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Water flow split in commercial T-junctions with outlet ends open to atmosphere

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ABSTRACT

It is impossible to construct piping networks without using pipe tees. The pipe tees are also called as T-junctions. They are used either for combining the streams or for splitting the streams. Also they act as separators of two-phase flow into individual phase-rich streams. Therefore, the T-junctions not only act as connecting junctions but can also perform other important tasks. In view of this the present experiment has been carried out to elucidate the effect of dynamic variable such as inlet flow rate and geometric variables such as diameters of the arms of T-junction, and angle of orientation of branch. Only inherent phase split has been studied i.e., the outlet ends of T-junction are open to atmosphere. That means the outlet arms of the T-junction are not kept installed in the piping network. It was observed that the split ratio defined as flow in branch to flow in run is strongly influenced by the inlet flow rate, diameters and orientation. The data obtained on split ratio were analyzed graphically.

KEYWORDS

Flow split;
T-junction;
Pipe tee;
Split ratio.

INTRODUCTION

Formation of pipe junctions occurs quite often in piping networks, in arranging feeding and discharging lines for process equipment etc. Understanding the flow phenomena through these pipe junctions is essential for successful design, effective operation and good control of the process industries. Among different pipe junctions that are likely to exist, T-junctions are the major ones in number that appear ubiquitously in the industrial piping. T-junctions are generally used as phase separators in gas-liquid flow, efficient compact oil-gas separators in off-shore oil rigs, compact and inexpensive separators in refineries, partial separators in natural gas production, static mixers etc. T-junctions also find wide uses in fluid piping networks such as pipe lines, inlet and exhaust sections of IC engines and compressors, in steam and gas turbines, in jet ejectors etc.

The studies on flow split have been mainly confined to phase split in gas-liquid flow systems[1], in microchannel T-junctions[2], solid-liquid separation of slurry[3] and in compressible fluids[4]. A major number of studies were focused on developing mathematical models for estimation of phase split[5]. Also one can presume that the T-junction can be used as a static mixer and a phase separator owing to its inherent geometry. A good number of studies have been carried out on mixing behavior in T-junctions[6]. Some studies were also conducted with liquid-liquid two-phase flow in T-junctions[7].

One can anticipate that the T-junctions could be used either for dividing the streams or for combining the streams. Whatever may be the activity, at the junction the hydrodynamics and transport phenomena can be expected to be highly complex in nature. Several studies were reported on pressure fluctuations with two-phase flow[8]. The bubbling phenomena in case of gas-liquid flow have also been investigated[9]. Studies on gas-liquid mass transfer in microchannel T-junction has been reported[10].

Majority of the situations in which the T-junctions used are for single phase liquid flow. It is important to know how much fraction of flow occurs in branch and how much occurs in run. In the present article, the ratio of flow in branch to the flow in run is defined as split ratio, which is an important parameter that enables one to predict the flow rates in branch as well as in run. Although many studies were reported on phase-split of gas-liquid flows and liquid-liquid flows, no comprehensive investigation has been ever conducted on flow split involving only liquid flow[11]. In this regard, an attempt is made to investigate the effect of pertinent variables on flow split ratio in commercially available T-junctions of different diameters.

In view of this the author has taken up the present investigation to study the flow split at a T-junction by changing the flow rate of water, orientation of T and diameters at inlet, run and branch. For the present study, only inherent split characteristics were obtained. Inherent characteristics mean that the T-junction is not connected to any pipe network at its exit ends. Understanding of the inherent characteristics is necessary to carry out further studies on installed split characteristics. In the present article the diameters of the arms of the T-junction are represented in the format {inlet; run; branch}. For example {1; 1 ; ¾ } means the inlet of the T-junction has a diameter of 1 inch, the run has a diameter of 1 inch and the branch has a diameter of ¾ inch. All T-junctions employed in the present experiment were or reputed brands purchased from open market. It is ensured that all these pipe tees correspond to the ASTM D2467 standard specification for PVC plastic pipe fittings of schedule 80. Various T-junctions employed in the present study were compiled in TABLE 1.

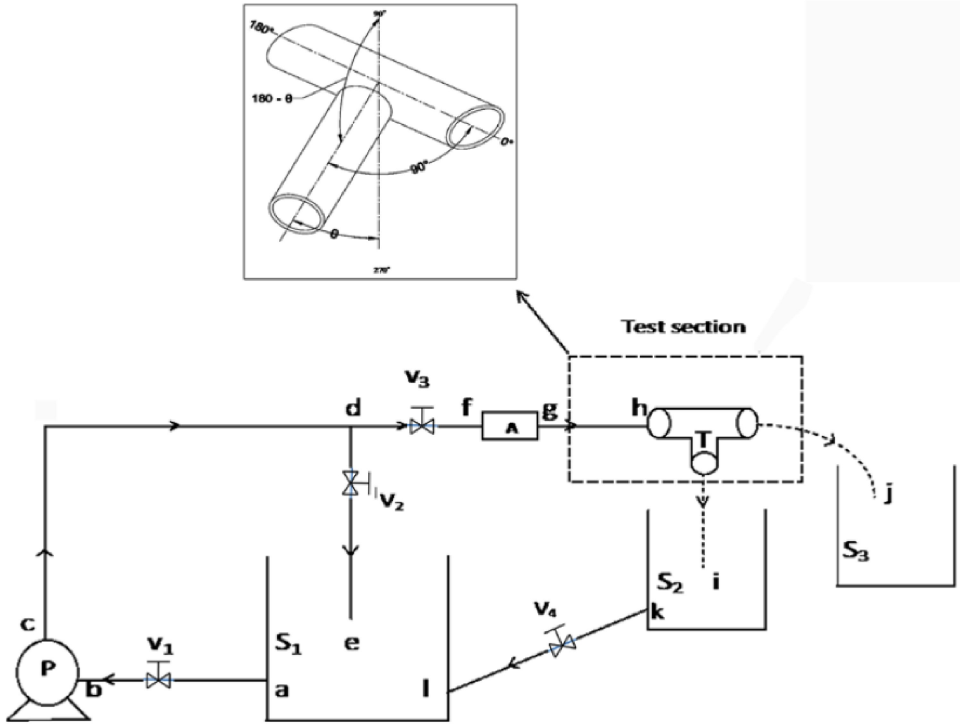
TABLE 1 : Dimensions of the T-junctions employed in the present study

S.No.	Inlet dia (inch)	Run dia (inch)	Branch dia (inch)	Representation
1	¾	¾	¾	{ ¾ ; ¾ ; ¾ }
2	1	1	1	{ 1; 1; 1}
3	1	1	¾	{ 1; 1; ¾ }
4	1 ¼	1 ¼	1 ¼	{1 ¼; 1 ¼; 1 ¼}
5	1 ¼	1 ¼	1	{1 ¼; 1 ¼; 1}
6	1 ¼	1 ¼	¾	{1 ¼; 1 ¼; ¾ }
7	1 ½	1 ½	1 ½	{1 ½; 1 ½; 1 ½}
8	1 ½	1 ½	1 ¼	{1 ½; 1 ½; 1 ¼ }

EXPERIMENTAL

The experimental test rig employed to carry out the present investigation has been specifically designed and fabricated as per the schematic shown in Figure 1. The apparatus and equipment essentially consisted of a centrifugal pump, three storage tanks with appropriate pipe connections and a stop watch. The piping section 'ab' connects pump 'P' to tank 'S_1' the main storage tank. Valve V_1 is provided in this section. V_1 is a gate valve which is closed when the pump is off and fully opened before switching on the pump. The discharge line 'cd' has two branches connected by a tee. Section 'de' is the bypass line, the flow through which is regulated by a globe valve V_2. Flow through the straight section 'df' is controlled by a globe valveV_3. At the end of the straight section 'df', an adaptor 'A' is provided. The main test section consists of sections 'gh', 'hj' and 'hi'. The flow split is studied for the T-junction 'T'. Section 'gh' is the inlet to the T-junction. The length of section 'gh' is taken as 2.5 m to ensure fully developed flow. The liquid jet flowing through the branch is shown as section 'hi' and the flow through the run is shown as section 'hj'. In the present experimentation, the orientation of branch was also varied. The angle of orientation is represented as θ which is shown as inset in Figure 1. The angle θ was taken as 0°, 30°, 60° and 90°.

The pump is switched on by keeping the bypass valve V_2 fully open and the control valve V_3 is fully closed. After 10 mins, the control valve V_3 is slightly opened allowing the flow into the test section. Initially the flow will appear in only one arm of the T-junction. Which arm will have flow is dependent on the orientation of the T-junction. Once flow is observed in two arms, then the system was kept unchanged in the same position for two to three minutes to get flow stabiliza-



A–adaptor, P–pump, T–T-junction, V_1 to V_4 – valves, S_1 to S_3 – storage tanks

Figure 1 : Schematic of experimental setup. Angle of orientation, θ is shown in the inset

tion. Then the flow rates are obtained. The split ratio is then computed as the ratio of the flow rate in branch to the flow rate in run.

RESULTS AND DISCUSSION

In certain circumstances, all liquid flows in branch and no liquid flow appears in run. In some other circumstances, all liquid flows in run and no liquid flow appears in branch. In between these two limits, there exist varied flow rates in the two arms.

Variation of fraction of flow in branch and run

Data on fraction of flow in branch obtained in the present experiment at 0^o orientation were plotted against total flow introduced into the T-junction {1; 1; 1} and shown as plot A in Figure 2. The fraction of flow in run can be computed by subtracting the fraction of flow in branch from unity. Observation of the plot A revealed that at very low inlet flow rates, entire liquid flow occurred only in branch and no flow appeared in run. The reason for this can be attributed to the fact that at very low velocities the liquid flow as a film on the surface. Since the branch of the tee is at 0^o orientation, i.e., downwards, the gravitational force naturally favors the flow of film downwards in the branch. Therefore, entire liquid flow took place through the branch.

As the liquid flow rate is increased the liquid gained momentum. Therefore, some part of the liquid is forced straight into the run and that portion of the liquid in the vicinity of the lower mouth passed through the branch. Therefore, there is a decrease in the fraction of flow in the branch, associated with an increase in the run. As the inlet liquid flow rate is further increased, the fraction of flow in the run steadily increased and the fraction of flow in the branch steadily decreased. At higher inlet liquid flow rates, the liquid possesses high momentum, so that due to inertia entire liquid goes towards run only and the flow through branch would disappear. Similar trends were observed at 30^o and 60^o orientations as revealed from plots B and C respectively. It is now understood that the flow in branch would be more at 0^o orientation and as the angle is increased, the net gravitational force acting on the fluid towards the branch decreases, rendering the flow rate through the branch to decrease. The gravitational force which is pulling the liquid into the branch acted totally in the case of 0^o orientation. Whereas, in 30^o orientation, only the component of the gravitational force acted thus there is a de-

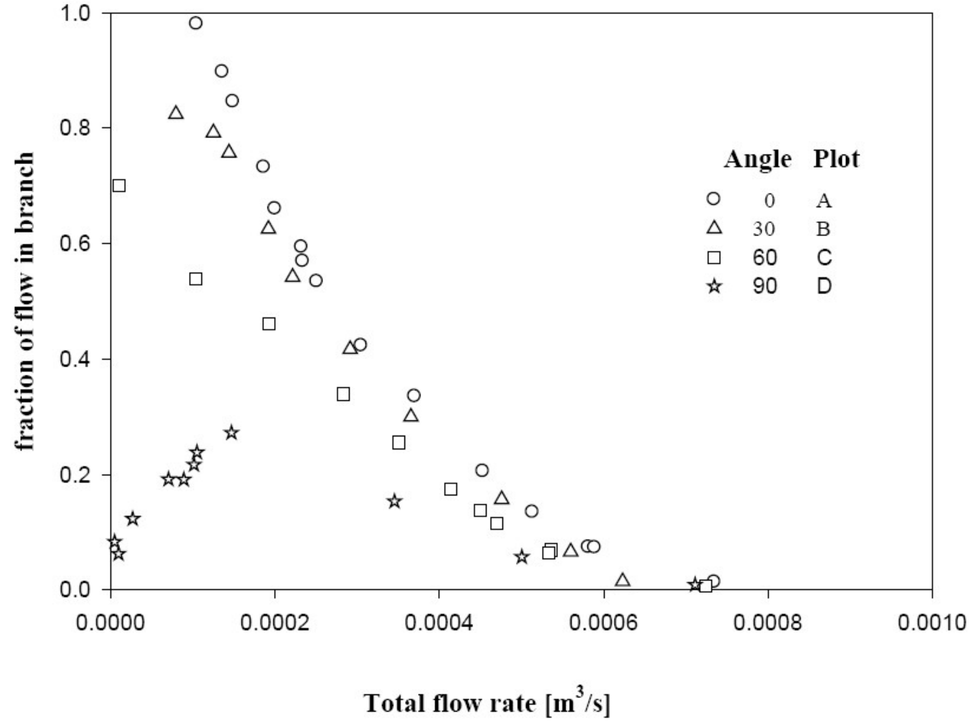


Figure 2 : Variation of fraction of flow in branch for the pipe tee {1; 1; 1}

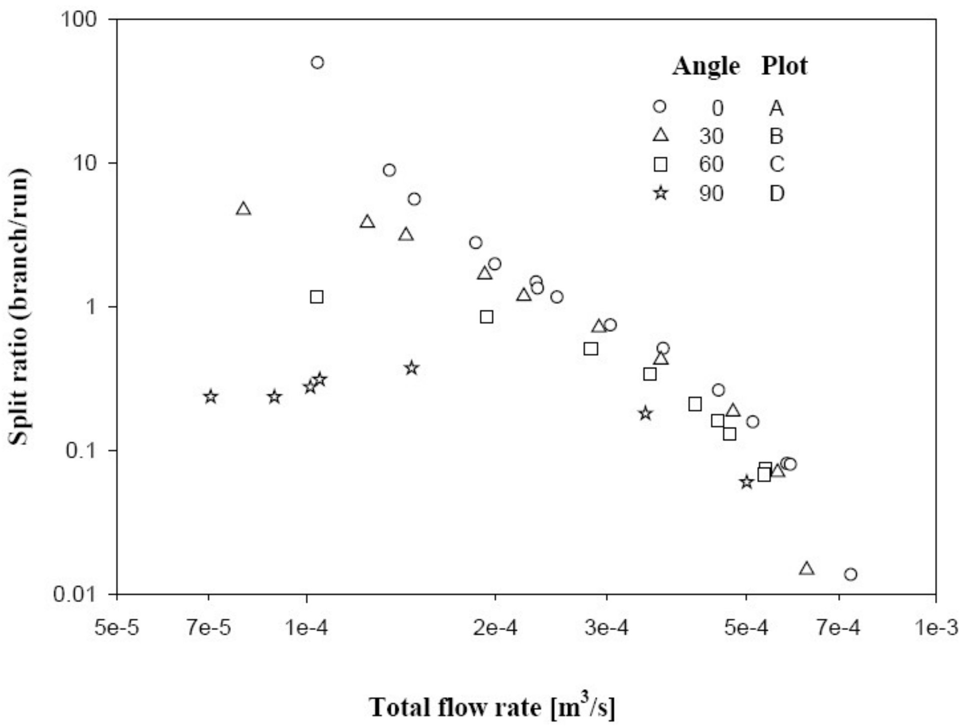


Figure 3 : Effect of orientation: Variation of flow split ratio for pipe tee {1; 1; 1}

crease in fraction of flow through branch which is clear from plot B. The component of the gravity is further less at 60° orientation. Consequently the flow rate in the branch decreases further at 60° orientation which is conspicuous from plot C. For 90° orientation different trends were observed as shown in plot D. Initially, at very low flow rates, more flow took place through run only because this is the straight arm and also due to film flow. As the inlet flow rate is slightly increased, the fraction in branch increased and reached a maximum. Fur-

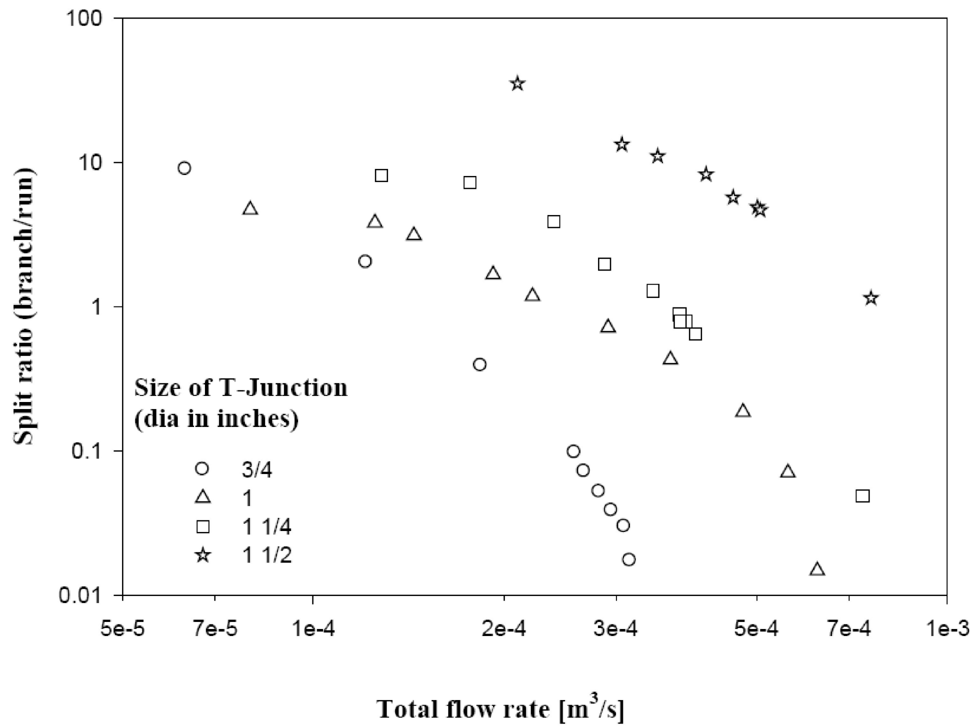


Figure 4 : Effect of size of equal T-Junctions: Variation of flow split ratio for 30° orientation

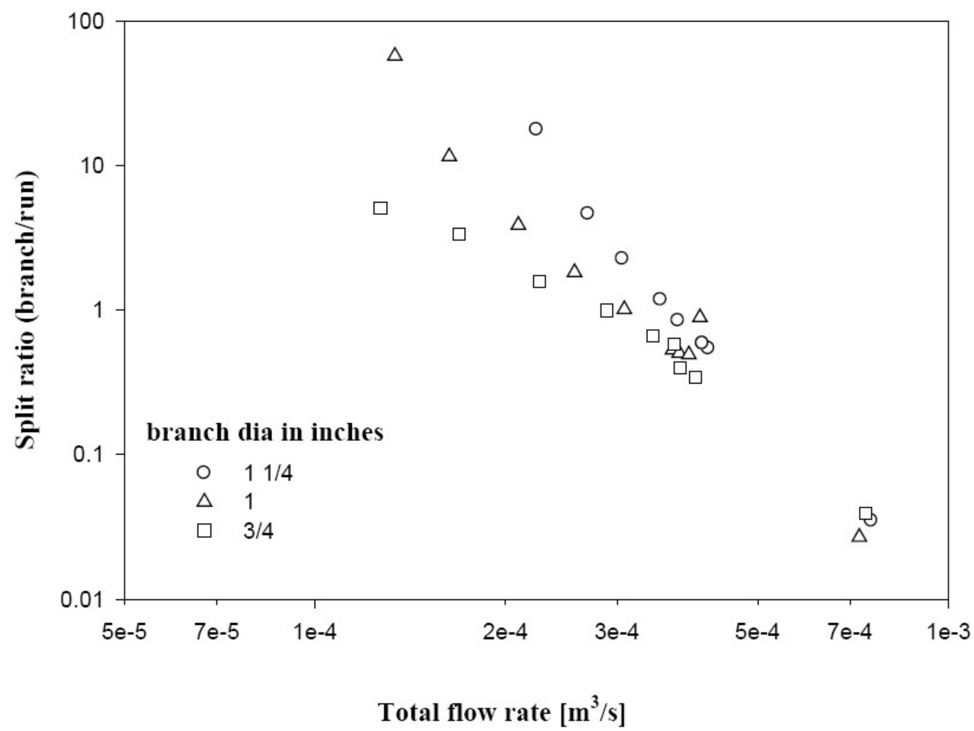


Figure 5 : Effect of branch diameter: Variation of flow split ratio for 0° orientation of reducing T-Junction having 1 1/4-inch dia of inlet and run

ther increase in inlet flow rate caused a decrease in flow through the branch. Exactly opposite trends could be observed with the fraction in run. At higher flow rates, entire flow took place through run only owing to the momentum of the liquid. Similar trends were observed for all other T-junctions employed in the present study.

Effect of orientation

The flow split ratio, defined as the ratio of flow rate in the branch to the run is the useful form of representation of the flow split. Based on the discussion provided in subsection on Variation of fraction of flow in branch and run, it can be inferred that the split ratio will vary from ∞ to 0. Knowledge of flow split is essential to the design engineer in carrying out design of pipe lines. The flow split ratio thus obtained was plotted against inlet flow rate for a pipe tee {1; 1; 1} for all orientations and is shown in Figure 3. It is clear from the plots of all these figures that the flow split ratio decreased with increasing velocity at all orientations except 90°. For the case of 90°, the split ratio increased initially, reached a maximum and decreased with further increase in inlet flow rate. It can be understood from these plots that the branch has more priority at lower liquid flow rates and the run is preferred at higher liquid flow rates. In the middle range there occurs flow in both branch and run. It is clear from the plots of the figures that the split ratio decreased with increasing flow rate. In plot A the trend followed a linear variation for the arrangement of 0° orientation. The plot B for the case of 30° orientation obeyed a concave curve unlike the straight line variation as in the case of 0° orientation. As revealed from plot C, the flow split ratio appeared as a concave curve again but with more curvature in the case of 60° orientation. The plot D corresponding to 90° orientation also behaved as a concave curve with higher curvature. It can be reasoned that the flow split ratio would decrease with increase in orientation, which is clear from the plots of Figure 3. Similar trends were observed for all other T-junctions considered in the present study.

Effect of size of equal T-junction

In this section the effect of size of equal T-junctions employed in the present experiment { ¾ ; ¾ ; ¾}, {1; 1; 1}, {1 ¼; 1 ¼; 1 ¼} and {1 ½; 1 ½; 1 ½} has been discussed. As a sample case, for 30° orientation, data obtained on split ratio were compared and presented in Figure 4. It can be anticipated that the more the size of the branch, the more the flow through the branch. Hence more split ratio is expected for higher diameter. The trends observed from the plots of the figure are also according to the expected trend. Similar comparative trends were noticed for all other orientations (graphs not shown).

Effect of branch dia of reducing T-junctions

In this section the effect of branch dia of reducing T-junctions employed in the present experiment i.e., {1 ¼; 1 ¼; 1 ¼}, {1 ¼; 1 ¼; 1} and {1 ¼; 1 ¼; ¾} has been discussed. For 0° orientation, data obtained on split ratio was compared and presented in Figure 5. It can be expected that for the case of constant inlet diameter of 1 ¼ inch and constant run diameter of 1 ¼ inch, the branch diameters were varied as ¾ inch, 1 inch and 1 ¼ inch. It can be expected that as the branch diameter is increased the flow through the branch would be more, hence more split ratio would be observed. The plots of the figure revealed the same trend.

Correlation

An attempt has been made to obtain a correlation equation for predicting the split ratio as a function of Reynolds number at inlet, branch to inlet diameter, angle of orientation using nonlinear least squares regression. However, the correlating equations obtained represented data very poorly having a very high average and standard deviations. All possible combinations have been tried but no reasonable correlation could be obtained by the author.

CONCLUSIONS

The present investigation was carried out to study the flow split ratio by T-junctions of different diameters of inlet and branch arms by employing flow of water. Based on the analysis of these data, the following conclusions were drawn:

1 The split ratio is strongly dependent on inlet flow rate and orientation of T-junction.
2 At 0° orientation the split ratio decreased linearly with increase in total flow.
3 At 30°, 60° and 90° orientations, the variation in split ratio with total flow followed a concave curve.
4 The split ratio is found to decrease with increase in angle of orientation.
5 At a given flow rate, higher split ratio was realized for higher diameter of equal T-junction.
6 The higher the branch diameter, the higher the split ratio in case of reducing T-junctions.

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