Gas-Liquid Separation in T-Junction

by

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15024

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
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(MECHANICAL)

Approved by,

____

(Dr. William Pao King Soon)

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHAMAD IZAT FIKRI BIN AMER

ABSTRACT

T-junctions are widely used in piping network for distributing multiphase flows, especially in oil and gas industries. Mal-distribution of the phases flowing through a T-junction poses a challenge in maintaining homogenous splitting across a T-junction at the same time, a potential as a simple, compact partial phase separator. However, the behavior of two-phase flow complicates the process of understanding the phenomena as there are many inter-related parameters that influences the mal-distribution. In order to seriously consider T-junction as a partial phase separator, its geometry and operating condition that for efficient separation must be identified. This project aims to identify the geometric and operating conditions effects on the separation efficiency of a T-junction in terms of gas fraction in branch arm. The concerned parameters under this study are the operating pressure, oil flow rate, GOR, and arms' length of the T-junction. OLGA Multiphase Simulator is used to model the T-junction for the parametric study. The findings conclude that operating pressure as the most influential parameter in ensuring efficient separation. At the end of this project, sufficient amount of data is collected and the phenomenon of phase mal-distribution when a two-phase mixture passes through a T-junctions is well understood. Hence, redefined the potential of T-junction as a simple, cost saving, passive partial separator for separation process in the petroleum industry.

ACKNOWLEDGEMENT

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CHAPTER 1: INTRODUCTION

1.1. Project Background

Gas-Liquid flow is a form of multiphase flow where both the immiscible phases flow simultaneously in a pipeline or equipment. Multiphase flows can be termed as any flow which has at least two unmixable phases; solid, liquid, and gas flow simultaneously in a pipe. Wren (2001) and Baker (2003) explained that the interface between the two phases affect the behavior of the combined flow, where some of the formations are easily classified some are harder to identify. The characteristic of its flexile interface and the compressibility of one of the phases make gas-liquid flow very complex in nature. Since gas-liquid flow's complexity affects many industrial process applications; chemical, power generation, and production industries many research had been instigated focusing around it.

A T-junction made up of main arm, run arm, and branch arm is very common in any pipelines system. When a two-phase mixture flows through a T-junction, an uneven phase distribution tends to occur between the outlet arms. The phase mal-distribution occurs in such a way that one stream will be richer in gas than the initial feed and the other richer in liquid. The lighter phase will tend to be diverted into an upward branch arm, creating a gas rich flow along the branch arm.

Since many industrial process applications involve multiphase flow, thus emerged the need to separate the phases to ease the transportation and for suitability to the downstream equipment. Separation of phases normally achieved using bulky separator vessel which mainly utilizing the effect of gravity for the separation process. Separator vessels are proven for its reliability and effectiveness, but in terms of its bulkiness, capital, operation cost, and space efficiency they are at disadvantage. The utilization of T-junction as partial phase separator can minimize the reliance for the large separator.

1.2. Problem Statement

Phase mal-distribution phenomenon in T-junctions can be utilized as continuous, compact and economical partial phase separator. In spite of its simple geometry, T-junction can have very complex flow dependent on many parameters that dictate the phase separation efficiency. To seriously consider T-junction as a partial phase separator, its geometry and operating condition that for efficient separation must be identified.

1.3. Objectives

This project aims to:-

- Identify geometric effect on two phase separation efficiency across T-junction in terms of gas fraction in branch arm.
    - Effect of arm length ratio
- Identify the correlation of operating and inlet conditions with two phase separation efficiency in terms of gas fraction in branch arm.
    - Effect of oil flow rate
    - Effect of Gas-Oil ratio (GOR)
    - Effect of pressure

1.4. Scope of Study

This project focuses on analyzing the geometry and operating conditions that maximize the phase separation across a T-junction. This study will analyze the parameters of arm length ratio, oil flow rate, gas-oil ratio (GOR), operating pressure and temperature.

Analysis of these parameters will be made on the scope of circular cross sectional T-junction with 1 inch branch arm diameter. The upward oriented T-junction model will be used throughout the study. The operational condition of the flow will only be limited within certain envelope which will be discussed in Chapter 3.

CHAPTER 2: LITERATURE REVIEW

2. Representing the Phase Separation Data

In order to study the phase separation efficiency, a method to represent the separation data is needed to compare its efficiency. For simplicity, the representation of phase separation will be done using the method as used by (Azzopardi & Rea, 2000; Baker, 2003; Wren, 2001). Based on Figure 2-1, the fraction of liquid diverted into branch arm is denoted as, *L'* and fraction of gas diverted as, *G'*. The phase separation data will be plotted as *L'* versus *G'*, and a diagonal line *y=x* from (0, 0) to (1, 1) indicates same fraction of both phase in branch arm (no separation). Data lying on the above of diagonal line will indicate liquid only extraction, and below the line will indicate gas only extraction. The separation efficiency, S can be expressed as:

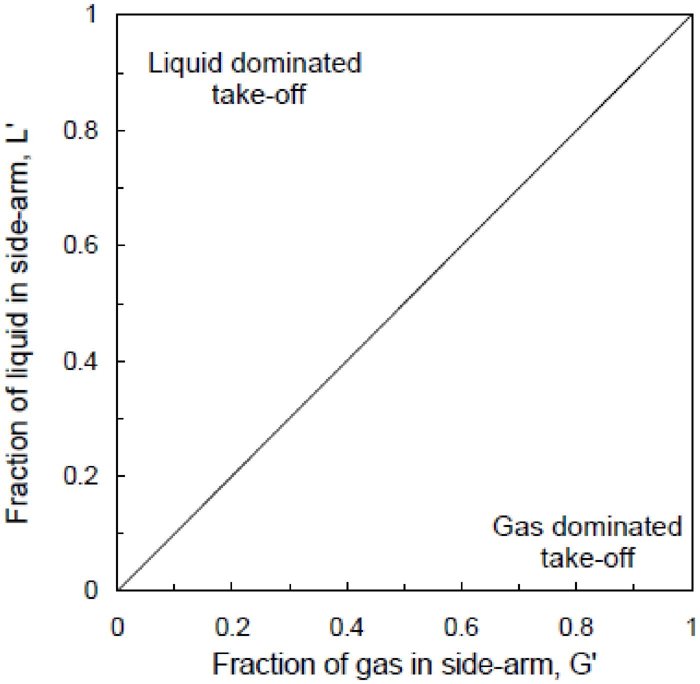


Figure 2-1: Graphical representation of phase split (Baker, 2003)

$$S = \sqrt{\left(1 - G'^2\right) + L'^2}$$

Equation 2—1

The minimum value of parameter, *S* indicates the best separation that in T-junction.

2.1. Dominant Forces on Phase Separation T-Junction

In a T-junction, (Baker, 2003; Wren, 2001) agreed that there are dominant forces that affect the separation in a T-junction namely gravity, inertia, and pressure.

2.1.1. Gravity force on phase separation in T-junction

Gravity exerts a strong force on the liquid phase. Depending on the density difference of the phases the liquid will tend to enter the downward oriented branch arm. On the other side, gravity will minimize the liquid diverted into an upward oriented branch arm. This can be supported by the experiment conducted by (Penmatcha, Ashton, & Shoham, 1996) on effects of rotating the branch arm around the pipe to the separation efficiency. They reported almost 100% of the liquid was diverted into a -60°downwards branch arm.

2.1.2. Inertia force on phase separation in T-junction

Due to the difference in gas' and liquid's density, higher axial momentum flux of the liquid phase will increases its tendency to flow straight along the pipe ignoring the branch arm. The smaller diameter of the branch arm will dramatize this effect as the liquid flows will pass the junction faster. This reduces the time for the liquid phase to be able to enter the side arm (Baker, 2003). Hence, lessens its chance to enter the branch arm.

2.1.3. Pressure force on phase separation in T-junction

Figure 2.1-1 shows the pressure distribution across a T-junction where observable loss occurred between the inlet and branch arm, is recovered on the run arm. ΔP_{12} indicates the pressure difference in main and run arm, while ΔP_{13} represents pressure drop along main to run arm. Decrease in flow velocity in the run arm creates this Bernoulli Effect where the static pressure is increased in the run arm.

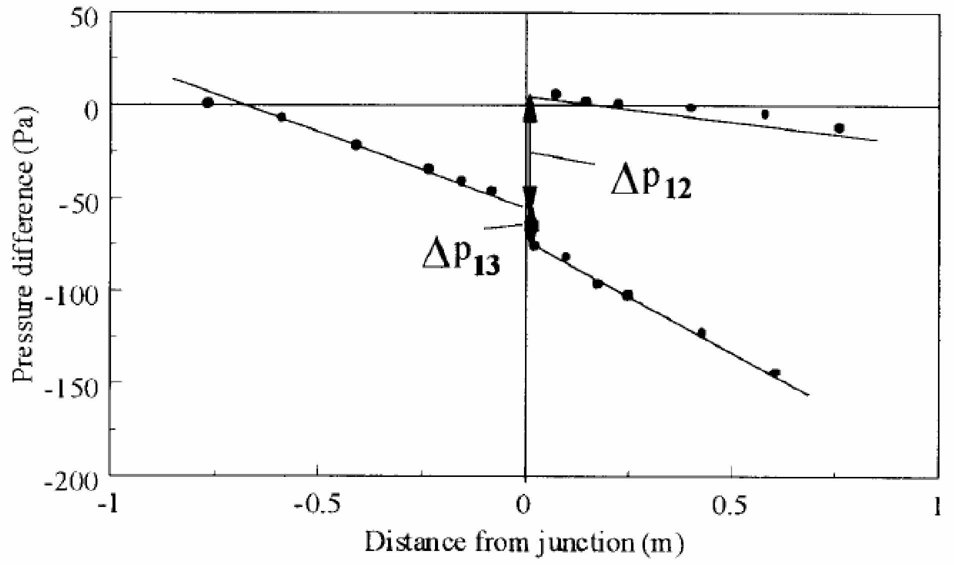


Figure 2.1-1: Pressure distribution across the T-junction, (Baker, 2003)

2.2. Reduced branch arm diameter effect on T-junction

The major effects of reduced branch arm T-junction will be; the greater **pressure difference** between the main and branch arm, and lesser **axial distance available** on the branch arm. These two effects, as were agreed by (Baker, 2003; Wren, 2001) will significantly affect on phase separation along the T-junction.

2.2.1. Pressure Difference on reduced T-junction

The increase in pressure drop in a reduced T-junction is in accordance with the Bernoulli's equation. Referring to Figure 2.2-1, pressure drop between main and run arm, ΔP_{12} is comparatively small and not influenced by the branch arm diameter. On the other hand, main to branch arm pressure drop, ΔP_{13} experience a significant increment as the branch arm diameter is reduced. Theoretically, if the reduced diameter ratio of main to branch arm is 2:1, the gas velocity in the reduced branch arm increased by four times for the same fraction of gas entered the branch arm. This high pressure drop can be inferred by the higher gas phase velocities in the reduced branch arm compared to regular branch arm (for the same amount of inlet gas inside branch arm). According to (Hart, Hamersma, & Fortuin, 1991) the liquid phase in T-junction will have a *route preference* in which, the pressure difference in run to branch arm, ΔP_{23}, is one of the driving force for this preference. This route preference is dependent on the equilibrium of the ΔP_{23} and axial momentum of the liquid.

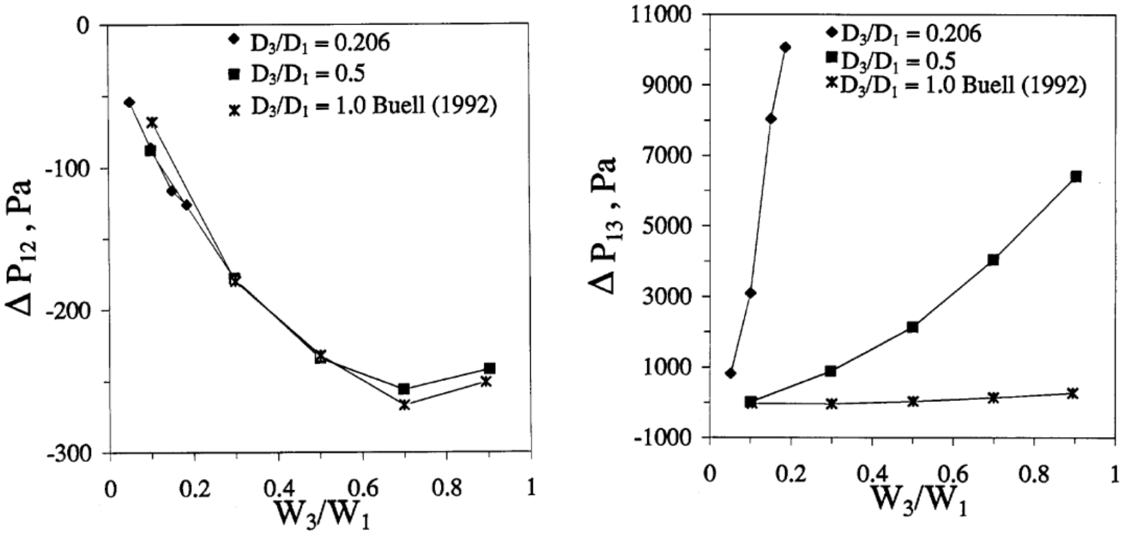


Figure 2.2-1: Pressure difference between main and run arm, ΔP_{12} (left) and pressure difference between main and branch arm, ΔP_{13} (right). (Walters et al., 1998)

2.2.2. Axial distance available for take off

As the branch arm diameter reduced, the axial distance available for liquid's takeoff is decreased hence, reduces the fraction of liquid into branch arm. (Wren, 2001) agrees on the systematic study on the diameter ratio effect on the phase separation that was pioneered by (Azzopardi & Whalley, 1982) where they found that there is an obvious but not always clean cut trend of diameter ratio. They inferred that the **greater diameter ratio gives lesser axial distance available** for diversion into branch arm especially for a stratified flow in an upward oriented branch arm. This makes the liquid to have lesser liquid travel time, the time available for the liquid to be diverted into branch arm hence, lesser chance for it to occur. As liquid dragged to the branch arm by the gas leaving for the branch arm, it hits the pipe wall instead and proceed to the run arm, as inferred by (Baker, 2003).

(Walters et al., 1998) conducted an experiment varying the diameter of branch arm to study its effect on the phase separation where they used three D_3/D_1 ratios: 1.0, 0.5, and 0.206 (as plotted in Figure 2.2-2). It was conducted using air-water flow (stratified, wavy, and annular) at 1.5bar in a 38.1mm internal diameter inlet horizontal junction. They found a very significant increment in separation efficiency in 0.5 diameter ratios T-junction compared to that of 1.0 diameter ratio (for stratified flow). They inferred the phenomenon as the liquid flowing along the bottom of the pipe must climb the wall before entering the branch. Since the branch's diameter reduced and axial distance available for takeoff decrease, the liquid will has lesser chance to enter the branch arm. However, as they further reduce the ratio to 0.206, the trend for the phase separation is not as consistent. At low extraction rates, the trend follows as that of 0.5 diameter ratio. However, further increase in extraction rates causes the trend to emulate the trend for 1.0 diameter ratio. This phenomenon was inferred as the effect of liquid entrainment.

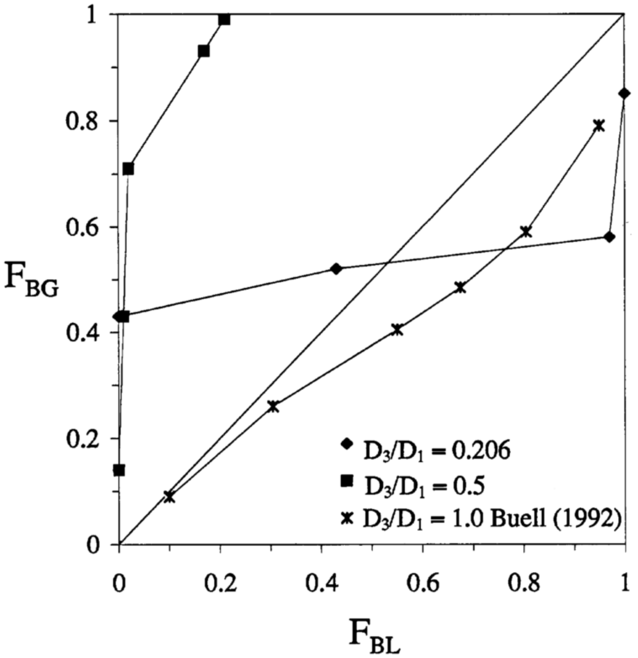


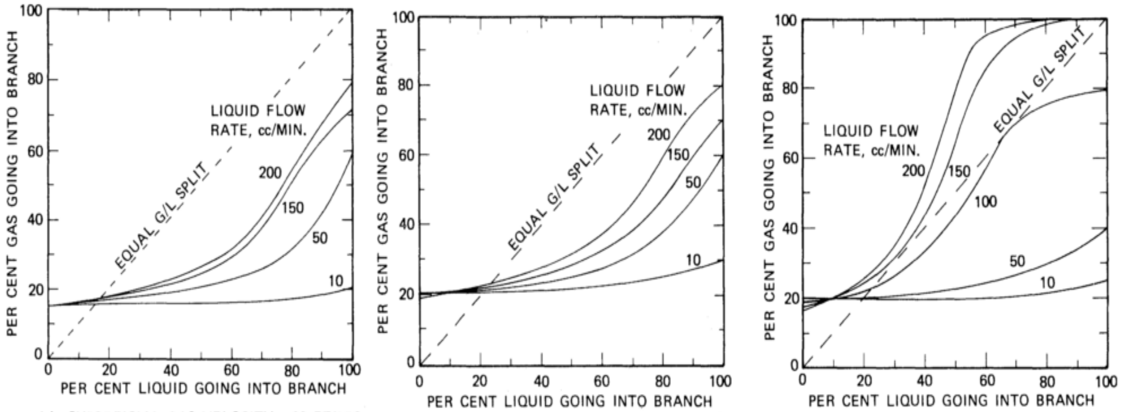
Figure 2.2-2: Fraction of gas/liquid into branch arm with different diameter ratio, (Walters, Soliman, & Sims, 1998)

The concluding effect of reduced diameter T-junction will be the combination of the two factors above and coupled with the pattern of the multiphase flow. Decreasing the diameter ratio will promote the phase separation. However, this will in turn draws liquid into the branch arm.

2.3. Effect of viscosity of working fluid on the phase separation efficiency

2.3.1. Viscosity of working fluid

Hong (1978) studied the effect of liquid viscosity on the separation efficiency in T-junction. He conducted an experiment with air and plain/viscous water flowing into a downward branch T-junction. Figure 2.3-1 shows the result obtained from this experiment we can see the pattern for fraction of liquid entering the branch is decreasing (approaching the equal gas-liquid split line) as the viscosity of the liquid is decreased. Hong (1978) inferred this phenomenon due to increase in velocity of the liquid, caused by decreasing viscosity. As liquid's velocity increases, its inertia (momentum) also increases. As the liquid's momentum increased to exceed the centripetal force that promotes liquids into branch arm (created by the abrupt change in direction of gas flow into branch arm) this will in turn, drawing more liquid into the branch arm (since centripetal force is not directly affected by viscosity). Hence, decrease in liquid viscosity, will result in lesser liquid drawn into branch arm (in a fixed value of inlet gas velocity).



(a) SUPERFICIAL GAS VELOCITY: 30 FT/SEC (21.5 psia)
(a) SUPERFICIAL GAS VELOCITY: 30 FT/SEC (21.5 psia)
(a) SUPERFICIAL GAS VELOCITY: 30 FT/SEC (21.5 psia)

Figure 2.3-1: Effect of viscosity on separation (from left 10, 5, 1 centipoises) (Hong, 1978)

2.4. Flow Pattern

Gas-liquid flows are complicated to study due to the interface between the particles which enable the flow to assume different characteristics in different conditions. Over the years, researchers have made to characterization, identification, and mapping of gas-liquid flows inside a pipe.

2.4.1. Vertical Flow in Pipe

As shown in Figure 2.4-1 there are four major pattern for vertical up flow in a pipe. Since the gravity acts axially against the flow in the pie the flow will assume pattern as below(Azzopardi, n.d.; Baker, 2003; Wren, 2001).

Bubbly flow: Gas phase as non-uniformed sized bubbles dispersed within a liquid continuum. The bubbles travel in a complex motion and may seen to coalesce and break up as they travel along the pipe. At higher liquid velocity, the bubbles are created by turbulent breakup of larger bubbles, while in lower liquid velocity; the bubbles are generated either at gas distributor or in process of nucleate boiling. According to (Serizawa and Kataoka, 1988) depending volumetric flow rate of gas and liquid phase, bubbly flow can be sub-patterned into:

- Wall peaking – void fraction are highest near the pipe wall. This is associated with high liquid volumetric flux velocity
- Core peaking – void fraction are highest at the pipe core. This associated with high gas volumetric flux velocity.

Slug flow: Often referred as plug flow, occurs as bubbles start coalesce to form larger bubble in a bullet shape that have the diameter of the pipe; “Taylor Bubble”. A thin liquid film is seen to flow downwards between Taylor Bubble and the pipe. However, this flow pattern does not occur in pipe diameter of more than

(150 and 200 mm) where direct transition of bubbly flow to churn flow occurs.

Churn flow: Taylor Bubbles/ liquid slugs in slug flow break down into an unstable pattern at higher gas velocity, generating an unpredictable churning/oscillatory movement of the liquid. The film's flow direction changing and large waves are created. The instability and chaotic characteristic of this flow have an destructive effect on the piping system, therefore it is usually eluded.

Annular flow: In this flow, liquid travels as a film on the pipe walls or as droplets in the pipe core. The high velocity of gas become dominant over gravity and it flow on the pipe core as a continuum. Wispy annular will start to form as the transient coherent structure is formed by the entrained droplets leading the formation of liquid cloud in center vapor core.

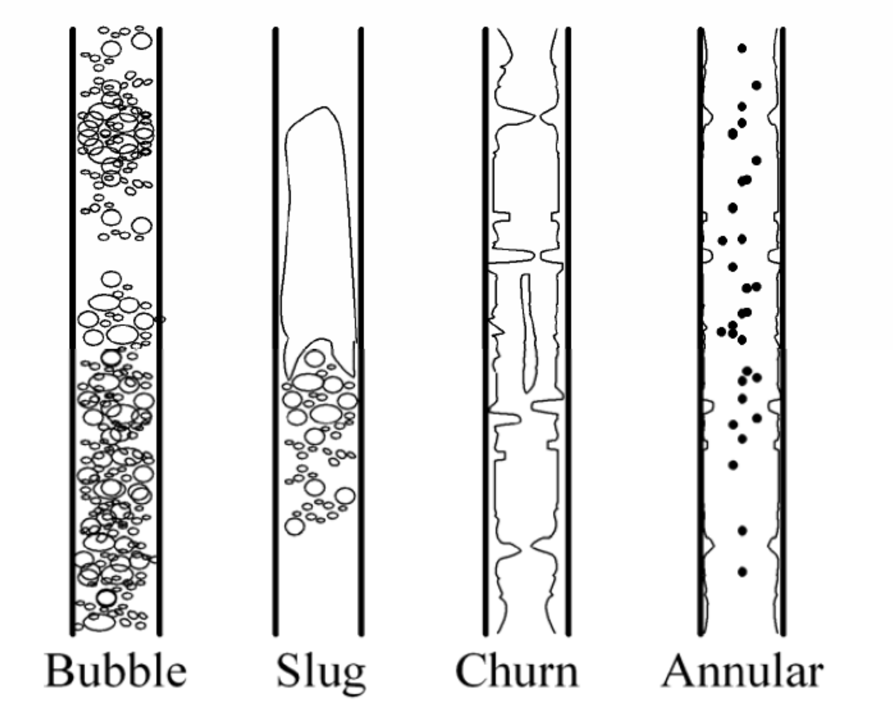


Figure 2.4-1: Two phase flow regime inside vertical pipe, Azzopardi (n.d.)

2.4.2. Horizontal Flow in Pipe

In horizontal flow, gravity acts perpendicular to tube axis, hence the flow will assume slightly different behavior in pipe. As shown in Figure 2.4-2 There are four major flow patterns in the horizontal flow; bubble, intermittent/slug, stratified and annular flow(Azzopardi, n.d.; Baker, 2003; Wren, 2001)

Bubbly flow: Similar to Bubbly flow in vertical pipe, gas bubbles uniformly distributed throughout continuous liquid flow but due to buoyancy, bubbles are accumulated in the upper part of pipe. In high turbulent when liquid velocity increased, the bubbles will distribute about pipe cross section.

Stratified flow: Gas flows above a liquid continuum separated by a smooth interface. Increase in gas velocity will generate waves between the phases forming **Stratified-Wavy Flows.**

Plug flow: Formation of bullet-shaped gas bubbles on the upper part of pipe indicates plug flow.

Slug flow: Increase in liquid superficial velocity enlarge the waves until enough to fill up the pipe diameter creating an intermittent flow. Gas bubble's size increased and travels in the upper part of pipe separated by liquid slugs containing smaller bubbles inside. Cause large pressure and liquid flow rate fluctuations.

Annular flow: Increase in gas velocity creates a gas continuum on the pipe's core and liquid travels as film on the pipe wall. The liquid film is thicker on the bottom due to gravity, but then uniformed around the pipe as gas velocity increases.

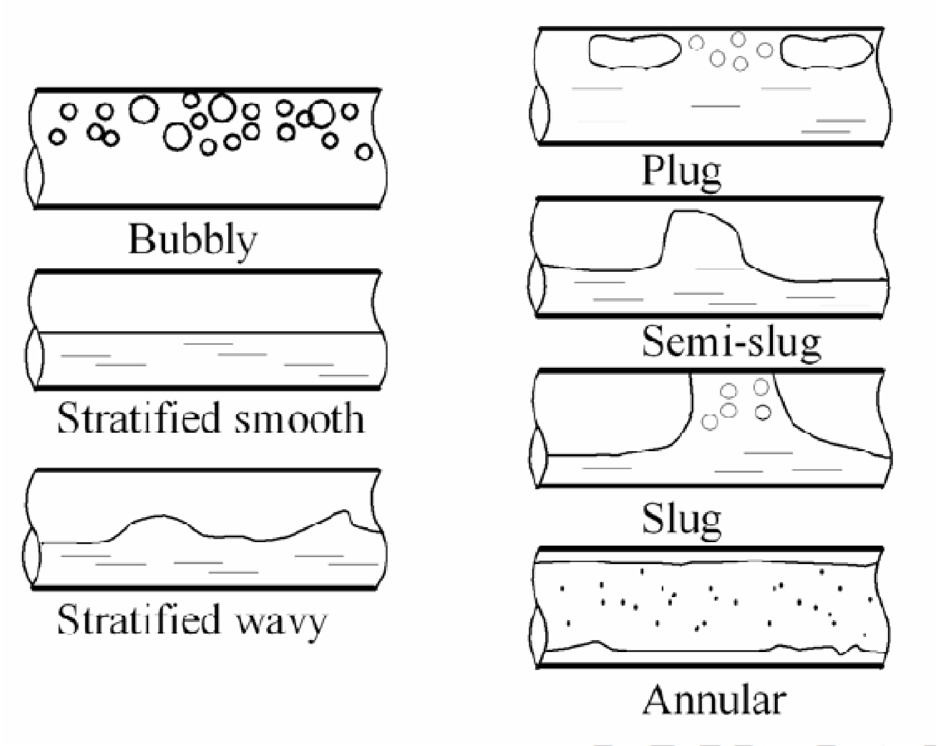


Figure 2.4-2: Flow pattern in horizontal pipe, (Azzopardi, n.d.)

2.4.3. Flow Pattern Map

According to (Azzopardi, n.d.), the early study of flow pattern is commonly observed on two-dimensional diagram in terms of system variable. Superficial velocity; (volumetric flow rate/cross sectional area of the pipe) is the common variable used in this line of study. Among early prediction in flow pattern, map produced by Taitel and Dukler (1976), as Figure 2.4-3 model is a popular one for its simplicity. The map was produced based on mechanism of flow regime transitions of; stratified smooth, stratified wavy, intermittent/slug, annular and bubbly. Stratified smooth flow is the initial flow pattern in the analysis and mechanism of its transition into the final regime was examined and mapped. (Baker, 2003) stated that although in the pipe, stratified flow may not initially exist, but assumption was made that the final steady flow pattern observed from the liquid and gas superficial velocities was not dependent on path used to arrive at that condition.

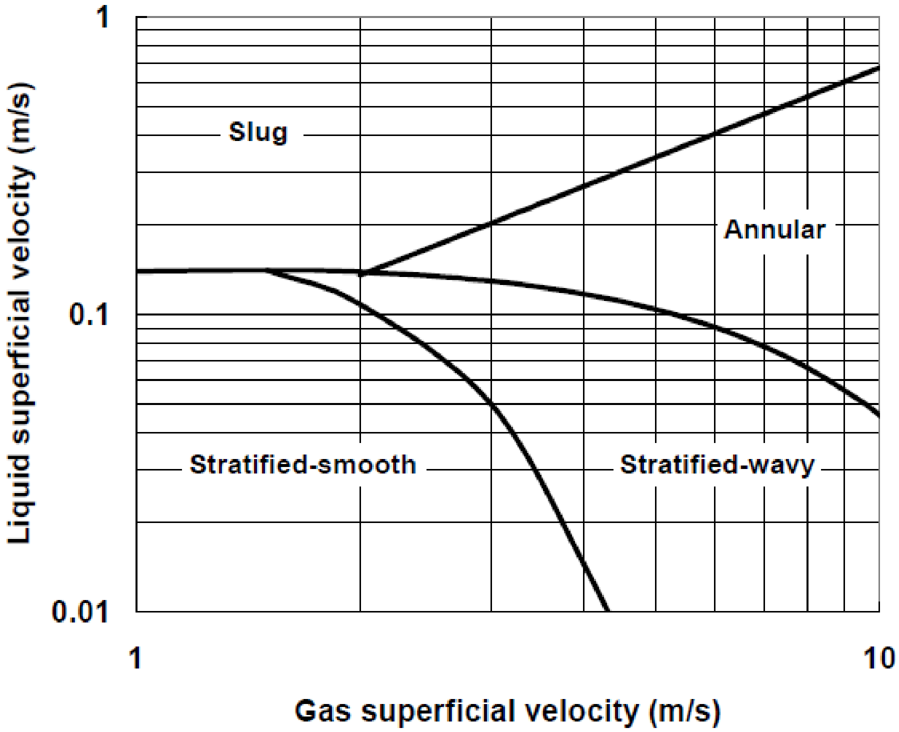


Figure 2.4-3: Flow map based on methodology of Taitel and Dukler (1976)

However, (Azzopardi, n.d.; Baker, 2003) did criticize the reliability of the flow pattern map where in transition zones (area near the lines) the experiment data might lie on the wrong side of line.(Azzopardi, n.d.) propose to treat the area near the lines as transition zone with indefinite width.

2.5. Concluding Remarks

Based on the background study and literature review, the separation efficiency of the gas-liquid flow in a T-junction is dominantly affected by the gravity, inertia, and pressure. The parameters that affect this phenomenon include diameter ratio, and viscosity of the working fluid. However, these are not only factors for phase separation as there are also other parameters; flow rate of liquid and gas, initial gas saturation (gas-oil ratio), arm length, operating pressure and temperature. This literature review had given a perspective towards parameters selection before the author proceed to conducting the project.

CHAPTER 3: METHODOLOGY

3. Project methodology

This chapter describes the methodology used in the study to achieve the pre-defined objectives as stated in section 1.3: Objective.

3.1. Project Framework

This project aims to identify the effect of selected parameters on separation efficiency of the T-junction (gas fraction in side arm), pressure drop along the main arm, and pressure drop along the branch arm. The results of the studied parameters will be used to propose an operating envelope which effectively utilizes phase maldistribution across a T-junction. This study is be carried out by simulating the two phase flow in T-junction using OLGA Dynamic Multiphase Simulator software.

Simulation is carried out in OLGA by varying the geometry of the T-junction and inlet condition of the two phase flow inside the T-junction.

3.1.1. Varying the geometry

The geometry of the T-junction are be varied in terms of:-

- The length ratio – the main and run arm length, L_1 and branch arm length, L_2 will be varied.

3.1.2. Varying the inlet condition

The inlet conditions that are studied are:-

- The gas-oil ratio
- Oil flow rate
- Operating pressure

3.1.3. Parameters for the study

Figure 3.1-1 shows geometry for the T-junction in the study where diameter of the branch arm, D_3 will be fixed at 1 inch and the main and run diameter, $D_1 = 6\ inch$. L_1Will be varied from 5, 10, 15 meters and L_2 = 800 millimeters.

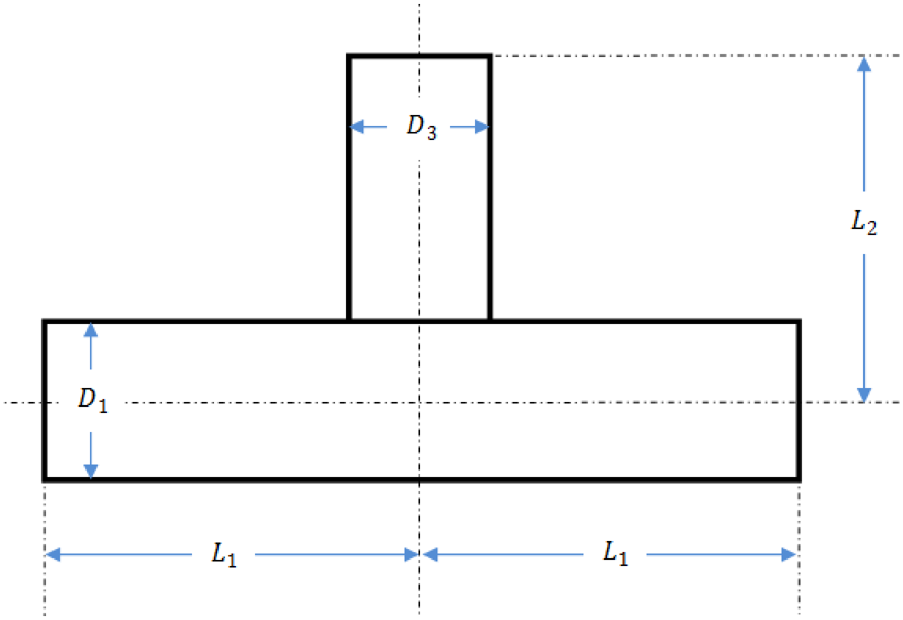


Figure 3.1-1: geometry of the T-junction

Table 3.1-1: Input parameters for the study

INPUT PARAMETERS	PRESENT STUDY
Main & run arm diameter, D_1 & D_2(mm)	**6 inch (152.4 mm)**
Branch arm diameter, D_3(mm)	**1 inch (25.4 mm)**
Main & run arm length, L_1 (m)	**10, 15, 20**
Branch arm length, L_2 (mm)	**800**
Operating pressure, P (bar)	**10-100**
Operating temperature, T °C	**60, 70**
Gas-oil ratio (scf/stb)	**500-2000**
Oil flow rate (m^3/hr)	**1000-10 000 bbl/day (6.624-66.25 m^3/hr)**

Table 3.1-1 summarizes all the parameter to be tested throughout the simulation. The lowest and highest limits for the parametric studies have been determined in order to study the parameters specified.

3.2. Predicting flow inside a T-junction

Geometry of a T-junction affects flow of the fluid travelling inside; the flow split and fluid's properties are highly affected while travelling in a T-junction.

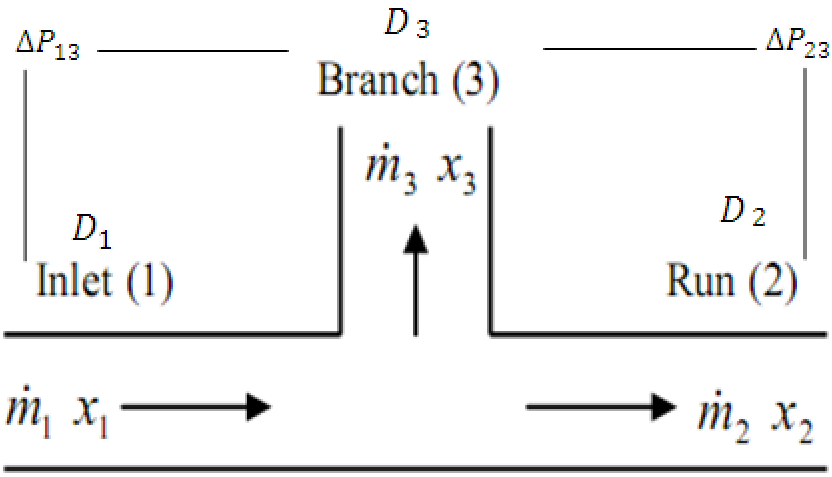


Figure 3.2-1: Main parameters associated with T-junction as stated by Puspitasari et al. (2012)

Figure 3.2-1: Main parameters associated with T-junction as stated by Puspitasari et al. (2012)Figure 3.2-1 shows main parameters that must be considered to predict what will probably happen to a given flow pattern approaching the junction. Other than the junction's geometry, the parameter that defines the flow split includes; mass flowrates $(\dot{M}_1,\dot{M}_2,\dot{M}_3)$, the mixture quality of each arm, (x_1,x_2,x_3) and associated pressure drops, $\Delta P_{12}\ and\ \Delta P_{13}$. The subscripts indicates main, run, and branch arm respectively.

The unknown variables stated above can be related using conservation of mass, momentum equation, and energy balance equation. Given the inlet condition on the inlet, the flow rate and quality of run and branch arm can be calculated.

3.3. Simulation using OLGA

Development of model for T-junction two-phase separation simulation is done in OLGA Multiphase Flow Simulator Software. OLGA is commonly used to simulate multiphase flow behavior which it can give valuable insights into flow behavior and the physics describing the flow. OLGA models transient flow (time-dependent behavior) to predict system dynamics; changes in flow rate, fluid compositions, temperature, solids depositions and operational changes.

This simulation applies OLGA Extended Two-Fluid Model to simulates two-phase flow by separately solves **three separate continuity equations** (for liquid bulk, gas, and liquid droplets, which may be coupled through interphasial mass transfer), **Two momentum equations** (one for liquid film, and a combined equation for gas and possible liquid droplets), and one **energy-conservation equation** (for the mixture of gas and liquid) (Bendiksen et al., 1991; Irfansyah, Widyoko, Gunarwan, & Lopez, 2005).

3.3.1. OLGA Extended Two Fluid Model

For the extended two fluid model in OLGA, main equations applied are as follows (Bendiksen et al., 1991):-

Conservation of mass:-

- Gas phase:

$$\frac{\partial}{\partial t}(V_g\rho_g) = -\frac{1}{A}\frac{\partial}{\partial z}(AV_g\rho_g v_g) + \psi_g + G_g$$

Equation 3.3—1

- Liquid phase:

$$\frac{\partial}{\partial t}(V_L\rho_L) = -\frac{1}{A}\frac{\partial}{\partial z}(AV_L\rho_L v_L) - \psi_g\frac{V_L}{V_L+V_D} - \psi_e + \psi_d + G_L$$

Equation 3.3—2

- Liquid droplets:

$$\frac{\partial}{\partial t}(V_D\rho_L) = -\frac{1}{A}\frac{\partial}{\partial z}(AV_D\rho_L v_D) - \psi_g\frac{V_D}{V_L+V_D} + \psi_e - \psi_d + G$$

Equation 3.3—3

In Equation 3.3—1 through Equation 3.3—3, V_g, V_L, V_D =gas, liquid-film, and liquid droplet volume fractions, ρ = density, v = velocity, p = pressure, and A = pipe cross-sectional area. ψ_g = Mass-transfer rate between the phases, ψ_e, ψ_d = the entrainment and deposition rates, and G_f = possible mass source of Phase f. Subscripts g, L, i and D indicate gas, liquid, interface, and droplets, respectively.

Momentum equation:-

- Gas phase:-

$$\frac{\partial}{\partial t}(V_g\rho_g v_g) = -V_g\left(\frac{\partial p}{\partial z}\right) - \frac{1}{A}\frac{\partial}{\partial z}(AV_g\rho_g v_g^2) - \lambda_g\frac{1}{2}\rho_g|v_g|v_g$$

Equation 3.3—4

$$\times\frac{S_g}{4A} - \lambda_i\frac{1}{2}\rho_g|v_r|v_r\frac{S_i}{4A} + V_g\rho_g g\cos\alpha + \psi_g v_a - F_D$$

- Liquid phase:-

$$\frac{\partial}{\partial t}(V_D\rho_L v_D) = -V_D\left(\frac{\partial p}{\partial z}\right) - \frac{1}{A}\frac{\partial}{\partial z}(AV_D\rho_L v_D^2) + V_D\rho_L g\cos\alpha$$

Equation 3.3—5

$$-\psi_g\frac{V_D}{V_L+V_D}v_a + \psi_e v_i - \psi_d v_D + F_D$$

In Equation 3.3—4 through Equation 3.3—5, α = pipe inclination with the vertical and S_g, S_L, S_i = wetted perimeters of the gas, liquid, and interface. the internal source, G_f, is assumed to enter at a 90° angle to the pipe wall, carrying no net momentum.

3.3.2. Energy-conservation Equation

- A mixture energy equation is applied:-

$$\frac{\partial}{\partial t}\left[m_g\left(E_g + \frac{1}{2}v_g^2 + gh\right) + m_L\left(E_L + \frac{1}{2}v_L^2 + gh\right)\right.$$

$$\left. + m_D\left(E_D + \frac{1}{2}v_D^2 + gh\right)\right] = -\frac{\partial}{\partial z}\left[m_g v_g\left(H_g + \frac{1}{2}v_g^2 + gh\right)\right.$$

Equation 3.3—6

$$\left. + m_L v_L\left(H_L + \frac{1}{2}v_L^2 + gh\right) + m_D v_D\left(H_D + \frac{1}{2}v_D^2 + gh\right)\right] + H_S + U,$$

Where E = internal energy per unit mass, h = elevation, H_s = enthalpy from mass source, and U = heat transfer from pipe wall.

By using these equation, OLGA simulates the two-phase flow in the T-junction, and display the pre-determined desired result

By applying OLGA Extended Two-Fluid Model, the flow inside a T-junction is simulated. A T-junction model is developed in OLGA consisting of main, run, and branch arm as will be described in next section.

3.3.3. OLGA simulation model development

An OLGA model have been built for the parametric studies by using the geometric specification of the T-junction. Figure 3.3-1 shows developed model for the parametric study using OLGA.

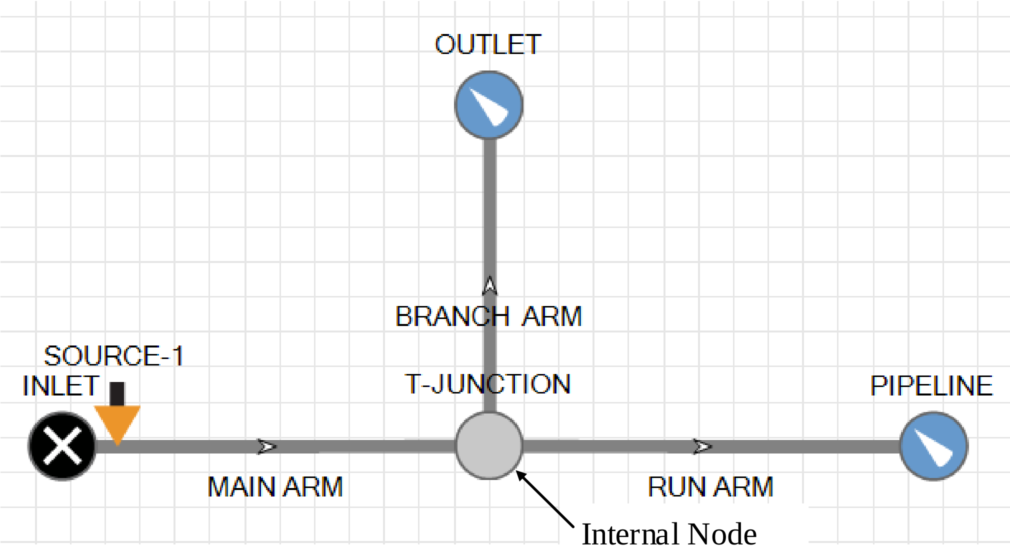


Figure 3.3-1: T-junction model in OLGA

In modeling the T-junction, the following items are the important factors to be considered in developing the T-junction in OLGA.

- Fluid File:-

  OLGA requires the user to input a PVT file containing the fluid properties; density, temperature, pressure and other properties in various conditions. For the T-junction model, "Harthun.tab" file which is provided in the software is used. Since no water is assumed present in this simulation, the "harthun.tab" file is used since this fluid file contains only oil and gas. Table 3.3-1 lists the properties of Harthun fluid file that is used throughout the simulation. The GOR of the fluid can be input into OLGA prior to running of the simulation, enabling the parameter to be changed without switching the fluid file used.

Table 3.3-1: Properties of Fluid File used

Fluid file name	**Harthun**
Phase	2 phases (oil, and gas)
Standard Gas Density	1.18699 kg/m3
Standard Oil Density	73.9434 kg/m3
Critical Pressure	164.607 ATM
Critical Temperature	548.130 K

- Junction model:-

  The junction is modeled using internal node model in OLGA (as labeled in Figure 3.3-1**Error! Reference source not found.**). The model for internal nodes (merge/split nodes) uses more or less the same physics and the numerical methods as the sections in the pipes. Pressure, temperature and masses are calculated. Interphasial mass transfer is included in the node, but entrainment/deposition of liquid droplets is ignored.

  Heat exchange with the surroundings is accounted for in an internal node. It gets the overall heat transfer coefficients and the corresponding ambient temperatures from the connected pipes. However, the node does not take into account the heat loss to the surroundings.

Internal nodes require a finite volume in the node, a default volume is calculated by OLGA using Equation 3.3—7 based on sizes of incoming and outgoing sections:-

$$V = \max \left\{ \frac{1}{3} \cdot \min \left\{ 100 \cdot D_i , \cdot L_i \right\} \cdot A \right. \quad \textbf{Equation 3.3—7}$$

Where i is taken over all incoming or outgoing sections.

- Fluid Source:-

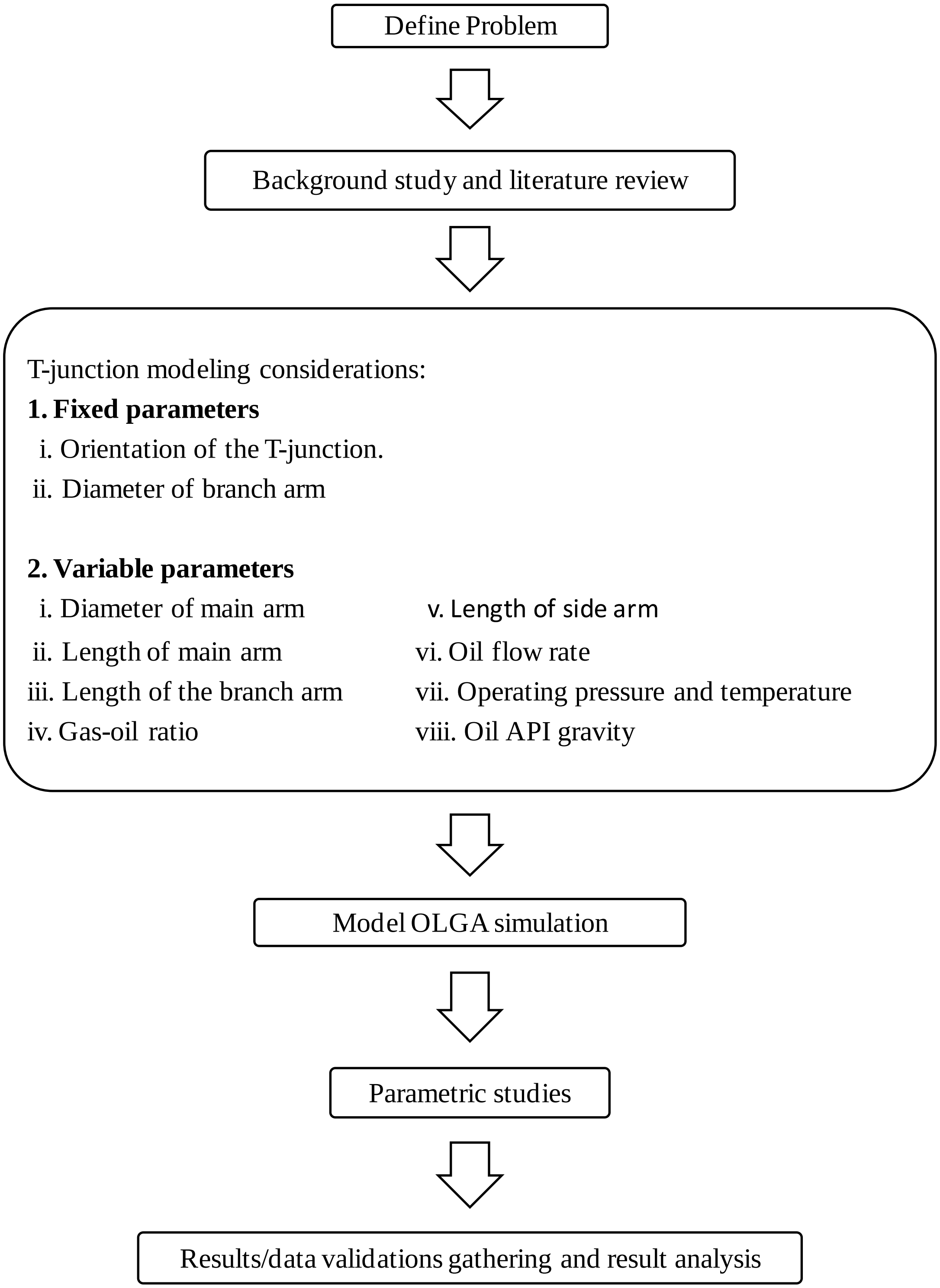
  The fluid source (labeled SOURCE-1 in Figure 3.3-1) is where the parameters like flow rate, temperature, and GOR are specified. This

- Nodes:-

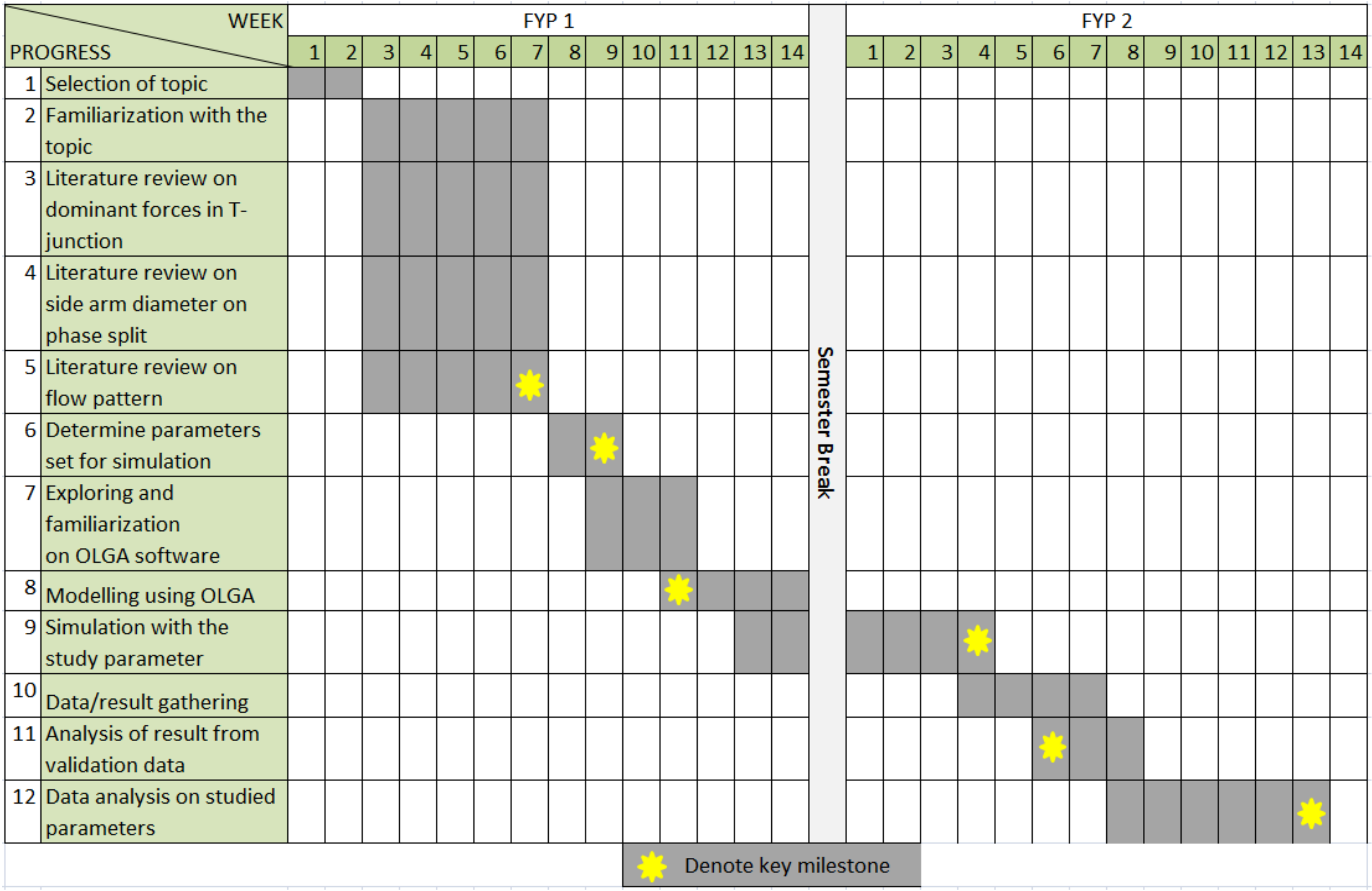
  ‘OUTLET’ and ‘PIPELINE’ (as shown in Figure 3.3-1) are two pressure nodes which the pressure, temperature, and the fluid file can be specified.

3.4. Project activities

3.4.1. Project Process Flow Chart



3.4.2. Project Gantt Chart



	WEEK / PROGRESS	FYP 1														Semester Break	FYP 2													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of topic	▨	▨																											
2	Familiarization with the topic			▨	▨	▨	▨	▨																						
3	Literature review on dominant forces in T-junction			▨	▨	▨	▨	▨																						
4	Literature review on side arm diameter on phase split			▨	▨	▨	▨	▨																						
5	Literature review on flow pattern			▨	▨	▨	▨	✹																						
6	Determine parameters set for simulation								▨	✹																				
7	Exploring and familiarization on OLGA software									▨	▨	▨																		
8	Modelling using OLGA											✹	▨	▨	▨															
9	Simulation with the study parameter													▨	▨		▨	▨	▨	✹										
10	Data/result gathering																			▨	▨	▨	▨							
11	Analysis of result from validation data																					✹	▨	▨						
12	Data analysis on studied parameters																							▨	▨	▨	▨	▨	✹	

✹ Denote key milestone

CHAPTER 4: RESULT AND DISCUSSION

4. Validation of OLGA T-junction model

Since no one has done this study using OLGA, reproduction of SINTEF's experiment result was done, to validate author's understanding and competency in using OLGA.

4.1.1. Reproduction of SINTEF experiment result using OLGA

(Bendiksen et al. (1986)) conducted a two-phase flow research at SINTEF lab with 450 meter long 19-cm diameter pipes. This study has been producing result for oil and gas flow in a pipe with setup as shown in Figure 4-1. For the transient inlet flow experiment, a time-dependent inlet flow rates were applied on the experiment setup as in Figure 4-1, where the inlet liquid superficial velocity is kept constant at 1.08 m/s, while gas superficial velocity was increased from 1.0 m/s to about 4.2 m/s in a period of 20 seconds. By applying OLGA's Extended Two Fluid Model, this experiment was simulated to yield similar results that are in high agreement with the experiment's.

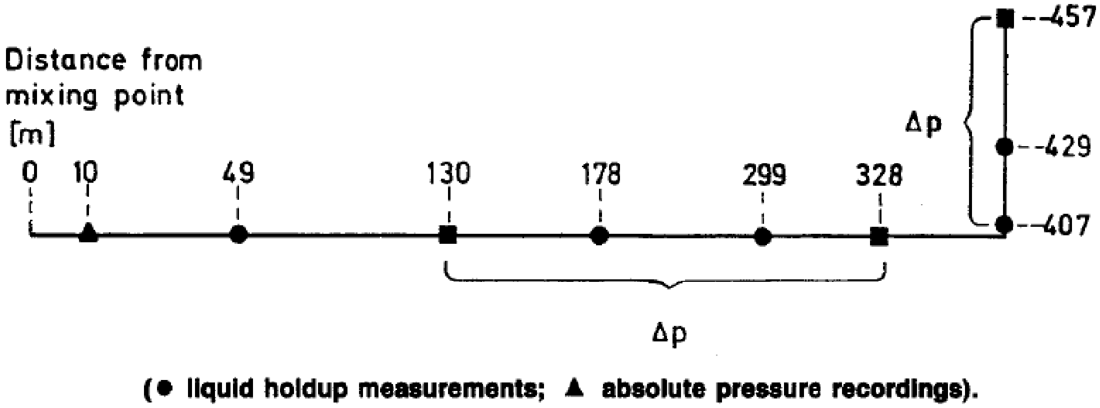


Figure 4-1: Test section of the SINTEF Two-Phase Flow Laboratory for the experiment. (Bendiksen et al., 1991)

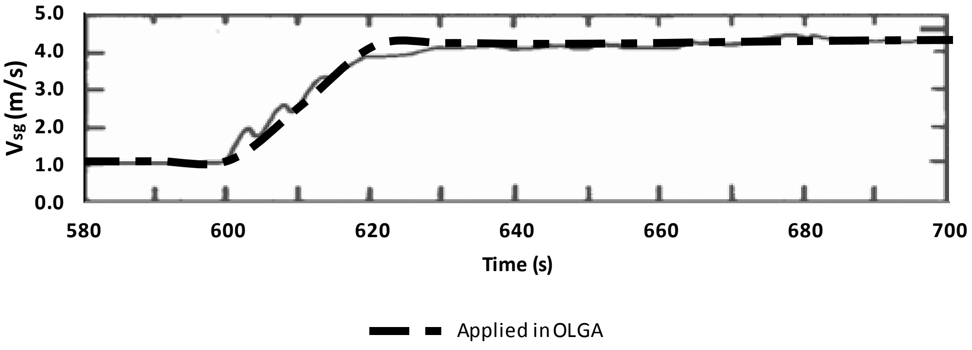


Figure 4-3: Superficial gas velocity recordings 10 meters from mixing point (solid lines represents experiment values) (Bendiksen et al., 1991)

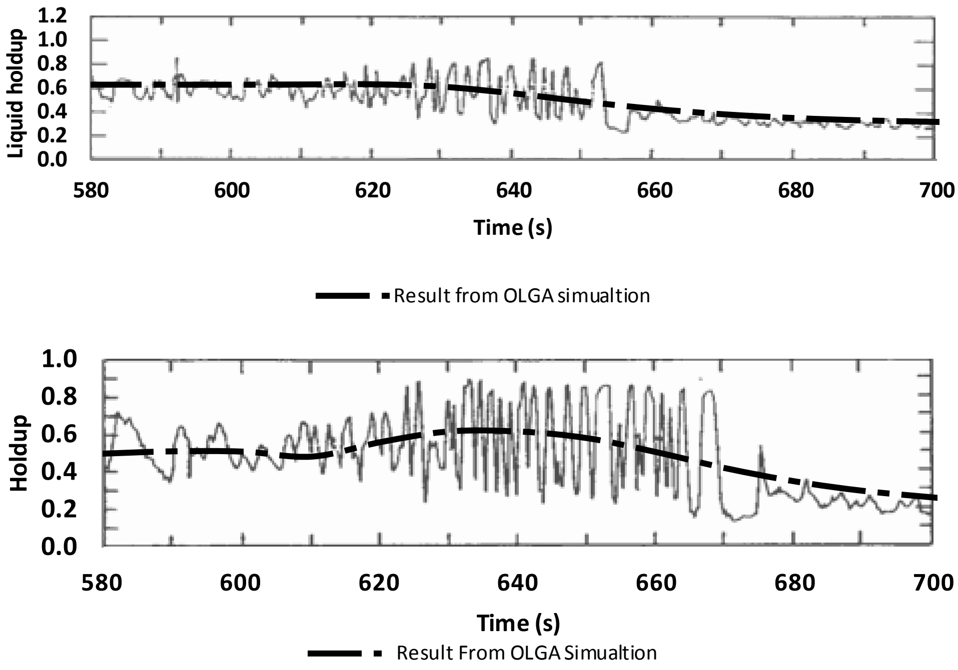


Figure 4-2: Liquid holdup recordings in horizontal pipe at 299 m and 7 m from mixing point (solid lines represents experiments values) (Bendiksen et al., 1991)

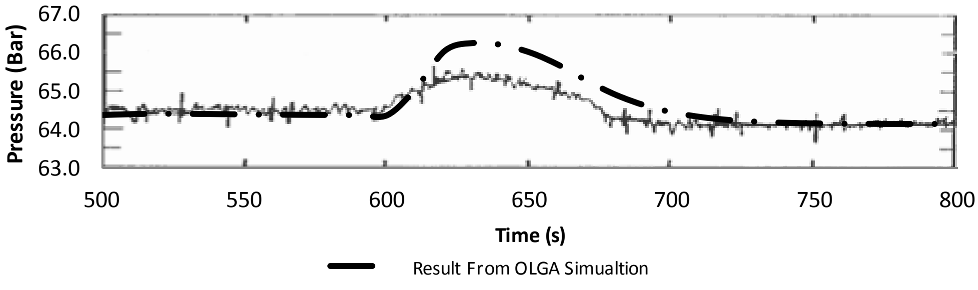


Figure 4-4: Absolute pressure recorded 10m from mixing point (solid lines are experiment values) (Bendiksen, Maines, Moe, & Nuland, 1991)

Reproduction of SINTEF results (Figure 4-2 to Figure 4-4) shows results from OLGA are in very high agreement with the experimental results except for Figure 4-4, where the peak pressure is higher than experimental result by 1 Bar.

4.2. Parametric Study

4.2.1. Effect of operating pressure

The effect of operating pressure is studied by prescribing pressures of the nodes at the end of branch arm and run arm, then observe the separation performance of the T-junction in terms of gas fraction in the branch arm. As in Figure 4.2-1, pressures are prescribed at both 'OUTLET_BRANCH' and OUTLET_RUN' nodes and noted as P_3 , and P_2 respectively. the corelation is denoted as pressure raito, P_r where, P_r = ${}^{P_3}/_{P_2}$.

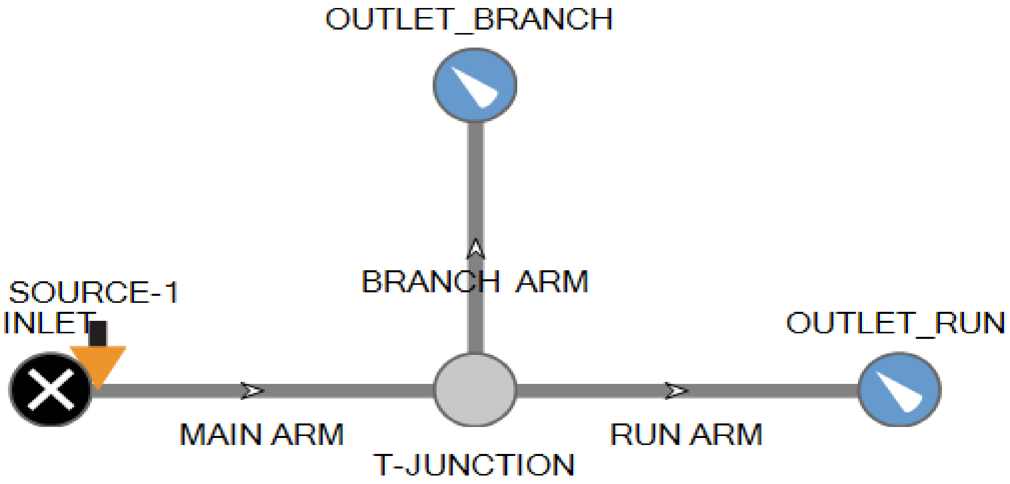
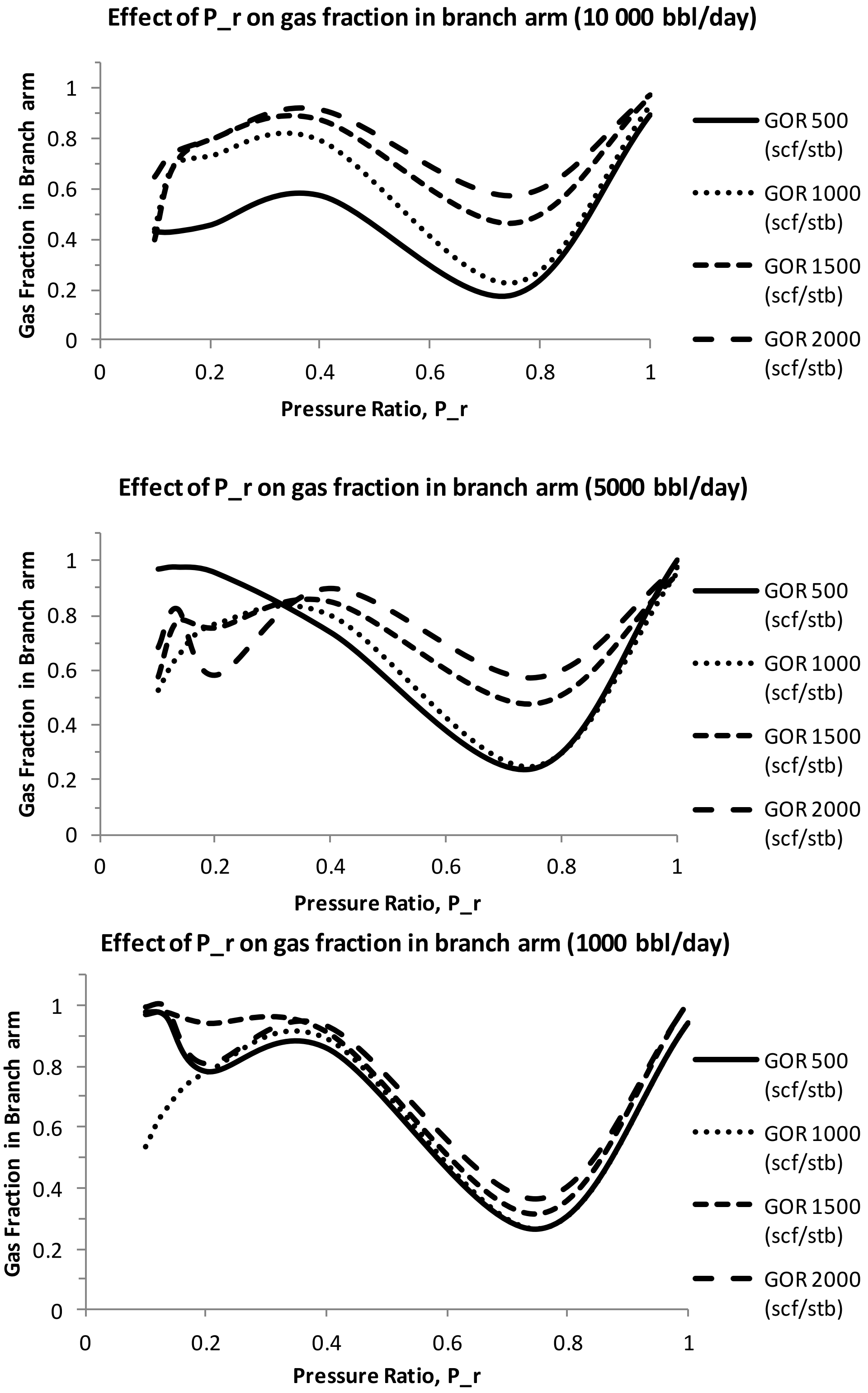


Figure 4.2-1: T-junction Model in OLGA

Figure 4.2-2 shows the effect of operating pressure on the gas fraction inside the branch arm, for different GOR (scf/stb) in different oil rate. High gas fraction in branch arm can be observed for P_r = 0.1 to 0.4, then declined before increases again after P_r = 0.75. This trend can be observed on all cases of the for oil rate of 1000 to 10 000 bbl/day. However, when the P_r ratio exceeds 1, the gas fraction in branch arm will have a negative value, which indicates backflow in the branch arm, the ideal P_r ratio should never exceeds 1.



Effect of P_r on gas fraction in branch arm (10 000 bbl/day)

Effect of P_r on gas fraction in branch arm (5000 bbl/day)

Effect of P_r on gas fraction in branch arm (1000 bbl/day)

Figure 4.2-2: Effect of P_r on gas fraction in branch arm for different GOR and oil rate for oil rate of 10 000, 5000, and 1000 bbl/day

The analysis of the simulation results reflects the effects of operating pressure on the performance of T-junction as a separator. Generally, ideal P_r value for effective separation is within the range of 0.1-0.4, and 0.75-1. This value can be determined by considering the operating envelope (Oil rate a& GOR).

4.2.2. Effect of GOR

The effect of GOR is analyzed in two perspective; by keeping the oil rate (bbl/day) constant, and by keeping the P_r ratio constant. Figure 4.2-3 reflects the gas fraction in branch arm in different GOR under different P_r ratio with oil rate of 5000 bbl/day. Figure 4.2-4 depicts the gas fraction in branch arm in respect to different GORs under different oil rate. From these data representation, we can observe that generally, gas fraction in branch arm increases in the oncrement of GOR. However, the almost-flattened lines on the graph in Figure 4.2-3 indicate the GOR effect on the gas fraction in branch arm are that of low-significant. Figure 4.2-4 reflects that the effect of GOR on gas fraction in branch arm is dramatized as the oil rate is increased.

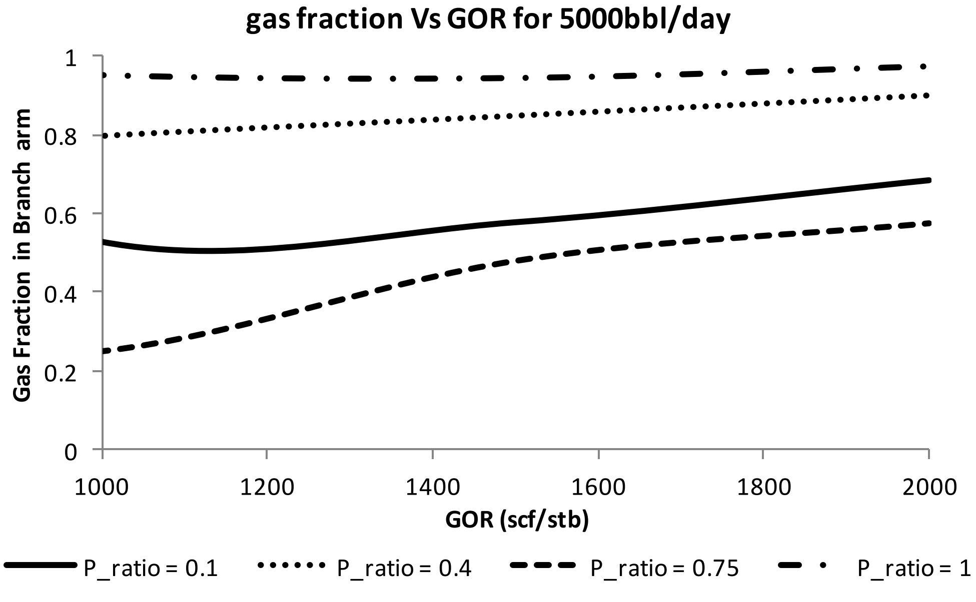


Figure 4.2-3: Effect of GOR on gas fraction in branch arm

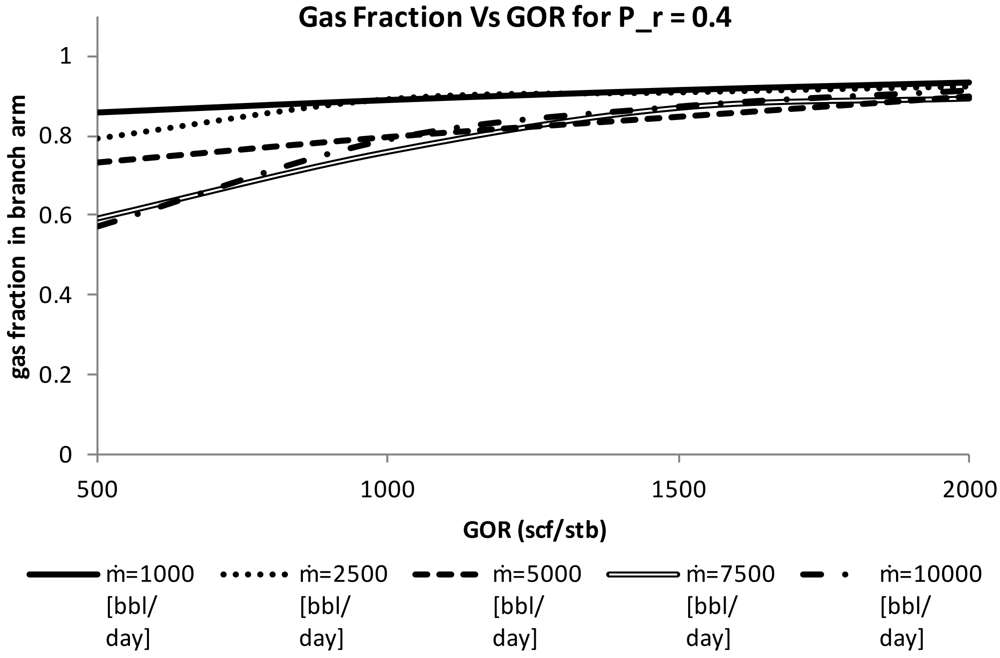


Figure 4.2-4: Effect of GOR on gas fraction in branch arm for P_r = 0.4

4.2.3. Effect of oil flow rate, ṁ

From Figure 4.2-5, we can observe that in general, gas fraction in branch arm decreases as the oil rate is increased. This effect is more significant when coupled with low GOR of the oil. however, as the GOR increased, the effect of changing oil rate towards gas fraction in branch arm are diminished.

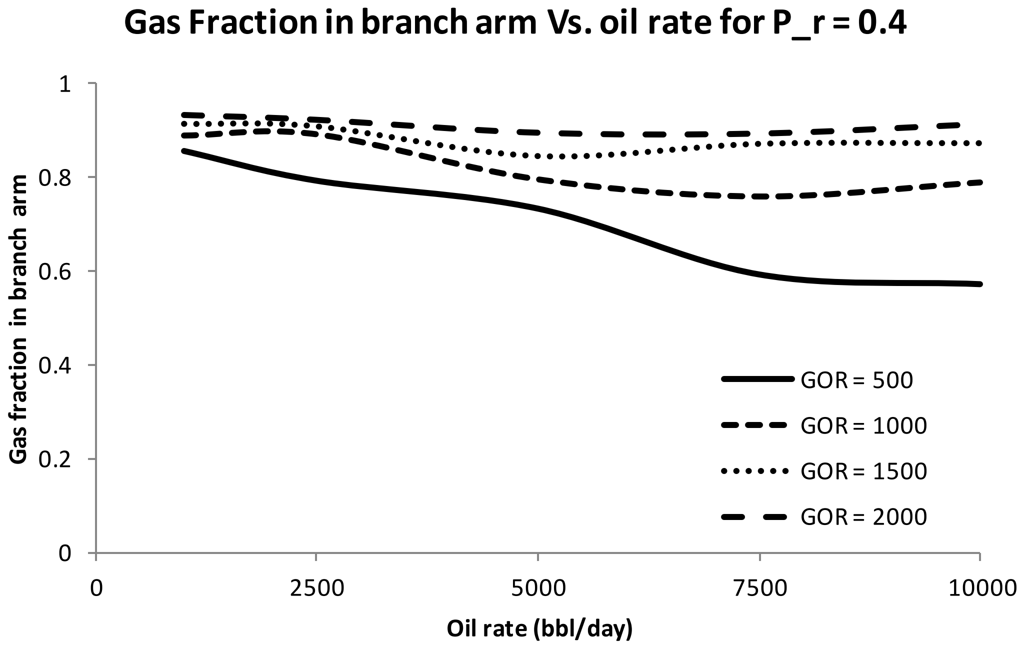


Figure 4.2-5: Effect of oil rate on gas fraction in branch arm

4.2.4. Effect of arm length

The effect of arm length ratio is studied by keeping the branch arm length, $L_2 = 0.8\ m$, and varying the main and run arm length, $L_1 = 10\ m, 15m$. It is then expressed in term of length ratio, L_r = ${}^{L_2}/{}_{L_1}$. Figure 4.2-6 illustrates effect of arm length ratio, L_r on gas fraction in branch arm where the gas frction in branch arm is slightly decreased as the L_r ratio increased. However, the effect of arm length on gas fraction in branch arm are that of very low significant. The arm length affects the flow regime and the pressure approaching the junction. However, for the arm length that is within the scope of study, its effect towards gas fraction in branch are low significant.

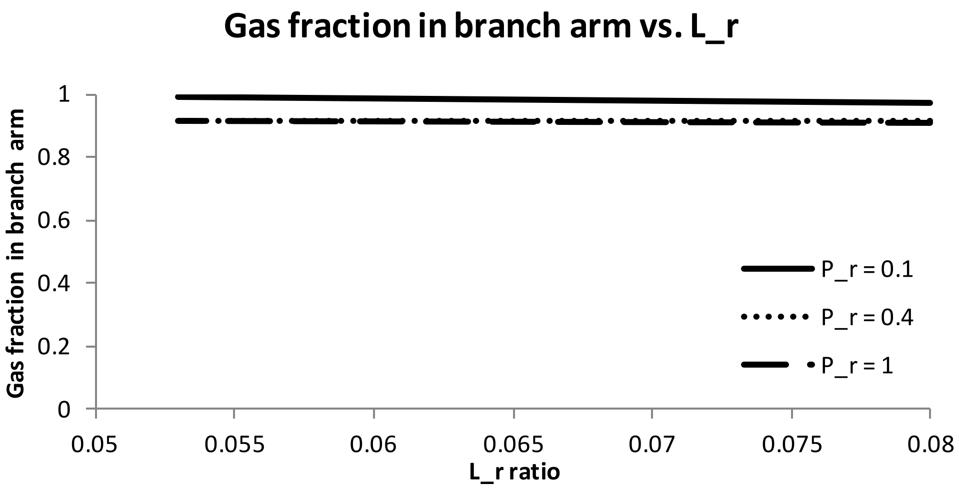


Figure 4.2-6: Effect of arm length ratio, L_r on gas fraction in branch arm

4.2.5. Concluding remarks

Based on the analysis of results, we can conclude that the most influential parameter is operating presure as was discussed in section 4.2.1. which described the range of P_r value that optimized the gas fraction in the branch arm. For GOR, gas fraction in branch arm increase as the GOR increases however, this effect is diminished as the oil rate decreases and the P_r value positively approaching 1. For oil rate, in general, the gas fraction in branch arm decrases in decreasing oil rate, and this effect is dramatized in lower GOR.

CHAPTER 5: CONCLUSION & RECOMMENDATIONS

In conclusion, operating conditions and geometry are affecting the efficiency of T-junction as a partial phase separator. Using the developed T-junction model, effect of arm length ratio, operating pressure, GOR, and oil rate on separation efficiency are identified. Among the studied parameters, the operating pressure has the highest significant effect on the separation efficiency of a T-junction. With the generated data, the behaviour of a two phase flow in a T-junction can be predicted, and a suitable operating envelope for efficient separation can be developed based on individual application. These generated data can be utilized for further study on this phenomena to perfect our understanding in application of T-junction as partial separator.

Besides the studied parameters in this project, many other parameters can be studied to better the understanding of the phenomena and improve efficiency of phase separation in T-junction. Future study can be focused on the viscosity of the working fluids, and operating temperature. Therefore, a higher controlability of the separation can be achieved and the application of the T-junction in industry can be more practical and reliable alternative to current separator.

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