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A Novel Method of Atomization with Potential Gas 'urbine Applications

Arthur H. Lefebvre

Purdue University, W. Lafayette, IN 47907, USA

ABSTRACT

In conventional airblast or air-assist nozzles the bulk liquid to be atomized is first transformed into a jet or sheet before being exposed to the atomizing air. In the method of atomization described in this paper, the air is introduced into the bulk liquid at some point upstream of the nozzle discharge orifice. This injected air forms bubbles which 'explode' downstream of the injection orifice thereby shattering the liquid into small drops.

Experiments carried out on this atomizer, using water as the working fluid and nitrogen as the driving gas, show that good atomization can be achieved using only small amounts of atomizing gas at injection pressures as low as 173 kPa (25psi). It is found that atomization quality is largely independent of the size of the nozzle discharge orifice. Thus the system appears to have good potential for applications where small holes and passages cannot be employed due to the risk of blockage by contaminants in the fuel.

NOMENCLATURE

A – area

C_D – discharge coefficient

d_o – injector orifice diameter

l_o – length of discharge orifice

ΔP_L – injection pressure differential

ΔP_{G-L} – pressure differential between gas and liquid

$\dot{m}$ – mass flow rate

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U – velocity

ρ – density

Subscripts

G – gas

L – liquid

1. INTRODUCTION

For almost half a century, pressure-swirl nozzles have been used for fuel atomization in gas turbine engines. These nozzles are usually of the simplex, duplex, or dual-orifice types. In all cases the major problem is one of achieving good atomization over a wide range of liquid flow rates. If the nozzle discharge orifice is made small enough to ensure good atomization at low flow rates, then the delivery pressure required at high flow rates is often excessive. On the other hand, if the orifice is made larger, the delivery pressure at low flow rates may be inadequate for good atomization. One solution to this problem is to use a nozzle having flow passages large enough to accommodate the maximum liquid flow rate at the available delivery pressure, and then use air to enhance atomization at low flow rates where the quality of atomization would otherwise be unsatisfactory. This type of nozzle is generally referred to as an 'air-assist' nozzle. For aircraft gas turbines a more convenient form of twin-fluid atomizer is the so-called 'airblast' atomizer.

In principle, the airblast atomizer functions in exactly the same manner as the air-assist atomizer, because both employ the kinetic energy of a flowing air stream to shatter the fuel jet or sheet into ligaments and then drops. The main difference between the two systems lies in the quantity of air employed and its atomizing velocity. With the air-assist nozzle, where the air is supplied from a compressor or a high pressure cylinder, it is important to keep the air flow rate down to a minimum. However, as there is no special restriction on air pressure, the atomizing air velocity can be made very high. Thus air-assist atomizers are characterised by their use of a relatively small quantity of very high velocity air. However, because the air velocity through an airblast atomizer is limited by the pressure differential across the combustor liner, a large amount of air is required to achieve good atomization.

All the atomizers described above, in which air is used either to augment atomization or as the primary driving force for atomization, have one important feature in common, namely, that the bulk liquid to be atomized is first transformed into a jet or sheet before being exposed to the atomizing air. In the method of atomization that forms the subject of this paper, the atomizing air is introduced directly into the bulk liquid at some point upstream of the nozzle discharge orifice. As this air is not intended to impart kinetic energy to the liquid stream, it can be injected at low velocity, so that the pressure differential between the air and the liquid is very small, and is only what is needed to persuade the air to enter the flowing liquid. The injected air forms bubbles which are conveyed by the liquid stream to the injection orifice, downstream of which the bubbles 'explode', thereby shattering the surrounding liquid into small drops.

2. AERATED-LIQUID ATOMIZER

A simple form of aerated-liquid atomizer is shown in Fig. 1. In this design the liquid is supplied to a tube, 25.4 mm (1 inch) in diameter, which terminates at its downstream end in a round discharge orifice. This orifice is drilled in a replaceable screw cap. Several screw caps are available to provide different values of injector orifice diameter.

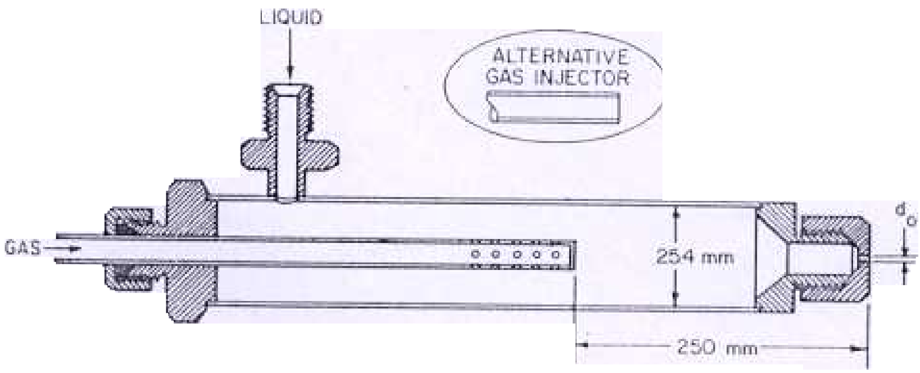

Figure 1. Cross sectional view of aerated atomi:

The central air tube has an internal diameter of 6.3 mm. It features 20 holes, each 0.5 mm in diameter, through which air is injected into the flowing water at a distance of 250 mm from the exit of the final discharge orifice. The choice of this distance was quite arbitrary, and no attempt has yet been made to examine the effect of varying this distance on atomization characteristics.

Essentially, the injector consists of a plain-orifice atomizer with means for injecting gas into the liquid flow at some distance upstream of the discharge orifice. It should be noted that this system is not an air-assist atomizer because the gas is introduced into the liquid stream at low velocity, and the pressure difference between the injected gas and the liquid, $\Delta P_{G\text{-}L}$ is only a few inches of water, even when the liquid pressure is of the order of 690 kPa (100 psi). In fact, the gas pressure is only what is needed to prevent the liquid from flowing back up the gas line. Measurements of $\Delta P_{G\text{-}L}$ for various values of liquid injection pressure and nitrogen flow rate, are shown in Fig. 2.

3. ATOMIZER PERFORMANCE

Some of the results obtained[1] by Lefebvre *et al.* using the atomizer (Fig. 1) are shown in Figs. 3 to 5. Figure 3 shows the Sauter Mean Diameter (SMD) of the spray plotted against Gas/Liquid Ratio my mass (GLR) for four different values of liquid injection pressure. In these experiments nitrogen gas was used in preference to air in order to avoid the risk of explosion when conducting tests on liquid fuels. 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.

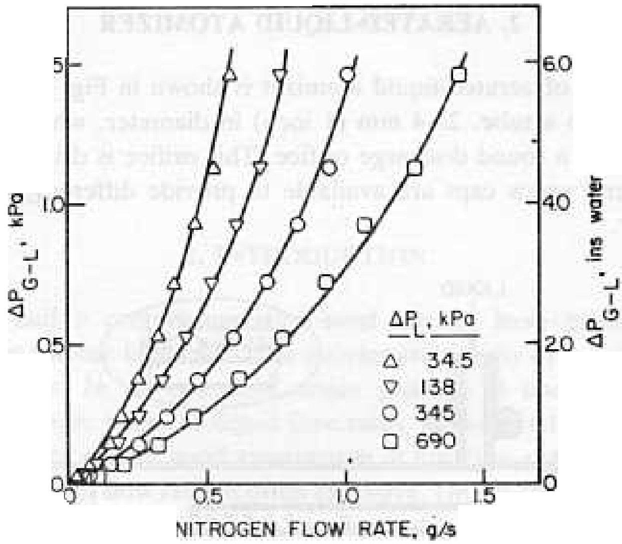

Figure 2. Pressure-differential between atomizing gas and liquid.

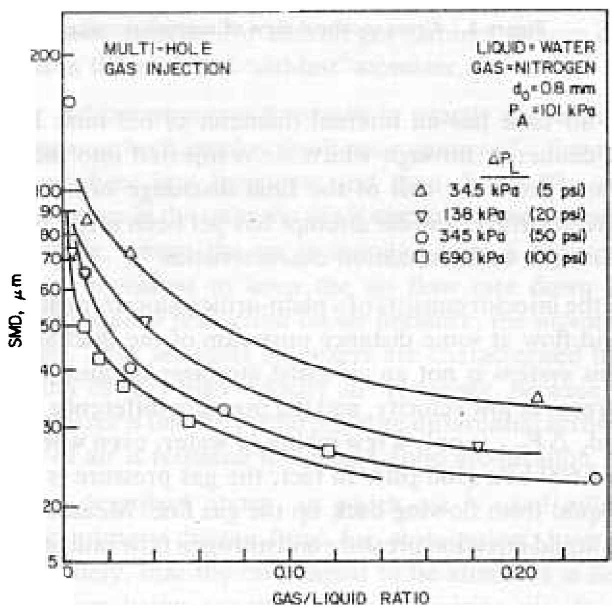

Figure 3. Influence of gas/liquid ratio and injection pressure on SMD for $d_0 = 0.8$ mm.

The atomization quality demonstrated in Fig. 3 is clearly quite high. Even at a water pressure of only 138 kPa (5 psi), mean drop sizes of less than 50 μm are obtained at a GLR of 0.04, i.e., when using only one part by mass of nitrogen for every 25 parts of water. Fig. 3 also shows that increases in gas flow rate and/or liquid injection pressure, lead to significant improvements in atomization quality. Similar results to

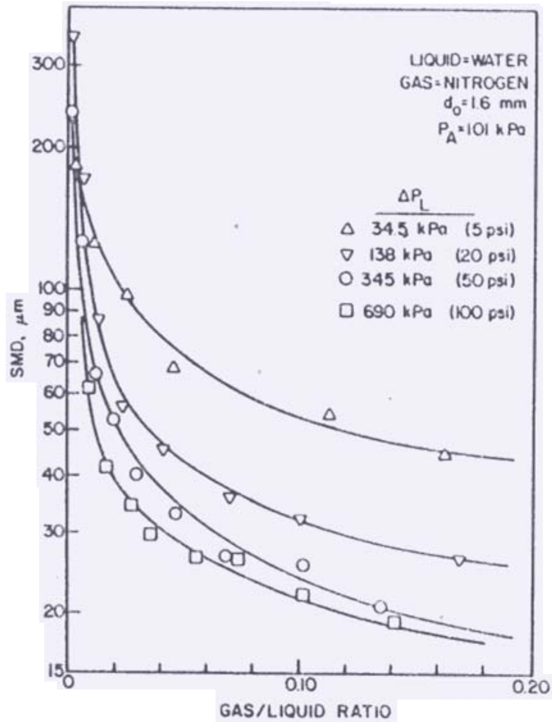

Figure 4. Influence of gas/liquid ratio and injection pressure on SMD for d_o = 1.6 mm

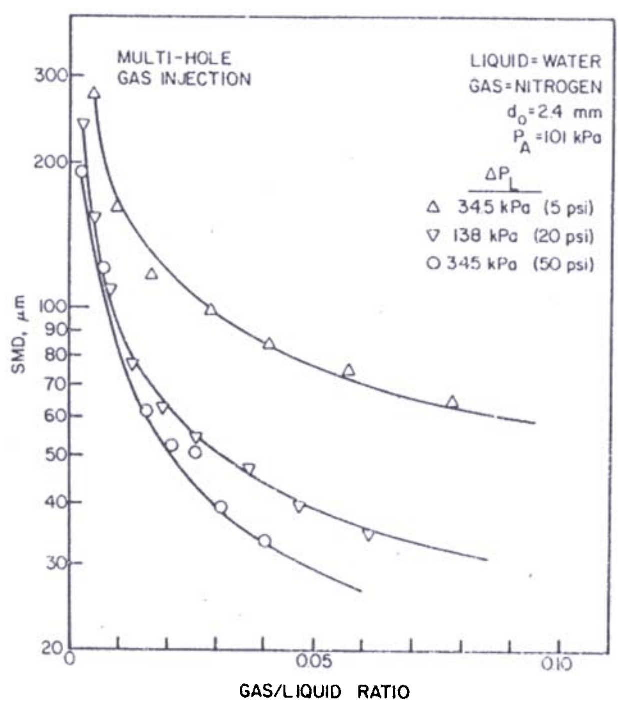

Figure 5. Influence of gas/liquid ratio and injection on SMD for d_o = 2.4 mm

those contained in Fig. 3 are shown in Figs. 4 and 5 for larger injection orifice diameters of 1.6 and 2.4 mm, respectively. Figs. 4 and 5 exhibit the same general features as Fig. 3 is showing the beneficial effects on atomization quality of increases in GLR and ΔP_L. However, a more striking feature of these figures is the relatively small difference in the mean drop sizes shown for the three different injector orifice diameters. Thus a general conclusion to be drawn from Figs. 3–5 is that, except for the lowest values of GLR, where the smallest injector orifice yields the smallest drops, the mean drop sizes produced by this form of atomization are fairly insensitive to the diameter of the final discharge orifice. Furthermore, above a certain minimum-orifice diameter, the influence of orifice diameter on atomization quality is quite small.

The influence of gas injector geometry on atomization performance has been investigated[2] by Wang *et al.* Two different gas injectors were used, one having a single hole of 0.63 mm diameter, and the other 20 holes, each of 0.5 mm diameter, as shown in Fig. 1. These two configurations were selected to provide a wide variation in gas injector geometry. Figures 6 and 7 show mean drop sizes obtained with single hole and multi-hole gas injection for two different injection orifice diameters. The data contained in these two figures show that SMD is largely independent of the geometry of the gas injector.

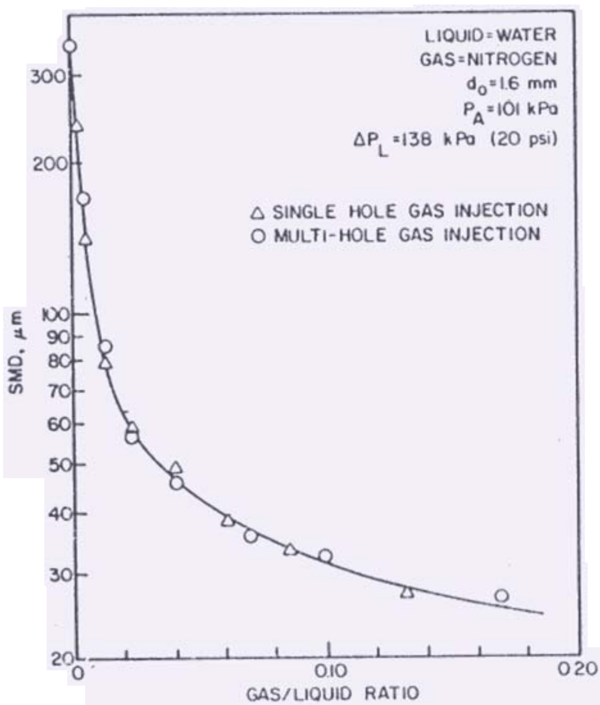

Figure 6. Effect of gas injector geometry on SMD for d_o = 1.6 mm.

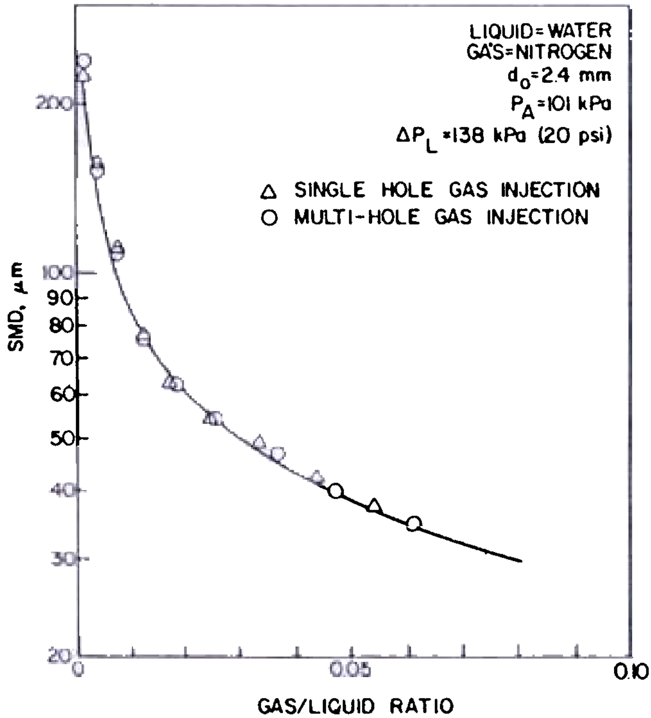

Figure 7. Effect of gas injector geometry on SMD for d_o = 2.4 mm.

4. DISCUSSION

Although the basic mechanisms of aerated-liquid atomization have not yet been studied in detail, it is believed that the liquid flowing through the injector orifice is 'squeezed' by the gas bubbles into thin shreds and ligaments. This is an important aid to atomization because it is well-established that the drop sizes produced in a spray, whether by pressure or airblast atomization, are roughly proportional to the square root of the initial thickness of diameter of the ligaments from which they are formed[3]. Thus, the larger the amount of gas used in atomization, the larger will be the number and/or size of the bubbles flowing through the injector orifice, and the smaller will be the drops produced in atomization. When the gas bubbles emerge from the nozzle they 'explode', thereby shattering the surrounding liquid shreds and ligaments leaving the final orifice into small drops.

If we now consider the flow of gas through the injector orifice, for continuity we have

$$m_G = \rho_G A_G U_G \tag{1}$$

where A_G is the average cross-sectional area occupied by the gas flow, and U_G is the mean gas velocity through the injection orifice.

From the above equation it follows that, for a constant gas flow rate, a reduction in ρ_G must lead to an increase in A_G or U_G, or both. Increase in gas flow area is beneficial to atomization because it reduces the area available for the liquid flow, i.e., i.e., it squeezes the liquid into thinner films and ligaments as it flows through the injector orifice. Increase in gas velocity is also beneficial to atomization because it accelerates the flow of liquid through the injector orifice, causing it to be discharged at a higher velocity. Thus, when operating at high injection pressures, atomization quality is high for two reasons. One is the high pressure drop across the exit orifice. This represents the atomization that would have been achieved in the absence of any injected gas. The second reason stems from the beneficial effects of the injected gas (a) in squeezing the liquid into fine ligaments as it flows through the injector orifice, and (b) in 'exploding' downstream of the nozzle exit to shatter these ligaments into small drops. With decrease in injection pressure, the 'natural' atomization, i.e., the atomization that occurs solely as the result of the pressure drop across the nozzle, is impaired, but this is compensated in large measure by the relatively bigger role played by the gas which expands in volume with reduction in pressure, leading to increases in the number and/or size of the gas bubbles in the flow. Both these effects are conductive to better atomization.

The aerated nozzle described in this paper has an important advantage over conventional nozzles in that it does not require small holes and passages to achieve good atomization. This asset is especially useful from a combustion standpoint because it means that good atomization can be achieved at low fuel injection pressures when using holes and flow passages which are so large in cross-section that problems of clogging by contaminants in the fuel are greatly diminished.

The variation of discharge coefficient with injector-orifice diameter and gas/liquid ratio, for a constant injection pressure of 138 kPa (20 psid), is shown in Fig. 8. The actual values of discharge coefficient plotted in this figure were obtained by substituting the appropriate measured values of liquid flow rate and injection pressure differential into the equation

$$C_D = \frac{m_L}{(\pi/4)d_o^2(2\rho_L\,\Delta P_L)^{0.5}}$$

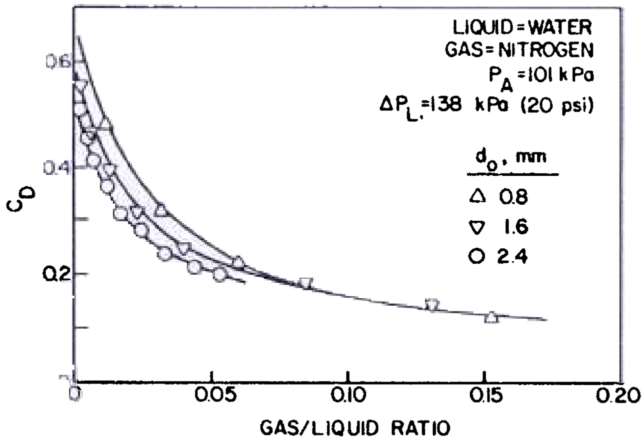

Figure 8. Effect of gas/liquid and injector orifice diameter on discharge coefficient.

Typical values of discharge coefficient for a plain-orifice atomizer are between 0.7 and 0.8, depending on the l_o/d_o ratio. The measured values of discharge coefficient shown in Fig. 8 are clearly much lower, especially for high gas/liquid ratios, where C_D values fall to around 0.1. In fact, the true C_D values could be even lower than 0.1. This is because acceleration of the gas through the injector-orifice augments the liquid velocity also, so that the average liquid velocity through this orifice is somewhat higher than calculations of velocity based on ΔP_L would indicate.

5. CONCLUSIONS

The advantages offered by aerated-liquid atomization are the following :

i) Very good atomization even at very low injection pressures and low gas flow rates.

ii) The system employs large holes and passages so that problems of 'plugging' are greatly reduced. This could be an important advantage for combustion devices that burn residual fuels, or slurry fuels, or any type of fuel where atomization is impeded by the necessity of using large hole and passage sizes to avoid plugging of the nozzle.

iii) For combustion applications, the aeration of the spray created by the presence of the air bubbles should prove very beneficial in alleviating soot formation and exhaust smoke.

iv) Drop size distributions appear to be little affected by the geometry of the gas injector.

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