Amplitude of Liquid Droplet Oscillation

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Angelo et al. (1966) described the surface area of an oscillating liquid drop as a function of the surface area of a sphere of equal volume.

$$S = S_0(1 + \epsilon \sin^2 \omega t) \quad (1)$$

This approximation can be used to describe the area normal to a heat or mass flux if both the frequency and amplitude of oscillation are known. The frequency of oscillation ω can be predicted by the correlation presented by Schroeder and Kintner (1965), but there is no published means of direct prediction of the amplitude of oscillation.

Angelo et al. (1966) developed a model for mass transfer to oscillating liquid drops based on the time dependent surface area described by Equation (1). Succeeding models, based on the area given by Equation (1), have been presented for mass transfer with no reaction (Brunson and Wellek, 1970), first-order reaction (Wellek et al., 1970), and second-order reaction (Shah, 1972). None of these models for mass transfer are useful without some approximation of the amplitude of oscillation.

Rose (1965) has tabulated major and minor axis lengths from photographs of several liquid-liquid systems. Within experimental error, the maximum axis dimension divided by the equivalent spherical diameter A/d is a constant for each system studied by Rose. If it is assumed that the oscillation is from spherical to oblate ellipsoidal, the amplitude of oscillation can be written as a function of the ratio A/d

$$\epsilon = \frac{1}{2}\left(\frac{A}{d}\right)^2 + \frac{1}{4G}\left(\frac{d}{A}\right)^4 \ln\left(\frac{1+G}{1-G}\right) - 1 \quad (2)$$

where

$$G = \sqrt{1 - \left(\frac{d}{A}\right)^6} \quad (3)$$

The amplitude of oscillation for the systems studied by Rose (1965) are given in Table 1. The physical properties for these systems are given elsewhere (Schroeder and Kintner, 1965). Except for one low interfacial tension system, the amplitude of oscillation possesses a rank order correlation with $\Delta\rho/\sigma$, as shown by Figure 1.

Since the ratio A/d did not change with droplet diameter, the amplitude of oscillation ϵ is not expected to be a function of the droplet diameter. This absence of correlation is possibly for the same reasons that the velocity of an oscillating drop is almost independent of droplet diameter. (Klee and Treybal, 1956). Inclusion of the droplet diameter in the abscissa of Figure 1 to form an Eotvos number as suggested by Harmathy (1960) only increases the scatter of the data.

The amplitude of oscillation does not vary with the viscosity of the continuous or dispersed phase. The continuous phase viscosity increases almost fourfold for systems M through 0, while the other physical properties and the amplitude of oscillation remain essentially constant. For systems P through S, the dispersed phase viscosity is increased by a factor of 26 without affecting the amplitude of oscillation.

Figure 1 is recommended to estimate the amplitude of oscillation in the absence of experimental data for a specific system. However, the amplitude of oscillation is sub-

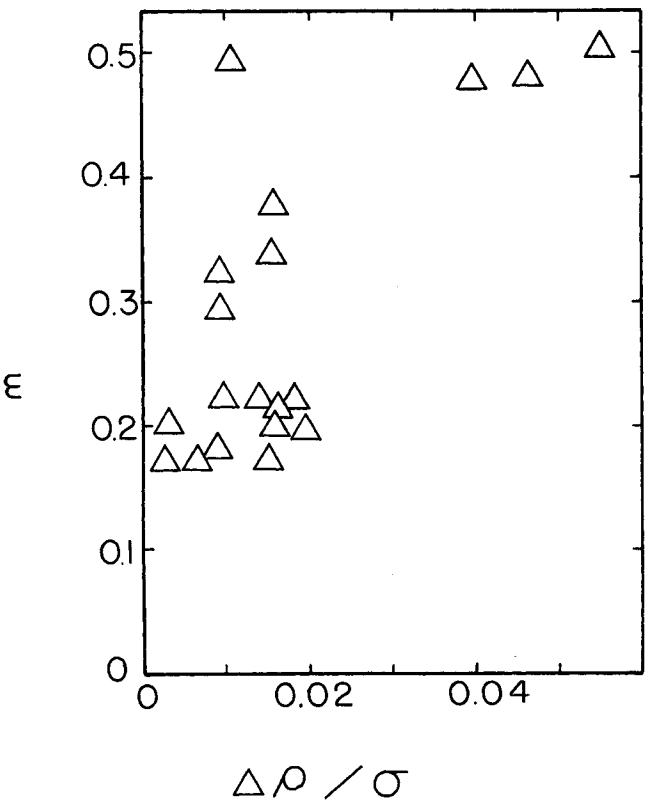

Fig. 1. Amplitude of oscillation of liquid drops.

TABLE 1. AMPLITUDE OF OSCILLATION FOR SYSTEMS STUDIED BY ROSE (1965)

System number	Dispersed phase-continuous phase	$\Delta\rho/\sigma$	ϵ
A	Benzyl Alcohol-Water	0.0097	0.29
B	Nitromethane-Water	0.0103	0.49
C	Carbon Tetrachloride-Water	0.0162	0.38
D	Ethylchloroacetate-Water	0.0094	0.32
E	Nitrobenzene-Water	0.0091	0.18
F	Tetrabromoethane-Water	0.0549	0.50
G	Chlorobenzene-Water	0.0029	0.17
H	*o*-Nitrotoluene-Water	0.0061	0.17
I	Bromobenzene-Water	0.0158	0.17
J	Ethylene Bromide-Water	0.0399	0.48
K	Dibromomethane-Water	0.0466	0.48
L	Tetrachloroethane-Water	0.0168	0.34
M	Tetrachloroethylene-Water	0.0167	0.20
N	Tetrachloroethylene-23.3% Glycerine Solution	0.0155	0.22
O	Tetrachloroethylene-40.7% Glycerine Solution	0.0172	0.21
P	Water-Toluene	0.0039	0.20
Q	49.5% Glycerine Solution-Toluene	0.0181	0.20
R	63.3% Glycerine Solution-Toluene	0.0124	0.22
S	71.4% Glycerine Solution-Toluene	0.0163	0.21

ject to a certain amount of uncertainty. A 5% error in the slope of a plot of the major axis dimension versus the equivalent spherical diameter would result in a 50% error in the amplitude of oscillation. This magnitude of uncertainty would account for most of the system to system variation seen in Figure 1. Brunson and Wellek (1970) reviewed several theories for physical mass transfer in drops whose surface area could be described by Equation (1). For the reviewed theories, the percent error in the mass transfer coefficient is one-fourth as large as the percent error in the amplitude of oscillation. Thus, a 50% error in the amplitude of oscillation would lead to less than a 13% error in the calculated mass transfer coefficient. It must be kept in mind, however, that the data in Table 1 is based on chemically pure systems. Impurities could cause even greater deviation in the amplitude of oscillation and the rate of mass transfer.

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Diffusivities of Propane in Normal Paraffin, Chlorobenzene, and Butanol Solvents

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Liquid phase diffusion coefficients for dilute solutes are commonly related to some parameter describing the solute molecular size, solvent viscosity, and solvent molar volume as well as many other parameters, but almost without exception including the system temperature. The relationship between these variables has been investigated based on hydrodynamic considerations, absolute rate theory, and by assuming similarity between diffusion processes in gases and liquids. In all cases, however, it would be desirable to test the functional dependence of diffusivity on each different variable by actual experiment. Such a procedure was alluded to by Hildebrand (1971) in his discussion concerning studies of liquid phase diffusion. Unfortunately, solute and solvent properties cannot be independently changed since all fluid properties vary with temperature, for example. Nonetheless, it is noted that although most empirical correlations contain the system temperature as a separate variable, strong support for its inclusion in correlations appears to be lacking, particularly for simple (nonaqueous) liquid solutions. The temperature range for diffusivity measurements is often small and experiments are seldom chosen to separate the effect of temperature.

It has been previously shown by Hayduk and Cheng (1971) that for many systems the diffusivity is simply related to the solvent (or solution) viscosity and apparently not dependent on temperature as a primary variable. This was expressed as

$$D = A\,\mu^B \tag{1}$$

EXPERIMENT

Experiments were performed using the steady state capillary cell method described earlier by Malik and Hayduk (1968). Each cell was constructed of a 0.1080 ± 0.0005 cm precision bore capillary, sealed into a glass tube equipped with two vacuum stopcocks for charging and purging the cell with deaerated solvent. The top portion of the capillary was joined to a second capillary stem, which was at least 10 cm in length, also of the same size precision bore for some experiments, and of smaller bore (0.0504 ± 0.0005 cm) for others. Both types of cells were found to be equally satisfactory. The cells were completely filled with deaerated liquid up to a level of at least 2 cm in the lower capillary, and immersed in a constant temperature bath controlled to ± 0.01°C. The stem of the capillary was continually exposed to a small flow of propane gas while a steady state concentration profile was allowed to develop in the solution, a procedure requiring about 10 to 24 hours. The absorption rate was subsequently measured by introducing a bead of propane-saturated solvent into the top of the capillary stem by means of a syringe. An accurate measurement by