CHAPTER 2

LITERATURE REVIEW

Drop phenomena studies in spray columns have been conducted by only a few research groups. In this review we have attempted to present the present status of knowledge in the related areas of drop size calculation, size distribution, velocity of drops, general drop characteristics and drop dynamics in spray columns.

2.1 Drop sizes in spray columns

In spray columns the dispersed phase drops (or bubbles) are formed through distributors. The important parameters observed are nozzle diameter, velocity of the dispersed phase through the nozzle, interfacial tension, viscosity of continuous phase, density of both dispersed and continuous phases etc.[6]

From drop size measurements in a spray column it has been observed that at low flow rates through the nozzle, drops produced were fairly uniform. At low flow rates and up to a flow rate equivalent to the critical velocity (varicose region), drop uniformity was found to be good; beyond this region (sinuous region) nonuniformity of drop increased up to the jet disruption velocity at which level atomization occurs[7].

Drop size measurements for liquid-liquid systems have prompted many investigators[5, 6, 8, 9, 10, 11, 12] to obtain correlations for predicting the size of drops produced when dispersed phase is injected through a nozzle or orifices into a stationary continuous phase. Table 1 presents a

Table 1 Literature review of important systems studied in spray columns.

Research group and date of Publication	Experimental details	Column geometry	Distributor geometry		Continuous phase	Dispersed phase	Experimental result
			Nozzle diameter mm.	No. of nozzles in distributor			
Vedaiyan, Degaleesan and Laddha[11], 1974	Spray Column	5 cm. diameter 1 m. long	1.00 2.00 2.90 3.70 4.75 2.90 1.00	24 12 12 12 12 22 12	Water Water Water CCl_4	M.I.B.K. Isoamyl alcohol Benzene Water	The equation for the Sauter mean diameter size is as follows $$d_{vs}/\left(\frac{\gamma}{\Delta\rho g}\right)^{1/2} = 1.59\left(\frac{v_n^2}{2gd_n}\right)^{-0.067} \quad (1)$$
Horvath, Steiner and Hartland[5], 1978	Spray Column	0.1 m. diameter 1.95 m. long	Material: Stainless steel needles in teflon plates Number of nozzle: 177 or 121 Nozzle diameter: 1 mm. Nozzle spacing: 7 mm., rectangeclar grid		Water	O-xylene	The equation for the mean drop size is as follows $$\frac{d_{32}}{d_{jc}} = \frac{2.06}{v_n/v_{nc}} + 1.47 \ln \frac{v_n}{v_{nc}} \quad (2)$$ Where the critical velocity is given by Skelland and Johnson[9] as $$v_{nc} = 2.69\left(\frac{d_{jc}}{d_n}\right)^2\left[\frac{\gamma}{d_{jc}(0.514\rho_d+0.472\rho_c)}\right]^{1/2} \quad (3)$$ d_{jc} is the critical diameter of the jet formed which is given as $d_{jc} = d_n/(0.485K^2 + 1.0)$ for $K<0.785$ (4a)

Table 1 (Cont.)

Research group and date of Publication	Experimental details	Column geometry	Distributor geometry	Continuous phase	Dispersed phase	Experimental result
						and $d_{jc} = d_n/(1.51K + 0.12)$ for $K \geq 0.785$ (4b) The factor K is calculated from the following equation $K = d_n/\left(\frac{\gamma}{\Delta\rho g}\right)^{1/2}$ (4c)
Skelland, and Johnson[9], 1974	Single nozzle	An aquarium 12 x 7 x 6 inches.	Inside diameter of nozzle cm. 0.1575 0.2337 0.3327 0.3937 0.4750	Heptane Ethyl Acetate Water Water	Water Water CCl_4 Chlorobenzene	The equation for drop size is given as $\frac{d_F}{d_{jc}} = 2.6051 - 0.7747\left(\frac{v_n}{v_{nc}}\right) + 0.3994\left(\frac{v_n}{v_{nc}}\right)^2$ (5)
Hayworth and Treybal[6], 1950	Single nozzle	Square Tower 925 inches on side and 47 inches high	Inside diameter of nozzle cm. 0.155 0.310 0.472 0.632 0.786	Water Water Water Benzene Water	Benzene Kerozene CCl_4 Water CCl_4	The equation for drop size is given as $V_F + 4.11(10^{-4})\, V_F^{2/3}\left(\frac{\rho_d v_n^2}{\Delta\rho}\right) = 21(10^{-4})\left(\frac{\gamma d_n}{\Delta\rho}\right) + 1.069(10^{-2})\left(\frac{d_n^{0.747}\, v_n^{0.365}\, \mu^{0.186}}{\Delta\rho}\right)^{3/2}$ (6)

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Research group and date of Publication	Experimental details	Column geometry	Distributor geometry	Continuous phase	Dispersed phase	Experimental result
Scheele and Meister[8], 1968	Single nozzle	Square cross section 1 ft. 2.5 ft. high	Five nozzle made of stainless stell tubing 4 ft. long, inside diameters ranging from 0.0813 to 0.688 cm.	Water Water Water Water Water	Heptane Butyl Alcohol 55% CCl_4 45% Heptane Paraffin Oil Benzene	The drop size equation for low velocities is given as $$V_F = F\left[\frac{\pi\gamma d_n}{g\Delta\rho} + \frac{20\mu Q_d d_n}{d_F^2\, g\Delta\rho} - \frac{\Delta\rho_d Q_d v_n}{3g\Delta\rho} + 4.5\left(\frac{Q_d^2 d_n^2 \rho_d \gamma}{(g\Delta\rho)^2}\right)^{1/3}\right] \quad (7)$$ The term F in equation 7 is the Harkin's Brown correlation factor defined as $$F = 0.6 + 0.4\ \exp.\ (-2\Theta) \quad (7a)$$ where $$\Theta = d_n\left(\frac{\Delta\rho g}{\pi\gamma d_n}\right)^{1/3} \quad (7b)$$ The equation to obtain jetting velocities is given by $$v_j = 1.73\left[\frac{\gamma}{\rho_d d_n}\left(1 - \frac{d_n}{d_F}\right)\right]^{1/2} \quad (8)$$

short summary of prior investigations concerning drop sizes in liquid-liquid systems with various systems, column geometrics and distributor geometrics.

Horvath et al.[5] measured drop diameters by photographing each drop in two positions in the column and evaluating the pictures on an XY reader. About 200 drops were used for each value of the average drop diameter, and the basic assumption was that the drops were ellipsoids of rotation. Vedaiyan et al.[11] measured drop diameters from photographs of drop swarms using a camera with a visoflex attachment for closeup photography. An aperture opening of 3.5 and a shutter speed of 0.001 sec. was used. Drop size measurements were made directly from the processed negatives. Five to ten exposures were made, depending upon the drop population in the column to obtain a representative sample of the drop swarms. Correction factors for the column curvature and refractive index effects of the column and field liquid were obtained by photographing a glass bead of known dimensions suspended in the field of focus. From the processed negatives, horizontal and vertical diameters of drops were measured and to these values, the corrections factors were applied indicidually in order to translate the photographic image to a true image, d_1 and d_2 were the true diameters of the major and minor axes with the equivalent diameter of drop being $d_e = \sqrt[3]{d_1^2 d_2^2}$. The number of drops photographed for each flow rate in the present investigation varied from 25 drops when the drops were fairly uniform at low rates to about 100 when the sizes varied considerably at high flow rates. The Sauter mean diameter, d_{vs}, of the drop swarm was calculated from the equation

$$d_{vs} = \frac{\Sigma n d_e^3}{\Sigma n d_e^2} .$$

Horvath et al.[5] had used critical velocities predicled by Skelland and Johnson[9] (equation 3) which experiments had been conducted for single nozzle operation for in order to predict drop sizes in their spray column. It is generally belived that the size of drops produced through single nozzle experiments and that produced by the distributor in spray columns should be equivalent when the column does not experience coalescence and breakup of the dispersed phase.

Scheele and Meister[3] found that the Hayworth and Treybal[6] correlation for predicting drop sizes and jetting velocities was not satisfactory. Scheele and Meister presented a correlation to obtain drop columns at low velocities and an equation to determine the velocity above which a jet forms (jetting velocity) when one Newtonian liquid is injected into a second stationary immiscible liquid.

Vedaiyan et al.[11] measured drop size in a 5 cm diameter and 1 m long spray column, water was used as dispersed phase and CCl_4 was used as continuous phase, this system was one of four systems studies. Skelland and Johnson predieted a critical velocity for use in the equation to obtain drop size at jet breakup conditions. In this set of experiments CCl_4 was used as dispersed phase and water was used as continuous phase. This system was one in four systems studied in a single nozzle column. Hovarth et al. used critical velocities predicted by Skelland and Johnson for use in the equation to obtain drop size in a 0.1 m. diameter and 1.95 m. long spray column. An O-xylene and water system was used in that particular study. From these three research groups were obtained useful correlations to predict drop sizes in spray columns, The most important parameters for predicting dispersed phase drop sizes formed through distributors have been found by short summary of prior investigations concerning drop sizes in liquid-liquid systems with various systems, column geometrics and distributor geometrics.

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2.2 Drop size distribution

The drop size distribution is known to be important, particularly in the accurate evaluation of the interfacial area.

Vedaiyon et al.[12] observed drop size distributions in spray, columns for the isoamyl alcohol-water system with flow through a nozzle with nozzle velocity varying between 9 and 88 cm/s. The author's conclusions were that for low flow rates (v_n = 9.08, 12.37 and 23.21 cm/s) the distribution remains normal (or Gaussian) with minimum deviation. An increase in flow rate (v_n = 23.21 cm/s) improves the distribution, showing more uniformity in drop size. At higher flow rates (v_n = 42.26-58.47 cm/s) the distribution becomes bimodal. At still higher flow rates (v_n = 67.67-87.60 cm/s) the second of the two modes increases in area while the first decreases and, at still higher flow rates, the bimodal curve again becomes monomodal but skews toward larger drop sizes. Size frequency distribution curves prepared for other systems and nozzles show that the distribution of drop sizes always vary from a near normal distribution (Gaussian) to a bimodal one and back again to monomodal with changing nozzle velocities for all systems studied.

Horvath et al.[5] obtained diameter distributions for xylene drops formed at different nozzle velocities in spray column. For low nozzle velocities (v_n = 10 cm/s) the distribution remains normal. At increased nozzle velocities (v_n = 20 cm/s) the distribution become bimodal. At higher nozzle velocities (v_n = 30 cm/s) the second of the two modes increases in area while the first decreases. At high nozzle velocities (v_n = 40 cm/s) the bimodal curve again becomes monomodal and skews towards larger drop sizes.

Vedaiyan et al. and Horvath et al. experimental results for size distribution curves do agree in trend. These size distribution curve could conceivable by used to predict the size curves for other spray columns for similar systems.

2.3 Velocities of drops

The movement of a polulation of drops through a continuous phase medium is of importance since the velocity of the drop phase determines the extractor capacity and efficiency and the relative motion between drop and bulk fluid affects the convective mass transfer between phases. The dynamics of a single drop as a function of drop size and the characteristics of various liquid systems have been extensively investigated[7].

Orman and Foster[13] observed terminal velocities of chains of spherical drop and bubble for Re>1, and concludes that the theory of chain motion is generally applicable with internal circulation and deformation, and predicted velocities in a re-circulating flow driven by drops or bubbles on the axis of a tube.

Vedaiyan et al.[11] generalized a correlation for characteristic velocities by the relationship between the characteristic velocity and such variables as the nozzle diameter, nozzle velocity and physical properties of the dispersed and continuous phases ascertained through dimensional analysis. Mathematical analysis of the data fives exponent values in the equation for the characteriatic velocity.

A spray column mathematical model which takes into account drop phenomena has never been presented. The hydrodynamics of the continuous and dispersed phases are not well known. And no research groups has looked into the velocities of drops and the shapes of the drop velocity profiles in spray columns.

2.4 Hold-up of the dispersed phase

The hold-up is defined as the volumetric fraction of the dispersed phase which is the total volume of all drops present in unit volume of the column[8].

Determination of the dispersed phase hold-up was made by simultaneously shutting off the inlet and exit valves when the column was maintained under steady state operation. The dispersed droplets in the column then settled, lowering down the interface level. When all the droplets had coalesced into the layer above the interface, the continuous phase supply was turned on gradually to regain the original interface level and the displaced light liquid was measured and expressed as a fraction of the effective column volume[5, 11]. The equation used to predict hold-up for this work is

$$\phi = \frac{Q_d}{Ad_{43}} \tag{9}$$

The hold-up of dispersed phase is an important parameter that must be used to predict surface of transfer area when drop sizes or drop size distributions are known.