International Journal of Technology and Emerging Sciences (IJTES)

www.mapscipub.com

Volume 01 || Issue 03 || October 2021|| pp. 1-6 E-ISSN: 2583-1925

Computational Study of Drop Dynamics Through A Capillary Tube

Ravi Ratna[1], Pardeep Bishnoi[2], M.K. Sinha[3]
[1]PG Scholar, Dept. of Mechanical Engineering, NIT Jamshedpur
[2]Assistant Professor, Dept. of Mechanical Engineering, CEC Mohali
[3]Professor, Dept. of Mechanical Engineering, NIT Jamshedpur

---***---

Abstract - *The formation of droplets is a research field with a rich and varied history, but it still attracts great interest today. The dynamics of droplet growth and separation from capillary or nozzle to surrounding fluid has attracted attention in various applications including inkjet printing, dynamic surface tension measurement and separation, DNA arrays, deposition of reagents on diagnostic strips, and manufacturing of capsules in pharmaceutical industries. In this analysis a model is developed and validated. ANSYS 15.0.7 has been used for simulation and analysis of glycerin drop. The effects of variation of different parameters such as capillary diameter and velocity of flow on dynamics of drop growth and breakup are investigated.*

***Key Words*:** drop dynamics, CFD, Volume of fluid

1. INTRODUCTION

Droplet development is a developing field of study, since its wide application in different fields, for example, food handling [1], inkjet innovation, and natural chemistry [2, 3] has drawn in numerous specialists. Understanding the different elements that lead to the crumbling of the hanging drop configuration is vital, in light of the fact that it can handle these boundaries to accomplish the ideal objectives. Zhang and Basaran [4] studied the effects of physical and spatial factors on the shape and volume of droplets at low flow rates through experiments later Pardeep et. al.[5] validates it by using computational techniques. Rothert et al.[6] and Wehking [7] experimentally proved that the pinch-off process slows down as the viscosity increases. The formation of droplets is the result of the stability between viscosity and surface tension as described by Vladimir and Marko [8]. Dravid [9], and Tirtaatmadja, etc. applied various analytical and numerical methods to determine the dynamics of the method. [10]. Pardeep et al. [11][12] studied the Weber number of state transition, that is, from dripping to spraying. The resulting flow pattern is consistent with the experiments of Clanet and Lasheras [13]. The basic aim behind this work is to analyze the effects of various parameters, such as orifice size and flow rate on the dynamics of glycerin drop formation. Through this work, we investigate the effects of different orifice configurations on drop formation and validating the result with the experimental results available in literature.

2. METHODOLOGY

2.1 Computational Model and Domain

The mathematical model includes mainly the equations of conservation of mass, momentum related to the assumptions and boundary conditions. Fluent is used to evaluate the drop fraction together with the pressure change phenomenon in the drop dynamic process. The physical diagram of a capillary tube consists of two areas (chambers): one is the primary phase fluid, or also known as the continuous phase. In our work, the air is used as a continuous fluid. Another area is the secondary phase fluid, or discrete phase fluid, which is the main fluid for which drop formation is investigated. For the study of droplet dynamics, 50% of the multiphase fluid consists of an aqueous solution of glycerin and air. The modeling of the drop dynamics is performed in ANSYS 15.0 software. The domain has a dimension of 19 mm x 5 mm. Figure 1 represents the physical model of the computational domain.

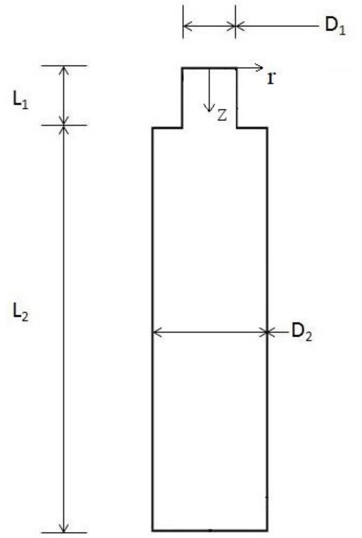


Figure 1 Schematic of the Problem

In order to make our numerical calculations achievable, several assumptions were taken into account which contains basic controls. Evaporation of liquids is neglected as all properties are calculated at 20 ° C [Table 1]. The thickness of the capillary tube is neglected in the present study as investigated by several researchers [4][14]. Volume of fluid method was used to track the drop motion in the capillary tube. To make our numerical calculations achievable, we made several assumptions that contain the essential control mechanisms but disregard the less influential factors. For all numerical simulations, we understand that the fluid is Newtonian and flows within laminar limits. The surrounding air is considered incompressible. The inlet of fluid flow from the capillary tube is considered to be a fully developed flow.

Table 1 Physical Property of fluid [14]

Property / fluid	Surface Tension (Dyn/cm)	Density (g/cm^3)	Viscosity (poise)
Glycerin	63.4	1.26108	14.10
Water	71.68	0.99823	0.01005

2.2 Boundary conditions

The boundary conditions include the velocity inlet, pressure outlet, and free-slip velocity near the capillary wall as depicted in Figure 2The flow rate at the nozzle inlet is 1 mL/min. The PISO algorithm scheme was used to solve the pressure-velocity coupling along with a second-order upwind scheme to solve the momentum. Computational simulation is performed on Intel 7500U with 2.70 GHz and 2.90 GHz processors and 16 GB of RAM. The user-defined function (UDF) source code was developed and connected to a solver for a fully developed flow.

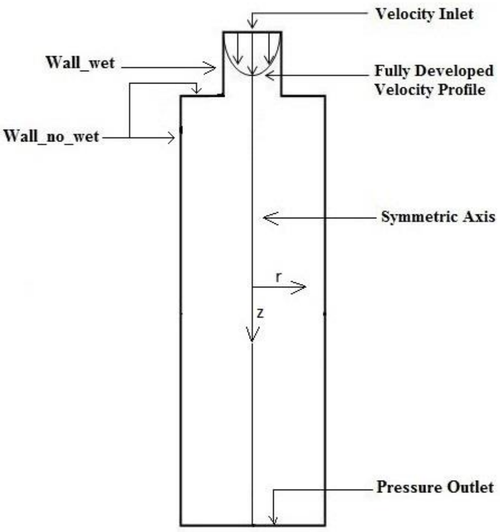


Figure 2 Boundary Condition of the problem

2.3 Grid Generation

As shown in Figure 3, the free surface of the drop profile for the dense mesh is better to locate as compared to the lighter mesh size. For further computation, 30,000 cells meshing are considered better than 8,000 in tracing the free surface and efficient than 50,000 cells in overall computational time. According to the numerical solution procedure, the meshing should be fine, but it will increase the time of the entire simulation. The basic purpose of grid sensitivity testing is to check the accuracy of computational results for different meshing conditions. Cells are denser near the axisymmetric axis than in other regions. Since the droplet's path profile is around the axisymmetric axis. In this way, the base size between the cells is 4.01e-3 mm and the most extreme size between the cells is 0.80 mm. In the VOF approach, the way profile of the moving drop is found. In the case of lattice is poor, then, at that point, the area of the fluid drop isn't really exact when contrasted with better cross section.

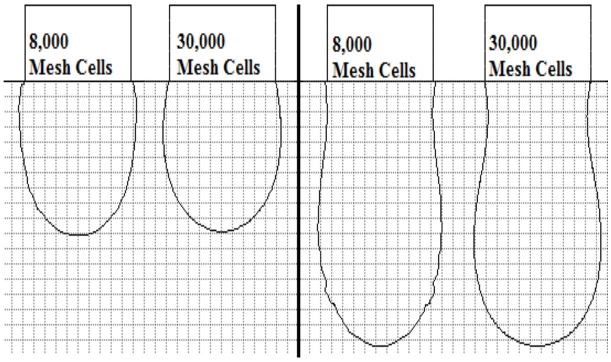


Figure 3 Grid Independence Test

3. RESULT AND DISCUSSIONS

3.1 Result validation

Here we compare the CFD analysis result with Edward D. Wilkes et al. [14] computational and experimental results. The result found (shown in figure 4) is in good agreement with the computational and experimental result with minimum deviation. So, through this, the model is validated and can predict accurately the surface profile of the drop formation by changing various parameters.

3.2 Drop formation analysis

In this section, we analyze the formation, extension, and breakup of the drop. Figures 5(a-p) show a typical sequence of surface profiles obtained by the numerical model for a glycerin drop forming in ambient air from a tube having an inner diameter of 2 mm, at a constant flow rate of 1mL/min.

The drop evolves through a sequence of nearly spherical shapes during the early stage of drop formation. Examination of shapes also reveals that the neck is initially nearly symmetric about its midpoint in the axial direction and remains so until the minimum neck radius reached. As the time approaches to break up, this symmetry is lost as the minimum radius of the neck diminishes and the primary thread forms a micro thread at its bottom end. The computed time in this case has been found to be 2.2700s after the flow was started.

3.3 Analysis by varying various factors

By varying various factors such as diameter of capillary tube and velocity of flow we can analyze the effect on drop formation.

3.3.1 Influence of capillary size on drop formation

Here comparison shows the behavior of drop formation with different inlet diameter of capillary tube 2 mm and 3.2 mm diameter (shown in figure 6) are taken for simulation.

Figure 6 shows the computed instantaneous shape of glycerin drop for 2 mm and 3.2 mm diameter capillary tube having (a) flow velocity 0.00415m/s (b) 0.0072625 m/s just before breakup. On increasing the diameter of the inlet, more fluid enters into the hanging ligament as well as pendant droplet which leads to increase in the breakoff thread length of the droplet.

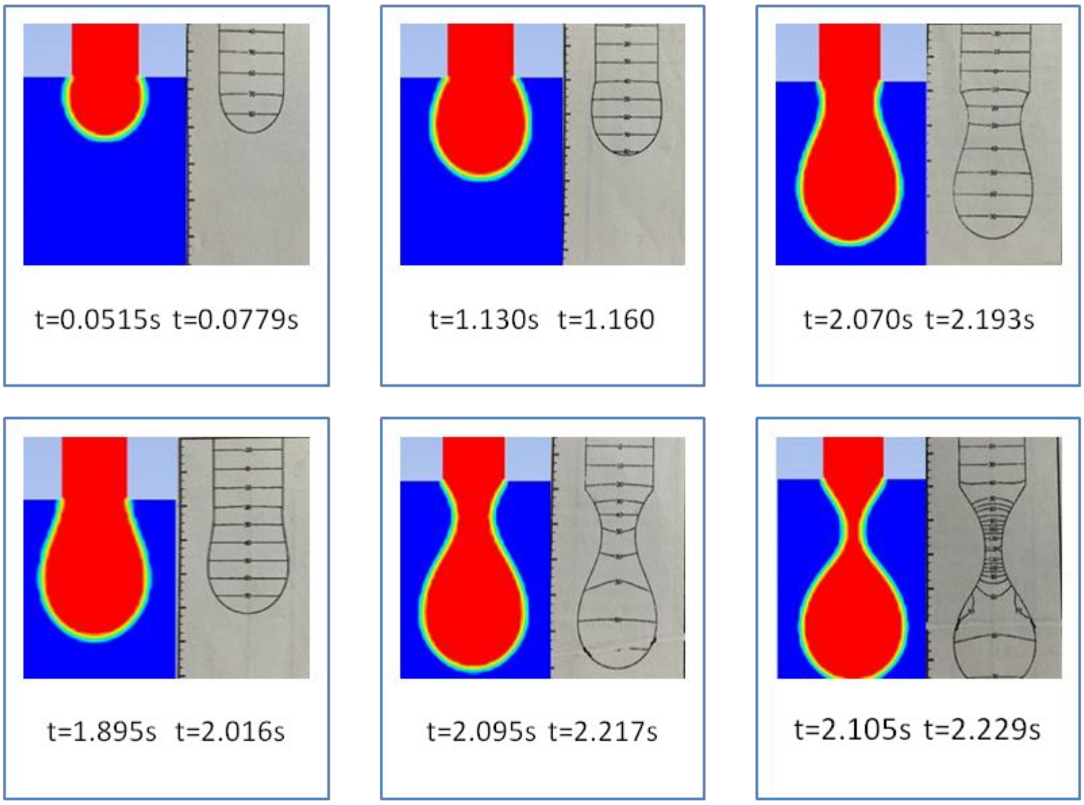


Figure 4 Shows comparison between CFD result and experimental result

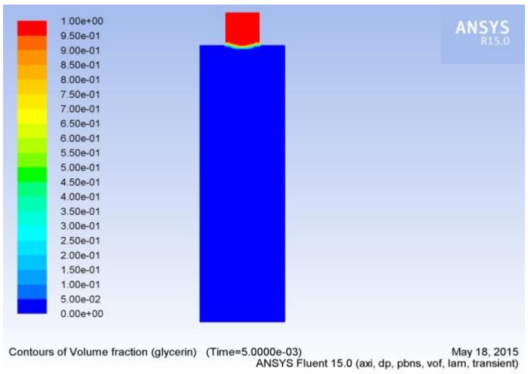


Figure 5 (a) t=0.0050s

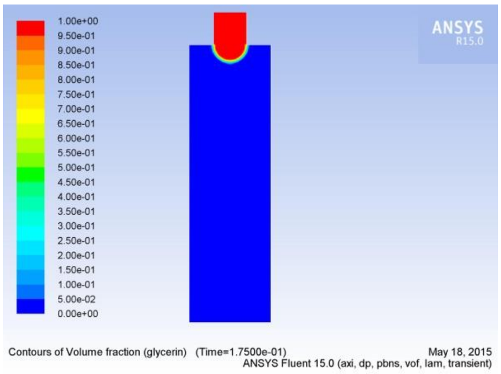


Figure 5 (b) t= 0.1750s

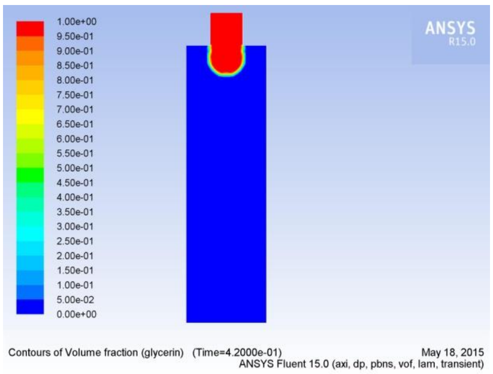


Figure 5 (c) t=0.4200s

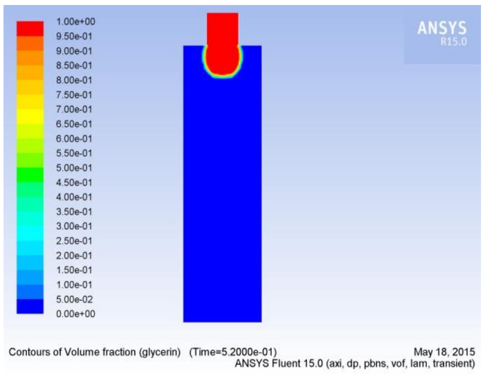


Figure 5 (d) t= 0.5200s

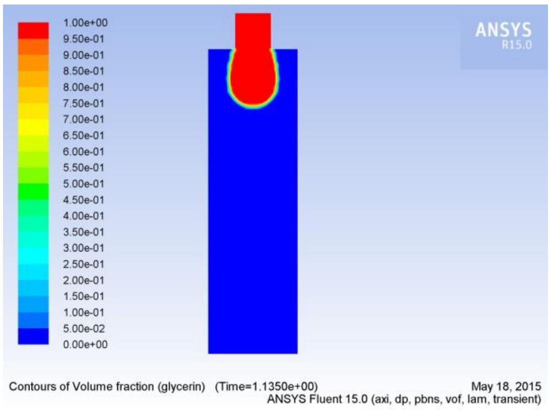


Figure 5 (e) t=1.3500s

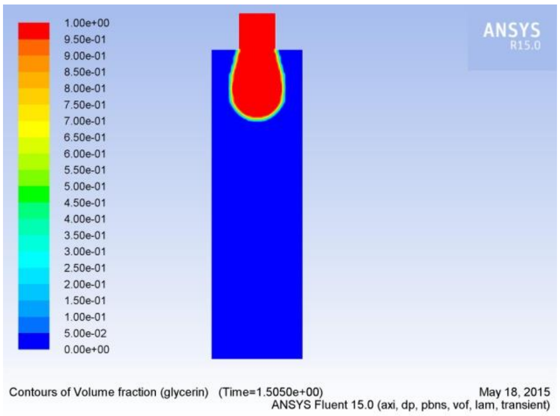


Figure 5 (f) t=1.5050s

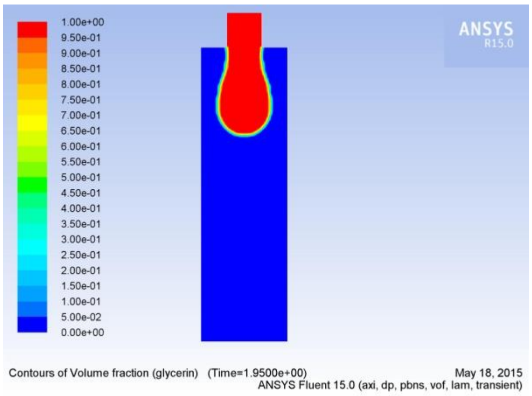


Figure 5 (g) t=1.9500s

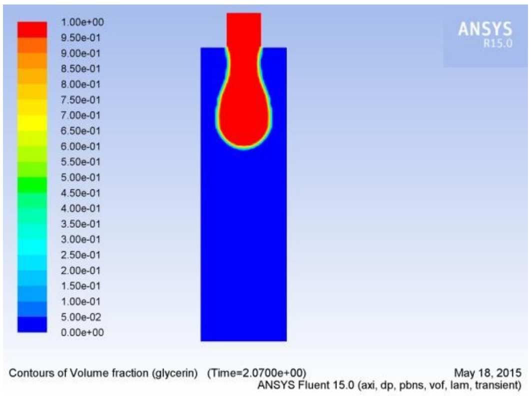


Figure 5 (h) t=2.0700s

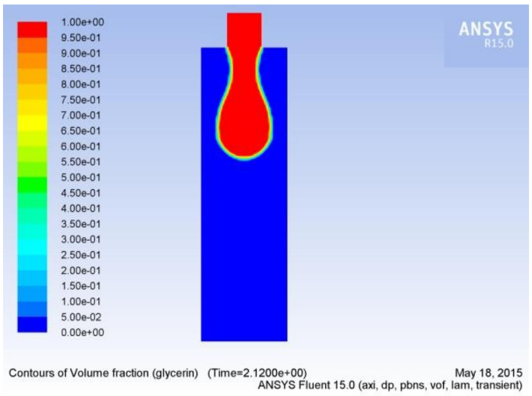


Figure 5 (i) t= 2.1200s

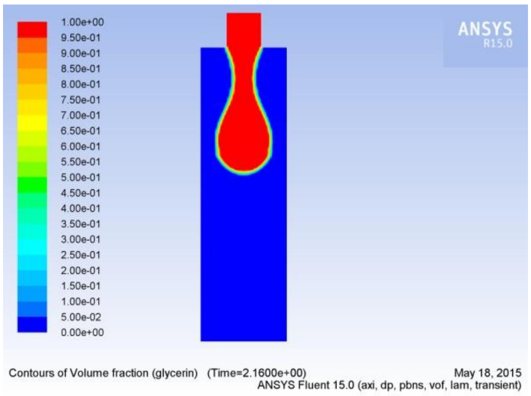


Figure 5 (j) t= 2.1600s

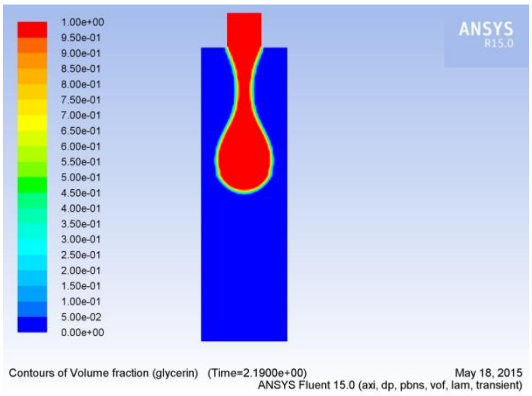


Figure 5 (k) t= 2.1900s

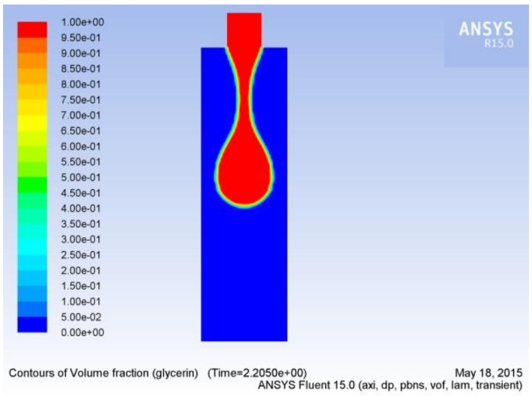


Figure 5 (l) t= 2.2050s

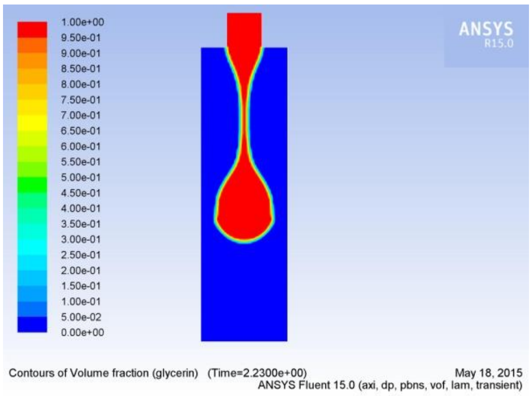


Figure 5 (m) t= 2.2300s

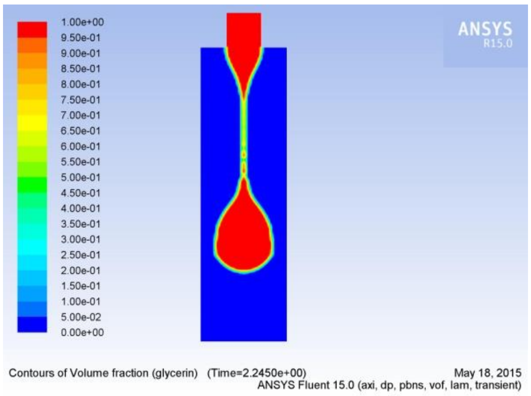


Figure 5 (n) t= 2.2450s

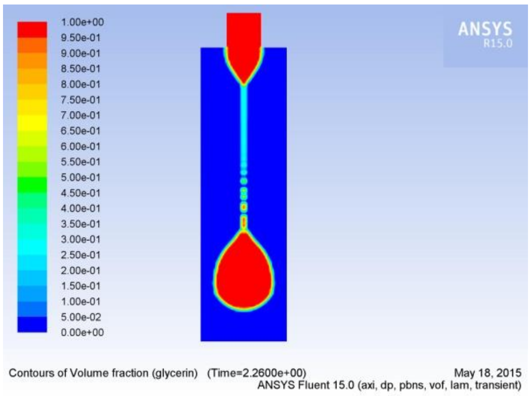


Figure 5 (o) t= 2.2600s

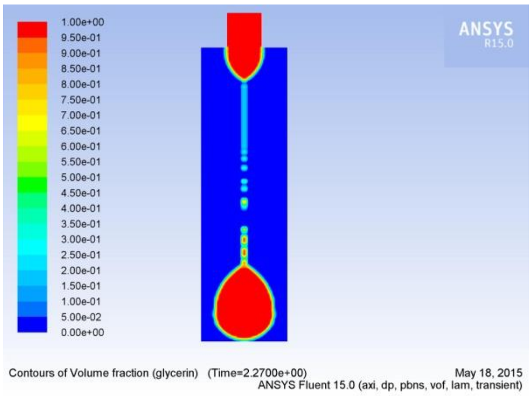
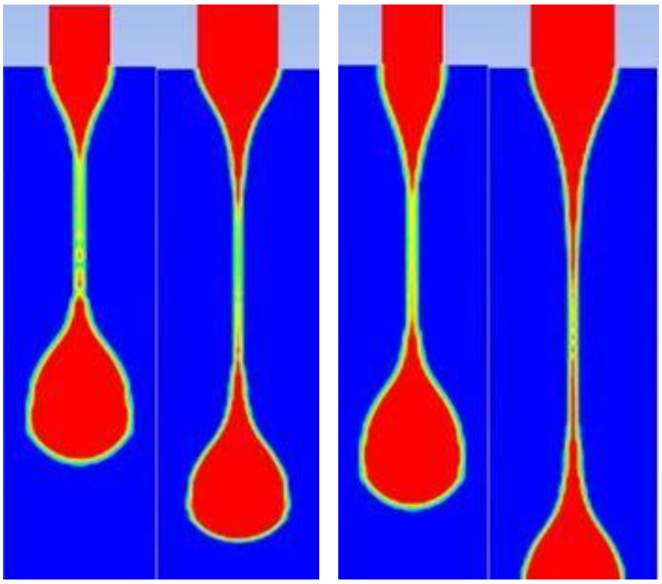


Figure 5 (p) t= 2.2700s

Figure 5 (a-p) the sequence profile of glycerin drop's in air growing out of a capillary of diameter (d) =0.002m and flow rate (Q) =1ml/lt

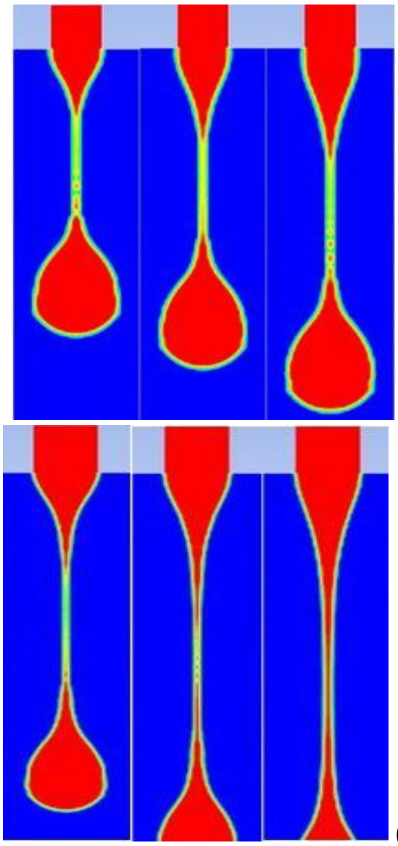


a) Flow velocity 0.00415m/s **(b)** Flow velocity 0.0072625m/s

Figure 6 Comparison of glycerin drop at different capillary size at flow rate 0.00415m/s

3.3.2 Influence of velocity on drop formation

Here comparison shows the behavior of drop formation with different inlet velocity of capillary tube. The velocity taken is 0.00415, 0.0072625, and 0.010375m/s (shown in figure 7).



(a) 2 mm

(b) 3.2 mm

Figure 7 Comparison of glycerin drop at different velocity

Figure 7(a) illustrates the computed instantaneous shape of drop of glycerin at different velocity growing out of capillary tube of diameter 2mm at breakoff time 2.24s, 1.40s and 1.06s respectively whereas Figure 7(b) demonstrations the computed instantaneous shape of glycerin at different velocity growing out of capillary tube of diameter 3.2mm at time 1.73s, 1.16s and 0.915s respectively. On increasing the flow rate, the inertial forces dominate over the viscous forces and the surface tension forces. Due to high flow energy, the length of the hanging ligament increases which finally converted into the necking regimes for the droplet.

4. CONCLUSIONS

By varying parameters such as capillary diameter and velocity, some of the salient conclusions emerge out from the present investigation are:

i. Small capillary size leads to less kinetic energy transmitted to the fluid column. But if the capillary size is too large, thicker and longer threads consume more kinetic energy. Large capillary size causes the longer break up thread length. 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 drop.

ii. If velocity remains the same but the size of capillary increases the formation of the drop will take less time.

By increasing velocity means more flow rate from the capillary tube so the more kinetic energy of the fluid. So longer threads will form which consumes more kinetic energy. The flow rate of incoming liquid significantly affects the flow circulation pattern within drop formation in their governing period. The flow velocity within the falling portion of the drop is dominant over that of the entering liquid and increases as the drop approaches detachment.

REFERENCES

1. P. Sanguansri, M.A. Augustin, "Nanoscale materials development – a food industry perspective", Trends Food Sci. Technology, vol. 17, pp. 547–556, 2006.
2. S. Mashaghi, A. Abbaspourrad, D.A. Weitz, A.M. van Oijen, "Droplet microfluidics: A tool for biology, chemistry, and nanotechnology", TrAC Trends Anal. Chem, vol. 82, pp.118–125, 2016.
3. Bishnoi, P. and Sinha, M.K., "A new approach to determine the diabetic level in patients", vol. 80, issue 1, pp. 71-84, 2018.
4. X. Zhang and O. A. Basaran, "An experimental study of dynamics of drop formation", Phys. Fluids, vol. 7, pp. 1184–1203, 1995.
5. Pardeep, Srivastava M., Sinha MK: Numerical simulation of dynamics of the drop formation at a vertical capillary tube. Applications of fluid dynamics, LNME, Springer, Singapore, pp. 371–381, 2018.
6. Rothert A, Richter R, Rehberg I, "Formation of a drop: viscosity dependence of three flow regimes", New J Phys, vol. 5:59.1–59.13, 2003
7. Wehking JD, "Effects of viscosity, interfacial tension, and flow geometry on droplet formation in a microfluidic T-junction", Microfluid Nanofluid, vol.16, pp. 441–453, 2014.
8. Vladimir G, Marko M, "Drop formation in a falling stream of liquid", Am J Phys vol. 73, issue 5, pp. 415–419, 2005.
9. Dravid V, "Drop formation in non-Newtonian jets at low Reynolds", J Fluids Eng ASME, vol. 130, pp. 081504(1)–081504(8), 2008.
10. Tirtaatmadja V, MecKinley GH, Cooper JJ White, "drop formation and breakup of low viscosity elastic fluids: effects of molecular weight and concentration", HML report, Department of Mechanical Engineering, MIT, USA, 2006.
11. Pardeep B, Sinha MK. Computational Investigation of Various Transition Stages in the Drop Formation Process. Advances in interdisciplinary engineering lecture notes in mechanical engineering. Kumar M, Pandey R, Kumar V, editors. Singapore: Springer, pp. 249-261, 2019.
12. Pardeep Bishnoi, S. Jeeva Chithambaram, Abhijeet Singh, Prabhat Kumar, S.K. Khatkar, M.K. Sinha, "Investigation of drop's instability under different transition stages on axisymmetric flow model", Computers & Fluids, 104673, 2020.
13. C. Clanet and J. C. Lasheras, "Transition from dripping to jetting", J. Fluid Mech, vol. 383, pp. 307–326, 1999.
14. Wilkes, E.D., Phillips, S.D. and Basaran, O.A., "Computational and experimental analysis of dynamics of drop formation". Physics of fluids, vol. 11, issue 12, pp.3577-3598, 1999.