DROP SIZE MEASUREMENTS IN STIRRED VESSELS

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ABSTRACT
Drop size distributions during the mixing of water and kerosene (5.5mPa.s viscosity and 828kg/m^3 density) in a stirred vessel were studied with two techniques based on light back scattering and on high speed video recording through an endoscope, respectively. The two techniques offer in-situ measurements and visual observation of the dispersion at any location within the vessel. The average drop sizes at impeller height were found to decrease with impeller speed, while for the conditions used, the dispersed phase volume fraction did not have a significant effect on drop size.

INTRODUCTION
Two-phase liquid turbulent dispersions appear in many contactors (e.g. pipelines and stirred vessels) and industrial applications (e.g. oil transportation, emulsification, two-phase (bio)reactions). Despite their importance, however, few theoretical models exist for the prediction of system parameters and especially drop size distribution.

The competing phenomena of break-up and coalescence will determine the drop size distribution in a two–phase liquid dispersion. From the different suggested mechanisms [1], break-up in the inertial subrange of turbulence is the prevailing one in dilute dispersions. The maximum drop size that can resist break-up, d_{max}, will, in this case, depend on the balance between external turbulent fluctuations (which tend to break the drops) and surface tension (which tends to stabilise the drops) [2,3]. In a stirred vessel, d_{max} will be given from [4]:

$$d_{max} \propto We_T^{-0.6} \tag{1}$$

where, We_T is the Weber number in the stirred tank, $We_T = \rho_c N^2 D^3 / \sigma$, ρ_c is the continuous phase density, N is the impeller speed, D is the impeller diameter and σ is the interfacial tension. The dispersed phase viscosity will stabilise the drops and its effect is accounted for by introducing a viscosity number.

Coalescence will occur at high dispersed phase volume fractions and will result in increased drop sizes. For drops to coalesce they must first collide and then remain in contact for sufficient time to allow the film of the continuous phase that has been trapped between them to drain to a critical thickness and finally rupture. The mechanisms relevant to drop-drop coalescence are detailed in Chesters (1991) [5]. However, even when coalescence is prevented, increasing the amount of the dispersed phase will decrease the intensity of turbulence and, therefore, increase the drop size. To account for the effect of volume fraction on the maximum

drop size, investigators have used a linear concentration correction function. Since the Sauter mean diameter, d_{32} (defined by equation (2)), is often used to calculate the interfacial area available in a dispersion, investigators have attempted to relate d_{32} to d_{max}; diverse correlations have, however, been reported.

$$d_{32} = \sum_{i=1}^{n} d_i^3 \Big/ \sum_{i=1}^{n} d_i^2 \qquad (2)$$

where, n is the number of drops in the distribution and d_i is the diameter of drop i in the distribution.

The amount of experimental information on drop size and distribution in stirred vessels is limited, largely due to the difficulty in measuring drop size. Photography can be applied at low dispersed phase volume fractions, although it provides information close to the vessel wall. At high dispersed phase fractions, the few data available has mainly been obtained with the sample withdrawal technique, which is unsuitable for unstable dispersions. This paper presents drop size measurements with an in-situ, light back scattering probe. The results are also compared with drop sizes obtained with an imaging technique deploying a high speed camera coupled to an endoscope, which can record the dispersions at any point within the mixing vessel.

EXPERIMENTAL SET UP AND EQUIPMENT USED

Dispersions of kerosene (ρ= 828kg/m^3 and μ=5.5mPa.s) in water were studied. The set up consisted of a baffled cylindrical tank (i.d. 14cm) equipped with a Rushton turbine (6.5cm in diameter) (Figure 1). For the drop size distribution measurements an Optical Reflectance Measurement (ORM) particle size analyser (by MTS) was used, which can provide in-situ and on-line measurements. The technique uses a laser beam which, through a lens, is focused at a short distance in front of the instrument, to a high intensity focal point and is rotated at a known velocity within the sample. When the rotating beam intercepts a drop, light is scattered
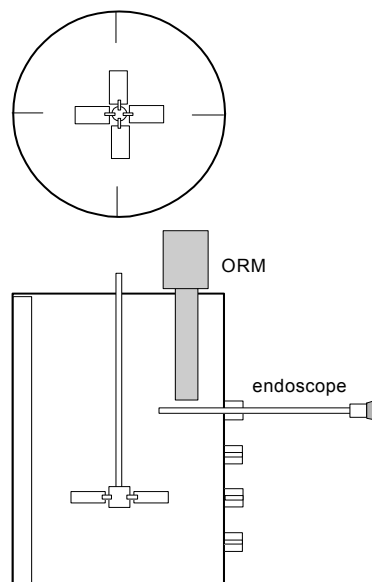

Figure 1. Schematic of the experimental setup.

back, through the optical system of the instrument, to a detector and the chord of the drop is determined. Operating for a period of time will produce a distribution of drop chord lengths. This is then transformed to a drop diameter distribution, assuming that the drops have spherical shape. The laser beam is focused only at a short distance away from the instrument and does not have to pass through the dispersion; it is, thus, not restricted to low volume fractions, a common limitation with other light-based drop size analysers. Since the probe can be used in-situ, the problems associated with sample withdrawal are also avoided. The technique has previously been used in various aqueous-organic systems, where it has been found to respond swiftly to any changes in process conditions which affect drop size [6].

The results from the ORM probe were complemented with in–situ visual observation of the dispersions using an endoscope attached to a high speed camera with maximum recording rate of 1000fps. Special provision was taken for the insertion of the 4mm endoscope at different heights in the vessel (Figure 1). Subsequent image analysis provided the sizes of the dispersed drops.

Experiments were performed at impeller speeds 350rpm and 450rpm and dispersed kerosene volume fractions 5% and 10%. Data was collected with both techniques at 6cm from the vessel bottom (at the height of the impeller).

RESULTS

The experimental Sauter mean diameters for the two impeller speeds used are shown in Figure 2 against the dispersed oil fraction. Clearly, higher impeller speed results in smaller drop sizes. The effect of impeller speed on the drop size distribution can be seen in Figure 3. In the range used, the dispersed phase fraction does not seem to affect the drop size, indicating that coalescence is not significant. The Sauter mean diameters are, therefore, compared in Figure 3 with the predictions of equation (3), suggested by Wang and Calabrese (1986) [7], for non-coalescing systems:

$$d_{32} / D = 0.053 \, (We_T)^{-0.6} \, (1 + 0.97Vi^{0.79})^{0.6} \tag{3}$$
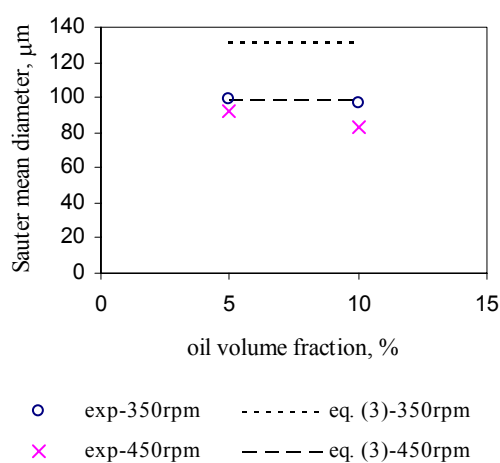

Figure 2. Comparison of the experimental Sauter mean drop diameters with equation (3).
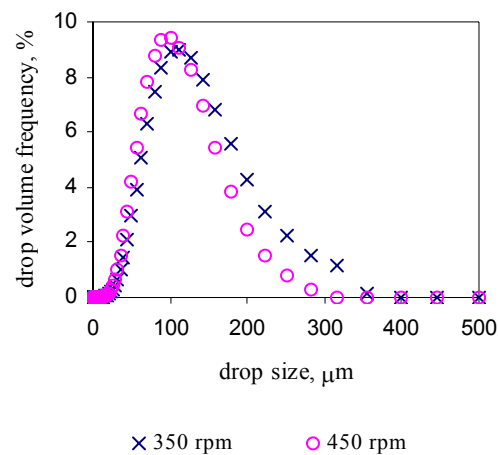

Figure 3. Drop size distribution for 10% dispersed phase fraction at different impeller speeds.

where, Vi is the viscosity number, $Vi = (\mu_d ND)(\rho_c / \rho_d)^{0.5}$, μ is the dispersed phase viscosity and ρ_c and ρ_d are the continuous and dispersed phase densities respectively. This equation follows the general form suggested by equation (1), while it also takes into account the stabilising effect of the dispersed phase viscosity through the viscosity number, Vi. Equation (3) predicts slightly higher average drop diameters. This could be due to the different technique (photography outside the stirred vessel) used by Wang and Calabrese. Figure 4 presents an image of the kerosene-water dispersion, taken with the high speed camera through the endoscope. This image justifies the assumption of spherical drops used in processing the results from the ORM probe; it also shows that the drop sizes are indeed within the range given by the probe.
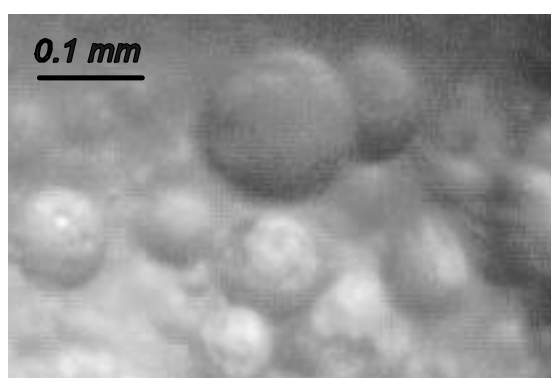

Figure 4. Kerosene drops in water during mixing at 350rpm impeller speed and 5% kerosene fraction.

CONCLUSIONS

Two techniques were used to measure drop size distributions during the mixing of two immiscible liquids in a stirred vessel. The first technique, based on light back scattering, can provide fast, in-situ measurements even at high dispersed phase fractions. The second technique, based on video recording, provides information on the actual shape of the dispersed drops and will allow phenomena such as break-up and coalescence to be monitored. Further investigations will concentrate on the effect of impeller speed and particularly dispersed phase fraction on drop size. The variation of drop size and distribution with position in the stirred vessel will also be studied.

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