

TOWARDS CONTROLLED LIQUID ATOMIZATION

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Abstract

The present study discuss controlling mechanisms of air-blast atomization and the prospect of external triggering for enhancing atomization quality of a planar liquid sheet. The investigation builds on previous experimental evidence provided by flow visualization of 2-D liquid sheets formed between two co-flowing air streams at variable velocities, and is particularly aimed to improve our understanding on air-blast atomization for lean combustion and low-emission engines. The study is extended by varying the sheet thickness and through the detailed analysis of physical processes occurring at the liquid-gas interface, namely the liquid surface wave growth characteristics due to viscous shear. The results show that the influence of waves on liquid sheet break-up is confined only to a thin region near the interface, and thus require properly tuned, and externally-controlled, excitations for effective atomization.

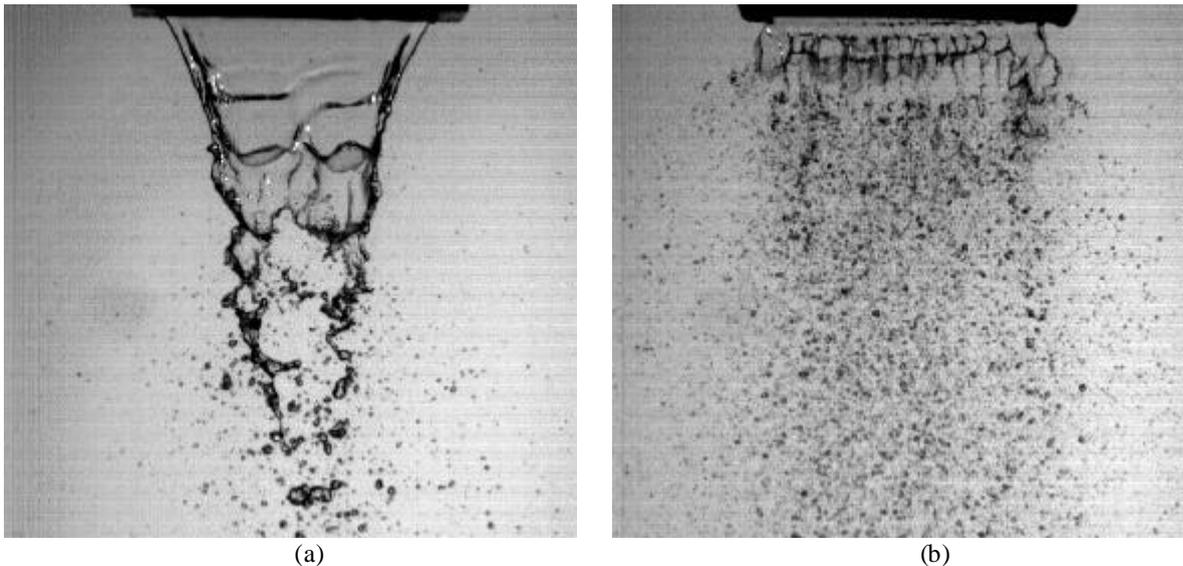


Figure 1 Air-blast atomization of a planar liquid film

[liquid velocity = 1.3 m/s; film thickness = 0.4 mm; (a) air velocity = 10 m/s (b) air velocity = 20 m/s]

1. Introduction

Liquid atomization is known as a process in which the disruptive action of externally-applied aerodynamic forces are opposed by the consolidating influence of the liquid viscosity and surface tension forces: theoretical and experimental analysis on the mechanism of atomization have been carried-out since Rayleigh (1879) and Tyler (1933) and detailed reviews of the earlier work have been published by Chigier (1991) and Lefebvre (1989). The complexity of phenomenon is associated with the influence of various parameters in the initial break-up of a liquid jet / sheet, which include flow conditions inside the injector, turbulence properties and its decay along the liquid core prior to break-up, interaction of liquid with surrounding medium, the development of waves along liquid surface which under certain condition collapse to form ligaments and droplets and the two- phase nature of the flow domain (e.g., Lozano et al., 1996; Carvalho et al., 2000).

Even-though our understanding of sprays is relatively limited, research in this area has progressed considerably due to the recognized potential of air-blast atomizers for minimizing the output of pollutant emissions from air-breathing engines. Air-blast or twin-fluid atomizers have a number of advantages over pressure atomizers including lower requirements of fuel injection pressure and generating finer sprays (e.g., Arai and Hashimoto, 1985; Mansour and Chigier, 1990; Lozano et al., 1996). The authors have utilized planar liquid sheets to allow a direct examination of the air-liquid interface without the added complexity of axi-symmetric configurations.

In this paper, we follow a similar approach and extend the work of Carvalho et al. (2000) on planar liquid films by reducing the liquid sheet thickness and introducing external triggering for achieving effective atomization. The following sections include the analysis of atomization process and the liquid-air interface, description of the experimental set-up and measurement techniques, discussion of the results obtained and the scope of future work . The final section briefly present the main conclusions of the work.

2. The Analysis of the Process of Liquid Atomization in Retrospective

Sprays and other dispersed flows are normally divided into dense and dilute regimes, Faeth (1987). Dense spray region occurs near the exit of an injector, which is the transition between liquid film and the dilute dispersion of droplets. Dense spray regions are characterized by irregularly shaped liquid elements e.g., ligaments, phenomena of collisions between liquid elements, effects of volume fractions on interface transport rates and the break-up of liquid elements. Thus, it is difficult to describe this region both theoretically and experimentally. The experimental difficulties arise because the flow is generally opaque to optical diagnostics. Thus, optimization of an atomizer design requires good understanding of the physical process associated with sprays.

Instability at the liquid sheet interface are generated due to the imbalance of forces, such as the momentum force of the liquid and the opposing surface tension force. This will occur at high Weber numbers ($800 < We_{\text{liquid}} < 30,000$), accompanied by large amplitude asymmetric waves which enhances liquid sheet disintegration, Taylor (1959). The waves are induced by aerodynamic forces acting on the air/liquid interface and its initial amplitude and growth rate will be determined by the relative magnitude of the forces. The amplitude of the wave increases as it propagates down-stream till it become unstable and breaks. By increasing the relative velocity between the liquid and the surrounding gas, the amplitude and growth rate of surface waves at the interface are enhanced and fine ligaments and small droplets are stripped or peeled from the liquid surface. However, as the liquid momentum increases, the inner core of the liquid will not get affected by the surrounding gas. In other words, the influence of shear will be confined to a thin region near the surface, that is, the characteristic length scales of perturbations that can cause break-up are small compared to those of the liquid sheet thickness. This suggests that, shear force cannot break-up the inner core and achieve complete disintegration of the liquid sheet. The latter statement highlight the point that atomization process is not a pure shear-driven phenomena, especially for high liquid momentum. Of-course the shear can influence atomization at the interface and at far down-stream locations where viscous effects dominate. That is, at the down-stream distance, the inner core thickness becomes of the same order of magnitude as the size of perturbations and thus large scale disintegration will commence. The process will continue until the surface tension forces on the droplet surfaces are sufficiently strong to prevent any further break-up.

Therefore, to improve atomization, the intact inner core of the liquid sheet must be influenced by artificial or external excitation initially. The significance of air-blast atomization should be viewed in this context. The required power of excitation depends upon the specific atomizer flow configurations. The perturbation can be introduced at the upstream of the nozzle or at the nozzle outlet plane. In the following, a 2-D air-blast atomizer of variable thickness utilizing impinging air-streams and also an imposed acoustic oscillation are described.

3. Atomizer Flow Configuration

Figure 2 shows a schematic layout of the liquid film generator, which is adapted from the design used by Carvalho et al. (2000). It consists of an inner slit of exit thickness, $t = 0.7 \text{ mm} / 0.4 \text{ mm}$ corresponding to an aspect ratio of $114 / 200$, to produce planar liquid films of variable thickness. The film is sandwiched between air flows of thickness 7 mm on either side and will impinge the liquid sheet with an angle of 30° at the nozzle outlet plane. Water is used as a test liquid, and the results reported here are for a liquid velocity of maximum 4.3 m/s under different air flow rates. The facility also consists of provisions to impart high frequency oscillations in the water-line as depicted in Figure 2. The present study will qualitatively analyze the break-up characteristics of variable liquid sheet thickness and based on this develop future strategies for improvement in atomization for given flow configurations. Measurements are carried-out by flow visualization utilizing a high speed digital camera, with a framing rate of $10,000 \text{ fps}$, and different illumination techniques such as laser light sheet, synchronized stroboscope, and light projector. The break-up length can be quantified from the images by measuring the axial distance from the nozzle outlet plane to the point where the central part of the sheet is clearly non-existent as a cohesive liquid film.

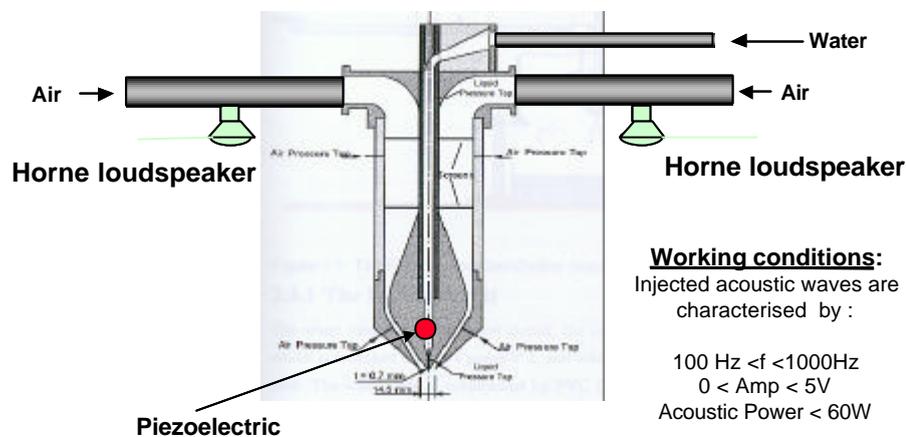


Figure 2 Atomizer configuration

4. Results and Discussion

Figure 3 depicts images of the liquid film of thickness 0.7 mm , under the influence of variable air and liquid velocities, as initially obtained by Carvalho et al. (2000). It shows both front and side view images of the interacted flow field. Strobe-light is used for illumination and the images are acquired with an exposure time of $1.2 \mu\text{s}$. Their study, based on dimensional analysis of the characteristic length scales of disintegration, revealed that air-to-liquid momentum ratio is an important parameter in the atomization process. Visual inspection of the images, Figure 3, reveal that as the liquid velocity increases the membrane-type disintegration mode dominates. This implies that poor quality atomization is taking-place, in accordance with the morphological classification proposed by Faragó and Chigier (1992). In other words, gas-to-liquid momentum had a limiting influence on atomization as the liquid velocity increases. Thus, increasing air velocity further will not achieve improvement in atomization. This conclusion is supported by the results of Reitz and Bracco (1982), which show that the mean drop size is attained at an air velocity of about 45 m/s and further increase in air velocity does not produce any improvement in drop size characteristics. So based on theoretical considerations discussed in section-2, for effective disintegration, the characteristic length scale of perturbations for a given gas-to-liquid momentum should be of the order of liquid sheet thickness. This in-turn necessitates to study the influence of liquid sheet thickness on atomization quality by considering a smaller sheet thickness, $t = 0.4 \text{ mm}$.

Figure 4 shows images of this configuration for the respective liquid and air velocities. A light-projector is used for illumination and the images are obtained by a high speed digital CCD camera (Kodak Ektapro) at an exposure time of $10 \mu\text{s}$. A qualitative comparison of the present images, Figure 4, with the previous results of Carvalho et al. (2000) reveal that the fiber-type disintegration mode dominates over the membrane-type disintegration for the corresponding gas-to-liquid momentum. In other words, improvement in atomization can be achieved by reducing the liquid sheet thickness.

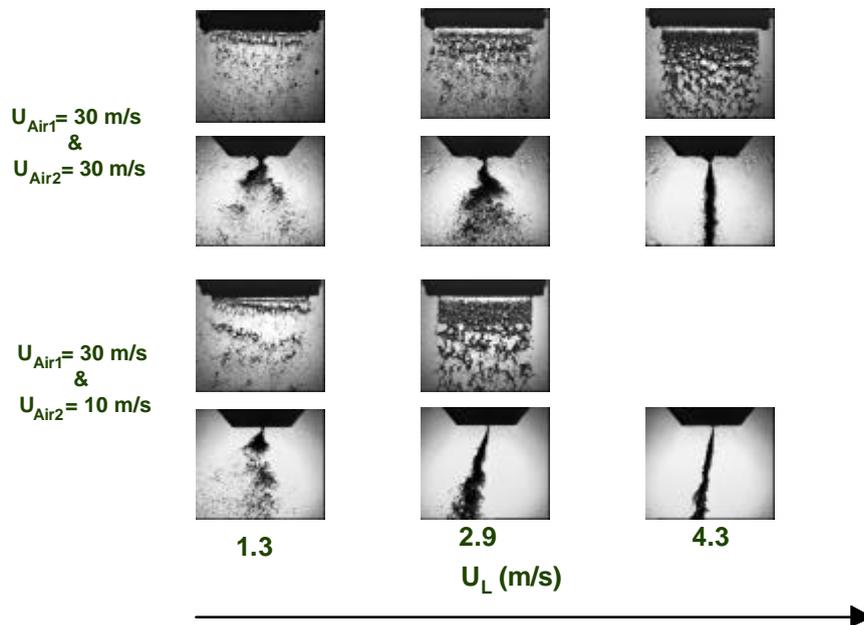


Figure 3 Images of planar liquid film [Carvalho et al.(2000)]

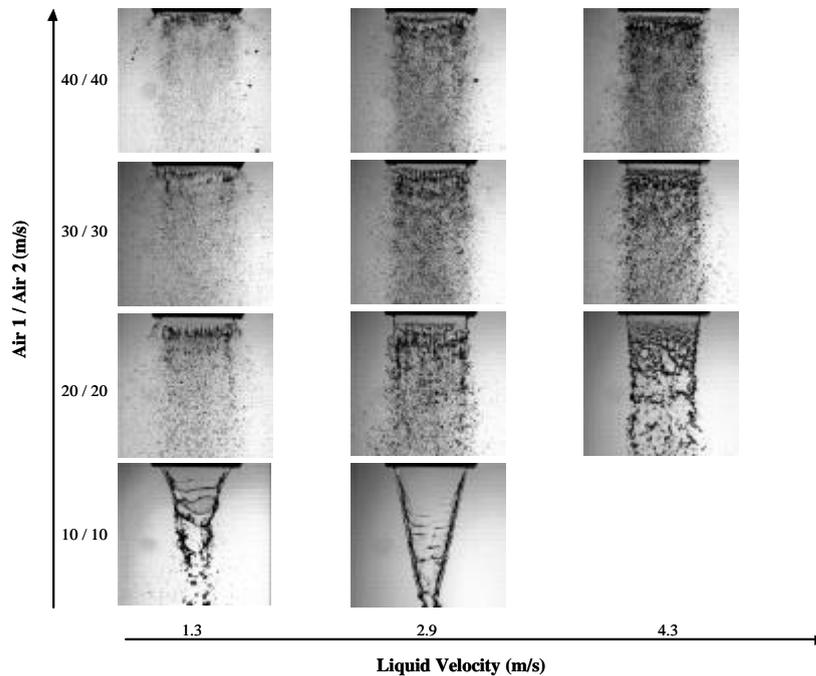


Figure 4 Images of planar liquid film ($t = 0.4 \text{ mm}$)

However, for high liquid momentum, the spray quality still needed improvement especially near the outlet of the injector. In this context, one has to look for artificially imposed modulations such as acoustic oscillation in the liquid-line at the upstream of the nozzle. In doing so, the acoustic waves will create pressure gradient across the sheet and will affect the development of potential core in the liquid. Thus, the effectiveness of acoustic modulation in the subsequent disintegration will be determined by the strength of the initial pressure gradient generated. It should be noted that the effective modulation wavelength depends on the driving frequency. In other words, increase of modulation power improves

atomization only at resonant frequencies Chung et al. (1998). This implies that once the wave growth characteristics of a given atomizer flow configuration have been identified, corresponding in-phase acoustic oscillations can be applied to augment the wave growth rate and hence more rapid and improved atomization. The future work will be aimed at achieving the desired atomization quality over a very wide range of conditions by utilizing external triggering mechanisms.

5. Conclusions

The effectiveness of air-blast atomization depends on the initial liquid sheet thickness, in addition to the air-to-liquid momentum ratio. However, for high liquid momentum, the affect of viscous shear on liquid sheet break-up is confined to a thin region near the interface. Thus, properly tuned artificial modulations are needed to influence the undisturbed inner core of the liquid for improving atomization.

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