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SIMULATION OF TWO PHASE OIL-GAS FLOW IN PIPELINE

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ABSTRACT

T-junction, or commonly known as stand pipe appendage, is used by oil/gas industries to tap gas from existing production header for the purpose of downstream pipeline instrumentation. The appendage is either pre-design or retrofitted with minimum internals for maximum reliability for remote deployment. The motivation for this research originated from the lack of stand-pipe design method to correctly account for the splitting/separation nature of multiphase fluid within the pipeline straight from the production header. Consequently, a certain amount of liquid migrates together with the gas, resulting in the so-called carryover issue. This situation is further aggravated by the different flow regimes in the header pipeline which is not taken into account by the design practice. The negative consequences of this carryover on the operation of downstream unit have often led to frequent trip and maintenance issues. This paper presents the preliminary research in the finding of the two phase oil/gas separation in T-junction. The computed solutions are compared with experimental data and a good agreement is achieved.

Keywords: two-phase flow, gas-liquid flow, T-junction.

INTRODUCTION

Gas-liquid two-phase flow in pipes is a common occurrence in the petroleum industry production and transportation of oil and gas. Accurate prediction of the flow pattern, pressure drop and liquid holdup is imperative for the design of production, transport systems and for maintenance and operation of the downstream facilities. Two-phase flow presents a complex flow configuration. Flow behaviour is a function of flow variables such as gas and liquid flow rates, pipe diameter, inclination angle and fluid properties (gas and liquid density, viscosities and surface tension) [1]. In the petroleum industry application, phase separation in T-junctions has been observed as early as 1973 by Oranje [2]. He noticed that condensate in gas lines did not appear equally at all terminal points on branched pipelines.

The most useful methods of representing the phase split data is a plot of the fraction of the inlet liquid diverted into the branch arm against the fraction of the inlet gas diverted into the same branch. By calculation, the fraction of gas taken off and the fraction of liquid taken off could be obtained based on the following formulas [3-26].

$$\text{Gas taken off} = \frac{\text{Gas mass flow rate of side branch}}{\text{Gas mass flow rate of inlet}} \quad (1)$$

$$\text{Liquid taken off} = \frac{\text{Liquid mass flow rate of side branch}}{\text{Liquid mass flow rate of inlet}} \quad (2)$$

According to Wren, Baker and Baker *et al.*, [3-5] there are many physical factors and dominant forces that affect how the two-phase flow approaching the junction may be divided between the outlets. These are considered to be gravity, inertia and pressure.

Altering the orientation of the side arm will influence the phase separation as it will change the orientation of the gravitational force acting on the fluid [3-5]. Studies [3, 5, 6, 27] have concluded that when the side arm is oriented vertical upward pointing 12 o'clock, more gas is found in the side arm. At 3/9 o'clock, phase splitting is equal and when the side arm is oriented vertically downward at 6 o'clock, more liquid is discovered at the side arm.

Conte and Azzopardi [7] studied experimentally the division of gas/liquid flow at a large diameter T-junction. The separation of the phases has been quantified for horizontal semi-annular flow. Film thickness variations about the circumference of the inlet and outlet pipes have been obtained using conductivity techniques. In addition, liquid depth profiles within the junction have been measured. It has shown that the phase split of semi-annular flow at a large diameter T-junction is liquid dominated with less than 20% of the liquid is taken off for 80% gas take off.

Das *et al.*, [8] reported a study of phase split at a horizontal T-junction with main and side branches of 0.005m in diameters. The results were compared with those reported for larger T-junctions. It has been reported that, the side arm take-off tends to be richer in the gas phase with increase in pressure under all flow conditions. The reason has been attributed to the complex effect of pressure on the interface position which in turn determines the gas and liquid momentum.

Yang and Azzopardi [9] provided data on the split of liquid/liquid two-phase flow at a horizontal T-junction with equal pipe diameters, horizontal main pipe and side-arm. According to the authors there is little phase separation and hence this configuration of T-junction would not be efficient as a partial separator.

In horizontal T-junction, the associated pressure drop along the side arm and axial distance available for take-off into the side arm will be altered by the reduced side arm diameter (reduced T-junction) [3-5, 10].

Studies undertaken by [3-5, 11, 12] compared the pressure drops for both a regular and reduced fully horizontal T-junction with similar inlet flow rates. The pressure drop between the inlet and the run arm is relatively small and unaffected by the diameter of the side-arm. However, the inlet to side-arm pressure drop increases significantly with a decrease in the side-arm diameter ratio. So, for the same inlet conditions, a higher pressure drop is associated with the reduced T-junction. This is due to the higher gas velocities within the reduced diameter pipe for the same mass fraction extracted through the branch, as demonstrated by Bernoulli's equation.

Hong [13] studied the effect of liquid viscosity on the phase separation in horizontal T-junction where the viscosity of the liquids were 1 cP for water and 5 ~ 10 cP for mixture of water and hydroxyethyl cellulose. His result showed that the amount of liquid diversion into the side arm increased with increasing of liquid viscosity and this scenario can be explained by using the inertial and centripetal forces theory.

They explained that the velocity of the liquid flow was decreased as the liquid viscosity increased for the fixed inlet of gas velocity. Thus, the low liquid velocity will have lower inertial effect on the liquid. At the same time, the two phase flow through the T-junction will be subjected to the centripetal force due to the existing bending corner. The effect of the centripetal force will remain constant and unaffected by the liquid viscosity. Hence, for the fixed value of inlet gas velocity and increasing of liquid viscosity, the centripetal force will overcome low liquid inertial in order to draw more liquid into the side arm.

Brito *et al.*, [1] studied the effect of medium oil viscosity on two-phase oil-gas flow behaviour in horizontal pipes, experimental program on medium oil viscosities (39 cP< μ_{oil} <166 cP). The experiments are performed using a flow loop with a test section of 50.8-mm ID and 18.9-m-long horizontal pipe. The range of superficial liquid and gas velocity are 0.01 m/s to 3.0 m/s and 0 to 7.0 m/s, respectively. The existing flow patterns: stratified smooth, stratified wavy, elongated bubble, slug, dispersed bubble and annular, were observed for the studied flow conditions. Most of the experimental points observed in this study correspond to slug flow. The stratified smooth region decreases when the oil viscosity increases. Liquid viscosity increase delays the formation of an eddy at the liquid slug front, thus increasing the region of the elongated bubble flow. Gas bubble entrainment in the elongated bubble region increases when oil viscosity increases. For the lower oil viscosities (39 cP and 60 cP), transition from intermittent flow to dispersed bubble flow occurs at higher superficial gas velocities in comparison with higher oil viscosities (108 cP and 166 cP). Annular flow was only observed for the highest oil viscosity (166 cP).

Studies [3-5, 27] have shown that the flow pattern approaching T-junction would affect the phase separation. The type of flow pattern in the pipe is dependent on the superficial velocity of gas and liquid. The effect of the flow pattern onto the phase separation in vertically upward and downward T-junction was firstly noticed that the flow at the top section of the pipe would be influenced by the vertical upward side arm.

This paper presents a dynamic two-fluid model, in detail, stressing the basic equations and the two-fluid models applied. The SINTEF experimental data [28] are used to make comparisons for validation and predictions of steady-state pressure drop, liquid hold-up, and flow-regime transitions.

METHODOLOGY

This simulation applies OLGA Extended Two-Fluid Model to simulate two-phase flow by separately solving three separate continuity equations for liquid bulk, gas, and liquid droplets, which are coupled through interphasial mass transfer.

Conservation of mass for the gas phase reads,

$$\frac{\partial}{\partial t}(V_g \rho_g) = -\frac{1}{A}\frac{\partial}{\partial z}(A V_g \rho_g v_g) + \psi_g + G_g \quad (3)$$

Conservation of the liquid phase is given by,

$$\frac{\partial}{\partial t}(V_L \rho_L) = -\frac{1}{A}\frac{\partial}{\partial z}(A V_L \rho_L v_L) - \psi_g \frac{V_L}{V_L + V_D} - \psi_e + \psi_d + G_L \quad (4)$$

For Liquid droplets,

$$\frac{\partial}{\partial t}(V_D \rho_L) = -\frac{1}{A}\frac{\partial}{\partial z}(A V_D \rho_L v_D) - \psi_g \frac{V_D}{V_L + V_D} + \psi_e - \psi_d + G_D \quad (5)$$

V_g, V_L, V_D=gas, liquid-film, and liquid droplet volume fractions, $\rho =$ density, $v =$ velocity, $p =$ pressure, and A = pipe cross-sectional area. $\psi_g =$ Mass-transfer rate between the phases, $\psi_e, \psi_d =$ the entrainment and deposition rates, and G_f = possible mass source of Phase f. Subscripts g, L, i *and* D indicate gas, liquid, interface, and droplets, respectively.

Conservation of momentum is expressed for three different fields, yielding the following separate 1D momentum equations for the gas, liquid droplets, and liquid bulk or film.

For the gas phase,

$$\frac{\partial}{\partial t}(V_g \rho_g v_g) = -V_g\left(\frac{\partial p}{\partial z}\right) - \frac{1}{A}\frac{\partial}{\partial z}(A V_g \rho_g v_g^2) - \lambda_g \frac{1}{2}\rho_g |v_g| v_g$$
$$\times \frac{S_g}{4A} - \lambda_i \frac{1}{2}\rho_g |v_r| v_r \frac{S_i}{4A} + V_g \rho_g g \cos\alpha + \psi_g v_a - F_D \quad (6)$$

For the liquid droplets,

$$\frac{\partial}{\partial t}(V_D \rho_L v_D) = -V_D\left(\frac{\partial p}{\partial z}\right) - \frac{1}{A}\frac{\partial}{\partial z}(A V_D \rho_L v_D^2) + V_D \rho_L g \cos\alpha$$
$$-\psi_g \frac{V_D}{V_L + V_D} v_a + \psi_e v_i - \psi_d v_D + F_D \quad (7)$$

Equations. 6 and 7 were combined to yield a combined momentum equation, where the gas/droplet drag terms, F_D, cancel out:

$$\frac{\partial}{\partial t}(V_g\rho_g v_g + V_D\rho_L v_D) = -\left(V_g + V_D\right)\left(\frac{\partial p}{\partial z}\right) - \frac{1}{A}\frac{\partial}{\partial z}\left(AV_g\rho_g v_g^2 + AV_D\rho_L v_D^2\right) - \lambda_g\frac{1}{2}\rho_g\left|v_g\right|v_g\frac{S_g}{4A} - \lambda_i\frac{1}{2}\rho_g\left|v_r\right|v_r\frac{S_i}{4A} + \left(V_g\rho_g + V_D\rho_L\right)g\cos\alpha + \psi_g\frac{V_L}{V_L+V_D}v_a + \psi_e v_i - \psi_d v_D \quad (8)$$

For the liquid at the wall,

$$\frac{\partial}{\partial t}(V_L\rho_L v_L) = -V_L\left(\frac{\partial p}{\partial z}\right) - \frac{1}{A}\frac{\partial}{\partial z}\left(AV_L\rho_L v_L^2\right) - \lambda_L\frac{1}{2}\rho_L\left|v_L\right|v_L\frac{S_L}{4A} + \lambda_i\frac{1}{2}\rho_g\left|v_r\right|v_r\frac{S_i}{4A} + V_L\rho_L g\cos\alpha - \psi_g\frac{V_L}{V_L+V_D}v_a - \psi_e v_i + \psi_d v_D - V_L d\left(\rho_L - \rho_g\right)g\frac{\partial V_L}{\partial z}\sin\alpha \quad (9)$$

$\alpha =$ pipe inclination with the vertical and $S_g, S_L, S_i =$ wetted perimeters of the gas, liquid, and interface. the internal source, G_f, is assumed to enter at a 90° angle to the pipe wall, carrying no net momentum.

The above conservation and momentum equations can be applied for all flow regimes. However, certain terms may drop out for certain flow regimes; e.g., in slug or dispersed bubble flow, all the droplet terms disappear.

VALIDATION

The validation of the two-phase flow set up is based on the experimental data published by SINTEF flow laboratory. The experiment consists of an 8-inch (0.2032 m) diameter pipe extending 400 m out and back, with a 55 m riser tower. Fluid properties for the fluids used in the model are given in Table-1 [28, 29].

The inlet conditions are the gas-oil ratio, oil flow rate, operating pressure and temperature, oil API gravity.

Table-1. Fluid properties for SINTEF flow loop [29].

Fluid	Density (kg/m³)	Viscosity (kg/m-s)
Nitrogen gas (20 bar)	22	1.80×10^{-5}
Nitrogen gas (45 bar)	50	1.80×10^{-5}
Nitrogen gas (90 bar)	90	1.80×10^{-5}
Naphtha	673	3.00×10^{-4}
Diesel	825	2.57×10^{-3}

For the transient inlet flow, a time-dependent inlet flow rates were applied on the experiment setup as in Figure-1, where the inlet liquid superficial velocity is kept constant at 1.08 m/s, while gas superficial velocity was increased from 1.0 m/s to 4.2 m/s in a period of 20 seconds.

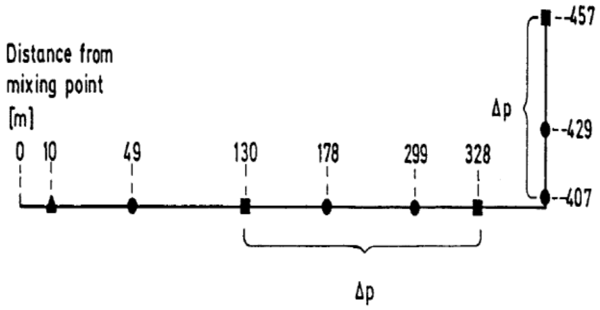

Figure-1. Test section of the SINTEF two-phase flow laboratory for the dynamic inlet experiment (● liquid holdup measurement; ▲ absolute pressure recordings).

In this section, the results obtained with the present program of dynamic two fluid model are compared with experimental data from SINTEF. The comparison of results are shown in Figures-2 to 9.

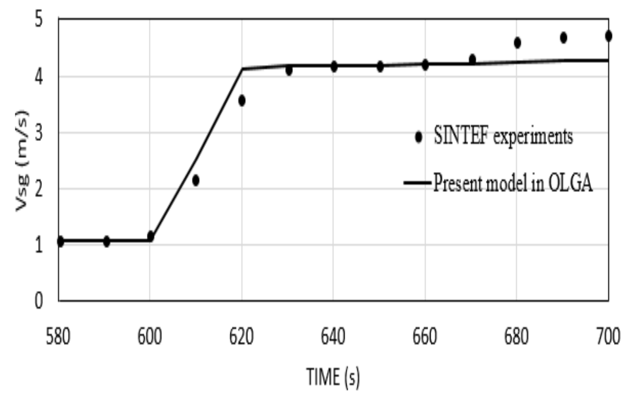

Figure-2. Superficial-gas-velocity recording for the dynamic inlet-flow experiments at the SINTEF two-phase flow laboratory.

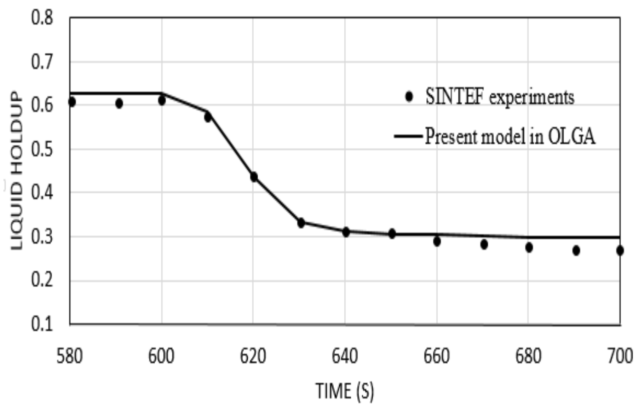

Figure-3. Liquid-holdup recordings in the horizontal pipe at location 49 m from the mixing point.

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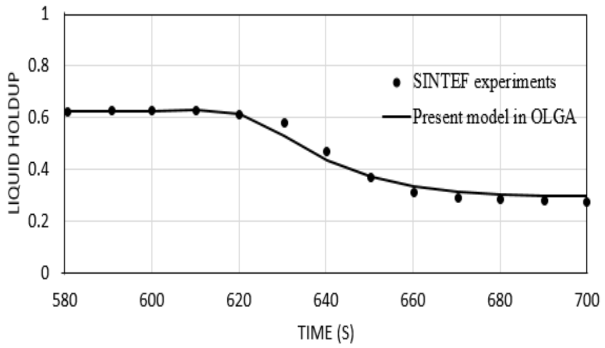

Figure-4. Liquid-holdup recordings in the horizontal pipe at location 178 m from the mixing point.

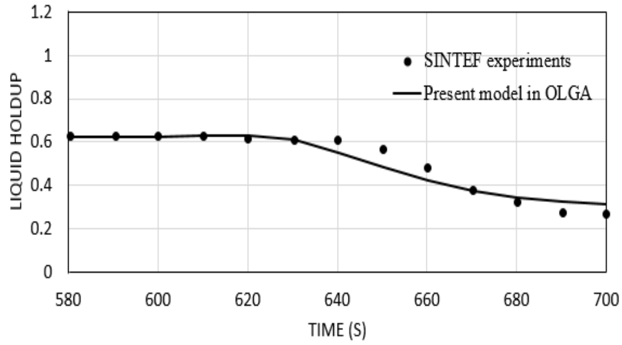

Figure-5. Liquid-holdup recordings in the horizontal pipe at location 299 m from the mixing point.

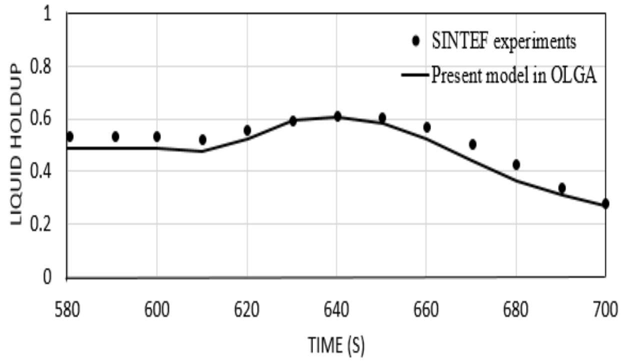

Figure-6. Liquid-holdup recordings in the riser at location 7 m from the riser bottom.

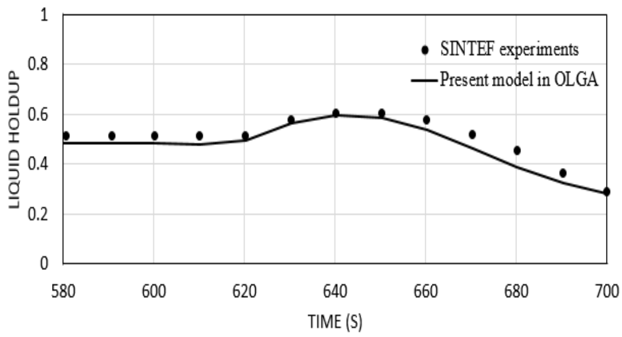

Figure-7. Liquid-holdup recordings in the riser at location 29 m from the riser bottom.

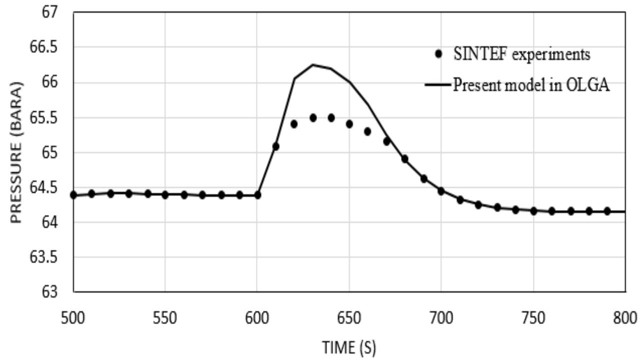

Figure-8. Absolute pressure recorded 10 m from the mixing point.

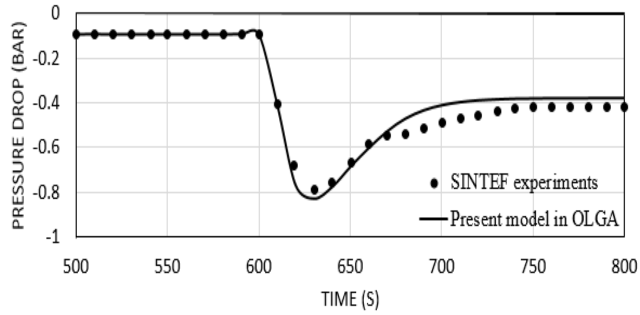

Figure-9. Pressure difference over a part of the horizontal line.

Figure-2 shows that the inlet liquid superficial velocity was kept constant at 1.08 m/s, while the superficial gas velocity was increased from 1.0 to about 4.2 m/s in a period of 20 seconds. A very good agreement can be observed between the present model and the experimental data.

Figure-3 through 7 illustrates that the increase in the gas flow rate results in a decrease in the liquid holdup. This discontinuity in liquid holdup tends to be smeared out and broken up into slugs as it travels along the pipeline. It is noteworthy that the simulation model applies a mean-slug-flow description, but it is able to simulate the time evolution of holdup and the pressure responses (see Figures-8 and 9) to the inlet conditions. The predicted time response is good, but slightly too slow, especially in Figure-8, where the peak pressure is higher than the experimental results by approximately 1 bar.

CONCLUSIONS

The OLGA model was presented, with emphasis on the particular two-fluid model applied and the flow-regime description. The model gives reasonable results compared with transient data in most cases.

The model was also tested on a number of different oil and gas field lines. The model predictions are generally in good agreement with the measurements.

For the liquid hold-up, the deviations between experimental data and model prediction as estimated by the one-dimensional two-fluid model had the same overall deviation.

The actual number of available field lines where the fluid composition and line profile are sufficiently well documented for a meaningful comparison is, however, still limited. Further verification of this type of two-phase flow models is clearly needed.

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REFERENCES

[1] R. Brito, E. Pereyra, and C. Sarica, "Effect of Medium Oil Viscosity on Two-Phase Oil-Gas Flow Behavior in Horizontal Pipes," presented at the Offshore Technology Conference, Houston, Texas, USA, 2013.

[2] L. Oranje, "Condensate behavior in gas pipelines is predictable," Oil Gas J, vol. 32, pp. 39-44, 1973.

[3] E. M. K. Wren, "Geometric effects on phase split at a large diameter T-junction," University of Nottingham, 2001.

[4] G. Baker, W. Clark, B. Azzopardi, and J. Wilson, "Controlling the phase separation of gas–liquid flows at horizontal T-junctions," AIChE journal, vol. 53, pp. 1908-1915, 2007.

[5] G. Baker, "Separation and control of gas-liquid flows at horizontal T-junctions," University of Nottingham, 2003.

[6] B. Azzopardi and S. Rea, "Phase separation using a simple T-junction," in SPE Annual Technical Conference and Exhibition, 2000.

[7] G. Conte and B. Azzopardi, "Film thickness variation about a T-junction," International journal of multiphase flow, vol. 29, pp. 305-328, 2003.

[8] G. Das, P. Das, and B. Azzopardi, "The split of stratified gas–liquid flow at a small diameter T-junction," International Journal of Multiphase Flow, vol. 31, pp. 514-528, 2005.

[9] L. Yang and B. Azzopardi, "Phase split of liquid–liquid two-phase flow at a horizontal T-junction," International Journal of Multiphase Flow, vol. 33, pp. 207-216, 2007.

[10] W. Pao, F. M. Hashim, and L. H. Ming, "Computational Analyses of Passive Wet Gas Separation in Branched Piping," in MATEC Web of Conferences, 2014, p. 03009.

[11] L. Walters, H. Soliman, and G. Sims, "Two-phase pressure drop and phase distribution at reduced tee junctions," International journal of multiphase flow, vol. 24, pp. 775-792, 1998.

[12] B. J. Azzopardi, "The Effect of Side Arm Diameter on Phase Split at T-Junctions," in SPE Annual Technical Conference and Exhibition, Houston, Texas, 1999.

[13] K. Hong, "Two-phase flow splitting at a pipe tee," Journal of Petroleum Technology, vol. 30, pp. 290-296, 1978.

[14] C. Bertani, M. Malandrone, and B. Panella, "Experimental study on the flow patterns and the two-phase pressure drops in a horizontal impacting T-Junction," in Journal of Physics: Conference Series, 2014, p. 012013.

[15] C. Bertani, D. Grosso, M. Malandrone, and B. Panella, "Air Water Two-phase Flow in a Horizontal T-junction: Flow Patterns, Phase Separation and Pressure Drops," 2011.

[16] M. Davis and B. Fungtamasan, "Two-phase flow through pipe branch junctions," International Journal of Multiphase Flow, vol. 16, pp. 799-817, 1990.

[17] T. Ellison, D. Hatziavramidis, B. Sun, and D. Gidaspow, "Computational fluid dynamics (CFD) model for phase separation at branching tee junctions," in SPE Western Regional Meeting, Long Beach, California, 1997.

[18] A. El-Shaboury, H. Soliman, and G. Sims, "Two-phase flow in a horizontal equal-sided impacting tee junction," International journal of multiphase flow, vol. 33, pp. 411-431, 2007.

[19] J. Hart, P. J. Hamersma, and J. M. H. Fortuin, "Phase Distribution During Gas/Liquid Flow Through Horizontal Dividing T Junctions," in SPE Annual Technical Conference and Exhibition, New Orleans, LA, 1990.

[20] R. Issa and P. Oliveira, "Numerical prediction of phase separation in two-phase flow through T-junctions," Computers & fluids, vol. 23, pp. 347-372, 1994.

[21] Y. Liu and W. Li, "Numerical Simulation on Two-Phase Bubbly Flow Split in a Branching T-Junction," International Journal of Air-Conditioning and Refrigeration, vol. 19, pp. 253-262, 2011.

[22] S. Marti and O. Shoham, "A unified model for stratified-wavy two-phase flow splitting at a reduced T-junction with an inclined branch arm," International journal of multiphase flow, vol. 23, pp. 725-748, 1997.

[23] M. Mohamed, H. Soliman, and G. Sims, "Experimental investigation of two-phase flow splitting in an equal-sided impacting tee junction with inclined outlets," Experimental Thermal and Fluid Science, vol. 35, pp. 1193-1201, 2011.

[24] F. Peng and M. Shoukri, "A Study of Dividing Steam-Water Flow In T-Junctions: Experiments and Analyses," Mechanical Engineering, McMaster University, 1994.

[25] T. Stacey, B. Azzopardi, and G. Conte, "The split of annular two-phase flow at a small diameter T-junction," International journal of multiphase flow, vol. 26, pp. 845-856, 2000.

[26] S. Wang, K. He, and J. Huang, "Phase splitting of a slug–annular flow at a horizontal micro-T-junction," International Journal of Heat and Mass Transfer, vol. 54, pp. 589-596, 2011.

[27] B. J. Azzopardi, "Multiphase Flow" Chemical Engineering and Chemical Process Technology, vol. 1.

[28] K. H. Bendiksen, D. Maines, R. Moe, and S. Nuland, "The dynamic two-fluid model OLGA; Theory and application," SPE (Society of Petroleum Engineers) Production Engineering; (United States), vol. 6, 1991.

[29] T. Danielson and Y. Fan, "Relationship between mixture and two-fluid models," in Proceedings of 14th International Conference on Multiphase Production Technology, Cannes, France, 2009, pp. 17-19.