International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Acute Behavior of the Ink Physics inInkjet Printers

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Abstract: ***What happens in the inkjet nozzle when a multiphase flow for fluids which have distinct density and dynamic viscosity that forms a typical interface between the physics of the fluid comes in contact? To answer this question, several attempts are made with various configurations such as type of the physics, geometry, mesh, and flow conditions with various fluid characteristics are numerically simulated to realize the behaviour of the multiphase flow. The current article emphasizes various intricacies that are encountered during the simulation of these flow characteristics cited from the literature. This article helps researchers to take immense care while setting various parameters suitable for numerical simulations.***

Keywords: Level set, Bubbly Flow, Mixture model, Phase transport, Reinitialization

1. Introduction

There are two types of inkjet printer nozzle controllers namely, piezo, and thermal for the print heads such as drop-on-demand and continuous inkjet printing [1-2]. The nozzle geometry is one of the most crucial segments of the inkjet printer since it gives provision to alter the interface characteristic of the multiphase flow. Most widely used nozzle geometries to study the multiphase flow characteristic are T-section [3] and L-section [4] that are widely cited in the literature. At the same time, it can be inferred from the literature that, level set method is most preferable as it gives the transition mechanics at the interface of two fluids/inks inherently. The advantage of this method is that it requires fewer inputs and is compatible for dispersion fluids in base fluid [5]. But there are also other methods which can generate proper multiphase characteristics such as formation of bubble and traversing through the base fluid until ejected out from the print head of the nozzle. The methods include phase field [6], bubbly flow [7], mixture model [8], phase transport [9] and moving mesh [10] alongside level set method.

However, each of these methods have their own pros and cons, their applications and type of the fluid and flow characteristics decides the type of the technique to choose. A prior to that, it is advised that there must be knowledge on understanding the physics of the various fluids and methods which decides the type of the nozzle and nozzle geometries. The flow characteristics such as Reynolds number to determine the laminar or turbulent behaviour, weber number to identify interphase line and Ohnesorge number which allows to study whether the dispersed bubbles flow with the base fluid or whether they fly away. Each of these number are dependent on the density, dynamic viscosity, surface tension and the characteristic length.

For low and moderate Reynolds number, more predominantly used technique is bubble and mixture flow in laminar region and high Reynolds number in turbulent region [11]. On the other hand, phase transport mixture model simulates the integration between the phase transport and the fluid flow. Phase transport is more often intended to study the transport of the immiscible fluids that are dispersed in the base fluid, and when these are combined with the fluid flow characteristics such as density, pressure, and dynamic viscosity [12]. Basically, the physics interface associated with the phase transport model behaves well in Mach number less than 0.3, i.e., incompressible. But it is interesting to track the position of fluid-fluid interface which allows to morph the nozzle geometry flow characteristics, for which, a numerical simulation technique known as moving mesh is preferred [13]. This method has an advantage of studying the larger distortion in the continuum model when compared to the Lagrangian model.

Though the existing methods are most widely used, they still exhibit few constraints to realize the flow characteristics feasible for inkjet printer applications. Hence in the current paper, we shall highlight the various complexities and constraints. To surmount these challenges, we shall discuss the constitutive relations of the multiphase flow with various methods and their effect on the nozzle geometry and numerical solutions.

2. Level Set Method

It is an implicit function that is used to realize the mechanics of fluid-fluid interface and their moving contours. This method is assumed to be the most amenable method for the use in finite element analysis. The application of this method includes to study the fluid-fluid interface, dispersion of particles in fluid, particle tracking, bubble and droplet sustainability in the base fluid.

The dependent variables to use the level set function are velocity field and components followed by pressure. The controlled phase initialization time dependent equation is given by Eq.1[14].

$$\frac{\partial \emptyset}{\partial t} + u.\nabla\emptyset = \gamma\nabla.\left(\epsilon_{ls}\nabla\emptyset - \emptyset(1-\emptyset)\frac{\nabla\emptyset}{|\nabla\emptyset|}\right) \quad (1)$$

Herein the model uses reinitialization to avoid the deterioration of the interface, as mentioned early this is an advantage over Lagrangian but at the same time produces numerical errors which can controlled using reinitialization. In the above equation γ represents the reinitialization parameter, here it takes the form of initialization of velocity as the interface is moving [15]. This reinitialization parameter produces few drawbacks such as distortion of fluid-fluid interface and lack of conservation of momentum equation. To surmount this problem, a novel scheme is introduced in the work from [16]. Under the no flow condition, the Eq.1 will be rewritten by Eq. 2.

$$\mathrm{n}.\left(\epsilon_{ls}\nabla\emptyset-\emptyset(1-\emptyset)\frac{\nabla\emptyset}{|\nabla\emptyset|}\right)=0 \quad (2)$$

Few works pertaining to the level set method can be cited from the literature [17-19]. A swirling two phase flow was numerically simulated using the mass conservative level set method which displayed excellent numerical convergence [17]. The aim of using this approach is to capture the gas-liquid interface and the jump conditions across this interface. Interesting facet of the work is that the authors have used hyperbolic tangent function rather than signed distance function. But still, it was reported that hyperbolic tangent function is contaminated and resulted in loss of mass and hence use of reinitialization has been performed implicating the importance of reinitialization parameter. Another interesting work on the application of this method to simulate the collision of droplets through interface tracking. The level set function comprised of coupled incompressible NS equation with the transport equation to obtain the following relation in Eq.3.

$$\frac{\partial v}{\partial t}+(\boldsymbol{V}.\nabla)\boldsymbol{V}+\frac{\nabla p}{\rho(\emptyset)}=\frac{\nabla(2\mu(\emptyset)\boldsymbol{D})}{\rho(\emptyset)},\boldsymbol{D}=\frac{1}{2}(\nabla\mathbf{V}+\nabla\boldsymbol{V}^{\boldsymbol{T}}),\nabla.\mathbf{V}=0 \quad (3)$$

An absolute coalescence is observed between the droplets after head on collisions and then followed by separation was captured as shown in the Figure 1below [18].

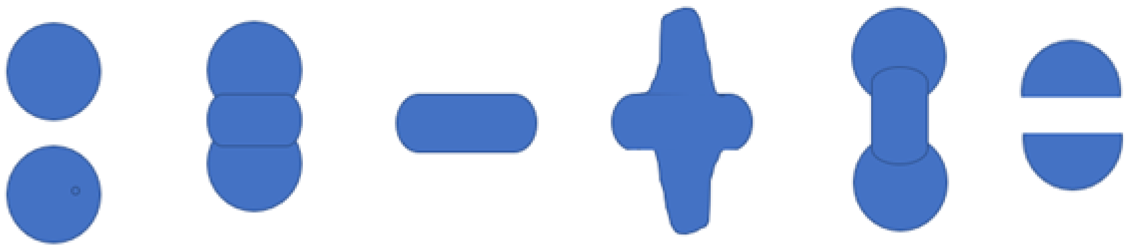

Figure 1: Head on collision for oh=0.0047

An advanced work for simulation of 3-dimensional dynamical simulations to study the forced liquid jets into another liquid was performed by [19]. The work emphasized on the tracking the interface between immiscible liquids. One interesting comment was made by the authors that, for capturing the laminar surface phenomena, it requires very fine grid solution i.e., weber number. This problem comes when surface tension is included in the physics model.The interface tracking and capturing is most important result of the multiphase flow simulation, these depend on the weber-ohnesorge plane and hence Reynolds number. Thus, level set plays an important role in integrating NS equation with various other models.

3. Bubbly Flow

Bubbly flow is referred to as a bubble dispersed in a continuous flow forming an interface between the fluid and bubble. Numerical simulation methods such as level set method realizes the interface kinetics, but it is difficult for them to study the deformable interfaces. To simulate the dispersion of bubble in a deformable interface is one of the challenging and the bubble flow is subtle to it. The stationary, and time dependent studies are widely available in the literature, but when fluids such as two particle free metal inks flow together, the mechanism to model the bubble becomes difficult. Most of these bubbly flows are studied for biomedical drug delivery applications and channel flow in curved pipes [20-21]. The NS time dependant equation for the bubbly flow is given by Eq.4 and the modified equation will be written as Eq. 5.

$$\rho_i\frac{\partial u_i}{\partial t}+\rho_i(u_i.\nabla)u_i=\nabla.[-p\boldsymbol{I}+\boldsymbol{K}]+\emptyset_i\rho_i g+\boldsymbol{F},\boldsymbol{K}=\mu_i(\nabla u_i+(\nabla u_i)^T) \quad (4)$$

$$\frac{\partial\emptyset_g\rho_g}{\partial t}+\nabla.\boldsymbol{N}_{\rho_g\emptyset_g}=-m_{gI} \quad (5)$$

The above equations haveeffective gas density, which when two fluids are gas-liquid interface, but if the interface is liquid-liquid interface, effective gas density of the dispersed fluid bubble needs to be considered. This is one of the most common errors that happens with in the numerical simulation. Since the bubble is in moving interface, an immense care must be taken, i.e., in a high-density fluid, a low-density fluid must be dispersed. With slip velocity and divergence of the velocity components rendering to zero, a laminar bubble flow must be numerically simulated. The same is the case with the turbulent flow condition to simulate the bubbly flow. Studies pertaining to the bubbly flow can be cited from the literature [22-24].

An excellent work from [22] discussed bubble flow interaction through numerical simulations envisaged from quasi uniform flow to vertical flow fields. Author discussed the bubble splitting criteria which are captured through various predictive models [24-25]. Authors have emphasized various bubble flow phenomena such as bubble flow in cavitation, modelling of real liquid nuclei fluid (effect of propeller) can be visualized inFigure 2, bubbly flow on hydrofoil as shown in Figure 3, bubble augmentation propulsion in Figure 4.

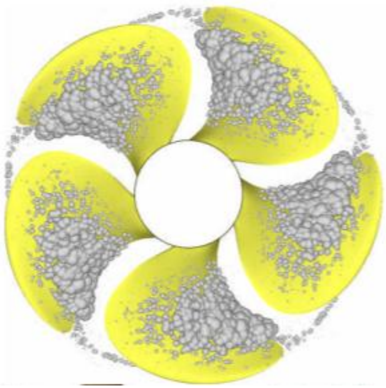

Figure 2: Bubble flow on propeller blade [22]

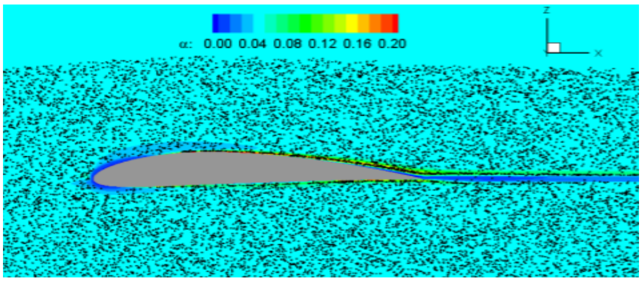

Figure 3: Bubble flow on hydrofoil [24]

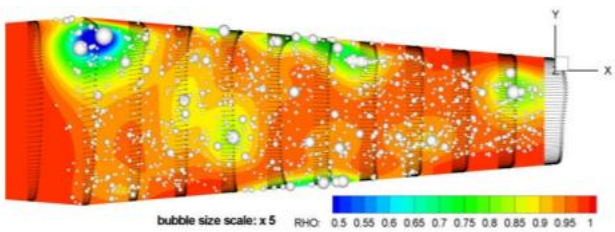

Figure 4: Bubble flow in propulsion system [25]

Figure 2shows the bubble formation within in the fluid when they come in contact with the rotating propeller blade, studying this characteristic is very important as they oxidize and corrode the layer of the propeller following a declining the wear resistance in hydrothermal environment. This may over the time result in the structural catastrophe, hence the kind of study requires bubble flow interaction studies. The problems that may be encountered during the bubble flow may be effect of the shear thinning and Pseudo elasticity. On the other hand, the phase distribution is interconnected with the interface and turbulence or laminar flow (i.e., method adopted for turbulence modelling). A triangle against understands these combinations is given by [26] as displayed in the Figure 5. A detailed emphasize of the Figure 5 displayed is given in reference [26]. Figure 3 depicts the flow of fluid over a hydrofoil in hydrothermal environment, which is almost like the flow of fluid over an aerofoil. This study of the flows refers to the naval applications where the aerofoil contours can be found to the propeller blades of the ship. Erosion and impact of fluid particles on the aerofoil counter helps in deciding the choosing the material and design. In similar context, Figure 4 also serves the purpose for the propulsion systems used in the aerospace and aviation industry for the generating thrust from the engine. During the pre-combustion process, fuel and oxidizer are combined through a stoichiometric chemical splitting. This splitting allows to mix and react such that ignition takes place, during this phenomenon, ignition begins and bubbles with the viscosity generate huge pressure difference and hence creating a momentum in the particles to the exhaust. It is an interesting study to understand the effect of bubbles that are created and their impact on the generation of the thrust, hence a study in this context is also cited in the scientific literature.Of all the above-mentioned applications, when these bubbles are similarly created in the nozzle, the effect of the geometry on the droplet or the bubble will undergo dimensional distortion, due to the pressure and gravity that these metal inks get effected. As a result, the droplet or the bubble might not be able to traverse along the chamber and comes out of the nozzle. Hence there is need for the numerical simulation in terms of bubble traversing whole nozzle. In current numerical simulations, it is difficult to bring in a bubble traversing with enough pressure is difficult to model and hence an alternative is required.

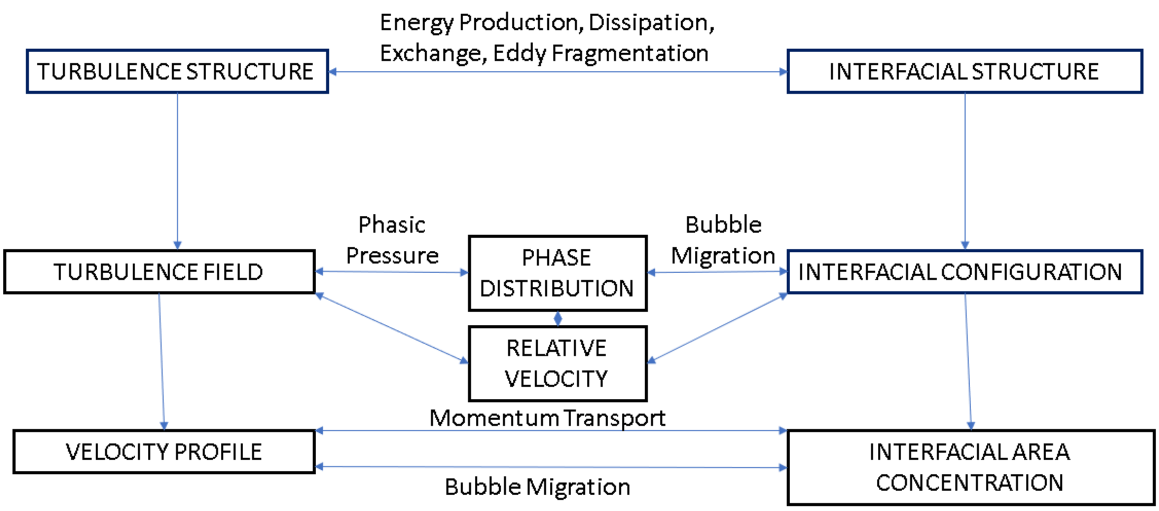

Figure 5: Bubble flow linkages

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4. Mixture Model

Mixture models are also like that of bubble models as themselves also study the properties of the dispersed phases in a continuous phase. But the only difference is that the density of the dispersed and continuous phase is nearly equal alongside it also accounts the momentum contribution of the dispersed phase. This model mostly serves with the phase characteristics such as liquid-gas and liquid-solid phase, i.e., the gas molecules dispersed in the liquid phase, or the solid nanoparticles dispersed in the liquid phase [27]. For an instance, once can infer from the Figure 6 below on the reduction of the bubble size with size of the orifice as mentioned earlier that bubble formation, size, traversing and stability depend on the geometry of the nozzle.

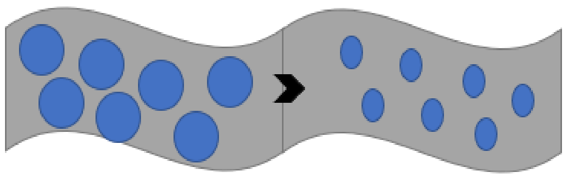

Figure 6: Change in the bubble size

For study-controlled physics, the governing equations for the time dependent flow are given by equation.5.

$$\rho\frac{\partial \boldsymbol{j}}{\partial t} + \rho(\boldsymbol{j}.\nabla)\boldsymbol{j} + (\rho_d - \rho_c)(\boldsymbol{j}_{slip}.\nabla)\boldsymbol{j} = \nabla.[-p2\boldsymbol{I} + \boldsymbol{K}] - \nabla.\boldsymbol{K}_m + \boldsymbol{F_m} \quad \textbf{(6)}$$

For a stationary flow condition, the above equation.5 is written as equation.6

$$\rho(\boldsymbol{j}.\nabla)\boldsymbol{j} + (\rho_d - \rho_c)(\boldsymbol{j}_{slip}.\nabla)\boldsymbol{j} = \nabla.[-p2\boldsymbol{I} + \boldsymbol{K}] - \nabla.\boldsymbol{K}_m + \boldsymbol{F}_m + \rho\boldsymbol{g} \quad \textbf{(7)}$$

$$\nabla.\boldsymbol{j} = m_{dc}\left(\frac{1}{\rho_c} - \frac{1}{\rho_d}\right) \quad (8)$$

$$\boldsymbol{K} = \mu(\nabla\boldsymbol{j} + (\nabla\boldsymbol{j})^T) - \frac{2}{3}\mu(\nabla.\boldsymbol{j})\boldsymbol{I} \quad \textbf{(9)}$$

Followed by the slip conditions which includes the diameter of the droplet and droplet characteristics. The Krieger type viscosity [28] is most widely used for solid-liquid interactions in a multiphase flow. Few works pertaining to the mixture based multiphase flow can be inferred from [29-31]. A work in this context from [29] presented a fully hyperbolic conservative mixture model in a two-dimensional model. Authors mostly emphasized on the non-equilibrium flow models, the idea behind the simulation is to see that a relative velocity term is introduced in the mass and momentum equation for each phase so that source term effects may be avoided. A generalization of mixture velocity and relative velocity are given for the inference at time t=1.3e-4 and CFL number=0.33 as shown in the Figure 7 below.

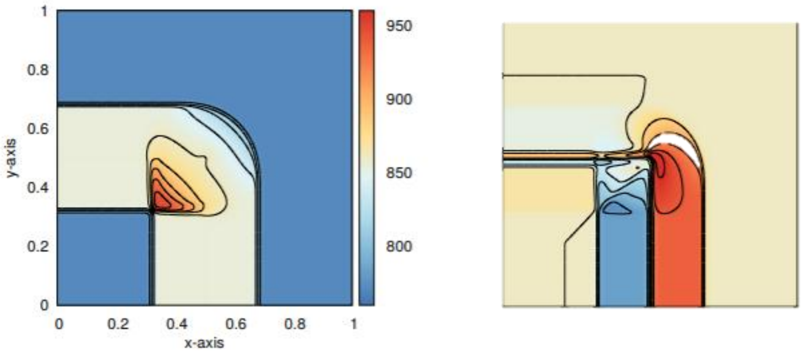

Figure 7: Mixture velocity (left) and relative velocity (Right) [30]

Some dispersed coarse metal particles when mixed with water is numerically simulated in various pipe configuration and are absolutely stratified. This behaviour on various vertical, horizontal, and inclined pipe configurations were discoursed in reference [30]. The effect of the particle degradation on horizontal and vertical pipe aremodified as per the requirement. The degradation of the particle depends on concentration, velocity, and time, i.e., faster degradation for higher velocities. This particle degradation has impact on pressure drop and slurry/continuous fluid velocity. They have also concluded that frictional pressure drops in the vertical pipe when compared to the horizontal pipe due to the contact load produces energy loss in the horizontal pipe. It is implicative that, design of the inkjet nozzles in the vertical direction has less energy loss and subtle for the dispersed particle or bubble to traverse throughout the nozzle and exit out. The conveying, either vertical, horizontal, and inclined pipe configurations have larger effect on pressure drop and slurry velocity.

5. Phase Transport

The phase transport model is used to determine the position of the interface between the two immiscible fluids containing both fluids of low to high Reynolds number. The Navier-Stokes (NS) equations will be solved for conservation of both mass and momentum. The only difference from level set method is that it uses additional two set of variables where one is inherent with the phase, and another is the mixing energy density [31]. Mixing energy density is highly complicated in terms of mixing high density layers. This behaviour is well understood in terms of instability referred to as Rayleigh-Taylor instability [32]. Where the interface movement becomes difficult to capture, i.e., the state of the interface system is unpredictable, hence one must look for minimization of the free energy such that the state of the system can be achieved. As the name redirects, phase transport simulations are always time dependant as position of the interface dependent on its history. The phase field equation for the study-controlled flow is given by equation.7.

$$\frac{\partial \emptyset}{\partial t} + \boldsymbol{u}.\nabla\emptyset = \nabla.\frac{\gamma\lambda}{\epsilon_{pf}^2}\nabla\varphi \qquad (10)$$

$$\varphi = -\nabla.\epsilon_{pf}^2\nabla\emptyset + (\emptyset^2 - 1)\emptyset + \frac{\epsilon_{pf}^2}{\lambda}\frac{\partial f}{\partial \emptyset} \qquad (11)$$

$\frac{\partial f}{\partial \emptyset}$ is the external free energy which will be minimized to ensure that the state of the system i.e., interface can be realized. Very less works pertaining to the use of phase transport model can be realized from the scientific literature [33]. Author in the work proposed various numerical problems to realize the physical characteristics of the system in which multiphase and phase transport rise. For researchers working with multicomponent fluids, an intense care must be taken since each phase may rise a transport because of the bulk phase convection. This may result in the molecular diffusion and mechanical dispersion. These measures must be taken a prior performing the numerical analysis. The analysis contains derivation of mass flux equations which includes convective mass transport, diffusive mass transport, mechanical dispersion, combined mass flux equations, continuity equations for transport and phase-summed equation for local equilibrium transport.

Few case studies such as oil infiltration on a fluctuating water table which studies free oil saturation against the depth. Another case study to study the viscosity and density effects on spill migration, which inclines with the current interest of study. Since the multiphase flow which inkjet nozzle has two different density and viscosity and they come in contact display an intriguing behaviour. Finally, one more case study phase transport of hydrocarbon plume using a coupled flow model. However not much interest in this context is required as the inkjet nozzle has complete particle free ink which refers to high energy fluid-fluid interaction and interface.

6. Conclusion

This article emphasizes the basic understanding of various numerical simulation model that are in practice to simulate multiphase flow characteristics in an inkjet nozzle. We have described NS equation in various forms depending on the type of the application. The current article described on various parameters and their dependency on the solution. Methods such as level set, bubbly flow, phase transport and mixture model are most widely accepted methods in the current scientific community.

7. Future Scope

This research work can be used as the guideline for simulation models. In future the problems that occurs during the simulation of various models will be discussed.

References

[1] Dong, H., Carr, W.W., and Morris, J.F., 2006. Visualization of drop-on-demand inkjet: Drop formation and deposition. *Review of Scientific Instruments*, *77*(8), p.085101.

[2] Hoath, S.D. ed., 2016. *Fundamentals of inkjet printing: the science of inkjet and droplets*. John Wiley & Sons.

[3] Oliveira, P.J.D.S.P.D., 1992. Computer modelling of multidimensional multiphase flow and application to T-junctions.

[4] Michaelides, E., Crowe, C.T. and Schwarzkopf, J.D. eds., 2016. *Multiphase flow handbook*. CRC Press.

[5] Tornberg, A.K. and Engquist, B., 2000. A finite element-based level-set method for multiphase flow applications. *Computing and Visualization in Science*, *3*(1-2), pp.93-101.

[6] Lamorgese, A.G., Molin, D. and Mauri, R., 2011. Phase field approach to multiphase flow modelling. *Milan Journal of Mathematics*, *79*(2), pp.597-642.

[7] Tryggvason, G., Bunner, B., Esmaeeli, A., Juric, D., Al-Rawahi, N., Tauber, W., Han, J., Nas, S. and Jan, Y.J., 2001. A front-tracking method for the computations of multiphase flow. *Journal of computational physics*, *169*(2), pp.708-759.

[8] Manninen, M., Taivassalo, V. and Kallio, S., 1996. On the mixture model for multiphase flow.

[9] Parker, J.C., 1989. Multiphase flow and transport in porous media. *Reviews of Geophysics*, *27*(3), pp.311-328.

[10] Quan, S. and Schmidt, D.P., 2007. A moving mesh interface tracking method for 3D incompressible two-phase flows. *Journal of Computational Physics*, *221*(2), pp.761-780.

[11] Hasan, A.R. and Kabir, C.S., 1988. A study of multiphase flow behaviour in vertical wells. *SPE Production Engineering*, *3*(02), pp.263-272.

[12] Gray, W.G., 1975. A derivation of the equations for multi-phase transport. *Chemical Engineering Science*, *30*(2), pp.229-233.

[13] Quan, S., Lou, J. and Schmidt, D.P., 2009. Modelling merging and breakup in the moving mesh interface tracking method for multiphase flow simulations. *Journal of Computational Physics*, *228*(7), pp.2660-2675.

[14] Olsson, E. and Kreiss, G., 2005. A conservative level set method for two phase flow. *Journal of computational physics*, *210*(1), pp.225-246.

[15] Hartmann, D., Meinke, M. and Schröder, W., 2010. The constrained reinitialization equation for level set methods. *Journal of computational physics*, *229*(5), pp.1514-1535.

[16] Parameswaran, S. and Mandal, J.C., 2020. A Novel Reinitialization Scheme for Conservative Level Set Method. *arXiv preprint arXiv:2012.08747*.

[17] Shao, C., Luo, K., Yang, Y. and Fan, J., 2017. Detailed numerical simulation of swirling primary atomization using a mass conservative level set method. *International Journal of Multiphase Flow*, *89*, pp.57-68.

[18] Tanguy, S. and Berlemont, A., 2005. Application of a level set method for simulation of droplet collisions. *International journal of multiphase flow*, *31*(9), pp.1015-1035.

[19] Pan, Y. and Suga, K., 2003. Capturing the pinch-off of liquid jets by the level set method. *J. Fluids Eng.*, *125*(5), pp.922-927.

[20] Lu, J., Fernández, A. and Tryggvason, G., 2005. The effect of bubbles on the wall drags in a turbulent channel flow. *Physics of Fluids*, *17*(9), p.095102.

[21] Santarelli, C. and Fröhlich, J., 2015. Direct numerical simulations of spherical bubbles in vertical turbulent channel flow. *International Journal of Multiphase Flow*, *75*, pp.174-193.
[22] Chahine, G.L., 2009. Numerical simulation of bubble flow interactions. *Journal of Hydrodynamics, Ser. B*, *21*(3), pp.316-332.
[23] Chahine, G.L., Hsiao, C.T., Choi, J.K. and Wu, X., 2008, October. Bubble augmented waterjet propulsion: two-phase model development and experimental validation. In *27th Symposium on Naval Hydrodynamics, Seoul, Korea* (pp. 5-10).
[24] Choi, J.K. and Chahine, G.L., 2003. Non-spherical bubble behaviour in vortex flow fields. *Computational Mechanics*, *32*(4), pp.281-290.
[25] Choi, J.K. and Chahine, G.L., 2004. Noise due to extreme bubble deformation near inception of tip vortex cavitation. *Physics of Fluids*, *16*(7), pp.2411-2418.
[26] Choi, J.K. and Chahine, G.L., 2004. Noise due to extreme bubble deformation near inception of tip vortex cavitation. *Physics of Fluids*, *16*(7), pp.2411-2418.
[27] Jiang, Y., Li, C., Deng, S. and Hu, S.M., 2020, December. A Divergence-free Mixture Model for Multiphase Fluids. In *Computer Graphics Forum* (Vol. 39, No. 8, pp. 69-77).
[28] Bertevas, E., Tran-Duc, T., Le-Cao, K., Khoo, B.C. and Phan-Thien, N., 2019. A smoothed particle hydrodynamics (SPH) formulation of a two-phase mixture model and its application to turbulent sediment transport. *Physics of Fluids*, *31*(10), p.103303.
[29] Zeidan, D., Bähr, P., Farber, P., Gräbel, J. and Ueberholz, P., 2019. Numerical investigation of a mixture two-phase flow model in two-dimensional space. *Computers & Fluids*, *181*, pp.90-106.
[30] Vlasák, P., Chára, Z., Krupicka, J. and Konfrst, J., 2014. Experimental investigation of coarse particles-water mixture flow in horizontal and inclined pipes. *Journal of Hydrology and Hydromechanics*, *62*(3), p.241.
[31] Parker, J.C., 1989. Multiphase flow and transport in porous media. *Reviews of Geophysics*, *27*(3), pp.311-328.
[32] Youngs, D.L., 1984. Numerical simulation of turbulent mixing by Rayleigh-Taylor instability. *Physica D: Nonlinear Phenomena*, *12*(1-3), pp.32-44.
[33] Gray, W.G., 1975. A derivation of the equations for multi-phase transport. *Chemical Engineering Science*, *30*(2), pp.229-233.

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