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CFD ANALYSIS OF THE FACTORS AFFECTING THE SATELLITE DROP FORMATION

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ABSTRACT

The objective of this paper is to investigate the impact of variable flow rate on the formation of satellite drop. In first case, we change the flow velocity and determine that when we increase the velocity for lower size capillary, the more satellite droplets formed. Similarly when we increase the size of the capillary tube, the amount of satellite droplet is more as compared to the previous dimension. Further it is shown that velocity effect is less on the smaller sized capillary tube as compared to the larger sized capillary tube.

Keywords: *VOF, Satellite drop, capillary tube, flow rate, Fluent*

I. INTRODUCTION

Droplet formation is used in a wide range of engineering applications. Droplet formation also plays an important role in inkjet printing process, spray cooling, and encapsulation process. In all of these applications, it is important that the droplets land predictably at their intended destination. During the drop formation, the primary droplet is the largest drop that is ejected from the capillary tube. Along with primary droplets some extra droplets (known as satellite droplet) are occasionally generated due to the collapse of the liquid column by surface tension. These satellite droplets are usually smaller than intended primary droplet. There are four types of satellite droplets generation mechanisms. The first type is mist of droplets. The droplet tail travels with primary droplet, however it is unstable when it becomes smaller and smaller. A certain source of perturbation will get enough amplitude to destabilize the tail. As a result, the small tail will break up randomly or another micro- thread will be formed randomly. The second type is known as Rayleigh instability. Generally the droplet is of high velocity. At this situation a long tail will be formed, which is unstable. At this time, capillary waves are excited by perturbation. However currently the perturbation is not the direct cause for breakup, it is only the initiation for break up. After that, the radius is reduced further due to surface tension. And finally, the long tail breaks up. The third type of satellite is a part of the droplet moves away in front of the head of the droplet. This kind of satellite droplets results from a supercritical acceleration at the start of the droplet formation process. Mostly, when liquid flows from the tail to the head of the droplet and surface tension is able to hold the liquid together. But if some part of liquid exceeds the maximum velocity, a new spherical droplet is formed. The fourth type of satellite, slow satellite, similarly is caused by a part of liquid with slow velocity.

NOMENCLATURE

v Fluid velocity (m/s),

p Pressure (Pa),

g Gravitational acceleration (m/s^2),

T Stress Tensor,

C Geometric Constant

t Time period (s)

L_1Length of glycerine-85% chamber (mm)

L_2 Length of air chamber (mm)

D_1 Diameter of glycerine-85% chamber (mm)

D_2Diameterof air chamber (mm)

Greek Symbols

ρ Density of the fluid (g/cm^3),

μ Dynamic viscosity of the fluid (cp),

σ Surface tension of the fluid (dyne/cm)

Dimensionless Number

Re Reynolds Number

G Gravitational Bond Number

Ca Capillary Number

The first mention of drop formation in the scientific literature is in a book by Mariotte (1686) on the motion of fluids. He notes that a stream of water flowing from hole in the bottom of container decays in to drops. Then after more understanding of drop formation is laid by Savart (1833), who very carefully investigated the decay of fluid jets. Different method for drop formation and application of it describe by Osman A. Basaran [1] and Pardeep P. Bhat [2]. Numerous researchers have since made significant experimental and numerical contributions to the field, providing insight into the discrete behaviour of Newtonian fluids on approach to and past the "pinch" region during dripping and jetting. Jens Eggers [3], [4] studied the basic of drop dynamics. Detail of different regime explains in that like dripping and jetting. Also the Navier-stokes one dimensional equation how describe the droplet with different method is discussed.

Simplified formulations of the Navier-Stokes equations for incompressible flow with a free surface have been produced in a number of studies in an effort to understand the physical mechanisms governing drop formation. So for numerical analysis of drop formation different algorithm made which predict the drop profile like the natural phenomenon. Edward D. Wilkes, Scott D. Phillips and Osman A Basaran [5] and V. Dravid, P. B. Loke,

C. M. Corvalan, P. E. Sojka [6] did the numerical analysis of drop capillary tube into ambient air by making Finite Element Algorithm which shows good agreement of his experimental data. Also D. F. Zhang and H. A. Stone [7] did drop formation at the tip of a vertical, circular capillary tube immersed in a second immiscible fluid is studied numerically for low Reynolds number flows using the Boundary Integral Method. Xiaoguang Zhang [8] developed model to predict the evolution of drop shape and its breakup from tip of vertical, circular tube in to ambient air based on Volume-of fluid/continuum-surface-force method. A model is developed by Xiaoguang Zhang [9] to predict the evolution of drop shape and its breakup based on RIPPLE, which is solution algorithm for computing transient, two-dimensional, incompressible fluid flow with surface tension of free surface of general topology. Brian Chang, Gary Nave, Sunghwan Jung [10] investigates the formation of a liquid droplet from a wettable nozzle. In the experiments, drops forming from a wettable nozzle initially climb the outer walls of the nozzle due to surface tension. Then, when the weight of the drops gradually increases, they eventually fall due to gravity. By changing the parameters such as the nozzle size and fluid flow rate, he observed different behaviors of the droplets. M.TjahjadI, H.A.Stone and J.M.Ottino [11] did complementary boundary-integral calculations to study numerically the evolution of the filament of drop from capillary as a function of the viscosity ratio of the fluids.

The goal of this research is to study the effect of various operating and design parameters, such as volume flow rate, thecapillary tube diameter on the satellite droplet.

II. METHODOLOGY

In the present study, the computational approach adopted is the finite volume method for two dimensional unsteady pressure based on the Navier-Stokes equation with volume of Fluid model and laminar flow model. When there are two or more immiscible fluids are present in the system then Volume of Fluid method is required to track and locate the movement of the two or more immiscible fluids.Here all the fluid shared the same single set of equations, and the volume fraction of each of the fluids in each computational cell is tracked throughout the domain. A single momentum equation has been used for both the fluid.

The numerical methodology assumes in this study is finite volume method of the two dimensional unsteady pressure based on the Navier-Stokes equation with Volume of Fluid model and laminar flow model.

To analyze the satellite drops during the drop formation process from capillary tube into ambient air we use ‘Volume of Fluid model’ i.e. VOF model in FLUENT. To detect the capillary effect on the glycerin-85%, the surface tension and prescription of the wetting angle are specified.

The inner surface of the capillary tube is neutrally wettable whereas the surface around the capillary orifice is non-wettable. At time zero, glycerin-85% fills the capillary, while the rest of the domain is filled with air. Both fluids are assumed to be at rest. To initiate the ejection, the glycerin-85% velocity at the inlet boundary suddenly rises from 0 to 0.00415 m/s with fully developed profile and drops according to a gravitational law occur.Gravity is included in the simulation. The problem is considers as two dimensional because of the axial symmetry of the geometry. The domain consists of two regions: a glycerin- 85% chamber (capillary tube) and an air chamber as shown in Fig. 1.

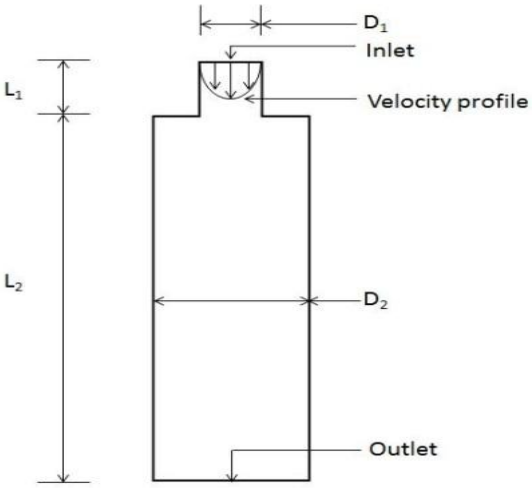


Figure 0Schematic of the Problem

2.1. BASIC ASSUMPTION

To make our numerical calculations realizable and achievable, we should make several assumptions that only contain the essential control mechanisms but disregard less influential factors. For all the numerical simulations, we assume:

1. The Fluid flows are laminar.
2. The model is axisymmetric.
3. The surrounding air can be considered as incompressible.
4. The liquid properties are known and constant.
5. The evaporation of the liquid is ignored.
6. At inlet of capillary tube fluid flow is assume fully developed flow.

2.2 BASIC CONSERVATION EQUATION

The Continuity Equation:-The Continuity Equation describes the mass conservation inside a volume element. The in streaming mass and the out streaming mass are balanced.

$$\frac{\partial \rho}{\partial t} + \nabla(\rho . v) = 0 \qquad \dots (1)$$

$$\frac{\partial \rho}{\partial t} + \rho \frac{\partial v_x}{\partial x} = 0 \qquad \dots (2)$$

The Momentum Equation:-In VOF model a single momentum equation has been used throughout the domain and it is given as,

$$R_e\left(\frac{\partial v}{\partial t} + v . \nabla v\right) = \nabla . T + (G/Ca) \dots (3)$$

$$\rho\left(\frac{\partial v}{\partial t}+v_x.\frac{\partial v_x}{\partial x}\right)=-\frac{\partial p}{\partial x}+\mu C\frac{\partial^2 v_x}{\partial x^2}+\rho g \quad \text{... (4)}$$

2.3 INITIAL AND BOUNDARY CONDITION

The following initial and boundary conditions are:

1. Inlet of the domain is Velocity inlet.
2. Flow rate is 1 ml/min.
3. Thickness of the nozzle is neglected [5].
4. Free slip velocity condition near wall because the fluid near the wall is air.
5. Outlet of the computational domain is pressure outlet.

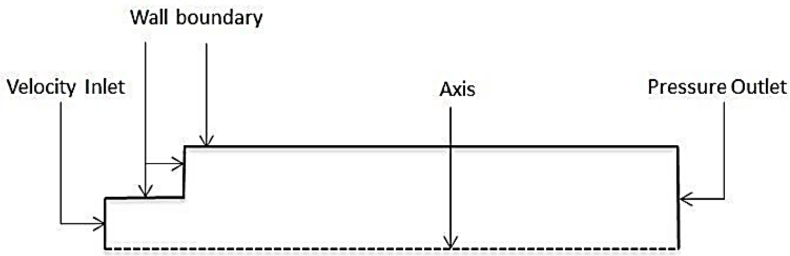
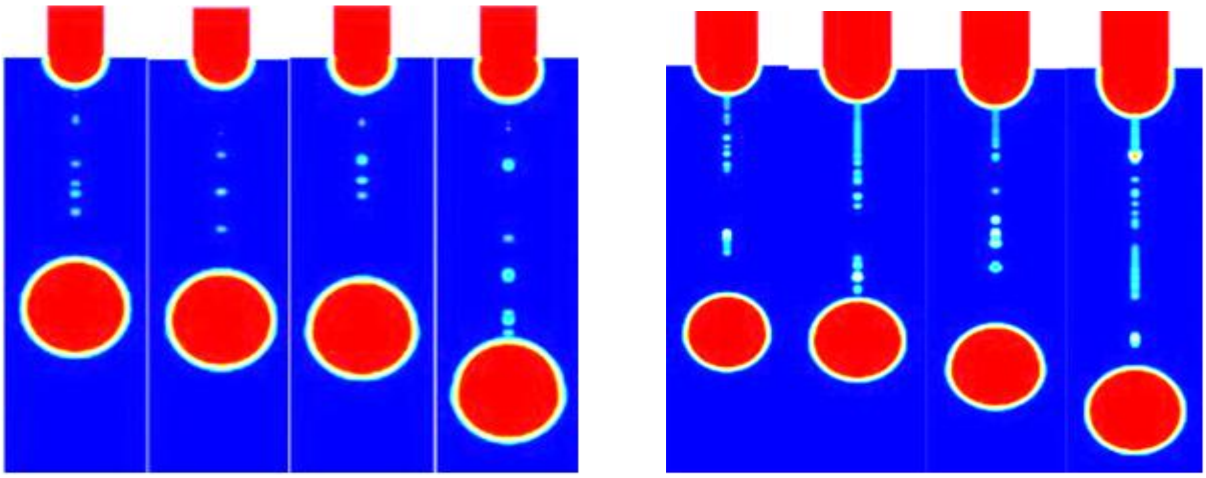


Figure 2 Computational Domain with boundary conditions

III. RESULT AND DISCUSSION

3.1 INFLUENCE OF VELOCITY ON THE SATELLITE DROP

The behaviour of satellite droplets with different velocity at the inlet of the capillary tube is shown in Fig.3. The velocity is 0.00415, 0.005187, 0.01037; 0.02075 m/s .images are compared after 0.2 second after breakup of the drop.As shown in Fig. 3, the number of satellite drops increases when the flow rate increases.



(a) (b)

Figure 3 Satellite droplets with different velocity for (a) 2 mm and (b) 3.2 mm capillary tube

3.2 INFLUENCE OF CAPILLARY SIZE ON SATELLITE DROPLETS

The behavior of satellite droplets with different inlet diameter of capillary tube has shown in Fig. 4 and 5. The diameter is taken for simulation is 2 and 3.2 mm.

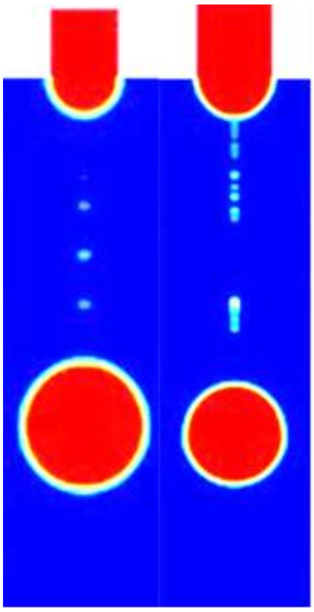


Figure 4 Satellite droplets at diameter 2 and 3.2 mm sequentially for velocity 0.00415m/s from capillary tube after 0.02 second after breakup of primary drop

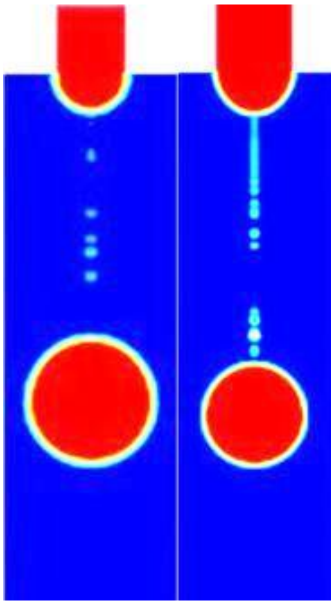


Figure 5 Satellite droplets at diameter 2 and 3.2 mm sequentially for velocity 0.005187m/s from capillary tube after 0.02 second after breakup of primary drop

IV. CONCLUSION

According to the simulation results, clearly different behavior of satellite droplets was detected. By analysis we concludethat the effect of inlet velocity and capillary size on satellite droplets.

4.1 Inlet velocity influence

By increasing velocity, more flow rate from capillary tube so more kinetic energy of fluid. So the longer ligament which consumes more kinetic energy and more satellite droplets generated. At lower capillary size velocity effect is less on satellite droplets. But at capillary size increase the effect of increasing velocity is more cause of generation of satellite droplets.

4.2 Capillary size influence

Small capillary size lead to small kinetic energy transmitted to liquid column and thus results to slow droplet velocity. But if the capillary size is too large, thicker and longer ligament consumes more kinetic energy as well. In addition, large capillary sizes bring in more satellite droplets, which should be avoided. Large capillary size causes longer break up length and longer break up time. As the process before breaking up is an energy consuming procedure, we need to shorten the time of this process so as to increase the energy remaining in droplet.

Increasing velocity is more cause of generation of satellite droplets from capillary tube than increasing capillary size.

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