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Study on Hybrid Airblast Atomization

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To provide a better understanding of the performance of the hybrid atomizer, where the atomization process is accomplished under the combined effects of liquid pressure and airblast, an investigation has been conducted. Several fuel-injector configurations were selected in such a way to enable the evaluation of the actual role played by the air/liquid relative velocity and other key factors in the atomization process. A number of pressure swirl liquid atomizers that varied significantly in flow capacity, and several air nozzles of different flow areas, were employed in the tests. A calculation approach was formulated to ensure that more realistic liquid and air velocities at the exit of the atomizer were estimated. The spray measurements were performed using a Malvern particle analyzer. The results indicated that the utilization of the airblast effect in the atomizer was not always beneficial. It was also observed that the liquid pressure associated with minimum relative velocity did not coincide with the value that resulted in the least efficient atomization at a given air pressure drop. It was, thus, concluded that the relative velocity was not the only parameter controlling the spray quality. The separate effect of the air/liquid ratio on atomization was found to be most beneficial under low air pressure drop and over a range of low air/liquid ratios. The relative importance of various parameters was investigated by conducting the test under conditions selected in such a way to maintain the same relative velocity while varying either liquid pressure or air pressure drop. The results demonstrated that better atomization could be achieved under high liquid pressure than that obtained under low liquid pressure for the same level of relative velocity. The effects of both liquid pressure and relative velocity were significantly reduced at a higher air pressure drop.

Nomenclature

A_g = geometrical flow area of air nozzle, m^2
C_{DL} = liquid nozzle discharge coefficient
d_0 = liquid nozzle orifice diameter, m
k_v = velocity coefficient for pressure atomizer
m_L = liquid flow rate, kg/s
V_A = air velocity, m/s
V_L = liquid injection velocity, m/s
V_R = liquid/air relative velocity, m/s
X = ratio of air core area to liquid nozzle area
ΔP_L = liquid pressure drop
θ_A = airflow angle with centerline, deg
θ_L = half spray cone angle, deg
μ_L = liquid viscosity, kg/ms
ρ_L = liquid density, kg/m^3

Introduction

IN today's gas-turbine combustors, the fuel atomization is accomplished either by fuel pressure, airblast forces, or the combined effect of fuel pressure and airblast atomization in the concept known as hybrid fuel injection. The incorporation of a pilot pressure nozzle in airblast atomizer is a widely used concept to obtain efficient combustion at startup and low-power conditions. On the other hand, improved atomization and mixing in the fuel pressure injection system is achieved through the utilization of the available pressure drop to provide the airblast needed to assist the atomization process. Although many studies have been conducted on the atomization process,[1–3] there are fewer studies that actually address the combined effect of air momentum and fuel pressure utilized in the hybrid atomizer.

Suyari and Lefebvre[4] studied an external-mixing air-assist atomizer to determine the effect of the interaction between the conical sheet of liquid produced by the pressure swirl nozzle and a swirling airblast flow. Their results showed that the increase in liquid velocity may help or hinder the atomization process, depending on the impact of the velocity increase on the relative velocity between the liquid and surrounding air. It was observed in their measurements that the initial increase in spray Sauter mean diameter (SMD) with the increase in liquid pressure was followed by a reduction in SMD at higher levels of injection pressures. The conclusion drawn in Ref. 4 was that the least-efficient atomization occurred when the relative velocity between the liquid sheet and the atomization air approached a value of zero.

Simmons,[5] in an attempt to bridge the gap between pressure atomization and airblast concepts, acquired a wide database for both types of atomizer. He recommended an equation for estimating the SMD of spray in terms of air velocity, liquid velocity, and the air/liquid ratio. The combination of the liquid velocity and liquid flow rate in the equation allows the SMD value to have a peak at a certain liquid velocity level. However, the equation predicts that the SMD will always decrease with an increase in air pressure drop. It is also noticed in the proposed calculation approach that the empirical constant used in the equation accounts for the atomizer type but not for the atomizer size. For instance, at given air and liquid velocities and air/liquid ratio, a simultaneous increase of both the air and liquid flow rates to maintain a constant ratio would not have any effect on SMD, according to the equation.[5]

Hybrid airblast atomization was studied in Ref. 6 using four atomizers of different designs and flow capacities. The results indicated that no simple correlation could describe the effect of air pressure drop on SMD because the dependency of SMD on air pressure drop significantly changed with changes in the air/fuel ratio level. It was observed that, at high fuel pressure, increasing the air pressure drop did not offer any benefit to the atomization process, whereas at low fuel pressure, the atomizer acted more or less as an airblast type. Based on the wide da-

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tabase obtained in these tests, it was concluded that the performance of the hybrid atomizer, when utilizing both fuel pressure and airblast modes of operation, was quite dependent on the actual levels of air pressure drop and fuel pressure used.

The present investigation represents an experimental study with a main objective of providing a better understanding of the hybrid atomization process. The study involves the evaluation of the actual role played by the air/liquid relative velocity in governing the breakup mechanism of liquid in the hybrid atomizer. Several fuel injection configurations were employed in the present effort to enable changing the magnitude and direction of the air and liquid velocities, and flow rates, independently. In the following sections, a description of the experimental results obtained in the present study and discussions of the results are presented.

Design of Experiment

Several factors have been considered in designing the experiment to ensure that the important parameters affecting the hybrid atomization process are more accurately evaluated. One of the most important factors affecting the spray SMD is the relative velocity between the air and liquid streams at the point of atomization. In fact, many studies have suggested that the relative velocity is the only parameter controlling the spray quality. To evaluate the separate effect of the relative velocity on SMD, a number of aspects was carefully considered. They involved the calculation of the actual air and liquid velocities, the spray angle, and the airflow direction at the atomizer exit.

To obtain a better estimate of the liquid velocity (V_L), at the final orifice of the pressure swirl atomizer, a calculation approach was used, based on the liquid pressure drop across the atomizer (ΔP_L), and a velocity coefficient (k_v). The approach was first proposed by Rizk and Lefebvre,[7] in a study that utilized the data of a large number of pressure atomizers. The velocity coefficient is defined as

$$k_v = V_L/(2\Delta P_L/\rho_L)^{0.5} \tag{1}$$

and is related to atomizer dimensions through the following expression:

$$k_v = C_{\mathrm{DL}}/[(1 - X)\cdot\cos\theta_L] \tag{2}$$

where C_{DL} is the discharge coefficient of the pressure atomizer, ρ_L is liquid density, θ_L is the half spray cone angle, and X is the ratio of the air core area to the geometric area of the exit orifice. As described in Ref. 7, Eq. (2) is valid over a wide range of X values. Making use of the calculation method of X, reported in Ref. 7, yields the following equation:

$$(1 - \sqrt{X})^2(1 - X)^2/(1 + X) = 6240 m_L\mu_L/(\rho_L d_0^3 \Delta P_L) \tag{3}$$

Using the conventional definition of the liquid discharge coefficient in Eq. (2) leads to the following equation for the velocity coefficient:

$$k_v = 4m_L/[\pi d_0^2(2\Delta P_L/\rho_L)^{0.5}(1 - X)\cdot\cos\theta_L] \tag{4}$$

Using the measured values of m_L, ΔP_L, θ_L, and d_0, the velocity coefficient can be determined and used to calculate the actual total velocity of the liquid leaving the atomizer.

The air velocity at the exit of the air passage was calculated using the measured airflow rate, exit area of the atomizer, and air pressure drop across the atomizer. The discharge coefficient of the air passage was, thus, calculated with and without liquid flow, over a wide range of air pressure drop and liquid injection pressure. The spray angle was measured experimentally, using a direct photography technique, at the exit of the atomizer. A range of air pressure drop and fuel-injection pressure was covered in these measurements. The airflow direction at the exit of the atomizer was determined by the geometry of the air nozzle used. Nozzles with different degrees of inclinations toward the atomizer centerline were selected for this study. No swirling motion was imparted to the air, so that the estimation of the relative velocity between the air and liquid could be performed more accurately. The relative velocity is calculated by assuming that the radial velocity of liquid at exit of atomizer is negligible compared with the axial and tangential components, and using the conventional form given by

$$V_R = [(V_A\cos\theta_A - V_L\cos\theta_L)^2 + (V_A\sin\theta_A)^2 + (V_L\sin\theta_L)^2]^{0.5} \tag{5}$$

where V_A is the air velocity at the exit of the atomizer, θ_A is the air nozzle angle toward the atomizer centerline, and θ_L is the half cone angle of spray at the exit of the atomizer.

It should be emphasized that the calculation approach given in this section was used to select the test conditions needed to provide understanding of the operation of the hybrid atomizer. The approach is, thus, not intended for providing a detailed calculation method for atomizer performance. It is worth mentioning that a detailed two-dimensional fuel-injection model has been recently developed to support the development of such atomization concepts, as described in Ref. 8.

One requirement of the present study was to evaluate the separate effect of each key factor on SMD. It is, however, realized that it is often difficult to change one parameter without affecting other parameters involved in the atomization process. For instance, increasing fuel-injection pressure at a fixed value of air pressure drop results in simultaneous changes in liquid exit velocity, liquid/air relative velocity, air/liquid ratio, liquid film thickness, and spray angle. The effect of changes in liquid film thickness on atomization is, however, less significant than that of the relative velocity. To perform a parametric study needed to provide better understanding of the effect of each variable with less interference from the effects of other parameters, the following test configurations were defined:

1) Selecting two liquid injection pressures at a fixed air pressure drop to give the same liquid/air relative velocity enables evaluating the combined effect of liquid pressure and air/liquid ratio.

2) Using the same liquid fuel pressure, and selecting two levels of air pressure drop to yield the same relative velocity, enable evaluating the combined effect of air pressure drop and air/liquid ratio.

3) Keeping fuel-injection pressure and air pressure drop constant, and changing either the fuel nozzle tip or air nozzle allows studying the separate effect of air/liquid ratio on SMD.

4) Changing the exit angle of the airflow by using different air nozzle enables investigating the effect of relative velocity.

5) Effect of the liquid nozzle flow number is studied by selecting nozzles with different flow capacities and using no air.

Experimental Configurations

A schematic diagram of the test rig used in the present investigation is illustrated in Fig. 1. The liquid atomizers were mounted at the end of an air box and sprayed downward into a tank. A blower exhausted the vapor from the tank, and the static pressure inside the air box was measured with an electric capacitance gauge. Liquid flow through the atomizer was delivered using a positive displacement, dc-driven pump. The data were taken at room temperature and pressure, and the liquid used in all tests was a calibration fluid MIL-C-7024-B. The density, surface tension, and viscosity of this liquid at a standard temperature of 298 K are 765 kg/m^3, 0.025 N/m, and 0.00092 kg/ms, respectively. A Malvern particle analyzer, model 2600, was employed to measure drop size distribution in the spray at a downstream distance of 0.051 m from the exit plane of the atomizer. The distribution was then used to calculate the SMD of the spray.

Two types of liquid pressure swirl atomizers, designated A and B, were used in the tests. Atomizer A produced a hollow cone spray of 90-deg angle, with a baseline flow number of 23.7 lb/h/$\sqrt{}$psig, and two modifications of flow numbers 1.26 and 12.2. Atomizer B was of the solid cone spray type with a baseline flow number of 3.13, and two modifications of flow numbers of 2.07 and 4.92. A summary of liquid injector characteristics is given in Table 1. Two air nozzle configurations were used in the tests, as shown in Fig. 2. The nonswirling air exits the nozzle, in a direction parallel to the atomizer centerline in the first design, and at an angle of 45 deg toward the centerline in the other one. Several nozzle parts with different sizes were fabricated to enable changing the geometric area of the nozzle passages. For the 0-deg nozzle, the i.d. at exit could be either 0.024 or 0.026 m, and the o.d. could vary between 0.03 and 0.041 m. The i.d. of the air passage of the 45-deg air nozzle is 0.01 m, and the o.d. could be either 0.015 or 0.023 m. By changing a spacer between the air nozzle and air box, the flow area of the nozzle may be varied over a wider range.

Table 1 Liquid nozzle characteristics

Atomizer configuration	Flow number	Orifice diameter, m
Atomizer A	23.7	0.0019
mod 1	1.26	0.0004
mod 2	12.2	0.0014
Atomizer B	3.13	0.0007
mod 1	2.00	0.0005
mod 2	4.90	0.0008

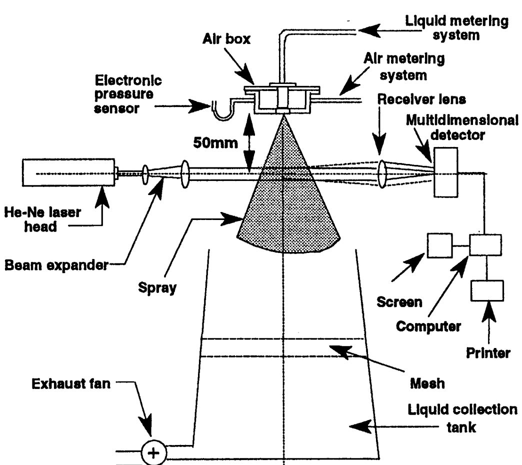

Fig. 1 Schematic diagram of test rig.

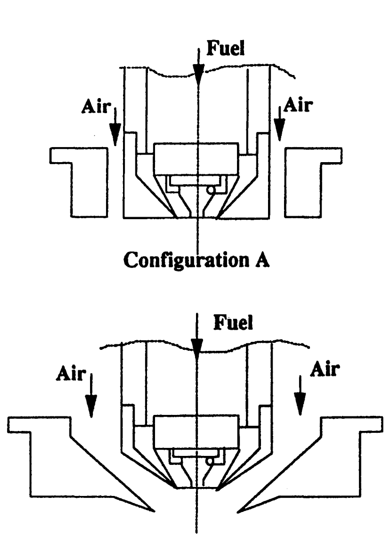

Fig. 2 Hybrid atomizer configurations used in tests.

The tests were conducted over a range of air pressure drop across the atomizer from 0.0 to 9.0%, and a range of liquid injection pressure that varied between 69 and 2800 kPa. At each test point, the air and liquid velocity components were calculated from the flow measurements, using the procedure given in the previous section.

By this means, changes in the flow characteristics of the liquid and air nozzles as a result of changes of operating conditions could be more accurately accounted for. For instance, significant variation in the liquid nozzle flow number or discharge coefficient might occur over the range of liquid pressure and air pressure drop used in the tests. The calculated velocity components using this approach were then used to determine the overall relative velocity between the air and liquid streams.

Results and Discussion

The experimental results obtained in the present investigation are presented in this section in such a way to demonstrate the separate effects of the important factors controlling the hybrid atomization process. Discussions of the results are also given in this section to provide a better understanding of the atomizer operation that can be used to establish a basis for improving the performance of such an atomizer type.

The measurements obtained at each test point were used to calculate the air and liquid velocities, as described earlier. Examples of the measured spray angle for the 45-deg air nozzle, with and without air flow, are given in Fig. 3. It is observed that the spray angle changes significantly with air pressure drop, in particular at lower liquid injection pressure. The measured angle and flow conditions, together with Eqs. (3) and (4) given earlier, are used to calculate the velocity coefficient (K_v) for baseline liquid pressure atomizers A and B. The calculated K_v for the two baseline atomizers A and B are plotted in Fig. 4. The results show that the actual exit velocity of the liquid sheet is much less than that based on the overall liquid pressure drop across the atomizer. This is more pronounced at low liquid pressures and for the smaller atomizer. The calculated liquid velocity is plotted against the liquid pressure drop for a range of atomizer air pressure drop in Fig. 5. The presence of the air alters many factors affecting the liquid exit velocity, such as liquid flow rate through the atomizer and the exit spray angle.

The airflow discharge coefficient was determined by measuring the airflow through the atomizer divided by the geometric airflow area. The results obtained using the 0- and 45-deg air nozzles under a range of liquid pressure are plotted in Fig. 6. Based on these results, the exit air velocity at each test

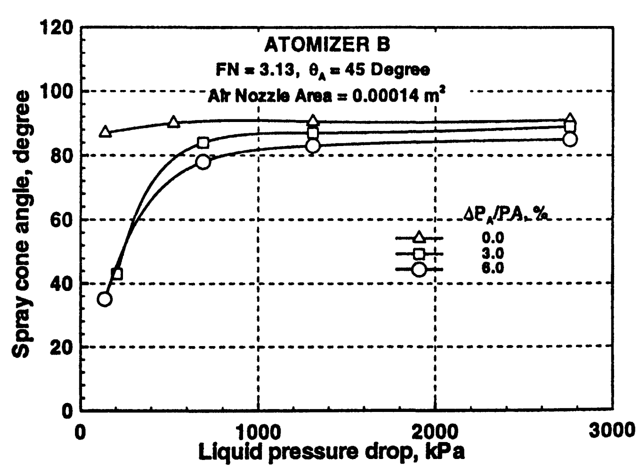

Fig. 3 Variation of spray angle with atomizer operating conditions.

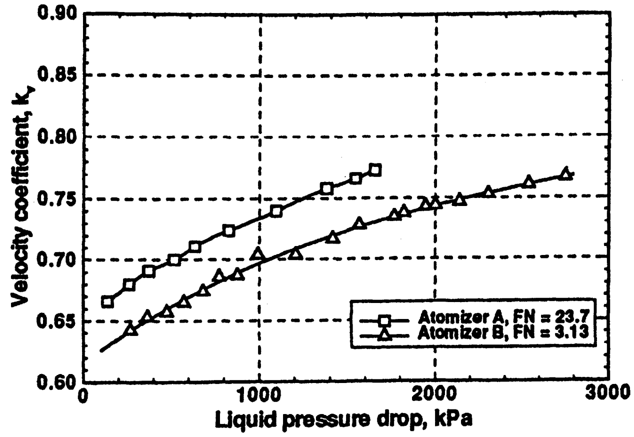

Fig. 4 Calculated liquid nozzle velocity coefficient.

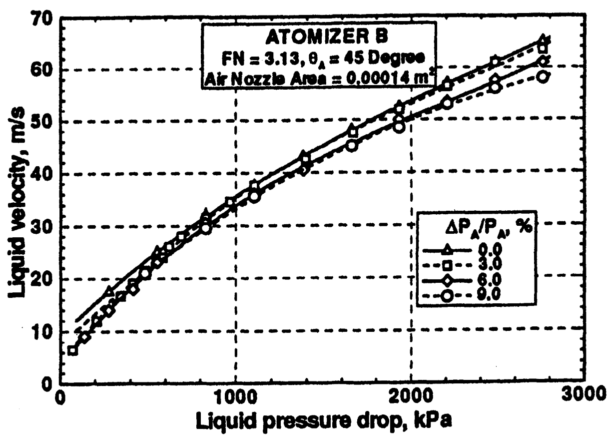

Fig. 5 Calculated liquid velocity at exit of atomizer.

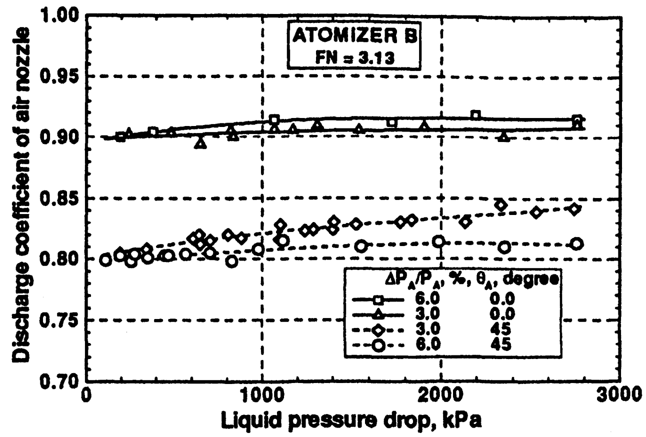

Fig. 6 Air nozzle flow discharge coefficient.

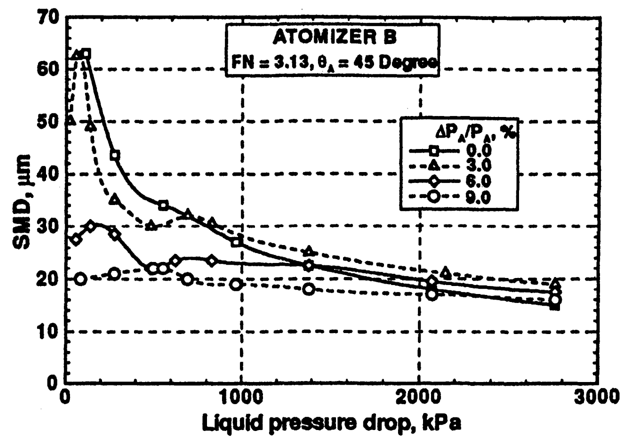

Fig. 7 Variation of SMD with liquid pressure for atomizer B.

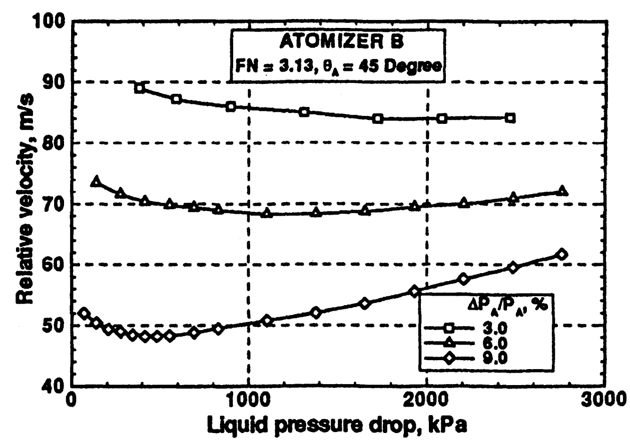

Fig. 8 Calculated relative velocity for atomizer B.

point was calculated and used to estimate the relative velocity between the liquid sheet and air, with full consideration of the velocity components in the three dimensions.

Figure 7 illustrates the variation in measured SMD with the liquid pressure under a range of air pressure drop for a combination of atomizer B and the 45-deg air nozzle. The figure indicates the presence of peak value of SMD for each level of air pressure drop. The results also show that the effect of incorporating air in the atomizer design is not always beneficial. For instance, it can be seen that when the liquid pressure exceeds a certain level, the SMD values obtained under each air pressure drop become higher than those measured with no air is employed in the atomizer. The corresponding values of the calculated relative velocity between liquid and air at different air pressure drop levels are plotted in Fig. 8. The figure illustrates that there is a minimum value of relative velocity for each level of air pressure drop. It is also observed that the liquid pressure corresponding to the minimum relative velocity increases with the increase in air pressure drop. At a high air pressure differential, the change of relative velocity with the liquid pressure is not significant, which is consistent with the fairly constant SMD obtained under such conditions.

It is obvious in Figs. 7 and 8 that the liquid pressure that results in the minimum relative velocity between the liquid and air does not coincide with the value that yields the least-efficient atomization at a given air pressure drop. In fact, the liquid pressure at maximum SMD was always lower than that at minimum relative velocity. These observations indicate that although the relative velocity is an important factor in hybrid atomization, it is not the only one governing the spray SMD. The SMD results obtained at a constant liquid pressure are plotted against air pressure drop in Fig. 9. The results confirm the conclusion that the increase in air pressure drop can have an opposite effect on SMD, depending on the actual levels of the air pressure drop and liquid injection pressure used in the test. The calculated relative velocity levels at the test conditions shown in Fig. 9 are plotted in Fig. 10. At a given liquid pressure, the air pressure drop resulting in the largest SMD is always higher than the one associated with the minimum relative velocity. An interesting feature in Figs. 9 and 10 is that, at an air pressure drop greater than 6%, a reduction in liquid pressure at a certain air pressure drop can have opposite effects on relative velocity and SMD. This, once again, demonstrates that the relative velocity cannot by itself fully account for the trends observed of the spray characteristics. The results obtained for a combination of atomizer B and the 0-deg air nozzle confirmed the main conclusions drawn from the data of the 45-deg air nozzle. These include the features of having a

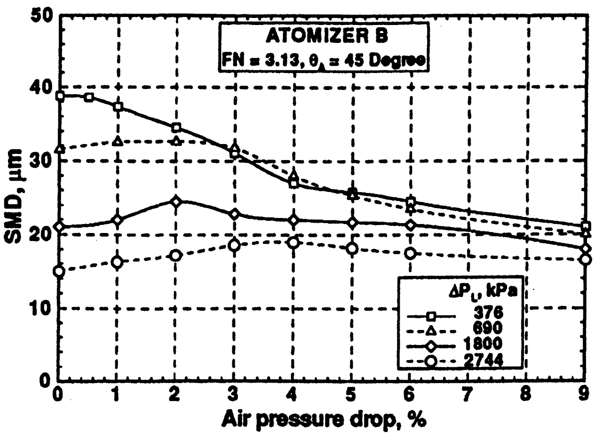

Fig. 9 Variation of SMD with air pressure drop for atomizer B.

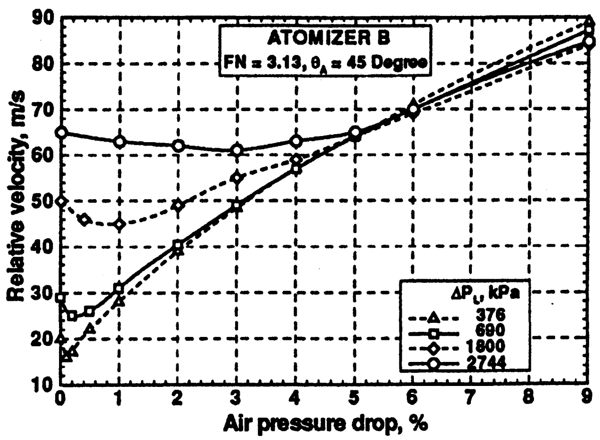

Fig. 10 Variation of relative velocity with air pressure drop.

maximum SMD value under conditions that did not coincide with those associated with the minimum relative velocity.

To evaluate the impact of the atomizer size on the performance of the hybrid atomizer, the larger liquid injector A combined with the 0-deg air nozzle was tested over a wide range of operation. Figure 11 contains the results of the measured SMD plotted against liquid pressures, at different levels of air pressure drop.

The calculated relative velocities at these test conditions are given in Fig. 12. The trends observed in these figures regarding the changes of SMD with the increase in liquid pressure are similar to those obtained with the smaller atomizer B. It is also observed that the liquid pressures associated with the maximum SMD and minimum relative velocity are significantly different. One interesting point noticed in these figures is the almost constant relative velocity achieved under liquid pressures above about 800 kPa, accompanied with a continuous decrease in SMD. Moreover, under conditions of high air pressure drop, a reduction of liquid pressure from the value associated with the maximum SMD, initially brings a reduction in SMD. An increase in SMD occurs with a further reduction of liquid pressure. This is attributed to the decrease in the capability of the large atomizer to spread the liquid sheet outward under conditions of high air pressure drop and very low liquid pressure. The atomizer, therefore, cannot fully utilize the air pressure drop or achieve sufficient contact between the liquid sheet and atomizing air under these conditions.

The effect of the air/liquid ratio on the spray characteristics of the hybrid atomizer was investigated through two different approaches. In the first one, a number of liquid injectors of different flow capacities was tested with the same air nozzle, in such a way that, for a given air pressure drop and liquid injection pressure, the air/liquid ratio would vary from one atomizer to another. The other approach involved changing the flow area of the air nozzle while using the same liquid atomizer. It is, however, realized that changing a characteristic dimension of the atomizer in both approaches may still have some impact on SMD. Figure 13 shows the results obtained for baseline atomizer B and a smaller atomizer of similar design. Both atomizers were tested with the same 0-deg air nozzle. With no air used in the test, the smaller-flow-number atomizer was marginally better than the larger one. The difference in performance is attributed to the effect of liquid atomizer size on atomization. When air was utilized in the hybrid atomizer, the air/liquid ratio of the smaller atomizer was less than twice the ratio used in the larger one, at given air and liquid pressure drop levels. The difference in performance

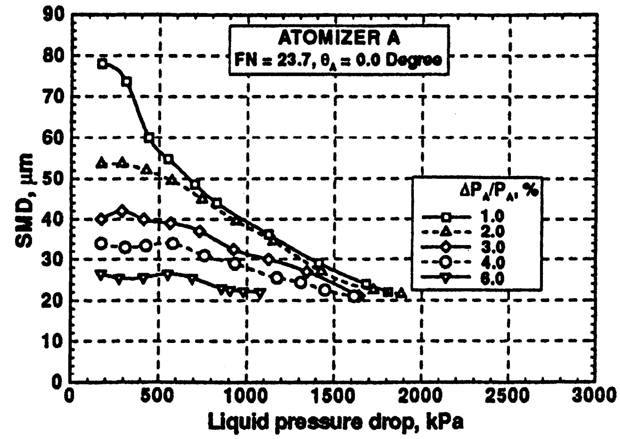

Fig. 11 Spray characteristics of larger atomizer A.

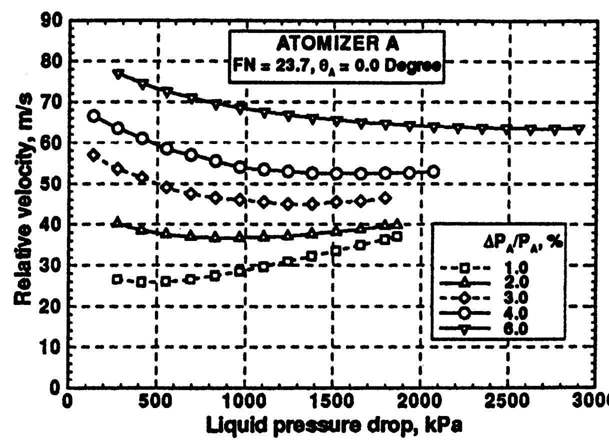

Fig. 12 Calculated relative velocity for atomizer A.

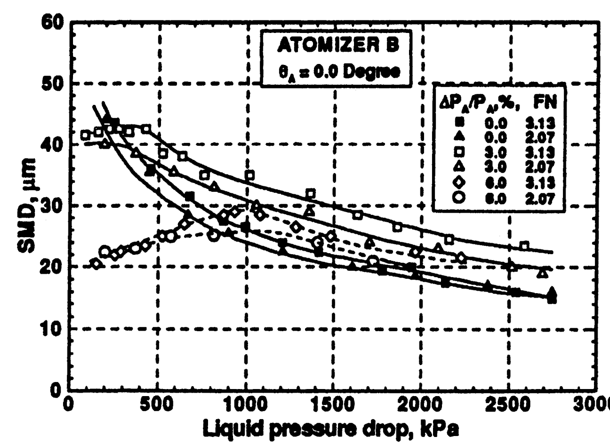

Fig. 13 Effect of air/liquid ratio on SMD for atomizer B.

between the two atomizers with and without air is almost the same, implying that the separate effect of air/liquid ratio is insignificant. It is shown in Fig. 13 that when an air pressure drop increased from 0.0 to 3.0%, the atomization became less efficient. This is mainly a result of the reduction in relative velocity that adversely affects atomization. However, with a further increase in air pressure drop to 6.0%, the airblast effects become dominant, resulting in a better atomization.

On the other hand, when the air/liquid ratio variation was brought into effect through changing the flow area of the air nozzle, the performance of the hybrid atomizers followed the trends shown in Fig. 14. In this group of tests, a liquid atomizer A with flow number 12.2 was used in conjunction with three 0-deg air nozzles of different flow areas. The results show that, at given air and liquid pressure drop levels, increasing the flow area of the air nozzle improves the atomizer performance because of the increase in air/liquid ratio. It should be emphasized that the air/liquid ratio of the largest air nozzle used in these tests was more than triple the value obtained with the smallest one. The more pronounced effect of air/liquid ratio observed in this figure is attributed to the fact that the large-capacity atomizer used in this test caused the hybrid atomizer to operate under a significantly lower air/liquid ratio range. In airblast atomization, the effect of increasing the air/liquid ratio is usually most beneficial under low air/liquid ratio conditions. When this ratio exceeds a certain limit, almost no further improvement in spray quality is achieved.

The actual role played by the relative velocity between the liquid and air in controlling the atomization process was also examined in the present investigation from a different angle. The approach was to achieve a constant relative velocity in the tests by selecting a fixed value of air pressure drop and two different liquid pressures that would result in the same relative velocity. A fixed value of liquid pressure and two levels of air pressure drop were also selected in the tests to yield a constant relative velocity level. The selection of the appropriate air and liquid pressure drop levels was made with the help of Eq. (5), given earlier. By maintaining a constant relative velocity, it would be easier to determine whether this velocity is the only parameter affecting atomization, or it acts together with other parameters.

Examples of the results obtained in this group of tests are illustrated in Figs. 15 and 16. Figure 15 shows the SMD data obtained for each pair of test points that shared a common relative velocity and air pressure drop, but different liquid pressures. The hybrid atomizer used to produce the results shown in this figure incorporated a liquid nozzle of flow number 3.13 and a 45-deg air nozzle. The results clearly indicate that atomization process is governed by both relative velocity and liquid pressure drop, at lower levels of air pressure drop and liquid pressure. In other words, by maintaining a constant level of relative velocity, a significant improvement in atomization could still be achieved if the liquid pressure is increased. It is believed that the improvement in atomization under higher liquid pressure is a result of the increase in the instability of the liquid film and a reduction in film thickness, both of which promote the atomization process. The effects of both parameters diminish at higher levels of air pressure drop, as shown in Fig. 15. Figure 16 includes the results obtained for a hybrid atomizer with a larger liquid atomizer of flow number 23.7 and a 0-deg air nozzle. Similar conclusions regarding the roles played by the relative velocity and liquid pressure could be observed in this figure. It is also noticed that the beneficial effect of increasing the liquid pressure at a constant relative velocity is extended to higher levels of liquid pressure.

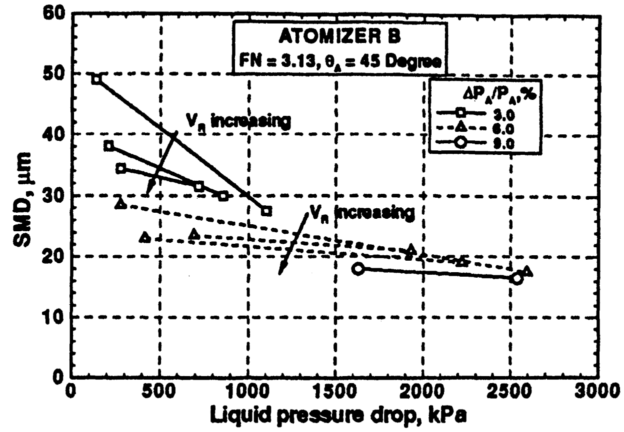

Fig. 15 Effect of liquid pressure drop at constant relative velocity.

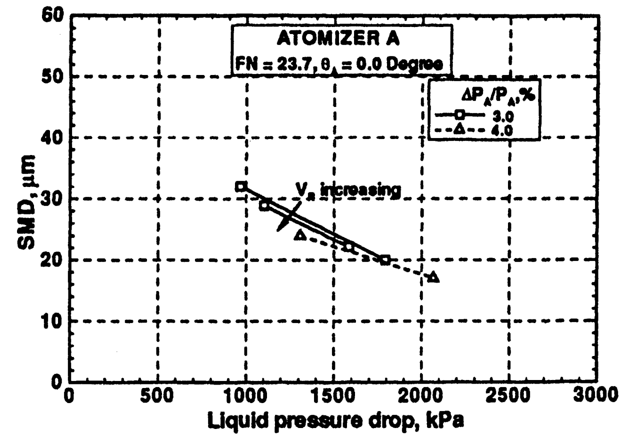

Fig. 16 Effect of liquid pressure at constant relative velocity for 0-deg air nozzle.

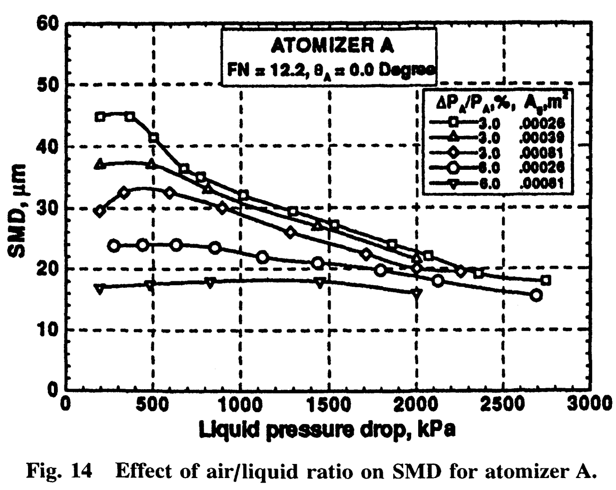

Fig. 14 Effect of air/liquid ratio on SMD for atomizer A.

The results discussed in this section were presented in terms of spray SMD. It is, however, recognized that the spread in drop sizes in spray is an equally important parameter needed to characterize the atomizer performance. According to Ref. 9, it was observed that both the SMD and drop size distribution were closely connected to each other. In other words, as SMD decreases, the spread in drop sizes become wider. Thus, from the knowledge of SMD, one can mathematically evaluate the whole drop size distribution in spray.[9]

Summary and Conclusions

An investigation has been conducted with the objective of providing a better understanding of the operation of the hybrid airblast atomizer. This type of atomizer utilizes both liquid pressure and air pressure drop across the combustor liner to achieve efficient atomization of liquid. The study involved the evaluation of the actual role played by the air/liquid relative velocity and other key parameters in governing the atomization process. Several liquid injection configurations were employed in the present effort to enable changing the magnitude and direction of air and liquid velocities and flow rates independently. The measurements of the spray characteristics were performed using the Malvern particle analyzer.

To evaluate the effects of the liquid and air velocities on the hybrid atomizer performance, a calculation approach was formulated. It involved the estimation of liquid velocity coefficient and air effective area through the measurements of spray cone angle and flow rates. The results showed that the actual exit velocity of the liquid sheet could be much less than that based on overall liquid pressure drop across the atomizer.

The variation of measured SMD with liquid pressure demonstrated a peak value for each level of air pressure drop. The results also showed that the effect of incorporating air in the atomizer design was not always beneficial. It was observed that the liquid pressure that resulted in the minimum relative velocity between liquid and air did not coincide with the value that caused least efficient atomization at a given air pressure drop. This observation indicates that, although the relative velocity is an important factor in hybrid atomization, it is not the only one governing the spray SMD. Both small and large liquid nozzles showed the same trends of performance regarding the combined effect of liquid pressure and airblast on atomization.

The separate effect of air/liquid ratio on SMD was evaluated through two different ways. They involved either using a number of liquid injectors of different capacities with an air nozzle, or varying the flow area of the air nozzle and using one liquid nozzle. The results indicated that the effect of increasing the air/liquid ratio was most beneficial under low air pressure drop and range of low air/liquid ratio.

A special test was conducted in which a constant relative velocity was achieved by using two levels of liquid pressure at a given value of air pressure drop. The purpose of this test was to determine the relative importance of the other parameters, in addition to the relative velocity, to the atomization process. The results indicated that both liquid pressure and relative velocity between air and liquid had a significant impact on spray quality, when air pressure drop and liquid pressure were on the low side. In other words, better atomization could be achieved under a high liquid pressure than that obtained under low liquid pressure for the same level of relative velocity. The effects of both parameters on atomization diminished at higher air pressure drop.

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