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Experimental Investigation of Breakup Characteristics of Elliptical, Rectangular and Circular Water Jets

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1- Introduction

The injection of a liquid jet into quiescent air is a fundamental flow phenomenon that is relevant to many applications in everyday life. These applications range from agricultural irrigation systems, medical inhalers, firefighting, paint sprays and printers to name a few. Numerous theoretical and experimental studies have been performed to investigate the flow physics associated with the injection of a liquid jet into a stagnant gaseous medium. Different factors can affect the injection of a liquid jet however the geometry of nozzle is one of the most important ones that highly change the physics of the liquid jet injected into stagnant air.

Many investigations focused on the circular jets, however recently a great attention has been paid to non-circular jets as they can bring in new characteristics to the liquid jet flow. Indeed, non-circular liquid jets have a potential to be used as passive flow controllers in different industrial applications. Elliptical jets have been studied more than any other geometry. Several studies have revealed the formation of axis-switching phenomenon which the alteration of major and minor axes of the jets. The length characteristics of this phenomenon including wavelength and amplitude were reported in details. Moreover, it has been shown that rectangular jet manifests similar behavior, though in contrast to elliptical jets the quantitative results are scarce. In this study, we deal with the shape of nozzle by using a rectangular and elliptical nozzle in order to draw a comparison between the flow characteristics of both jets. Furthermore, a circular jet with equal cross sectional area is also implemented to be used as the reference geometry. The main flow characteristics of the jets flows including breakup length and axis-switching wavelength and amplitude are obtained and compared.

2- Experimental Setup

The experimental setup used in this investigation was the conventional setup widely employed in the experiments of liquid injection. A liquid storage tank was pressurized by a compressed nitrogen capsule. The liquid tank was fed with tap water before performing tests and a baffle avoided undesirable interactions between high pressure gas and resting liquid. In the whole experiments, steady liquid flow was produced with a constant pressure difference of 4 bar between the ambient air and liquid tank. The liquid volumetric flow rate was controlled and measured via rotameter-type flowmeters. Shadowgraph technique along with a high speed camera were employed for the purpose of flow visualization. Moreover, the flow rate of water was varied from 2 to 120 liters per hour that is correspondent to Weber numbers ranging from 0.5 to approximately 1100. Three injectors were manufactured from stainless steel with Electro Discharge Machining (EDM) technique that is known to provide the best quality among other methods. The schematic of the nozzle assembly and photos of the constructed geometries are provided in Fig. 1.

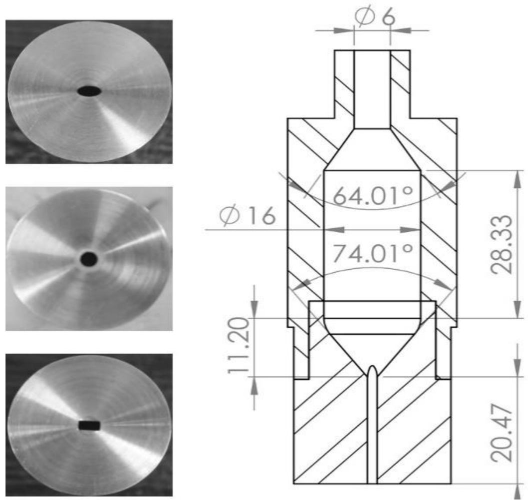

Fig. 1. Details of the injectors geometry.

3- Results and Discussion

The breakup characteristics of a liquid jet discharged into quiescent air vary in accordance with several factors. Variation of these factors determines the dominance of main governing forces of the liquid jet dynamics which are capillarity, aerodynamics and inertia forces. This diagram which is known as stability curve clearly distinguish between different regimes of jet breakup. Based on stability curve, jet breakup regimes are divided into three groups including Rayleigh regime, first wind-induced regime and second wind-induced regime. The breakup length of rectangular, elliptical and circular jets at the Weber numbers corresponding to the Rayleigh, first wind-induced and second wind-induced regimes is illustrated against the squared root of Weber number in Fig. 2. As seen, in low Weber numbers corresponding to Rayleigh regime, the breakup length of all jets increase linearly with Weber numbers until reaching a maximum. After that, the jets enter the first wind-induced regime at which the

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aerodynamic forces reduced the jets length. It is well shown that elliptical and rectangular jets are affected by surrounding air sooner than the circular jets. This is due to larger perimeter of the non-circular jets.

At higher jet velocities, where jets are in the second wind-induced regime, the length of the circular jet is much shorter than other jets. However, the comparison between elliptical and rectangular jets reveal that the different between them is negligible as they both are governed by the presence of axis-switching phenomenon.

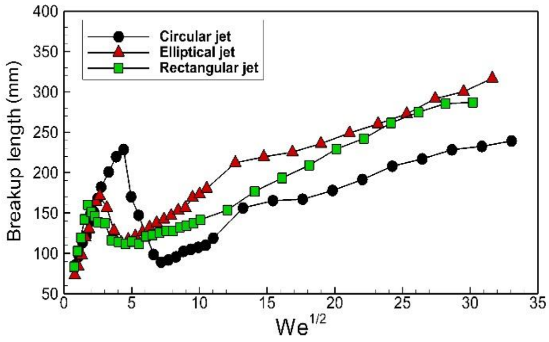

Fig. 2. Breakup length of rectangular, elliptical and circular jets.

For every elongated nozzle such as rectangles or ellipses, there is a minimum We at which liquid jet begins to display interfacial oscillations that are known as axis-switching. Prior to this minimum We, the liquid jet transforms into a circular column due to the work of capillary forces. The characteristics of axis-switching phenomenon which are wavelength and wave amplitude have been investigated for both of the rectangular and the elliptical jets. The variation of the axis-switching wavelength with square root of Weber number is illustrated in Fig. 3. This figure demonstrates that the axis-switching wavelength grows linearly for both rectangular and elliptical jets. It is seen that the wavelength of both jets are nearly the same.

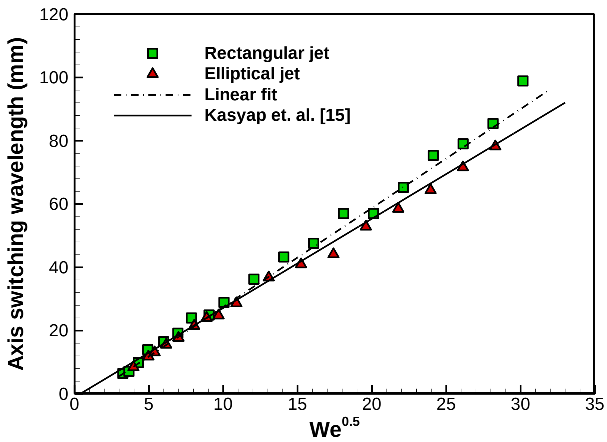

Fig. 3. Variation of axis-switching wavelength.

The measurements of axis-switching amplitude were performed for both elliptical and rectangular jets for a wide range of velocities. The variation of D_{max} with the square root of Weber number is shown in Fig. 4. According to this figure, two distinguish behaviors can be observed for the axis-switching amplitude. At the first stage, the amplitude of rectangular jets increases monotonically with $\sqrt{We}$. This stage is in coincidence with the strengthening of jet lateral inertia that happens due to the increase of jet velocity. After reaching a maximum point, the slope of D_{max} begins to decrease gradually.

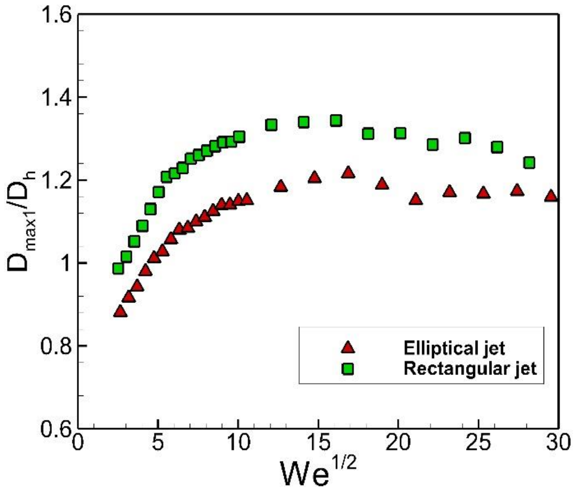

Fig. 4. Variation of axis-switching amplitude.

4- Conclusion

In this study, the flow characteristics of rectangular, elliptical and circular jets were experimentally investigated. Using shadowgraphy technique and high speed photography, the jets flow was captured at different flow conditions. Different parameters of the liquid flows were obtained and compared between different geometries. It was revealed that at high jet velocities the mean breakup length of elliptical and rectangular jets is nearly equal and longer than the circular jet. It was also shown that the non-circular jets enter the first wind-induced and second wind-induced regimes at lower velocities in comparison with circular jet. The variation of axis-switching wavelength were measured for both elliptical and rectangular jets and it was figured out that wavelength increases linearly with jet velocity. Further, the different between the wavelengths of elliptical and rectangular jets was negligible at lower velocities, while their difference increased at higher velocities. Based on this results, a semi-empirical relation was developed for describing the axis-switching wavelength of non-circular liquid jets.