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Experimental Comparison of Injection Characteristics of Elliptical and Circular Liquid Jets into an Air Crossflow

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ABSTRACT: The flow characteristics of liquid jets issuing from elliptical and circular injectors into an air crossflow were experimentally investigated. Two elliptical injectors with different aspect ratio and a circular injector as the reference case with the same cross-sectional area was employed. The major axis of the elliptical nozzles was aligned parallel and perpendicular to the air crossflow direction. The liquid jet was visualized using shadowgraph technique and a high-speed camera was used to record the instantaneous status of the jets. The liquid/air momentum flux ratio and air Weber number were varied to examine their effects on different parameters of the flow like liquid jet column trajectory, breakup point and breakup regimes. The results revealed that some characteristics of injected liquid jets into the air crossflow such as penetration depth and the trajectory of liquid jet were affected by changing the nozzle exit shape. Based on the obtained results elliptical liquid jets because of the lower stability than circular jet, break up sooner and penetrate lower into the air crossflow. As the normalized breakup height of the circular jet is obtained 29.5 but the normalized breakup height of the elliptic jet with the aspect ratio of 3 and when its major axis was perpendicular to the crossflow direction, is obtained 21.53. In this study two different breakup regimes were observed, column breakup and bag breakup regimes.

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1. INTRODUCTION

The injection of liquid jets into an air crossflow also called Jet in Crossflow (JICF) has many practical applications in the air breathing engines such as diesel engines, gas turbine engines, ramjet and scramjet engines [1, 2]. The efficiency of these engines depend on dispersion, atomization and vaporization processes of injected liquid fuel jet [1]. According to Schetz et al. [3] the maximum penetration height of the injected liquid jet is the distance that the momentum of liquid jet required to redirect in the crossflow direction. Chen et al. [4] divided the injection of the liquid jet into three regions: liquid column, ligament and spray plume regions. Breakup regimes and locations of injected liquid jet were obtained by Wu et al. [5]. They investigated the breakup properties and the trajectory of injected liquid jets in subsonic air crossflow. They classified the column breakup region into four sub-regions: liquid column/capillary breakup, bag breakup, multi-mode breakup and shear breakup. Birouk et al. [6] studied the effect of changing the liquid viscosity on the primary breakup regimes. They found that the liquid viscosity has no effect on the mechanisms of breakup of jets in crossflow. Tambe et al. [7] investigated the effect of surface tension on the jet column behavior and they found in the surface breakup regime a liquid jet with low surface tension (Jet-A) produced smaller droplets than the other liquid with high surface tension (Water).

The main aim of this work is to study the effect of injection liquid jet from elliptical nozzle on characteristics such as liquid column trajectory, breakup location and the size of established bags on the liquid column and also compare them with a circular jet having the same cross-sectional area.

2. EXPERIMENTAL APPARATUS

The wind tunnel is capable to provide a uniform air stream in the test section with a velocity raging between 0.2 m/s to 45.5 m/s. The test liquid was stored in the storage tank and pressurized with high pressure nitrogen gas. The liquid jet was injected into the air crossflow from the top of the test section through a nozzle which is mounted 200 mm downward of the inlet of the test section. Shadowgraph technique used for taking photos, an image processing code was developed to obtain required data from the photos. It should be noted that within this paper, “C” and “E” are abbreviations for circular and elliptical nozzle. Moreover, “E(0°)” means that the major axis of elliptic nozzle is parallel to the crossflow direction and “E(90°)” for when major axis of elliptic nozzle is perpendicular. The experimental details of the current study are presented in Fig. 1.

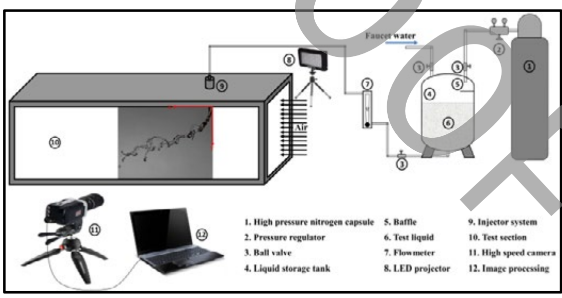

Fig. 1. Schematic of the experimental setup.

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3. RESULTS AND DISCUSSION

In this study two different breakup regimes which are column breakup, bag breakup regimes were observed. The visualized shadowgraphs of these breakup regimes, at two different air Weber numbers of We_a = 2 and 7 and the same momentum ratio q = 20 are presented in Fig. 2.

3.1. Liquid Column Trajectories

As shown in Fig. 3 the elliptical jet deflected more towards the air crossflow direction specially when the major axis of the nozzles was aligned perpendicular to the air crossflow direction. This is because of the fact that the elliptical liquid jet has frontal area as flat shape and this causes elliptical jet is more affected by the aerodynamic drag force which is consistent with the experiment observations of Song et al. [8].

3.2.Bag Formation

As air Weber number increases, the liquid jet deforms from its initial shape as a flat sheet. This deformation of the liquid column is due to the uneven pressure distribution at its sides. Bags appear and grow on the leeward side of the liquid column. These bags expand until the membrane of bags become thinner enough and surface tension of the liquid jet cannot hold them [9]. Fig. 4 illustrates bag formation and breakup process for 10 ms.

Fig. 2. Breakup regimes. A) Column, B) Bag.

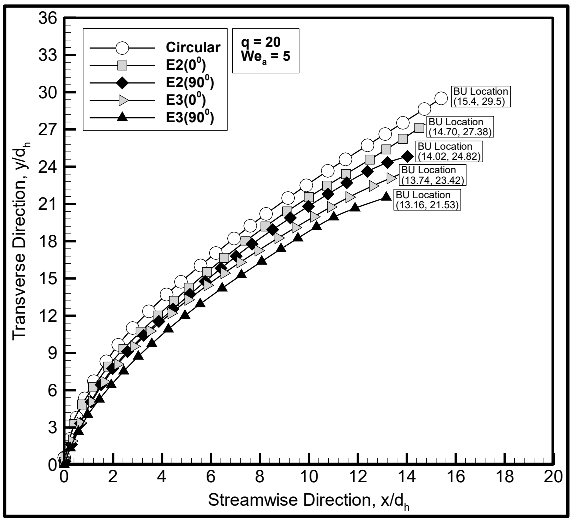

Fig. 3. Circular and elliptical liquid jet trajectories.

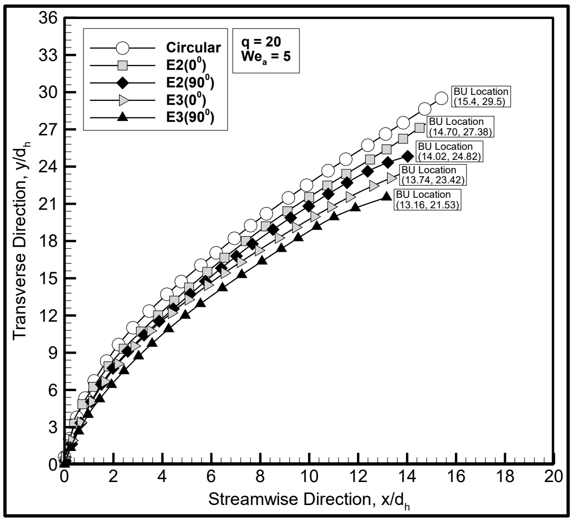

Fig. 4. Bag Formation and breakup Process.

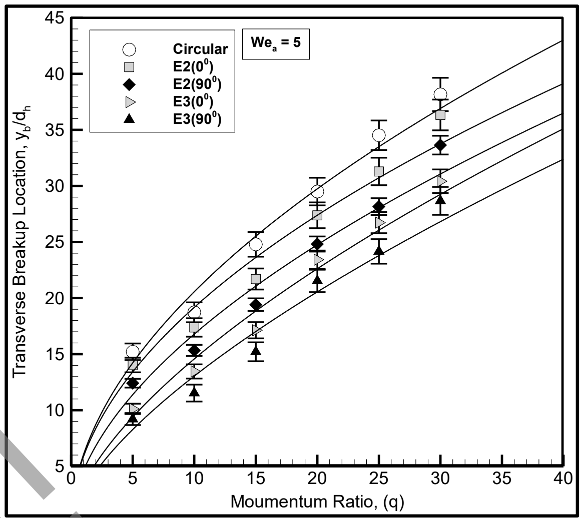

Fig. 5. Breakup location of circular and elliptical jets.

3.3. Column Breakup Location

As notable from the Fig. 5 circular jet penetrated more than the elliptical liquid jet. This may due to the elliptic jet is affected more by the aerodynamic forces and consequently the penetration of the elliptic jet is fewer than circular.

4. CONCLUSIONS

The main results of this paper can be summarized as follows: Elliptic jets curve more toward the air crossflow direction and even more than circular jet and also from measured data at the same conditions, elliptic jets show less penetration than the circular jet especially when the major axis of the elliptical nozzles is placed perpendicular to the crossflow direction. This may due to the fact that in this situation elliptical liquid jet has frontal area as flat shape and this causes the jet affected more by the aerodynamic drag force. In the elliptical liquid jets, formation of the breakup regimes is at the low air Weber number. The size of bags which are formed on the column of elliptical jet, are bigger than the bags formed on the circular jet. The membrane of a bag growths more than its ring.

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