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Study on the Base Flow of Two-Dimensional Liquid Jets Injected Into Quiescent Air

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ABSTRACT: The flow dynamics of two-dimensional liquid jets issued into still air were experimentally studied. Three injectors with a thickness of 0.35 mm and aspect ratios of 30, 60 and 90 were used. The experiments were performed for volume flow rates ranging from 10 to 120 liter per hour. High speed photography was employed for capturing physics of the jet flows. The flow development of two-dimensional liquid jets was categorized into four groups including 1) dripping regime, 2) column regime, 3) triangular regime, and 4) perforation regime. Also, different parameters of liquid sheet such as convergence angle, convergence length, and retraction velocity were also measured. The obtained results showed that the convergence length of the jets increases with aspect ratio. Furthermore, it was revealed that the convergence angle and retraction velocity were independent of the aspect ratio. Based on the experimental data, several empirical relations were developed for description of different flow parameters.

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1- Introduction

The experimental studies focusing on the fluid flow of a two-dimensional liquid sheet discharged into quiescent air are rare. Indeed, the liquid sheets produced by two-dimensional injectors, have been mostly investigated in the presence of co-flow air to assist and accelerate the breakup process and achieve better mixing between liquid fuel and oxidant in the combustors.16 This method that has been the subject of many studies is well-known as airblast atomization. Rizk and Lefebvre [1], Stapper et al. [2], Mansour and Chigier [3], Carvalho et al. [4], Lozano et al. [5], and recently Oshima and Sou [6] are some known works that have studied the instability characteristics and breakup mechanisms of air-blasted two-dimensional liquid sheets. However, the flow pattern of resulted two-dimensional liquid sheets in the absence of air co-flow was shortly mentioned in the works of Mansour and Chigier [3] and Carvalho et al. [4] According to their observations, the edge of the sheet recedes toward the axial axis due to the work of surface tension and thick blobs are formed at the edge. The length of the converging part of the sheet was obtained and reported in both studies, though a significant difference existed between the two sets of results as was shown by Carvalho et al. [4]. As far as the authors are aware, no more quantitative or qualitative results about the flow physics of liquid sheets issuing from two-dimensional orifices have been reported. In this study, the flow characteristics of liquid sheets injected from thin slits with high aspect ratios were experimentally investigated. The flow features were captured from both front and side views and corresponding quantitative results were reported and discussed. To the authors' knowledge, the instabilities studied in this work had never been previously derived from experimental measurements.

2- Experimental Setup

The experimental setup used in this study is the same one previously employed and well described by Jaberi and Tadjfar [7]. Two-dimensional liquid jets were produced through slits of very high aspect ratios. Three injectors with an equivalent thickness of 0.35 mm and aspect ratios of 30, 60 and 90 were manufactured from stainless steel. These injectors are respectively indexed as TD1, TD2, and TD3. The injectors were accommodated into a settling chamber with diameter of 45 mm and length of 800 mm. The schematic of the injector and settling chamber assembly is provided in Fig. 1. In order to visualize the details of the jet flow structure, diffused backlight shadowgraphy was implemented. Moreover, a high speed camera was implemented to capture the instantaneous features of the flow at high frame rates and low exposure time. The photos were taken by a Nikon 1 J4 camera, equipped with a Macro-NIKOOR AF-S 60 mm lens. All the photos of this study were taken with 1200 fps and exposure time of 62.5

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μs. An in-house code was developed to process the photos taken from two-dimensional liquid jets injected into still air.

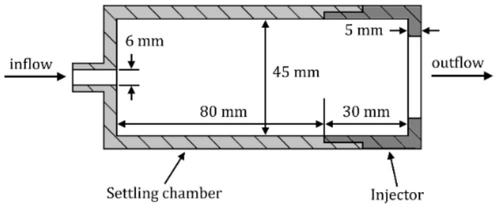

Fig. 1. Schematic of the injector assembly.

3- Results and Discussion

Different regimes associated with the development of a two-dimensional liquid jet that is emanated into stagnant air is represented in Fig. 2. We have proposed four regimes which are: 1) Dripping regime, 2) Column regime, 3) Triangular regime, and 4) Perforation regime. Dripping regime happens at low jet velocities where jet inertia is very small and surface tension is completely prominent. With increase of jet velocity, liquid jet leaves the injector as a column that breaks at a distance downstream.

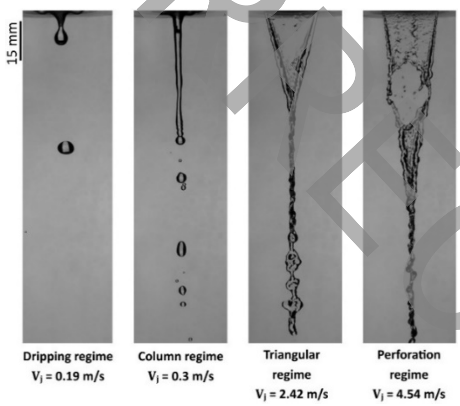

Fig. 2. Different regimes of two-dimensional liquid jets.

The triangular regime is shown in Fig. 2 for the velocity of 2.42 m/s, wherein the liquid inertia was increased gradually so that the liquid leaves the injector as a sheet. Due to the work of surface tension, the edges of the liquid jet retreat towards its central axis and establishes thick borders. This retraction of jet borders and its convergence towards the central axis forms a triangular shape. By more increase of jet velocity, instabilities are emerged and grown within the liquid jet. These instabilities are well seen immediately downstream of the jet exit in Fig. 2 for the photo representing perforation regime. Due to the growth of these instabilities, some local ruptures occur across the thin liquid sheet. These perforations become larger in time and finally reach the thick borders of the liquid jet and then disintegrates. In Fig. 3, the variation of jet convergence angle with jet exit velocity is plotted. As seen, convergence angle exhibits an asymptotic behavior so that by increase of jet velocity, β_c approaches to 90°. For jet velocities smaller than 2 m/s, the variation of convergence angle is very extreme but for higher velocities, it increases at a slower pace.

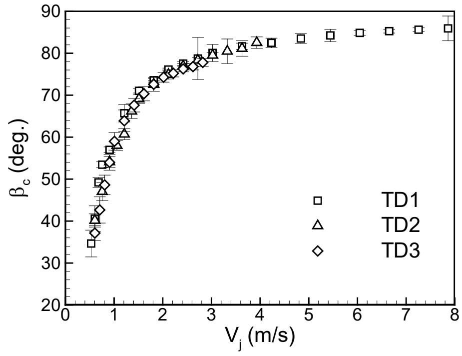

Fig. 3. Convergence angle of liquid jets.

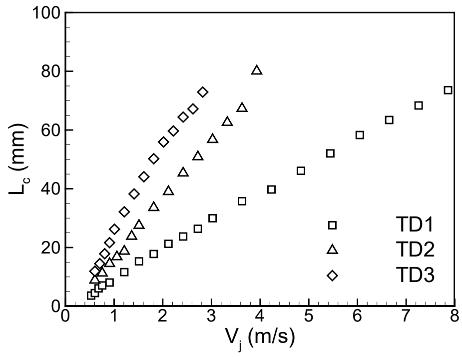

Fig. 4. Variations of convergence length.

According to Fig. 4, for all jets, the convergence length increases linearly with velocity. The increase of jet velocity leads to the strengthening of jet inertia which competes with surface tension that attempts to retract the jet boundaries. Resultantly, the process of jet convergence happens slower that makes the convergence length longer. On the other hand, this increase of convergence length is completely depending on aspect ratio, so as for the TD1 jet the rate of L_c increase is slower than others and for TD3 jet, L_c increases with a steeper slope. For low jet velocities where surface tension is dominant, the retraction velocity is high, but with increase of jet velocity and jet inertia, retraction velocity decreases as well. The variations of retraction velocity, V_R, with jet velocity are given in Fig. 5 for TD1, TD2, and TD3 jets. As seen, at low velocities where surface tension forces are dominant, retraction velocity is high, but with jet velocity increase, it decreases gradually until reaching a constant value.

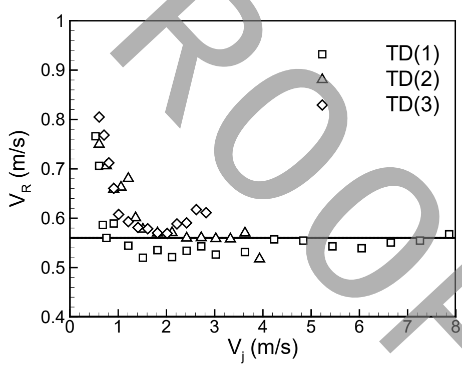

Fig. 5. Retraction velocity of liquid jets.

4- Conclusions

The main flow characteristics of two-dimensional liquid jets issued into still air were experimentally investigated. The flow of the two-dimensional liquid jets was categorized into four different regimes including the dripping regime, column regime, triangular regime, and perforation regime. The main features of the two-dimensional liquid jets in triangular regime were measured.

5- References

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