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# *ANALYSIS OF BEHAVIOUR OF T JUNCTIONS BY VARYING ANGLES AND TYPE OF FLOW*


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*Abstract*— T-junctions are one of the most difficult pipe fitting in terms of calculation of the head loss occurring through it. Various attempts have been made to derive the value of loss coefficients of the two branches of the t-junctions. Some formulas which involve area ratios and flow ratios are available. However, the use of these coefficients has to be further scrutinized. The erroneous effect of the use of constant loss co-efficients needed to understood and reviewed. This has been done, through the use of a standard network and the simplest network having one T-junction. Further efforts have been made to minimize the losses occurred at t-junctions and the implications of it in engineering design have been discussed.



***Keywords***- T-junction loss, Flow ratio, loss co-efficients


## I. INTRODUCTION

T-junctions available in the market are of various angles. In fact they are sometimes custom-manufactured in order to match the water pipelines with the overlying street angles. The use of constant loss co-efficients have been extensively mentioned in the literature. The practical repercussions of using constant loss co-efficients had to be tested to understand the fairness of their application in modern day Engineering and scientific research work. The current study aims at improving our understanding of T-junction and analyzing their behaviour when they interact with fluid.

## II. LITERATURE REVIEW

Use of constant loss co-efficients lead to much error in results when large pipe networks are modeled. [1] The calculations may be bettered by use of energy and momentum equations. [11] K-factor charts are available for use, for determination of various co-efficients across different legs of crosses. [6]CFD and Finite Element Method are two methods which are used for numerical determination of loss co-efficients. [5] A summary of loss co-efficients is available (C. T. Michalos, P.E) one inference is that different investigators have given different values which agree in some range and disagree in others. The use of artificial neural networks for determination of loss co-efficients have been looked into and presented. The loss co-efficients decrease with the increase in Reynolds's number of flow (Yousaf et. al.) Flow distributions and characteristics can be predicted using inflow power ratios. Control volumes for the study of T-junctions have been established. Formulas were derived based on angle and area ratio of the two pipes involved. [2] A practical experiment has been described and the importance of measuring the flow in all pipes simultaneously to obtain correct readings has been expressed. (Stigler et. al.)

## III. METHODOLOGY

### A. *Software tools used for the study*

The software Pipe flow expert was used in the study it is widely used and popular software used for testing and experimenting with pipelines.

It can model T-junctions effectively. It balances the node pressure up to many decimal places of accuracy.

It has a wide variety of tools which include:

- Add pipes –It lets us add pipes at nodes.
- Drag and Move – It helps us move components of a network.
- Selection Tool Bar- It lets us drag pipes to new locations. Values of displaced components can be changed by updating attributes on the left hand side of the screen.
- Tanks- They represent fluid supply/reservoir. The fluid level and the elevation of the bottom of the tank, can be modified as per need.
- Copying attributes from an existing pipe- This enables copying of dimensions of one pipe to another.

### B. *Parameters of the system involved in the study*

Angle of T-junction

It shows the angle made by the branch line of a T- junction with the through line of a T-junction.

T-junction loss:

It is the loss at every T-junction branch, be it at the entrance or exit. It is the minor loss in our analysis work.

Total loss:

It is the sum total of all the losses.

Discharge:

It is the value of discharge set in the control valve.

### C. *Selection of network*

A simple pipe network, which is typically present in a single storey of a building, is taken for study. The outer branches of the network are flexible and can be kept at varying angles. A control valve is put at the joint of the pipe from reservoir, to the next pipe.

### D. *Investigation of losses with changing T-junction angles in network*

From the software, we could get the friction loss for each pipe and the minor loss corresponding to each T-fitting. The data was imported into MS excel, the friction loss for each pipes were added to get the total friction (major) loss for the network and the losses at each T-junction were added to get the total loss due to T-junctions . Standard values of loss coefficient as available in the software: for through tees -0.46, for branch tees -1.38 were used.

The discharge was increased from 1000 l/hr in increments of 100l/hr upto 3000 l/hr at the control valve and the corresponding losses were noted. The same procedure was repeated for all the varying angles of T-junctions. The corresponding results are shown in tables 1-5.

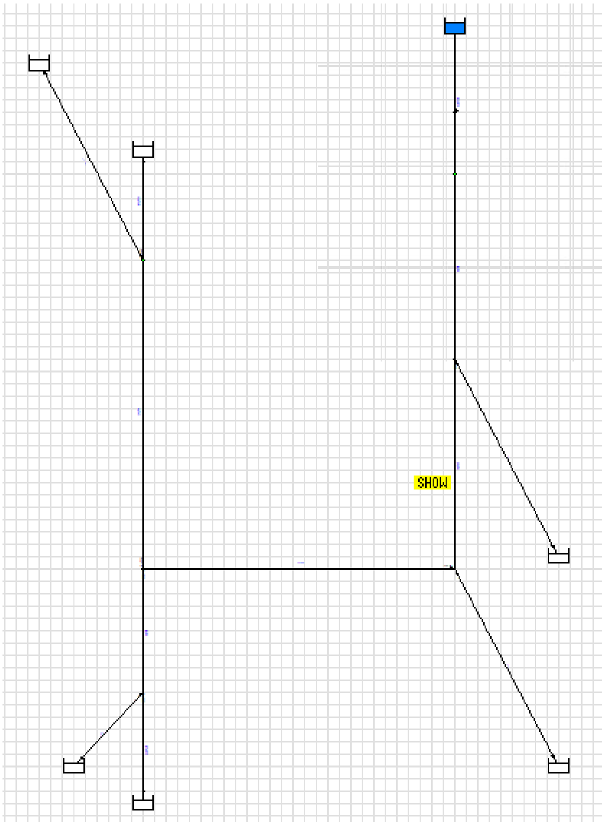


Figure 1: Image of network with 30° t-junction

Table 1: Losses for network with 30° t-junction

| Discharge | T-junction loss | Major loss | Total loss |
|---|---|---|---|
| 1000 | 0.01 | 0.175 | 5.523 |
| 1100 | 0.013 | 0.21 | 5.53 |
| 1200 | 0.014 | 0.245 | 5.533 |
| 1300 | 0.017 | 0.284 | 5.54 |
| 1400 | 0.021 | 0.325 | 5.547 |
| 1500 | 0.024 | 0.37 | 5.555 |
| 1600 | 0.028 | 0.415 | 5.561 |
| 1700 | 0.03 | 0.465 | 5.567 |
| 1800 | 0.034 | 0.516 | 5.575 |
| 1900 | 0.037 | 0.571 | 5.583 |
| 2000 | 0.043 | 0.627 | 5.592 |
| 2100 | 0.046 | 0.685 | 5.598 |
| 2200 | 0.05 | 0.749 | 5.609 |
| 2300 | 0.056 | 0.814 | 5.62 |
| 2400 | 0.06 | 0.882 | 5.63 |
| 2500 | 0.065 | 0.951 | 5.64 |
| 2600 | 0.071 | 1.022 | 5.65 |
| 2700 | 0.075 | 1.098 | 5.661 |
| 2800 | 0.082 | 1.175 | 5.673 |
| 2900 | 0.087 | 1.256 | 5.685 |
| 3000 | 0.093 | 1.339 | 5.698 |

(Source –Primary data analysis)

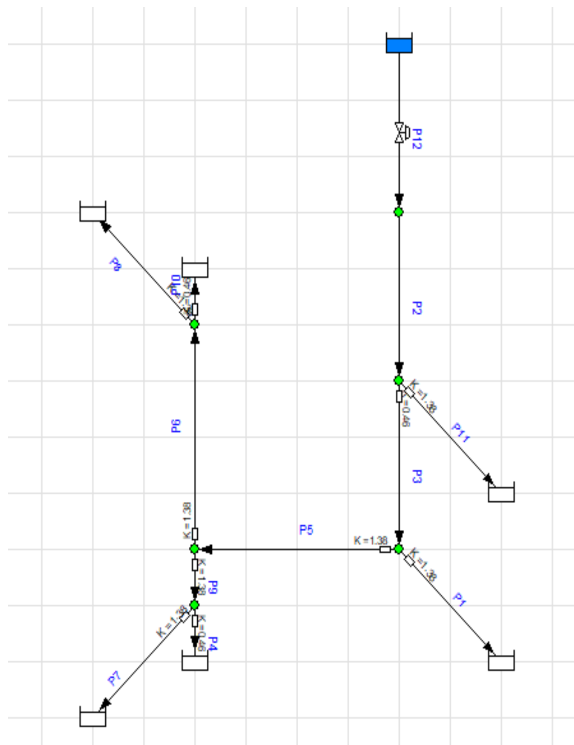


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Figure 2: Image of network with 45° t-junction

The above network shows all the side branches of the original network rotated at 45°.

Table 2: Losses for network with 45° t-junction

| Discharge | T-junction loss | Major loss | Total loss |
|---|---|---|---|
| 1000 | 0.01 | 0.175 | 5.523 |
| 1100 | 0.013 | 0.21 | 5.53 |
| 1200 | 0.014 | 0.245 | 5.533 |

| | | | |
|---|---|---|---|
| 1300 | 0.017 | 0.284 | 5.54 |
| 1400 | 0.021 | 0.325 | 5.547 |
| 1500 | 0.024 | 0.37 | 5.555 |
| 1600 | 0.028 | 0.415 | 5.561 |
| 1700 | 0.03 | 0.465 | 5.567 |
| 1800 | 0.034 | 0.516 | 5.575 |
| 1900 | 0.037 | 0.571 | 5.583 |
| 2000 | 0.043 | 0.627 | 5.592 |
| 2100 | 0.046 | 0.685 | 5.598 |
| 2200 | 0.05 | 0.749 | 5.609 |
| 2300 | 0.056 | 0.814 | 5.62 |
| 2400 | 0.06 | 0.882 | 5.63 |
| 2500 | 0.065 | 0.951 | 5.64 |
| 2600 | 0.071 | 1.022 | 5.65 |
| 2700 | 0.075 | 1.098 | 5.661 |
| 2800 | 0.082 | 1.175 | 5.673 |
| 2900 | 0.087 | 1.256 | 5.685 |
| 3000 | 0.093 | 1.339 | 5.698 |

(Source –Primary data analysis)

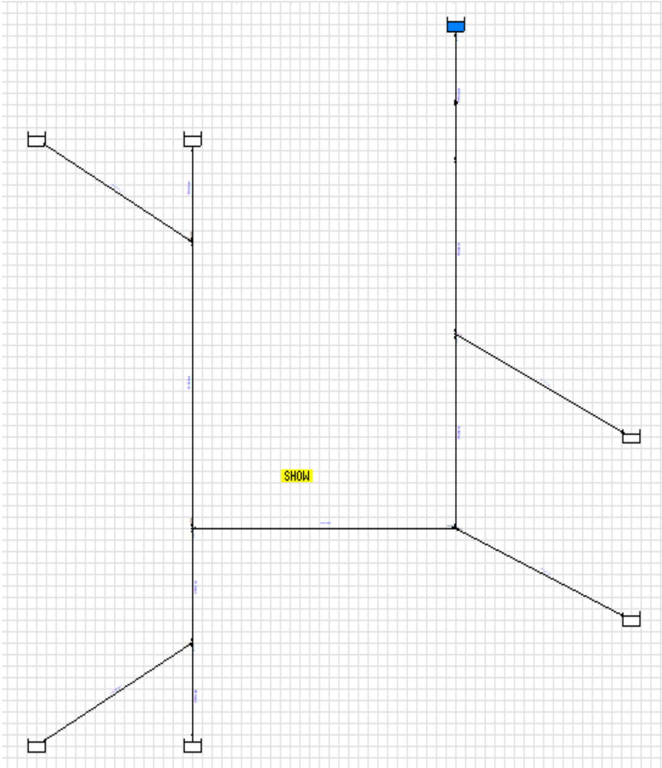


Figure 3: Image of network with 60° t-junction

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The above network shows the condition when side branches of the parent network are rotated at 60°.

Table 3: Losses for network with 60° t-junction

| Discharge | T-junction loss | Major loss | Total loss |
|---|---|---|---|
| 1000 | 0.01 | 0.175 | 5.523 |
| 1100 | 0.013 | 0.21 | 5.53 |
| 1200 | 0.014 | 0.245 | 5.533 |
| 1300 | 0.017 | 0.284 | 5.54 |
| 1400 | 0.021 | 0.325 | 5.547 |
| 1500 | 0.024 | 0.37 | 5.555 |
| 1600 | 0.028 | 0.415 | 5.561 |
| 1700 | 0.03 | 0.465 | 5.567 |
| 1800 | 0.034 | 0.517 | 5.576 |
| 1900 | 0.037 | 0.571 | 5.583 |
| 2000 | 0.043 | 0.627 | 5.592 |
| 2100 | 0.046 | 0.685 | 5.598 |
| 2200 | 0.05 | 0.749 | 5.609 |
| 2300 | 0.056 | 0.814 | 5.62 |
| 2400 | 0.06 | 0.882 | 5.63 |
| 2500 | 0.065 | 0.951 | 5.64 |
| 2600 | 0.071 | 1.022 | 5.65 |
| 2700 | 0.075 | 1.098 | 5.661 |
| 2800 | 0.082 | 1.174 | 5.672 |
| 2900 | 0.087 | 1.225 | 5.684 |
| 3000 | 0.093 | 1.338 | 5.697 |

(Source –Primary data analysis)

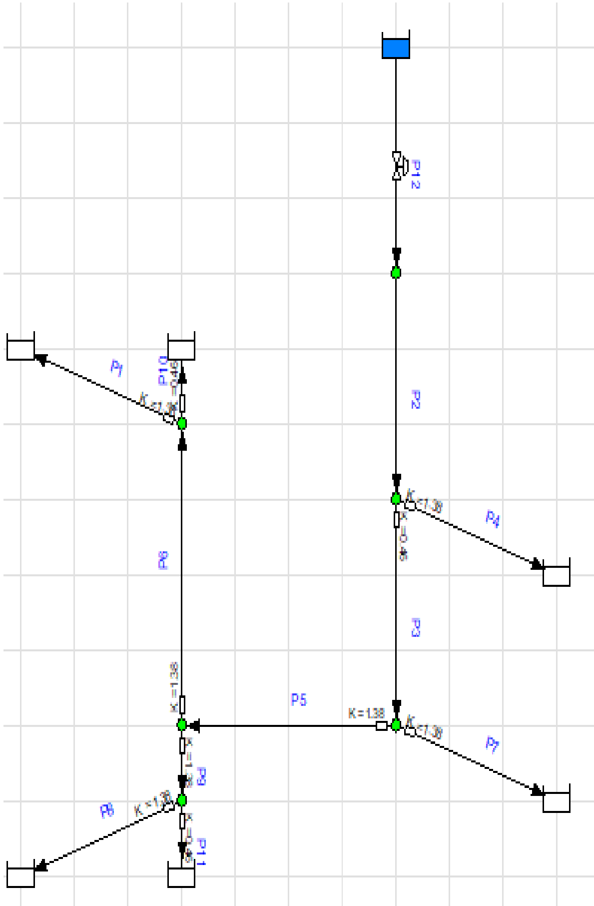


Figure 4: Image of network with 75° t-junction

Table 4: Losses for network with 75° t-junction

| Discharge | T-junction loss | Major loss | Total loss |
|---|---|---|---|
| 1000 | 0.01 | 0.175 | 5.523 |
| 1100 | 0.013 | 0.21 | 5.53 |
| 1200 | 0.014 | 0.245 | 5.533 |
| 1300 | 0.017 | 0.284 | 5.54 |
| 1400 | 0.021 | 0.325 | 5.547 |
| 1500 | 0.024 | 0.37 | 5.555 |
| 1600 | 0.028 | 0.415 | 5.561 |
| 1700 | 0.03 | 0.465 | 5.567 |
| 1800 | 0.034 | 0.517 | 5.576 |
| 1900 | 0.037 | 0.571 | 5.583 |
| 2000 | 0.043 | 0.627 | 5.592 |
| 2100 | 0.046 | 0.685 | 5.598 |
| 2200 | 0.05 | 0.749 | 5.609 |
| 2300 | 0.056 | 0.814 | 5.62 |
| 2400 | 0.06 | 0.882 | 5.63 |
| 2500 | 0.065 | 0.951 | 5.64 |
| 2600 | 0.071 | 1.022 | 5.65 |
| 2700 | 0.075 | 1.098 | 5.661 |
| 2800 | 0.082 | 1.174 | 5.672 |
| 2900 | 0.087 | 1.225 | 5.684 |
| 3000 | 0.093 | 1.338 | 5.697 |

(Source –Primary data analysis)

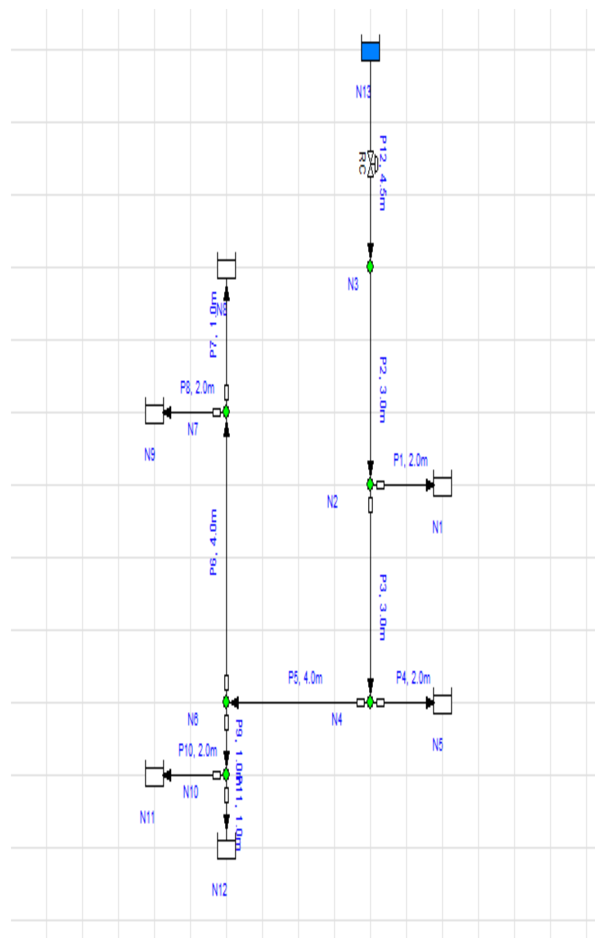


Figure 5: Image of network with 90° t-junction

Table 5: Losses for network with 90° t-junction

| Discharge | T-junction loss | Major loss | Total loss |
|---|---|---|---|
| 1000 | 0.01 | 0.175 | 5.523 |
| 1100 | 0.013 | 0.21 | 5.53 |
| 1200 | 0.014 | 0.245 | 5.533 |
| 1300 | 0.017 | 0.284 | 5.54 |
| 1400 | 0.021 | 0.325 | 5.547 |
| 1500 | 0.024 | 0.37 | 5.555 |
| 1600 | 0.028 | 0.415 | 5.561 |
| 1700 | 0.03 | 0.465 | 5.567 |
| 1800 | 0.034 | 0.517 | 5.576 |
| 1900 | 0.037 | 0.571 | 5.583 |
| 2000 | 0.043 | 0.627 | 5.592 |
| 2100 | 0.046 | 0.685 | 5.598 |
| 2200 | 0.05 | 0.749 | 5.609 |
| 2300 | 0.056 | 0.814 | 5.62 |
| 2400 | 0.06 | 0.882 | 5.63 |
| 2500 | 0.065 | 0.951 | 5.64 |
| 2600 | 0.071 | 1.022 | 5.65 |
| 2700 | 0.075 | 1.098 | 5.661 |
| 2800 | 0.082 | 1.174 | 5.672 |
| 2900 | 0.087 | 1.225 | 5.684 |
| 3000 | 0.093 | 1.338 | 5.697 |

(Source –Primary data analysis)

*E. Graphical Analysis*

The data from the tables was used to prepare graphs between the losses corresponding to a certain discharge for various angles.

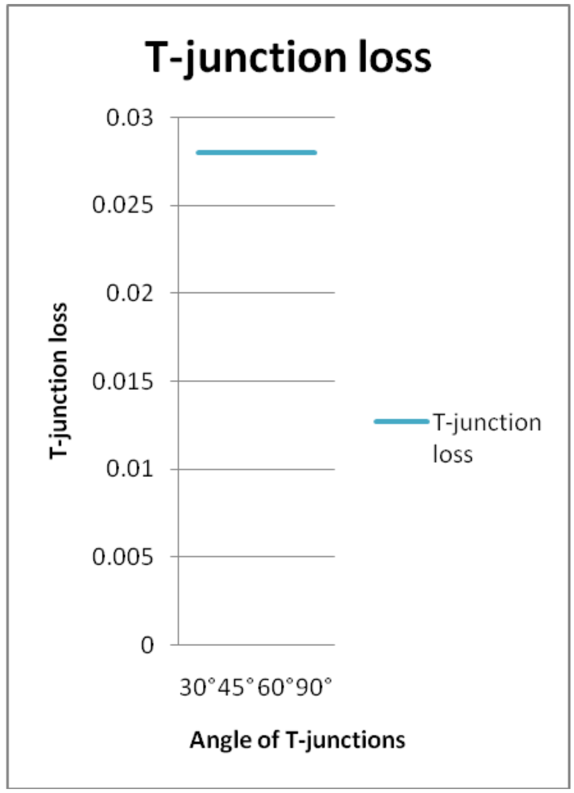


Figure 6: Graph showing variation of t-junction loss with angle of T-junction for discharges 1600 l/hr

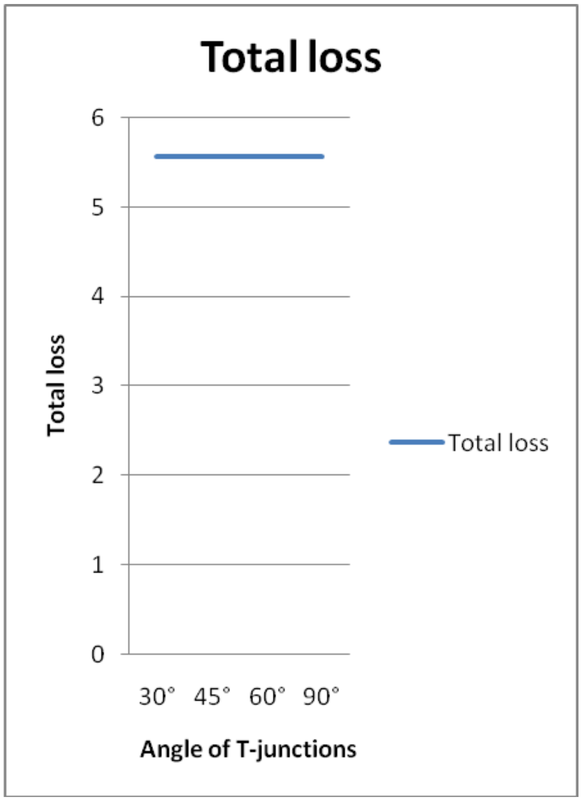


Figure 7: Graph showing variation of Total loss with angle of T-junction for discharge 1600 l/hr

The network with side branches rotated at 30° was analysed. Then 45° was taken for rotating the side branches and results were analysed. Then, the side branches were rotated at 60° and analysed. Firstly, the network with 90° T-junctions was taken and analysed. The results were such that when the network always showed equal values of T-junction loss and Total loss for all the angles.

From the graph it is quite evident that losses remains constant with the change in angle of T junction branches, but it is explicitly given in the research paper [Calculation of steady flow pressure loss coefficients for pipe junctions], that losses associated with the network changes by changing the angle of T junction, this loophole observed of our study lead us to analyse the network with 1 Reservoir with 2 outlets in form of empty reservoirs. Figure 8 shows network with 30 degree t junction.

*F. Investigation of losses with nnetworks of 1 Reservoir with 2 Outlets*

The simplest network which consists of one source of water and two outlets, the pipes joined together at one T-junction is modelled.

The T-junction loss and the total loss occurring in the network for the different angles of T-junction are calculated and taken from the software .The results are presented in table 6.

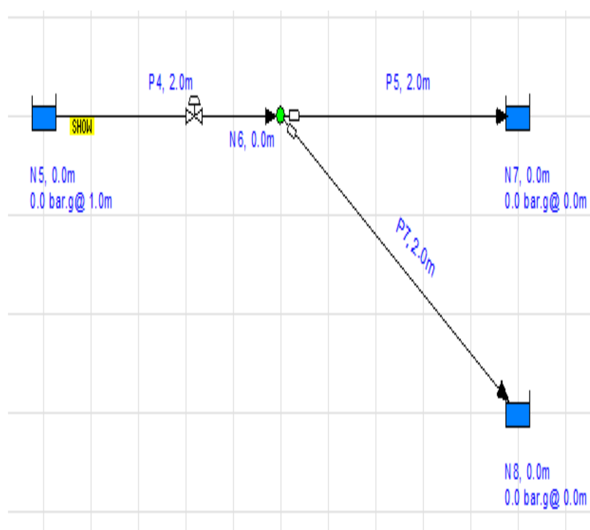


Figure 8: Network with 30 degree t junction

In figure 8, the branch line has been rotated at 30 degrees.

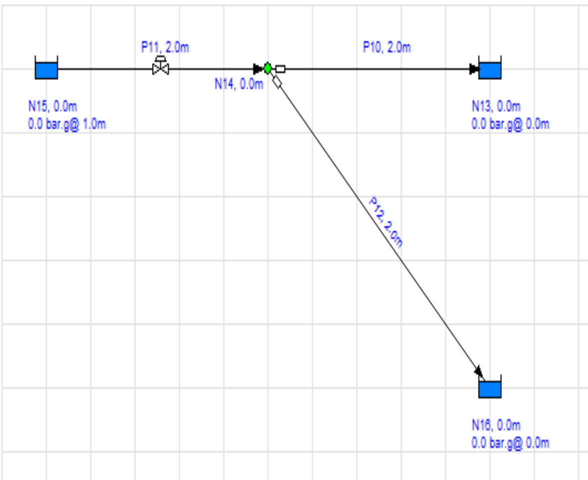


Figure 9: Network with 45 degree t junction

In figure 8, the branch line has been rotated at 45 degrees.

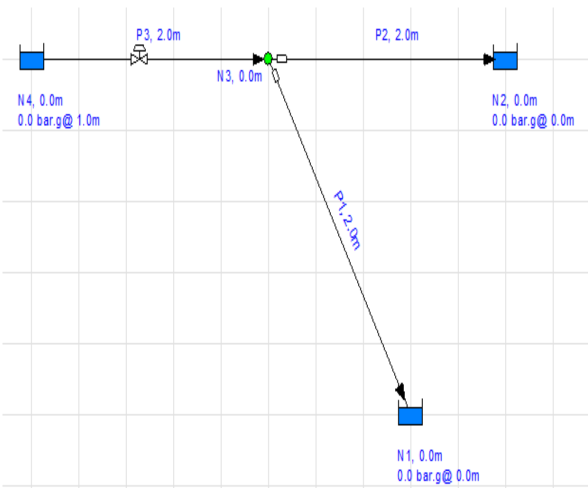


Figure 10: Network with 60 degree t junction

In figure 8, the branch line has been rotated at 60 degrees.

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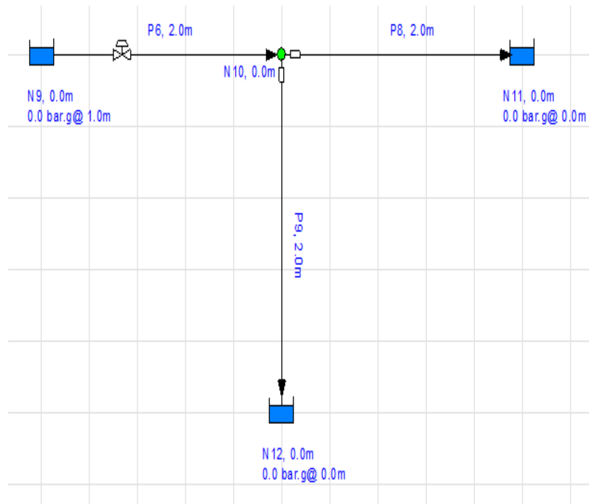


Figure 11: Network with 90 degree t junction

The angle was then changed to 90 degrees. This represents T-junction used in dead end distribution systems. This is shown in figure 5.

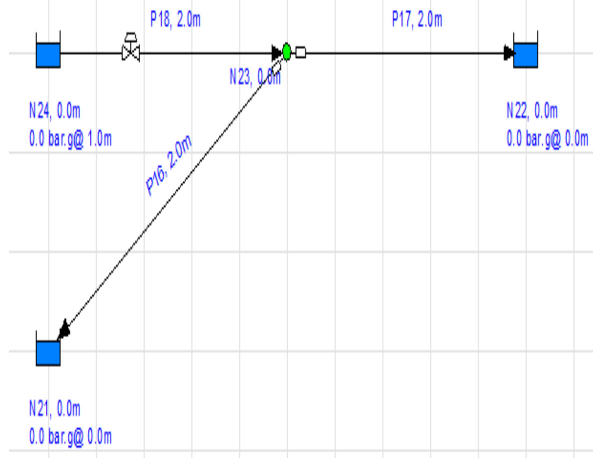


Figure 12: Network with 135 degree t junction

Figure 6 shows the T-junction at 135 degrees.

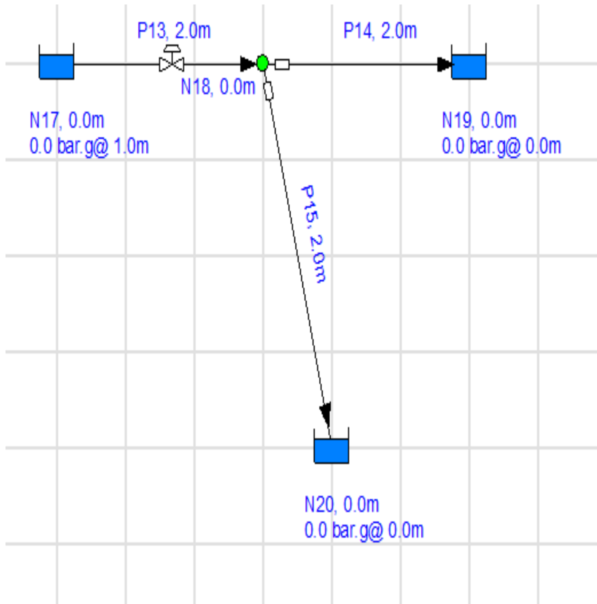


Figure 13: Network with t junction set at random angle

The T-junction was also set at a random angle, to test for consistency of parameters as shown in figure 13.

Table 5: Flow ratios obtained for various discharges

| Q | $q_1$ | $q_2$ | $q_1/Q$ | $q_2/Q$ |
|---|---|---|---|---|
| 1500 | 803.2 | 696.8 | 0.535 | 0.465 |
| 1600 | 857.19 | 742.81 | 0.536 | 0.464 |
| 1700 | 911.2 | 788.8 | 0.536 | 0.464 |
| 1800 | 965.22 | 834.78 | 0.536 | 0.464 |
| 1900 | 1019.26 | 880.74 | 0.536 | 0.464 |
| 2000 | 1073.31 | 926.69 | 0.537 | 0.463 |

(Source: primary data analysis)

Therefore, it can be inferred from table 5 that as long as the loss coefficients remain constant, the flows don't change with angle.

Table 6: Total loss for various angles

| Angle of T-junction | T-junction loss | Total loss |
|---|---|---|
| 30° | 0.015 | 0.14 |
| 45° | 0.015 | 0.14 |
| 60° | 0.015 | 0.14 |
| 90° | 0.015 | 0.14 |
| 135° | 0.015 | 0.14 |
| Random Angle | 0.015 | 0.14 |

(Source: primary data analysis)

Table 6 shows total loss for various angles of T-junctions in the network.

*G. Investigation of lowest total loss for T junction branches with different angles*

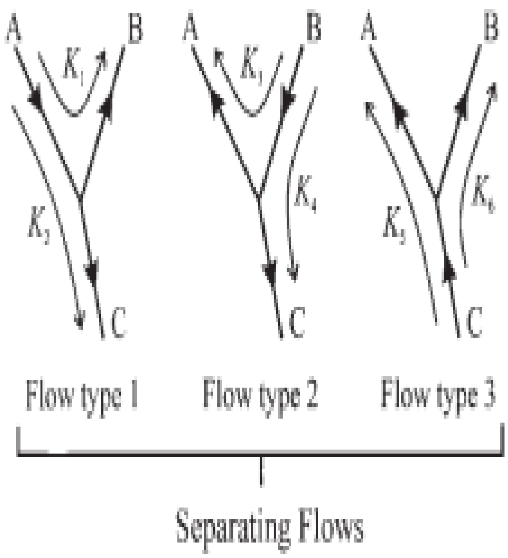


Image courtesy: [2]
Figure 14: Three types of dividing flows

Figure 14 shows the 3 types of dividing flows for the study. (Description of the three types of flows)

The formulas of loss co-efficients available for the study are:

$$q_1=q^2\psi^2+1-2q\psi\cos[3/4(q-\Theta)] \quad (1)$$

$$q=q^2-3/2q+1/2 \quad (2)$$

$$q_3= 1+q^2/\psi^2-2q/\psi\cos[3/4(q-\Theta)] \quad (3)$$

$$q_4=1+q^2/\psi^2-2q/\psi\cos(3/4\Theta) \quad (4)$$

$$q_5=q^2-3/2q+1/2 \quad (5)$$

$$q_6 = q^2 \psi^2 + 1 - 2q\psi\cos(3/4\Theta) \qquad (6)$$

Where, k1 &K2 are the loss coefficients corresponding to branch and through lines in flow type 1,

Similarly, the odd coefficients correspond to the branch lines and the even coefficients correspond to through lines for the second and third types of flow. Ψ is the area ratio of two lines

Involved for the respective loss coefficient, in our case it is 1.

The work consisted of selection of certain standard angles of T-junctions, and use of the networks shown in figures 8-12. The flow ratio is defined as the ratio of the flow going through the through line to the flow passing from the flow control valve. The flow control valve was set at a low discharge and the flow was incremented by small gaps to obtain various flow ratios. The corresponding T-junction loss and the Total loss were calculated and taken from the software to an excel sheet for preparation of tables and graphs.

For obtaining the value of flow ratio corresponding to lowest-junction loss & flow ratio corresponding to lowest Total loss, graphs are plotted between flow ratios and T-junction loss for particular angle of T-junction and between flow ratios and total loss for the same angle of T-junction.

All graphs showed a parabolic shape with one lowest point. The points corresponding to lowest losses are obtained from the graphs.

Observation of result obtained from graphs is stated below. Table 7 shows the results obtained from flow type 1. Minor loss refers to the T-junction loss and major loss refers to the total loss.

Table 7: Results obtained from Flow Type 1

| Angle | Angle in Rad | Flow ratio corresponding to lowest minor loss | Flow ratio corresponding to lowest major loss |
|---|---|---|---|
| 30° | 0.52358333 | 0.7359389 | 0.7359389 |
| 45° | 0.785375 | 0.7359389 | 0.6813736 |
| 60° | 1.04716667 | 0.7359389 | 0.6579938 |
| 75° | 1.30895833 | 0.7359389 | 0.614424 |
| 90° | 1.57075 | 0.6813736 | 0.5850516 |

Table 8 shows the results obtained from flow type 2

Table 8: Results obtained from Flow Type 2

| Angle | Angle in Rad | Flow ratio corresponding to lowest minor loss | Flow ratio corresponding to lowest major loss |
|---|---|---|---|
| 30° | 0.52358333 | 0.7359389 | 0.7359389 |
| 45° | 0.785375 | 0.7359389 | 0.7153527 |
| 60° | 1.04716667 | 0.7359389 | 0.6385277 |
| 75° | 1.30895833 | 0.6813736 | 0.5850159 |
| 90° | 1.57075 | 0.6813736 | 0.58505159 |

Table 9 shows the results obtained from flow type 3 for the present study.

Table 9: Results obtained from Flow Type 3

| Angle | Angle in Rad | Flow ratio corresponding to lowest minor loss | Flow ratio corresponding to lowest major loss |
|---|---|---|---|
| 30° | 0.52358333 | 0.415 | 0.415 |
| 45° | 0.785375 | 0.467 | 0.4411 |
| 60° | 1.04716667 | 0.5246 | 0.5121 |
| 75° | 1.30895833 | 0.585 | 0.5476 |
| 90° | 1.57075 | 0.681374 | 0.5850516 |

From the table for flow type 3, we have used the data and expressed the angle as a function of flow ratio for minimum T-junction loss by use of a data analysis software Tableau.

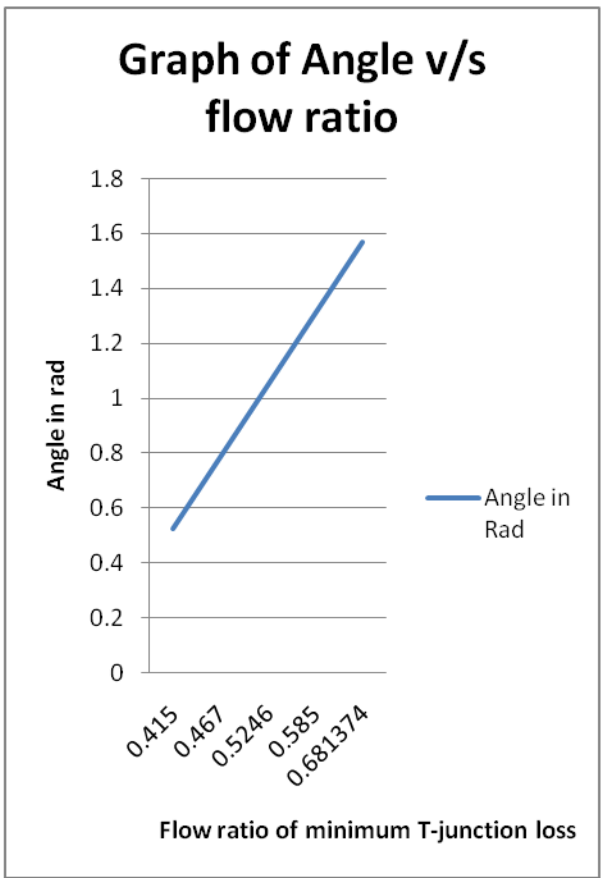


Figure 15: Graph showing variation of angle with flow ratio of lowest minor loss

Figure 15 shows the variation of angle with flow ratios of minimum minor loss for flow type 3.

The equation obtained is:

$$Angle=-6.129*fr^2+10.6906*fr-2.86553 \quad (7)$$

Similarly, we have expressed angle as a function of the minimum total loss.

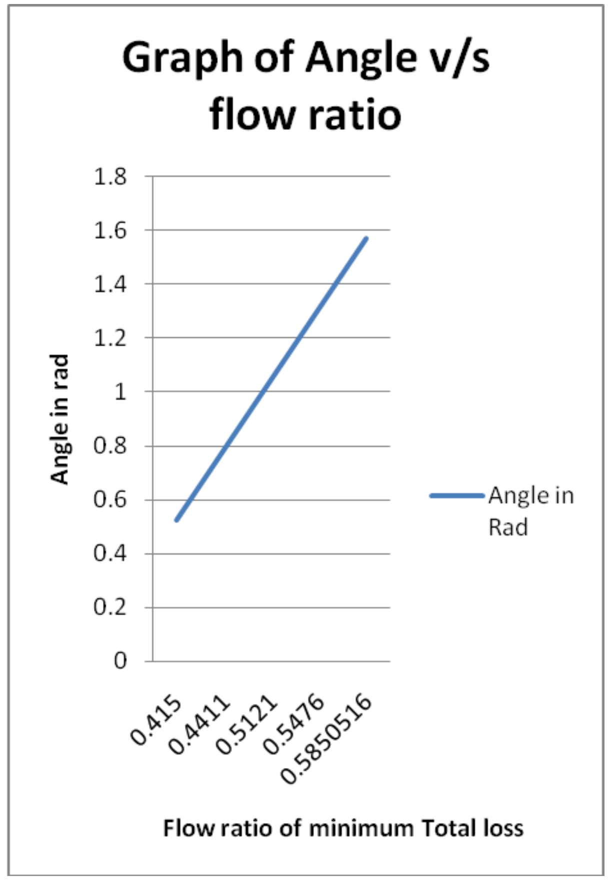


Figure 16: Graph showing variation of angle with flow ratio of lowest major loss

Figure 16 shows variation of angle with flow ratio of lowest major loss for the study.
Similarly, the equation obtained for lowest total loss is:

$$Angle=6.4462*fr^2-0.666*fr-0.2583 \quad (8)$$

The same action was repeated for all the flow types.
Similarly, from literature, other formulas were taken and the corresponding equations were found out.

For flow type 1

For lowest total loss

$$Angle=11.796*fr^2-27.568*fr+10.7358 \qquad (9)$$

Angle for lowest T-junction loss could not be determined.

## IV. Discussion

The error-prone use of constant loss co-efficients is known in the industry. An experiment to test and dramatise the fact was needed. Efforts have been made in this study to understand the same and provoke the further development of equations of loss co-efficients for varying angled T-junctions.

## V. Conclusions

- The use of constant loss co-efficients yields the same value of losses for all angles of T-junction. This results in error, now for a large network these errors get added up and ultimately affects the design of pipe networks.
- The wrong calculations may further lead to wrong selection of pumps and wrong sizing of various components.
- It can be inferred from table 5 that as long as the loss coefficients remain constant, the flows don't change with angle, which is contrary to observations made in field. This further enforces the use of angle dependent loss co-efficients for accuracy.
- The equations obtained can be used to decide the angle of T-junction for a certain flow ratio in the field which shall provide the minimum head loss. This equation will have use in engineering and architectural design.
- Future work can be on the methods of using these equations and preparation of SI.

For flow type 2

For lowest minor loss

Proper relationship was not observed

For lowest total loss

$$Angle=6.668xfr^2-14.373xfr+7.556 \qquad (10)$$

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