Primary breakup of gas-assisted liquid sheet atomizers - experiments and simulation

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Abstract

Spray generation in gas-assisted atomization processes has a wide applicability. Sheet atomizers with two co-flowing gas streams exhibit the highest potential of generating fine sprays at high mass flow rates. A frequent atomization event within the region of the primary breakup (PB) causes the liquid to accumulate at the atomizer exit and to disintegrate into relatively large droplets further downstream. This study provides a detailed characterisation and analysis of the liquid accumulations and their correlation to the liquid sheet thickness (s_l) using high-speed diagnostics and large eddy simulations with the volume-of-fluid approach (VOF-LES).

Keywords: Spray, Nozzle, Sheet Atomization, Primary Breakup, FFT, VOF, LES

Introduction

Atomization is an important step in a variety of engineering applications, e.g. entrained flow gasification, combustion, spray drying etc. In all cases, the resulting product quality is directly linked to the atomization performance in terms of droplet size. A sheet atomizer configuration consisting of an annular liquid sheet with two coaxial gas channels (inner circular and outer annular) shows the potential of overcoming the limitations of other gas-assisted atomizer configurations with respect to droplet size for large liquid flow rates [1, 2]. As the PB has a major influence on the resulting spray quality, it is crucial to obtain a detailed understanding of this process. Given the presence of velocity gradients between the liquid and the gas introduced by both the inner gas jet and the outer gas sheet, the liquid sheet is exposed to instabilities over a relatively large surface area. These instabilities propagate downstream as waves whose superposition leads to regular disintegration events at periodic intervals. These events are captured in experiments at atmospheric conditions and in numerical simulations using a combined VOF-LES method. Considering the influence of initial flow instabilities on the breakup process of liquid sheets [3], this study aims to analyse the impact of the liquid sheet thickness (s_l) on the pulsation events.

Experimental Framework

For the experiments, four sheet atomizers with different s_l (0.5 - 3 mm), identical inner (7.1 mm^2) and similar outer (122 - 124 mm^2) gas exit orifice areas are used for the atomization of water. The experimental setup consists of the ATMOspheric spray test rig, as described in [1], and a high-speed camera. The atomizer is mounted to a three-fluid lance, supplied with water by an eccentric screw pump and compressed air. A high-speed camera (2048 x 1952 pixel^2 resolution, 4.5 kHz frame rate, Phantom v1840) with backlight illumination is used.

Numerical Framework

The numerical investigation is carried out using the VOF method with LES, which captures and compresses the gas-liquid interface by solving a filtered transport equation for the liquid volume fraction α, accompanied by the filtered transport equations for total mass, momentum and energy. The open source toolbox OpenFOAM is used to simulate the experimental operating points.

Results and discussion

All four atomizers are used with a constant inner gas mass flow rate of 2 $\mathrm{kg \cdot h^{-1}}$ and a constant liquid mass flow rate of 60 $\mathrm{kg \cdot h^{-1}}$. The outer gas mass flow rate ($\dot{\mathrm{M}}_{\mathrm{g,o}}$), known to have a crucial impact on the droplet size distribution [1], is varied from 24 to 72 $\mathrm{kg \cdot h^{-1}}$. Figure 1 (a) shows that the PB of sheet atomizers with two co-flowing gas streams reveals periodic pulsations of the liquid sheet, following the same pattern for all investigated atomizers and operating points. Images from experiments (left half) and numerical simulations (right half) both show a repeated accumulation of liquid near the atomizer exit at the centerline of the spray. This liquid volume spreads radially until it finally disintegrates into droplets (Figure 1 (a), left to right). A frequency analysis highlights the close correlation between experiments and simulations, see Fig. 1 (b). The investigation of different $\mathrm{s_l}$ shows decreasing pulsation frequencies with increasing $\mathrm{s_l}$ for all $\dot{\mathrm{M}}_{\mathrm{g,o}}$, see Fig. 1 (c). This may be attributed to the larger liquid inertia with increasing $\mathrm{s_l}$ and a lower liquid velocity.

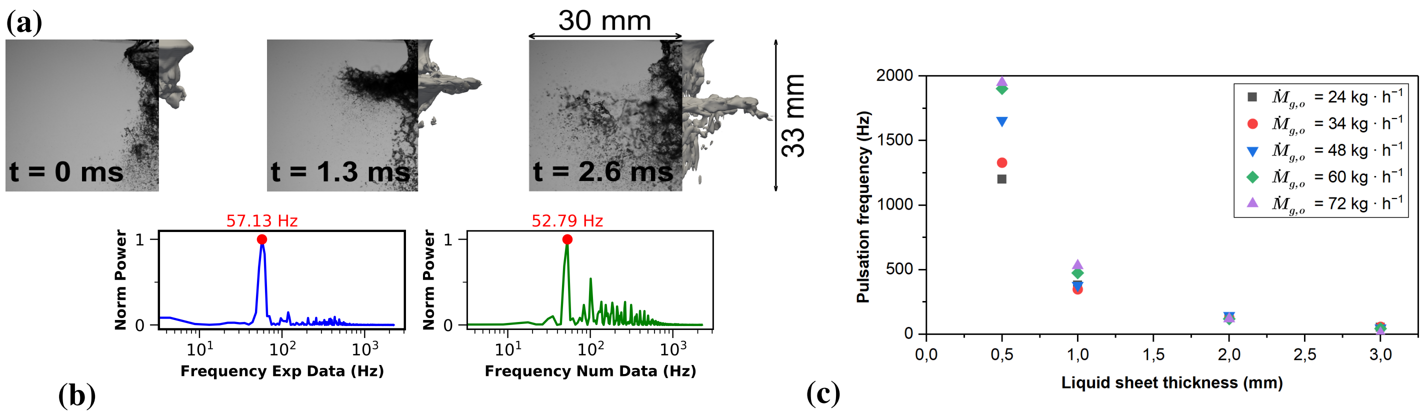

Figure 1: (a) and (b) show the PB and the frequency spectrum from experiments (left) and simulations (right) at the operating point $\mathrm{s_l}$ = 3 mm and $\dot{\mathrm{M}}_{\mathrm{g,o}} = 34\,\mathrm{kg \cdot h^{-1}}$. (c) shows the pulsation frequency as a function of $\mathrm{s_l}$ (experimentally derived).

Conclusion

The primary breakup of sheet atomizers shows the appearance of periodic pulsation events that affect spray quality and show a higher frequency with smaller $\mathrm{s_l}$. Experiments and simulations observe the same phenomenology of pulsation and comparable pulsation frequencies are obtained. Future work will characterize the downstream droplet size distributions as a function of $\mathrm{s_l}$ experimentally and focus on the modelling of the secondary breakup.

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References

[1] S Wachter & T Jakobs & T Kolb, *Comparison of central jet and annular sheet atomizers at identical gas momentum flows*, Ind. Eng. Chem. Res. **60**, 11502–11512 (2021).

[2] F Zhang & S Wachter & T Zirwes & T Jakobs & N Zarzalis & D Trimis & T Kolb & D Stapf, *Effect of nozzle upscaling on coaxial, gas-assisted atomization*, Phys. Fluids **35**, 1089–7666 (2023).

[3] S Wachter & T Jakobs & T Kolb, *Mass flow scaling of gas-assisted coaxial atomizers*, Applied Sciences **12(4)**, 2123 (2022).