A REVIEW OF T-JUNCTION GEOMETRICAL EFFECT ON TWO-PHASE SEPARATION

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ABSTRACT

T-junctions have been used in piping networks to fuse or split incoming fluids for decades. It is because of their massive utization specially in petroleum industry, that it is the subject of interest for many researchers to this date. In oil and gas sector, T-junctions are usually used as a partial two phase separator. Two-phase separation in a T-junction is a complex phenomena because of its dependence upon many parameters, one of which is the geometrical features of the T-junction. Here, in this paper the effect of different geometrical features of the T-junction on two-phase separation will be discussed to compile different concepts governing the phase separation in a T-junction. It was felt that further research is required to explore the effects of various inserts and combination of more than one T-junctions on phase separation.

Keywords: two-phase flow, t-junction, phase separation, geometrical features.

INTRODUCTION

T-junctions often find their application in chemical processing plants [1] and in petroleum industries [2], to serve as a fluids stream divider. The reason for such vast application of T-junction is that it acts as a partial phase separator, which is not only compact but it is also less expansive. Whenever, a two-phase fluid stream passes through a T-junction, it experiences uneven phase separation among the two outlets [3]. This phenomena is called phase maldistribution [4].

Oranje [5] noticed the phenomena of maldistribution of two phases in a T-junction for the first time. During winter season in Netherland, he observed that in the transmission pipe network of the natural gas, the condensate formed in the gas pipeline due to low temperature environment arrived at some delivery station and dry gas appears on the other delivery stations. Since the reporting of this phenomena T-junction is looked at like a partial phase separator.

Understanding the behaviour of the gas-liquid two phase flow is extremely important for the effective utilization of T-junction and for the proper controlling of the phase separation. It is also important because the maldistribution of phases occurring in a T-junction have a significant effect on the maintenance of downstream equipment [2]. To understand the behaviour of the two-phases in a T-junction one needs to look at parameters that effect the two-phase separation. A great deal of parameters are already explored by many researchers but up to this date phenomena of two-phase separation is not completely understood.

One of the important parameters that effect two-phase splitting behaviour in a T-junction is the geometrical features of the T-junction. A lot of work is done in this particular field such as regular diameter T-junction [6-8], reduced diameter T-junction [6, 9, 10], micro T-junction [11, 12], branching T-junction [13-15] and impacting T-junction [16, 17].

The purpose of this current paper is to compile some knowledge related to the effect of T-junction geometrical feature on gas-liquid two-phase separation and to make recommendation for future research work.

LITERATURE REVIEW

Geometry of the T-junction is one of the key factors that affect two-phase separation in a pipe Tee. With slight change in geometry there can be a dramatic effect on phase separation because the governing forces that are causing the two phases to split in different proportions at the junction can change with the T-junction geometry. As a result, in order to increase the two-phase separation efficiency of a T-junction, it is required to understand the effect of each geometrical feature on phase separation.

Conte and Azzopardi [18] performed experiments on a regular diameter horizontal T-junction with main and side arm diameter at 0.127m. They found that when the flow pattern is semi annular, then most of the liquid entering the pipe tee is concentrated at the bottom of the T-junction pipe, while, the remaining liquid flows along the wall of the pipe in the form of a thin film. Their results showed that the liquid film distribution in the T-junction is dependent on liquid and gas flow rates and up till 80% of the gas going in to the side arm, the liquid take off is less than 20%.

Another experimental study in which regular diameter branching T-junction was the subject of interest was by Yang and Azzopardi [19]. In their investigation they introduced kerosene-water liquid-liquid two phase flow into a horizontal uniform diameter T-junction. The diameter of inlet and both the outlet pipes were 0.0674 m. The flow regimes under consideration were stratified and dispersed. The outcomes of this experiments showed that a regular diameter horizontal T-junction do not act as a good two-phase separator. It was also observed that the two-phase separation depends on the densities of the continuous and dispersed phases.

Wren and Azzopardi [20] conducted experiments on T-junctions having main arm diameter of 0.125 m and diameter ratio of 1 and 0.6. They stated that by reducing

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the diameter of the side arm, better phase separation is achieved. In their experiments they have also worked on inserts of 30° and 45° cut. These inserts were protruded into main arm through the side arm at various protrusion values. With respect to the flow direction, these cuts could be either forward or backward facing, this is shown in Figure-1. The effect of these inserts on air-water two-phase separation were then measured. It was found that when an insert was placed in a reduced diameter T-junction the two-phase separation was slightly improved. On the other hand in a regular diameter T-junction the two-phase separation more or less remained similar to when the top cut of the insert was changed from 30° to 45°.

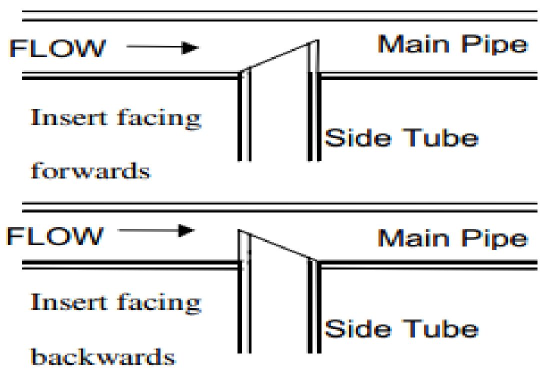

Figure-1. Position of inserts relative to the flow [21].

Walters, *et al.* [13] tried to study the pressure drop and two-phase distribution among the two outlets of the T-junction by performing experiments on horizontal reduced diameter T-junctions of main pipe diameter of 0.0381 m and diameter ratios of 0.5 and 0.2. The two phases used for this experiment were air and water. Their analysis showed that when the T-junction with diameter ratio of 0.5 is used, flow patterns such as semi-annular, stratified wavy and smooth stratified flow were more inclined towards gas to exit through side arm. But, when the T-junction with diameter ratio 0.2 is used and the extraction rates are low then stratified smooth, stratified wavy and semi annular flow patterns prefers gas to go into side arm, but this trend is short lived because as soon as the extraction rate increases, then suddenly more portions of liquid will start getting into side arm along the gas.

Griston and Choi [22] performed experiments on regular and reduced diameter T-junctions to understand the splitting of steam, when passed through a T-junction. They used 3 regular diameter T-junctions of 2, 3 and 4 inch diameter. While, the reduced diameter T-junction they used in their study had main arm diameter of 3 and 4 inch and side arm diameter of 2 inch in both the T-junctions. They found that in both type of T-junctions side arm always received better steam quality in their study. They also observed that in all the cases reduced diameter T-junction had better two-phase separation. The comparison between two-phase separation performance of the uniform and reduced diameter T-junction is shown in Figure-2. In Figure-2, it can be observed that the branch arm of reduced diameter T-junctions received less amount of liquid as compared to the branch arm of regular diameter T-junctions.

Marti and Shoham [23] also worked on a reduced diameter T-junction with main pipe diameter of 0.051 m and 0.5 diameter ratio. They tried to find the effect of side arm orientation on the phase separation when two-phase stratified wavy flow passes through a reduced diameter T-junction. Beside horizontal side arm position they obtained results for various downward inclination angles (-60°, -40°, -25°,-10° and -5) and various upward inclination angles (+20°, +10°, +5° and +1°), measured from the horizontal reference plane. It was concluded that the gravitational force plays an important role in two-phase separation, because when the side arm is directed upward at different angles, gravitational force tries to prevent liquid from going into side arm by pulling it downwards, hence, less liquid flows into branch arm. On the other hand, when the side arm is positioned at various downward angles, the gravitational force tries to pull the liquid into side arm, thus, more liquid exits through the side arm.

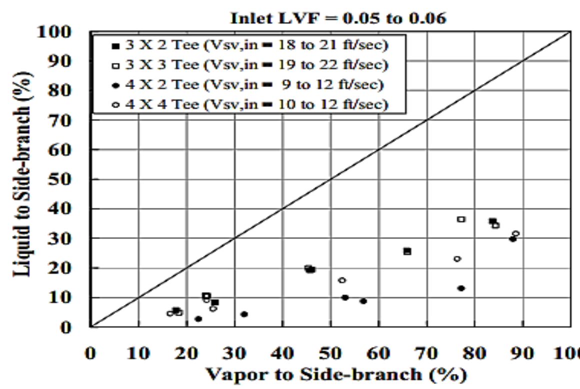

Figure-2. Comparison between two-phase separation data of regular and reduced diameter T-junctions [22].

Similarly, Penmatcha, *et al.* [24] also conducted experiments to understand the splitting behaviour of two-phase fluids at different branch arm orientations. They passed two-phase stratified wavy flow through a regular diameter T-junction which was inclined at different angles with reference to horizontal plane. In their experimentation the side arm was inclined at different angles from the horizontal plane such as 0° (horizontal position), upwards inclination of +35°, +20°, +10°, +5° and +1° and downward inclination of -60°, -40°, -25°, -10° and -5°. They also found that gravity plays an important role in two-phase separation. When the side arm was position at any of the upward inclination angles, less liquid exited through side arm as compared to when the side arm was positioned along the horizontal plane. As the side arm angle was further increased, the amount of liquid exiting through the side arm further decreased. It was found that at +35°, before any liquid get into side arm nearly 80% gas entering the T-junction had to pass into side arm. This

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phenomena is shown in Figure-3. On the other hand, when the side arm is directed downward at any angle, than more liquid tried to get into side arm, compared to when the branch arm was horizontal and at -60° from the horizontal plane almost all the liquid exits through the branch arm. This two-phase behaviour can be observed in Figure-4.

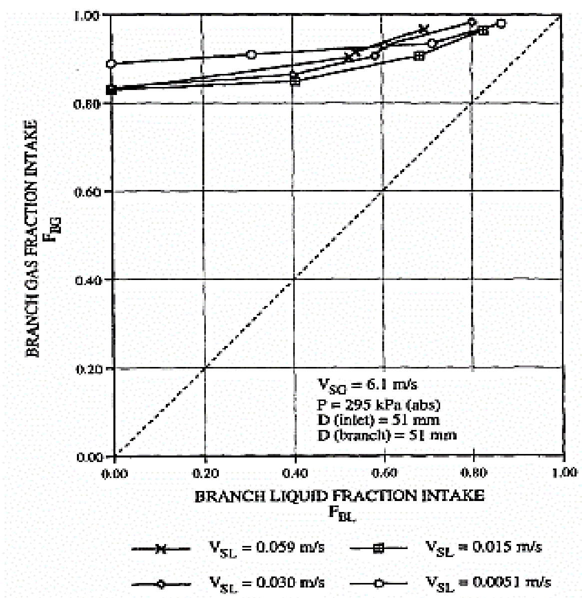

Figure-3. Graphical representation of two-phase separation when side arm of the horizontal T-junction is inclined at +35° from the horizontal plane [24].

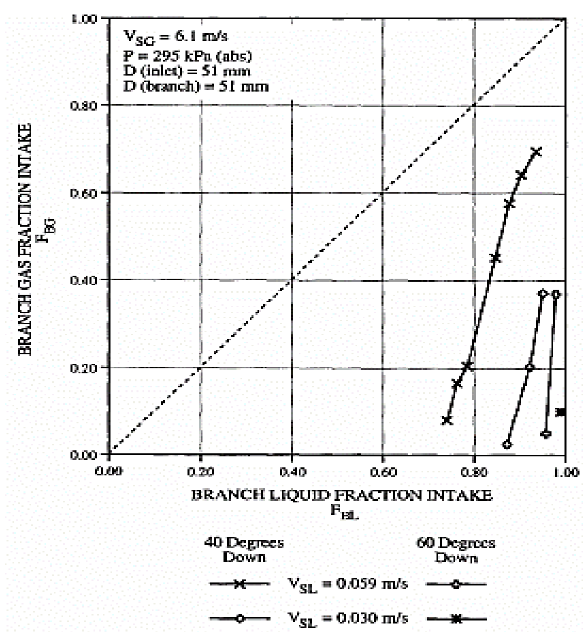

Figure-4. Graphical illustration of two-phase splitting behaviour when the branch arm of the horizontal T-junction is inclined at -60° from the horizontal plane [24].

Mohamed, *et al.* [25] used a 0.0135 m diameter regular T-junction in an impacting type configuration. They kept the inlet at the horizontal position but varied inclination of the two outlets. They tried to understand the effect of outlets inclination on two-phase separation. The flow pattern observed in this study were annular, wavy and stratified. It was observed that the orientation of the outlets affects the two-phase separation in an equal diameter impacting T-junction. But this effect is different at different flow regimes. They have taken measurement of phase separation at different flow regimes. The phase separation data they collected for stratified, wavy and annular flow at various outlet angles from the horizontal plane is illustrated in Figure-5 to Figure-7.

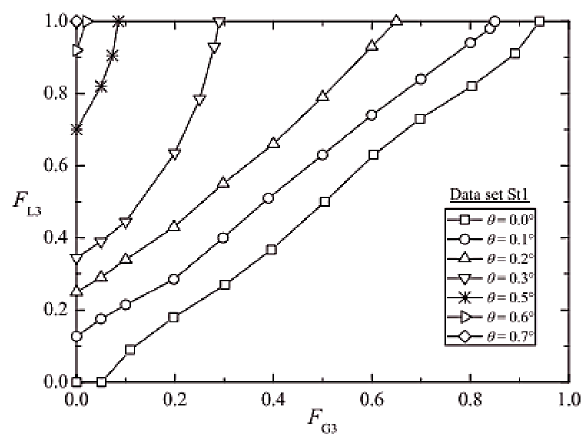

Figure-5. Two-phase separation data at stratified flow at various inclination angles of the outlets [25].

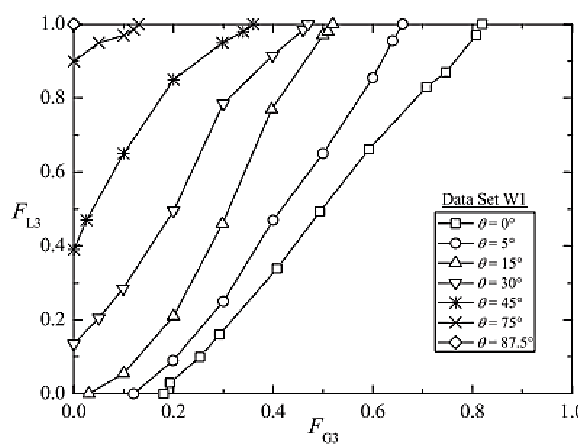

Figure-6. Two-phase separation data at wavy flow at various inclination angles of the outlets [25].

Here, F_{L3} and F_{G3} are the mass fraction of liquid and mass fraction of gas ending up into outlet number 3. Where, outlet 3 is the downward inclined outlet. It was noticed that the two-phase separation is most sensitive to the orientation of the outlets, when the two phases are flowing in stratified flow regime. But as the flow regime moves from stratified to annular flow pattern this sensitivity decreases.

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Chen, *et al.* [4] attempted to find the flow splitting behaviour of nitrogen and water two-phase annular flow in a micro-impacting horizontal T-junction, having 0.5 x 0.5 mm^2 square cross section. To study the effect of viscous force and surface tension on two-phase separation, carboxymethyl cellulose (CMC) and sodium dodecysulfate (SDS) aqueous solution were used to change the properties of the fluids. It was noticed that the two-phase separation behaviour in a horizontal micro-impacting T-junction is different from macro T-junctions, when the flow regime at the T-junction inlet is annular. This is because the two-phase separation in this case is not affected much by viscous forces and superficial velocities of the two phases. While, in this configuration the two-phase separation is greatly affected by surface tension.

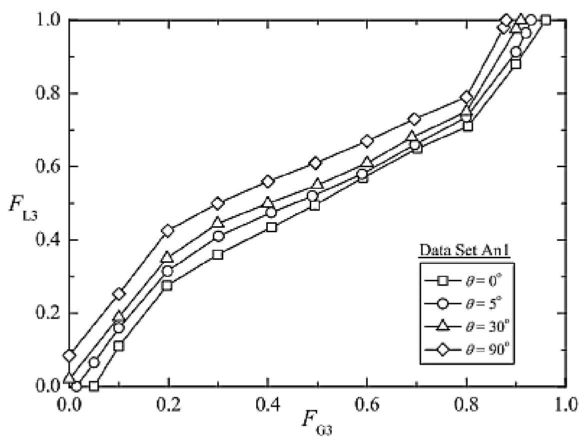

Figure-7. Two-phase separation data at annular flow at various inclination angles of the outlets [25].

Baker, *et al.* [26] experimented on a combination of two T-junctions in which the main pipe of both the T-junctions was horizontal but the side arm of the first T-junction was directed vertically upward, while, the side arm of the second T-junction was directed vertically downward. The two phases used in their study were air and kerosene oil and the flow pattern they work on were stratified and slug flow. They also used two valves in this combination of T-junctions. They fitted one valve in the run pipe of the second T-junction and this valve was manually operated. The second was fitted in the side arm of the second T-junction and it was an automatic valve. The purpose of this valve was to allow only liquid phase to exit through the second side arm by opening and closing, so that vertex formation is avoid and thus, air cannot be drawn into this side arm along liquid. This valve was actuated by a liquid level sensor. While, the manual valve is used to allow gas to exit through the run arm of the second T-junction by opening it to a certain percentage. It was found that, in case of stratified flow if the manual valve is 20% opened then the v/v percentage of liquid that pass into gas stream is less than 0.05%. Similarly, for slug flow when that manual valve is nearly 55% open then less than 5% v/v liquid ended up into gas stream. This is shown in the Figure-8.

Wren and Azzopardi [27] also conducted experiments on a combination of two T-junctions connected in series. In this experimental study, the first T-junction of the two T-junction combination was a uniform diameter T-junction having an internal diameter of 0.127 m. While, they used two T-junctions to be used as a second T-junction, one was a T-junction similar to the first T-junction of the system and the other was a reduced diameter T-junction having main arm diameter of 0.127 m and diameter ratio 0.6. They also tried to study the effect of separation distance, which is the perpendicular distance between the side arm of the first T-junction and the side arm of the second T-junction of the T-junction series combination, on two-phase split. The two separation distance they discussed in their work were 0.5 m and 1.2 m. It was found that the T-junctions with vertically upwards and vertically downwards side arm have better two-phase separation as compare to the one with horizontal side arm. While, in case of the series combination of T-junctions, it was noticed that impressive amount of phase separation can be achieved if reduced diameter T-junction is used as a second T-junction of the system. Another observation made in this experimental study is, two-phase separation is almost not affected by the separation distance at most of the inlet flow rates.

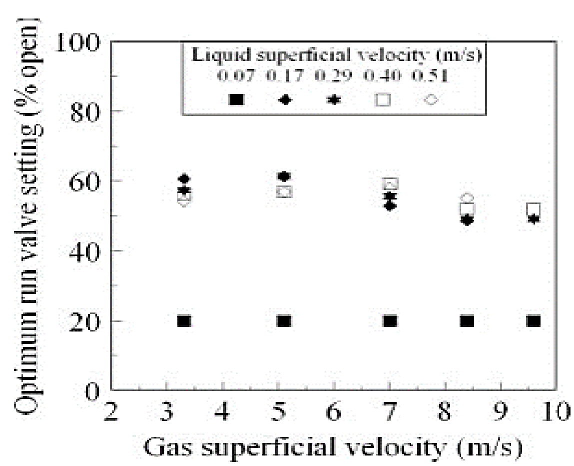

Figure-8. Performance dependence of manual valve in the run arm on two-phase inlet superficial velocities [26].

Mudde, *et al.* [28] investigated the two-phase splitting behaviour in an industrial size T-junction having a main and branch arm diameter of 23 cm and 10 cm, respectively. The test fluids in this study were air and water. They discovered that the flow pattern even at T-junction downstream have an effect on two-phase separation, especially if the flow is pulsating downstream.

CONCLUSIONS

The present paper summarized some published experimental work related to the effect of T-junction geometry on phase split. It was observed that flow pattern is a deciding factor in both a reduced and equal diameter T- junction as far as the phase split is concerned. It was found that gravitational force plays an important role in two-phase separation in a T-junction. . The orientation of the two outlets of the T-junction can alter the maldistribution of two phases. In micro T-junction (with less than 1 mm internal diameter), gravity do not play much role when it comes to two-phase separation but surface tension does. It was noticed that in case of phase misdistribution, reduced diameter T-junctions with diameter ratio ranging between 1 and 0.2 are better performers. From the literature review, it is noticed that a lot of work is done on simple regular and reduced diameter T-junctions but in case of inserts used in the T-junction and the combination of more than one T-junction, there is still a large room for research.

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