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Experimental Study of Hydrodynamic Behavior and Breakup of Liquid Jet with/without the Electric Field

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ABSTRACT: In this study, the hydrodynamic behavior of fluid jet with/without application of electric field is studied and intensity and direction of the electrical field are investigated experimentally on instability and jet breakup. The study of the shape and size of produced droplets after the fluid jet breakup are another cases in this study. Results show that fluid jet characteristics depend on Reynolds number in jets which are only based on gravity. Jet mean diameter and its breakup length in this type of jets are directly related to Reynolds number. Studies show that jet mean diameter is increased and breakup length is decreased by applying electrical field. According to investigations, increasing of electrical field intensity leads to decreasing in jet breakup length and direct field has a significant effect in comparison with reverse one on it. Studies show that jet mean diameter and breakup length are decreased by applying electrical field. Increasing of electrical field intensity leads to decreasing in jet breakup length and direct field has a significant effect in comparison with reverse one on it. By applying a 6 kV electric field, the upper jet breakup length can be reduced by 27% in comparison with non-field state. The standard deviation of produced droplets in non-filed state and reverse electrical field with 2kV intensity is equal to 1.3 and 1.1, respectively which indicates a more uniform droplet in presence of reverse electric field. The investigation of produced droplets in term of roundness showed that electrical field leads to producing circular droplets and reducing the frequency of irregular droplets.

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1- Introduction

A liquid jet flowing out from a nozzle into an ambient gas may breakup into small drops when it is exposed to even minute disturbances. These disturbances can be in the form of surface displacement, pressure or velocity fluctuations in the supply system or on the jet surface, as well as fluctuations in liquid properties such as temperature, viscosity, or surface tension coefficient. The instability and breakup of liquid jets into drops has been a subject of interest since the early nineteenth century [1].

Electrohydrodynamic as an active method has been applied in many fields such as heat transfer, electrospraying, and mixing. The electrification of jets has provided an enhanced control method on droplet forming as the electric forces may change the stability of the jet or the trajectory of the charged droplets created by the jet disintegration [2]. When a dielectric fluid jet flows through an electric field, three types of forces can be implemented to it; electrophoretic force that will be produced in the presence of free charges, dielectrophoretic force which will be produced because of permittivity difference between liquid jet and gaseous surrounding and electrostriction force which will be created in the presence of compressibility effects. These three forces can operate independently and be effective in hydrodynamics and stability of jet [3].

In this study, the hydrodynamic behavior of fluid jet, with/without application of electric field, has been studied as well as the effect of electric field on instability and breakup of jet

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2- Methodology

Fig. 1 shows the schematic view of experimental set up which consists of two parts: hydraulic part and electric part. The hydraulic part consists of a storage container to provide the required fluid to flow through the test section, an upper plenum to making constant and steady flow rates, a fluid collector container at lower part of the section, a steel capillary nozzle, and a number of control valves and height adjustment stands. The electric part consists of a HV power supply, electrodes, and a light source which provides suitable light to illuminate the jet interface at the darkroom. High Voltage power supply provides up to 35 kV electric potential difference between HV and GR electrodes.

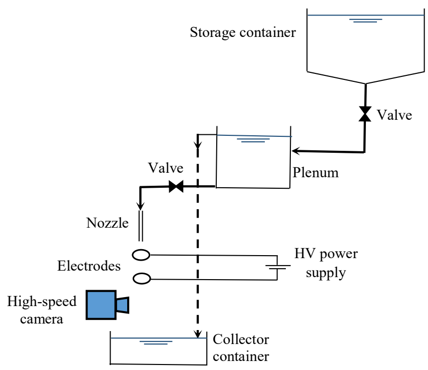

Fig. 1. The schematic view of the experimental setup

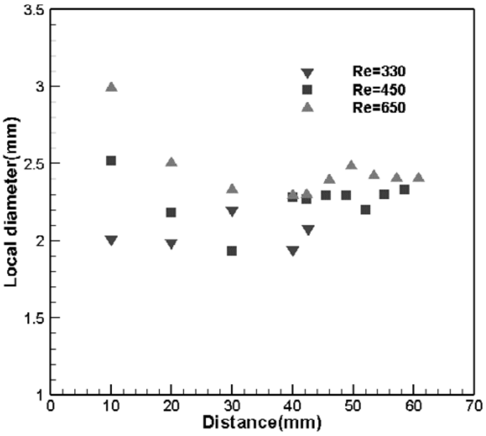

Fig. 2.The local diameter of water jet in different Reynolds numbers

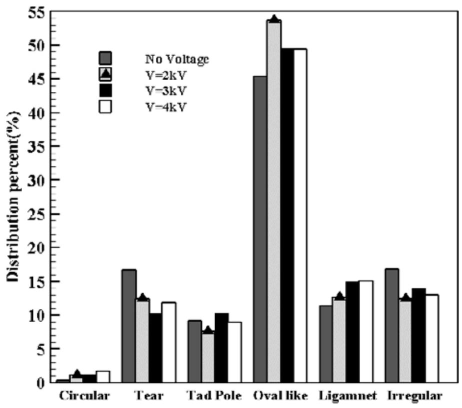

Fig. 4. Cracks grown in a sample that has been photographed with VMM

Movies from jet flow were recorded using high speed camera by the frame rate up to 304.8 m/s. The camera was set on outlet of nozzle and jet specifications can be extracted using image processing. An image processing code in MATLAB was written in order to capture and analyze the recorded high-speed movies of jet breakup. The code captures movies into Red, Green and Blue (RGB) images in which the illuminated boundaries of jet are recognized. Local and instantaneous diameter of jet can be calculated using these captured images.

Distilled water and transformer oil were used as working fluids. It should be noted that all of the experiments were in the atmospheric pressure and environment temperature. Considering the calibration of distances in captured frames, accuracy of length measurements was estimated as 0.1 mm.

3- Results and Discussion

Fig. 2 shows the local diameter of water jet in different Reynolds numbers. Jet diameter decreases by distance from nozzle due to gravity effect. However, it is increasing at the region close to breakup because of the breakup which raises the broken jet column elastically and thickens the jet. Fig. 3 shows the variation of jet breakup length with Reynolds number. Increase in Reynolds number increases the jet diameter. These results are in good agreement with empiric correlation proposed by Grant and middleman [4] for breakup length of free falling jets.

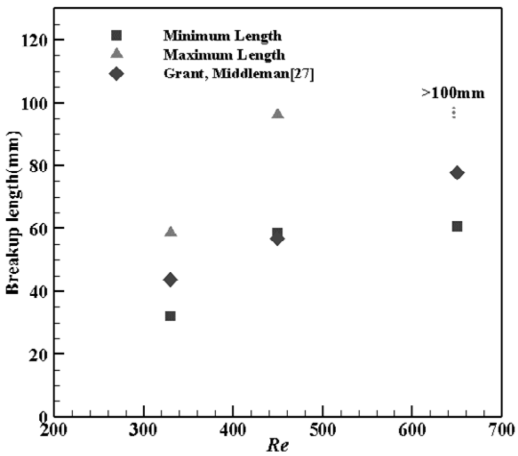

Fig. 3. The variation of jet breakup length with Reynolds number

In order to study the effect of electric field on jet breakup, transformer oil was used as working fluid that is a strong insulating fluid. Fig. 4 shows the effect of electric field on produced droplets' shapes. The existence of electric field leads to the formation of droplets with more roundness and reduces the production of irregular droplets. Increase in electric field intensity enhances the production of round droplets.

The standard deviation of droplets' size produced through unelectrified jet breakup was equal to 1.3 mm; nevertheless, this value was changed to 1.46 mm and 1.1 mm for the case with direct and reverse electric field application, respectively.

4- Conclusions

The study showed that in the case of unelectrified jets which disintegrate under the effect of gravity, in Rayleigh regime, the characteristics of jet and produced droplets depend on Reynolds number. Furthermore, mean diameter and breakup length of this type of jets are directly related to Reynolds number. The study of fluid jets in the presence of electric field indicated the considerable effect of electric field on important characteristics of jet and droplets produced by its breakup. As the field intensity increases, the size of the produced droplet changes and shape of these droplets become more uniform in special cases. Analyzing the produced droplets in terms of roundness showed that the electric field increases the round droplets production and reduces irregular ones.

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