THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
345 E. 47 St., New York, N.Y. 10017

87-GT-55

Influence of Ambient Air Pressure on Pressure-Swirl Atomization

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ABSTRACT

The spray characteristics of six simplex atomizers are examined in a pressure vessel using a standard light diffraction technique. Attention is focused on the effects of liquid properties, nozzle flow number, spray cone angle, and ambient air pressure on mean drop size and drop-size distribution. For all nozzles and all liquids it is found that continuous increase in air pressure above the normal atmospheric value causes the SMD to first increase up to a maximum value and then decline. An explanation for this characteristic is provided in terms of the measurement technique employed and the various competing influences on the overall atomization process. The basic effect of an increase in air pressure is to improve atomization, but this trend is opposed by contraction of the spray angle which reduces the relative velocity between the drops and the surrounding air, and also increases the possibility of droplet coalescence.

INTRODUCTION

The advantages offered by the airblast atomizer in terms of reduced soot formation and smoke have enabled it to replace the pressure-swirl (simplex) nozzle in advanced gas turbine engines of high compression ratio. However, considerable interest still remains in the pressure-swirl atomizer, due partly to its inherent simplicity and also to the fact that it serves as a pilot fuel injector for both dual-orifice nozzles and hybrid airblast atomizers.

In their application to gas turbines simplex atomizers are called upon to operate over wide ranges of ambient gas pressure. For aircraft engines it is especially important that good atomization be achieved over the entire operating range. At low ambient air pressures, which usually correspond to operation at high altitudes, fine atomization is an essential prerequisite to good ignition performance and wide stability limits. Good atomization is also important at high combustion pressures in order to combat the deleterious effects arising from soot formation in the flame. Thus, in the design of gas turbine combustion systems, and in the modeling of liquid fuel-fired combustion processes, a thorough knowledge is needed of the manner and extent to which the spray characteristics of simplex atomizers are influenced by wide variations in ambient gas pressure.

The effects on drop size of variations in fluid properties and injection pressure differential have been investigated by several workers, but usually the measurements have been confined to normal atmospheric presure. However, some studies of spray characteristics have been conducted at elevated gas pressures, and the results have been reviewed by Lefebvre (1983) and Dodge and Biaglow (1985).

Much of the early work on the effects of elevated air density on sprays was done with diesel nozzles using very high fuel injection pressures. Giffen and Lamb (1953), using a fuel pressure drop (ΔP_L) of 12.4 MPa (1800 psid), found a decrease in drop size with increasing gas density for air densities of 1.22 to 51.2 kg/m^3. Lee (1932a, 1932b) reported a negligible effect of ambient gas density on drop size for a ΔP_L of 28.4 MPa (4120 psid) and air densities of 5 to 25 kg/m^3. Retel (1936) reported a decrease in drop size with increasing air density up to densities of 4 kg/m^3, followed by an increase at higher air densities. All of these tests were with diesel nozzles using very high injection pressures and are not directly comparable with the simplex swirl atomizers used in gas turbines.

DeCorso (1960) examined a simplex swirl atomizer operating at ΔP_L's of 172 to 689 kPa (25 to 100 psid) and gas densities of 0.041, 1.17, and 9.27 kg/m^3. Increasing the density from 0.041 to 1.17 kg/m^3 led to a significant reduction in Sauter mean diameter (SMD). A further increase to 9.27 kg/m^3 led to a slight increase in SMD, but also resulted in an almost complete collapse of spray cone angle from about 80 degrees at atmospheric density to 28 degrees at 9.27 kg/m^3. This would probably be regarded as an unacceptable collapse of cone angle with pressure, and therefore not suitable to use for evaluating the effects of elevated densities on drop sizes.

Neya and Sato (1968) examined the influence of ambient air pressure on the spray characteristics of simplex atomizers and found that SMD α $P_A^{0.27}$. However, Abou-Ellail et al. (1978) reported a dependence of SMD on air pressure of SMD α $P_A^{-0.26}$ a relationship that subsequent work by Rizk and Lefebvre (1984) generally confirmed. For air pressures up to around 0.4MPa (4 atmos) they found that increasing the air pressure reduced the mean drop size

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Presented at the Gas Turbine Conference and Exhibition, Anaheim, California — May 31-June 4, 1987

according to the relationship SMD α $P_A^{-0.1}$, while at pressures greater than 0.4 MPa the effect of air pressure was stronger (SMD α $P_A^{-0.28}$). Rizk and Lefebvre suggest that a pressure exponent of -0.25 be used overall. Lefebvre's (1983) dimensional analysis of published experimental data on pressure-swirl atomization also led to a value for the air pressure exponent of -0.25.

The most recent investigation on the effect of air pressure on atomization is that of Dodge and Biaglow (1985). Their results, obtained with Jet A and DF-2 fuels, conform to the relationship SMD α $P_A^{-0.53}$, thereby indicating a very strong dependence of SMD on air pressure.

From the above discussion it is clear that the various reported studies on the effect of ambient air pressure on mean drop size have produced conflicting results, with pressure exponents ranging from +0.27 to -0.53. From a practical viewpoint this is very unsatisfactory, since it is obviously important to know the extent to which SMD data acquired in the laboratory at normal atmospheric pressure represent the actual drop sizes obtained when the atomizer is operating in an engine environment at elevated gas pressures. This lack of consistency in the published data on the effect of air pressure on atomization quality provided the incentive for the present investigation.

EXPERIMENTAL

The apparatus for studying spray characteristics comprises a cylindrical pressure vessel which is mounted on a stand with its axis in the vertical position. It is 120 cm long and 75 cm in diameter. The atomizer under test is located centrally at the top of the cylinder and sprays downward into the vessel which is pressurized to the desired level using gaseous nitrogen that is tapped from a large liquid nitrogen storage/evaporator system. The reason for using nitrogen instead of air is to avoid the risk of explosion. As the physical properties of nitrogen are very similar to those of air the results obtained with nitrogen are considered valid for systems using air. The droplets produced by atomization gravitate into a collection tank at the bottom of the chamber, from whence the liquid is either disposed of or is returned to the storage tank.

In addition to the nitrogen supply for tank pressurization, two extra nitrogen lines are connected to the tank. One line blows nitrogen over the windows to protect them from contamination by liquid drops or mist, while the other line is connected to a manifold located at the top of the tank which provides a gentle downdraft of nitrogen through a large number of small holes. The flow velocity around the nozzle is quite low, around 1 m/s, but this is considered adequate to keep droplet recirculation to a minimum.

Mean drop sizes are measured using a Malvern particle size analyzer. This instrument is based on the Fraunhofer diffraction theory of a collimated laser beam scattered by moving drops. All measurements were taken with the laser beam passing through the centerline of the spray at a distance of 150mm from the nozzle. The problems involved with such measurements have been discussed by various workers, including Dodge (1984), Felton et al. (1985), and Chin et al. (1986). Centerline measurements are generally preferred because they encompass both the smaller drops in the core of the spray as well as the larger drops at the spray periphery.

The following liquids were chosen to provide a wide variation in surface tension.

Diesel oil (DF 2): $\mu = 0.0026$ kg/(ms), $\sigma = 0.027$ kg/s^2, $\rho = 860$ kg/m^3

Water: $\mu = 0.001$ kg/(ms), $\sigma = 0.0734$ kg/s^2, $\rho = 1000$ kg/m^3

The effect of variation in liquid viscosity on mean drop size is examined by blending the diesel oil in varying concentrations with a commercially-available polybutene (Amoco L-100), to produce a range of viscosities from 0.0026 to 0.0152 kg/(ms). This wide range of viscosity is accompanied by only slight variations in surface tension.

The basic design features of the six simplex nozzles employed in this study are shown in Fig. 1. They were manufactured by the Delavan Corporation and were selected from a batch of available nozzles because they exhibited excellent spray symmetry, free from any streaks or voids. Three of the nozzles have a nominal cone angle of 90°, and nozzle numbers (NN) of 2, 4, and 8. The corresponding flow numbers in SI units are 6.25 x 10^{-8}, 12.5 x 10^{-8}, and 25 x 10^{-8}, while in conventional units (lb/hr/(psi)$^{0.5}$), the three flow numbers are 1.14, 2.28, and 4.56. The other three nozzles have the same three flow numbers, but their nominal cone angle is 60°.

The reason for choosing these values of flow number was partly to cover the range of interest to the designers of primary nozzles for aircraft gas turbines, and also to minimize the problem of laser beam obscuration that arises with nozzles of high flow rate. The Malvern instrument provides a direct indication of beam obscuration, and for all the measurements reported here it was always at an acceptably low value. Even so, the correction formula devised by Felton et al. (1985) was applied as a routine procedure in all cases, to eliminate any possibility of errors arising from this source.

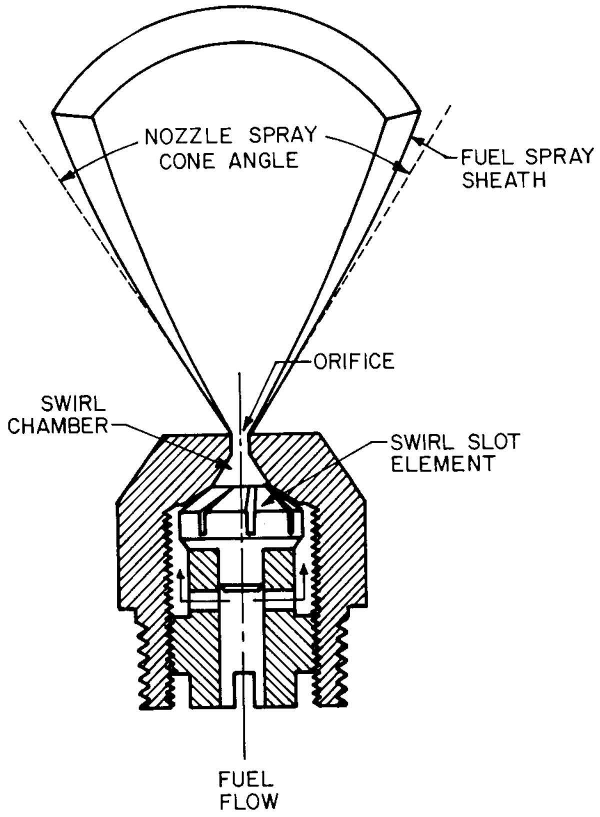

Fig. 1. Pressure-swirl simplex nozzle.

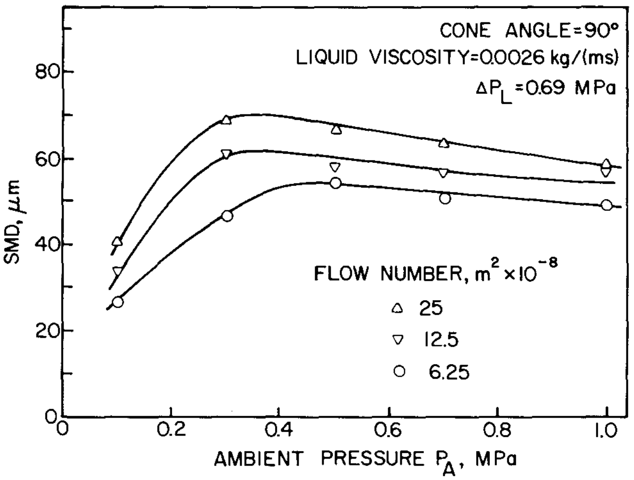

Fig. 2. Influence of ambient air pressure and nozzle flow number on mean drop size.

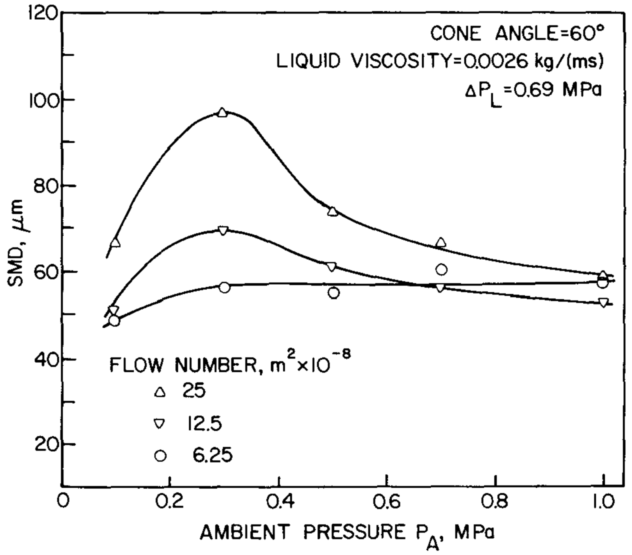

Fig. 3. Influence of ambient air pressure and nozzle flow number on mean drop size.

RESULTS

During the course of this investigation a large amount of experimental data was acquired for both mean drop size (SMD), and drop-size distribution. Limitations on space do not allow more than a small fraction of these data to be included in this paper. However, the results presented in Figs. 2 to 11 are typical of those obtained over broad ranges of liquid properties and nozzle operating conditions.

Mean Drop Size

Figure 2 shows the influence of ambient air pressure, P_A, on mean drop size for three nozzles having 90° cone angles and flow numbers of 6.25 x 10^{-8}, 12.5 x 10^{-8}, and 25 x 10^{-8} m^2. The liquid employed is diesel oil (DF 2), and the data were obtained at a liquid injection pressure differential of 0.69 MPa (100 psi). For the nozzle of highest flow number the SMD rises fairly steeply with increase in P_A up to a maximum value around 0.4 MPa (3 atmos) beyond which any further increase in P_A causes the SMD to decline. For the nozzle of lowest flow number the initial increase of SMD with P_A is also quite steep up to an air pressure of around 0.4 MPa. However, further increase in P_A above this pressure level appears to have little influence on SMD.

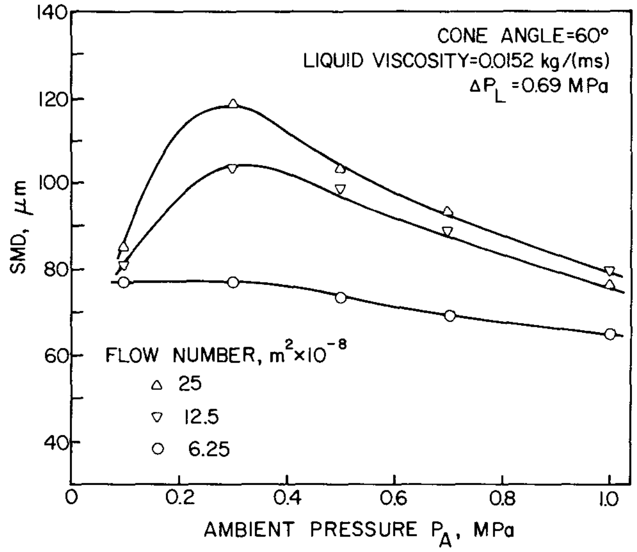

Fig. 4. Influence of ambient air pressure and nozzle flow number on mean drop size.

Figure 3 contains similar experimental data to those presented in Fig. 2. They both feature the same liquid (DF-2) and the same three values of nozzle flow number. However, for Fig. 3 the relevant spray cone angle is 60° as opposed to 90° in Fig. 2. Thus, comparison of these two figures allows an assessment to be made of the influence of cone angle on the variation of mean drop size with ambient air pressure. They show that for the lowest flow number nozzle there is little effect of cone angle, but for the largest nozzles the effect of reducing the spray angle is to increase the dependence of SMD on Pa.

Figure 4 shows similar data to Fig. 3, obtained with the same three nozzles, but for a liquid of much higher viscosity (0.0152 kg/ms). The general SMD levels are much higher, but for all three nozzles the SMD again rises with P_A, reaching maximum values at around 0.3 MPa. Further increase in P_A above 0.3 MPa causes atomization quality to improve quite markedly for all three nozzles. The conclusion to be drawn from Figs. 3 and 4 and from inspection of much additional data acquired at several intermediate values of liquid viscosity, is that the dependence of SMD on P_A is stronger for nozzles of higher flow number and liquids of higher viscosity. From inspection of Figs. 2 and 3 it is clear that, once the critical pressure has been reached, the decline of SMD with increase in P_A is more pronounced for the nozzle with the smallest cone angle. However, for the nozzle having the lowest flow number (FN = 6.25 x 10^{-8} m^2), the data show that SMD is sensibly independent of P_A, regardless of spray cone angle. Apart from water, which is characterized by an exceptionally high surface tension, a key feature of all the results obtained with the lowest flow number nozzles is that, once the critical pressure ratio has been reached, further increase in P_A causes the SMD to either increase slightly, for liquids of low viscosity, or decline slightly, for liquids of high viscosity, as illustrated in Fig. 5.

The variation of mean drop size with air pressure for the largest nozzle tested is illustrated in Fig. 6. Comparison with Fig. 5 shows that the peak values of SMD are higher for the larger nozzle, and the subsequent decline of SMD

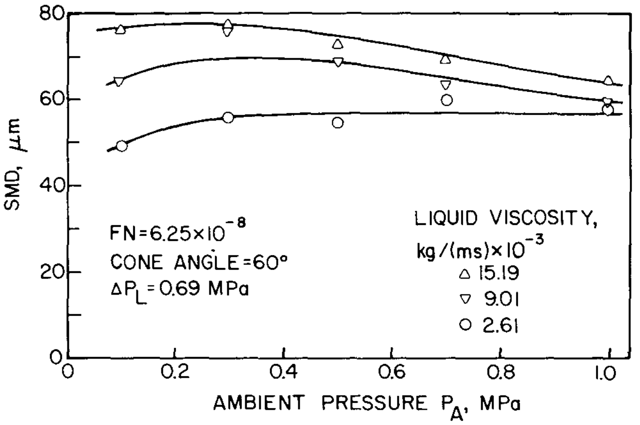

Fig. 5. Influence of ambient air pressure and liquid viscosity on mean drop size.

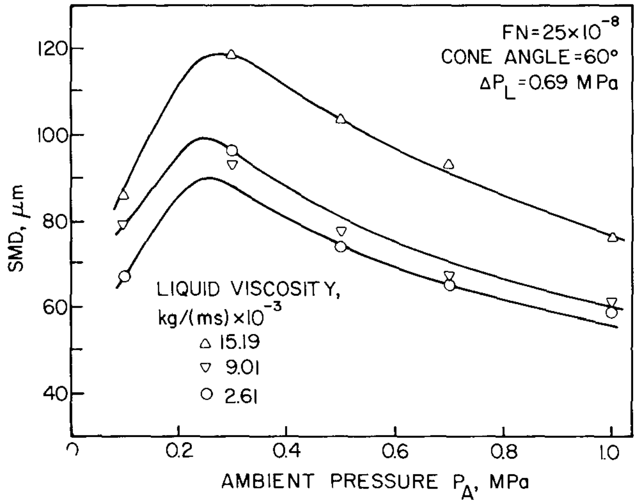

Fig. 6. Influence of ambient air pressure and liquid viscosity on mean drop size.

with further increase in air pressure is more steep than for the nozzle of low flow number.

The experimental data presented in Figs. 2 to 6 were obtained with liquids whose values of surface tension were all fairly constant at around 0.027 kg/s^2 (27 dyn/cm). Some of the results for water, which has a much higher surface tension of 0.0734 kg/s^2 (73.4 dyn/cm) are shown in Fig. 7. To ascertain the effect of surface tension on the relationship between mean drop size and air pressure this figure should be compared with Fig. 3, since both sets of data were obtained using the same nozzles at the same operating conditions, the only key difference being in the surface tension of the two liquids. (There is, in fact, a small difference in liquid viscosity also, but the effect of this is negligibly small in comparison to that of surface tension).

Figure 7 demonstrates a very strong dependence of mean drop size on ambient air pressure, the SMD rising steeply with increase in pressure above the normal atmospheric value. The critical pressure, i.e. the pressure above which any further increase causes the SMD to decline, is much higher than for liquids of low surface tension, being around 0.6 MPa for a nozzle flow number of 25 x 10^{-8} m^2, and around 0.7 MPa for a nozzle flow number of 12.5 x 10^{-8} m^2.

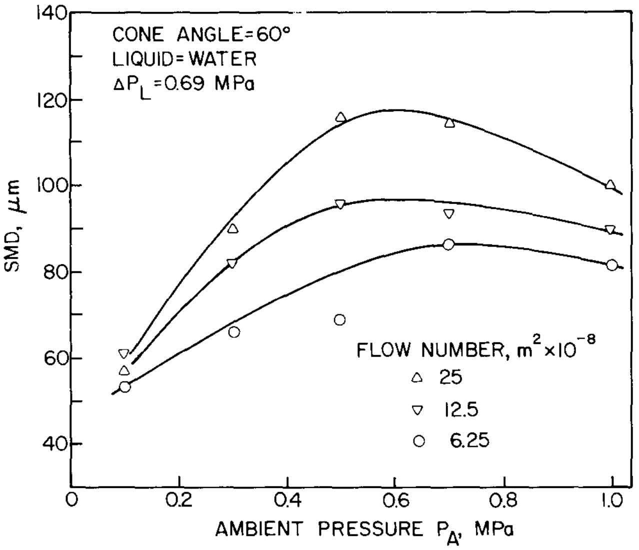

Fig. 7. Influence of ambient air pressure and nozzle flow number on mean drop size.

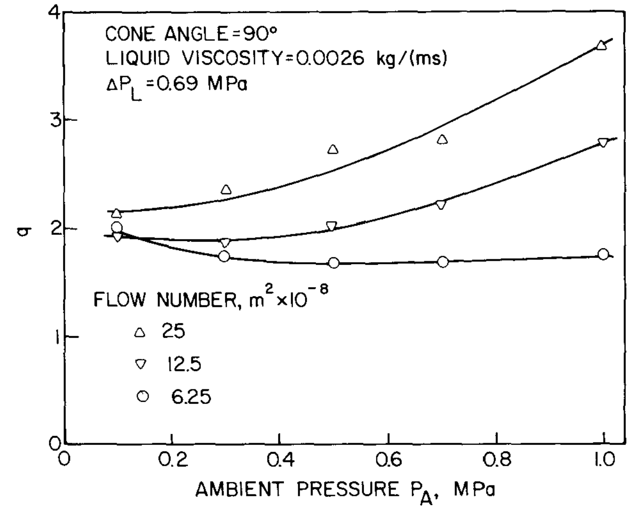

Fig. 8. Influence of ambient air pressure and nozzle flow number on drop-size distribution.

Drop-Size Distribution

Of the many drop-size distribution parameters contained in the literature, the most widely used is one that was originally developed for powders by Rosin and Rammler (1933). It may be expressed in the form

$$1 - \nu = \exp\,(-bx)^q$$

where ν is the fraction of the total volume contained in drops of diameter less than x, and b and q are constants. Thus, by applying the Rosin-Rammler relationship to sprays, it is possible to describe the drop-size distribution in terms of the two parameters b and q. The exponent q provides a measure of the spread of drop sizes. The higher the value of q, the more uniform is the spray. If q is infinite, the drops in the spray are all the same size. For most practical sprays the value of q lies between 2 and 4.

Although it assumes an infinite range of drop sizes, the Rosin-Rammler expression has the virtue of simplicity. Moreover, it permits data to be extrapolated into the range

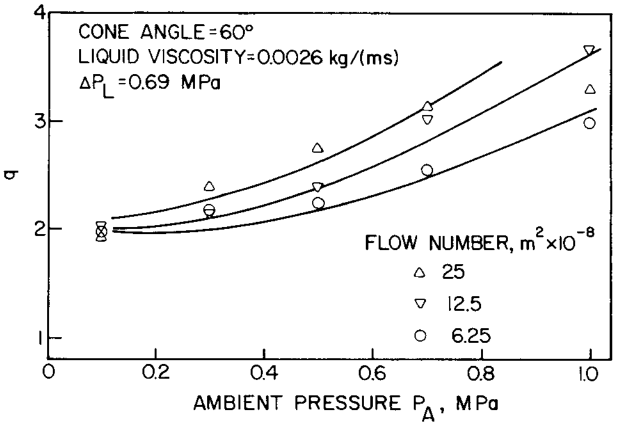

Fig. 9. Influence of ambient air pressure and nozzle flow number on drop-size distribution.

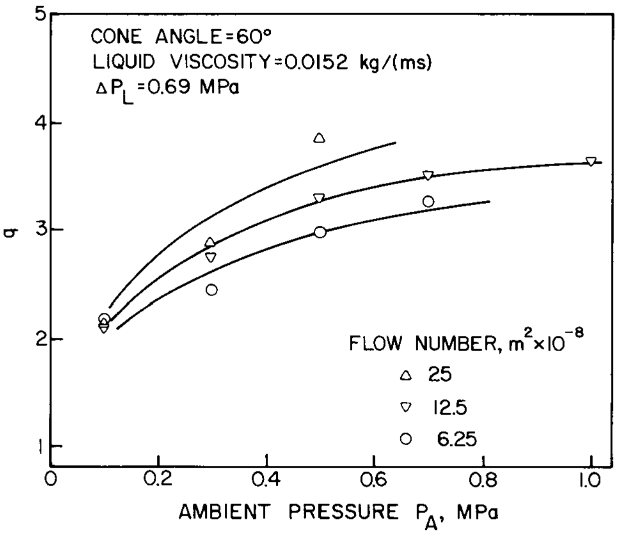

Fig. 10. Influence of ambient air pressure and nozzle flow number on drop-size distributions.

of very fine droplets, where measurements are most difficult and least accurate.

The variation of q with air pressure is illustrated in Figs. 8 to 11. The corresponding SMD values for these four figures are contained in Figs. 2, 3, 4, and 7 respectively. Figure 8 shows the variation of q with P_A for three nozzles of different flow number when spraying DF-2 fuel. It can be seen that the influence of P_A on q is quite small for the lowest flow number nozzle. As the corresponding variation in SMD is also small for this nozzle, the conclusion to be drawn is that for nozzles of low flow number and wide cone angle (90°) spray characteristics are fairly insensitive to variations in ambient air pressure. Reducing the cone angle from 90° to 60° gives the results shown plotted in Fig. 9. All three curves in this figure, drawn for different values of flow number, show q increasing with rise in air pressure. When these data are examined alongside the corresponding SMD data in Fig. 3, they indicate that increase in ambient air pressure beyond the critical value leads generally toward a more monodisperse spray of lower mean drop size.

Figure 10 shows drop-size distribution data for the same three nozzles employed in constructing Fig. 9, but for a liquid of much higher viscosity. The SMD data corresponding to Fig. 10 are contained in Fig. 4. From inspection of these figures it is clear that for high viscosity liquids the influence of ambient air pressure on spray characteristics is more marked. Increase in air pressure causes SMD to decline more rapidly (beyond the critical value), and q to rise more steeply, than for liquids of low viscosity. These observations are based on comparisons of Figs. 3 and 9 with Figs. 4 and 10. Both sets are data related to the same three nozzles, the only difference being in the level of liquid viscosity (0.0026 kg/(ms) in one case and 0.0152 kg/(ms) in the other). Generally it is found that when mean drop size is reduced by increase in air pressure the drop-size distribution becomes more uniform.

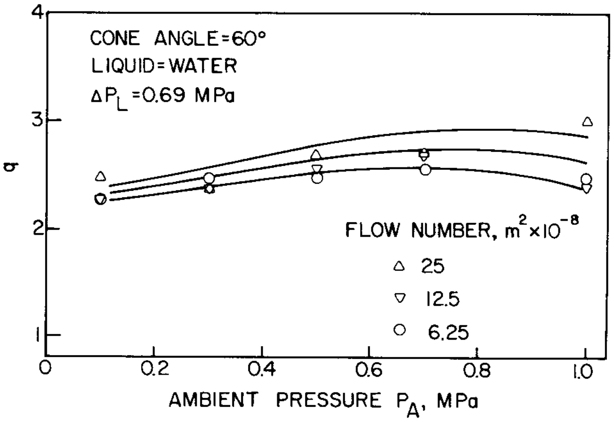

Fig. 11. Influence of ambient air pressure and nozzle flow number on drop-size distribution.

Of all the liquids tested the one exhibiting the least dependence of q on P_A is water, as illustrated in Fig. 11. It is also worthy of note that, over most of the range of air pressures covered in this investigation, water is also the only liquid for which increase in ambient air pressure usually leads to an increase in mean drop size. Thus as a generalization it can be stated that increase in ambient air pressure is always accompanied by an increase in q, i.e. the spray becomes more monodisperse. The extent to which q rises with increase in P_A is governed by the corresponding influence of P_A on SMD. In situations where the effect of an increase in P_A is to reduce the SMD the corresponding increase in q is quite large. However, under conditions where the general effect of an increase in P_A is to raise the SMD (as occurs, for example, with water) the corresponding increase in q is relatively small.

DISCUSSION

De Corso (1960) was among the first workers to investigate the influence of ambient air pressure on the spray characteristics of simplex swirl atomizers. Using a fuel of similar physical properties to the DF-2 employed in this study he measured an increase in drop size in going from 0.1 MPa (14.5 psia) to 0.79 MPa (114.5 psia). According to De Corso "from the aspects of spray breakup a continuing decrease in drop size with increase in ambient pressure would be expected, since the drag force on a drop increases with increasing density. Thus as ambient pressure rises, a decrease would be expected in the critical drop size, i.e. the maximum size that can withstand breakup, as indicated by Hinze (1948) and Lane (1951)." De Corso's attributed his actual observed increase in drop size to increased coalescence of the spray droplets as the ambient pressure is increased. Previous work by De Corso and Kemeny (1957) had shown a reduction in spray cone angle with increase in ambient pressure due to the action of induced gas currents which tend to 'collapse' the spray into a small volume. Thus De Corso's explanation for his 'anomalous' experimental data is that the actual measured values of mean drop size are the result of a competition between the breakup process and the drop coalescence process, with the opportunity for coalescence increasing with increase in gas pressure due to contraction of the spray volume.

Neya and Sato (1968) have also examined the influence of ambient air pressure on mean drop size and spray cone angle. Using water as the test fluid they obtained results similar to those of De Corso and Kemeny (1957) in regard to the contraction of spray cone angle with increase in air pressure. Over a pressure range of 0.1 to 0.5 MPa (1 to 5 atmos.) they observed a marked rise in the SMD with increase in P_A (SMD α $P_A^{0.27}$).

Neya and Sato also invoke droplet coalescence to explain this increase of SMD with P_A, but they assert that under certain conditions an additional factor which should be considered is a change in the atomization process. Based on instantaneous snapshots of the spray they concluded that, with increasing P_A, the waviness of the initial liquid sheet is intensified, and the distance from the atomizer tip for which the liquid sheet persists is shortened. The implication of this argument is that at high air pressures the disintegration process occurs in a thicker sheet, thereby producing larger drops.

Rizk and Lefebvre (1985) used a light aviation kerosine to study the influence of ambient air pressure on the drop sizes produced by a simplex nozzle of 60° spray cone angle. They also observed a decline in spray quality with increase in P_A. Their explanation for this unexpected result was that contraction of the spray angle reduces the volume of air that interacts with the spray. In consequence the aerodynamic drag forces created by the spray induce a more rapid acceleration of this smaller air mass in the direction of spray motion, thereby reducing the relative velocity between the drops and the air surrounding these drops. As mean drop size is inversely proportional to this relative velocity, the effect of a reduction in spray angle is to increase the mean drop size. Thus an increase in ambient air pressure has two opposing effects on SMD. Contraction of the spray angle tends to increase the mean drop size as discussed above. However, at higher air pressures the more densely packed air molecules greatly accelerate the processes whereby the liquid sheet emerging from the nozzle disintegrates into drops, thereby producing smaller drops. Which of these two opposing influences is most dominant in any given situation depends on the "nominal" cone angle of the spray. If the cone angle is wide the effect of increasing air density will outweigh that of reduced spray angle and the net result will be a decrease in mean drop size. However, if the initial angle is small, the further reduction in spray angle brought about by an increase in ambient air pressure leads to an increase in mean drop size. This increase in SMD is caused partly by the reduction in the mass of air that interacts with the spray, and also by the decrease in relative velocity between the fuel drops and the surrounding air.

Another explanation for the observed initial rise in SMD with increase in P_A may be found in the method employed to measure mean drop size. It is now well established [see, for example, De Corso and Kemeny (1957), Neya and Sato (1968), and Ortman and Lefebvre (1985)] that increase in ambient air pressure lowers the spray cone angle, thereby reducing the dispersion of the spray. In the present context, dispersion is defined as the ratio of the volume occupied by the spray (air plus liquid) to the volume of liquid contained within it. When a spray is formed at the outlet of a pressure-swirl atomizer, the larger drops penetrate farther radially than the smaller droplets. This causes the drops to be distributed radially from smaller drops at the center of the spray to larger drops at the edge. As the spray contracts with increase in ambient air pressure, the liquid volume fraction becomes distributed in a smaller circle, as shown in Fig. 12. The diameter of a light beam for measuring drop-size distribution is constant, as shown by d in Fig. 12. Thus at different spray cone angles the number of drops of any given size in the sampling volume will be different. In particular, reduction in spray cone angle will increase the proportion of large drops in the sampling volume and the instrument will indicate an increase in SMD even if, in fact, the SMD is unaffected by change in cone angle.

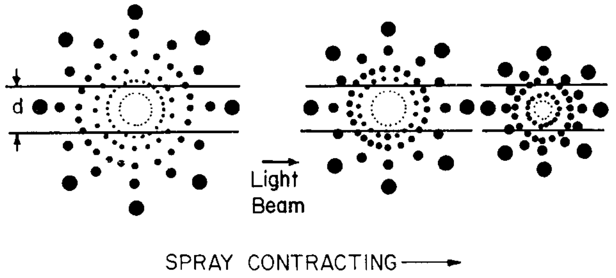

Fig. 12. Diagram illustrating influence of spray contraction on drop-size measurement.

Thus a feasible explanation for the results obtained in this study, which show that increase in ambient air pressure above the normal atmospheric value causes the SMD to rise initially before declining with further increase in pressure, could be that the reduction in spray cone angle which accompanies as increase in ambient air pressure, causes the Malvern instrument to record an erroneously high value of SMD. Only at air pressures above the critical value, where a change in air pressure has no effect on spray angle, does the instrument provide an accurate description of the influence of P_A on SMD. The experimental data show that this corresponds to the theoretical relationship, SMD $\alpha P_A^{-0.25}$. However, it is worthy of note that both De Corso (1960) and Neya and Sato (1968) also observed an increase in SMD with increase in P_A, although their methods of measuring SMD (direct photography is one case and immersion droplet sampling in the other) should be much less susceptible to the type of error associated with the light diffraction technique, as discussed above.

Quite apart from errors in drop-size measurement, there are other reasons why an increase in ambient air pressure could produce an increase in mean drop size. For example, increase in P_A causes disintegration of the liquid sheet to occur closer to the nozzle tip, so that the drops are formed from a thicker sheet and consequently are larger in size than when sheet disintegration occurs further away from the nozzle. Another potential cause of coarser atomization is droplet coalescence, as suggested by De Corso (1960). This is undoubtedly an attractive concept, but it is also one for which very little supporting evidence exists. Nevertheless, should it be found in due course that droplet coalescence plays a significant role in the overall atomization process, its importance must increase at high ambient air pressures due to contraction of the spray volume. Another important consideration is the reduction in relative velocity between the fuel drops and the surrounding air, which is caused by the contraction of the spray with increase in P_A. As SMD is roughly inversely proportion to relative velocity, this must have a significant effect on spray quality.

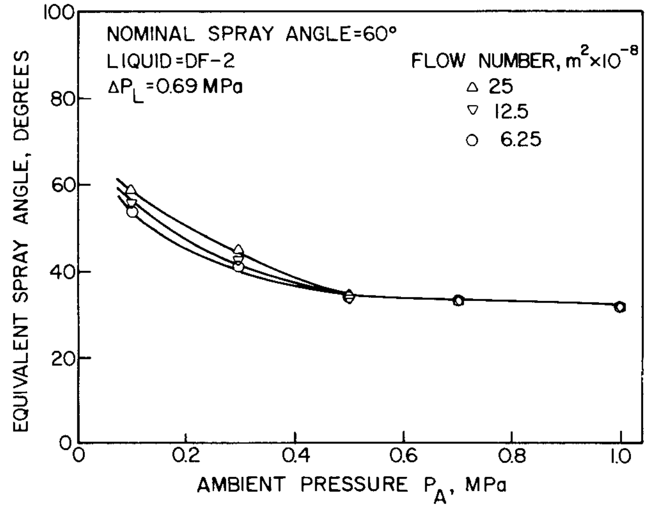

Fig. 13. Influence of ambient air pressure and nozzle flow number on spray angle.

More work is needed to determine the extent to which the observed initial increase in SMD with P_A is due to deficiencies in the method used to measure SMD. If errors arising from this source are neglected, then Figs. 2 thru 7 show that at low pressures the forces that inhibit atomization are predominant and the SMD rises with increase in P_A. With continuing increase in P_A the contraction in spray angle, which is initially quite steep, starts to diminish, and eventually becomes zero, as illustrated in Fig. 13. This allows the disintegration forces to become dominant, so that any further increase in P_A above the critical value causes the SMD to decline. Thus when SMD values are plotted against P_A their characteristic shape is one which shows SMD rising up to a maximum value and then falling with further increase in P_A. During this latter stage the variation of SMD with P_A roughly corresponds to the relationship SMD $\alpha P_A^{-0.25}$. Figures 2 thru 7 show that the critical pressure increases with increase in surface tension and diminishes with increases in liquid viscosity and nozzle flow number.

CONCLUSIONS

From measurements of spray characteristics carried out on six different simplex nozzles, over wide ranges of liquid properties and ambient air pressure, the following conclusions are drawn.

1. All the experimental data obtained on the influence of ambient air pressure on mean drop size show that continuous increase in P_A above the normal atmospheric value causes the SMD to first increase up to a maximum value and then gradually decline.
2. The value of P_A at which the SMD attains its maximum value is increased by increase in surface tension and reduction in nozzle flow number.
3. The characteristic shape of the plots of SMD versus P_A are attributed to the combined effects of several competing processes. The basic effect of an increase in ambient air pressure is to improve atomization according to the relationship SMD α $P_A^{-0.25}$, but this disintegration process is opposed by various factors, all of which tend to produce larger drops. One important factor is that increase in P_A causes atomization to occur closer to the nozzle, where the liquid sheet is thicker, so that larger drops are formed. Another adverse effect on atomization of an increase in P_A is to contract the spray into a smaller volume, thereby reducing the relative velocity between the drops and the surrounding air, and increasing the possibility of droplet coalescence. With gradual increase in P_A a pressure level is eventually reached at which the spray contraction virtually ceases. Moreover, sheet disintegration starts to occur very close to the nozzle discharge orifice, so that any further increase in P_A can no longer affect the initial mean drop size. Thus at higher levels of P_A the only factor governing SMD is the basic disintegration process, and the variation of SMD with P_A starts to approach the theoretical relationship, namely SMD α $P_A^{-0.25}$.
4. Increase in ambient air pressure causes the spray to become more monodisperse.

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