Propulsion and Power Research 2016;5(2):123–133

HOSTED BY

http://ppr.buaa.edu.cn/

Propulsion and Power Research

www.sciencedirect.com

ORIGINAL ARTICLE

Application of volume of fluid method for simulation of a droplet impacting a fiber

M. Khalili, H. Yahyazadeh, M. Gorji-Bandpy, D.D. Ganji[*]

Department of Mechanical Engineering, Babol University of Technology, P.O. Box 484, Babol, Mazandaran, Iran

Received 11 June 2014; accepted 5 May 2015
Available online 30 May 2016

KEYWORDS

Impact;
Newtonian drop;
Volume of fluid (VOF);
Numerical simulation;
OpenFoam®

Abstract In the present work, impact of a Newtonian drop on horizontal thin fibers with circular cross section is simulated in 2D views. The numerical simulations of the phenomena are carried out using volume of fluid (VOF) method for tracking the free surface motion. Impacting of a Newtonian droplet on a circular thin fiber (350 μm radius) investigated numerically. The main focus of this simulation is to acquire threshold radius and velocity of a drop which is entirely captured by the fiber. The model agrees well with the experiments and demonstrates the threshold radius decreased generally with the increase of impact velocity. In other words, for velocity larger than threshold velocity of capture perhaps only a small portion of fluid is stuck on the solid and the rest of the drop is ejected for impact velocity smaller than critical velocity the drop is totally captured. This threshold velocity has been determined when the impact is centered.

1. Introduction

Liquid aerosols have been widely used in many industrial applications, especially those need to be recovered from gas stream. Fibrous filters are commonly used to remove liquid aerosol particles from an exhaust stream. Filtration processes play an important role in many industrial, chemical, and mining operations such as fog nets, ventilation of atmospheric pollutions, removing of contamination in gases leaving compressors and so on. Even after a short period of running, liquids particles are captured on the surface of individual filter fiber, the filter becomes clogged, and the filtering characteristics may considerably change. The two main performance criteria of these filters are their efficiency and their pressure drop [1]. Contal et al. [2] described four

---

[*] Corresponding author.

E-mail address: ddg_davood@yahoo.com (D.D. Ganji).

Peer review under responsibility of National Laboratory for Aeronautics and Astronautics, China.

http://dx.doi.org/10.1016/j.jppr.2016.04.003

phases for clogging of fiber filters by liquid droplets. First, the droplets impact the wet fibers; then the amount of those droplets trapped on the fiber increases so that the nearest droplets coalesce. Third stage leads to a significant increase of the pressure drop and to a noticeable decrease in the efficiency of the filter. This is because of increasing of collected liquid which form liquid shells in the net. Finally, a pseudo-stationary state where pressure drop and efficiency leveled off can be established [3]. The phenomena included in drop impact onto surfaces were the subject of many studies. Rein [4] has presented a comprehensive review about these investigations. Much research has been conducted to understand the deformation of droplet during impact. Less attention has been paid to the phenomena taking place in the first stage of filtrations process. Patel et al. [5] described a critical offset for breakup during flow past a fiber to compare breakup probabilities experimentally and calculated breakup probabilities based on assuming straight center of mass trajectories. Hung and Yao [6] investigated the impaction of water droplets on isothermal cylindrical wires experimentally. To reveal the impaction characteristic, they evaluated the effect of droplet velocity and the wire sizes parametrically. Hardalupas et al. [7] discussed the phenomena occurring when mono disperse droplets impinge onto solid spherical target, with application to the operation of fluidized beds. Lorenceau et al. [8] studied the impact of a drop onto a solid plate pierced by a small hole and declared if the capillary force could not overwhelm drop weight, the drop eject out of the hole. In a later publication [3] they conducted many experiments to discuss the impact of a drop on horizontal fibers and determined the threshold velocity and radius of drops captured by thin fibers. The third scenario of their studies [9] was to investigate the effect of the relative position of the drop and the fiber on the impact. Therefore, they considered off-center impact where the drop trajectory and the fiber axis do not intersect.

In the case of numerical simulations, most studies have focused on simulating liquid droplets impacting onto a flat, horizontal plate [10,11]. Nevertheless, situations involved droplets impacting on non-flat surfaces still need more investigations. Bussmann et al. [12] modeled water droplets impacting onto either an inclined plane or the sharp edge. They applied a finite-difference, fixed-grid Eulerian model which used a volume-tracking algorithm to situate the free surface of droplet. The numerical results were compared with photographs of impacting droplets. Pasandideh-Fard et al. [13] have extended the model presented by Bussmann et al. [12] so that they could simulate arbitrary-shaped obstacles in the flow. They simulated droplets impacting on cylindrical tubes ranging in diameter 0.5 to 6.35 mm. Nevertheless, they only compared their numerical results of off-center impact of 2 mm diameter water droplet on 3.18 and 6.35 mm diameter tubes (larger than drop) with photographs. Because of the importance of the subject, numerous computational studies of these flows and nanofluid flows have been reported in the literature. Here only some relevant publications are mentioned [14–24]. Some reviews reflect that some aspects of the subject have been emphasized; and others have been omitted [24–33].

The main subject of the present study is the numerical investigations of a Newtonian drop impacting onto a horizontal thin fiber (350 µm radius). The impact is evaluated for various impact velocities, using water and silicon oil liquids. An interesting phenomenon, which appears at almost every drop impact on fiber, is the formation of a capillary wave after impact. The formation and evolution of this phenomenon are demonstrated in sequential images. A reliable prediction of separation in filters is aimed therefore the threshold radius of droplets in different impact velocities are calculated. The phenomena are carried out applying an advanced free-surface capturing model based on a two-fluid formulation of the classical volume of fluid (VOF) model in the frame work of finite volume numerical method. To adapt a thin circular fiber in computational domain and reduce the computational cost of modeling the grids are refined at the target and the region around it. The accuracy of the presented model is verified by comparisons between the computational results with those of the experiments performed by Lorenceau et al. [3].

2. Numerical method

2.1. Mathematical model

The gas–liquid interface needs to be tracked in order to recognize the position of the liquid phase. The most commonly used interface tracking is perhaps the VOF method. Volume of fluid (VOF) method was first presented by Hirt and Nichols [34,35]. Employing of the volume fraction γ (also known as the indicator function) is the important characteristic of the VOF method. The conventional VOF method computes the fluid volume at each cell. Mixed cells will have a volume fraction γ between zero and one and cells without interfaces will have a volume fraction equal to zero or unity. The isothermal, Navier-Stokes equations and advection equation can be written for the computational domain as follows:

$$\nabla \cdot \boldsymbol{U} = 0 \lim_{x \to \infty} \tag{1}$$

$$\partial_t \gamma + \nabla \cdot (\boldsymbol{U}\gamma) = 0 \tag{2}$$

$$\partial_t(\rho \boldsymbol{U}) + \nabla \cdot (\rho \boldsymbol{U}\boldsymbol{U}) = -\nabla p + \nabla \cdot \boldsymbol{T} + \rho \boldsymbol{f}_b \tag{3}$$

where $\boldsymbol{U}$ is the velocity vector, and ρ and μ are respectively the local fluid density and dynamic viscosity. $\boldsymbol{T}$ is the deviatoric viscous stress tensor $\boldsymbol{T} = 2\mu\boldsymbol{D} - 2\mu(\nabla \cdot \boldsymbol{U})\delta_{i,j}/3$, with the mean rate of strain tensor $\boldsymbol{D} = 0.5\left[\nabla\boldsymbol{U} + (\nabla\boldsymbol{U})^{\mathrm{T}}\right]$ and $\delta_{i,j}$ is the Dirac delta, p is pressure, and $\boldsymbol{f}_b$ are body forces per unit mass. In VOF simulations the latter forces include gravity and surface tension effects at the interface.