Numerical Simulation of Single Droplet Hydrodynamics Affected by Electrostatic Forces with the Aid of CFD: CFD Simulation of Single Droplet Hydrodynamics

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ABSTRACT

In this study, Electrospray hydrodynamics and electrical potential dependency of heat transfer coefficient were investigated by computational fluid Dynamics (CFD). VOF method was applied to solve momentum equation of these two-phase flow and Whitaker empirical relationship for gas, liquid flow on sphere was also applied to calculate the heat transfer coefficient. The results of simulation were in accordance with experiments and showed that because of domination of surface tension by gravity and electric forces, diameter of droplets and their formation time were decreased. In addition, applying electrical potential at the velocity of 0.007 m/s has led to formation of jet and small droplets of liquid. Formation time of the droplet was decreased by increasing the velocity ten times higher than the previous time, to 0.07 m/s. By using the results of hydrodynamic simulation of droplet, convective heat transfer coefficient of droplet was calculated in various electrical potentials that showed heat transfer coefficient increased by growth of electrical potential.

KEYWORDS
Electrospray, Ethylene Glycol, Heat Transfer Coefficient, Hydrodynamic

INTRODUCTION

Spraying is the physical process of dispersing a liquid as a stream of droplets in a gas form. The point of spraying is maximizing the liquid impressions by increasing its surface. Sprays are the instruments to simplify the spraying process of liquids and they typically include a nozzle through which liquid gets dispersed after passing through it, depending on various factors and spray type. There are different types of sprays that include in hydraulic, gaseous, supersonic and vibrant ones (Speranza & Ghadiri, 2003). When a specific process is sensitive to droplet size and its distribution, controlling the operation conditions such as flow rate, electric field strength, viscosity and electrical conductivity is very important in order to produce the desired and uniform size of droplet. Thus, according to the ability of the electro-spray method in producing the desired and uniform droplets, replacing the conventional methods by this one will lead to an improvement in spraying process. Electro-spray method can be applied instead of conventional methods in internal combustion engines, production of biodegradation polymer particles in the micrometer and nanometer dimensions (Xie, Lim, Phua, Hua, & Wang, 2006), Preparation of immobilized enzyme gel (Watanabe, Matsuyama, & Yamamoto, 2001), spraying outturns(crops) (Speranza & Ghadiri, 2003; Watanabe, Matsuyama,
& Yamamoto, 2003), color spray painting (Okuda & Kelly, 1996), and the pharmaceutical industry (Ijsebaert, Geerse, Marijnissen, & Scarlett, 1999; Jaworek & Sobczyk, 2008).

Electro-spray is a method that controls the distribution of droplets in spraying liquids by using an electrical field as an external factor (Lenggoro, Xia, Okoyama et al., 2002; Speranza & Ghadiri, 2003; Bock, Woodruff, Hutmacher et al., 2011). The theory of dispersing a liquid as tiny charged droplets was proposed nearly a century ago by Lord Rayleigh for the first time (Xie et al., 2006). Usually in this method, electrical field is created by a direct high voltage electrical stream and connection of anode to the nozzle and connection of cathode to a disk that is in a certain distance lower than nozzle (Jayasinghe & Edirisinghe, 2002). In some cases, the earth applies as the cathode (Watanabe et al., 2003). Using an electrical conductor liquid causes the external surface of the liquid flow pulled down by a determined force in the nozzle spout under the impression and control of the created electrical field and then the droplets are created by domination of this force on surface tension and tearing the liquid surface. Operation conditions and the liquid properties are two effective factors in electro-spray process. Some of the properties of the liquid which are effective in the electro-spray process are density, electrical conductivity, viscosity and surface tension (Camelot, Brunner, Hartman et al., 1998; Dudout, Marijnissen, & Scarlett, 1999). These properties have a determinant impress on the general state of the electro-spray process; especially in jet mode they have a main effect on creation of droplets from liquid jet. So far, many studies have taken place on the effect of operating parameters such as flow rate (Xie & Wang, 2007), the intensity of the electric field (Shin, Yiacoumi, & Tsouris, 2004) and nozzle diameter (Chen, Emond, Kelder et al., 1999) on the production and droplet size distribution. In the field of modeling, electro-spray process can refer to models offered by Hartmann et al. (1999) and Speranza et al. (2003). In these two models, a cone and a short jet have been used as the basic shape of a cone jet. The results showed good accordance with the results obtained from experiments in the range of 0-8 kV. Numerical modeling electro-spray of heptanes and methanol with CFD, without considering any basic shape or load distribution was done (Lastow & balachandran, 2006). The weakness of this simulation is that it does not show spray phenomena after formation of a stable cone jet. Sen et al. (2007), studied the electro-spray process using nano carbon fibers around multifold and parallel orifices and they showed the possibility of applying nano fibers to create unique electro-spray process for a wide range of flow rate, the electrical potential and fluid characteristics and the results can be used in mass spectrometry. In order to simulate the fluid flow distribution and free surface profile of perfectly conductive liquid jet under the effect of an electric field a numerical model was developed (passandideh Fard, Rahimzadeh, & Pooyan, 2010). Grifoll et al., (2011), studied what step times would be useful in modeling of electro-spray process. They found out that after the jet breaks, a volume of small droplets get form in a region. If in modeling the number of micro-droplets that fall outside the region is minor, it means that the chosen step time is better. So far, studies that have been done to identify the electro-spray process are divided into two laboratory studies and simulations. So many laboratory studies have been done in this field and different states of this process have been examined. But simulations conducted in this field have focused more on the process of jet mode formation and there has been less attention to formation of dripping mode. Therefore, in this study after discovering the accuracy of the results of hydrodynamic simulation of droplet formation process, the electrostatic dependency of heat transfer coefficient has been investigated.

MODEL AND EQUATIONS

Volume of Fluid Model (VOF)

VOF method applied to simulate the process. This finite difference model which used for the first time by Hirt and Nichols (1981), is a way to determine the surface path that is applied to a fixed
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