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Experimental Investigation of a High Aspect Ratio Rectangular Liquid Jet in Parallel Airflow

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ABSTRACT: In this study, the flow dynamics of a high aspect ratio rectangular liquid jet issued into parallel airflow was experimentally investigated using a proof of concept setup, a more appropriate setup will be designed for a complete study later. The liquid flow was emanated from a rectangular injector with a thickness of 0.64 mm and an aspect ratio of 21. The injector was set in the center of the test section and the effects of airflow on the liquid flow were evaluated. A particular holding mechanism was designed and built to minimize the induced perturbations on the liquid flow. To identify the physics of the liquid flow shadowgraphy technique and high-speed imaging were implemented. In order to provide a comprehensive study of the problem, the experiments were performed for a wide range of flow conditions, and flow visualizations were presented. Jet Weber number and Gas Weber number were varied from 3 to 120 and 0.2 to 12, respectively Also, five regimes of the liquid flow including column, column/gravity, arcade, bag, and multimode were recognized. A mapping with gas Weber number and momentum ratio as the determining variables was suggested to distinguish these regimes from each other. The breakup length of the liquid jet was also measured. It was found that with the increase of jet Weber number the breakup length was increased at constant gas speed. Moreover, it was revealed that the breakup length was elongated with the increase of gas Weber number.

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1- Introduction

Injection of liquid jets into gaseous medium finds numerous applications in different industries. Therefore, understanding the underlying physics of the liquid jet is critically important to optimize the liquid injection and achieve maximum performance [1]. Employing liquid injectors with non-circular external shapes has been suggested as a passive technique to manipulate and modify the liquid flow features [2]. Several studies have recently focused on investigating the liquid jets issued from non-circular jets [3-5].

Aside from changing the geometry of the liquid nozzle, premixing of the liquid jet with a gaseous flow has been significantly studied to enhance the liquid/air mixture quality. Transverse injection of a liquid jet into airflow was examined in several studies and it was shown that due to the shear forces exerted on the liquid jet from the airflow, the atomization was accelerated [6]. To keep the introduction concise, these studies are not mentioned here.

In this study, we have implemented a new method to introduce a liquid jet into a gaseous flow. Indeed, instead of transverse injection, the liquid jet is discharged parallel to the airflow. To increase the interaction between liquid and gas flows, a high aspect ratio rectangular nozzle was used as the liquid injector. The main flow features of the liquid flow were studied for the first time.

2- Experimental Setup

The experimental setup used in this study consisted of three systems: wind tunnel, liquid injection system, and the high-speed shadowgraphy system. The liquid injection system is the same employed in the previous study of the authors [3]. The implemented injector was of rectangular shape with a high aspect ratio of 21 and thickness of 0.64 mm. As shown in Fig. 1, it was designed in a particular shape in order to keep the shedding of disturbances into airflow at a minimum.

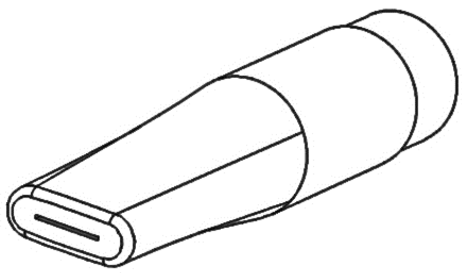

Fig. 1. Design of the injector

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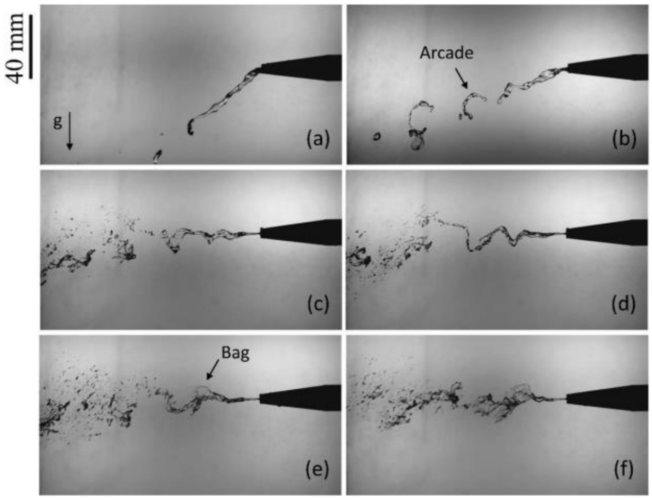

Fig. 2. Flow visualizations of the liquid sheet at the constant momentum ratio of 10 and for jet Weber numbers of: a) 3.39, b) 6.65, c) 19.5, d) 26.6, e) 34.7, f) 44.0

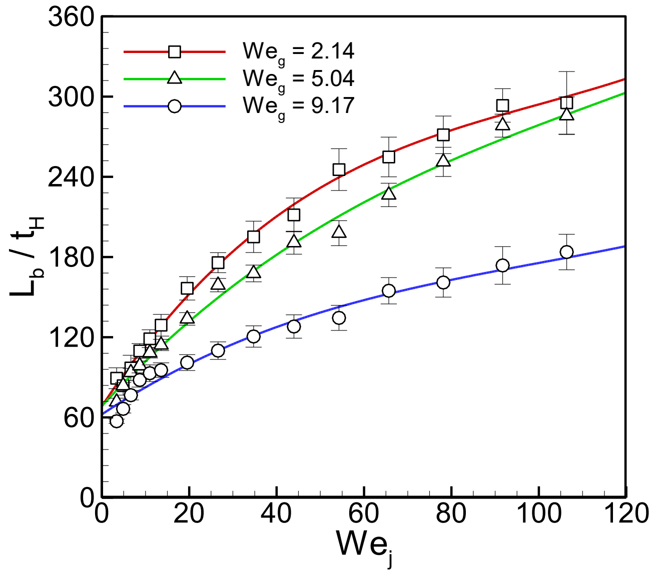

Fig. 3. Variation of breakup length with flow condition

The low-speed wind tunnel had a test section of 30 * 30 * 130 cm3 and its maximum velocity could reach 45 m/s. A unique mechanism was designed to hold the injector in the center of the test section. A shadowgraph system associated with a high-speed camera was implemented to visualize and capture the highly unsteady nature of the liquid flow. Photos were taken with a frequency of 1200 fps.

3- Results and Discussion

The physics of the liquid sheet was completely examined with the aid of rapid imaging. In Fig. 2, an example of these visualizations is given for the constant momentum ratio of 10 and at different jet Weber numbers. As seen, the flow regime is highly influenced and manipulated by flow conditions. Variation in jet Weber numbers results in a significant change in the instabilities that appear over the liquid flow. Also, it is very well captured that the breakup mechanisms are greatly impacted and changed by Weber number. It is observed that an increase of jet Weber numbers at constant momentum ratio leads to the strengthening of aerodynamic forces (due to the increase of gas Weber number) which consequently, intensifies the instabilities developing over the liquid flow

The breakup length of the liquid flow was also measured by post-processing the shadowgraphs. For each flow condition, 50 consecutive photos were processed to obtain the breakup length. The averaged value of breakup length at different flow conditions is reported in Fig. 3. As seen, with the increase of jet Weber number, the penetration of the liquid sheet into the gas has increased. Also, it can be observed that an increase in gas Weber number led to the decrease of breakup length. This is due to the intensification of shear forces that accelerate the breakup of the liquid flow.

4- Conclusions

An experimental study was performed to investigate the flow dynamics of a liquid sheet emanated into a parallel airflow. The liquid sheet was issued from a rectangular nozzle with an aspect ratio of 21 and a thickness of 0.64 mm. High-speed imaging and shadowgraphy methods were employed to visualize and freeze the unsteady nature of the fluid flow. Experiments were performed for a wide range of gas and jet Weber numbers. Finally, the penetration length of the liquid sheet into the gaseous medium was presented.

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