3 per cent based on area--a deviation equivalent to that of the area-light transmittance correlation.

(3) While the empirical correlation does not permit of theoretical interpretation, the predicted effects of geometric and physical variables are shown to be logical.

(4) A qualitative observation of the inversion of O/W to W/O dispersions is noted and the desirability of further study of this phenomenon indicated.

APPENDIX I
AREA AND SETTLING TIME DATA

Table 4. Area and Settling Time Data Obtained in 6" Tank^{a*}

Impeller		Interfacial Area, a, from		Set- tling ^c	Area Group Da	Weber No. $\frac{D^3 N^2 \rho_F}{\sigma_i}$	Impeller- Tank Ratio D/T	D/T Depend- ence ^d k	$Da^{e,j}$		$Da^{e,l}$	
Diam D ft	Rev N sec ⁻¹	light ^b cm ⁻¹	photo- graph cm ⁻¹	Time t min		$\left(\frac{D}{T}\right)^k \left(\frac{\nu_D}{\nu_F}\right)^{1/5} \exp\left[3.6 \frac{\Delta\rho}{\rho_F}\right] \left(\frac{t}{t_0}\right)^{1/6}$			$\left(\frac{D}{T}\right) \left(\frac{\nu_D}{\nu_F}\right)^{1/5} \exp\left[3.6 \frac{\Delta\rho}{\rho_F}\right]$			
Run 922 Cyclohexane in Water - Symbol A ^h												
0.167	8.98	49.3		0.76	250	216	0.359	0.86	265		291	
	13.7	61.8		0.80	315	503		0.925	357		366	
	17.9	68.7		0.78	350	854		0.97	413		404	
0.25	3.95	41.2		0.69	314	141	0.54	0.82	228		242	
	4.50	44.6		0.72	340	183		0.84	251		262	
	5.67	51.0		0.76	388	290		0.88	293		298	
	7.30	57.7		0.78	440	482		0.92	342		338	
0.333	2.73	43.0		0.63	435	154	0.72	0.83	250		250	
	3.95	53.5		0.71	540	324		0.89	318		313	
	4.50	56.5		0.73	570	412		0.91	337		329	
	5.67	64.0		0.71	648	690		0.95	389		375	
Run 31 Amsco ^f (untreated) in Water-Symbol B												
0.25	3.89		45.3	1.47	346	151	0.54	0.83	220		264	
	4.38		51.8		393	192		0.845	252		291	
	5.66		65.5		498	340		0.89	329		380	
Run 628 Amsco ^g (treated) in Water - Symbol C												
0.167	9.04	42.6		0.52	217	242	0.359	0.87	244		252	
	13.75	61.8		0.66	315	560		0.93	360		366	
	18.08	76.0		0.90	386	970		0.985	441		448	
0.25	4.38	37.5		0.39	285	192	0.54	0.845	233		220	
	5.66	48.6		0.56	370	320		0.89	293		285	
	7.27	60.5		0.65	460	528		0.93	362		357	
0.333	2.68	31.1		0.38	315	170	0.72	0.84	200		183	
	3.89	45.3		0.50	460	359		0.90	284		266	
	4.38	48.0		0.65	488	456		0.915	292		284	

*Lower case superscripts (except k) refer to footnotes on page 77.

Table 4 (Continued)^a

Impeller		Interfacial Area, a, from		Set- tling ^c		Weber No.	Impeller- Tank Ratio D/T	D/T Depend- ence ^d k	Da ^{e,j}		Da ^{e,l}	
Diam D ft	Rev N sec ⁻¹	light ^b cm ⁻¹	photo- graph cm ⁻¹	Time t min	Area Group Da	$\frac{D^3 N^2 \rho_F}{\sigma_i}$			$\left(\frac{D}{T}\right)^k \left(\frac{\nu_D}{\nu_F}\right)^{1/5}$	$\exp\left[3.6 \frac{\Delta\rho}{\rho_F}\right] \left(\frac{t}{t_0}\right)^{1/6}$	$\left(\frac{D}{T}\right) \left(\frac{\nu_D}{\nu_F}\right)^{1/5}$	$\exp\left[3.6 \frac{\Delta\rho}{\rho_F}\right]$
Run 23 Xylene in Water - Symbol D												
0.167	8.48	31.7		0.59	161	252	0.359	0.87		274		286
	13.5	40.2		0.62	204	640		0.945		366		363
	17.85	44.8		0.59	228	1120		1.0		445		407
0.25	3.62	26.2		0.61	199	155	0.54	0.83		232		236
	4.18	29.4	28.0	0.63	220	207		0.85		259		260
	5.38	34.3	31.8	0.65	252	344		0.89		304		297
	7.05	39.4	37.0	0.60	293	587		0.94		365		347
	8.48	40.7	43.4	0.57	320	852		0.97		409		380
0.333	3.62	32.3	32.7	0.56	335	368	0.72	0.90		316		297
	4.18	35.8	34.9	0.59	360	492		0.92		340		320
	5.38	41.2	44.2	0.59	425	815		0.97		410		377
Run 29 5% White Oil-Xylene in Water - Symbol E												
0.167	8.8	32.6		0.69	166	270	0.359	0.875		270		288
	13.5	43.5		0.71	222	636		0.945		388		385
	17.6	49.4		0.69	251	1080		0.99		459		437
0.25	3.66	27.1		0.52	206	157	0.54	0.83		238		238
	4.24	30.5	27.7	0.57	222	211		0.85		258		256
	5.45	36.0	30.1	0.57	252	350		0.895		302		292
	7.0	42.0	37.1	0.58	302	576		0.935		371		350
	8.8	46.3	41.7	0.54	336	910		0.98		423		389
0.333	2.45	25.2	23.2		247	167	0.72	0.84		228		214
	3.66	34.7	31.6	0.53	338	372		0.90		315		294
	4.24	37.5	33.3	0.50	366	500		0.925		346		318
	5.45	42.6	40.3	0.54	421	825		0.97		402		366

Table 4 (Continued)^a

Interfacial Area, a,				Set- tling ^c Time t min	Area Group Da	Weber No. $D^3 N^2 / \rho F$ σ_i	Impeller- Tank Ratio D/T	D/T Depend- enced ^k	Da _{e,j}		Da _{e,l}	
Impeller	Rev N	light ^b cm-1	photo- graph cm-1						$\exp \left[3.6 \frac{\Delta \rho}{\rho_F} \right]$	$\left(\frac{D}{T} \right) \left(\frac{\nu_D}{\nu_F} \right)^{1/5}$	$\exp \left[3.6 \frac{\Delta \rho}{\rho_F} \right]$	$\left(\frac{D}{T} \right) \left(\frac{\nu_D}{\nu_F} \right)^{1/5}$
Diam D ft	sec-1											
Run 214 28% White Oil-Xylene in Water - Symbol F												
0.167	8.8	37.2	34.3	0.80	183	270	0.359	0.875	263		289	
	13.5	46.8	47.4	0.84	238	635		0.945	366		375	
	17.6	54.5		0.81	276	1100		0.99	444		435	
0.25	3.66	30.4		0.85	231	157	0.54	0.83	225		243	
	4.24	33.7	32.8	0.85	254	212		0.85	250		265	
	5.45	39.2	40.3	0.93	304	349		0.895	308		318	
	7.0	45.4	47.5	0.87	355	576		0.935	369		372	
	8.8	49.8	51.5	0.83	386	910		0.98	412		405	
0.333	2.45	28.4		0.64	290	167	0.72	0.84	242		228	
	3.66	38.6	35.1	0.70	375	373		0.90	294		295	
	4.24	41.2	43.3	0.70	430	500		0.925	351		338	
	5.45	46.8	44.2	0.69	476	825		0.97	393		375	
Run 224 61% White Oil-Xylene in Water - Symbol G												
0.25	3.89	47.5	46.3	2.8	358	147	0.54	0.83	204		268	
	4.38	55.2	55.5	2.9	422	188		0.845	244		316	
	5.66	66.3		2.9	507	314		0.89	300		370	
	7.27	77.0		2.6	588	518		0.93	357		438	
0.333	2.68	45.7	42.2	2.7	448	167	0.72	0.84	203		251	
	3.89	63.1	61.7	2.7	636	348		0.89	291		357	
	4.38	72.7	70.8	2.7	732	446		0.91	336		412	
Run 314 Benzene in Water - Symbol H												
0.167	9.04	24.5		0.26	124	265	0.359	0.87	258		233	
	13.75	31.9		0.26	163	612		0.94	357		305	
	18.1	37.1		0.21	189	1060		0.99	452		357	
0.25	3.89	21.2		0.18	162	165	0.54	0.84	244		198	
	4.38	23.3		0.18	177	210		0.85	271		221	
	5.66	27.6	27.8	0.18	211	350		0.89	328		265	
	7.27	32.5	32.2	0.18	247	576		0.94	398		309	
0.333	3.89	28.9	30.7	0.22	304	394	0.72	0.90	358		283	
	4.38	32.4	31.6	0.22	327	500		0.925	388		306	
	5.66	38.3		0.22	390	833		0.97	468		366	

Table 4 (Continued)^a

Impeller		Interfacial Area, a, from		Set- tling ^c	Area Group Da	Weber No. $\frac{D^3 N^2 \rho_F}{\sigma_i}$	Impeller- Tank Ratio D/T	D/T Depend- ence ^d k	$Da^{e,j}$		$Da^{e,l}$	
Diam D ft	Rev N sec ⁻¹	light ^b cm ⁻¹	photo- graph cm ⁻¹	Time t min		$\left(\frac{D}{T}\right)^k \left(\frac{\nu_D}{\nu_F}\right)^{1/5}$			$\exp\left[3.6 \frac{\Delta\rho}{\rho_F}\right] \left(\frac{t}{t_0}\right)^{1/6}$	$\left(\frac{D}{T}\right) \left(\frac{\nu_D}{\nu_F}\right)^{1/5}$	$\exp\left[3.6 \frac{\Delta\rho}{\nu_F}\right]$	
Run 216 Hexone (Methyl Isobutyl Ketone) in Water - Symbol K												
0.167	8.8	38.9		0.11	198	940	0.359	0.98		413		286
	13.5	50.7		0.11	256	2220		1.06		572		370
	17.6	60.8		0.11	309	3760		1.11		745		448
0.25	3.66	31.2	35.0	0.10	267	550	0.54	0.93		366		258
	4.24	39.1	40.3	0.10	303	737		0.96		421		293
	5.45	46.3	45.6	0.11	350	1220		1.00		498		338
	7.0	54.0	53.3	0.11	409	2010		1.05		603		393
	8.8	67.6		0.11	516	3170		1.09		780		498
0.333	2.45	35.4		0.10	361	585	0.72	0.94		379		261
Run 927 Chlorobenzene in Water - Symbol L												
0.25	3.95	20.7		0.37	157	183	0.54	0.84		229		212
	4.50	22.6		0.43	172	237		0.86		245		231
	5.67	25.8		0.45	196	376		0.90		286		265
	7.30	29.5		0.50	225	624		0.94		328		303
	8.98	34.6		0.57	263	945		0.98		384		355
Run 730 Isobutanol in Water - Symbol M												
0.167	5.67	52.4	59.4		291	1390	0.359	1.01		495		412
	7.30	65.5	69.5		343	2300		1.065		622		487
	8.98	74.0	79.4		392	3490		1.10		714		557
	13.70	95.2			485	8100		1.16		1010		686
	17.9	111.0		0.33	563	13,850		1.235		1220		800
0.25	2.73	58.1	58.5		443	1080	0.54	1.00		497		420
	3.95	75.2	72.3		562	2275		1.06		668		531
	4.50	80.5	75.0		613	2950		1.085		723		578
	5.67	95.2			727	4660		1.12		878		687
	7.30	111.0		0.38	846	7750		1.17		1055		800

Table 4 (Continued)^a

Impeller		Interfacial Area, a, from		Set- tling ^c Time t min	Area Group Da	Weber No. $D^3 N^2 \rho_F / \sigma_i$	Impeller- Tank Ratio D/T	D/T Depend- ence ^d k	Da ^{e,j}		Da ^{e,l}	
Diam D ft	Rev N sec ⁻¹	light ^b cm ⁻¹	photo- graph cm ⁻¹						$\left(\frac{D}{T}\right)^k \left(\frac{\nu_D}{\nu_F}\right)^{1/5} \exp\left[3.6 \frac{\Delta\rho}{\rho_F}\right] \left(\frac{t}{t_0}\right)^{1/6}$		$\left(\frac{D}{T}\right) \left(\frac{\nu_D}{\nu_F}\right)^{1/5} \exp\left[3.6 \frac{\Delta\rho}{\rho_F}\right]$	
Run 810 Isoamyl Alcohol in Water - Symbol N												
0.25	2.73	52.5		0.40	400	680	0.54	0.95		343		302
	3.95	65.8		0.43	502	1430		1.02		445		380
	4.50	73.5		0.42	558	1850		1.04		504		421
	5.67	83.3		0.42	635	2930		1.08		586		480
	7.30	96.2		0.38	732	4875		1.12		695		553
Run 128 Tributyl Phosphate in Water - Symbol P												
0.167	3.66		25.9	0.90	132	248	0.359	0.87		223		254
	4.24		30.3	0.90	154	331		0.89		266		296
	5.45		40.6	0.90	206	549		0.93		372		398
0.25	1.88		25.9	1.00	198	221	0.54	0.86		234		254
	2.45		33.4	1.00	254	374		0.90		308		328
	3.66		50.3	1.00	382	835		0.97		484		494
	4.24		56.2	1.00	428	1120		1.00		548		553
	5.45		69.2	1.00	527	1850		1.04		695		682
0.333	1.31		26.3	1.00	268	254	0.72	0.87		247		259
	1.88		42.7	1.00	437	523		0.93		408		421
	2.45		49.7	1.00	508	887		0.975		485		490
Run 75 20% Carbon Tetrachloride-Benzene in Water - Symbol R												
0.25	2.73		21.0		178	90	0.54	0.79		206		331
	3.95		23.1		215	193		0.845		237		398
	4.50		25.2		231	250		0.87		263		430
	5.67		32.6	4.0	257	395		0.905		345		476

Table 4 (Continued)^a

Impeller		Interfacial Area, a, from		Set- tling ^c		Weber No.	Impeller- Tank Ratio D/T	D/T Depend- ence ^d k	$Da^{e,j}$		$Da^{e,l}$	
Diam D ft	Rev N sec ⁻¹	light ^b cm ⁻¹	photo- graph cm ⁻¹	Time t min	Area Group Da	$\frac{D^3 N^2 \rho_F}{\sigma_i}$			$\left(\frac{D}{T}\right)^k \left(\frac{\nu_D}{\nu_F}\right)^{1/5}$	$\exp\left[3.6 \frac{\Delta\rho}{\rho_F}\right] \left(\frac{t}{t_0}\right)^{1/6}$	$\left(\frac{D}{T}\right) \left(\frac{\nu_D}{\nu_F}\right)^{1/5}$	$\exp\left[3.6 \frac{\Delta\rho}{\rho_F}\right]$
Run 727 11% Carbon Tetrachloride-Benzene in Water - Symbol S												
0.25	2.73	21.5			164	107	0.54	0.805		224		282
	3.95	26.7			203	225		0.86		288		348
	4.50	28.7			219	292		0.88		313		375
	5.67	32.9		1.9	251	465		0.92		367		430
Run 728 25% Carbon Tetrachloride-Benzene in Water - Symbol T												
0.25	2.73	22.9			174	93	0.54	0.79		210		295
	3.95	27.1			206	197		0.85		258		350
	4.50	29.3			224	255		0.87		286		381
	5.67	33.4		3.3	254	404		0.905		330		432
Run 28 28% Carbon Tetrachloride-Benzene in Water - Symbol U												
0.25	3.58	24.0	19.6		183	163	0.54	0.835		256		274
	4.15	27.4	24.0		196	219		0.86		279		293
	5.37	31.3	29.4		231	368		0.90		337		346
	7.00	34.2	32.2	0.78	254	625		0.94		380		380

a Data are for 50 per cent O/W dispersions at 25C.

b Supporting data given in Table 7.

c Settling time taken from instant stirrer is stopped to first appearance of clear interface.

d A function of Weber Number shown in Figure 18.

e Values of correlating physical parameters given in Table 10.

f A kerosene as received from Central Solvents and Chemicals Co., Chicago, Ill.

g Same kerosene prewashed with caustic and water and then distilled.

h Used in correlating plots, Figures 18, 20, 21, and 22.

j Data used in correlation shown in Figure 21.

l Data used in correlation shown in Figure 22.

Table 5. Area and Settling Time Data Obtained in 12" Tank^{a*}

Impeller		Inter- facial Area, a, from light ^b	Set- tling ^c Time t min	Area Group Da	Weber No. $D^3 N^2 \rho_F$ σ_i	Impeller- Tank Ratio D/T	D/T Depend- ence ^d k	$Da_{e,f,h}$ $\left(\frac{D}{T}\right)^k \left(\frac{\nu_D}{\nu_F}\right)^{1/5} \exp\left(3.6 \frac{\Delta\rho}{\rho_F}\right) \left(\frac{t}{t_0}\right)^{1/6} \phi$	$Da_{e,f,j}$ $\left(\frac{D}{T}\right) \left(\frac{\nu_D}{\nu_F}\right)^{1/5} \exp\left(3.6 \frac{\Delta\rho}{\rho_F}\right) \phi$
Diam D ft	Rev N sec ⁻¹	cm ⁻¹							
Run 1121 Hexone (Methyl Isobutyl Ketone) in Water - Symbol K									
0.25	10.4	41.3	0.36	315	4500	0.264	1.12	645	
	15.5	54.2	0.36	412	10000		1.22	1015	
	20.5	62.7	0.36	477	17600		1.27	1260	
0.333	5.25	38.0	0.33	389	2710	0.35	1.08	586	
	6.7	48.1	0.34	491	4420		1.12	768	
	8.33	54.2	0.34	553	6830		1.16	906	
	10.4	61.1	0.34	625	10640		1.22	1090	
	15.5	72.3	0.34	738	23650		1.30	1400	
0.50	2.76	43.4	0.33	663	2530	0.526	1.07	636	
	3.2	51.1	0.33	781	3400		1.10	763	
	4.7	64.3	0.33	983	7350		1.17	1005	
	5.35	68.9	0.33	1050	9530		1.20	1105	
	6.8	78.2	0.33	1195	15400		1.25	1290	
Run 1028 Amsco ^g in Water - Symbol C									
0.25	8.3	63.3	6.0	482	690	0.264	0.95	398	
	10.3	77.7	8.0	593	1060		0.99	489	
0.333	5.6	63.8	7.8	652	738	0.35	0.96	398	
	6.8	81.4	12.6	831	1090		0.99	486	
0.50	2.38	51.2	3.3	782	454	0.526	0.915	381	
	3.22	72.7	8.3	1111	830		0.97	456	
	3.82	76.2	10.6	1165	1165		1.00	467	
0.667	1.55	50.7	3.4	1030	456	0.705	0.915	366	
	1.95	60.7	5.1	1235	722		0.96	413	
	2.70	84.1	12.6	1710	1385		1.01	500	

*Lower case superscripts (except k) refer to footnotes on page 80.

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Table 5 (Continued)^a

Impeller		Inter- facial Area, a,	Set- tling ^c Time t	Area Group Da	Weber No. $\frac{D^3 N^2 \rho_F}{\sigma_i}$	Impeller- Tank Ratio D/T	D/T Depend- ence ^d k	$Da^{e, f, h}$		$Da^{e, f, j}$	
Diam D ft	Rev N sec ⁻¹	from light ^b cm ⁻¹	min					$\left(\frac{D}{T}\right)^k \left(\frac{\nu_D}{\nu_F}\right)^{1/5}$	$\exp\left(3.6 \frac{\Delta\rho}{\rho_F}\right) \left(\frac{t}{t_0}\right)^{1/6} \phi$	$\left(\frac{D}{T}\right) \left(\frac{\nu_D}{\nu_F}\right)^{1/5}$	$\exp\left(3.6 \frac{\Delta\rho}{\rho_F}\right) \phi$
Run 119 Xylene in Water - Symbol D											
0.25	10.4	28.4	0.80	216	1250	0.264	1.0		416		361
	15.5	35.6	0.85	271	2780		1.08		573		452
	20.5	39.7	0.80	302	4880		1.13		686		503
0.333	5.33	24.5	0.69	250	780	0.35	0.965		357		315
	6.8	28.4	0.73	289	1270		1.0		427		364
	8.5	31.8	0.74	324	2000		1.05		503		407
	10.7	36.0	0.70	366	3150		1.09		581		459
0.50	2.85	25.8	0.65	393	750	0.526	0.96		384		329
	3.67	29.3	0.67	447	1250		1.0		445		374
	4.75	35.6	0.60	542	2090		1.05		571		453
	5.4	35.6	0.57	542	2700		1.10		594		453
0.667	2.04	26.8	0.47	544	910	0.705	0.98		429		338
	2.8	32.6	0.50	661	1720		1.03		521		412
	3.04	36.3	0.50	737	2030		1.05		585		461
Run 1128 Isobutanol in Water - Symbol M											
0.25	8.45	76.2	0.57	581	14850	0.264	1.25		1215		708
	10.5	87.4	0.57	664	23000		1.30		1480		814
	15.7	112.4	0.53	855	51200		1.39		2140		1045
	20.6	131.5	0.50	1005	88200		1.45		2705		1225
0.333	4.7	74.3	0.68	757	10900	0.35	1.22		1075		700
	5.33	83.3	0.68	851	14000		1.24		1235		786
	6.8	97.1	0.68	990	22800		1.29		1455		910
	8.45	110.5	0.65	1135	35200		1.34		1820		1040
	10.6	123.3	0.515	1260	55500		1.40		2140		1160

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Table 5 (Continued)^a

Impeller		Inter-facial Area, a,	Settling ^c Time t	Weber No.	Impeller- Tank Ratio		D/T Dependence ^d	Da ^{e, f, h}		Da ^{e, f, j}	
Diam D	Rev N	from light ^b	t	Area Group Da	D ³ N ² ρ _F σ _i	D/T	k	$\left(\frac{D}{T}\right)^k \left(\frac{\nu_D}{\nu_F}\right)^{1/5}$	$\exp\left(3.6 \frac{\Delta\rho}{\rho_F}\right) \left(\frac{t}{t_0}\right)^{1/6} \phi$	$\left(\frac{D}{T}\right) \left(\frac{\nu_D}{\nu_F}\right)^{1/5}$	$\exp\left(3.6 \frac{\Delta\rho}{\rho_F}\right) \phi$
ft	sec ⁻¹	cm ⁻¹	min	Da							
Run 1128 Isobutanol in Water - Symbol M (Continued)											
0.50	2.0	71.0	0.59	1085	6650	0.526	1.16		900		668
	2.7	88.4	0.59	1350	12100		1.22		1160		827
	3.2	99.1	0.57	1515	17000		1.26		1340		928
	4.8	124.6	0.53	1905	38200		1.35		1785		1165
	5.4	133.0	0.51	2010	48500		1.38		1950		1250
0.667	1.37	76.2	0.64	1550	7400	0.705	1.17		918		708
	2.1	102.7	0.57	2070	17400		1.26		1260		952
	2.9	125.3	0.54	2550	33000		1.33		1590		1165
	3.2	140.0	0.52	2840	40000		1.37		1800		1310
	3.6	146.9	0.50	2990	51000		1.39		1910		1370

a Data are for 50% O/W dispersions at 25C.

b Supporting data given in Table 8.

c Settling time taken from instant stirrer is stopped to first appearance of clear interface. When used in correlations the value given is divided by 2 to express as equivalent value in 6-inch vessel.

d A function of Weber No. shown in Figure 18.

e Values of correlating physical parameters given in Table 10.

f ϕ is scale-up factor obtained from Figure 20. $\phi = 1.46$ for 12" tank.

g A kerosene obtained from Central Solvents and Chemicals Co., Chicago, Ill. Solvent was prewashed with caustic and water and then distilled.

h Data used in correlation shown in Figure 21.

j Data used in correlation shown in Figure 22.

Table 6. Area and Settling Time Data Obtained in 18" Tank^{a*}

Impeller		Inter- facial Area, a, from light ^b cm ⁻¹	Set- tling ^c Time t min	Area Group Da	Weber No. $\frac{D^3 N^2 \rho_F}{\sigma_i}$	Impeller- Tank Ratio D/T	D/T Depend- ence ^d k	Da ^{e, f, h}		Da ^{e, f, j}	
Diam D ft	Rev N sec ⁻¹							$\left(\frac{D}{T}\right)^k \left(\frac{\nu_D}{\nu_F}\right)^{1/5}$	$\exp\left(3.6 \frac{\Delta\rho}{\rho_F}\right) \left(\frac{t}{t_0}\right)^{1/6} \phi$	$\left(\frac{D}{T}\right) \left(\frac{\nu_D}{\nu_F}\right)^{1/5}$	$\exp\left(3.6 \frac{\Delta\rho}{\rho_F}\right) \phi$
Run 1123 Hexone (Methyl Isobutyl Ketone) in Water - Symbol K											
0.333	10.4	40.6	0.50	414	10650	0.23	1.22		850		
	15.5	51.8	0.50	528	23650		1.30		1105		
	20.6	57.3	0.50	586	41800		1.36		1470		
0.50	4.6	50.9	0.50	777	7050	0.34	1.17		933		
	5.25	53.8	0.51	821	9170		1.19		1005		
	6.65	57.9	0.48	882	14700		1.24		1145		
	7.2	61.7	0.48	942	17250		1.26		1245		
0.667	2.6	46.2	0.44	936	5300	0.46	1.14		773		
	3.1	50.9	0.44	1040	7600		1.17		874		
	3.24	51.5	0.46	1045	8300		1.185		896		
0.75	2.07	41.2	0.40	924	4820	0.51	1.13		673		
	2.43	44.1	0.40	1005	6650		1.16		741		
	2.57	47.1	0.40	1075	7450		1.17		801		
1.0	1.22	40.0	0.37	1220	3960	0.685	1.11		632		
Run 113 Amsco ^g in Water - Symbol C											
0.333	9.5	75.9	5.2	774	2140	0.23	1.05		645		636
0.50	3.4	73.6	4.3	1125	925	0.34	0.98		586		624
	5.35	78.1	4.4	1190	2300		1.06		672		663
	6.8	85.1	4.8	1300	3700		1.11		765		723
	7.2	85.1	4.8	1300	4150		1.12		778		723
0.667	2.7	69.8	5.1	1415	1390	0.46	1.02		551		586
	3.05	77.4	4.8	1570	1770		1.04		627		645
	3.35	78.2	4.8	1585	2130		1.05		636		654
0.75	2.6	69.4	5.9	1590	1900	0.51	1.04		556		590
	2.6	72.0	6.0	1645	1900		1.04		569		608
1.0	1.17	52.0	2.1	1585	875	0.685	0.975		474		438

*Lower case superscripts (except k) refer to footnotes on page 83.

Table 6 (Continued)^a

Impeller		Inter- facial Area, a, from light ^b cm ⁻¹	Set- tling ^c Time t min	Area Group Da	Weber No. D ³ N ² ρ _F σ _i	Impeller- Tank Ratio D/T	D/T Depend- ence ^d k	Da ^{e, f, h}		Da ^{e, f, j}	
Diam D ft	Rev N sec ⁻¹							$\left(\frac{D}{T}\right)^k \left(\frac{\nu_D}{\nu_F}\right)^{1/5}$	$\exp\left(3.6 \frac{\Delta\rho}{\rho_F}\right) \left(\frac{t}{t_0}\right)^{1/6} \phi$	$\left(\frac{D}{T}\right) \left(\frac{\nu_D}{\nu_F}\right)^{1/5}$	$\exp\left(3.6 \frac{\Delta\rho}{\rho_F}\right) \phi$
Run 1111		Xylene in Water - Symbol D									
0.333	8.4	44.3	4.2	452	1940	0.23	1.05		609		576
	10.4	46.6		576	2980		1.08		663		604
	15.7	46.6		576	6780		1.16		768		604
0.50	4.7	44.2	3.85	672	2050	0.347	1.05		592		567
	5.33	45.7		697	2630		1.07		624		585
	6.75	45.7		697	4220		1.12		663		585
0.667	2.04	40.4	3.7	818	915	0.462	0.98		522		517
	2.83	44.6		906	1760		1.04		573		572
	3.07	44.6		906	2070		1.05		587		572
0.750	2.0	42.0	3.7	960	1250	0.52	1.00		535		539
	2.4	45.7		1045	1795		1.04		599		587
	2.47	45.7		1045	1910		1.05		602		587
1.0	1.17	36.6	3.3	1115	1015	0.693	0.99		466		471
	1.20	38.9		1190	1065		0.99		494		498
	1.20	38.9		1190	1065		0.99		494		498
Run 1130		Isobutanol in Water - Symbol M									
0.333	8.4	83.2	1.19	850	34800	0.23	1.34		1590		792
	10.4	93.3	1.17	951	55500		1.40		1940		887
	15.7	124	1.05	1270	121000		1.49		2950		1180
	20.6	142	1.01	1445	209000		1.55		3660		1345
0.500	3.2	86.0	1.20	1310	17000	0.347	1.26		1310		814
	4.8	108	1.20	1645	38200		1.35		1800		1015
	5.4	113	1.15	1730	48500		1.38		1950		1070
	6.75	130	1.10	1980	75500		1.43		2360		1225
	7.05	130	1.07	1980	82500		1.45		2410		1225

Table 6 (Continued)^a

Impeller		Inter- facial Area, a,	Set- tling ^c Time	Area Group Da	Weber No. $D^3 N^2 \rho_F$ σ_i	Impeller- Tank Ratio D/T	D/T Depend- ence ^d k	$Da^{e, f, h}$		$Da^{e, f, j}$	
Diam D ft	Rev N sec ⁻¹	from light ^b cm ⁻¹	t min		$\left(\frac{D}{T}\right)^k \left(\frac{\nu_D}{\nu_F}\right)^{1/5}$	$\exp\left(3.6 \frac{\Delta\rho}{\rho_F}\right) \left(\frac{t}{t_0}\right)^{1/6} \phi$	$\left(\frac{D}{T}\right) \left(\frac{\nu_D}{\nu_F}\right)^{1/5}$	$\exp\left(3.6 \frac{\Delta\rho}{\rho_F}\right) \phi$			
Run 1130 Isobutanol in Water - Symbol M (Continued)											
0.667	1.95	85.1	1.19	1730	15000	0.462	1.25	1190	786		
	2.6	98.8	1.18	2010	26600		1.31	1445	915		
	3.15	113	1.15	2305	39000		1.35	1725	1050		
0.75	1.28	76.4	1.16	1750	9200	0.52	1.20	1005	723		
	1.9	96.0	1.17	2195	20200		1.28	1325	905		
	2.4	112	1.15	2580	32200		1.33	1600	1060		
1.0	1.07	92.4	1.14	2815	15200	0.693	1.25	1165	869		
	1.18	98.4	1.13	3000	18500		1.27	1245	928		
	1.20	98.4	1.13	3000	19200		1.28	1255	928		

a Data are for 50% O/W dispersions at 25C.

b Supporting data given in Table 9.

c Settling time taken from instant stirrer is stopped to first appearance of clear interface. When used in correlations the value given is divided by 3 to express as an equivalent value in 6-inch vessel.

d A function of the Weber Number shown in Figure 18.

e Value of correlating physical parameters given in Table 10.

f ϕ is a scale-up factor obtained from Figure 20. $\phi = 2.15$ for 18" tank.

g A kerosene obtained from Central Solvents & Chemical Co., Chicago, Ill. Solvent was prewashed with caustic and water and then distilled.

h Data used in correlation shown in Figure 21.

j Data used in correlation shown in Figure 22.

APPENDIX II
LIGHT TRANSMITTANCE DATA

Table 7. Light Transmittance Data Obtained in 6" Tank^{a*}

Impeller		Assem- bly ^b	Probe			I_0^c	I^d	$\ln \frac{I_0}{I}$	Interfacial Area, a cu cm/sq cm
Diam D ft	Rev N sec ⁻¹		Dark Current	Zero Reading	Measured Current				
Run 922 Cyclohexane in Water									
0.167	8.98	B	8.948	0.185	8.651	8.763	0.297	3.38	49.3
	13.7		8.952		8.772	8.767	0.180	3.89	61.8
	17.9		8.952		8.817	8.767	0.135	4.17	68.7
0.25	3.95		8.953	0.237	8.463	8.716	0.490	2.88	41.2
	4.50				8.562		0.391	3.11	44.6
	5.67				8.674		0.279	3.42	51.0
	7.30				8.749		0.204	3.72	57.7
0.333	2.73		8.952	0.037	8.503	8.915	0.449	2.99	43.0
	3.95				8.696		0.256	3.55	53.5
	4.50				8.727		0.225	3.68	56.5
	5.67				8.782		0.170	3.96	64.0
Run 628		Amsco (treated) in Water							
0.167	9.04	B	8.827	0.128	8.513	8.699	0.314	3.32	42.6
	13.75		8.827		8.702	8.699	0.125	4.25	61.8
	18.08		8.832		8.759	8.704	0.073	4.77	76.0
0.25	4.38		8.854	0.278	8.424	8.576	0.436	2.99	37.5
	5.66		8.852		8.630	8.574	0.222	3.65	48.6
	7.27		8.854		8.727	8.576	0.127	4.20	60.5
0.333	2.68		8.843	0.247	8.185	8.596	0.658	2.57	31.1
	3.89		8.844		8.573	8.597	0.271	3.46	45.3
	4.38		8.843		8.623	8.596	0.220	3.67	48.0
Run 23		Xylene in Water							
0.167	8.48	D	9.325	0.365	9.045	8.960	0.280	3.47	31.7
	13.5		9.323		9.167	8.958	0.156	4.05	40.2
	17.85		9.323		9.203	8.958	0.120	4.31	44.8
0.25	3.62		9.284	0.132	8.830	9.152	0.454	3.00	26.2
	4.18		9.285		8.949	9.153	0.336	3.30	29.4
	5.38		9.281	0.02	9.063	9.149	0.218	3.74	35.7
	5.38		9.281		9.021	9.261	0.261	3.56	32.9
	7.05		9.301		9.125	9.281	0.176	3.97	39.4
	8.48		9.318		9.160	9.298	0.158	4.07	40.7
0.333	3.62		9.337	0.179	9.085	9.158	0.252	3.59	32.3
	4.18		9.334		9.121	9.155	0.213	3.76	35.8
	5.38		9.337		9.183	9.158	0.154	4.09	41.2

*Lower case superscripts refer to footnotes on page 88.

Table 7 (Continued)^a

Impeller		Assem- bly ^b	Probe			I_0^c	I^d	$\ln \frac{I_0}{I}$	Interfacial Area, ^a cu cm/sq cm
Diam D ft	Rev N sec ⁻¹		Dark Current	Zero Reading	Measured Current				
Run 29 5% White Oil-Xylene in Water									
0.167	8.8	D	9.352	0.445	9.122	8.907	0.230	3.45	32.6
	13.5		9.380		9.240	8.935	0.140	4.15	43.5
	17.6		9.378		9.273	8.933	0.105	4.44	49.4
0.25	3.66		9.350	0.472	8.913	8.878	0.437	3.01	27.1
	4.24		9.352		9.027	8.880	0.325	3.31	30.5
	5.45		9.351		9.133	8.879	0.218	3.70	36.0
	7.0		9.350		9.198	8.878	0.152	4.07	42.0
	8.8		9.352		9.229	8.880	0.123	4.29	46.3
0.333	2.45		9.340	0.380	8.815	8.960	0.525	2.84	25.2
	3.66		9.338		9.095	8.958	0.243	3.60	34.7
	4.24		9.343		9.140	8.963	0.203	3.79	37.5
	5.45		9.342		9.194	8.962	0.148	4.10	42.6
Run 214 28% White Oil-Xylene in Water									
0.167	8.8	D	9.332	0.150	9.115	9.182	0.217	3.74	37.2
	13.5		9.331		9.205	9.181	0.126	4.29	46.8
	17.6		9.331		9.234	9.181	0.089	4.65	54.5
0.25	3.66		9.352	0.131	9.00	9.221	0.352	3.26	30.4
	4.24		9.349		9.077	9.218	0.272	3.52	33.7
	5.45		9.343		9.152	9.212	0.191	3.88	39.2
	7.0		9.339		9.204	9.208	0.135	4.23	45.4
	8.8		9.338		9.230	9.207	0.108	4.44	49.8
0.333	2.45		9.337	0.055	8.925	9.282	0.412	3.11	28.4
	3.66		9.333		9.133	9.278	0.200	3.84	38.6
	4.24		9.333		9.165	9.278	0.170	3.99	41.2
	5.45		9.331		9.203	9.276	0.128	4.28	46.8
Run 224 61% White Oil-Xylene in Water									
0.25	3.89	D	9.409	0.358	9.281	9.051	0.128	4.25	47.5
	4.38		9.403		9.313	9.045	0.090	4.60	55.2
	5.66		9.411		9.349	9.053	0.062	4.99	66.3
	7.27		9.408		9.364	9.050	0.044	5.32	77.0
0.333	2.68		9.411	0.456	9.274	8.955	0.137	4.18	45.7
	3.89		9.413		9.346	8.957	0.067	4.90	63.1
	4.38		9.414		9.365	8.958	0.049	5.20	72.7

Table 7 (Continued)^a

Impeller		Assem- bly ^b	Probe			I_0^c	I^d	$\ln \frac{I_0}{I}$	Interfacial Area, ^a cu cm/sq cm	
Diam D ft	Rev N sec ⁻¹		Dark Current	Zero Reading	Measured Current					
Run 314		Benzene in Water								
0.167	9.04	D	9.382	0.21	8.86	9.172	0.522	2.86	24.5	
	13.75		9.380		9.10	9.17	0.280	3.48	31.9	
	18.1		9.380		9.19	9.17	0.190	3.87	37.1	
0.25	3.89		9.375	0.21	8.65	9.165	0.725	2.53	21.2	
	4.38		9.380		8.80	9.17	0.58	2.75	23.3	
	5.66		9.380		8.99	9.17	0.39	3.15	27.6	
	7.27		9.380		9.11	9.17	0.27	3.52	32.5	
0.333	3.89		9.380	0.21	9.027	9.17	0.353	3.25	28.9	
	4.38		9.380		9.107	9.17	0.273	3.51	32.4	
	5.66		9.380		9.197	9.17	0.183	3.91	38.3	
Run 216		Hexone in Water								
0.167	8.8	D	9.380	0.33	8.13	9.05	1.25	1.98	38.9	
	13.5				9.372	8.676	9.042	0.696	2.56	50.7
	17.6				9.375	8.90	9.045	0.475	2.95	60.8
0.25	3.66		9.37	0.43	7.55	8.94	1.82	1.59	31.2	
	4.24		9.37		8.15	8.94	1.22	1.99	39.1	
	5.45		9.37		8.53	8.94	0.84	2.36	46.3	
	7.0		9.372		8.77	8.942	0.602	2.70	54.0	
	8.8		9.375		9.01	8.945	0.365	3.20	67.6	
0.333	2.45		9.385	0.35	7.9	9.035	1.485	1.80	35.4	
Run 927		Chlorobenzene in Water								
0.25	3.95	B	8.971	0.209	8.576	8.762	0.395	3.08	20.7	
	4.50				8.971	8.649	8.762	0.322	3.29	22.6
	5.67				8.972	8.743	8.763	0.229	3.63	25.8
	7.30				8.972	8.806	8.763	0.166	3.96	29.5
	8.98				8.972	8.852	8.763	0.120	4.27	34.6
Run 730		Isobutanol in Water								
0.167	5.67	B	8.921	0.352	8.10	8.569	0.821	2.34	52.4	
	7.30				8.922	8.41	8.570	0.512	2.82	65.5
	8.98				8.920	8.528	8.568	0.392	3.08	74.0
	13.70				8.930	8.720	8.578	0.210	3.71	95.2
	17.9				8.925	8.785	8.573	0.140	4.11	111.0
0.25	2.73		8.925	0.045	8.22	8.880	0.705	2.53	58.1	
	3.95		8.925		8.535	8.880	0.390	3.13	75.2	
	4.50		8.930		8.601	8.885	0.329	3.30	80.5	
	5.67		8.930		8.713	8.885	0.217	3.72	95.2	
	7.30		8.930		8.785	8.885	0.145	4.11	111.0	

Table 7 (Continued)^a

Impeller		Probe					Interfacial		
Diam	Rev	Assem- bly ^b	Dark Current	Zero Reading	Measured Current	I_0^c	I^d	$\ln \frac{I_0}{I}$	Area, a cu cm/sq cm
D ft	N sec ⁻¹								
Run 810		Isoamyl Alcohol							
0.25	2.73	B	8.961	0.119	8.48	8.84	0.481	2.90	52.5
	3.95		8.972		8.69	8.85	0.282	3.45	65.8
	4.50		8.963		8.743	8.84	0.22	3.72	73.5
	5.67		8.972		8.819	8.85	0.153	4.05	83.3
	7.30		8.972		8.865	8.85	0.107	4.41	96.2
Run 727		11% Carbon Tetrachloride-Benzene in Water							
0.25	2.73	B	8.898	0.185	8.40	8.713	0.498	2.86	21.5
	3.95		8.898		8.601	8.713	0.297	3.38	26.7
	4.50		8.904		8.658	8.719	0.246	3.56	28.7
	5.67		8.904		8.726	8.719	0.178	3.89	32.9
Run 728		25% Carbon Tetrachloride-Benzene in Water							
0.25	2.73	B	8.919	0.056	8.40	8.863	0.519	2.86	22.9
	3.95		8.924		8.585	8.868	0.339	3.38	27.1
	4.50		8.922		8.640	8.866	0.282	3.56	29.3
	5.67		8.920		8.717	8.864	0.203	3.89	33.4
Run 28		28% Carbon Tetrachloride-Benzene in Water							
0.25	3.58	D	9.340	0.20	8.785	9.140	0.555	2.80	24.0
	4.15		9.340		8.87	9.140	0.470	2.97	27.4
	5.37		9.342		8.992	9.142	0.350	3.26	31.3
	7.00		9.340		9.07	9.142	0.270	3.52	34.2

a Data are for 50% O/W dispersions at 25C.

b B - RCA 1P41 Phototube 2404 Filter 1.5 cm Gap
Light Source as shown in Figure 4.

D - RCA 1P41 Phototube 2404 Filter 1.5 cm Gap
Light Source: Collimated through 18 mm aperture.

c I_0 = Dark Current - Zero Reading; Zero taken in clear
field phase.

d I = Dark Current - Measured Current.

Table 8. Light Transmittance Data Obtained in 12" Tank^a

Impeller		Assem- bly ^b	Probe				I_0^c	I^d	$\ln \frac{I_0}{I}$	Interfacial Area, ^a cu cm/sq cm
Diam D ft	Rev N sec ⁻¹		Dark Current	Zero Reading	Measured Current					
Run 1121		Hexone in Water								
0.25	10.4	B	8.969	0.268	7.981	8.701	0.988	2.19	41.3	
	15.5				8.447		0.522	2.82	54.2	
	20.5				8.596		0.373	3.15	62.7	
0.33	5.25		8.969	0.301	7.803	8.668	1.166	2.01	38.0	
	6.7				8.275		0.694	2.53	48.1	
	8.33				8.451		0.518	2.82	54.2	
	10.4				8.575		0.394	3.09	61.1	
	15.5				8.706		0.263	3.50	72.3	
0.50	2.76		8.969	0.343	8.093	8.626	0.876	2.29	43.4	
	3.2				8.371		0.598	2.67	51.1	
	4.7				8.623		0.346	3.22	64.3	
	5.35				8.672		0.297	3.37	68.9	
	6.8				8.753		0.216	3.69	78.2	
Run 1028		Amsco in Water								
0.25	8.3	B	8.970	0.215	8.859	8.755	0.111	4.37	63.3	
	10.3				8.902		0.068	4.86	77.7	
0.333	5.6		8.950	0.267	8.842	8.683	0.108	4.39	63.8	
	6.8				8.893		0.057	5.03	81.4	
0.50	2.38		8.950	0.168	8.758	8.782	0.192	3.82	51.2	
	3.22				8.872		0.078	4.72	72.7	
	3.82				8.952		8.883	8.784	0.069	4.85
0.667	1.55		8.950	0.152	8.753	8.798	0.197	3.80	50.7	
	1.95				8.826		8.798	0.124	4.26	60.7
	2.70				8.902		8.803	0.053	5.12	84.1
Run 119		Xylene in Water								
0.25	10.4	B	9.000	0.306	8.727	8.694	0.273	3.46	28.4	
	15.5				8.841		0.159	4.01	35.6	
	20.5				8.882		0.118	4.30	39.7	
0.333	5.33		9.000	0.309	8.605	8.691	0.395	3.09	24.5	
	6.8				8.742		0.258	3.46	28.4	
	8.5				8.802		0.198	3.72	31.8	
	10.7				8.846		0.154	4.03	36.0	

^aLower case superscripts refer to footnotes on page 90.

Table 8 (Continued)^a

Impeller		Probe					Interfacial		
Diam D ft	Rev N sec ⁻¹	Assem- bly ^b	Dark Current	Zero Reading	Measured Current	I ₀ ^c	I ^d	ln $\frac{I_0}{I}$	Area, a cu cm/sq cm
Run 119		Xylene in Water (Continued)							
0.50	2.85		9.000	0.217	8.648	8.783	0.352	3.22	25.8
	3.67				8.754		0.246	3.57	29.3
	4.75				8.841		0.159	4.01	35.6
	5.4				8.841		0.159	4.01	35.6
0.667	2.04		9.000	0.302	8.684	8.698	0.316	3.31	26.8
	2.8				8.803		0.197	3.79	32.6
	3.04				8.851		0.149	4.07	36.3
Run 1128		Isobutanol in Water							
0.25	8.45	B	8.972	0.148	8.557	8.824	0.415	3.06	76.2
	10.5				8.672		0.300	3.38	87.4
	15.7				8.812		0.160	4.01	112.4
	20.6				8.865		0.107	4.42	131.5
0.333	4.7		8.972	0.151	8.532	8.821	0.440	2.99	74.3
	5.33				8.635		0.337	3.27	83.3
	6.8				8.744		0.228	3.66	97.1
	8.45				8.803		0.169	3.96	110.5
	10.6				8.848		0.124	4.26	123.3
0.50	2.0		8.972	0.332	8.493	8.640	0.479	2.89	71.0
	2.7				8.687		0.285	3.42	88.4
	3.2				8.761		0.211	3.70	99.1
	4.8				8.852		0.120	4.28	124.6
	5.4				8.873		0.099	4.47	133.0
0.667	1.37		8.965	0.281	8.559	8.684	0.406	3.06	76.2
	2.1		8.968		8.772	8.687	0.196	3.79	102.7
	2.9		8.972		8.853	8.691	0.119	4.29	125.3
	3.2		8.980		8.887	8.699	0.093	4.58	140.0
	3.6		8.970		8.897	8.689	0.073	4.70	146.9

a Data are for 50% O/W dispersions at 25C.

b B - RCA 1P41 Phototube 2404 Filter 1.5 cm Gap
Light Source as shown in Figure 4.

D - RCA 1P41 Phototube 2404 Filter 1.5 cm Gap
Light Source: Collimated through 18 mm aperture.

c I_0 = Dark Current - Zero Reading; Zero taken in clear field phase.

d I = Dark Current - Measured Current.

Table 9. Light Transmittance Data Obtained in 18" Tank^{a*}

Impeller		Assem- bly ^b	Probe			I_0^c	I^d	$\ln \frac{I_0}{I}$	Interfacial Area, a cu cm/sq cm
Diam D ft	Rev N sec ⁻¹		Dark Current	Zero Reading	Measured Current				
Run 1123		Hexone in Water							
0.333	10.4	B	8.972	0.194	7.946	8.778	1.026	2.15	40.6
	15.5				8.381		0.591	2.70	51.8
	20.6				8.502		0.470	2.93	57.3
0.50	4.6		8.972	0.259	8.372	8.713	0.600	2.67	50.9
	5.25				8.436		0.535	2.79	53.8
	6.65				8.523		0.449	2.97	57.9
	7.2				8.581		0.391	3.11	61.7
0.667	2.6		8.972	0.231	8.219	8.741	0.753	2.45	46.2
	3.1				8.367		0.605	2.67	50.9
	3.24				8.374		0.598	2.68	51.5
0.75	2.07		8.973	0.116	7.976	8.857	0.997	2.18	41.2
	2.43				8.120		0.853	2.34	44.1
	2.57				8.238		0.735	2.49	47.1
1.0	1.22		8.962	0.109	7.892	8.853	1.07	2.12	40.0
Run 113		Amsco in Water							
0.333	9.5	B	9.000	0.220	8.930	8.780	0.070	4.84	75.9
0.50	3.4		9.000	0.226	8.925	8.774	0.075	4.76	73.6
	5.35				8.935		0.065	4.90	78.1
	6.8				8.950		0.050	5.17	85.1
	7.2				8.950		0.050	5.17	85.1
0.667	2.7		9.000	0.142	8.913	8.858	0.087	4.62	69.8
	3.05				8.932		0.068	4.87	77.4
	3.35				8.935		0.065	4.91	78.2
0.75	2.6		9.000	0.203	8.917	8.797	0.083	4.66	69.4
	2.6				8.920		0.080	4.70	72.0
1.0	1.17		9.000	0.149	8.814	8.851	0.186	3.86	52.0
Run 1111		Xylene in Water							
0.333	8.4	B	8.985	0.267	8.896	8.718	0.089	4.58	44.3
	10.4		8.985		8.906	8.718	0.079	4.70	46.6
	15.7		8.990		8.910	8.723	0.080	4.70	46.6
0.500	4.7		8.985	0.315	8.895	8.670	0.090	4.57	44.2
	5.33				8.903		0.082	4.66	45.7
	6.75				8.903		0.082	4.66	45.7

^aLower case superscripts refer to footnotes on page 92.

Table 9 (Continued)^a

Impeller		Probe				Interfacial			
Diam D ft	Rev N sec ⁻¹	Assem- bly ^b	Dark Current	Zero Reading	Measured Current	I ₀ ^c	I ^d	ln ^{I₀} I	Area, a cu cm/sq cm
Run 1111		Xylene in Water (Continued)							
0.667	2.04		9.000	0.256	8.887	8.744	0.113	4.35	40.4
	2.83				8.913		0.087	4.60	44.6
	3.07				8.913		0.087	4.60	44.6
0.750	2.0		9.000	0.142	8.896	8.858	0.104	4.44	42.0
	2.4				8.915		0.085	4.65	45.7
	2.47				8.915		0.085	4.65	45.7
1.0	1.17		9.000	0.159	8.851	8.841	0.149	4.09	36.6
	1.20				8.873		0.127	4.25	38.9
	1.20				8.873		0.127	4.25	38.9
Run 1130		Isobutanol in Water							
0.333	8.4	B	8.972	0.323	8.652	8.649	0.320	3.30	83.2
	10.4				8.732		0.240	3.58	93.3
	15.7				8.862		0.110	4.36	124
	20.6				8.892		0.080	4.69	142
0.500	3.2	B	8.972	0.287	8.677	8.685	0.295	3.38	86.0
	4.8				8.803		0.169	3.94	108
	5.4				8.826		0.146	4.08	113
	6.75				8.868		0.104	4.42	130
	7.05				8.868		0.104	4.42	130
0.667	1.95		8.985	0.231	8.678	8.754	0.307	3.35	85.1
	2.6				8.783		0.202	3.73	98.8
	3.15				8.837		0.148	4.08	113
0.75	1.28		8.985	0.197	8.583	8.788	0.402	3.09	76.4
	1.9				8.757		0.228	3.65	96.0
	2.4				8.832		0.153	4.05	112
1.0	1.07		8.985	0.219	8.736	8.766	0.249	3.56	92.4
	1.18				8.771		0.214	3.71	98.4
	1.20				8.771		0.214	3.71	98.4

a Data are for 50% O/W dispersions at 25C.

b B - RCA 1P41 Phototube 2404 Filter 1.5 cm Gap
Light Source as shown in Figure 4.

D - RCA 1P41 Phototube 2404 Filter 1.5 cm Gap
Light Source: Collimated through 18 mm aperture

c I_0 = Dark Current - Zero Reading; Zero taken in clear field phase.

d I = Dark Current - Measured Current.

APPENDIX III
PARAMETERS USED IN CORRELATION

Table 10. Parameters Used in Correlation

Run	System ^a	Relative Ref. Index η_D/η_F m	Lorentz ^b Coeff. M	Light ^c Tran. Coeff. α	Pertinent ^d Area-Light Correlation	$\frac{\Delta\rho}{\rho_F}$	$\exp\left[3.6 \frac{\Delta\rho}{\rho_F}\right]$	$\frac{\nu_D}{\nu_F}$	$\left(\frac{\nu_D}{\nu_F}\right)^{1/5}$
922	Cyclohexane	1.053	0.042	0.052	B	0.237	2.35	1.12	1.023
31	Amsco ^e	-	-	-	-	0.222	2.22	1.57	1.095
628	Amsco ^f	1.075	0.049	0.06	B	0.227	2.26	1.48	1.08
1028 113	Amsco ^f	1.076	0.05	0.061	B	0.223	2.23	1.59	1.081
119 1111	Xylene	1.1211	0.079	0.095	B	0.137	1.635	0.79	0.955
23	Xylene	1.1211	0.079	0.09	D	0.138	1.64	0.79	0.955
29	5% White Oil in Xylene	1.1191	0.0776	0.087	D	0.138	1.64	0.88	0.975
214	28% White Oil in Xylene	1.1170	0.0763	0.086	D	0.134	1.615	1.56	1.093
224	61% White Oil in Xylene	1.1125	0.0734	0.083	D	0.127	1.575	9.55	1.57
314	Benzene	1.1232	0.0802	0.09	D	0.125	1.56	0.77	0.95
216	Hexone ^g	1.0445	0.0294	0.038	D	0.196	2.02	0.78	0.95
1121 1123	Hexone ^g	1.045	0.0298	0.038	B	0.195	2.01	0.79	0.955
75	20% CCl ₄ in Benzene	-	-	-	-	0.0176	1.065	0.72	0.935
727	11% CCl ₄ in Benzene	1.1242	0.0808	0.098	B	0.039	1.15	0.74	0.94
728	25% CCl ₄ in Benzene	1.116	0.0766	0.092	B	0.041	1.16	0.74	0.94
28	28% CCl ₄ in Benzene	1.1146	0.0747	0.085	D	0.078	1.32	0.72	0.935
927	Chlorobenzene	1.142	0.092	0.112	B	0.105	1.45	0.78	0.95
730	Isobutanol	1.036	0.024	0.0315	B	0.150	1.70	2.06	1.155
1128 1130	Isobutanol	1.034	0.023	0.0305	B	0.154	1.73	2.84	1.23
810	Isoamyl Alcohol	1.0487	0.0322	0.041	B	0.169	1.83	4.27	1.34
128	Tributyl Phosphate	-	-	-	-	0.0182	1.068	4.45	1.35

a Dispersed phase - continuous phase distilled water in each case.

b Correlating parameter for Area-Light Transmission = $\frac{m^2 - 1}{m^2 + 2}$

c Correlating parameter found from Figures 13 and 14 and used in Figures 11 and 12.

d B refers to Figures 12 and 14; D refers to Figures 11 and 13.

e A kerosene as received from Central Solvents and Chemicals Co., Chicago, Ill.

f Same kerosene prewashed with caustic and water and then distilled.

g Methyl Isobutyl Ketone.

APPENDIX IV
EFFECT OF CONTAMINATION

Table 11. Data Illustrative of Effect of Contamination
on Settling Time and Interfacial Area

Impeller		Interfacial Area a cm ⁻¹	Settling Time t min	Interfacial Tension σ_i dynes/cm
Diam D ft	Rev N sec ⁻¹			
<hr/>				
Run 914	Hexone in Water			
0.25	4.38	38.6	0.19	-
		44.0	0.36	-
		49.3	0.78	-
<hr/>				
Run 31	Amsco (untreated) in Water			
0.25	4.38	51.8	1.47	44.1
<hr/>				
Run 628	Amsco (treated) in Water			
0.25	4.38	37.5	0.39	44.1

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