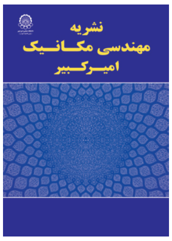

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 50(4) (2018) 247-250
DOI: 10.22060/mej.2017.12267.5302

Numerical Simulation of Drop Deformation and Breakup in an Electric Field

H. Dastourani[1], M. R. Jahannama[2*], A. Eslami Majd[3]

[1] Aerospace Research Institute, Tehran, Iran
[2] Space Transportation Research Institute, Iranian Space Research Center, Tehran, Iran
[3] Electrical and Electronics Department, Malek Ashtar University of Technology, Tehran, Iran

ABSTRACT: Liquid drop suspension in another fluid occurs in many natural processes. Applying electric field has shown a promising outlook for the control of motion, deformation, breakup and guidance of the drops. In this study, the dynamic response of a liquid drop suspended in another fluid across two conducting electrodes held at different electrical potentials has been simulated. In this regard, the effects of electric potential, electrical conductivity and relative permittivity have been studied. According to results, an increase in electric potential and conductivity leads to increasing trend in drop deformation whereas this trend converts into an ascending-descending pattern due to increase in electrical permittivity. An insight into the flow patterns inside and outside the drop shows that the positioning of a liquid drop in an external electric field in addition to drop polarization results in an electric field induced within the drop which causes the creation of vortices inside the drop. Magnitude of electrical conductivity and permittivity factors compared to each other apparently affect the accumulation area of electrical charges on the drop surface which in turn determines the circulating direction of vortices within the drop. Increasing electric field intensity due to an increase in electrical potential or change in magnitude of other physical properties would fortify the electric charge on the drop surface escalating drop deformation towards drop breakup. In this condition, the electrical polarization in addition to drop prolation causes jet exit from which a continuous line of droplets is emerged until the total dissipation of the drop.

Review History:

Received: 26 December 2016
Revised: 17 March 2017
Accepted: 21 May 2017
Available Online: 7 June 2017

Keywords:

Drop deformation
Electrical conductivity
Electrohydrodynamics
Numerical simulation
Relative permittivity

1- Introduction

Liquid drops (as a discrete phase) suspended in another fluid (as the continuous phase) exist in many natural processes such as blood flow in the body, petroleum refinement and bubbly flow reactors [1]. Applying an electric field has offered a promising outlook on the control of the drop motion and deformation. Dynamic Response of a drop under an electric field, in addition to the strength of the electric field, depends on the physical properties of the drop and its surrounding medium. The pertinent literature reveals various numerical research works in the field of drop deformation owing to an electric field. In these research studies, which are based on the simulation of two phase flow, tracking of the two phase interface can be considered as one of the most important differences in the solution methodology. For instance, level set, volume of fluid and phase field are the methods commonly used [2-4]. In the present study, an electrohydrodynamic solver has been developed employing the open source software of OpenFOAM based on the volume of fluid method for tracking the interface of two phases using the thorough structure of the governing equations. The solver has been used to investigate the deformation and breakup of a liquid drop positioned and imposed to an electric field.

2- Methodology

2- 1- Main formulations

The electrospray process includes a set of fluid flow and electrical equations. The equations of fluid flow include the Navier-Stokes equations as well as the volume fraction equation for tracking the liquid-gas interface as given by Saville [5]:

$$\nabla \vec{u} = 0 \tag{1}$$

$$\rho\left[\frac{\partial \vec{u}}{\partial t} + \vec{u}\cdot\nabla\vec{u}\right] = \nabla P + \mu\nabla^2\vec{u} + \vec{F}_{ST} + \vec{F}_{ES} \tag{2}$$

$$\frac{\partial C}{\partial t} + \nabla.(\vec{u}C) + \nabla.\left[\vec{u}_r C\,(1-C)\right] = 0 \tag{3}$$

where $\vec{u}$, ρ, μ, P and C are velocity vector, density, viscosity, pressure and volume fraction, respectively. In addition, $\vec{F}_{ST}$ represents the surface tension force on the interface and is given as the following [5]:

$$\vec{F}_{ST} = -\gamma\left(\nabla.\left(\frac{\nabla C}{|\nabla C|}\right)\right)\nabla C \tag{4}$$

In Eq. (2), $\vec{F}_{ES}$ is the electric force whose determination needs the electrical equations including Poisson and the electric charge conservation equations be taken into account as given by,

$$\nabla.(\varepsilon\nabla\Phi) = -\rho_e \tag{5}$$

$$\frac{\partial \rho_e}{\partial t} + \nabla.(\rho_e\vec{u}) - \nabla.(K\,\nabla\Phi) = 0 \tag{6}$$

Corresponding author, E-mail: m.jahannama@isrc.ac.ir

where ε, Φ, ρ_e and K are permittivity, electric potential, volume electric charge density and electrical conductivity, respectively. Accordingly, the electric force can calculated using the following equation [5]:

$$\vec{F}_{ES} = \rho_e \vec{E} - \frac{1}{2}\left(\vec{E}\right)^2 \nabla\varepsilon \tag{7}$$

where $\vec{E}$=-∇Φ represents the electric field. In this study, the aforementioned set of equations are coupled and solved simultaneously.

2- 2- Brief description

The theme studied in this research work consists of the deformation of a spherical drop inserted between two parallel disks held at different electric potentials as shown in the Fig. 1. The simulation is considered axisymmetric and the computational domain is discretized using a structured and non-uniform grid. After evaluating grid independency, the mesh size with $R_d/\Delta z$=200 at the drop region was chosen for the subsequent simulations.

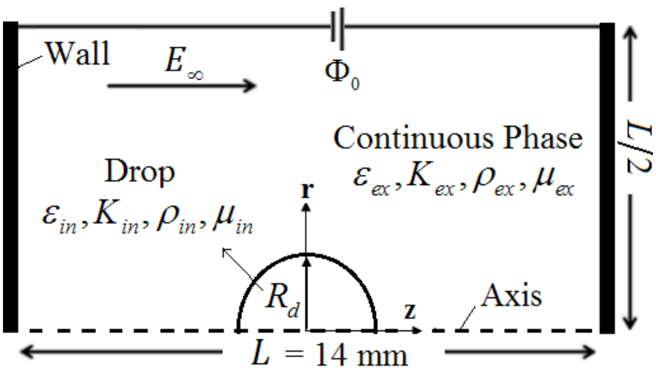

Fig. 1. A sketch of the theme geometry

3- Results and Discussion

In this study, the dynamic behavior of a liquid drop under the influence of an electric field has been studied both in small (deformation) and large (breakup) conditions for a prolate state.

3- 1- Small deformation of drop

In evaluating the small deformations, R_d=1mm and the physical properties of the drop and the surrounding fluid are considered according to Table 1. For this purpose, the effects of electric potential (Φ_0), electrical conductivity ratio (K_r) and relative permittivity (ε_r) have been examined and compared with the Taylor dielectric theory [6].

In evaluation of Φ_0 on drop deformation (D), the relative parameters are considered as K_r=10 and ε_r=2 while the simulations are performed for various values of Φ_0. Fig. 2 depicts the changes of drop deformation versus Φ_0. It can be seen in the figure that increasing in Φ_0 results in a larger drop deformation stemming from the rise in the electric field strength due to the higher electric potential.

Table 1. Physical properties of the fluid phases employed in the study of small deformations of drop

Property	ρ (kg m^{-3})	μ (mPa s)	K (S m^{-1})	ε	γ (N m^{-1})
drop	1000	0.001	20×10^{-13}	$2\varepsilon_0$	
surrounding fluid	1000	0.001	2×10^{-13}	$2\varepsilon_0$	0.0284

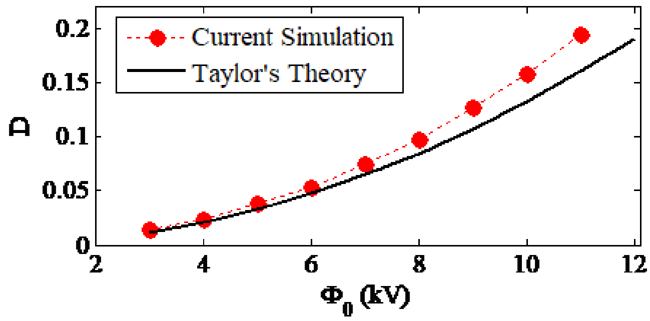

Fig. 2. Drop deformation versus electric potential for K_r=10 and ε_r=2

In evaluation of K_r on drop deformation, Φ_0=7 kV and ε_r=2 are taken and the simulations are performed for various values of K_r. Fig. 3 demonstrates the changes of D versus Kr. As can be seen, an increase in Kr causes an increase in the drop deformation with a descending growth rate.

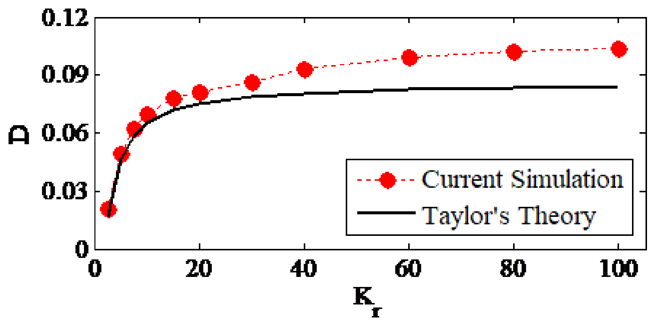

Fig. 3. Drop deformation versus electrical conductivity ratio for Φ_0=7 kV and ε_r=2

In evaluation of ε_r on drop deformation, Φ_0=7kV and K_r=10 are considered and the simulations are carried out various values of ε_r. Fig. 4 shows the variation of D versus ε_r. As the figure shows, increasing ε_r, by creating a descending-ascending trend for D, leads to a minimum value for D corresponding to ε_r=K_r.

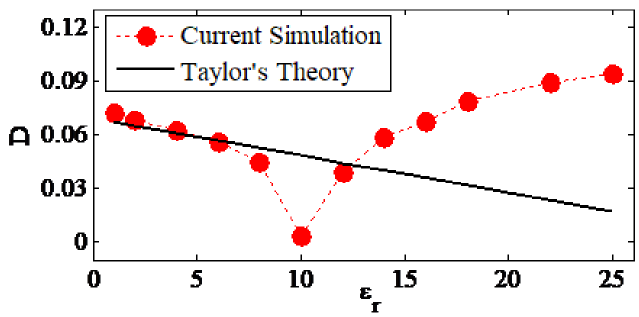

Fig. 4. Drop deformation versus relative permittivity for Φ_0=7 kV and K_r=10

3- 2- Large deformation and breakup of drop

For large deformation and breakup of drop, R_d=0.3mm, Φ_0=23kV and the physical properties of drop and the surrounding fluid are considered as given in Table 2. Fig. 5

Table 2. Physical properties of the fluid phases used in study of large deformations of drop

Property	ρ (kg m^{-3})	μ (mPa s)	K (S m^{-1})	ε	γ (N m^{-1})
Heptane	684	0.42	1.15×10^{-6}	$1.93\varepsilon_0$	
Air	1.225	0.0183	1.05×10^{-13}	$2\varepsilon_0$	0.0186

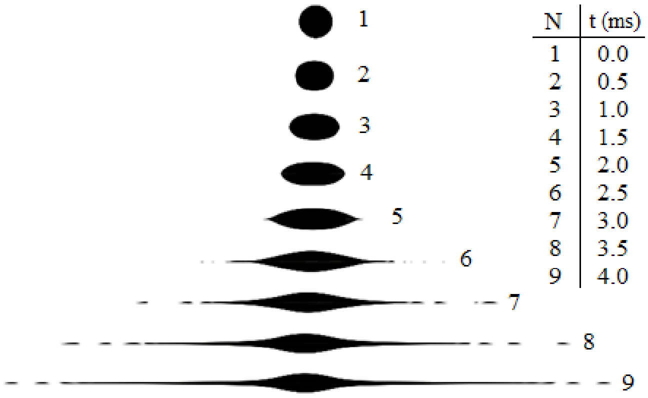

Fig. 5. Temporal pattern of drop deformation and breakup under the influence of an electric field

shows a temporal pattern of the drop deformation which leads to the continuous drop shrinkage owing to the emergence of liquid jet wherefrom the tiny liquid droplets are issued out.

4- Conclusions

The drop deformation and breakup is numerically studied in a prolate state. The results show that the increase in electric potential, electrical conductivity ratio and the relative permittivity lead to larger deformations owing to creation of higher electric field strengths as well as the inducement of greater amounts of electric charge on the drop poles. The conversion of drop deformation to drop breakup necessitates a considerable rise in the electric potential, which causes a strong polarization in the drop leading to an initial prolate deformation followed by the emergence of liquid jet from the drop poles issuing a stable line of droplets until the drop totally fades out.

References

[1] J. Hua, L.K. Lim, C.H. Wang, C.H., Numerical simulation of deformation/motion of a drop suspended in viscous liquids under influence of steady electric fields, *Physics of Fluids*, 20(11) (2008) 113302-16.

[2] O. Ghazian, K. Adamiak, G.S.P. Castle, Numerical simulation of electrically deformed droplets less conductive than ambient fluid, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 423(1) (2013) 27-34.

[3] J.M. López-Herrera, S. Popinet, M.A. Herrada, A charge-conservative approach for simulating electrohydrodynamic two-phase flows using volume-of-fluid, *Journal of Computational Physics*, 230(5) (2011) 1939-1955.

[4] Y. Lin, P. Skjetne, A. Carlson, A phase field model for multiphase electro-hydrodynamic flow, *International Journal of Multiphase Flow*, 45(1) (2012) 1-11.

[5] D.A. Saville, Electrohydrodynamics: the Taylor-Melcher leaky dielectric model, *Annual review of fluid mechanics*, 29(1) (1997) 27-64.

[6] G. Taylor, Studies in electrohydrodynamics. I. The circulation produced in a drop by electrical field, Proceedings of the Royal Society of London, Series A, Mathematical, *Physical and Engineering Sciences*, 291(1425) (1966) 159-166.

Please cite this article using:

H. Dastourani, M. R. Jahannama, A. Eslami Majd, Numerical Simulation of Drop Deformation and Breakup in an Electric Field, *Amirkabir J. Mech. Eng.*, 50(4) (2018) 767-784.

DOI: 10.22060/mej.2017.12267.5302