VISUALIZATION STUDIES OF AN ACOUSTICALLY EXCITED LIQUID SHEET

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Liquid sheet disintegration studies have been carried-out previously in the context of improving atomization quality[1]. Research in this area has progressed considerably due to the recognized potential of air-blast atomizers for minimizing pollutant emissions from air-breathing engines. Among various geometries, planar liquid sheets possess an added advantage that it allows direct examination of the air-liquid interface.

Under reduced atomizing airflow situations, the dynamical influence of the surrounding gas will not be sufficient to affect the inner core of the liquid. In other words, the characteristic length scales of perturbation that can cause break-up are small in comparison with the liquid momentum. Therefore, in order to achieve complete disintegration of the liquid sheet, the intact liquid-core near the nozzle outlet must be influenced by artificial or external excitation. To accomplish this, the present investigation utilizes a 2-D air-blast atomizer, with provisions to impart acoustic perturbations.

EXPERIMENTAL SYSTEM

Atomizer configuration

Figure 1 shows a schematic layout of the atomizer. The test liquid water emerges from a rectangular slit-orifice of aspect-ratio 200:1, with an exit thickness of 0.4 mm, and is sandwiched between two air-streams impinging at an angle of 30°. In the present investigation, the liquid velocity varies from 0.95 m/s to 1.8 m/s, while the atomizing air velocity kept at 10 m/s.

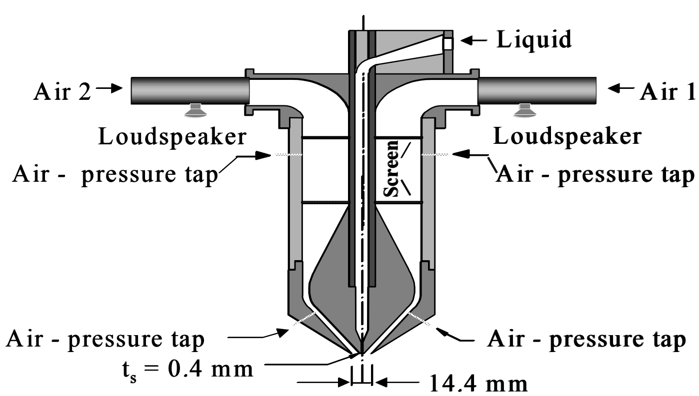

Fig. 1 Atomizer configuration

Acoustic perturbations are imparted to the liquid sheet by the loudspeaker system through the atomizing air (Fig. 1). Frequency tuning of the system is carried-out in such a way that the efficiency of electro-mechanical transudation for the combined loudspeaker system is maximized, which occurs at the resonant frequency of the system[2]; for the present experimental arrangement resonance occurs at 780 Hz. In other words, variation in the liquid sheet features at the nozzle outlet is significant at the resonant frequency of 780 Hz, with a narrow bandwidth. Other than at the resonant frequency, the liquid sheet is unaffected by the modulation signal for input powers between 0 to 60 Watts.

Measurement techniques

Qualitative and quantitative analysis of the flow-field is carried-out by flow visualization techniques. A white background illumination is used to obtain high contrast images of the liquid sheet. Images are acquired by a high-speed digital CCD-camera at a grabbing rate of 2000 fps, and with an exposure time of 10 μs. Correspondingly the maximum resolution of the camera is 256 x 120 pixels.

In order to characterize the length scales of disintegration, both front-view and side-view images of the flow-field are utilized. To acquire reliable data, 8 to 10 pairs of frames were used for each flow condition. This will ensure sampling of the highest amplitude waves, and hence with reasonably low-levels of measurement errors, the associated break-up length and break-up frequency can be estimated.

RESULTS AND DISCUSSIONS

Qualitative features

Figures 2(a) and 2(b) depict the front-view images of a liquid sheet of flow-rate 6.65 g/s in stagnant ambient, without and with perturbations respectively. From the images it's quite evident that the imposed perturbation directly influences the thick rim of the liquid sheet. Consequently, the surface tension force, which consolidates the liquid surface, will unable to withstand the disruptive external excitation. Thus, the imbalance of forces initiate the liquid sheet rupturing.

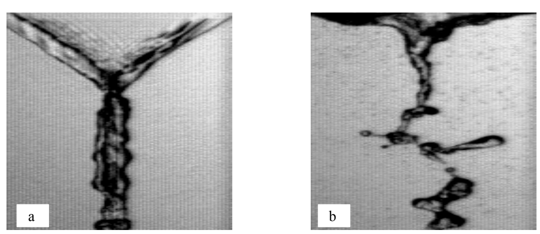

Fig. 2 Liquid sheet in stagnant ambient: (a) without perturbation; (b) with perturbation

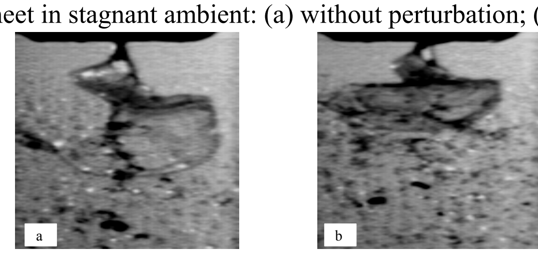

Fig. 3 Air-blast liquid sheet: (a) without perturbation; (b) with perturbation

The influence of acoustic modulation on an air-blast liquid sheet is shown in Figs. 3(a) and 3(b). It portrays the side-view images for non-imposed and imposed excitations respectively. The atomizing air flow-rate is 1.4 g/s, while the liquid flow-rate remains same as previous case. The associated waves exhibit distinct characteristics, such as sinusoidal and bubble-like pattern. Also, the images show that early bursting of waves and hence short break-up length is linked with acoustically modulated liquid sheet.

Length scale of disintegration

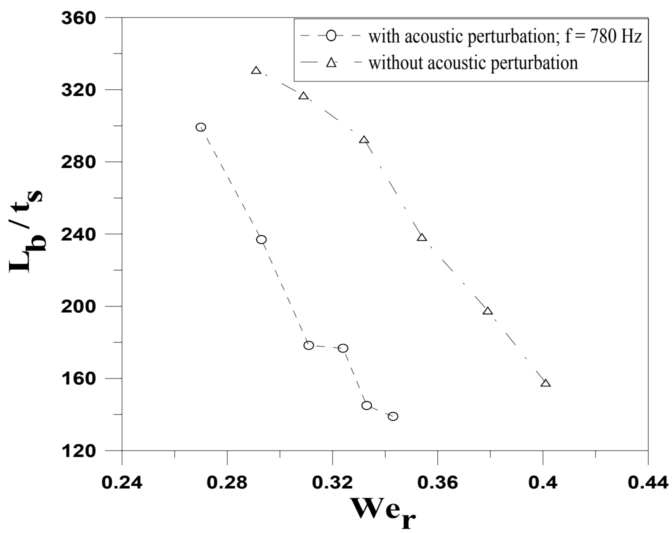

Fig. 4 Break-up length as a function of relative Weber number

Figure 4 shows the break-up length of an air-blast liquid sheet as a function of relative Weber number, with and without perturbations. Length 'L_b' is quantified from the front-view 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. It is non-dimensionalised by the initial liquid sheet thickness 't_s'. The Weber number (We_r) is based on the relative velocity between the liquid and the component of air-velocity parallel to the liquid sheet axis. The liquid flow-rate varies in the range of 6.65 g/s to 8.1 g/s, while the air flow-rate is kept constant at 1.4 g/s. Results show that, with imposed perturbations, steep decay in the break-up length can be achieved.

CONCLUSIONS

The present study revealed that properly tuned external perturbation could enhance the disintegration of liquid sheets. This will find practical relevance in air-blast atomizers, because its effective utilization can reduce the required atomizing air pressure.

REFERENCES

1. Mansour, A. and Chigier, N., Dynamic Behavior of Liquid Sheets, *Phys Fluids A*, Vol. No. 12, pp 2971-2980, 1991.

2. Chung, I.P., Presser, C., and Dressler, J.L., Effect of Piezoelectric Transducer Modulation on Liquid Sheet Disintegration, *Atomization and Sprays*, Vol. 8, pp 479-502, 1998.