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Spray Measurements of Aerothermodynamic Effect on Disintegrating Liquid Jets

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SPRAY MEASUREMENTS OF AEROTHERMODYNAMIC EFFECT ON DISINTEGRATING LIQUID JETS

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ABSTRACT

An experimental investigation was made to determine the effect of atomizing-gas mass-flux and temperature on liquid-jet breakup in sonic-velocity gasflow. Characteristic dropsize data were obtained by using the following atomizing-gases: nitrogen, argon and helium to breakup water jets in high-velocity gasflow. A scattered-light scanning instrument developed at NASA Lewis Research Center was used to measure SMD, Sauter mean diameter, i.e., D_{32}. The three gases gave a molecular weight range of 4 to 40 and atomizing-gas mass-flux and temperature were varied from 6 to 50 g/cm^2-s and 275 to 400 K, respectively. The ratio of liquid-jet diameter to SMD, D_o/D_{32}, was correlated with aerodynamic and liquid-surface force ratios, i.e., the product of the Weber and Reynolds number, We Re, the gas-to-liquid density ratio, ρ_g/ρ_l and also the molecular-scale dimensionless group, $\rho_l V_m^3/\mu_l\, g$, to give the following expression:

$$D_o/D_{32} = 0.90\times 10^{-8}(\mathrm{We\ Re}\ \rho_g/\rho_l)^{0.44}(\rho_l V_m^3/\mu_l\ g)^{0.67}$$

where We Re $= \rho_g^2 D_o^2 V_c^3/\mu_l\sigma$, μ_l is liquid viscosity, σ is surface tension, V_c is acoustic gas velocity, V_m is RMS velocity of gas molecules, g is acceleration of gas molecules due to gravity. Good agreement was obtained with atomization theory for liquid-jet breakup in the regime of aerodynamic stripping. Also, due to its low molecular weight and high acoustic velocity, helium was considerably more effective than nitrogen or argon in producing small-droplet sprays with values of D_{32} on the order of 5 μm.

NOMENCLATURE

A_o	atomizer orifice area, cm^2
D_i	diameter of ith drop, cm
D_o	diameter of liquid jet
D_{32}	Sauter mean drop diameter, $\sum n_i D_i^3 \Big/ \sum n_i D_i^2$, cm
k	correlation coefficient for gas mass-flux
k'	correlation coefficient for Eq. (1)
k*	correlation coefficient for Eq. (3)
M	molecular weight of gas
n	number of drops
R	gas constant, 8.31 J/kmol K
Re	Reynolds number, $D_o\rho_g V_c/\mu_l$
V	fluid velocity, cm/s
We	Weber number, $D_o\rho_g V_c^2/\sigma$
γ	kinematic viscosity, cm^2/s
σ	surface tension of liquid relative to air, dynes/cm
μ	absolute viscosity, g/cm s
ρ	fluid density, g/cm^3

Subscripts:

c	acoustic
g	gas
l	liquid
m	molecular

INTRODUCTION

Liquid jets of fuel disintegrating into clouds of very small drops can create large liquid surface-areas for highly efficient combustion of fuel sprays in gas-turbine and rocket combustors. However, in order to calculate vaporization and burning rates of fuel droplets, data are needed to characterize the spray in terms of dropsize distribution and mean drop sizes such as the Sauter mean diameter, D_{32}. These data can then be used to derive mathematical expressions that will adequately describe two-fluid atomization as a process in which a wide variety of liquid fuels and atomizing-

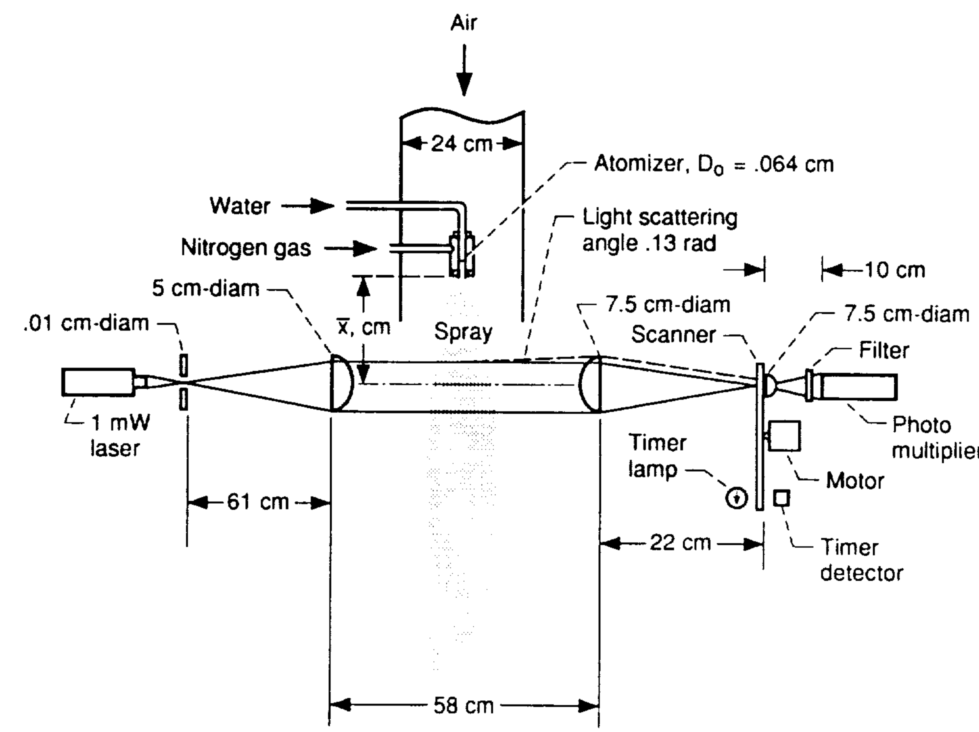

Figure 1.—Atmospheric pressure test section and optical path of scattered-light scanner.

gas combinations can be used to enhance spray combustion and yield high combustor performance over a wide range of operating conditions.

The effect of atomizing-gas temperature on fuel spray dropsize is somewhat complicated because gas temperature not only determines gas properties such as density and viscosity but it can also effect liquid surface temperature which in turn controls liquid properties, i.e., viscosity, density and surface tension. The effect of gas mass-flux on spray dropsize was investigated by Ingebo (1989) and it was found that reciprocal Sauter mean diameter, D_{32}^{-1}, varied directly with gas mass-flux, $\rho_g V_c$, raised to the 133 power. If only gas mass-flux controlled dropsize, Ingebo's (1989) results would predict that $D_{32} \sim T_g^{0.67}$. However, since it was also found that $D_{32} \sim (\rho_l \mu_l \sigma)^{0.44}$ it is apparent that liquid-surface temperature can effect D_{32} when it is affected by heat transfer from the atomizing-gas, especially when temperature gradients are high.

The ratio of liquid-jet diameter to SMD was also found by Ingebo (1989) to be a function of Weber number, We, Reynolds number, Re, and other dimensionless groups as follows: $D_o/D_{32} = f(We,\ Re,\ \rho_g/\rho_l,\ \rho_l V_m^3/g\mu_g)$ where ρ_g/ρ_l, is the gas-to-liquid density ratio, V_m is RMS velocity of gas molecules, g is acceleration of gas-molecules due to gravity and μ_g is gas viscosity. Nitrogen, argon, helium and carbon dioxide were used as atomizing gases with two-fluid nozzles, at a gas temperature of 293 K. As a continuation of that study, dropsize data were obtained in the present study, over an atomizing-gas temperature range of 275 to 400 K, using helium, argon and nitrogen gases. A number of studies of the effect of fluid properties on liquid-jet atomization have been reported in the literature. Ingebo (1989) found that acoustic mass-flux, $\rho_g V_c$, had the greatest effect on fineness of atomization obtained with two-fluid nozzles. However at present, the effect of gas temperature on spray dropsize has not been well established in the spray literature, as indicated by Kim and Marshall (1971), Lorenzetto and Lefebvre (1977), Nukiyama and Tanasawa (1939), Weiss and Worsham (1959), and Wolf and Anderson (1965).

Two-phase flow in fuel nozzles was experimentally investigated to determine the effect of atomizing-gas mass-flux and temperature on spray dropsize produced by liquid-jet breakup in high-velocity gas streams. Characteristic dropsize, D_{32}, was measured with a scattered-light scanner developed at the NASA Lewis Research Center by Buchele (1988). Sprays were sampled at a distance of 2.2 cm downstream of the fuel nozzle orifice to minimize the loss of small drops due to vaporization (Ingebo, 1988). Sauter mean diameters varying from 3 to 30 μm were produced by the breakup of small-diameter liquid jets in high-velocity gasflow.

APPARATUS AND PROCEDURE

The two-fluid fuel nozzle using assist gasflow is shown in Fig. 1. It was mounted at the center line of the 24-cm diameter duct and operated over pressure ranges of 0.2 to 1.0 MPa for both water and the atomizing gas. Water sprays were injected downstream into the airflow, just upstream of the duct exit, and sampled at a distance of 2.2 cm downstream of the atomizer orifice with the 5.0-cm diameter laser beam. The two fluid-nozzle was fabricated according to the diagram illustrated in Fig. 2, with an orifice diameter of 0.32 cm. Water at a temperature of 293 K was axially injected into the airstream by gradually opening the control valve until the desired flowrate of 3.15 g/s was obtained as indicated by a turbine flowmeter. The atomizing gas was then turned on and weight flowrate was measured with a 0.51-cm diameter sharp-edge orifice. After the air, atomizing-gas and water flowrates were set, the SMD, D_{32}, was measured with the scattered-light scanner.

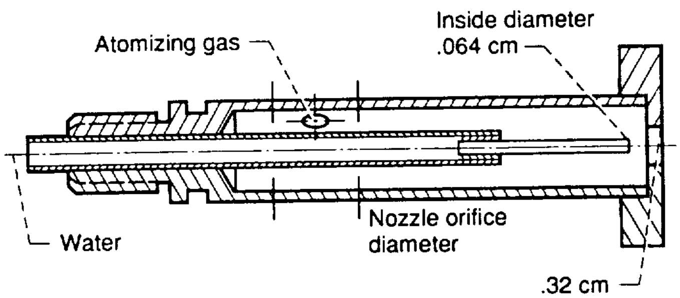

Figure 2.—Diagram of pneumatic two-fluid atomizer.

The optical system of the scattered-light scanner shown in Fig. 1 consisted of a laser beam expander with a spatial filter, rotating scanning-slit and a detector. The instrument measures scattered light as a function of scattering angle by repeatedly sweeping a variable-length slit in the focal plane of the collecting lens. The data obtained is scattered-light energy as a function of the scattering angle relative to the laser beam axis. This method of particle size measurement is similar to that described by Swithenbank, et al. (1977). According to Buchele (1988), measurements of scattered-light energy normalized by the maximum energy and plotted against scattering angle can be used to determine the Sauter mean diameter, D_{32}, as illustrated in Fig. 3. The dispersion of the size distribution can also be determined from this plot. Also, this method of determining characteristic dropsize and dispersion of dropsize can be used independent of the particle size distribution function, according to Buchele (1988). For a typical measurement, the scan is repeated 60 times per second to average out any temporal variations in the energy curve.

Spray pattern effects were minimized by measuring characteristic drop diameter, D_{32}, for the entire cloud of droplets. Calibration was accomplished with five sets of monosized polystyrene spheres having diameters of 8, 12, 25, 50, and 100 μm. Since the sprays were sampled very close to the atomizer orifice, they contained a relatively high-number density of very small drops. As a result, the light-scattering measurements required correction for multiple scattering as described by Felton, et al. (1985). Also, dropsize measurements were corrected to include Mie scattering theory when very small drop diameters, i.e., <10 μm, were measured. Reproducibility tests gave experimental dropsize measurements that agreed within ±5 percent. Background effects due to severe gas-density gradients were negligible due to taking background readings with a high-temperature atomizing-gas flowing through the nozzle and thereby obtaining corrected light-scattering curves for the spray tests.

EXPERIMENTAL RESULTS

Three atomizing-gases, i.e., helium, nitrogen and argon, were used with a two-fluid fuel nozzle to study the effect of heat and momentum transfer from high velocity gasflow to disintegrating liquid jets. Tests were made to determine the effects of atomizing-gas mass-flux and temperature on spray dropsize. Correlations of normalized reciprocal SMD's with dimensionless force ratios were obtained. Also, a new dimensionless group was derived to correlate dropsize data with atomizing-gas and liquid-jet properties.

Effect of Atomizing-Gas Mass-Flux and Temperature on Reciprocal SMD, D_{32}^{-1}

For each of the three atomizing gases, values of reciprocal SMD were measured and plotted against gas mass-flux at three different atomizing-gas temperatures, as shown in Figs. 4(a) to (c). From this plot, it is evident that: $D_{32}^{-1} = k(\rho_g V_c)^{1.33}$. This agrees well with atomization theory given by Adelberg (1986), which predicts an exponent of 1.33 for gas velocity.

In Table I, values of exponent n obtained from the spray literature are compared with the value of 1.33 obtained in the present study. Values of n less than that are attributed to losses of small drops due to vaporization. Ingebo (1988) found that the exponent for atomizing-gas mass-flux varied from $n = 1.33$ at a sampling location of $\bar{x} = 2.2$ cm downstream of the nozzle, to $n = 1.2$ at $\bar{x} = 4.4$ cm and as low as $n = 1.0$ at $\bar{x} + 6.7$ cm. Even at an atomizing-gas temperature of 400 K, the value of n remained at 1.33, which indicates there was a negligible loss of small drops due to vaporization. Also, since gas mass-flux is directly proportional to the atomizing-gas pressure and $D_{32}^{-1} \sim (\rho_g V_c)^{1.33}$, the dropsize data show that $D_{32}^{-1} \sim P_g^{1.33}$.

The mass-flux proportionality constant, k, is a function of atomizing-gas and liquid-jet properties.

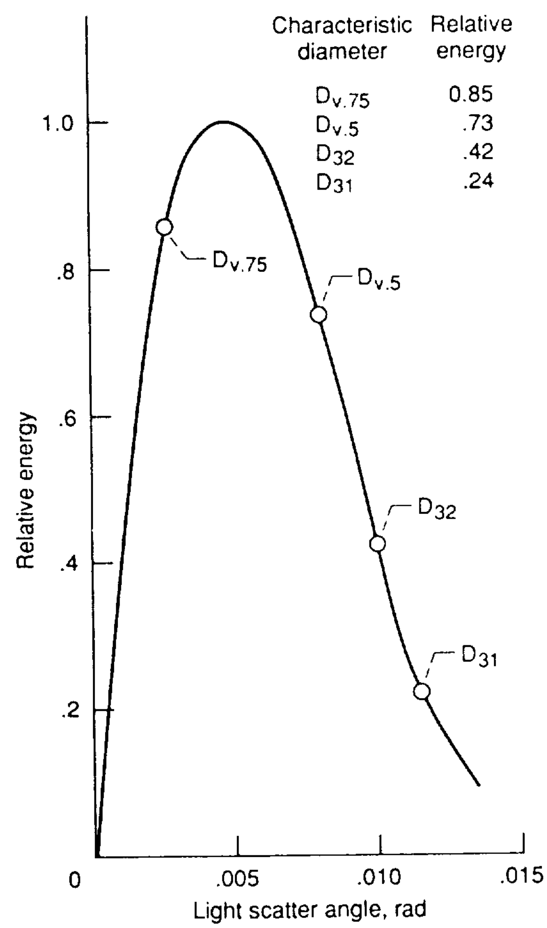

Figure 3.—Typical scattered-light energy curve with four characteristic diameters.

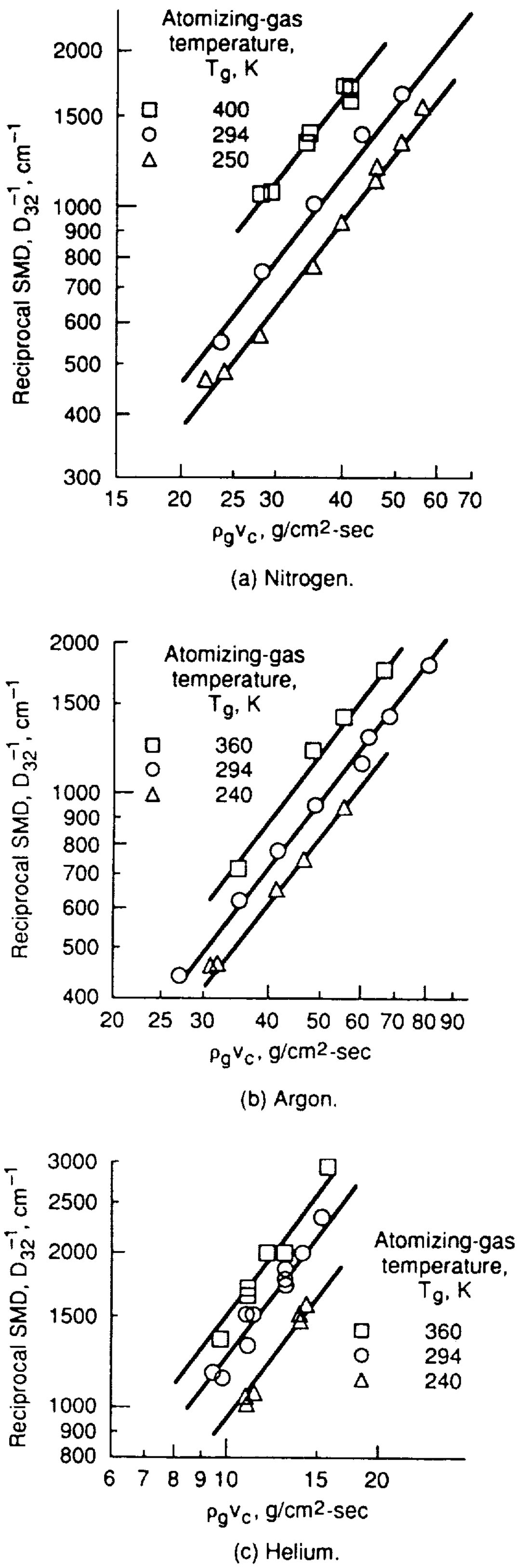

Figure 4.—Variation of reciprocal SMD with gas mass-flux, $\rho_g V_c$, for nitrogen, argon and helium.

TABLE I. - MASS-FLUX OR GAS VELOCITY EXPONENT, n, FOR LIQUID-JET BREAKUP IN HIGH VELOCITY GASFLOW

Source	Exponent n
Adelberg, 1986, theory	1.33
Present study, x = 2.2 cm	1.33
Kim and Marshall, 1971	[a]1.14
Lorenzetto and Lefebvre, 1977	1.00
Nukiyama and Tanasawa, 1939 x = 5 to 25 cm	1.00
Weiss and Worsham, 1959	[a]1.33
Wolf and Anderson	1.33

[a]Dropsize data for wax spheres.

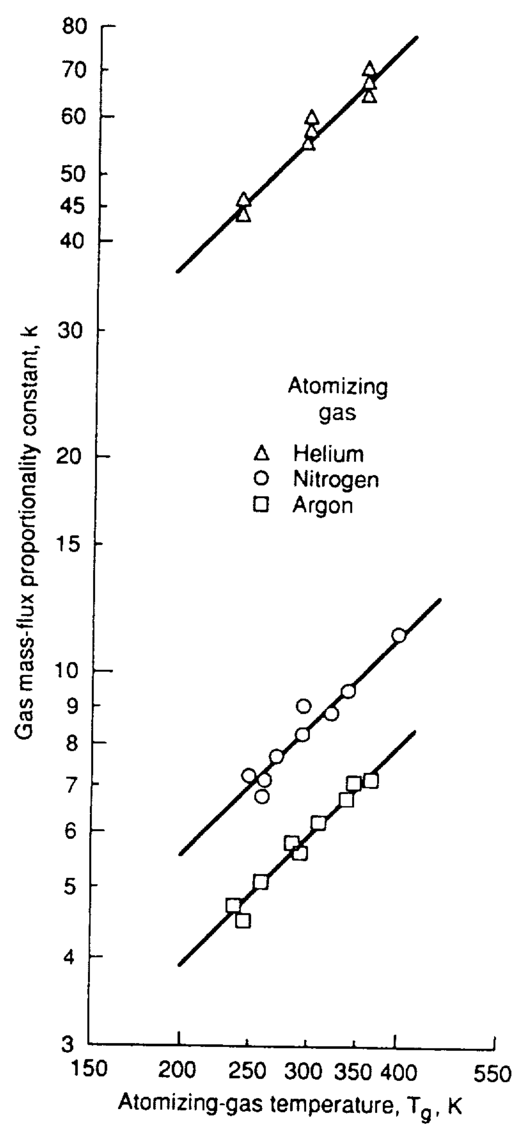

Figure 5.—Variation of gas mass-flux proportionality constant, k, with atomizing-gas temperature, T_g.

Values of k at the three different atomizing-gas temperatures are given in Table II for the three gases. They clearly show the marked improvement that is obtained in fineness of atomization when a low molecular weight gas such as helium is used as the atomizing gas for two-fluid nozzles operating at acoustic gas velocities. The large liquid-surface areas per unit volume of liquid, i.e., large values of reciprocal SMD obtained with helium, is attributed to its low molecular weight and therefore high acoustic velocity. On the other hand, the higher molecular weight and relatively low acoustic velocity of argon makes it much less efficient as an atomizing gas for two-fluid fuel nozzles.

To determine the effect of atomizing-gas temperature on reciprocal SMD, values of k were plotted against T_g as shown in Fig. 5. From this plot it is evident that $D_{32}^{-1} \sim T_g$, for the three atomizing gases. Thus, the following expression is obtained: $k = C\,T_g$, where C = 0.186, 0.028 and 0.020 for helium, nitrogen and argon, respectively, and $k = D_{32}^{-1}/(\rho_g V_c)^{1.33}$.

TABLE II. - MASS-FLUX PROPORTIONALITY CONSTANT, k, VALUES

Argon		Nitrogen		Helium	
T_g, K	k	T_g, K	k	T_g, K	k
360	6.5	400	12.4	360	70
294	5.3	294	8.6	294	58
240	4.7	250	7.0	240	44

TABLE III. - COEFFICIENT, k', FOR EQUATION (1)

Argon		Nitrogen		Helium	
T_g, K	k	T_g, K	k	T_g, K	k
360	4.1	400	7.8	360	44
294	3.3	294	5.4	294	36
240	2.9	250	4.4	240	28

Correlation of Normalized Reciprocal SMD with Dimensionless Groups

In studying liquid-jet disintegration in high-velocity nitrogen gasflow, as reported by Ingebo (1989), it was found that the reciprocal of the normalized SMD, $(D_{32}/D_o)^{-1}$, could be directly correlated with the product of the Weber and Reynolds numbers, We Re, multiplied by the gas-to-liquid density ratio, ρ_g/ρ_l, as follows:

$$D_o/D_{32} = k'(\mathrm{We\ Re}\rho_g/\rho_l)^{0.44} \tag{1}$$

where $\mathrm{We\ Re} = D_o^2\rho_g^2V_c^3/\mu_l\sigma$ and V_c is acoustic gas-velocity. Values of k′ are given in Table III.

To obtain a single correlating coefficient, k*, over the range of atomizing-gas molecular weights and temperatures that were investigated, a dimensionless group, $\rho_l V_m^3/\mu_l g$, was derived by means of dimensional analyses, as demonstrated in the Appendix. To determine its effect on spray dropsize, the dimensionless group, $\rho_l V_m^3/\mu_l g$, was plotted against gas mass-flux proportionality constant, k, as shown in Fig. 6. From this plot the following expression is obtained:

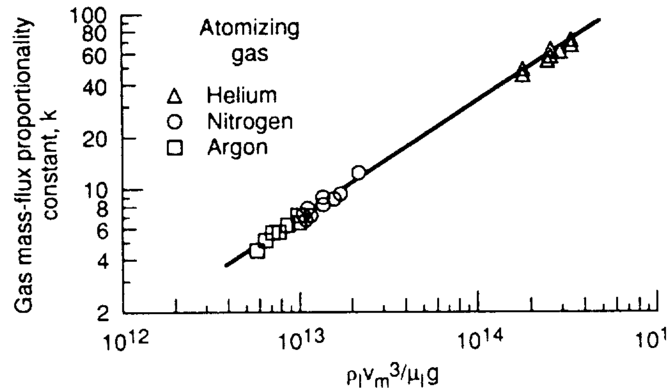

Figure 6.—Correlation of gas mass-flux proportionality constant, k, with molecular-scale dimensionless group, $\rho_l v_m^3/\mu_l g$.

$$k \sim \left(\rho_l V_m^3/\mu_l\ g\right)^{0.67} \tag{2}$$

Equations (1) and (2) may be combined to give the following expression:

$$D_o/D_{32} = k^* \left(\mathrm{We\ Re}\rho_g/\rho_l\right)^{0.44}\left(\rho_l V_m^3/\mu_l\ g\right)^{0.67} \tag{3}$$

By plotting D_o/D_{32} against the dimensionless groups, as shown in Fig. 7, all of the dropsize data was used to evaluate the single correlating coefficient, k*, and it was found that $k^* = 0.90\times10^{-8}$. In terms of atomizing-gas mass-flux, $\rho_g V_c$, Eq. (3) may be rewritten as follows:

$$D_o/D_{32} = 0.90\times10^{-8}\left(D_o^2/\rho_l\mu_l\sigma\right)^{0.44} \times \left(\rho_g V_c\right)^{1.33}\left(\rho_l V_m^3/\mu_l\ g\right)^{0.67} \tag{4}$$

where $\rho_g V_c = W_g/A_o$. From this expression, it is evident that the gas properties, i.e., acoustic gas-velocity, V_c, and molecular gas-velocity, V_m, have the greatest effect on reciprocal SMD. By increasing gas temperature and using a low molecular weight gas, the spray surface-area per unit volume of liquid was markedly increased. In terms of liquid properties, the expression shows that $D_{32}^{-1} \sim \rho_l^{0.23}$ and $\mu_l^{-1.11}$.

In determining the effect of atomizing-gas temperature on spray surface-area, it appeared that the new dimensionless group, $\rho_l V_m^3/\mu_l\ g$, not only accounted for this effect, it also correlates gas molecular-weight with characteristic dropsize. Also, heat transfer to the spray, especially at elevated gas temperatures, was assumed negligible in terms of drop vaporization or heating up of the liquid-jet surface. Liquid viscosity, surface tension and density were all evaluated at the liquid injection temperature of 293 K. By sampling close to the atomizer orifice, the loss of small droplets due to vaporization was negligible and effects of gas mass-flux on dropsize agreed well with atomization theory (Adelberg, 1986).

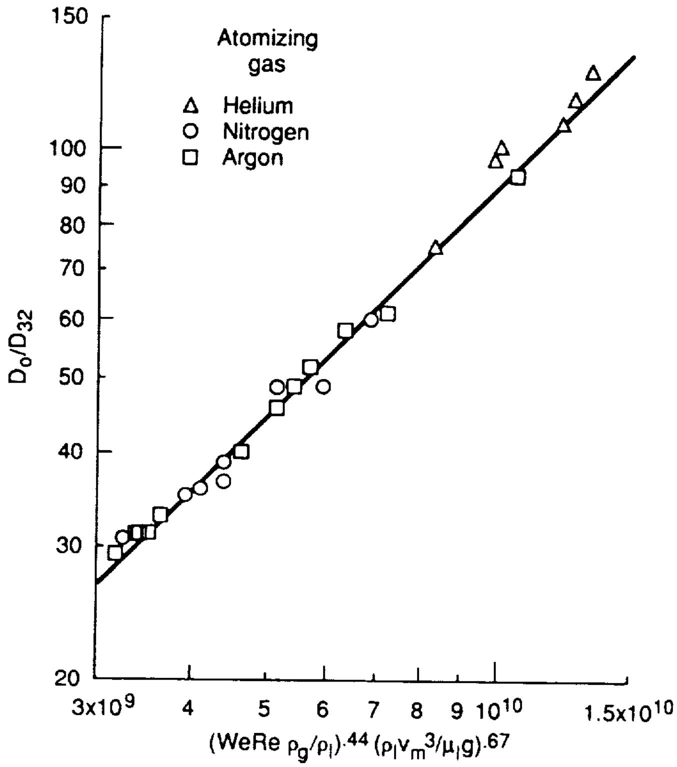

Figure 7.—Correlation of normalized reciprocal Sauter mean diameter with dimensionless groups.

CONCLUDING REMARKS

In this study of two-phase flow, it was found that atomizing-gas temperature and molecular weight are two very important basic properties that contribute markedly to atomization efficiency in producing sprays with large surface-areas per unit volume of liquid, i.e., large values of reciprocal SMD, D_{32}^{-1}. This is primarily due to their effect on atomizing-gas acoustic-velocity, V_c, and RMS molecular-velocity, V_m, since both vary directly with the square root of gas temperature and inversely with the square root of gas molecular weight. Also, it was found that momentum transfer, i.e., gas mass-flux $\rho_g V_c$, appeared to control the process of liquid-jet breakup to such an extent that heat transfer effects were negligible. Since droplet vaporization was negligible, liquid-jet physical properties were evaluated at the liquid-jet injection temperature, 293 K.

A new dimensionless group, $\rho_l V_m^3/\mu_l\, g$, was needed to obtain a correlating expression for the three atomizing gases. In a previous study (Ingebo, 1989), gas viscosity was used instead of liquid viscosity, in a similar grouping of physical properties. However, the present study shows that although gas temperature was varied from 275 to 400 K, gas viscosity effects appeared negligible. Therefore, liquid viscosity is used in the new dimensionless group, $\rho_l V_m^3/\mu_l\, g$, which could be rewritten as $V_m^3/g\gamma_l$, where γ_l is kinematic liquid viscosity. Further studies are needed to determine the effect of liquid-jet temperature on SMD.

APPENDIX - DEVIATION OF NEW DIMENSIONLESS GROUP

A molecular-scale momentum transfer group was derived by means of dimensional analysis in the following manner. The normalized reciprocal Sauter mean diameter, D_o/D_{32}, produced by liquid-jet breakup with two-fluid atomizers is assumed to be a function of the RMS velocity of the gas molecules, V_m, the acceleration of gas molecules due to gravity, g, liquid viscosity, μ_l, and liquid density, ρ_l. Using dimensional analysis, the following expression is obtained:

$$D_o/D_{32} = f\left(V_m, \mu_l, \rho_l, g\right) \tag{5}$$

where $V_m = \sqrt{3RT_g/M_g}$, (Glasstone, 1946). By rewriting Eq. (5), as follows:

$$D_o/D_{32} = f\,(\rho_l)^a (V_m)^b (g)^c (\mu_l)^d \tag{6}$$

This equation can be expressed in terms of the mass-length-time system (where M is mass, L is length and T is time) to give:

$$D_o/D_{32} = f\left(M/L^3\right)^a (L/T)^b \left(L/T^2\right)^c (M/LT)^d \tag{7}$$

so that for:

$$M,\ 0 = a + d$$

$$T,\ 0 = -b - 2c - d$$

$$L,\ 0 = -3a + b + c - d$$

which may be rewritten as:

$$a = -d$$

$$b = -2c - d = -3d$$

$$c = 3a - b + d$$

Substituting these values into Eq. (6) gives:

$$D_o/D_{32} = f\left(\rho_l V_m^3/g\mu_l\right)^{-d} \tag{8}$$

where the exponent is to be evaluated experimentally. Also, Eq. (8) may be rewritten in terms of kinematic liquid viscosity, γ_l, as follows:

$$D_o/D_{32} = f\left(V_m^3/g\gamma_l\right)^{-d} \tag{9}$$

REFERENCES

Adelberg, M., "Mean Drop-Size Resulting from the Injection of a Liquid Jet Into a High-Speed Gas Stream," AIAA Journal, Vol. 6, No. 6, June 1986, pp. 1143-1147.

Buchele, D.R., "Particle Sizing by Weighted Measurements of Scattered Light," NASA TM-100968, 1988.

Felton, P.G., Hamidi, A.A., and Aigal, A.K., "Measurement of Drop-Size Distribution in Dense Sprays by Laser Diffraction," 3rd International Conference on Liquid Atomization and Spray Systems, ICLASS - 85, Vol. 2, Eisenklam, P. and Yule, A., Eds., Institute of Energy, London, 1985, pp. IVA/4/1-IVA/4/11.

Glasstone, S., Textbook of Physical Chemistry, D. Van Nostrand Co., Inc., New York, 2nd Edition, 1946, p. 253.

Ingebo, R.D., "Experimental and Theoretical Effects of Nitrogen Gas Flowrate on Liquid Jet Atomization," Journal of Propulsion and Power, Vol. 4, No. 6, Nov.-Dec. 1988.

Ingebo, R.D., "Gas Density Effect on Dropsize of Simulated Fuel Sprays," AIAA Paper 89-2322, July 1989, NASA TM-102013.

Kim, K.Y. and Marshall, W.R., Jr., "Drop Size Distributions from Pneumatic Atomizers," AIChE Journal, Vol. 17, No. 3, May 1971, pp. 575-584.

Lorenzetto, G.E. and Lefebvre, A.H., "Measurements of Drop Size on a Plain-Jet Airblast Atomizer," AIAA Journal, Vol. 15, No. 7, July 1977, pp. 1006-1010.

Nukiyama, S. and Tanasawa, Y., "Experiments on the Atomization of Liquids by Means of a Air Stream, Parts III-IV," Transactions of the Society of Mechanical Engineers, Japan, Vol. 5, No. 18, Feb. 1939, pp. 63-75.

Swithenbank, J., Beer, J.M., Taylor, D.S., Abbot, D., and McCreath, G.C., "A Laser Diagnostic Technique for the Measurement of Droplet and Particle Size Distribution," Experimental Diagnostics in Gas Phase Combustion Systems, Zinn, B.T., and Bowman, C.T., Eds., Progress in Astronautics and Aeronautics, Vol. 53, AIAA, New York, 1977, pp. 421-447.

Weiss, M.A. and Worsham, C.H., "Atomization in High Velocity Airstreams," American Rocket Society Journal, Vol. 29, No. 4, Apr. 1959, pp. 252-259.

Wolf, H.E. and Anderson, W.H., "Aerodynamic Break-up of Liquid Drops," Proceedings of the 5th International Shock Tube Symposium, Z.I. Slawasky, J.F. Moulton, Jr., and W.S. Filler, Eds., Naval Ordnance Lab., White Oak, MD, 1965, pp. 1145-1169. (Avail. NTIS, AD-638011.)

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