Computational Analyses of Passive Wet Gas Separation in Branched Piping

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Abstract. Understanding the behavior of two-phase flow through a T-junction is very important as it could potential contribute to massive cost saving in partial phase separation. The objectives of this paper focuses on the effect the inlet flow conditions on two-phase split efficiency under constant pressure gradient, and the effect of averaged bubble diameter on the mass flow split at the side arm outlet Via computational fluid dynamics tool, preliminary investigation found that beyond side to main arm diameter ratio of 0.75, there is a drop of separation efficiency. The change of fraction of gas taken off is almost linearly and negatively proportional to the unit increment of initial gas saturation. When the side to main arm diameter ratios equal to 0.5 and 0.75, the fraction of gas taken off is almost similar as far as the initial gas saturation is concerned.

1. Introduction

A T-junction consists of three main components which are the main, run and side arms, as shown schematically in Figure 1(a). When a two-phase mixture flows through a T-junction, the phases tend to separate in different proportions among the outlet arms. This phenomenon of phase maldistribution through a T-junctions has enourmous potential as simple, cost saving, passive partial separator to be used in pipeline networks in the petroleum industry. However, the efficiency of partial separation is not well understood.
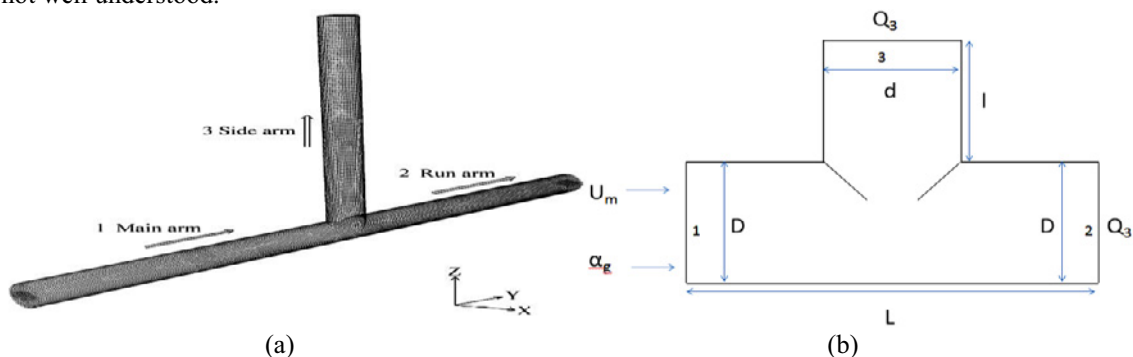
Figure 1. (a) Schematic of a T-junction [3]; (b) schematic T-junction with applied inlet and outlets boundary conditions

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2. Literature Review

According to Suzanne and Choi [1], less liquid was observed to split to the side-branch resulting in higher quality as the inlet liquid volume fraction increased in a uniform diameter T-junction. However, according to Azzopardi *et al.* [2], the degree of phase separation seems to depend on the transit time between liquid-gas mixtures and the junction. The slower flows have more time to separate than the faster flow. Liu, *et al.* [3] concluded that gas phase tend to flow into the side arm for bubbly flow because of the pressure difference of the side arm to main arm is much larger than that for the run arm. Thus, the lower density gas will respond more easily to pressure gradient than liquid phase for the same pressure force. In addition, Margaris [4] reported that the separation efficiency at uniform T-junction depends mainly on phase momentum, the existing flow pattern before the junction and also the gravity forces distribution on T-junction. Baker [5] stated that a reduction in the side-arm diameter will have two different effects which are the associated pressure drop and the axial distance available for take-off. The outlet with greater suction has a stronger influence on the flowing fluids and hence more significant the diversion in that direction.

According to Wren *et al.* [6,7], the main difference between a reduced and a regular T-junction is the pressure redistribution around the junction. For the same inlet conditions, the reduced side-branch causes a higher pressure drop compared with the uniform T-junction. This is mainly due to the higher gas phase velocities encountered in the reduced side-arm for the same fraction of inlet gas flowing down the side arm. Griston and Choi [8] reported that the percentage of liquid split to the side-arm decreased further as the inlet vapor velocity decreased. The field tests showed that reduced side-arm diameter further decreased the percentage of liquid split to the side-branch. The liquid have lesser tendencies to flow through the restricted cross-sectional area of the side-arm. Furthermore, Azzopardi [9] also concluded that the effect of diameter ratio is strongest at lower gas rates and least at high gas and lower liquid flow rate conditions.

Pao *et al.* [10] showed only the aspects of diameter ratios on the fraction of gas take off. The objectives of this paper focuses on the effect the inlet flow conditions on two-phase split efficiency under constant pressure gradient, and the effect of averaged bubble diameter on the mass flow split at the side arm outlet.

3. Governing Equations and Modeling Methodology

The governing equations for two-phase flow model, as presented by Liu *et al.* [3] can be summarized as follows.
Two-phase continuity equation:

$$\frac{\partial}{\partial t}(\alpha_i \rho_i) + \nabla \cdot (\alpha_i \rho_i \mathbf{v}_i) = 0 \qquad i = l \text{ or } g \tag{1}$$

Two-phase momentum balance:

$$\frac{\partial}{\partial t}(\alpha_i \rho_i \mathbf{v}_i) + \nabla \cdot (\alpha_i \rho_i \mathbf{v}_i \cdot \mathbf{v}_i) = -\alpha_i \nabla p + \nabla \boldsymbol{\tau}_i + \alpha_i \rho_i \mathbf{g} \pm \mathbf{R}_{i,j}; \quad i, j = \begin{cases} l, g \\ i \neq j \end{cases} \tag{2}$$

where $\mathbf{v}$ is the phase velocity, α is the volume fraction, ρ density, p is the hydrostatic pressure, $\mathbf{g}$ is the gravity vector, $\mathbf{R}$ is the interfacial interaction force between two phases and $\boldsymbol{\tau}$ is the stress tensor of the constituents. The subscript i and j refer to either liquid (*l*) or gas (*g*). The interfacial interaction force depends on pressure, cohesion and other effects and is subject to the conditions such that

$$R_{l,g} = -R_{g,l}, \ R_{l,l} = 0, \ R_{g,g} = 0. \tag{3}$$

The stress tensor is given as follows:

$$\boldsymbol{\tau}_i = \alpha_i \mu_i \left(\nabla \mathbf{v}_i + \nabla^T \mathbf{v}_i \right) + \alpha_i \left(\lambda_i - \tfrac{2}{3} \mu_i \right) \left(\nabla \cdot \mathbf{v}_i \right) \mathbf{I} \tag{4}$$

where μ_i and λ_i are the viscosity coefficients of the constituents. These equations are available in ANSYS Fluent 14.5, under the Eulerian Multiphase Model and hence will not be further elaborated. The development of numerical model of T-junction for two-phase separation is based on the schematic T-junction in Figure1(b), where it consists of the main arm (1), run arm (2) and side arm (3), with symbols indicating the applied inlet/outlet conditions and geometric parameters considered in the present study. Other parameters such as the velocity inlet for water and gas, inlet gas saturation, flow rate weighting factor for both outlets and others are taken into consideration as shown in Table 1.

Table 1. Input paramètres for validation and parametric studies

Input Parameters	Parametric Study
Main and run arm diameter, D [mm]	200
Side arm diameter, d_3 [mm]	100, 150, 200
Total length of horizontal arm, L [mm]	4200
Total length of vertical arm, l_3 [mm]	2000
Density of liquid phase, ρ_l [kg/m^3]	998.2
Density of gas phase, ρ_g [kg/m^3]	0.6 – 0.75
Initial gas saturation, α_{gi}	0.7 – 0.96
Inlet mixture velocity, U_m (m/s)	8 – 15
Inclination angle of gravity(clockwise)	0º – 45º
Overall mass split ratio, Q [-]	0.3 – 0.97
Operating pressure, P [kPa]	101

Mesh independent study and model validation were described in the previous paper [10] and hence will not be repeated here. It is thus summarized here that the mesh used were having a density in between 4.6 – 4.8 tetrahedrons/mm^3 and the FLUENT models were validated using experimental data from Davis *et al.* [11].

4. Results and Discussions

In order to simplify the discussion, the fraction is gas taken off is designated *f*. The effect of initial gas saturation with U_m=15m/s and gas density of 0.6679kg/m^3 is shown in Figure 2. The higher the mass split ratio, the change of *f* per unit increment of initial gas saturation increases, indicating the decline of separation efficiency. Interestingly, *f* almost coincides with each other for diameter ratio of 0.75 and 1.0 for different mass split ratio. In other words, the perturbation of diameter ratio to fraction of gas taken off is minimal as far as the same mass split ratio is concerned. While *f* exhibits a linear variation for diameter ratio of unity, the same cannot be said for diameter ratio 0.75 and 1.0. If we denote the initial gas saturation as S_{gi}, the non-linearity of $\partial f / \partial S_{gi}$ is most obvious when the prescribed mass split ratio close to unity. An interesting observation is that for diameter ratio 0.5, mass split ratio does not seem to affect the gradient of the curve at all and $\partial f / \partial S_{gi}$ remains more of less constant.

Figure 3 shows the effect of gas density on fraction of gas taken off with different mass split ratio and an inlet mixture velocity of 12 m/s. Unsurprisingly, the change of fraction of gas taken off per unit of gas density variation decreases. In other words, the smaller the density difference between the two-phase, the less effective it is to divert the gas phase into the side arm.
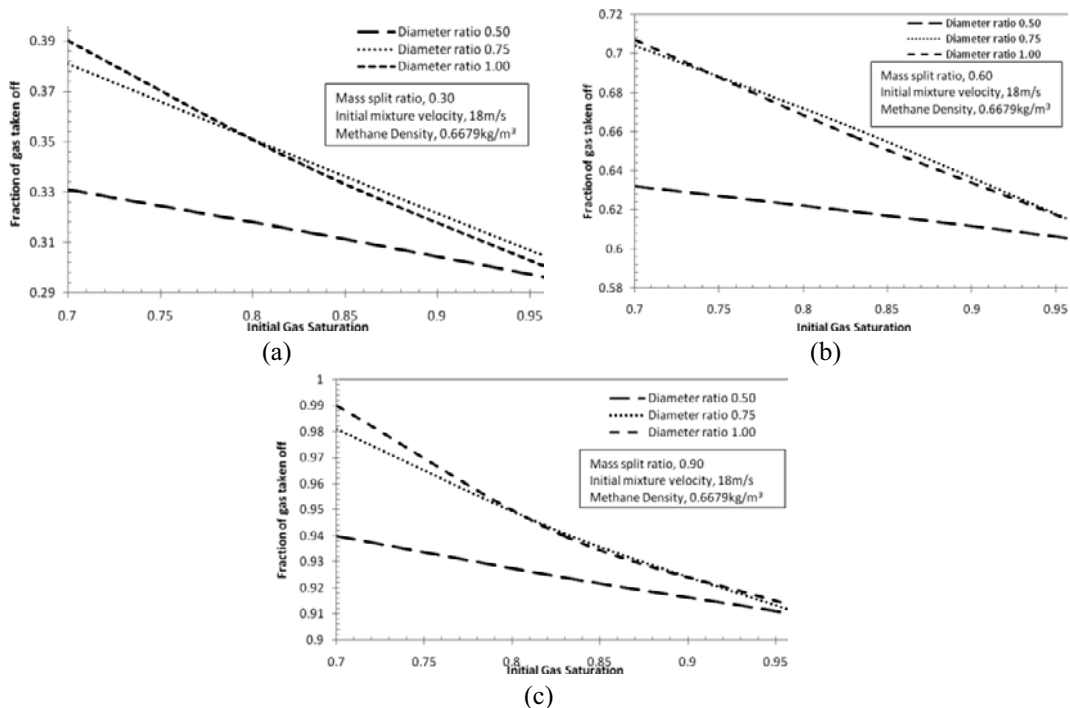
Figure 2. Effect of Initial gas saturation on Fraction of gas taken off with initial mixture velocity of 15m/s and Methane density of 0.6679kg/m^3 (methane)
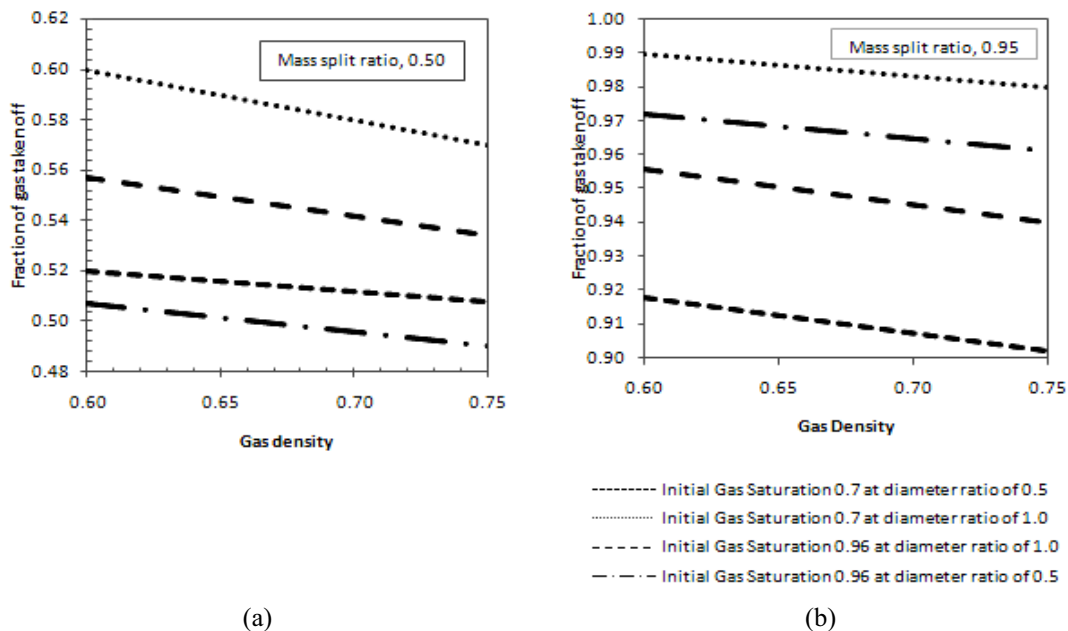
Figure 3. Effect of gas density on fraction of gas taken off with overall mass split ratio of 0.50 and 0.95 with an inlet mixture velocity of 12 m/s

5. Conclusion

This present paper focused on two-phase wet-gas separation in T-junction with horizontal main arm and vertical side arm using methane gas and water as working fluids. Through numerical simulation, the significance of diameter ratio, initial gas saturation, overall mass split ratio, averaged inlet mixture velocity and gas density are studied. It is found that the most influential factor is the overall mass split ratio followed by the initial gas saturation and diameter ratio of the T-junction. The effects due to inlet velocity of the mixture and gravity inclination are almost negligible relative to other factors. The diameter ratio of 0.5 - 0.75 is determined to be the optimum range for an efficiency separation and beyond 0.75, the efficiency starts to flatten. The higher the gas saturation, the less efficient it is for the split to happen.

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