PHASE-SPLIT IN TWO-PHASE FLOW THROUGH T-JUNCTION

Thesis submitted in partial fulfillment of the requirement for the degree of

Master of Technology

In
Mechanical Engineering

By
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Under the guidance of
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CERTIFICATE

*This is to certify that the thesis entitled "***Phase-Split in Two-Phase Flow through T-Junction***", submitted by* ***Ananta Kumar Das (Roll Number: 213ME3430)*** *to National Institute of Technology, Rourkela, is a record of bona fide research work under my supervision, to the best of my knowledge in partial fulfilment of the requirements for the degree of* ***Master of Technology*** *in the Department of Mechanical Engineering, National Institute of Technology Rourkela.*

Place: Rourkela
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DECLARATION

I certify that

a. The work contained in the thesis is original and has been done by myself under the general supervision of my supervisor(s).
b. The work has not been submitted to any other Institute for any degree or diploma.
c. I have followed the guidelines provided by the Institute in writing the thesis.
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e. Whenever I have used materials (data, theoretical analysis, and text) from other sources, I have given due credit to them by citing them in the text of the thesis and giving their details in the references.
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Ananta Kumar Das (Roll Number: 213ME3430)
Signature of the Student

Curriculum Vitae

Ananta kumar das was born on 12th June 1990. He passed his matriculation from **Capital High School, Bhubaneswar** in 2005. In 2007, he completed his intermediate from **Rajdhani Junior College, Bhubaneswar**. He graduated from **Balasore College of Engineering and Technology**, **Balasore** in 2011.

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I would like to thank Mechanical Engineering Department for providing the CFD lab, where I completed the maximum part of my project work. I finally expressed my sincere gratitude to all those who have directly or indirectly helped me in completing this project work.

Date: Ananta Kumar Das (213ME3430)
Place: Rourkela

CONTENTS

List of Symbols

d	Diameter of pipe
V	Velocity of mixture
L	Length of the pipe

List of Greek Symbols

$\boldsymbol{\alpha_q}$	Volume fraction of qth phase
$\boldsymbol{\rho_q}$	Density of qth phase
$\boldsymbol{\mu_t}$	turbulent viscous coefficient
$\boldsymbol{\overline{\overline{\tau_q}}}$	stress-strain tensor of qth phase

List of Abbreviations

VF	Volume fraction
FVM	Finite Volume Method
VOF	Volume of Fluid

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ABSTRACT

A numerical investigation is made on the Phase-split phenomena in liquid-liquid two-phase flow through T-junction. The phenomena are studied by varying the fluid-pair, branch position, diameter of the pipe and the angle between the branch and run. For better understanding, both horizontal and vertical T-junction arrangements are considered in the present case. To simulate the problem, Finite Volume Method (FVM) with 3D Volume of Fluid (VOF) model have been used. The results are shown in terms of phase-contour in the mid plane, variation of volume fraction along the length of the individual pipe and the distribution of phase in several cross-section. There is a difference in the phase variation along the run and branch. This difference is more prominent in vertical T-Junction compare to that in the horizontal T-Junction. The volume fraction of the oil is always decreasing along the branch and run, and it is irrespective of the vertical and horizontal arrangement. But volume fraction almost remain constant along the inlet section in the horizontal T-junction and increases along the inlet section in the vertical T-junction.

Keywords—Phase-split; T-junction; Two-phase; Finite Volume Method (FVM); Volume of Fluid (VOF); Inlet; Branch; Run

CHAPTER 1:

INTRODUCTION & LITERATURE REVIEW

This chapter, at first, introduces the multiphase flow and T-Junction. Then, the literatures are extensively and rigorously surveyed. Attempt is made to identify the gaps in the literatures. And at last, the aims and objectives of the present work are narrated.

1.1 INTRODUCTION TO MULTIPHASE FLOW

Multiphase flow is an interacting flow of two or more phases where the interface between the phases is influenced by their motion. The simplest form of the multiphase flow is the two-phase flow. It is considered as a very important topic in academic, because of its wide application in the industries. It may happen that both the components of a two-component flow, are in the same phases (mostly liquid-liquid). In spite of that, they are frequently called two-phase flow. Here the phases are recognized as the continuous and discontinuous components. The various combination of two-phases are

- ✓ Gas-Solid
- ✓ Gas-Liquid
- ✓ Liquid-Solid
- ✓ Liquid-Liquid

1.2 INTRODUCTION TO T-JUNCTION

Figuure1.1 shows a T-Junction which is frequently occurred in pipe-line networks of any petroleum or chemical industries. If two-phase flow passes through T-Junction, the phase distribution would unavoidably ocurrs between the branch and the run. This phenomena has a deep effect on the flow control. In the pipe line network of petroleum industries, chemical industries or any other industries, flow through T-Junction frequently encountered. Generally the flows inside the pipe in these industries are multiphase flow. To decrease the load of the main separator, a T-Junction can be used to partially separate the phases of a two-phase flow. To separate the flashed products from the reactor in a chemical industry, it can also be used as a partial seperator. In the gas distribution unit, it is also used to overcome the problem that will arise in winter. Therefore, it is a prime importance to investigate the flow structure along the pipe with T-Junction.

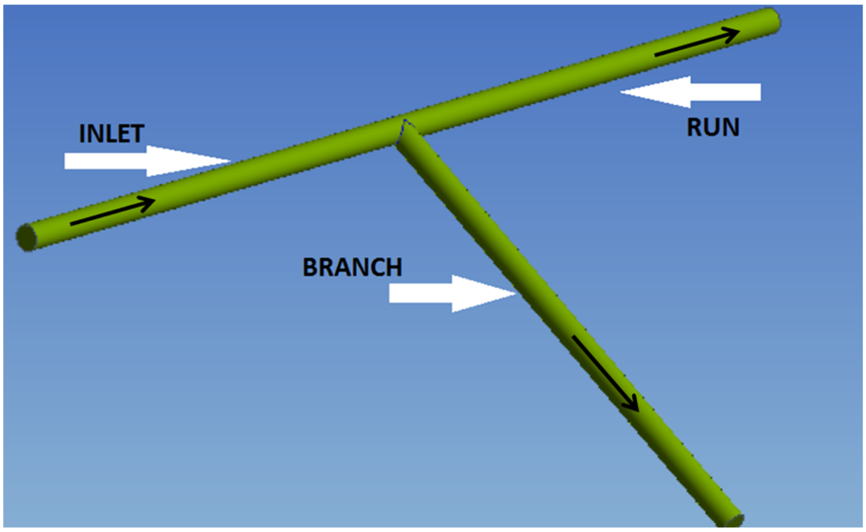


Figure 1.1: A schematic of the T-Junction (T-Junction with Inlet, Branch and Run)

T-Junction is the primary component that is used to distribute water in the large city and industries. It can also be used to accumulate water from many pipes in to single one. In industries, the pipeline networks are quite large and require more attention to maintain the pressure in the network. This can be overcame by the use of T-Junction. In a city, it is required to maintain the flow of water to distribute it equally in every house. This problem can also be eliminated by the use of T-Junction.

1.3 LITERATURE SURVEY

A model for phase-splitting phenomena for the stratified wavy and annular flow in a horizontal T-Junction was presented by Shoham et al. (1986). Mudde et al. (1993)

studied the splitting phenomena in a T-Junction having horizontal pipe (of diameter 0.23 m) and vertical branch of diameter 0.1 m. Here the experiment was carried out for stratified, semi-annular and annular flow. Roberts et al. (1994) studied the phase split phenomena in T-Junction of 0.125 diameter in which all the pipes are on the horizontal plane. In this paper, the experiment was carried out for stratified and annular flow regimes. Azzopordi et al. (1996) developed a model to for the splitting phenomena in a horizontal T-Junction with an inclined branch for annular flow. The amount of liquid poured into the branch (side arm) increased abruptly due to the liquid come to rest in the main pipe. For annular flow at small diameters in the range of 0.009-0.127 m, phase splitting phenomena was studied by Stacey et al. (1999).The results obtained from larger diameter compared with the present data, and it was observed that the liquid volume-fraction increases as the pipe diameter decreases. An experimental investigation was made by Conte et al. (2002) on the film thickness for gas-liquid flow through a T-Junction having larger diameter. The film thickness variation was obtained using conductivity techniques at the perimeter of the different pipe sections. They observed that the liquid dominated the semi-annular flow through a T-Junction having larger diameter. Wren et al. (2005) studied the phase split at T-Junction for the slug flow. The experiment has been carried out for the fluid pair air-water in pipes of diameter more than 0.01 m at atmospheric pressure. The results were obtained using a high-speed camera for different inlet super facial velocities and these were different for slug and annular flow at same size T-Junction. An experimental attempt was made by Das et al. (2005) to investigate the phase splitting phenomena in a horizontal T-Junction having diameter of 0.005 m. It was revealed that the gas take off increases with increase in pressure under all flow condition along the side arm. Pandey et al. (2006) investigated the flow patterns of two-phase flow (liquid-liquid) in a horizontal T-

Junction. The experiment has been carried out for the different superficial velocities of two liquids. Yang et al. (2006) studied the phase split of liquid-liquid two-phase flow at a horizontal T-Junction. The experiment has been carried out to measure the phase distribution for water-kerosene with pipe diameter 67.4 mm.

For annular flow, Adehcy et al. (2003) presented a computational model for two-phase flow in a T-Junction. Margaris (2006) presented a mathematical model to study the pressure loss and phase arrangement in T-Junction. The results were calibrated with the experimental observations, and it was observed that the mathematical model was very useful for the phase separator. Li-yang et al. (2008) numerically simulated the oil-water two-phase flow in a horizontal T-Junction. They solved it by using 3D two-fluid model. They got a good agreement between the experiment and numerical results.

1.4 GAPS IN LITERATURE REVIEW

The Literatures obtained so far is focused just on the gas-liquid stream inside the T-Junctions. A very few deal with the liquid-liquid two-phase flow through T-Junction, so there is a necessity to investigate it numerically for different physical conditions.

1.5 AIMS AND OBJECTIVE

The objective here is to capture the phase distribution along the inlet section, branch and run of the T-Junction. For better understanding, the investigation is carried out by varying the fluid pairs, pipe diameters, branch position and the angle between branch and run.

1.6 ORGANISATION OF THE THESIS

Chapter 2 includes the problem description along with basic assumptions. The information regarding the properties of the fluids is also given in this chapter. The methodology used to solve the above problem is included in chapter 3. The information about the grid pattern, governing equations, boundary conditions and residual convergence is also described in this chapter. The results and its corresponding discussions are considered in chapter 4. Chapter 5 includes the conclusions and future work.

CHAPTER 2:

PROBLEM FORMULATION

In this section, the problem is formulated for both horizontal and vertical T-Junction to study the phase splitting phenomena with different physical conditions.

2.1 HORIZONTAL T-JUNCTION

A uniform mixture of two-phase flow with the given inlet velocity (v) and volume fraction (VF) is flowing in a horizontal T-Junction. The length of each of the section (i.e. Inlet, Branch and Run) is 1 m. The exit section of the run and branch are exposed to the atmosphere. By making the horizontal arrangement (as shown in the Figure 2.1) of the T-Junction, several cases are studied as shown below.

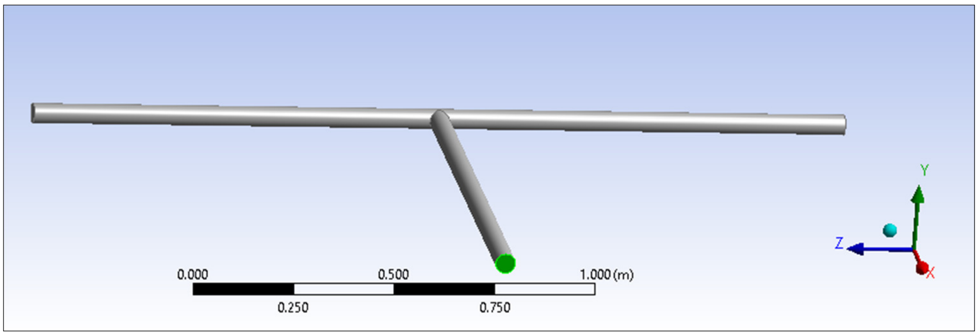


Figure 2.1: Geometrical representation of horizontal T-Junction

2.1.1 Effect of Fluid Pair: By considering the branch position as 1 m from the run exit & angle of the branch with run as 90^0, the effect of fluid pair is studied for three different diameter as described below

2.1.1.1 Effect of Fluid pair with diameter 0.05 m: Here the effect of fluid pair as described above is captured by considering the diameter as 0.05 m.

2.1.1.2 Effect of Fluid pair with diameter 0.04 m: In the same way, the effect of fluid pair is again observed by considering the diameter as 0.04 m.

2.1.1.3 Effect of Fluid pair with diameter 0.03 m: This study is concerned about the effect of fluid pair for the diameter 0.03 m.

2.1.2 Effect of position of the branch: The branch position is varying from the run exit as 0.5, 0.75, 1, 1.25 & 1.5 m for different fluid pair and diameter as 0.05 m.

2.1.2.1 Effect of the branch position with water-kerosene: Here the effect of position of the branch from the run is studied for the fluid pair water-kerosene.

2.1.2.2 Effect of the branch position with water-diesel: In this section, the effect of the branch position is observed for the water-diesel fluid pair.

2.1.2.3 Effect of the branch position with water-petrol: For the water-petrol fluid pair, the effect of the branch position is studied here.

2.1.3 Effect of the diameter: The diameter is varying as 0.03, 0.04 & 0.05 m for different fluid pair to study its effect through T-Junction.

2.1.3.1 Effect of the diameter with water-kerosene: The effect of diameter is considered for the fluid pair water-kerosene.

2.1.3.2 Effect of the diameter with water-diesel: In this section, the study is focused on the effect of diameter for the fluid pair water-diesel.

2.1.3.3 Effect of the diameter with water-petrol: The effect of diameter is studied here for water-petrol fluid pair.

2.1.4 Effect of the angle between the branch and run: The inclination of branch with the main pipe is varying as 30^0, 45^0, 60^0 & 90^0 with the diameter 0.05 m & the position of branch as 1 m for each fluid pair.

2.1.4.1 Effect of the angle between the branch and run with fluid pair water-kerosene: The effect of angle is studied here for the fluid pair water-kerosene.

2.1.4.2 Effect of the angle between the branch and run with fluid pair water-diesel: The study is focused on the effect of angle for water-diesel fluid pair.

2.1.4.3 Effect of the angle between the branch and run with fluid pair water-diesel: In this section, water-petrol is taken as fluid pair to study the effect of angle.

2.2 VERTICAL T-JUNCTION

The same flow and conditions as considered in the section 3.1 are reconsidered with vertical arrangement of the T-Junction.

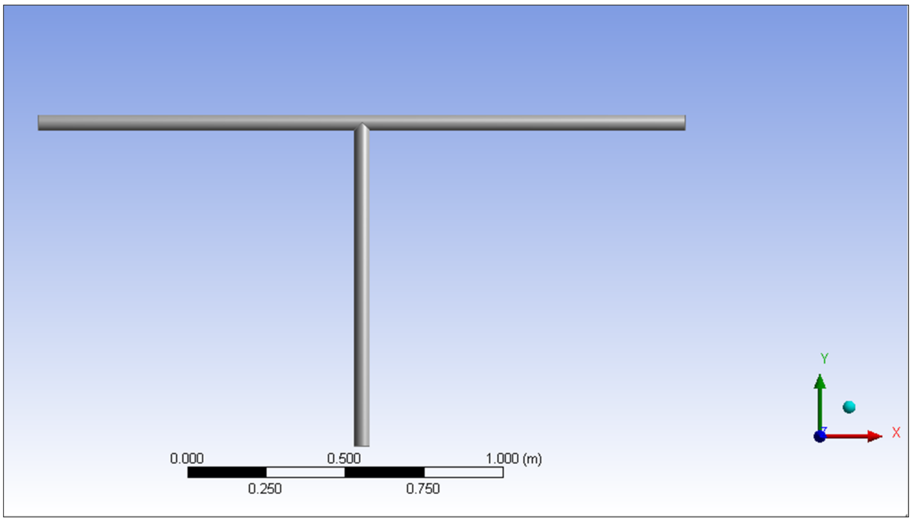


Figure 2.2: Geometrical representation of vertical T-Junction

In the same way as described in the previous section (section 2.1) several cases are considered as described below.

2.2.1 Effect of Fluid Pair: By considering the branch position as 1 m from the run exit & angle of the branch with run as 90^0, the effect of fluid pair is studied for three different diameter as described below

2.2.1.1 Effect of Fluid pair with diameter 0.05 m: Here the effect of fluid pair as described above is captured by considering the diameter as 0.05 m.

2.2.1.2 Effect of Fluid pair with diameter 0.04 m: In the same way, the effect of fluid pair is again observed by considering the diameter as 0.04 m.

2.2.1.3 Effect of Fluid pair with diameter 0.03 m: This study is concerned about the effect of fluid pair for the diameter 0.03 m.

2.2.2 Effect of position of the branch: The branch position is varying from the run exit as 0.5, 0.75, 1, 1.25 & 1.5 m for different fluid pair and diameter as 0.05 m.

2.2.2.1 Effect of the branch position with water-kerosene: Here the effect of position of the branch from the run is studied for the fluid pair water-kerosene.

2.2.2.2 Effect of the branch position with water-diesel: In this section, the effect of the branch position is observed for the water-diesel fluid pair.

2.2.2.3 Effect of the branch position with water-petrol: For the water-petrol fluid pair, the effect of the branch position is studied here.

2.2.3 Effect of the diameter: The diameter is varying as 0.03, 0.04 & 0.05 m for different fluid pair to study its effect through T-Junction.

2.2.3.1 Effect of the diameter with fluid pair water-kerosene: The effect of diameter is considered for the fluid pair water-kerosene.

2.2.3.2 Effect of the diameter with fluid pair water-diesel: In this section, the study is focused on the effect of diameter for the fluid pair water-diesel.

2.2.3.3 Effect of the diameter with fluid pair water-petrol: The effect of diameter is studied here for water-petrol fluid pair.

TABLE 2.1 Properties of Kerosene

DESCRIPTION	VALUE	UNITS
DENSITY	780.0000	Kg/m^3
VISCOSITY	0.0024	Kg/m-s
INTERFACIAL TENSION(WATER)	0.0480	N/m

TABLE 2.2 Properties of Diesel

DESCRIPTION	VALUE	UNITS
DENSITY	730.0000	Kg/m^3
VISCOSITY	0.0024	Kg/m-s
INTERFACIAL TENSION(WATER)	0.0280	N/m

TABLE 2.3 Properties of Petrol

DESCRIPTION	VALUE	UNITS
DENSITY	726.0000	Kg/m^3
VISCOSITY	0.0006	Kg/m-s
INTERFACIAL TENSION(WATER)	0.0220	N/m

TABLE 2.4 Properties of Water

DESCRIPTION	VALUE	UNITS
DENSITY	998.200000	Kg/m^3
VISCOSITY	0.001003	Kg/m-s

2.3 BASIC ASSUMPTION

- ✓ Steady state flow conditions were assumed.
- ✓ All the fluids were considered as incompressible with the constant property.
- ✓ A uniform mixture is flowing at the inlet.

CHAPTER 3:

NUMERICAL CALCULATION

The advancement of high-speed computing with high accuracy of numerical methods for the solution of physical problems has made a big revolution in the way the approach has been made to solve fluid dynamics and heat transfer problems. Computational Fluid Dynamics (CFD) made the analysis of complex flow geometries much easier as compared to the earlier conventional methods. CFD reduces the total cost and total time required for the analysis of a problem by replacing the analytical studies and experimental testing with numerical simulation methods. It gives the useful data that can be used to get the final result and to draw some conclusion. The results that obtained here may be in the form of vector plots of vector quantities such as velocity or in the form of contour plots of scalar quantities such as temperature, pressure etc.

3.1 CFD PROCEDURE

In this problem, Finite Volume Method (FVM) with 3D Eulerian-Multi Fluid VOF model in ANSYS FLUENT is used to investigate the phase distribution along the pipe. Pressure based solver is used to analyse the complex and nonlinear phenomena and for turbulence k-ϵ model is used.

3.1.1 GEOMETRY CREATION: The geometry of the T-junction is created by the help of ANSYS 15 WORKBENCH software for both horizontal and vertical T-junction. The horizontal T-junction is drawn in the DESIGN MODLER. To create the geometry, a circle is drawn in XY plane with required dimension and all the units are taken in metre. After that another circle is drawn in Plane with same dimension. Then these two circles are extruded to the desired length as mention in the problem and the required geometry is obtained. Similarly the geometry of vertical T-junction is created but the only difference is that those circles are drawn in YZ & XZ plane.

3.1.2 GRID GENERATION: To grid the total geometry, the meshing is done by MESH in ANSYS WORKBENCH software. To understand and solve the problem correctly a tetrahedron mesh is considered for the simulation. The size of the mesh is defined in sizing. The sizing of the mesh for the different diameter is given in table 3.2. To capture the laminar sub-layer effect, the small size mesh is generated near the wall. This is done by selecting the *inflation option* as *programme controlled* in MESH. The maximum five layers are taken near the wall with growth rate 1.2. (See figure 3.2.2)

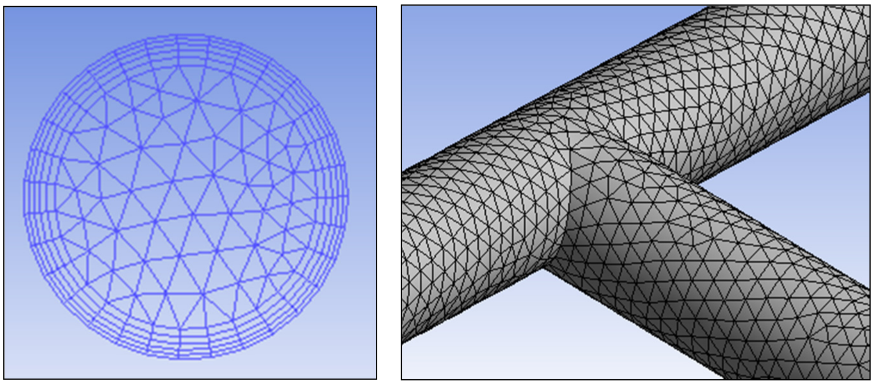


Figure 3.1: Grid pattern employed for the present case

TABLE 3.1 Size of the Mesh for the different diameter

Diameter	Max. face size (in metre)	Max. size (in metre)	Min. size (in metre)
0.05 m	3.36e-02	6.72e-02	3.36e-04
0.04 m	3.34e-02	6.68e-02	3.34e-04
0.03 m	0.11	0.22	1.347e-03

3.2 GOVERNING EQUATION

The governing equations solved for the fluid flow are continuity equation, Navier-stokes equation and equations in multi-fluid-VOF.

3.2.1 CONTINUITY EQUATION:

$$\frac{\partial}{\partial t}\left(\alpha_q \rho_q\right) + \nabla.\left(\alpha_q \rho_q v \vec{v}_q\right) = \sum_{p=1}^{n}(\dot{m}_{pq} - \dot{m}_{qp}) + S_q \qquad (3.1)$$

3.2.2 NAVIER-STOKES EQUATION:

$$\frac{\partial}{\partial t}\left(\alpha_q \rho_q \vec{v}_q\right) + \nabla.\left(\alpha_q \rho_q \vec{v}_q \vec{v}_q\right) = -\alpha_q \nabla p + \nabla.\overline{\overline{\tau_q}} + \alpha_q \rho_q \vec{g} + \sum_{p=1}^{n} \vec{R}_{pq} +$$

$$\dot{m}_{pq} \vec{v}_{pq} - \dot{m}_{qp} \vec{v}_{pq}) + (\vec{F}_q + \vec{F}_{lift,q} + \vec{F}_{wl,q} + \vec{F}_{vm,q} + \vec{F}_{vm,q} +$$

$$\vec{F}_{td,q}) \qquad (3.2)$$

3.2.3 TURBULENCE MODELLING:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\varepsilon - Y_M +$$

$$S_k \qquad (3.3)$$

$$\frac{\partial}{\partial \mathrm{t}}(\rho\varepsilon) + \frac{\partial}{\partial \mathrm{x_i}}(\rho\varepsilon \mathrm{u_i}) = \frac{\partial}{\partial \mathrm{x_j}}\left[\left(\mu + \frac{\mu_\mathrm{t}}{\sigma_\mathrm{i}}\right)\frac{\partial\varepsilon}{\partial \mathrm{x_j}}\right] + \mathrm{C_{1i}}\frac{\varepsilon}{\mathrm{k}}(\mathrm{G_k} + \mathrm{C_3 G_b}) - C_{2i}\rho\varepsilon 2\mathrm{k} +$$

$$\mathrm{Se} \qquad (3.4)$$

Where μ_t is called as turbulent viscous coefficient and is given as;

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon} \qquad (3.5)$$

3.2.4 VOLUME FRACTION EQUATION:

$$v_q = \int \alpha_q \, dv \qquad (3.6)$$

$$\sum_{q=1}^{n} \alpha_q = 1 \qquad (3.7)$$

3.3 BOUNDARY CONDITIONS

To simulate the above problems the following boundary conditions are considered.

- At inlet : mixture velocity =0.8 m/s, volume fraction=0.4.
- At run outlet : Pressure outlet (Atmospheric pressure i.e. P_{atm}=101325pa).
- At branch outlet : Pressure outlet (Atmospheric pressure i.e. P_{atm}=101325pa).
- At wall : No slip ($U_x = 0$) and no penetration ($U_x = 0$ and $U_y = 0$).

3.4 RESIDUALS AND CONVERGENCE

To increase the accuracy of the solutions all the scaled residuals value (continuity, u-water, v- water, w-water, u- kerosene, v- kerosene, w-kerosene, k and ϵ, VF) selected to 10^{-6}.

CHAPTER 4

RESULTS & DISCUSSION

4.1 GRID INDEPENDENCE TEST

Grid independent test is performed to check whether the results depend upon the number of grids or not. Here, this test is carried out for each of the diameter separately as shown in the Figures 4.1-4.3.

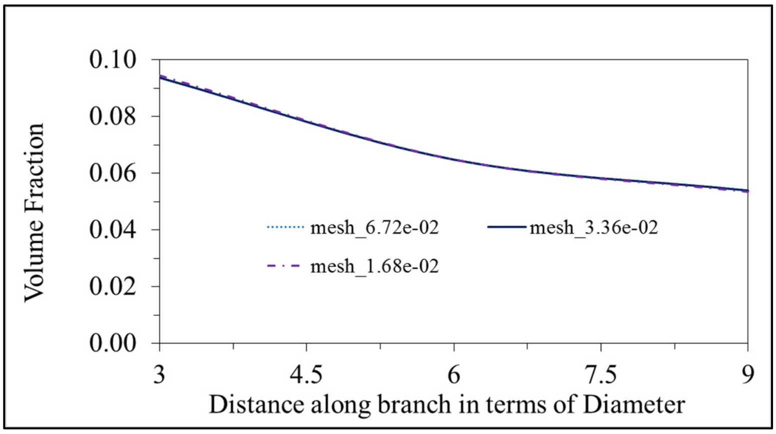


Figure 4.1: Variation of VF with Grid for vertical T-Junction with diameter 0.05 m

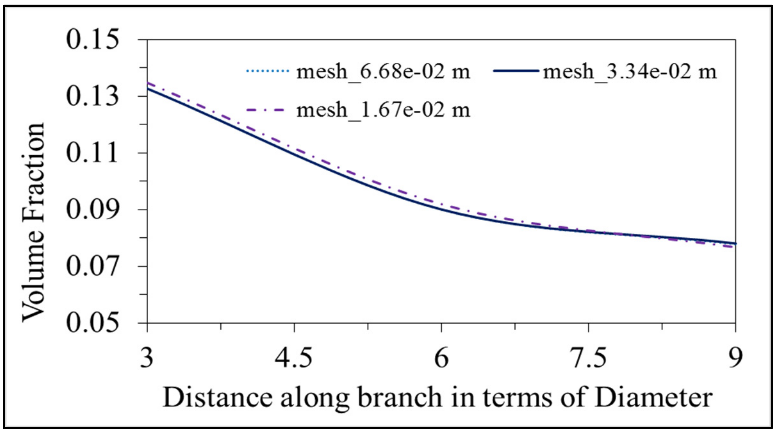


Figure 4.2: Variation of VF with Grid for vertical T-Junction with diameter 0.04 m

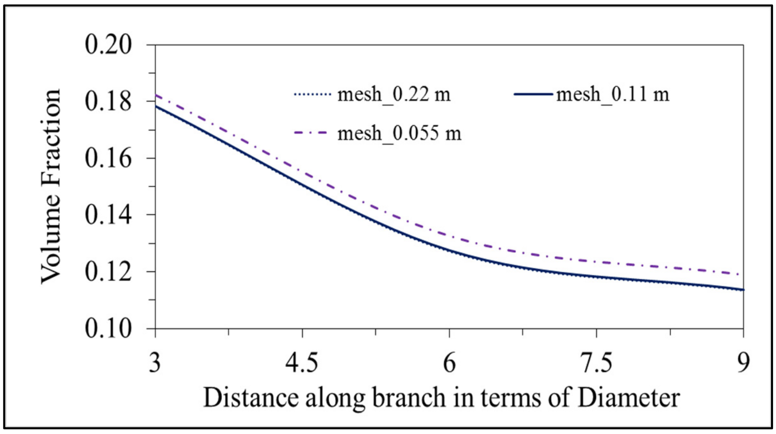


Figure 4.3: Variation of VF with Grid for vertical T-Junction with 0.03 m.

From the grid independent test, it is clear that the variation of volume fractions along the branch are independent grid size when the grid size is lower than 6.72e-02 m. Therefore, the grid size as 6.72 e-02 m can be taken as the standard grid size for rest of the calculation with diameter 0.05 m. In the same way, through grid independent test the standard grid size are obtained as 6.68e-02 m & 0.22 m for the diameter 0.04 and 0.03 m respectively.

4.2 VALIDATION

The result obtained here using Eulerian-Multi Fluid VOF model is compared with the results of Yang Li Wang et al. There is a huge similarity obtained between the results.

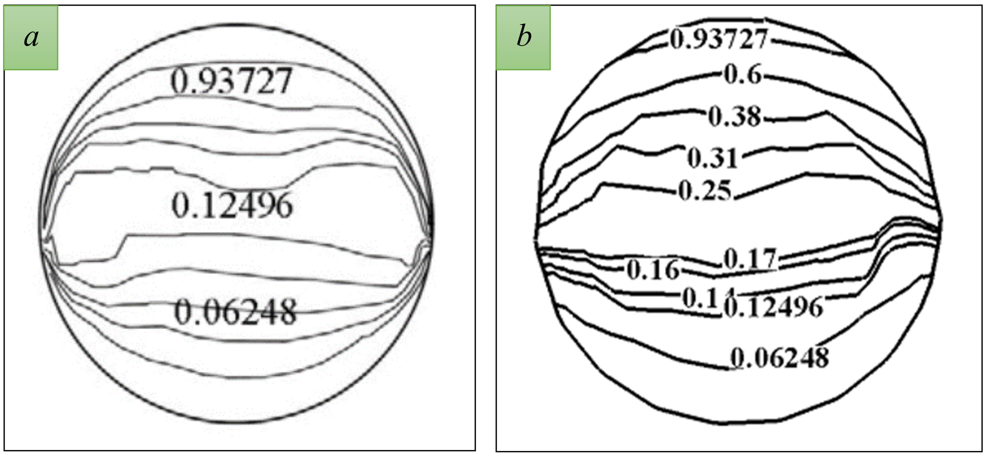


Figure 4.4: Distribution of oil volume fraction lines at a cross-section (at a distance 3*d* from the junction) in the Inlet: (a) in li yang et.al (b) in the present case.

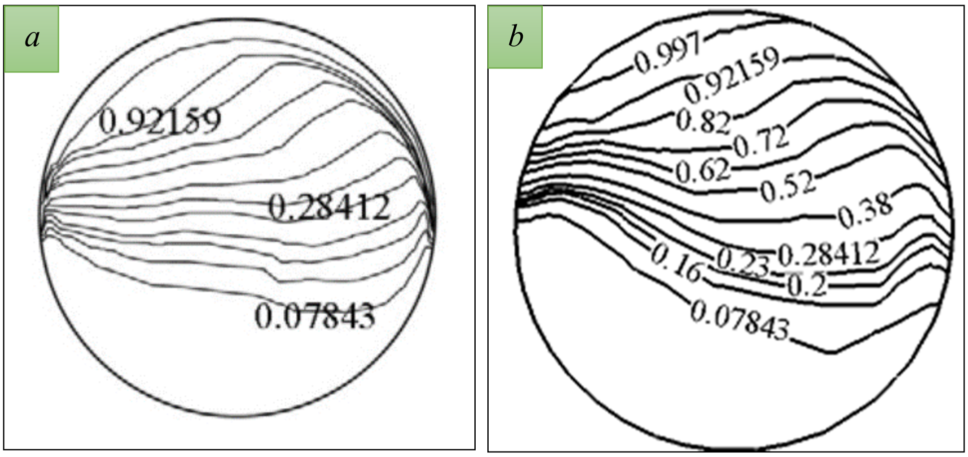


Figure 4.5: Distribution of oil volume fraction lines at a cross-section (at a distance 3*d* from the junction) in the Branch: (a) in li yang et.al (b) in the present case

4.3 HORIZONTAL T-JUNCTION

At first the phase contour at the horizontal midplane is shown in the Figure 4.6 for the diameter of 0.05 m , branch position as 1 m from the run exit, angle of branch with run as 90^0 & the fluid pair as water-keresone.

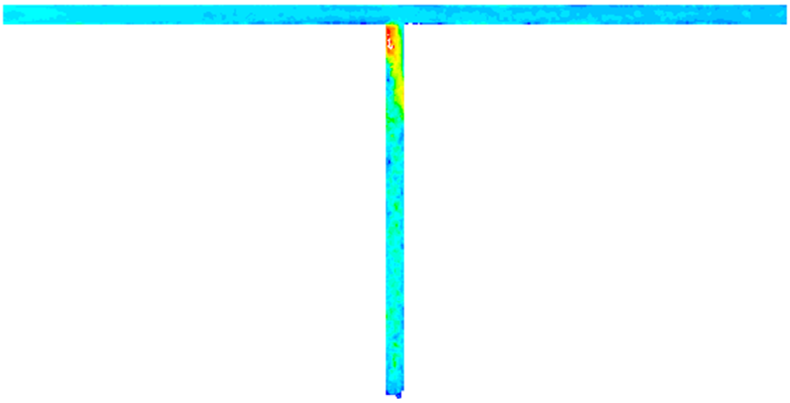


Figure 4.6: Phase contour at the horizontal midplane of the T-junction where, fluid pair is water-keresone, diameter is 0.05 m, velocity is 0.8 m/s & volume fraction is 0.4.

For the same combination, three planes are created from the junction. These planes are selected at a distance 3, 6 & 9 times of the diameter from the junction along the inlet, run and branch. The volume fraction contours are plotted at these planes which as shown Figure 4.7.

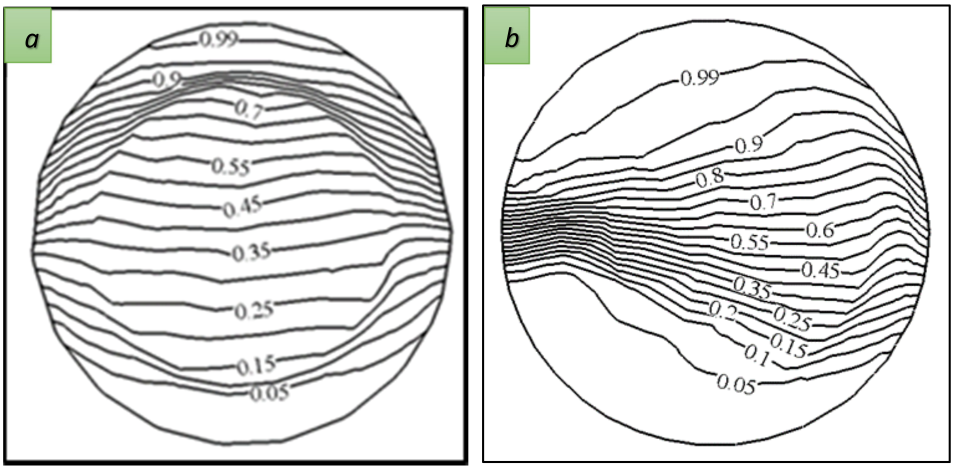
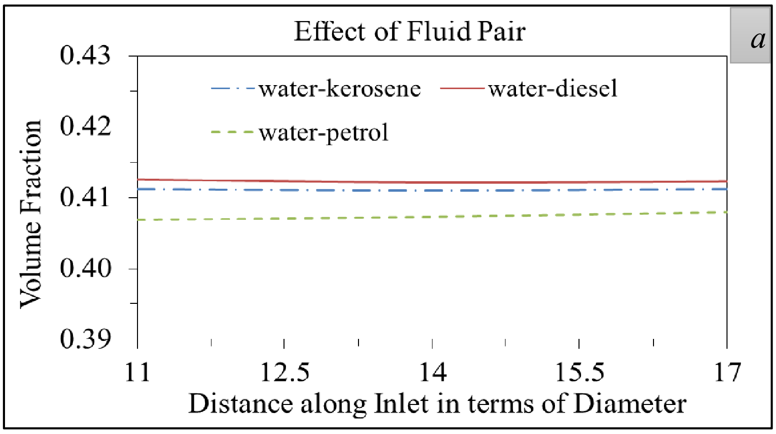


Figure 4.7: VF contour of water-kerosene at a distance 3*d* from the junction: (a) inlet (b) branch

4.3.1 Effect of Fluid Pair: The effect of fluid pair for different diametr of the pipe (as described in section 2.1.1) are shown below.

4.3.1.1 Effect of Fluid pair with diameter 0.05 m: The effect of fluid pair on the phase splitting phenomena in inlet section, branch and run are shown in Figure 4.8.



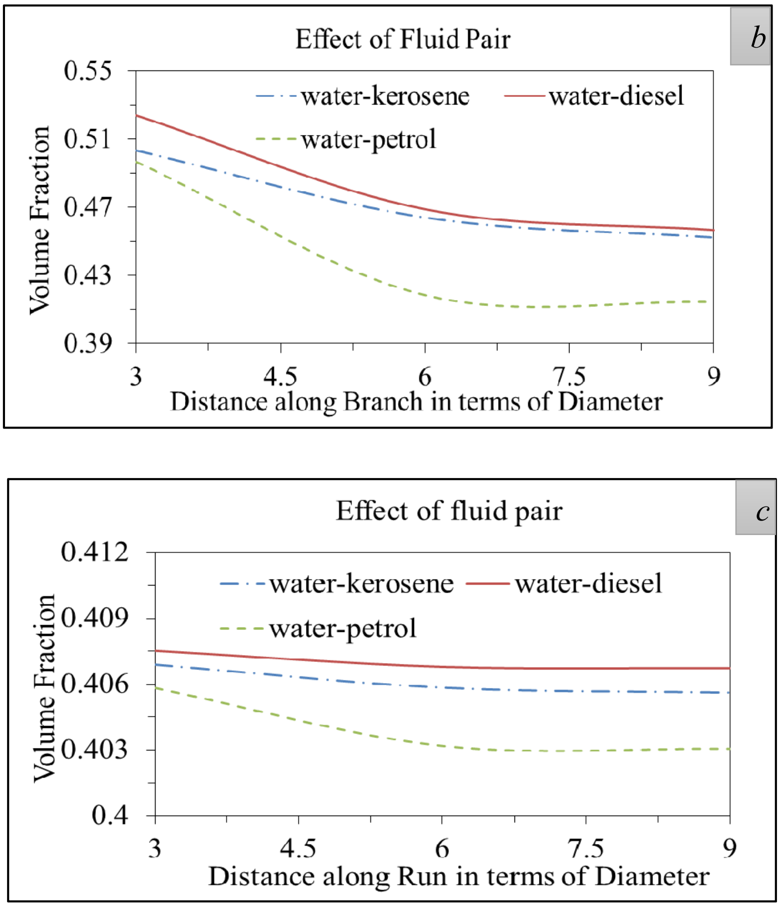


Figure 4.8: Variation of VF along the length of the different sections with diameter 0.05 m: (a) at Inlet (b) at Branch & (c) at Run

The variation of volume fraction along the length does not vary significantly along the inlet and run (See Figure 4.8(a) & (c)). Figure 4.8(b) shows that the rate of change of volume fraction along the branch, which is higher compared to the inlet and run. Also shows that near the junction volume fraction of oil is more and after that it remains unchanged as the distance increases along the branch. From this study, it reveals that the phase-splitting phenomena depends upon the viscosity. The phase separation is lower for the low viscous fluid.

4.3.1.2 Effect of Fluid pair with diameter 0.04 m: The effect of fluid pair on the phase splitting phenomena in inlet section, branch and run are shown in Figure 4.9.

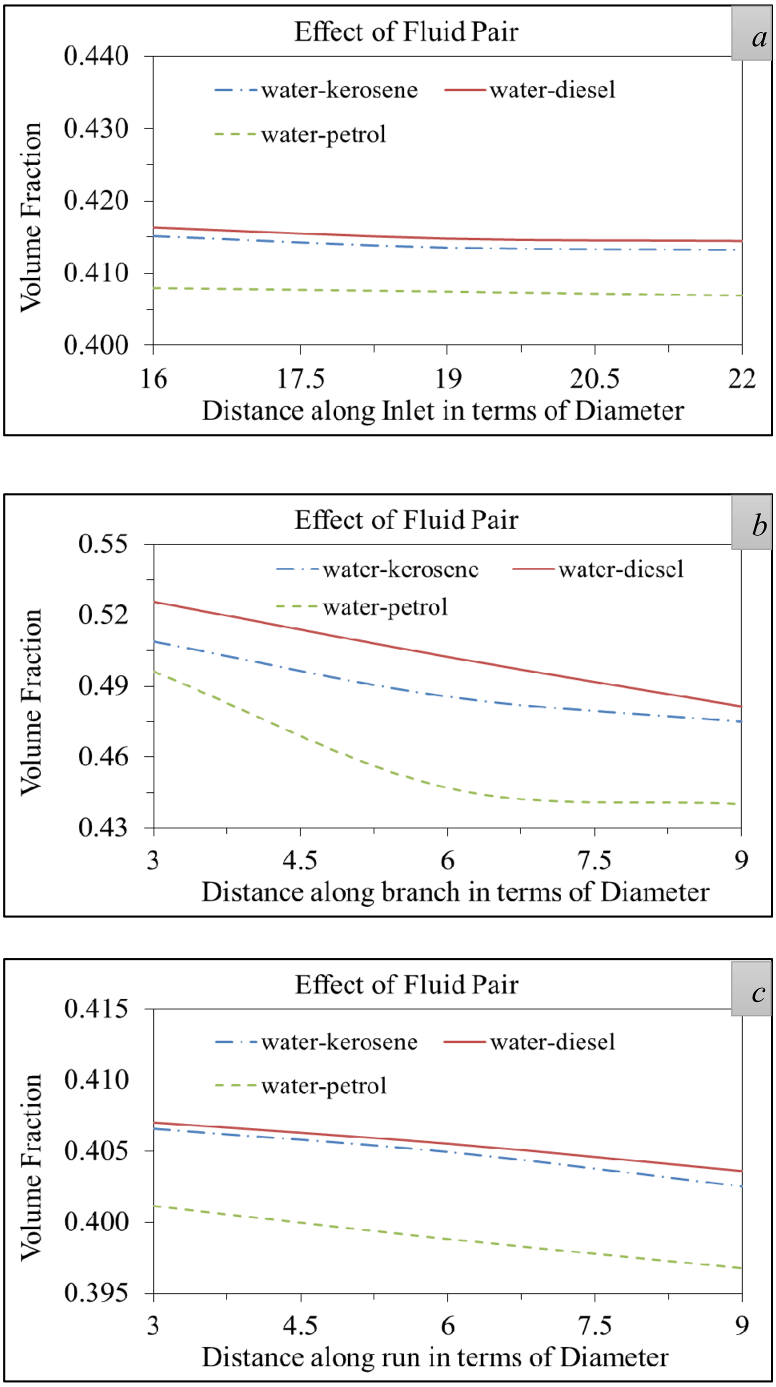


Figure 4.9: Variation of VF along the length of the different sections with diameter 0.04 m: (a) at Inlet (b) at Branch & (c) at Run

4.3.1.3 Effect of Fluid pair with diameter 0.03 m: The effect of fluid pair on the phase splitting phenomena in inlet section, branch and run are shown in Figure 4.10. Here the same observations have been obtained as in section 4.3.1.1 for both the diameter 0.04 and 0.03 m.

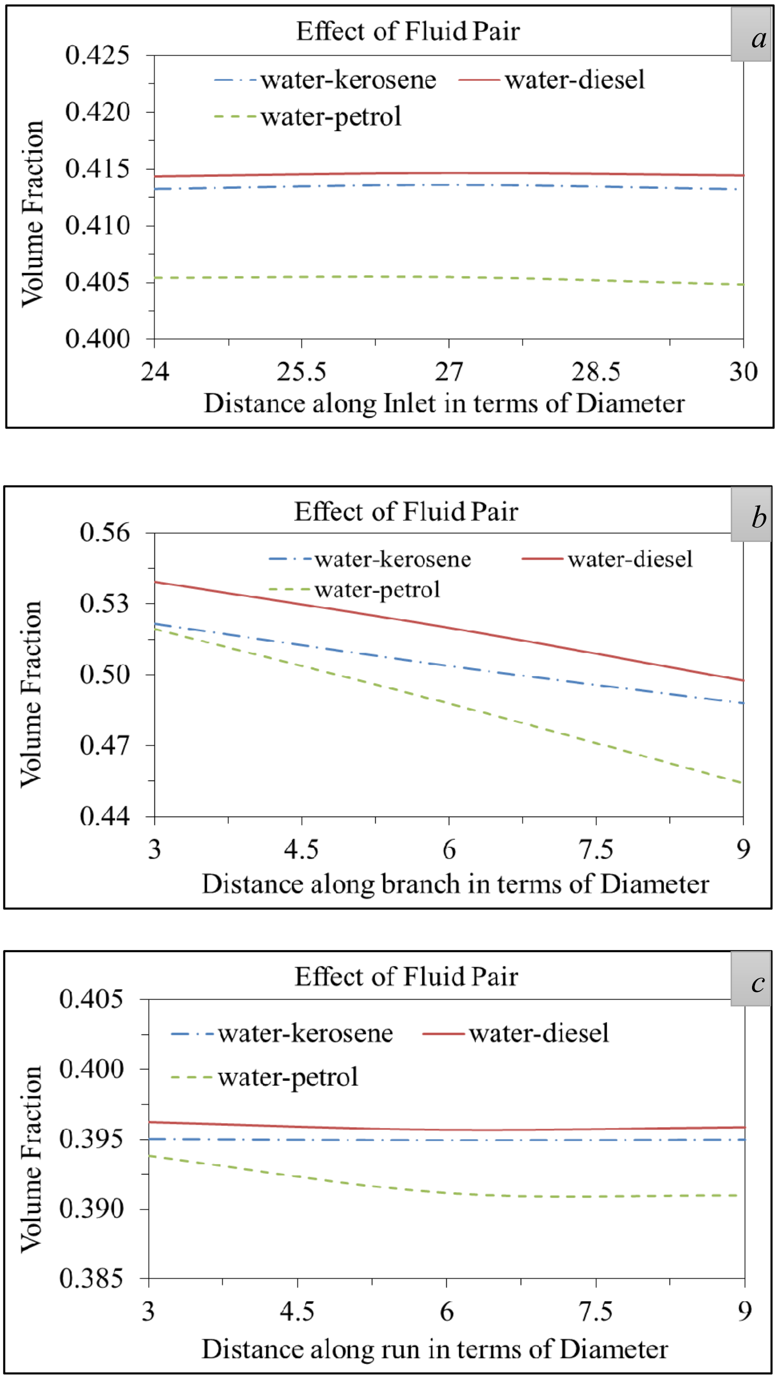


Figure 4.10: Variation of volume fraction along the length of the different sections with diameter 0.03 m: (a) at Inlet (b) at Branch & (c) at Run.

4.3.2 Effect of position of the branch: The effect of position of the branch for different fluid pair (as described in section 2.1.2) are shown below.

4.3.2.1 Effect of the branch position with fluid pair water-kerosene: The effect of branch position on phase splitting phenomena in inlet section, branch and run are shown in Figure 4.11.

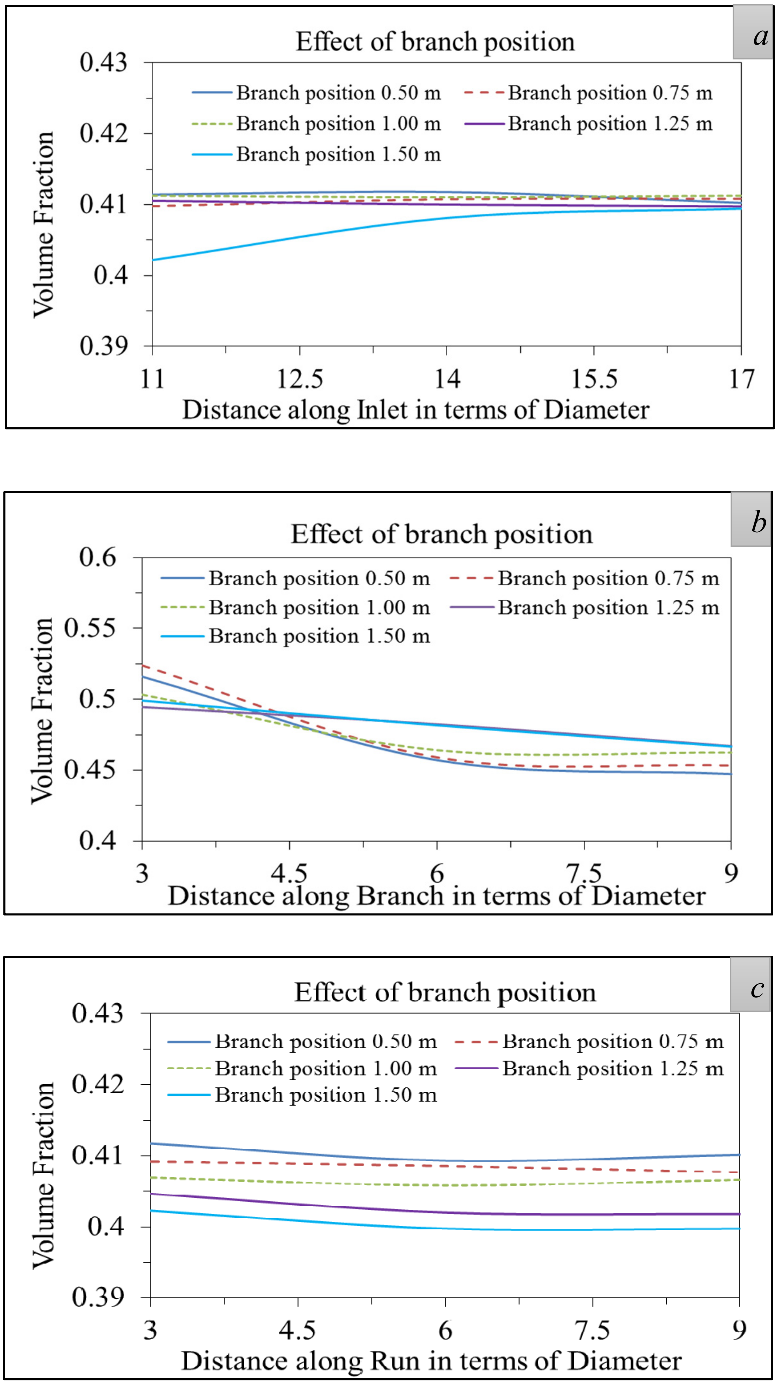
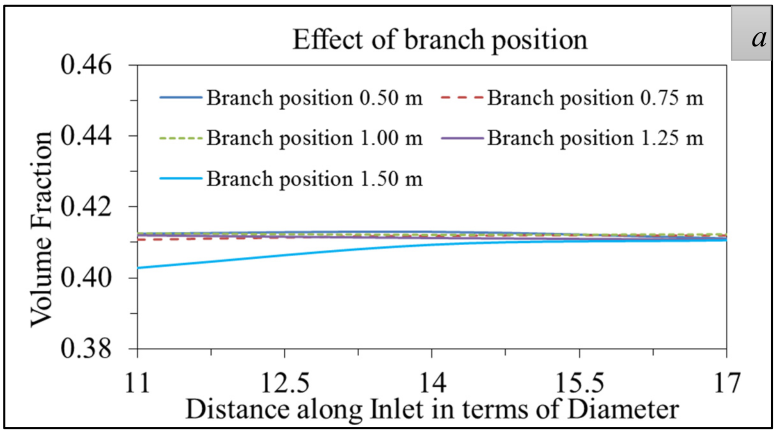
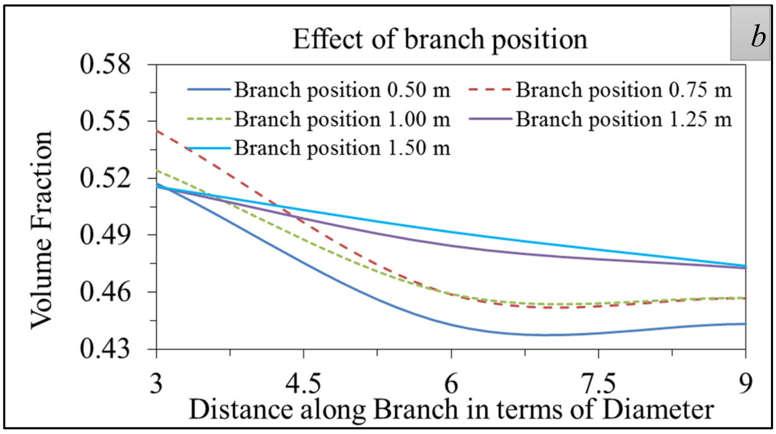


Figure 4.11: Variation of VF along the length of pipe with diameter 0.05 m & fluid-pair water-kerosene: (a) at Inlet (b) at Branch & (c) at Run.

Figure 4.11(a) shows the variation of volume fraction along the inlet. There is no variation of volume fraction along the inlet for all the position of the branch except at the postion of branch 1.5 m from the run. This variation ocurrs due to the numerical oscilation error. The rate of change of volume fraction is more near the junction for the position of the branch 0.5, 0.75 & 1m from the run (see Figure 4.11(b)). After that it remains unchanged for all the positions of the branch. Figure 4.11(c) shows that variation of volume fraction is less along the run. But in the branch, at a particular position from the junction, the volume fraction increases with the branch position away from the run-exit.

4.3.2.2 Effect of the branch position with fluid pair water-diesel: The effect of fluid pair on the phase splitting phenomena in inlet section, branch and run are shown in Figure 4.12.





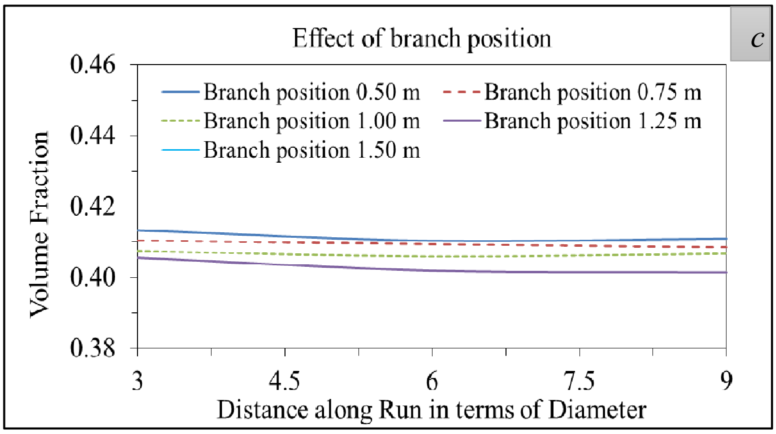
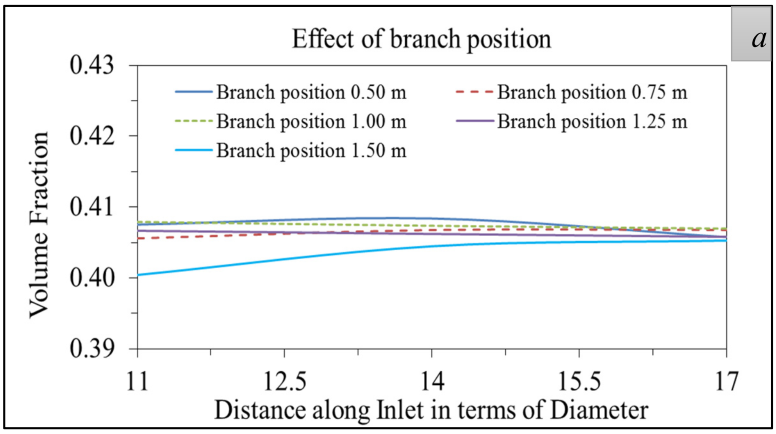


Figure 4.12: Variation of VF along the length of pipe with diameter 0.05 m & fluid-pair water-diesel: (a) at Inlet (b) at Branch & (c) at Run.

4.3.2.3 Effect of the branch position with fluid pair water-petrol: The effect of branch position on the phase splitting phenomena in inlet section, branch and run are shown in Figure 4.13. Here the same observations have been obtained as in section 4.3.2.2 for both the fluid diesel and petrol.



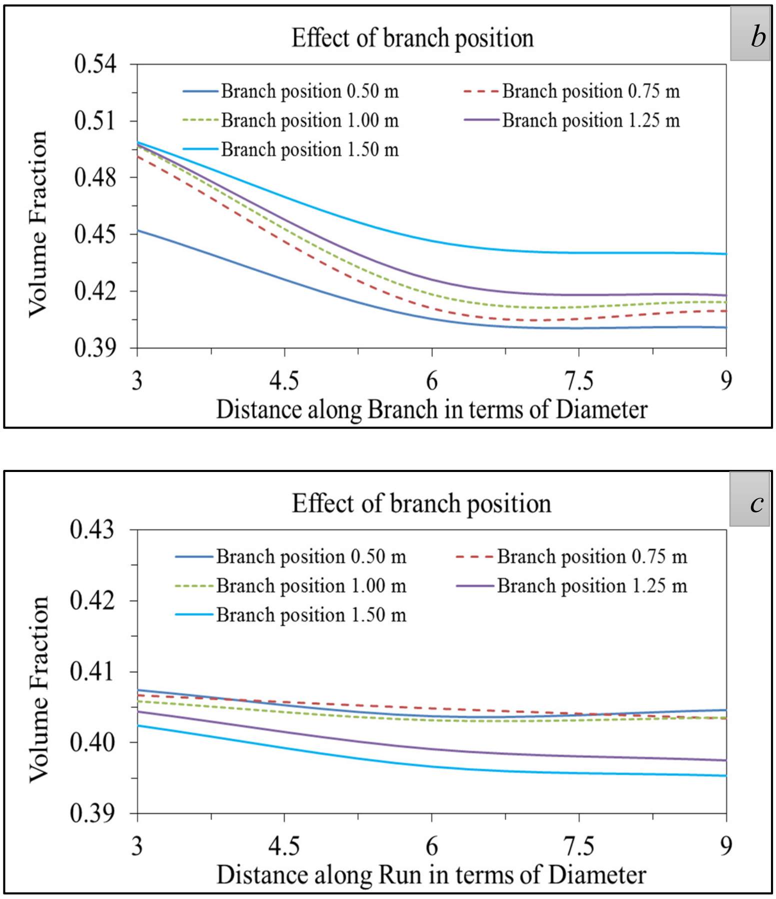


Figure 4.13: Variation of VF along the pipe with diameter 0.05 m & fluid-pair water-petrol: (a) at Inlet (b) at Branch & (c) at Run.

4.3.3 Effect of the diameter: The effect of diameter for different fluid pair (as described in section 2.1.3) are shown below.

4.3.3.1 Effect of the diameter with fluid pair water-kerosene: The effect of diameter on the phase splitting phenomena in inlet section, branch and run are shown in Figure 4.14.

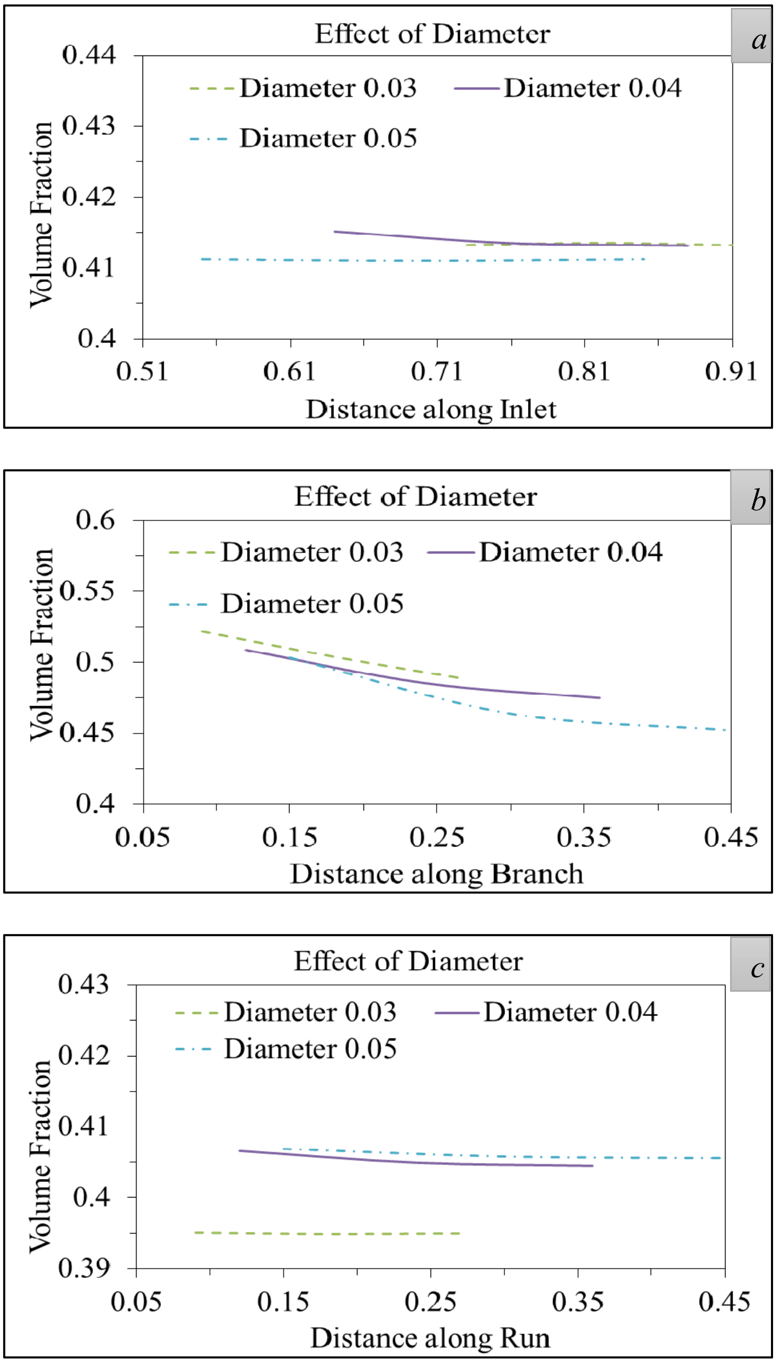


Figure 4.14: Variation of VF along the pipe with fluid-pair water-kerosene: (a) at Inlet (b) at Branch (c) at Run.

The variation of volume fraction is very less along the inlet for all the diameters as shown in Figure 4.14(a). Figure4.14(c) shows that, the variation of volume fraction is not varying along the run. But some deviation has been found for the diameter 0.03 m. The variation of volume fraction along the branch is more compared to the inlet and run. As the diameter decreases, the volume fraction increases at a particular position from the junction along the branch (see figure 4.14(c)).

4.3.3.2 Effect of the diameter with fluid pair water-diesel: The effect of diameter on the phase splitting phenomena in inlet section, branch and run are shown in Figure 4.15.

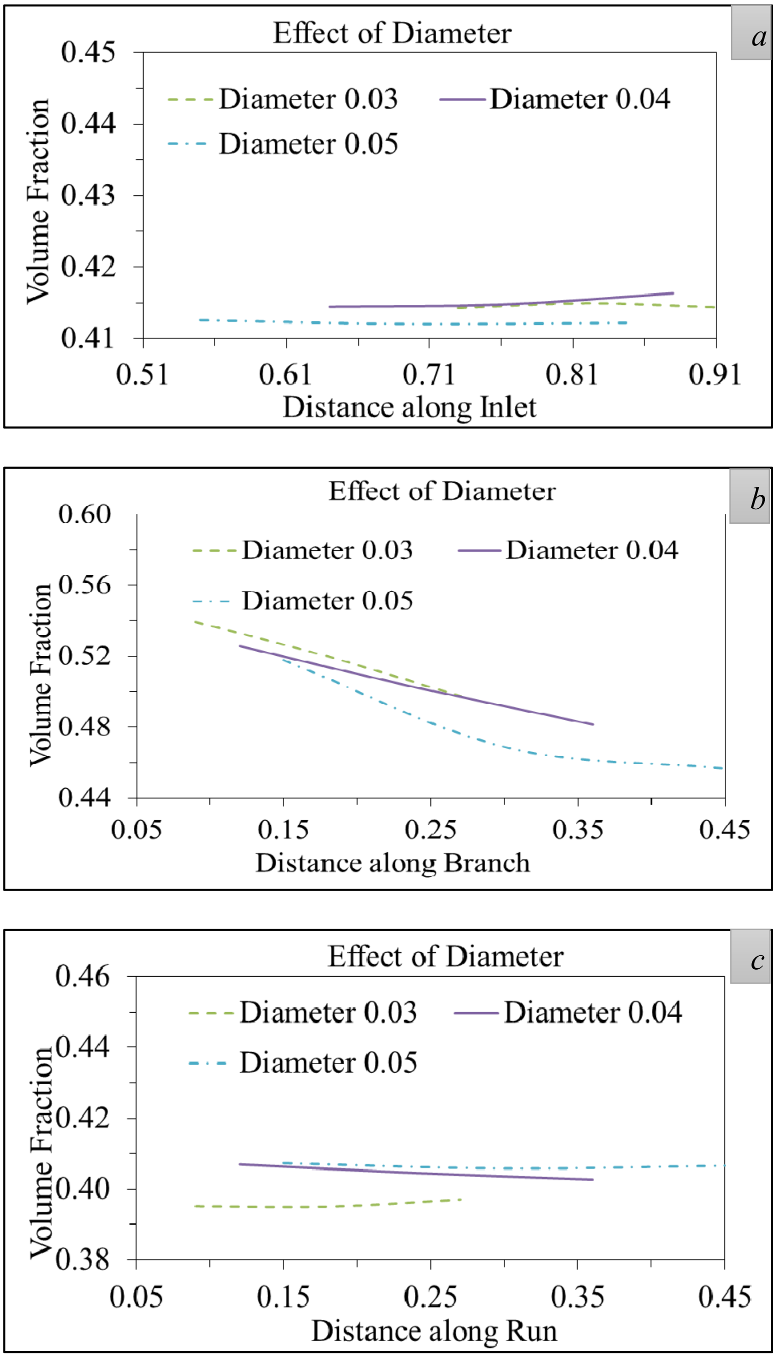


Figure 4.15: Variation of VF along the length of pipe with fluid-pair water-diesel: (a) at Inlet (b) at Branch (c) at Run.

4.3.3.3 Effect of the diameter with fluid pair water-petrol: The effect of diameter on the phase splitting phenomena in inlet section, branch and run are shown in Figure 4.16. Here the same observations have been obtained as in section 4.3.3.1 for both the fluid diesel and petrol.

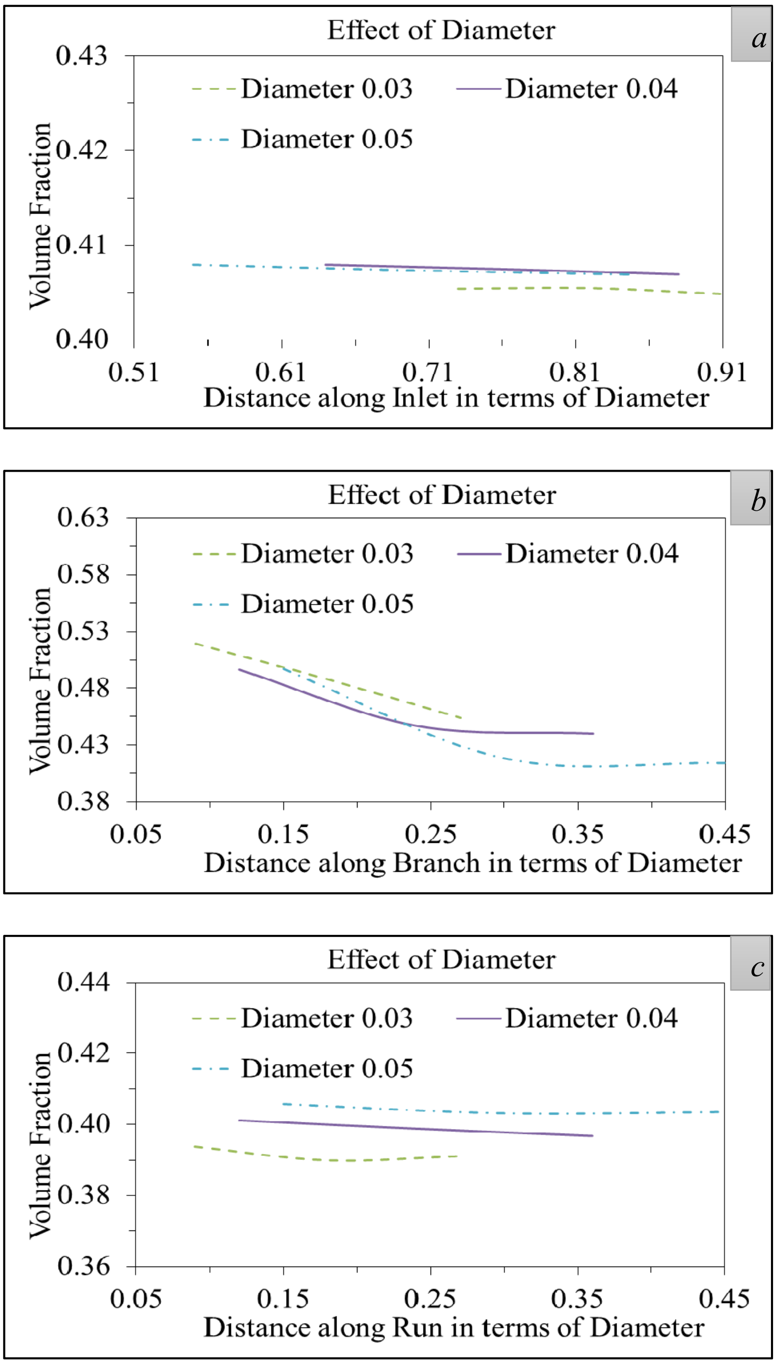


Figure 4.16: Variation of VF along the length of pipe with fluid-pair water-petrol: (a) at Inlet (b) at Branch (c) at Run.

4.3.4 Effect of the angle between the branch and run: The effect of angle between the branch and run for different fluid pair (as described in section 2.1.4) are shown below.

4.3.4.1 Effect of the angle between the branch and run with fluid pair water-kerosene: The effect of angle on the phase splitting phenomena in inlet section, branch and run are shown in Figure 4.17.

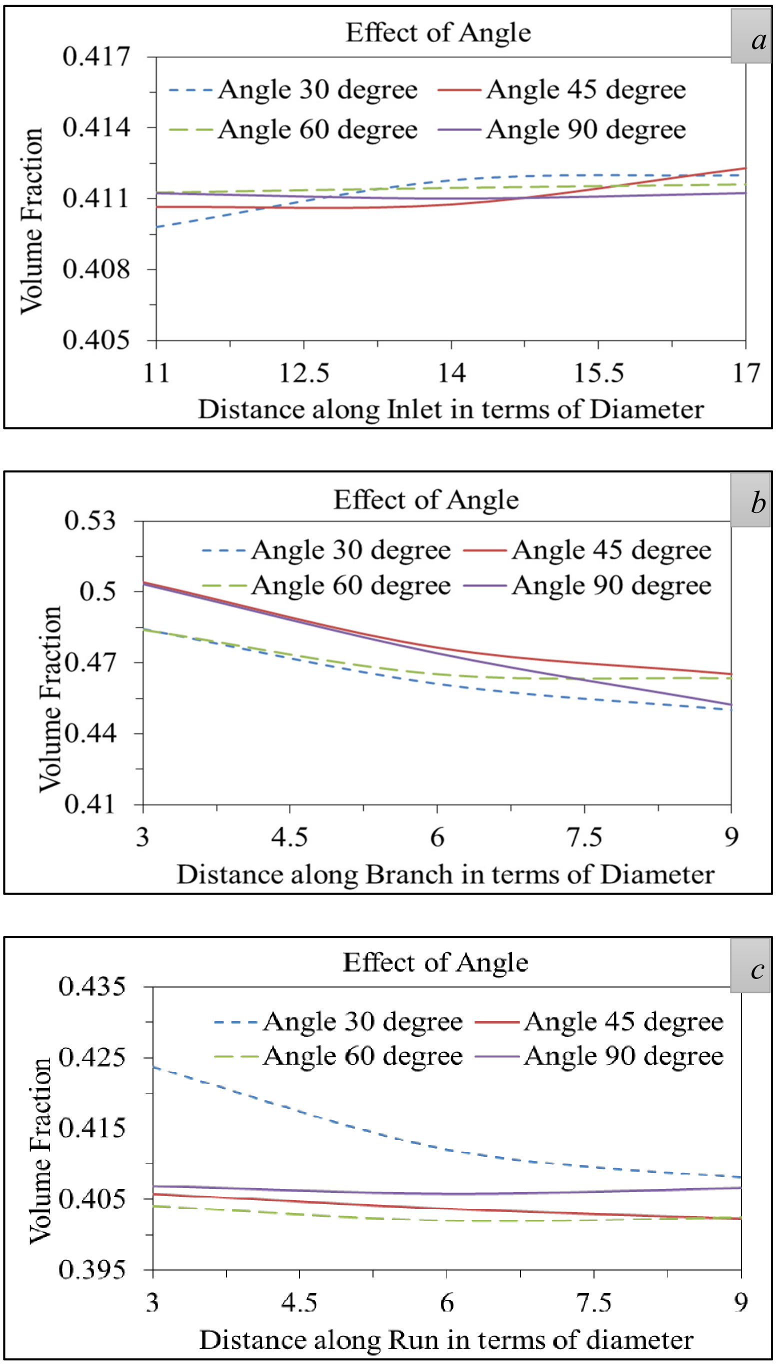
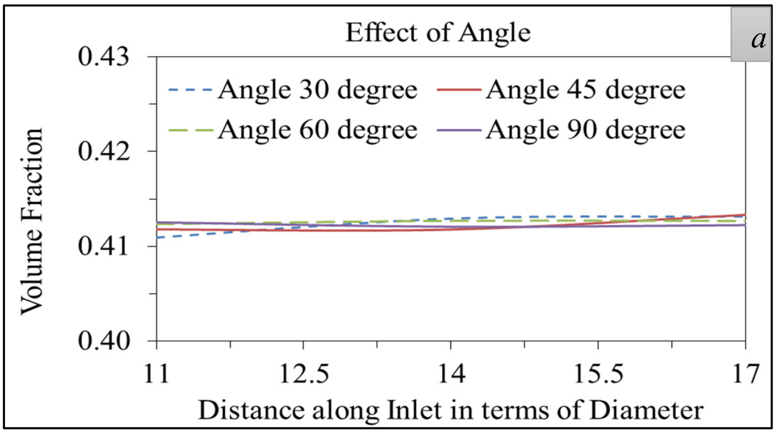
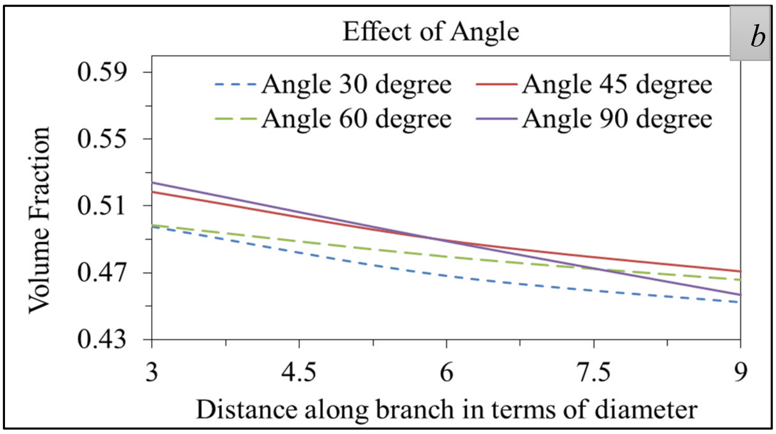


Figure 4.17: Variation of VF along the length of pipe with fluid-pair water-kerosene: (a) at Inlet (b) at Branch & (c) at Run.

The variation of volume fraction along the inlet is very less i.e. the volume fraction changes in a narrow range(see figure 4.17(a)). Figure 4.17(b) shows the variation of volume fraction along the branch. The rate of change of volume fraction along the barnch is same for the angle 30^0 and 60^0 between the branch & run. For the angle 45^0 and 90^0 , the variation is undergoing in a simillar way. The variation of volume fraction along the run is shown in Figure 4.17(c). There is a deviation near the junction for the angle 30^0 (see Figure 4.17(c)).

4.3.4.2 Effect of the angle between the branch and run with fluid pair water-diesel: The effect of angle between branch and run on the phase splitting phenomena in inlet section, branch and run are shown in Figure 4.18.





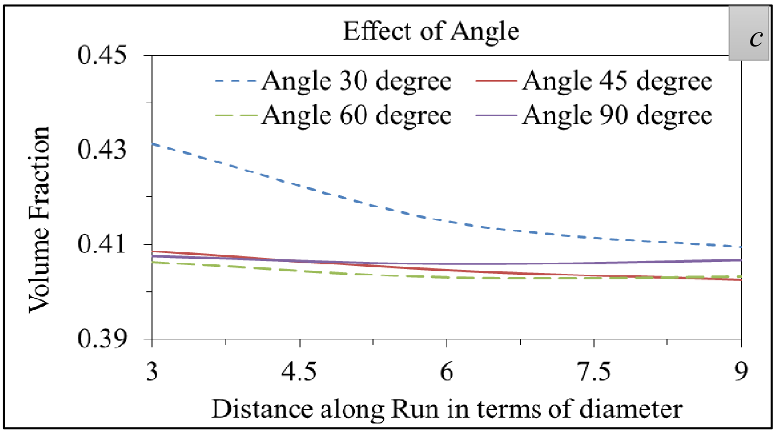
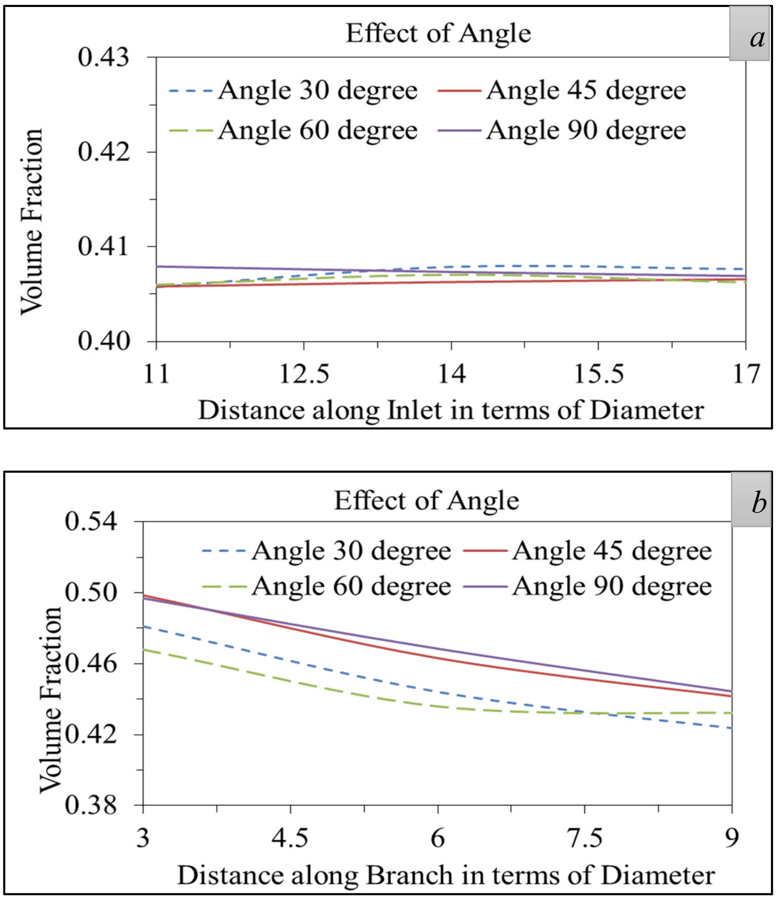


Figure 4.18: Variation of VF along the length of pipe for diameter 0.05 m & fluid-pair water-diesel: (a) at Inlet (b) at Branch & (c) at Run.

4.3.4.3 Effect of the angle between the branch and run with fluid pair water-petrol: The effect of angle between the branch and run on the phase splitting phenomena in inlet section, branch and run are shown in Figure 4.19. Here the same observations have been obtained as in section 4.3.4.1 for both the fluid diesel and petrol.



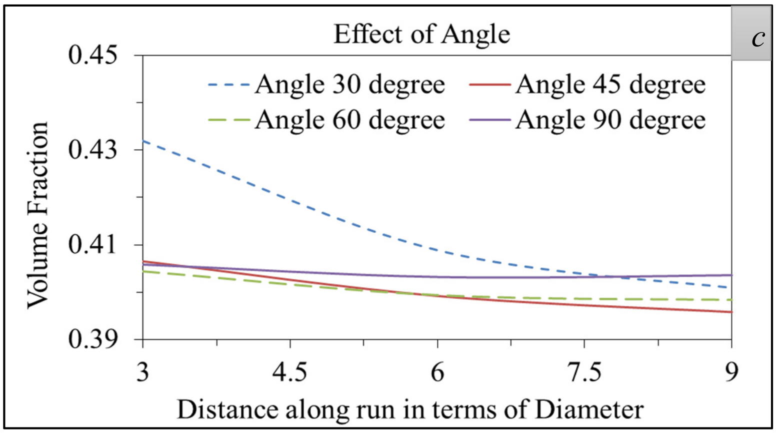


Figure 4.19: Variation of VF along the length of pipe for diameter 0.05 m & fluid-pair water-petrol: (a) at Inlet (b) at Branch & (c) at Run.

4.4 VERTICAL T-JUNCTION

At first the phase contour at the vertical midplane is shown in the Figure 4.20 for the diameter of 0.05 m, branch position as 1 m from the run exit, angle of branch with run as 90^0 & the fluid pair as water-kerosene.

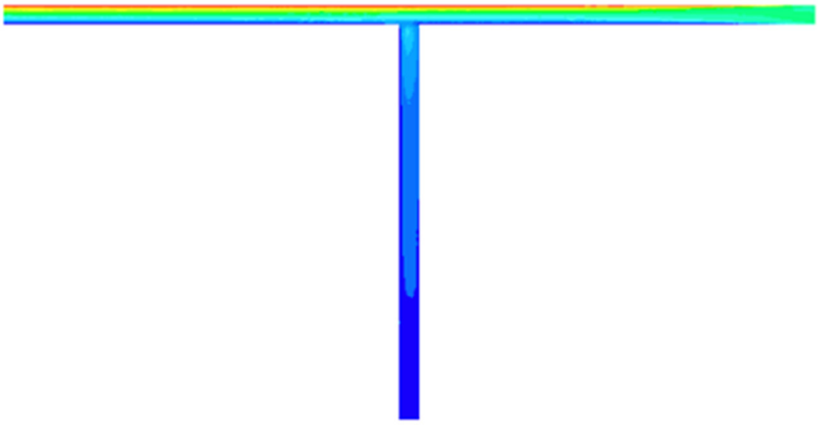


Figure 4.20: Phase contour at the vertical midplane of the T-junction with fluid pair water-kerosene, diameter of the pipe is 0.05 m, velocity 0.8 m/s & volume fraction 0.4.

4.4.1 Effect of Fluid Pair: The effect of fluid pair for different fluid pair (as described in section 2.2.1) are shown below.

4.4.1.1 Effect of Fluid pair with diameter 0.05 m: The effect of fluid pair on the phase splitting phenomena in inlet section, branch and run are shown in Figure 4.21.

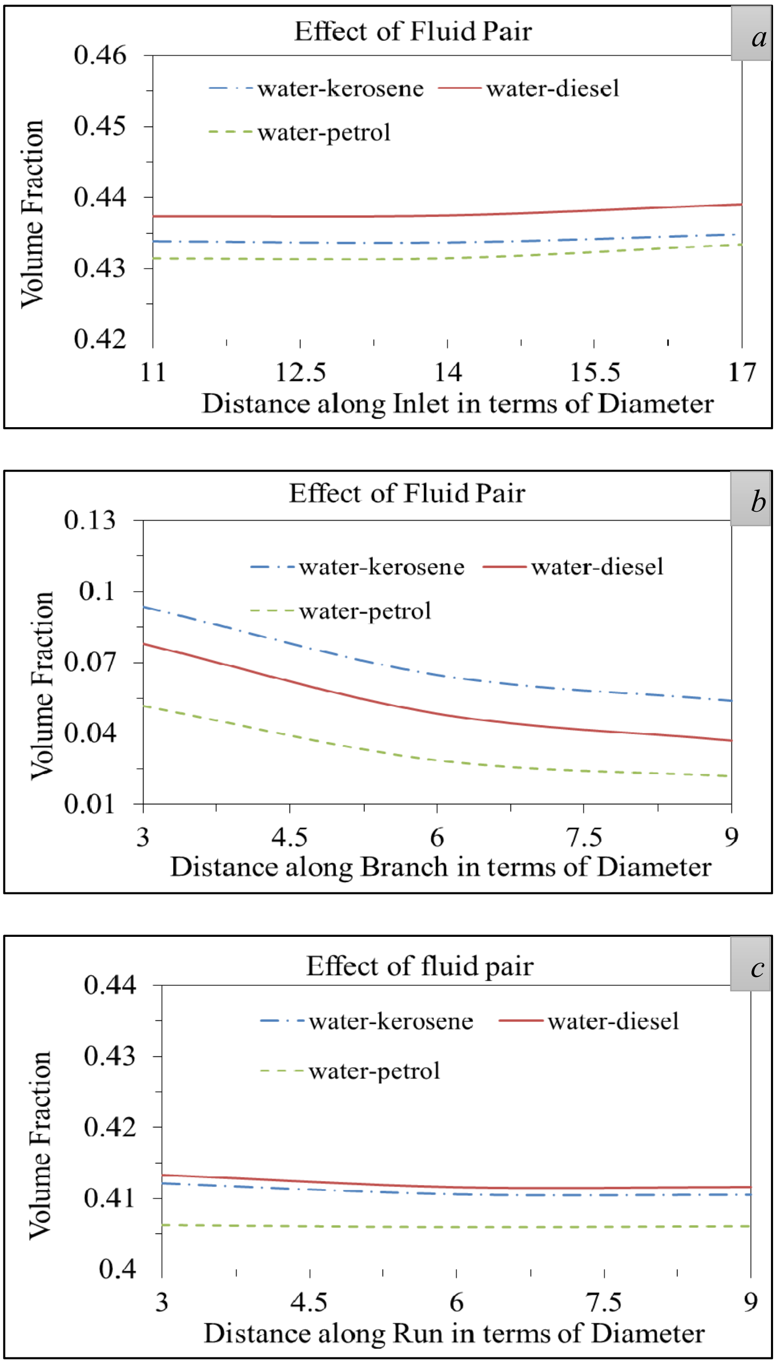
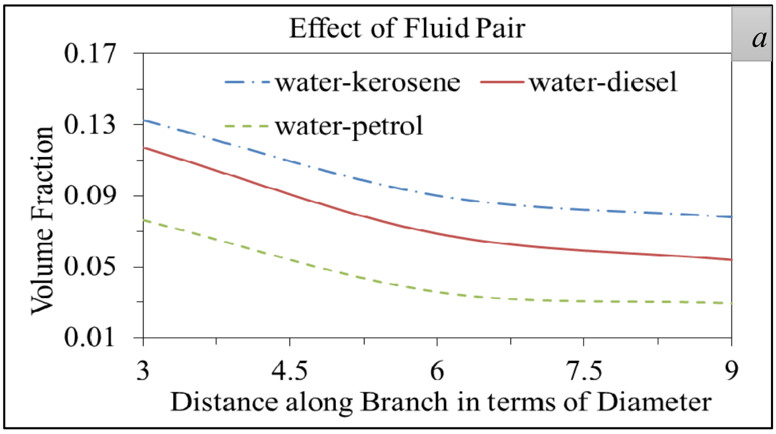
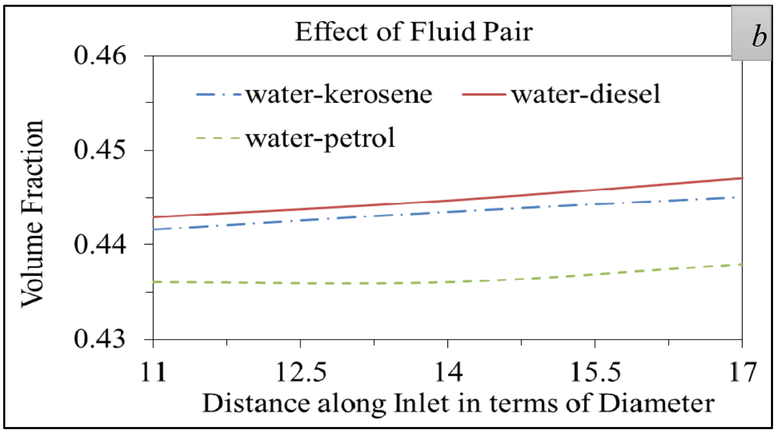


Figure 4.21: Variation of VF along the length of pipe with diameter 0.05 m & branch position 1 m from the run (a) at Inlet (b) at Branch & (c) at Run.

The volume fraction along the inlet increases compared to horizontal T-junction(see figure 4.21(a). Due to the inertia of the water, the flow rate at which water is escaping through the branch is higher than that of the oil. As a result volume fraction increases along the inlet. The volume fraction of oil decreases more along the branch because the gravity force is more prominent here compared to horizontal T-junction(see Figure 4.21(b)). As a reslult less oil is flowing through the branch as it is lighter than water. So the volume fraction of oil is less in the branch. There is no variation of volume fraction along the run (see Figure 4.21(c)).

4.4.1.2 Effect of Fluid pair with diameter 0.04 m: The effect of fluid pair on the phase splitting phenomena in inlet section, branch and run are shown in Figure 4.22.





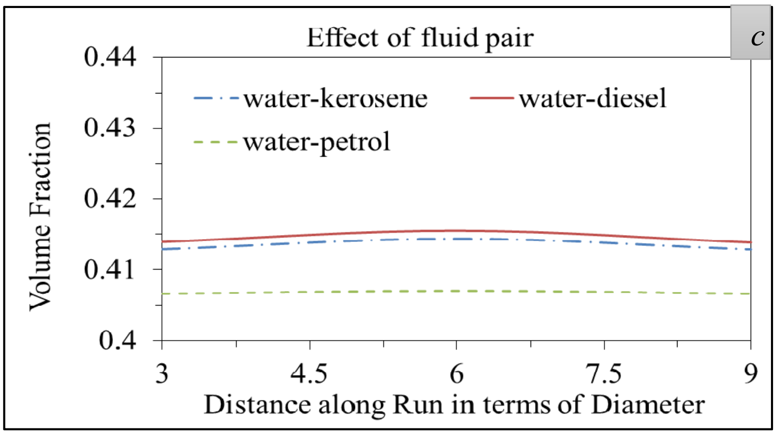
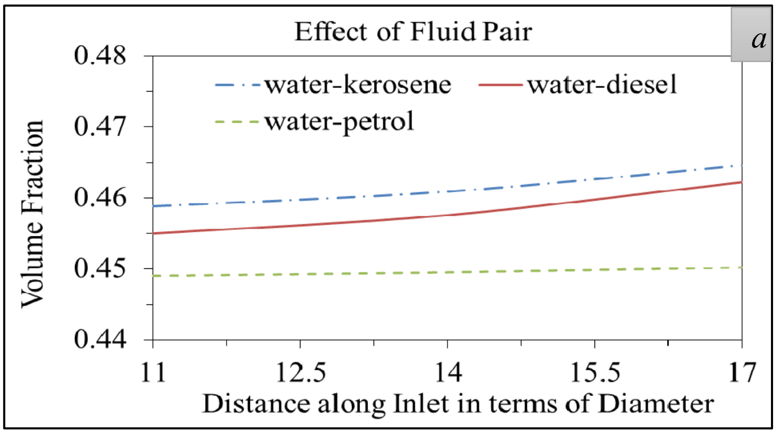
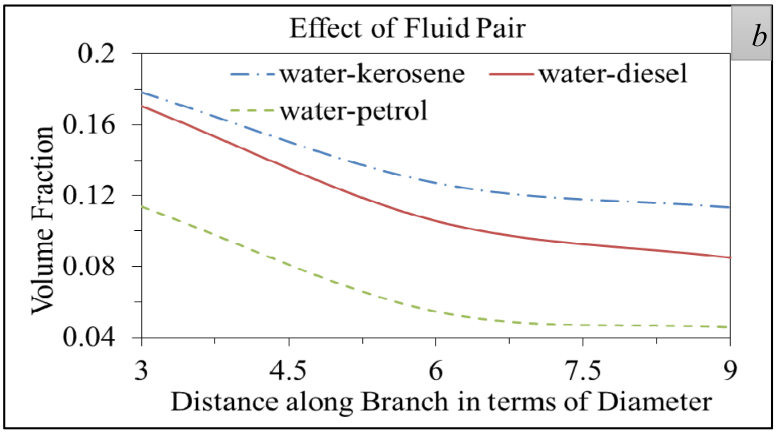


Figure 4.22: Variation of VF along the length of pipe with diameter 0.04 m & branch position 1 m from the run: (a) at Inlet (b) at Branch & (c) at Run.

4.4.1.3 Effect of Fluid pair with diameter 0.03 m: The effect of fluid pair on the phase splitting phenomena in inlet section, branch and run are shown in Figure 4.23. Here the same observations have been obtained as in section 4.4.1.1 for both the fluid diesel and petrol.





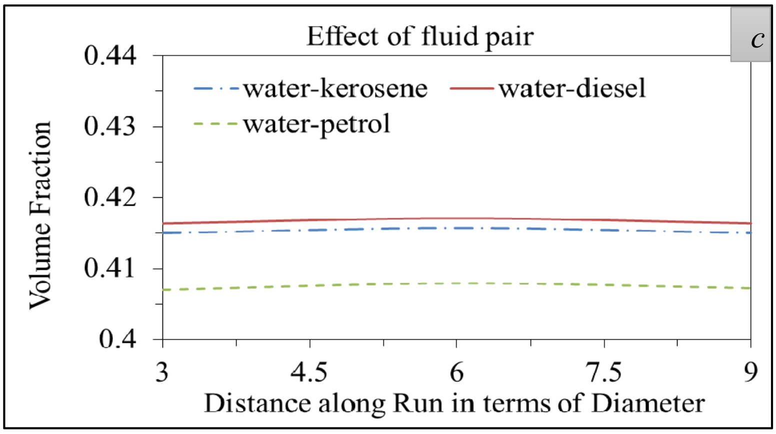
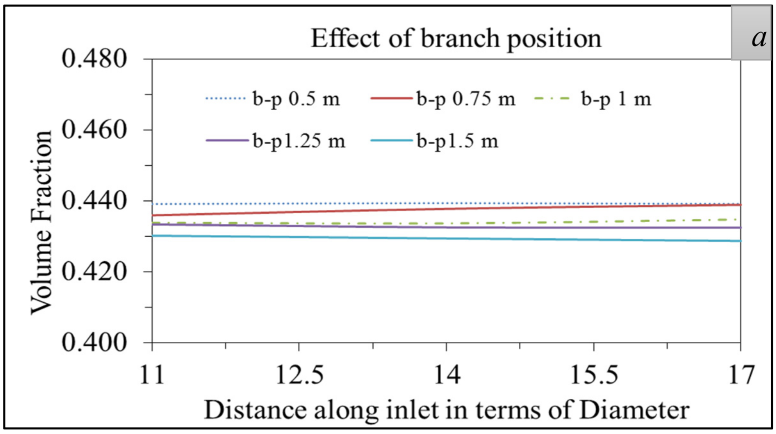
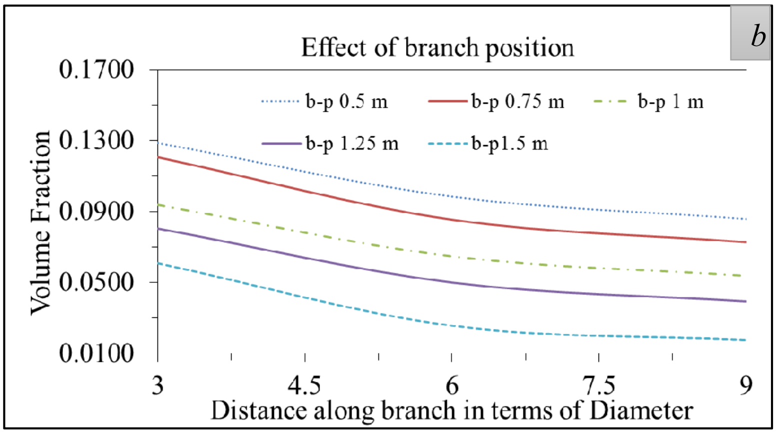


Figure 4.23: Variation of VF along the length of pipe with diameter 0.03 m & branch position 1 m from the run (a) at Inlet (b) at Branch & (c) at Run.

4.4.2 Effect of position of the branch: The effect of branch position for different fluid pair (as described in section 2.2.2) are shown below.

4.4.2.1 Effect of the branch position with fluid pair water-kerosene: The effect of branch position on the phase splitting phenomena in inlet section, branch and run are shown in Figure 4.24.





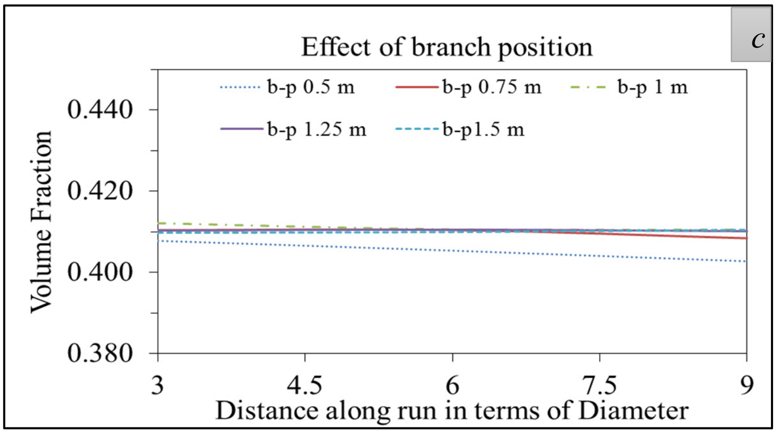
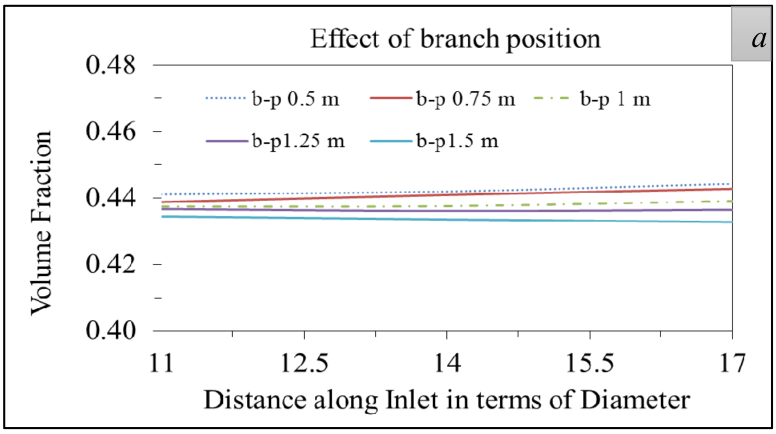
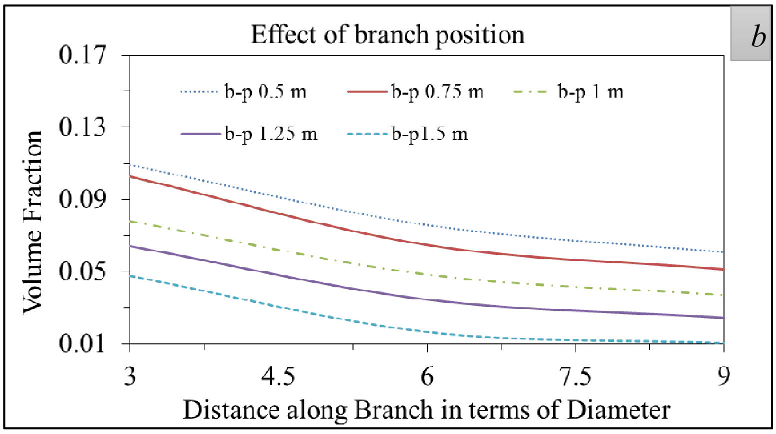


Figure 4.24: Variation of VF along the length of pipe with diameter 0.05 m and fluid pair water-kerosene (a) at Inlet (b) at Branch (c) at Run.

Figure 4.24(a) shows the variation of volume fraction along the inlet and it increases along the inlet. From Figure 4.24(b), it is clearly seen that the volume fraction decreases smoothly along the branch. At a particular location of the branch, the volume fraction increases as the position of the branch moves towards the inlet. There is no variation of volume fraction of oil along the run (see Figure 4.24(c)).

4.4.2.2 Effect of the branch position with fluid pair water-diesel: The effect of branch position on the phase splitting phenomena in inlet section, branch and run are shown in Figure 4.25.





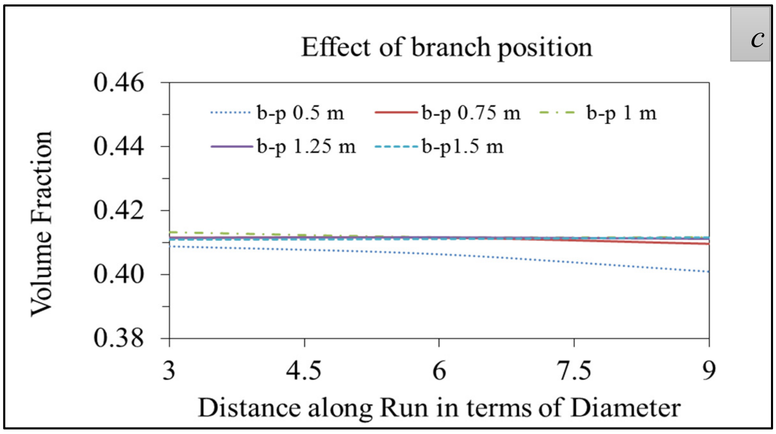
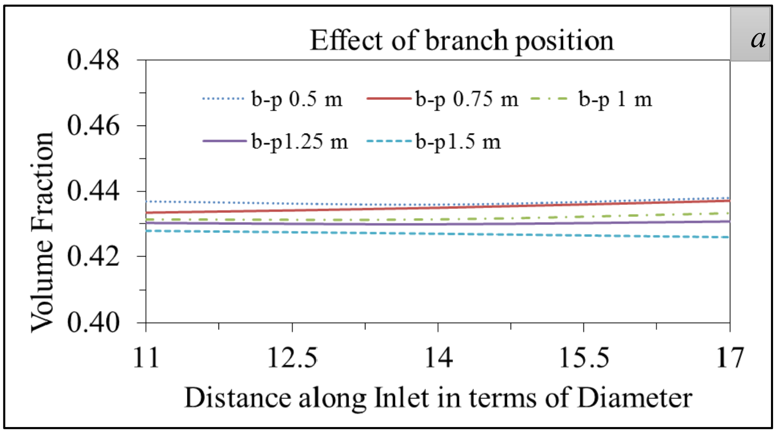
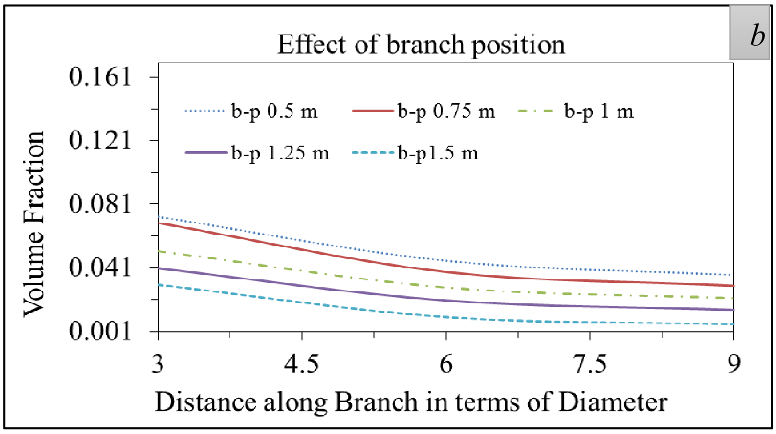


Figure 4.25: Variation of VF along the length of pipe with diameter 0.05 m and fluid pair water-diesel: (a) at Inlet (b) at Branch (c) at Run.

4.4.2.3 Effect of the branch position with fluid pair water-petrol: The effect of branch position on the phase splitting phenomena in inlet section, branch and run are shown in Figure 4.26. Here the same observations have been obtained as in section 4.4.2.1 for both the fluid diesel and petrol.





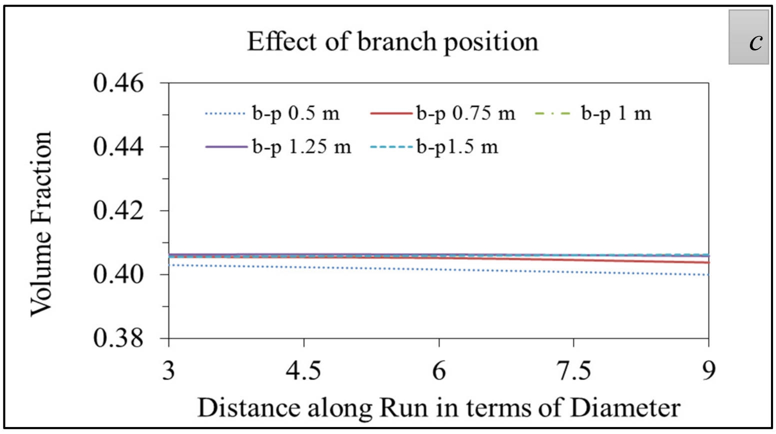


Figure 4.26: Variation of VF along the length of pipe with diameter 0.05 m and fluid pair water-petrol (a) at Inlet (b) at Branch (c) at Run.

4.4.3 Effect of the diameter: The effect of diameter for the different fluid pair (as described in section 2.2.3) are shown below.

4.4.3.1 Effect of the diameter with fluid pair water-kerosene: The effect of fluid pair on the phase splitting phenomena in inlet section, branch and run are shown in Figure 4.27.

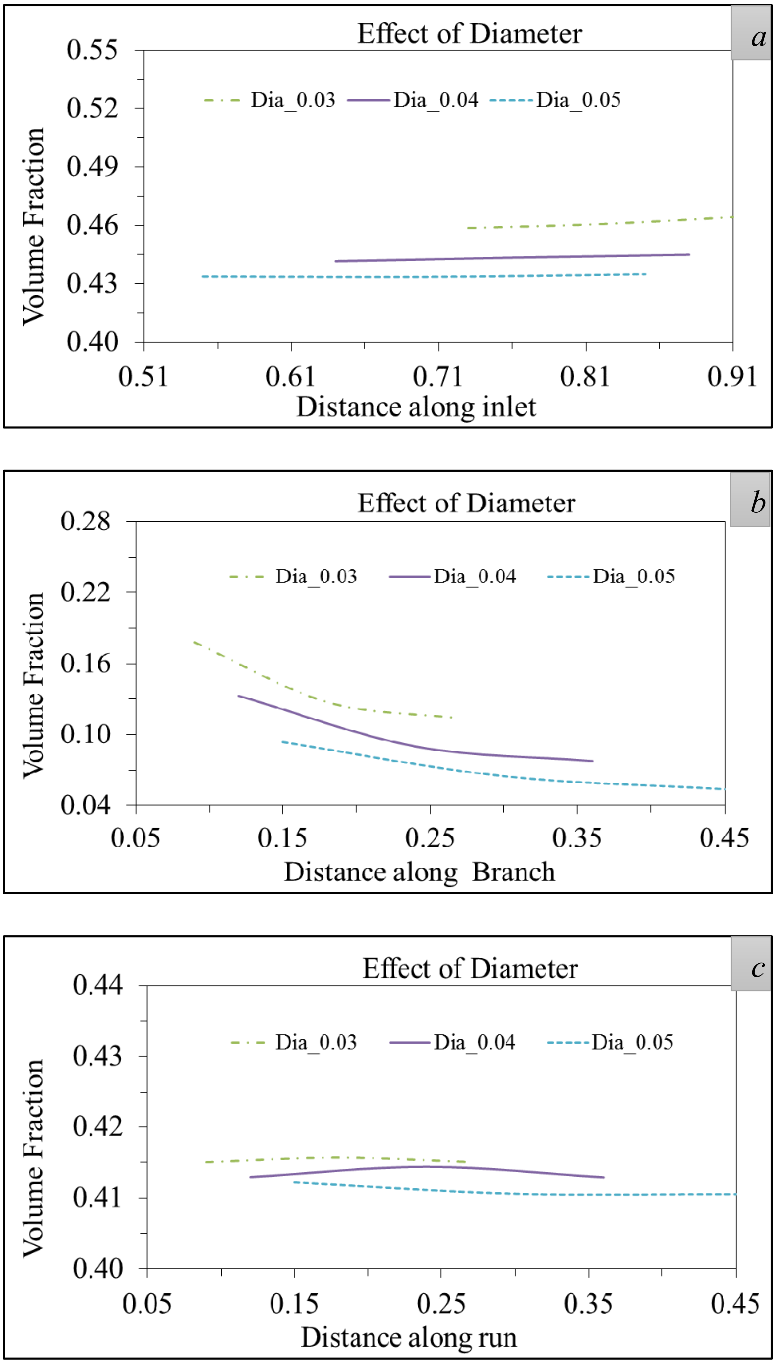


Figure 4.27: Variation of VF along the length of pipe with fluid pair water-kerosene: (a) at Inlet (b) at Branch (c) at Run

Figure 4.27(a) shows the variation of volume fraction along the inlet. The volume fraction increases along the inlet due to the density difference between the two liquids. From the Figure 4.27(b), it reveals that the rate of change of volume fraction is more along the branch. There is no variation of volume fraction along the run (see Figure 4.27(c)).

4.4.3.2 Effect of the diameter with the fluid pair water-diesel: The effect of diameter on the phase splitting phenomena in inlet section, branch and run are shown in Figure 4.28.

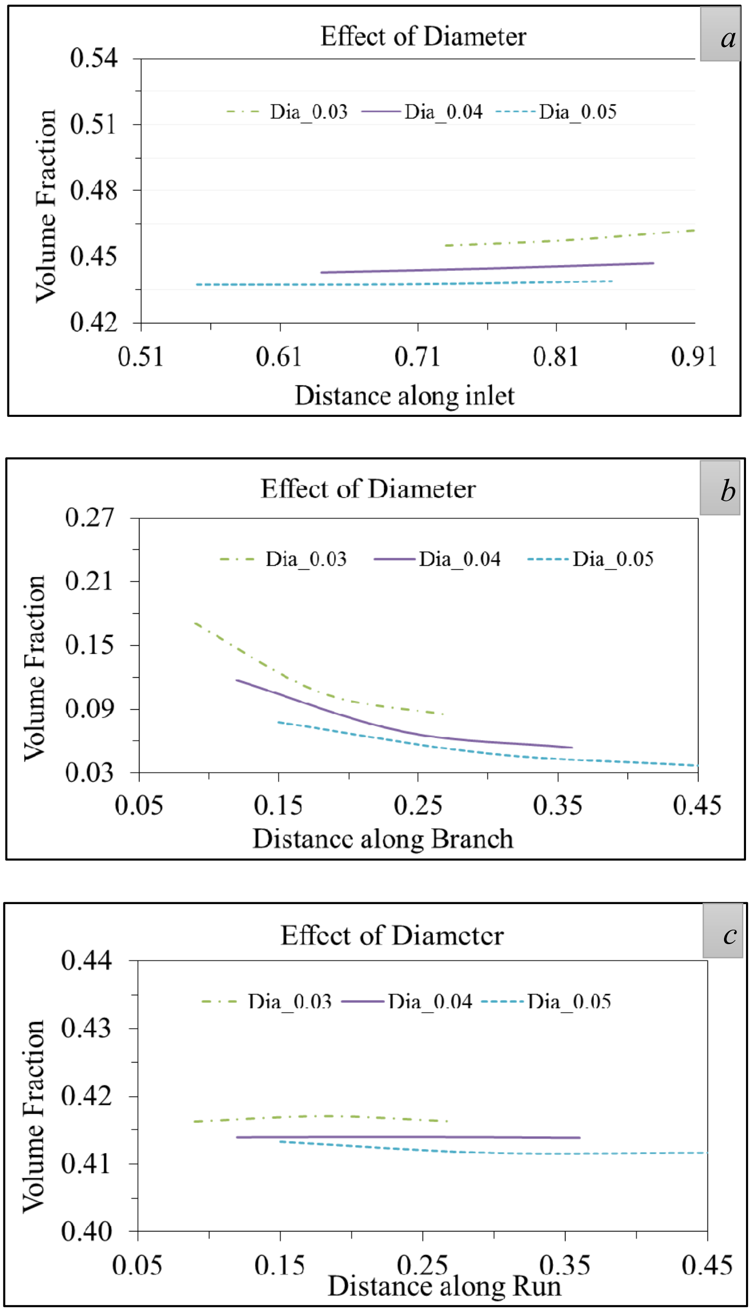


Figure 4.28: Variation of VF along length of pipe with fluid pair water-diesel (a) at the inlet (b) at the branch (c) at the run.

4.4.3.3 Effect of the diameter with fluid pair water-petrol: The effect of fluid pair on the phase splitting phenomena in inlet section, branch and run are shown in

Figure 4.29. Here the same observations have been obtained as in section 4.4.3.1 for both the fluid diesel and petrol.

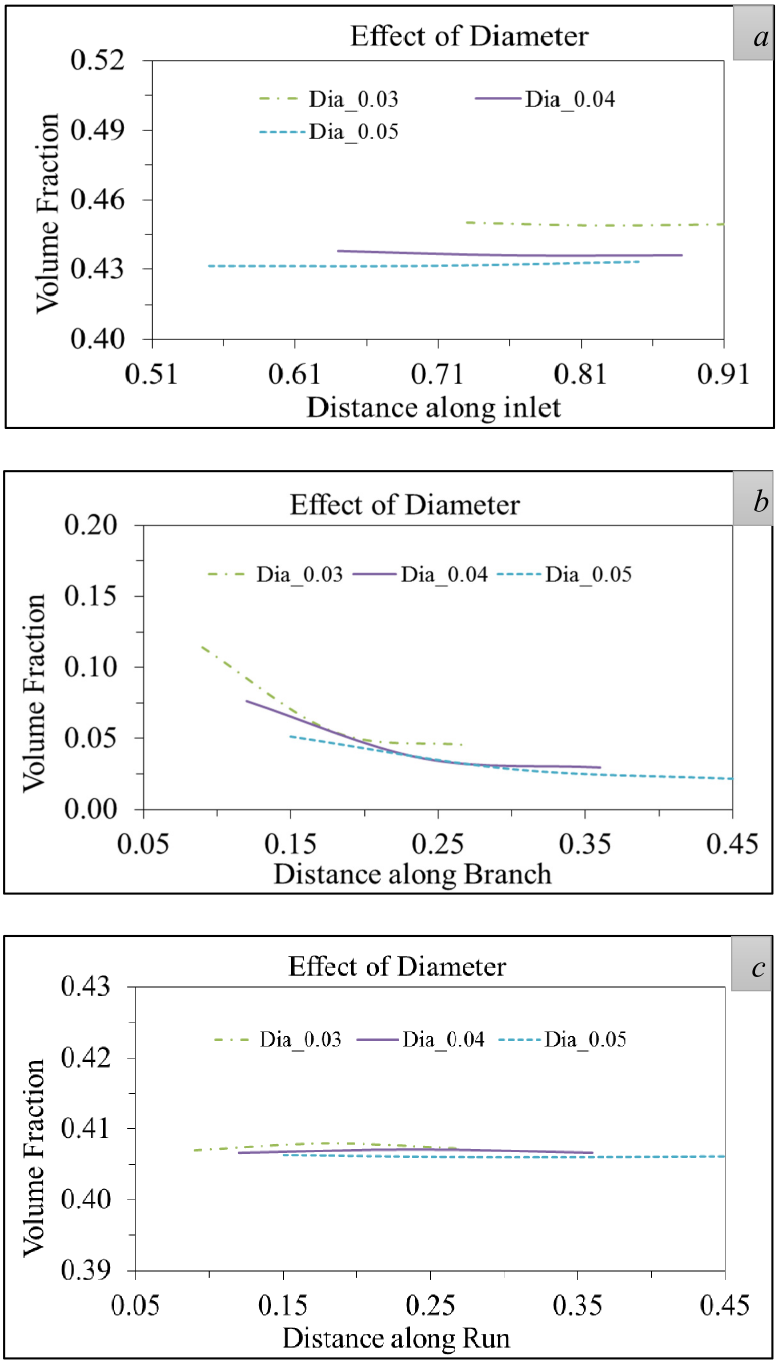


Figure 4.29: Variation of VF along the length of pipe with fluid pair water-petrol (a) at Inlet (b) at Branch (c) at Run.

CHAPTER 5:

CONCLUSION & FUTURE SCOPE

5.1 CONCLUSION

A numerical investigation has been made to study the phase separation of liquid-liquid two-phase mixture flowing through T-Junction. Both for horizontal and vertical arrangement of the T-Junction, the present investigation has been made. FVM with 3D VOF model have been used to simulate the problem. The phenomena are studied by varying the fluid-pair, branch position, diameter of the pipe and the angle between the branch and run.

In the obtained results, a difference has been observed between the phase variation along run and branch. The difference is more prominent in vertical T-Junction compare to that in the horizontal T-Junction. The volume fraction of the oil is always decreasing along the branch and run, and it is irrespective of the vertical and horizontal arrangement. But volume fraction almost remain constant along the inlet section in the horizontal T-Junction and increases along the inlet section in the vertical T-Junction.

Some important findings have been extracted from the obtained results of the present study are shown below.

- ✓ The variation of VF along the inlet and run almost remain unchanged for horizontal T-Junction. At the branch, the variation is more due to the centrifugal force.
- ✓ The VF is always decreasing along the branch whether the junction is horizontal or vertical.
- ✓ The flow rate at which water is escaping through the branch is higher compared to oil in the vertical T-junction. The VF slightly increases along the inlet due to the acceleration of water.

- ✓ In the branch, at a particular position from the junction, the VF increases with the branch position away from the run-exit for vertical T-junction.
- ✓ In the horizontal T-Junction, branch angle has not much effect on the phase separation.
- ✓ The rate at which the VF decreases along the branch is higher for the higher diameter.
- ✓ When the density difference between the fluids is high, the vertical T-Junction is more effective to get the phase separation effect.

5.2 FUTURE SCOPE

The experimental work will be done for the present study. Besides that the effect angle will be simulated for the vertical T-Junction.

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