OIL-SAND PARTICLES (SOLID-LIQUID) PASSIVE SEPARATION IN PIPING SYSTEM

By

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Dissertation submitted in partial fulfillment

of the requirements of the

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CERTIFICATION OF APPROVAL

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Approved:

____

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Project Supervisor

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TRONOH, PERAK

September 2013

CERTIFICATE 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.

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Muhammad Fareez bin Muhammad Idris

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ABSTRACT

Sand presences in oil flow of production are one of the most undesirable problems to happen in oil and gas industries. Sand particles in the piping will cause erosions to the pipe inner wall and wear to the rotating equipment, thus lessen the life span of equipment. Installation of sand filtration systems and separation vessels to remove the sand are costly but yet sand particles are not totally removed from the system. By understanding the behavior of two-phase flow through a T-junction elbow is very important as it has significant effect as the mechanism will allow the sand particles to deposit at the bottom of the pipe, leaving oil to flow with lower volume fraction of sand. This project intended to study multiphase flow in piping system and the geometry effects on passive separation in piping.Specifically, this project aims to determine the effect of inlet flow conditions on phase separation effectiveness by focusing on passive separation in piping using pipe elbow. From the result observations, it is observed that there are sand particles deposited along the horizontal pipe and high amount of that are deposited at the extended arm of closed-end of the pipe. Applying vertical side arm with extended closed-end had increased the amount of sand deposited compared to the horizontal pipe without side arm. As conclusion, geometry alteration is one of important criteria in order to achieve a low-cost separation mechanism to increase the separation efficiency.

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ABBREVIATIONS AND NOMENCLATURES

API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
CFD	Computational Fluid Dynamic
MTV	Minimum Terminal Velocity
CDV	Critical Deposition Velocity
CFV	Critical Foam Velocity
CTFV	Critical Transport FluidVelocity

CHAPTER 1

INTRODUCTION

1.1 Project Background

Sands are solid particles naturally found beneath the earth and formed by porous rock, mixed together with the hydrocarbons such as crude oil, natural gas in the reservoir. Due to high pressurized drilling fluid during drilling process, these sand particles will be disintegrated from the parent rocks and transported together with the hydrocarbons, mixing with crude oil to form two-phase solid and liquid flow (slurry) up through the drilling bore into the production lines.

Presences of sand particles are unfavorable in the production facilities especially for oil and gas industry. It is found that about 70% of oil and gas reservoirs worldwide are unconsolidated (Chen et al. 2010), lacking of proper sand management and sand-control applications. Thus initiatives are taken to install complex and high-maintained sand filtration systems to filter sand particles from going further into the process facilities and equipment. Although there are sand filtration system and separation vessel are installed, there are cases reported that sand breakthrough occurred from time to time. Sand breakthrough can be considered as major problems as the sand particles which seeping through the filters flowed into equipment and will cause blockages as the sand particles accumulated at the equipment.

Based on the problems identified, extensive researches had been done and title was proposed to materialize the theory on two-phase (solid-liquid) passive separation in piping system. This theory is based on multiphase flow behavior and characteristic including solid and liquid physical characteristics that assist on the separation of both phases. The model is visualized as the mixture of sand particles and oil flowing into the horizontal piping, hitting pipe-end before flowing upward into smaller side-arm branch, leaving denser sand particles, accumulated in the horizontal pipe.

1.2 Problem Statement

Even though the industry is depending on the sand filtration system to work efficiently keeping the sand particles out of production lines, some cases reported that there are sand breakthroughs, meaning that sand particles seeping through the filtration system. These are quite an alarming situation as;

a) Presence of sand particles in the hydrocarbon flow, resulting in the difference in density of mixtures that will cause turbulences or instable flow in the piping and thus causing erosion by the solid particles drag against the piping walls.
b) Sand breakthrough in the piping system will be flowing to the facilities' equipment, resulting in blockages and wear to the equipment as the solid particles struck and deposited, directly reducing the efficiency of the equipment while causing reduction in production generally.

1.3 Objectives

This project aims to:

a) To investigate multiphase flow characteristic in piping system, with emphasis of inlet velocities, relative densities and viscosity, initial volume fraction of sand particles and sizes on the flow pattern.
b) To investigate the geometry on passive separation mechanisms in piping, in particular, the elbow/junction design and inlet/outlet diameter ratios.

1.4 Scope of Study

The scope of this study is focused on oil and sand particles passive separation in piping using pipe elbow consists of horizontal and vertical flow, including the study of relationship between the multiphase flow characteristic and parameters such as inlet velocity, phase's density, pressure, and flow model.

1.5 Feasibility of Study

The project was initially planned and reviewed to understand the complete concept and mechanism of the in-piping passive separation involving different phases and parameters. Based on the scopes of study done among the published journals and articles, it is feasible to develop in-piping passive separation system involving oil and sand particles via piping elbow adopting the physical elements of phases such as density, pressure, velocity, and flow model.

CHAPTER 2

LITERATURE REVIEW

2.1 Multiphase Flow Patterns

Flow patterns or flow regimes are among the types of geometric distribution of components within the flow. These geometric distributions are strongly affecting the interfacial area available for momentum,mass, or energy exchange if available, between the phases. Multiphase flow patterns can be classified by examining the flow visually, while other methods such as analyzing the spectral content of unstable pressure and volume fraction imbalances. According to previous investigation done, flow patterns are depending on component volume fluxes of volume fraction, and fluid properties such as density, viscosity, radial pressure and surface tension. Boundaries between various flow patterns occur because a flow regime becomes unstable as growth of instability of flow causes transition to another flow patterns. Based on the transport mechanism of solid and liquid phases in piping system, flow velocity and particle sizes are among the most important parameters that will determine the flow characteristics or patterns. These parameters are important prior to the project for the passive separation to effectively separate both phases as the flow velocity and particles sizes determine the distance and amount of solid particles depositing in the pipe

2.1.1. Horizontal Flow Characteristic

According to Li et al. (2005), the flow pattern during the solid transportation is essential when dealing with horizontal liquid-solid transport. When the solid particles sizes are small, their minimum terminal velocity or the settling velocity are much lesser compared to turbulent-mixing velocity. Diagram by Simon Lo (2013) below showed the characteristic of liquid and solid of slurry flow in horizontal pipe. We can observe that velocity of liquid is high at the upper middle of the pipe cross-section compared to that of sand particle while the particle volume of sands are high at the bottom of the pipe.

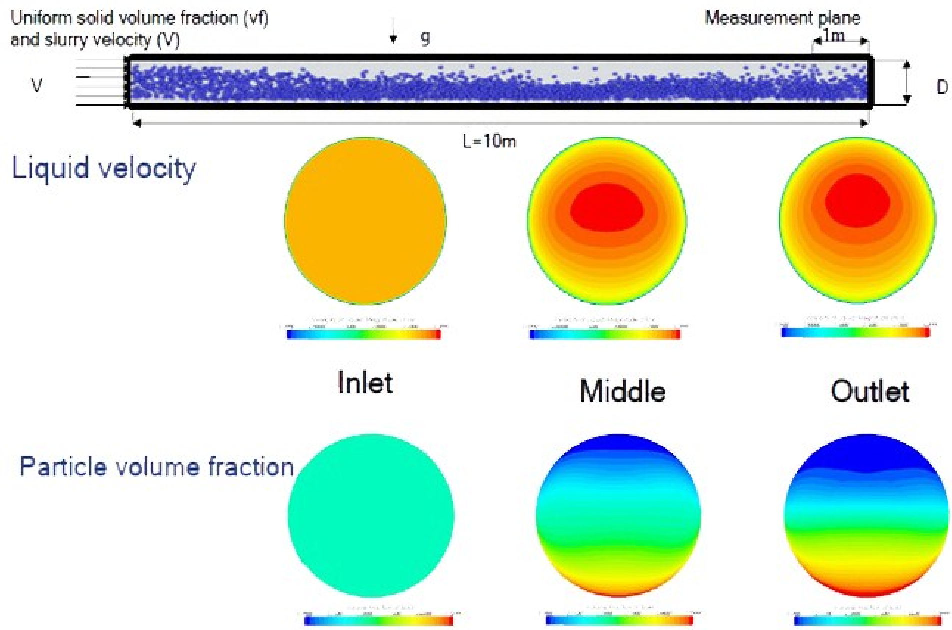

Figure 2.1 Slurry flow in horizontal pipe (Simon Lo, 2013)

One of the most fundamental characteristics of multiphase flow pattern involves the separation of phases in flow. The degree of separation of different phases can be described as *dispersed* and *separated*. *Dispersed* flow pattern in which one phase is largely distributed as bubbles or particles while the other phase is continuous. *Separated* flow consists of separate, parallel streams of two or more phases. In addition, the degree of separation is determined by initial conditions of multiphase flow generation and balance between fluid mechanical processes. According to Ramesh, L.G.(2000), “flow of slurry in pipes depends upon the interaction between the solids and liquid as well as between the slurry and the pipe”. Depending on the parameters that determine the flow characteristics, there are four characterized regime of solid-liquid flow in a horizontal pipe. These are; homogeneous flow, heterogeneous flow, intermediate regime and saltation regime.

Homogeneous flow: the solid particles and uniformly distributed across the pipe cross section. This flow type is most encountered in high concentrations and fine particles sizes of slurries such as drilling mud

Heterogeneous flow: this flow is referred to the concentration gradient across the pipe cross section as it is encountered in slurries of low concentration with rapidly settling solids.

Intermediate regime: this type of flow involves solid particles distributed both in homogeneous and heterogeneous flow.

Saltation regime: the upper particles travel by jumps or rolls along the sliding or stationary bed of solid particles on the bottom of pipe, as the fluid turbulence is not sufficient to maintain the fast settling particles in the liquid flow. A schematic diagram of solid-liquid flow pattern is shown in Figure 2.2

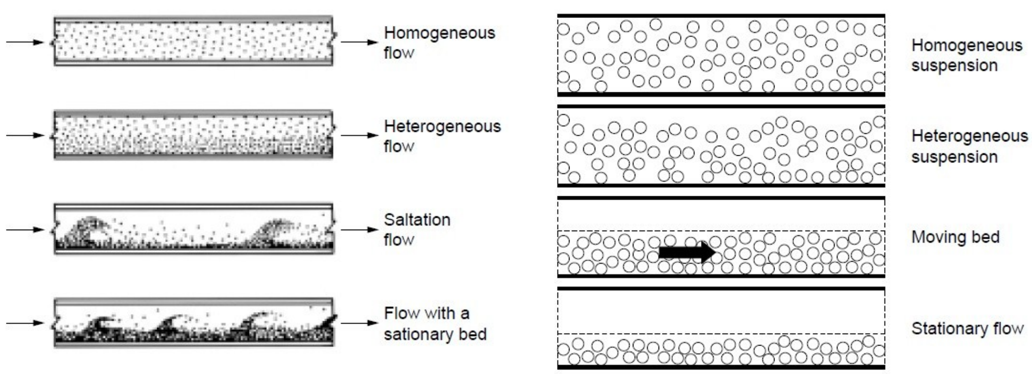

Figure 2.2: Flow regimes for solid liquid transport (Peysson 2004)

This study is focused on the transportation and separation of oil and sand particles from the parent rocks in the reservoir. The size of these particles ranges from 100micrometers to 1 millimeter. Sand particles are most likely transported in a saltation mode due to high density of sand compared to flowing fluid and relatively low fluid velocity.Solid particles can be deposited horizontally when the transport condition, which is when fluid velocity lower than the minimum terminal velocity.

2.1.2. Minimum Terminal Velocity

Deposition of sand particles to form sand bed occurs when the mixture velocity is lower than certain terminal velocity. The minimum average fluid velocity required to initiate solid bed formation is defined as the minimum terminal velocity (MTV). Mingqin et al. (2007) explained that "there are a number of different names for this parameter, such as critical deposition velocity (CDV), critical transport fluidvelocity (CTFV), and more recently critical foam velocity (CFV). They all indicatethe same condition". Relationship between fluid minimum terminal velocity and sand particles deposition can be explained as the mixture velocity is lower than the minimumterminal velocity, sand will separate from carrier fluid and form thick, stationary sand bed. As the sand bed formed continously,the fluid above the bed is forced into a smaller cross-sectionalarea, causing the fluid velocity to increase. When the velocityreaches a critical value which is the terminal velocity, sand is transported along on the top of the sand bed. At higher velocity, the sandbed begins to break up into a series of moving dunes. As the velocity increases, the sand dunes break up entirely, and the sand forms amoving bed along the bottom of the pipe. As the liquid flows above the maximum terminal velocity, the sand is fully dispersed in the fluid phase.It is observed that smaller sand particles are easier to flow in suspension, butit would be difficult to re-suspend once it deposit and forms sand bed. This is because smaller particles tend to form more compact bed than larger sand particles due to less space pore between the particles.

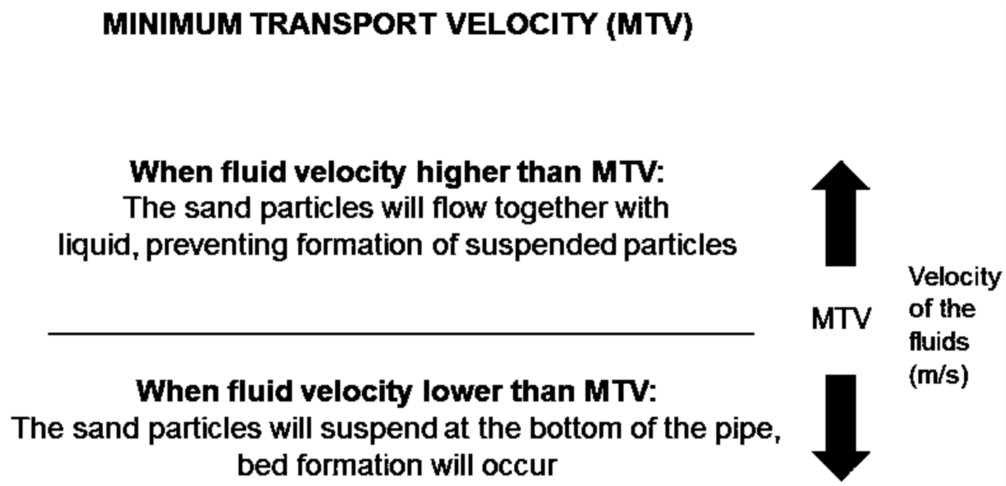

Figure 2.3 Effect of fluid velocity on particles deposition (Weber, 2012)

According to Peyson et al (2004), “When the bed of sand particles starts to flow, dunes and waves can appear at the interface. A two layer bed can form with a stationary layer at the bottom and a moving bed on top of it”. In order for the phase’s separation to perform effectively, the sand particles need to be deposited at bottom of pipe so that there will less sand particles flowing to the side arm, limiting the flow to liquid only.Mixture velocity need to be lower than the minimum terminal velocity for the sand particles to separate from the carrier fluid and deposited, forming sand bed. Below the minimum terminal velocity, two flow regimes are considered which are: moving bed or stationary bed where the sand particles accumulated.

Bed becomes stationary when the total driving force acting on the bed is lower than the total forces opposing the bed motion. When there is increased velocity of fluid, sand particles will roll or saltate through the top of the sand bed. According to Bello et. al (2011), “The development of minimum transport velocity models for suspension and rolling based on the concept of particle velocity profiles is a significant breakthrough in particle transport in multiphase flow”. This breakthrough is able to solve problems and risks of sand deposition & bed formation, elimination of dependence to complex mechanism to separate different phases involving solid particles.

2.2. Flow Model

According to Lahiri et al., S.K. (2010), “CFD studies on solid-liquid slurry flow in pipelines have not been widely studied as observed from the literature and majority of the documented data focuses on empirical correlations of concentration profile of water-based slurries of fine particles”. Computational fluid dynamics (CFD) has become an important tool in studies of multiphase flows as its approach has been used to simulate single-phase and multiphase flow. Modeling flow model is a generalization of the modeling used in two-phase flow to cases where the two phases are not chemically mixed or more than two phases are present in the flow. Each of the phases present is considered to have a separate inlet volume fraction and velocity. Governing equations for the flow of each model can then be calculated through breakdown of more detailed flow model available. Described are the types of fluid modeling based on multiphase flow.

2.2.1. Euler-Lagrangian Approach

The fluid phase is assumed as a continuum by solving the Navier-Stokes equations, while the dispersed phase is solved by tracking a large number of particles through the calculated flow mixture. The dispersed phase can exchange momentum, mass, and energy with the fluid phase. A fundamental assumption made in this model is that the dispersed second phase occupies a low volume fraction, even though high mass loading is acceptable. The particle or droplet trajectories are computed individually at specified intervals during the fluid phase calculation. This makes the model appropriate for the modeling of solid particle suspensions flow, but inappropriate for the modeling of liquid-liquid mixtures, fluidized beds, or any application where the volume fraction of the second phase is not negligible.

2.2.2. Euler-Euler Approach

In the Euler-Euler approach, the different phases are assumed mathematically as penetrating continua as the volume of phase cannot be occupied by other phases, the concept phase volume fraction is applied. This volume fraction is assumed to be continuous functions of time. The three different Euler-Euler approaches are volume of fluid, mixture, and Eulerian model.

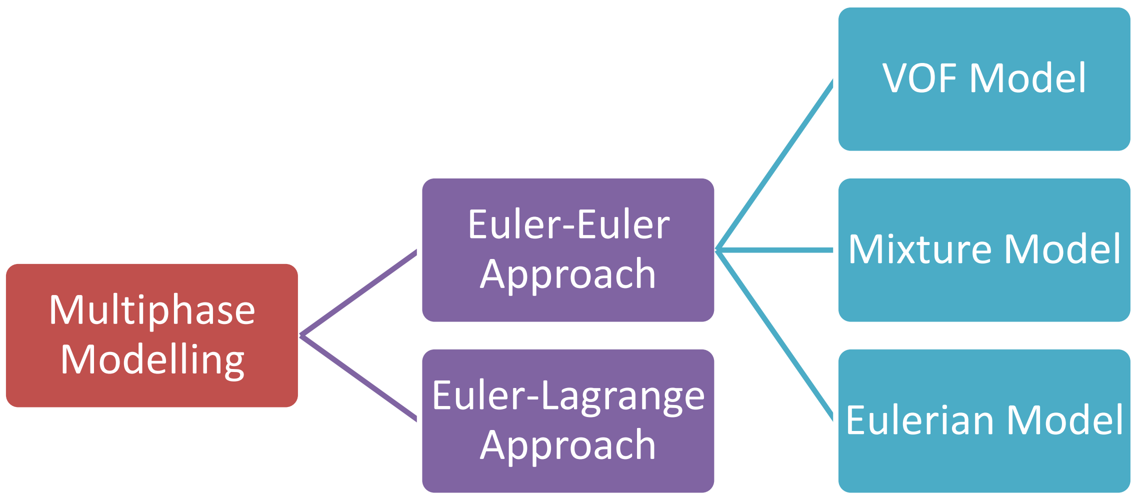

Figure 2.4 Approach Breakdowns in Multiphase Modeling (Lahiri et al., S.K., 2010)

2.2.2.1. Volume of Fluid (VOF) Model

In computational fluid dynamics, the Volume of fluid method is one of the most well-known methods for volume tracking and locating the free surface applied to fixed Eulerian approach. It is designed for two or more immiscible fluids where it only accounts to the position of interface between the fluids. It is also defined as numerical concept that allows the user to track the shape and position of interface. Application of VOF model includes free surface flow, motion of large bubbles, and stratified flows.

2.2.2.2. Mixture Model

The mixture model is designed for two or more phases (fluid or particulate) that can be used in different ways and can be applied to model multiphase flows where the different phases move at different velocities. The mixture model can model and phases (fluid or particulate) by solving both the continuity equation and the momentum equation for the mixture, where mixture can be a combination of continuous phase and the dispersed phase. It is applicable in the particle-laden flows with low loading, and bubbly flows where the gas volume fraction are low. In addition, the mixture model solves the energy equation for the mixture, and the volume fraction equation for the secondary phases.

2.2.2.3. Eulerian Model

Eulerian model is the most general model for solving multiphase flows. In the presentwork, we are using Eulerian model to simulate two-phase and three-phase flow. The Eulerian model is the most complex of the multiphase models. It solves a set of momentum and continuity equations for each phase.

CHAPTER 3:
METHODOLOGY

3.1. Data Collection and Calculation

3.1.1. Minimum Terminal Velocity (MTV)

The significant of velocity profile established in pipe flow can be applied to multiphase flow but need to be treated differently as different flow patterns have different complexities. Studies of multiphase flow pattern are essential in determining the transport velocity. The theory of minimum terminal velocity is applied to find the minimum velocity for the sand particles to suspend for bed formation to occur. A critical velocity is required for each of the aforementioned sand deposition to occur. The theory of this terminal velocity defines the minimum point velocity that decides either the sand particles moving along, rolling on the top of sand bed with the fluid flow or suspended stationary. When the fluid velocity is higher than the minimum terminal velocity, the sand particles will continuously moving, thus avoiding the particles to settle.These are referred to as the MTV for rolling and MTV for suspension, expressed as;

For suspension: $$V_m = A * \left[\frac{g d_p}{C_L \rho_L} * (\rho_P - \rho_L)\sin\theta\right]^B \left[\frac{D\rho_L}{\mu_L}\right]^C \quad (1)$$

For rolling, $$V_m = \left[\frac{A * d_p\left[\frac{\rho_P}{\rho_f} - 1\right] g * [\cos\theta + f_s * \sin\theta]}{[C_D + f_s C_L]}\right]^B \quad (2)$$

Where C_D and C_L are drag and lift coefficients, ρ_P and ρ_f are particles density and fluid density, d_p is the particle sizes, A, B& C are constants as defined in the table (Bello et al. 2011).

Drag coefficient, $$C_D = \left[\frac{a}{{Re_p}^b}\right] \quad (3)$$

Lift coefficient, $C_L = \left[\frac{c}{{Re_p}^d}\right]$ (4)

Reynolds Number for particles, $Re_p = \left[\frac{\rho_f v_p d_p}{\mu_f}\right]$ (5)

$*Re_p = Particle\ Reynolds's Number$

a,b,c& d are empirical constants

Table 3.1 Constants of equations for different flows

MTV	A	B	C
Suspension	0.01-0.03	0.5-1	0.5-1
Vertical Pipe	4-6	0.1-1	-

For velocity below the minimum terminal velocity (MTV) for suspension, the solid particles will slide along on the sand bed or the pipe wall, accumulating to the bottom of pipe which may eventually result in stationary bed as the pressure drops along the pipeline causing reduction in the particle drag force.

3.1.2. Relationship between the particles size and MTV

According to Richard (2012), “The sizes of sand particles have effect on the MTV of the liquid, which they are transported in”. A monographic chart containing parameters such as pipe diameter, particle size and particle density is shown below.

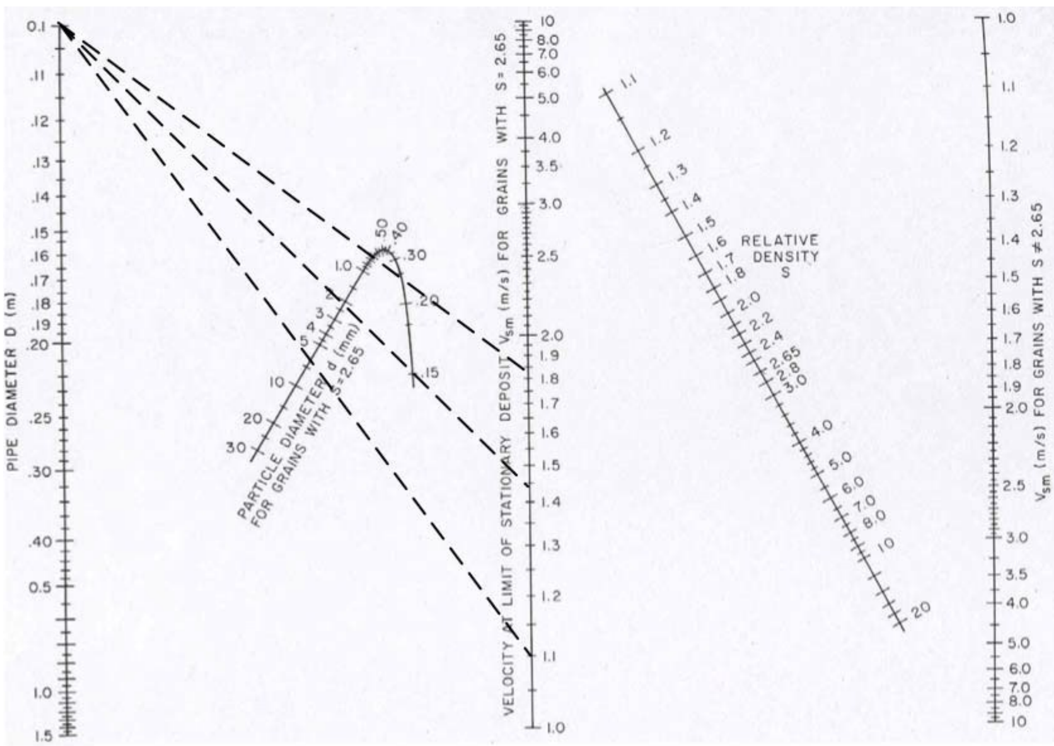

Figure 3.1 Monographic Charts for Minimum Terminal Velocity (Li and Wilde, 2005)

According to Michael (2012), another relationship for minimum terminal velocity in horizontal pipe involving particle sizes is

Terminal velocity, $$V_t = F[2g(s-1)D]^{1/2}\left(\frac{d_p}{D}\right)^{1/6} \quad (6)$$

Where,

F empirical constant (0.5),

G gravitional acceleration (9.81m/s^2),

s relative density of sand

D diameter of pipe, d_p diameter of particles

3.1.3. Slurry Density, Viscosity and Volume Fraction

Since the slurry consists of solid particles suspended in a liquid, the properties of a slurry mixture will depend upon those of the constituents. The density of slurry can be calculated from the following equation:

$$\rho_m = \frac{100}{\left[\frac{C_w}{\rho_s}+\frac{(100-C_w)}{\rho_l}\right]} \tag{7}$$

Where:

ρ_m =density of slurry mixture, kg/m^3

C_w = solids concentration by weight, %

ρ_s = density of solid in mixture, kg/m^3

ρ_L = density of liquid in mixture, kg/m^3

The variable C_w represents the amount of solid in the mixture by weight. The term C_v is a corresponding value in terms of volume. The term volume fraction represented by the symbol Φ is equal to $C_v/100$. The term volume ratio represents the ratio of the volume of solid to the volume of liquid.

Equation for the volume fraction and volume ratio:

$$\Phi = \frac{C_v}{100} \tag{8}$$

$$\text{Volume Ratio} = \frac{\Phi}{1-\Phi} \tag{9}$$

where:

C_v = Concentration of solids by volume, %

Φ = Volume fraction

The concentration of solids by volume C_v and the concentration of solids by weight C_w are correlated to the solid density and the mixture density by the following equation:

$$C_v = C_w * \left(\frac{\rho_m}{\rho_s}\right) \quad (10)$$

where:

C_v = solid concentration by volume, %

The viscosity of a mixture consisting of solids in a liquid can be calculated from the volume fraction Φ and the viscosity of the liquid using the following equation:

$$\mu_m = \mu_L * (1 + 2.5\Phi) \quad (11)$$

where:

μ_m = viscosity of slurry mixture, cP

μ_L = viscosity of liquid in slurry mixture, cP

3.1.4. Tools and Equipment

A simulation program is based on the modeling processof real phenomenon with a series of built-in mathematical formulas. It allows the user to observe an operation through simulation without actually performing that operation used widely to design equipment without expensive in process modification. Based on the requirement of design and parameters, ANSYS Fluent is chosen. ANSYS Fluent is powerful and flexible computational fluid dynamics software used to model flow, turbulence for industrial applications. The physical models allow accurate CFD analysis for a wide range of fluids problems which is integrated into ANSYS Workbench.

3.1.5. Development of model simulation

The development of a two dimensional (2D) piping elbow model is created with pipe length measured 10m, with inlet diameter of 0.2m while side arm diameter is reduced to 0.1m as shown in Figure 3.1. The total surface area generated is 3.5m^2. Fine mesh is applied to the model and then followed by simulation using the CFD program solver (ANSYS Fluent). Parameters such as the velocity inlet for sand particles and oil, oil viscosity, density of both and others are taken into consideration.

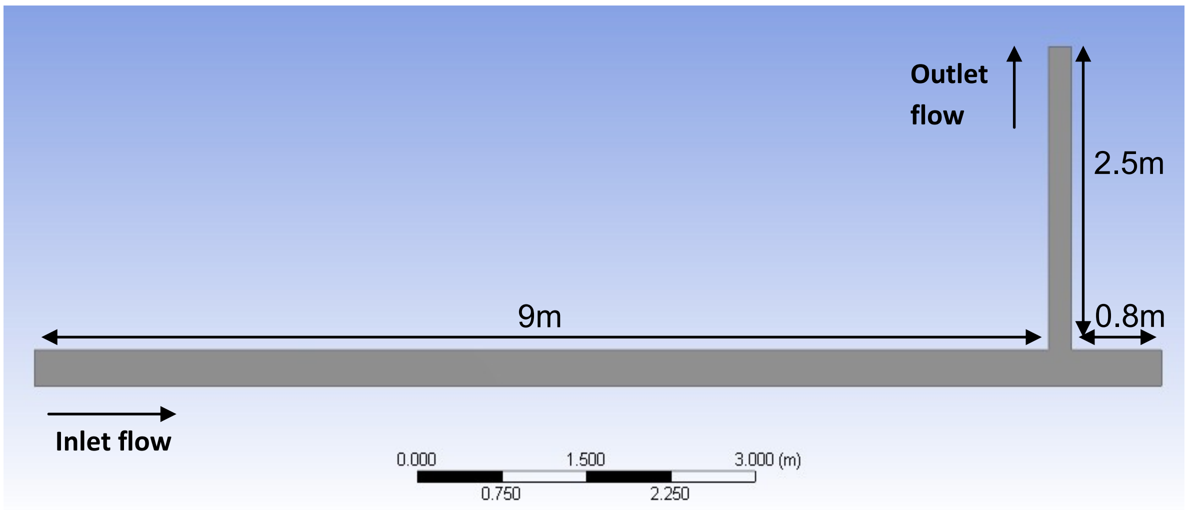

Figure 3.2 2D Piping elbow model

3.1.6. Mesh Analysis

This analysis is one of the approaches to study the dependences of sand volume fraction based on different mesh density. Simulations had been performed with two different sets of total number of nodes. All the figures below illustrate the contours of sand volume fraction of the flow. Basically, the comparison are made between the coarsest mesh and the finest mesh which have total number of 1657nodes and total number of 20546nodes respectively. It is shown that the contours differ from the coarsest and the finest meshes. These depict that the contours are more precise and accurate as the mesh is refined.

Comparison of sand volume fraction contours by applying different mesh densities.

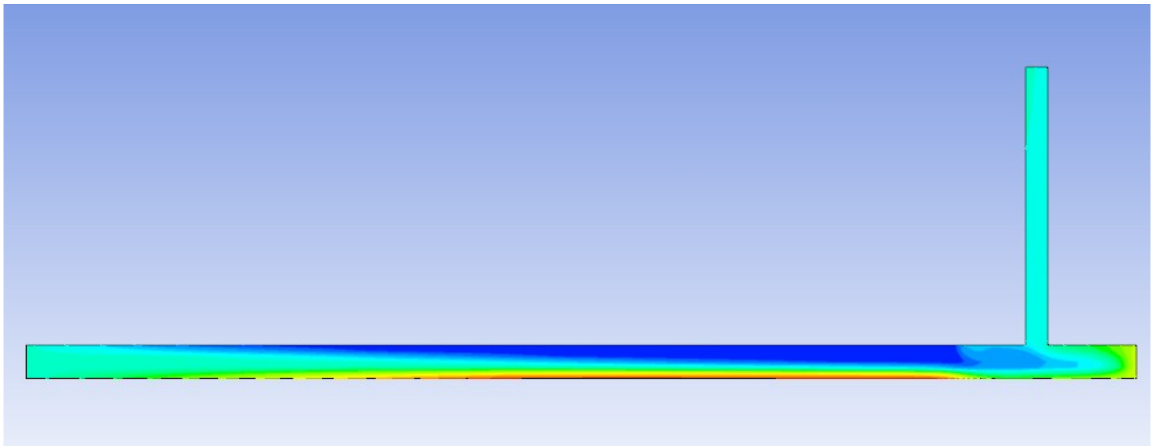

Figure 3.3 Pressure contour of mixture phase with total number of 1657 nodes

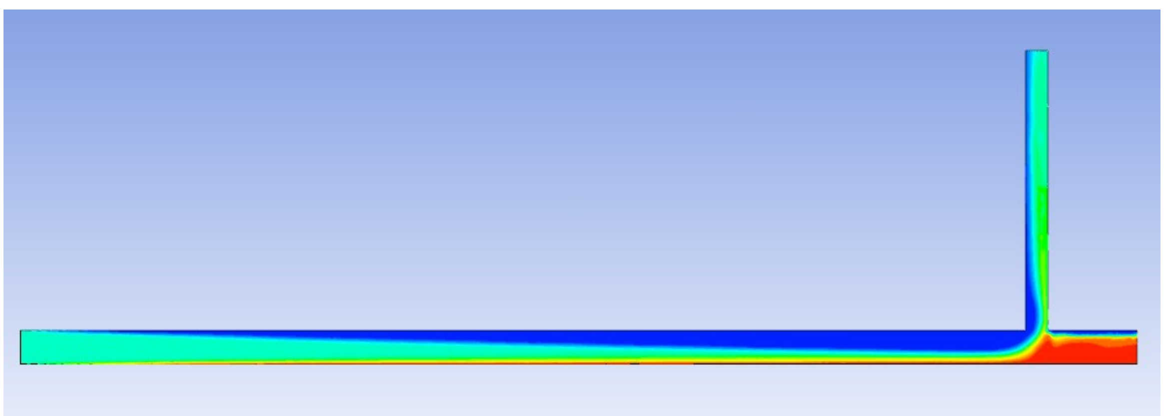

Figure 3.4 Pressure contour of mixture phase with total number of 20546 nodes

3.1.7. Project Methodology Summary

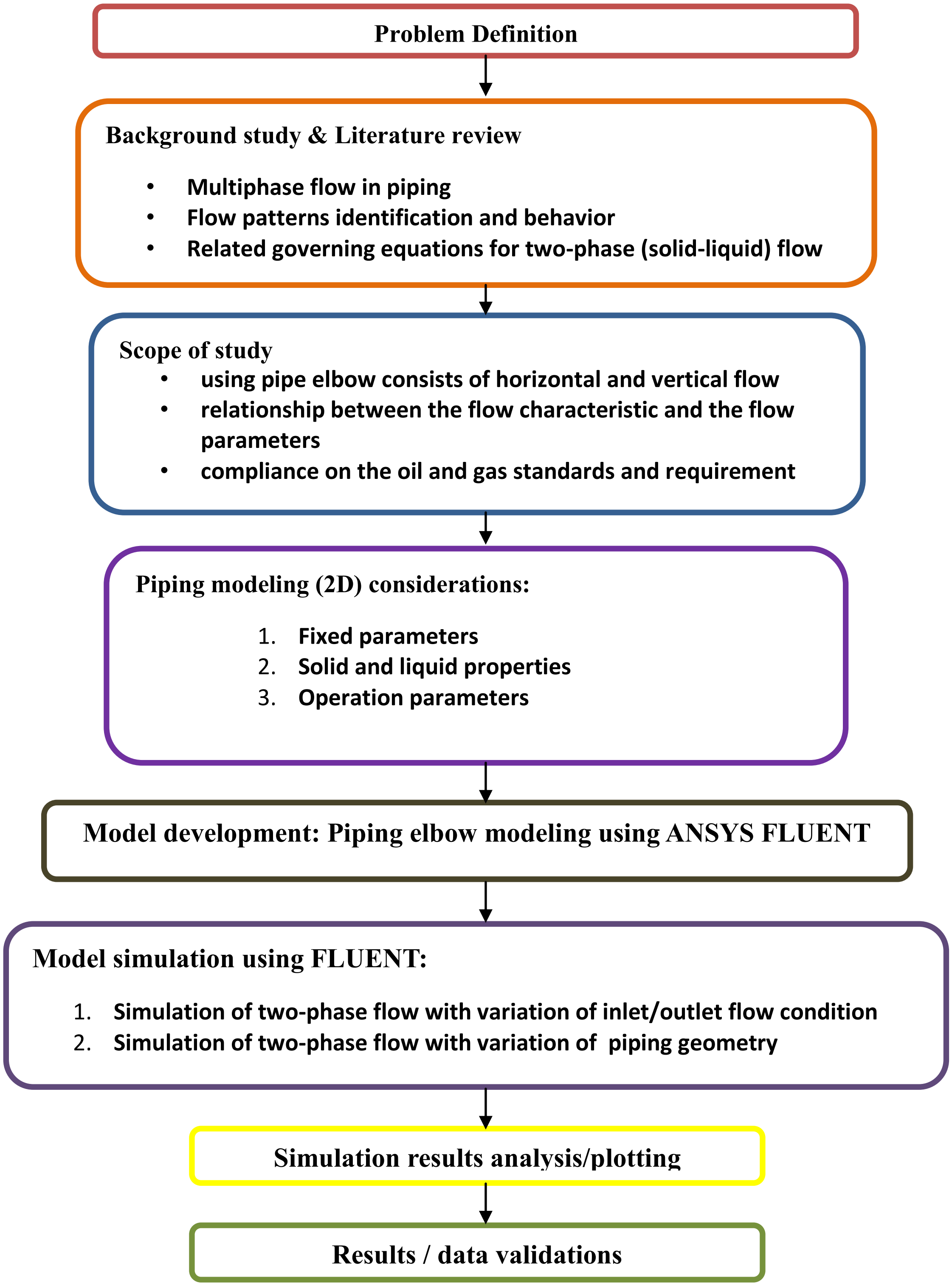

Figure 3.5Project Methodology

3.2.Project Activities

Figure below shows the project current and expected flow. The project is divided into four phases which are background study & literature review, 2D/3D modeling, model simulation, and simulation result analysis.

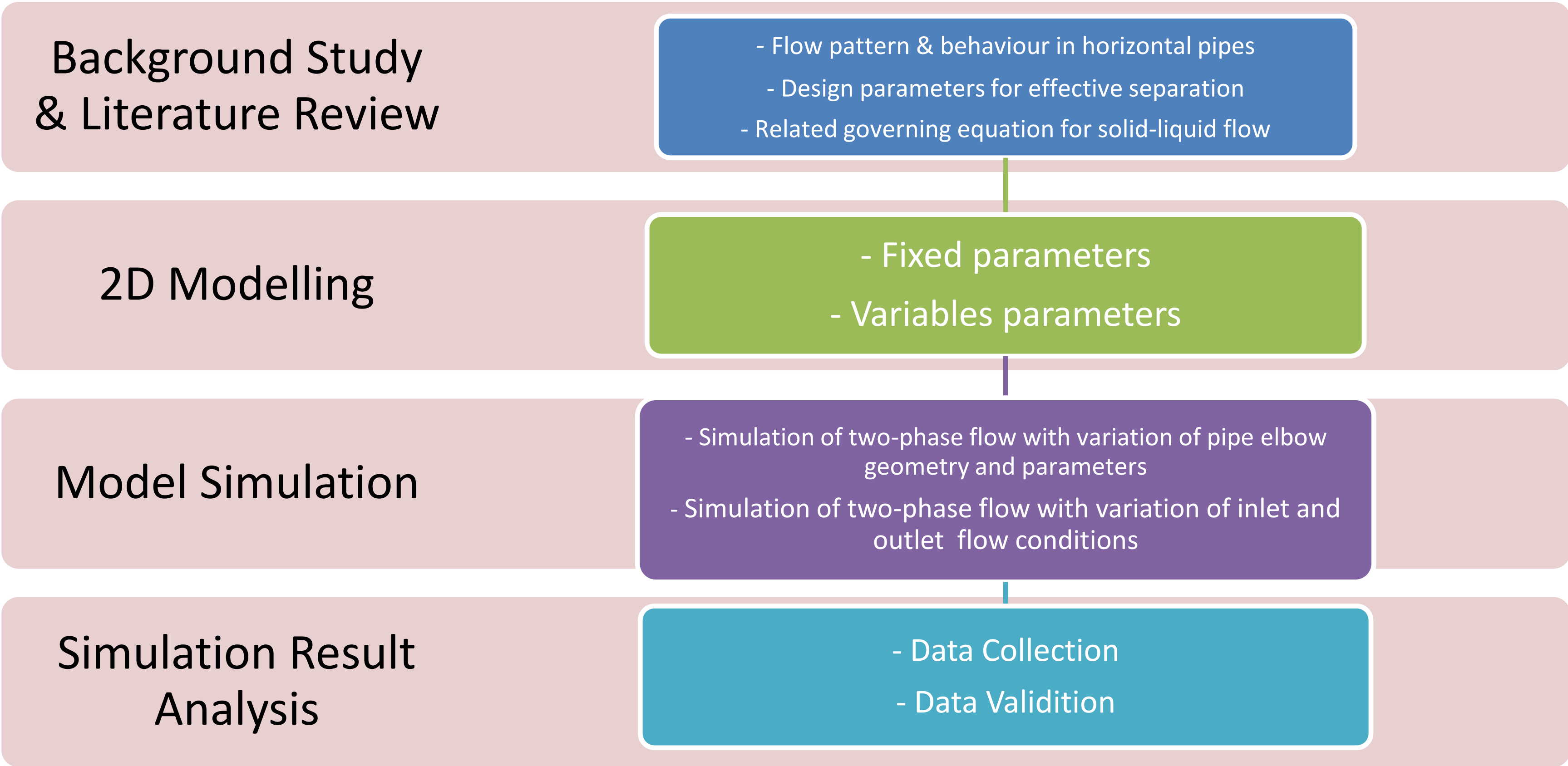

Figure 3.6 Project Activities

3.3. Gantt Chart and Key Milestones

Table3.2 Project Gantt Chart & Milestones

	Activities	FYP I													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Topic Selection	■	■												
2	Preliminary research and feasibility		■	■											
3	Literature review on oil-sand			■	■	■	■★								
4	Software acquisition and learning					■	■	■	■	■					
5	Determine the design parameters, variables, and data associated						■	■							
6	Model development (piping elbow) using ANSYS Fluent							■	■★	■					
7	Model simulation of the separation process								■	■★	■	■	■		
8	Interim report preparation											■	■	■	■★
9	Piping elbow modelling with variation geometry														
10	Model simulation of solid-liquid separation with variation of geometry														
11	Simulating results analysis														
12	Results and data validation														
13	Thesis preparation														

Semester Break

	Activities	FYP II													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Topic Selection														
2	Preliminary research and feasibility														
3	Literature review on oil-sand														
4	Software acquisition and learning														
5	Determine the design parameters, variables, and data associated														
6	Model development (piping elbow) using ANSYS Fluent														
7	Model simulation of the separation process														
8	Interim report preparation														
9	Piping elbow modelling with variation geometry	■	■	■	■	■									
10	Model simulation of solid-liquid separation with variation of geometry				■	■	■	■							
11	Simulating results analysis								■	■★	■				
12	Results and data validation										■★	■★	■		
13	Thesis preparation												■★	■★	

★ Denoting key milestones

CHAPTER 4:

RESULT AND DISCUSSIONS

4.1. Verification of the Simulation Model with Experiment Data

Zhenjin et al. (2010) did an experiment to study the effect of sand presence in petroleum pipelines on the fluid flows including the effect of cross sectional area reduction to the flow, and the hydrodynamic of fluids boundary layer in horizontal pipe flow. In this experiment setup, a mixture of oil and sand particles was introduced into a horizontal pipe with length of 10m and diameter of 0.3m to compare the amount of sand deposited in horizontal pipe for simulated result and experimental result.

Uniform velocity profile is applied for single phase oil at the inlet boundary through empirical formula, which all data samples are selected from Zhenjin's experiments. Specifically for developed turbulent and laminar flow ;

For fully turbulent; $$\frac{U}{U_{max}} = \left(\frac{r_0 - r}{r_0}\right)^m \quad (12)$$

Where

U_{max}Maximum velocity,r distance to centerline,r_0 pipe radius,
mExponent for the power law (Table 2)

Table 4.1 Exponents for Power Law Equation and velocity ratio

Re	$4x10^3$	$2.3x10^4$	$1.1x10^5$	$1.1x10^6$	$3.2x10^6$
m	1/6.0	1/6.6	1/7.0	1/8.8	1/10.0
$\frac{U}{U_{max}}$	0.791	0.807	0.817	0.850	0.865

In this study, the diameter for main tube, sand particles sizes, phase's density and viscosity are specified and the outcome is predicted by the sand volume fraction at outlet and amount of sand deposited in main tube. Drag function is assumed to be Gidaspow Model that is widely used for calculating solid liquid flow, which is recommended for dense fluidized beds. Standard k-ε turbulence model is used as in this study, both phases are assumed to share the same k and ε values therefore interphase turbulence transfer is not considered. The data collected from the Zhenjinet al.'s experiment is used to compare with the data collected from the simulation model on the similar case of horizontal pipe. Figure 4.1 shows the horizontal pipe designed with 0.3m diameter for main tube and 10m length.

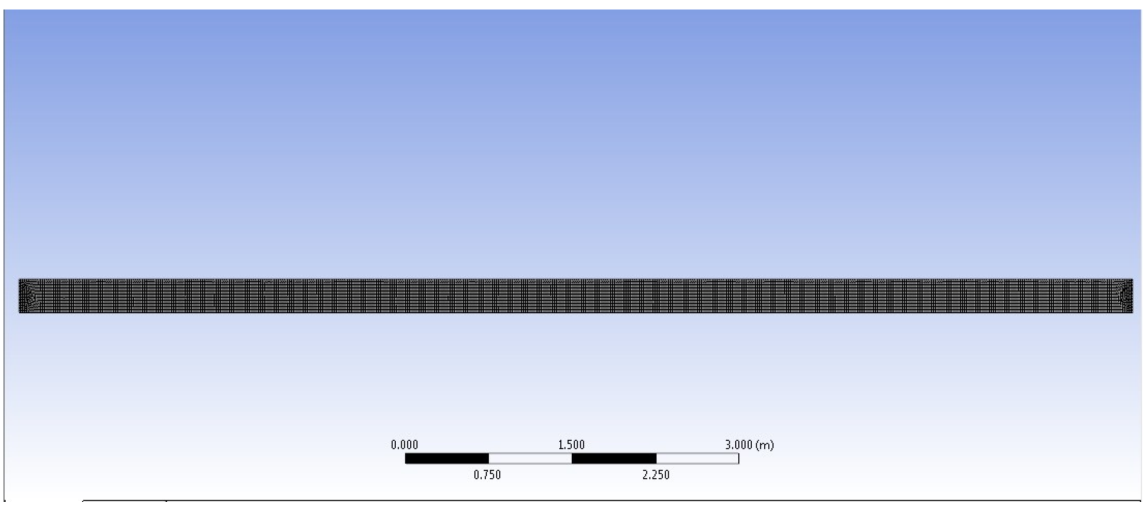

Figure 4.1 Computational grid of horizontal pipe

The results collected from both simulations and Zhenjin's experiment are almost identical for the case of horizontal pipe. Table 3 and Figure 4.2 shows the calculations and comparison of data obtained from the experiment and the simulation model for amount of sand deposited in the main tube against the horizontal length of pipe.

Table 4.2 Volume of sand deposited from horizontal pipe

Pipe length (m)	Area reduced (m^2)	Cumulated area reduced (m^2)	Area under graph , volume deposited (m^3)	Cumulated volume deposited (m^3)
0	0.0000	0.0000	0.0175	0.0175
1	0.0350	0.0350	0.0425	0.0600
2	0.0150	0.0500	0.0125	0.0725
3	0.0100	0.0600	0.0138	0.0863
4	0.0175	0.0775	0.0138	0.1000
5	0.0100	0.0875	0.0100	0.1100
6	0.0100	0.0975	0.0075	0.1175
7	0.0050	0.1025	0.0038	0.1213
8	0.0025	0.1050	0.0038	0.1250
9	0.0050	0.1100	0.0038	0.1288
10	0.0025	0.1125	0.0013	0.1300

The table above showed the total volume deposited at length of 10m from inlet. The volume of sand deposited is calculated from the reduction in height of sand volume fraction profile for every one meter. From the difference in height, area reduced is calculated and from the graph of cumulated area reduced against the length, area under the graph is calculated to produce the data for volume deposited. The mixture volume at inlet is assumed to be at $1.0m^3$; with sand volume at inlet is $0.2m^3$. The volume of sand deposited is $0.13m^3$.

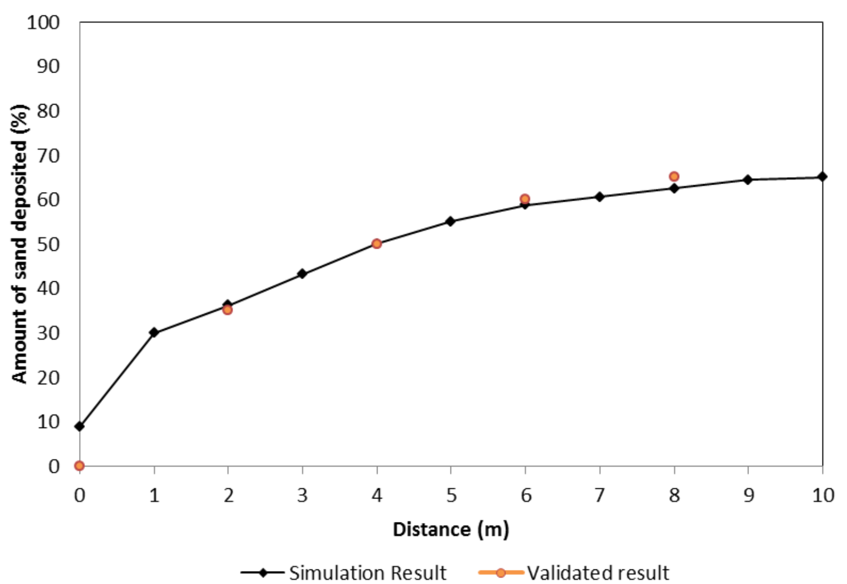

Figure 4.2 Simulated amount of sand deposited compared with experimental results

From the graph above, the result form simulated data showed the amount of sand particles deposited increased gradually with length of pipe from the inlet. This result is identical to the experimental data from Zhenjin's experiment on amount of sand deposited in horizontal pipe. Based on the graph, it is concluded that amount of sand particles deposited to form sand bed increased with respect of horizontal distance from the inlet.

In this study, additional side arm is applied to the geometry with extended closed-end with idea to improve on separation process through the convergence flow of mixture from inlet. The diameter of side arm is set to be lower than the main tube in order to limit the amount of sand particles in the outflow. Figure 4.2 shows the horizontal pipe designed with 0.3m diameter for main tube and 10m length with additional side arm, diameter of 0.2m and length of 2.5m.

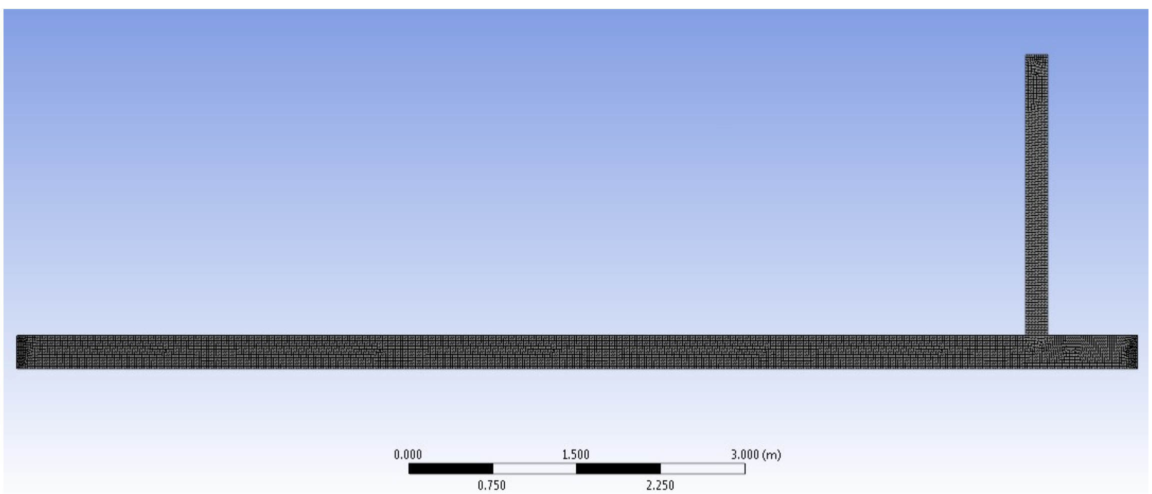

Figure 4.3 Computational grid of horizontal pipe with side arm

Table 4.3 Volume of sand deposited from horizontal pipe with side arm

Pipe length (m)	Area reduced (m^2)	Cumulated area reduced (m^2)	Area under graph , volume deposited (m^3)	Cumulated volume deposited (m^3)
0	0.0000	0.0000	0.0175	0.0175
1	0.0350	0.0350	0.0425	0.0600
2	0.0150	0.0500	0.0125	0.0725
3	0.0100	0.0600	0.0138	0.0863
4	0.0175	0.0775	0.0138	0.1000
5	0.0100	0.0875	0.0100	0.1100
6	0.0100	0.0975	0.0075	0.1175
7	0.0050	0.1025	0.0038	0.1213
8	0.0025	0.1050	0.0200	0.1413
9	0.0375	0.1425	0.0200	0.1613
10	0.0025	0.1745	0.0013	0.1773

From the simulated data of horizontal pipe with side arm, the amount of sand deposition at the main tube is observed. The mixture volume at inlet is assumed to be at 1.0m^3, with sand volume at inlet is 0.2m^3. The volume of sand deposited is approximately 0.18m^3.

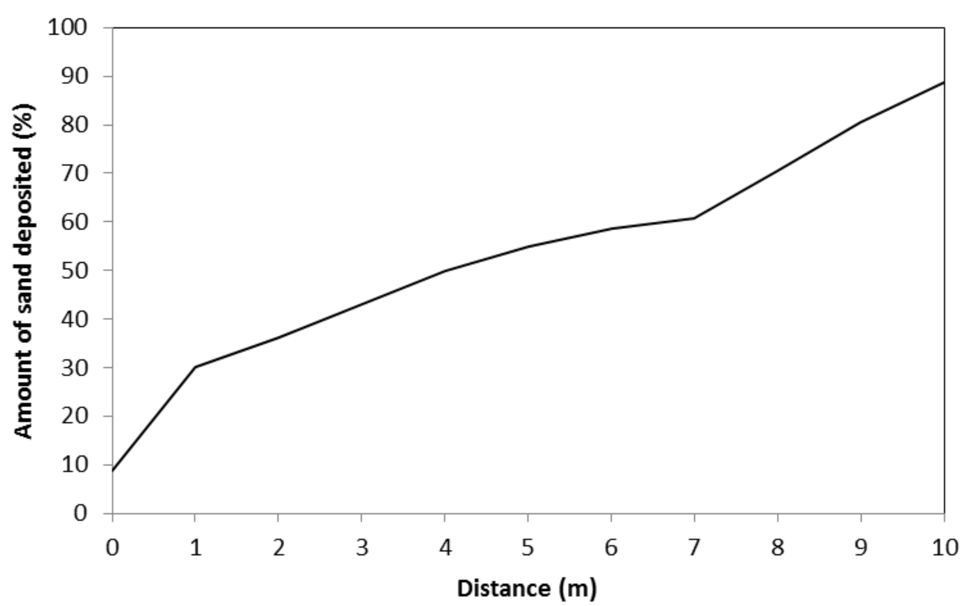

Figure 4.4 Simulated amount of sand deposited with addition of side arm

4.2. Concluding Remarks

Based on the comparison between the simulated data and experimental data, the simulated data showed the amount of sand particles deposited in horizontal pipe increases gradually with length and this result is proven with the experimental data by Zhenjin's experiment that amount of sand particles deposited at the bottom of pipe, forming sand bed increases with length of pipe from inlet. These results explained the multiphase pattern of slurry flow involving liquid with relatively low density and viscosity and solid particles with high density and viscosity. From the simulated data, the volume of mixture at inlet is assumed to be at 1.0m^3 with volume of sand at 0.2m^3. The total volume of sand deposited is 0.13m^3, which is 65% of total volume of sand at inlet.

With addition of side arm will assists on the phase's separation of the flow.From the simulated data of horizontal pipe with vertical side arm, volume of mixture at inlet is assumed to be at 1.0m^3 with volume of sand at 0.2m^3. The total volume of sand deposited is 0.18m^3, which is 87% of total volume of sand at inlet. The volume of sand deposited for horizontal pipe with side arm is higher than the volume of sand deposited with only horizontal pipe by 22%. This reduction is due to deposition of sand particles in the horizontal with extended closed-end pipe and effect of gravity that limits the amount of sand particles in vertical side arm. Thus the combination of horizontal pipe with vertical side arm increases the volume of sand deposition, thus enhancing the phases separation.

CHAPTER 5:

CONCLUSIONS AND RECOMMENDATIONS

In production facilities of oil and gas industry, piping elbow are very common within pipe networks as they are commonly used to transport the components which are oil, gas, water and solid particles prior to flow tothe production facilities for processing. It is important to understand the efficiency of the multiphase separation and the geometric effect of the piping elbow on the flow patterns in order to achievea better separation performance for optimal operation of downstream.This study is mainly focus on phase separation in piping elbow with horizontal tube and vertical side arm using mixture of oil and sand particles as inlet slurry flow.Based the developed simulation model, the significance of associated parameters on two-phase separation efficiency in T-junction is studied. From the tabulated result, it shows that presence of vertical side arm with extended closed-end horizontal tube increases the volume of sand deposited in the horizontal pipe, as the high density and viscosity of sand particles are limiting themselves to flow together with oil, which has relatively lower density and viscosity than sand particles. Fixed parameters such as gravity affects the sand particles flow in vertical side arm as it reduces the volume of sand particles in vertical flow thus contributing in enhancing the phases separation compared to the simulated data without vertical side arm. As a conclusion, application of a piping elbowelbow with horizontal tube and vertical side arm has the potential to be an alternative and cost-effective partial phase separator for separation processes in the industries.

Since geometrical configurationplays an important role in phase separation, it would be interesting to examine different configurations of piping elbow to determine the best selection criteria for a much wider range of flow conditions. Hence, future research can be done to study the effect of altering horizontal pipe to side arm diameter ratio and the orientation of vertical side arm with horizontal pipethat should not be fixed only at 90^o only. The effect of inclination angle of gravity also should be taken into consideration in order to achieve the desired separation flows.

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