THE STUDY OF TWO-PHASE FLOW FOR CRUDE OIL PRODUCTION USING COMPUTATIONAL FLUID DYNAMICS (CFD)

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ABSTRACT

Modeling the liquid-gas phase flow inside the horizontal and inclined pipe using CFD analysis is difficult due to continuously changing flow patterns. The main objectives of this research are to investigate the flow pattern of liquid-gas phase inside the horizontal and inclined pipe. Two-phase flows specifically on the liquid-gas flow have a complex flow pattern that can be observed by develop the 3-Dimensional model using the Computational Fluid Dynamic (CFD) software that consist of Gambit for develop the model of horizontal and inclined pipe and then transfer the data to Fluent for further analysis. The simulation was conducted by modelling the horizontal and inclined plane with the length of 7 m and 0.08 m of inner diameter. This simulation was carried out under adiabatic condition and operating at normal temperature which was 298 K. The gravity was enabled in order to differentiate the phase flow inside the horizontal and incline pipe due to the density of liquid-gas phases. The simulation was run using the Volume of Fluid (VOF) for the solver. The manipulated variables which were velocity of the liquid and gas are been changed in order to predict the various flow pattern for both horizontal and inclined pipe. The results of flow pattern are been analyzed and compared with the previous researchers' results. This can be concluded that all flow patterns appearing in the Baker chart can be simulated using existing CFD. In order to improve the effectiveness of the model developed, the simulation needed to be run until the iteration is converging.

KAJIAN ALIRAN DUA FASA BAGI PRODUKSI MINYAK MENTAH MENGGUNAKAN 'COMPUTATIONAL FLUID DYNAMICS' (CFD)

ABSTRAK

Permodelan aliran fasa cecair-gas di dalam paip mendatar dan condong menggunakan analisis CFD adalah sukar kerana pertukaran corak aliran yang berterusan. Objektif utama kajian ini adalah untuk menyiasat corak aliran fasa cecair-gas di dalam paip mendatar dan condong. Aliran dua fasa khususnya fasa cecair-gas mempunyai corak aliran yang tidak menentu dapat dikaji dengan membina model 3-Dimensi menggunakan perisian Computational Fluid Dynamic (CFD) yang terdiri daripada Gambit untuk membangunkan model paip mendatar dan condong dan kemudian memindahkan data ke Fluent untuk analisis selanjutnyaSimulasi telah dijalankan dengan model satah mengufuk dan condong dengan panjang 7 m dan 0.08 m diameter dalaman. Simulasi ini telah dijalankan dalam keadaan adiabatic dan beroperasi pada suhu 298 K. Graviti telah diaktifkan untuk membezakan aliran fasa dalam paip mendatar dan condong disebabkan oleh kepadatan fasa cecair-gas. Simulasi telah dijalankan menggunakan Volume of Fluid (VOF) sebagai penyelesai. Halaju cecair dan gas adalah pembolehubah dimanipulasikan diubah untuk meramalkan pelbagai corak aliran bagi kedua-dua paip mendatar dan condong. Keputusan corak aliran telah dianalisis dan dibandingkan dengan keputusan penyelidik sebelumnya. Ini dapat disimpulkan bahawa, semua corak aliran yang terdapat dalam carta Baker boleh disimulasikan menggunakan perisian CFD. Dalam usaha untuk meningkatkan keberkesanan model, simulasi perlu berjalan sehingga pengulangan menumpu.

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LIST OF SYMBOLS

°	–	Degree
f	–	Frictional factor
g	–	Gravitational force (-9.81 m/s)
kg	–	Kilogram
m	–	Meter
m^2	–	Meter square
m^3	–	Cubic meter
Pa	–	Pascal
Δp	–	Pressure drop
s	–	Second (time)
U	–	Superficial velocity (m/s)
v	–	Velocity (m/s)
σ	–	Surface Tension (N/m)
ε	–	Turbulent energy dissipation rate
Φ	–	Dimensionless parameter
θ	–	Inclination angle with respect to horizontal, °
$\dot{m}$	–	Superficial mass velocity (kg/(m^2/s))
ρ	–	Density (kg/m^3)
T	–	Temperature
λ	–	Dimensionless parameter
ψ	–	Dimensionless parameter
μ	–	Viscosity (Pa s)

LIST OFABBREVIATIONS

3-D	–	3 Dimension
CFD	–	Computational Fluid Dynamic
et. al.	–	and others
Fr	–	Froude number
Ku	–	Kutadelaze number
Mesh	–	Meshing
Re	–	Reynolds number
SKE	–	Standard k-ε
VOF	–	Volume of Fluid
X	–	Martinelli parameter

CHAPTER 1

INTRODUCTION

1.1 General Overview

One of the world's largest contributors of energy sources is the petroleum industry. Extremely high production of crude oil often contains some portion of gas that attribute from the nature of the reservoir formation itself. Inside the pipelines that are lie in a horizontal positioning or nearly horizontal on the seabed, the co-current two-phase flow specifically on liquid-gas flow are frequently encounter alongside the pipeline. Due to the complex nature of the liquid-gas phase, these flows mostly been investigated experimentally. Variety of the flow pattern can be observed and might affect the transportation process. The prediction of the liquid-gas flow pattern inside the horizontal and inclined pipe are investigate and analyze by developing the model by using Computational Fluid Dynamic (CFD) software and come out with the solution for the analytical support based on the computational models, and numerical simulation.

1.2 Research Background

The presence of gas inside the pipeline mix with the oil from the reservoir will caused such a complex flow pattern. Flow pattern for such two-phase flow can be divided into several categories which are bubbly flow, stratified flow, intermittent flow (plug flow and slug flow), churn flow, annular flow, and dispersed flow. The viscosity and gravity effects relative to the inertial forces of the flow govern the pipe flow behaviour essentially. Inside the horizontal pipe, the simultaneous flow of liquid-gas are flowing vigorously to the heavy liquid flow through the bottom of the pipe meanwhile the gas flow over the liquid and separated by a smooth liquid-gas interface. Naturally, the density and viscosity of the liquid phases, which is higher will cause the liquid flow slowly, compare to the lower density and viscosity of the gas phase. These phenomena are known as slippage of the liquid phase.

There are several types of flow patterns usually occurs in the horizontal pipe which are bubbly flow, stratified flow, stratified-wavy flow, plug flow, slug flow, annular flow and dispersed flow. For the inclined pipe, mostly the pattern flow of bubbly flow, slug flow, churn flow and annular flow. There are different effects on different type of flow pattern for the transportation of crude oil production and transportation. The modeling of the two-phase liquid-gas flow pattern are been generated by using CFD software of Gambit and Fluent. Some of the crucial parameter needed to fill in the Gambit software and then transfer to Fluent to run the simulation based on the numerical method which are already been programmed in the both CFD software. The results of the simulation were discussed and compare with the others researchers' results.

1.3 Problem Statements

Two-phase flow been deeply investigated by the researchers focusing on the flow pattern of the liquid-gas phase. Unfortunately, the flow pattern was such a subjective term that makes the flow once unpredictable because of some factor that affects the flow of the liquid-gas phase. In fact, the liquid-gas phase was not always exhibit completely developed equilibrium condition makes the characterizing the flow pattern more complicated. The two-phase flow inside the pipe were investigated with the assumption made by considering the gravity alongside with fluid motion and from this equation, the modeling of the two-phase flow inside the pipe was referred and generated using the parameters in the equation.

Generally, the application to specific problems begin with the flow assumption and the initial boundary condition formulation and been followed by the detailed analysis to further simplify the problem arise. CFD software used to develop a modelling for the two-phase flow of the crude oil inside the pipe by using the numerical method. CFD is such software that can automatically generate and analyse the modelling and gain the result based on the particular parameter but not considering some of the effect that might intervene the natural processes and the result might be somehow inaccurate. The temperature condition was considered to be constant as this essential parameter which exposed the crude oil in pipeline to the variable conditions that may raise the problem in solving the simulation.

1.4 Objectives

The objectives of this research are to:

i. investigate the flow pattern of liquid-gas phase inside the horizontal pipeline.

ii. study the flow pattern of liquid-gas phase inside the 45° inclined pipeline.

1.5 Research Project

1.5.1 Stage 1

Based on the related journal, the main focus was determined. The introduction part included the overview and objectives of the research project. Besides that, problem statements must be clear before proceeding to the research methodology by list out the important parameter from the literature review. The ideas from the journal will be guide to proceed to the next stage.

1.5.2 Stage 2

Research methodology was the heart of the research project where the part of preparing to run the simulation was the crucial part. All the parameters must be identified first in order to run the simulation. CFD software which includes the Gambit to develop the model then running the simulation by using Fluent for analyse process.

1.5.3 Stage 3

The final stage was the part where the data from the simulation will be verified. The result of the data verification was then be optimized to get the most accurate result. After that, the result was discussed in order to meet the objectives of the research project. The result was also been compared with the previous researchers finding in order to improve the effectiveness of the model based on the formula and the model created.

1.6 Research Scope

This project focused on the flow pattern of two phase flow inside the horizontal and inclined pipe. The gas mixed with oil produced such a vigorous flow pattern inside the pipe that affect by the viscosity and the gravitational force acted towards the liquid and gas. When the gas flow rate was increasing together with the constant liquid flow rate or otherwise vice versa, three main conditions was appeared alternatively between the gas phase and the liquid phase known as gas dominant, liquid-gas dominant and liquid dominant. For the gas dominant pattern, the gas phase dominate the whole area of the pipe and some of the liquid exist in a droplet and the same concepts occur in the liquid dominant pattern, which was the gas bubble occurs inside the wholly dominated area of the liquid phase. The horizontal and 45° inclined pipe are been modeled to analyze the flow pattern on each of the pipe.

1.7 Thesis Outline

The structure of the thesis is outlined as follow:

Chapter 2 is the literature review and the general features of the crude oil production and flow inside the pipe. The characteristics of each flow inside the horizontal and inclined pipe are mentioned in this chapter. Other than that, a brief discussion about the previous research related to the flow pattern inside the pipe and the correlations and parameters of the flow pattern are stated.

Chapter 3 shows the steps of the research methodology. This chapter discusses through the procedures in modeling the horizontal and inclined pipe and then each parameters are been set up in computational approach. The two-phase flow was applied with the consideration of gravity, turbulent flow and adiabatic condition. Each model is run by varying the velocity inlet of each liquid and gas phase.

In chapter 4, it provides the result and discussion of the two-phase flow inside the horizontal and inclined pipe. The flow pattern occurred inside the pipe are analyzed and compared with the other researchers' result.

Meanwhile chapter 5, the last chapter conclude all the research results, it also elaborates some recommendation for the future study of two-phase flow inside horizontal and inclined pipe.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The study of petroleum exploration that consists of transportation and processing is largely been develop because of its importance in the industrial and automotive world. A large number of investigations have been carried out based on the transportation of the crude oil alongside the pipeline which lied horizontally on the sea bed. The hydrodynamic characteristic of the flow inside the pipeline which are consist of many material have been transport from the petroleum reservoir to the processing plant. The common materials are oil and gas that are also based on the types of reservoir. The flow of these two common materials of liquid and gas phase created such a complex flow pattern that affect the transportation of the oil and gas inside the pipeline. A model of the flow pattern for the horizontal and inclined pipe are been developed using the software. A brief discussion of the two-phase flow pattern comparing between the horizontal pipe and inclined pipe been discussed.

2.2 Crude Oil Production

Petroleum production formation occurs millions years ago when there are very large amount of animal and plant were buried on the sea floor. Over the years, the layer of sand and mud were flowing down into the seas carried such large amount of sedimentary materials. The sedimentary materials and mud was deposited layer after layer over the sea floor. The accumulation of large area of sediment and mud cause the sea floor to slowly go down and pressed. Then the layers become sedimentary rocks where the formations of crude oil are trapped inside the rocks known as source rock. The reaction of the buried organisms caused by the compressed pressure and temperature then formed hydrocarbon that consist of carbon and hydrogen into the petroleum with the addition of certain substance primarily sulphur. Petroleum in its natural form when first collected is usually named crude oil. The gas formed under the high temperature condition whereas the oil was formed under the lower temperature conditions. The theories was been proposed to explain the formation of oil and gas which mostly covered in the Arabian Gulf and the Mexico Gulf. **Figure 2.1** shows the formation of crude oil and natural gas clearly by Intermediate Energy Infobook, (2008).

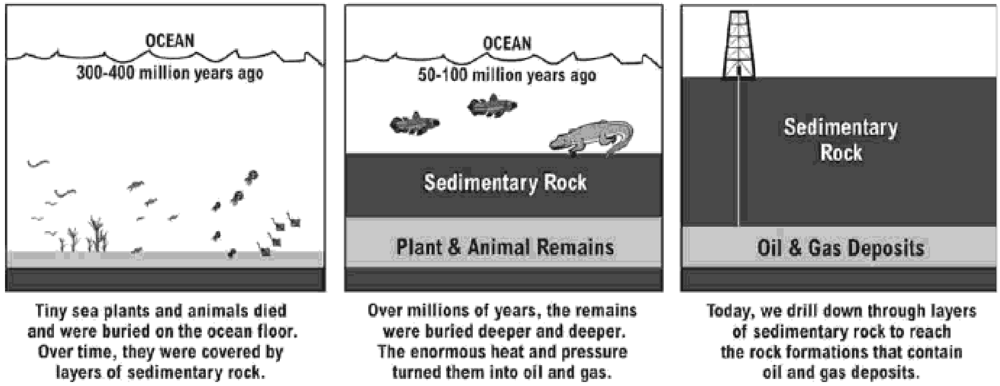

Figure 2.1: Formation of Petroleum Sources (Intermediate Energy Infobook, 2008)

2.3 Flow Pattern Classification Inside the Horizontal Pipe

Two-phase flows are the physical phenomenon occurs in many flow types which are gas-solid phase, liquid-gas phase and liquid-liquid phase. The complexities of two-phase flows from physical and numerical point of view are the reason for the lack of fundamental knowledge. Despite of the two-phase flow complexity, several empirical correlations have been proposed for the prediction of the two-phase flow pattern mostly on the liquid-gas flow.

Investigation of the flow patterns occurs in the horizontal pipe was the main problem in two-phase flow analysis. The liquid-gas flow of in horizontal flows basically influence mostly by the gravity which acted to stratify the liquid to the bottom of the pipe and the gas to the top. Several types of flow were distinguished in **Figure 2.2** based on Schepper et. al., (2008).

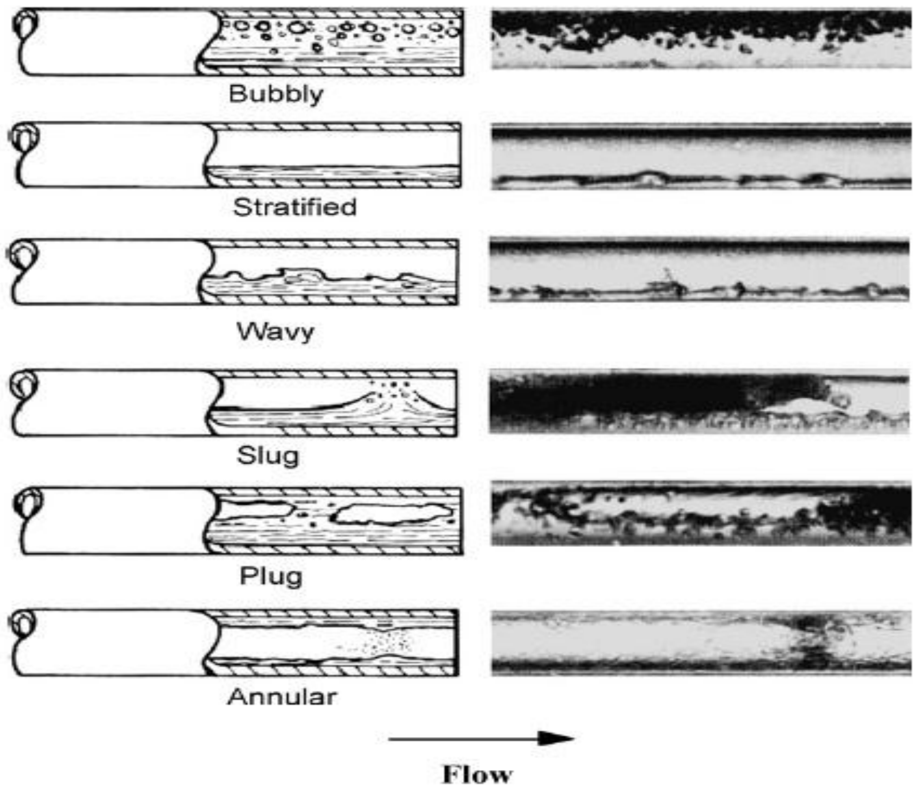

Figure 2.2: Two-phase flow pattern in horizontal flow (Schepper et. al., 2008).

The types of flow inside the horizontal pipe are:

i. Bubbly flow. The gas bubbles are dispersed in the liquid with a high concentration of bubbles for the continuous flow. This type of flow typically occurs in the horizontal flows at the high mass flow rates.

ii. Stratified Flow. At low velocities of the liquid and gas, complete separations of the two-phases are existed. Under normal gravity condition, the gas float at the top of the liquid and clearly separated by an undisturbed horizontal interface.

iii. Wavy Flow. Increasing the gas velocity in the stratified flow resulted in the formation of the waves on the liquid-gas interface and travel in the direction of flow. The amplitude of the waves influences by the relative velocity of the liquid-gas phases and properties of the fluids such as density and the surface tension.

iv. Intermittent Flow. When the gas velocity is being increasing, these interfacial waves created large enough to climb up until the top of the pipe. This flow pattern was characterised by the large amplitude of the waves in the continuous flow. There are two subcategories of the intermittent flow which are plug flow and slug flow.

a. Plug Flow. This flow pattern arises at low gas flow rates and moderate liquid rates that are separated by the elongated gas bubbles. The diameters of the elongated bubbles are smaller than the diameter of the pipe as the liquid flow continuously along the bottom of the pipe below the elongated bubbles. These flows are also known as elongated bubble flow.

b. Slug Flow. At higher gas flow rates, the larger amplitude of waves are formed and become more hectic compared to the plug flow. The liquid slugs contain small gas bubbles and the interface between both liquid and a gas bubble becomes smoother.

v. Annular Flow. Further increasing the gas flow rates caused the formation of the continuous annular film. The liquid film are much thicker at the bottom of the pipe compared to the top depends on the velocity of the gas. The interface of the liquid annulus and the gas core are slightly been disturbed by small amplitude of waves and the liquid droplets are been dispersed inside the gas core. This types of flow are also been classify as stratified-wavy flow.

2.4 Two-phase Flow Pattern Map

For the specific case of liquid-gas flow systems, Baker (1954) had quoted the flow pattern maps for horizontal flow to predict and calculate the pressure drop, heat and mass transfer and others parameter related to the flow pattern, **Figure 2.3**.

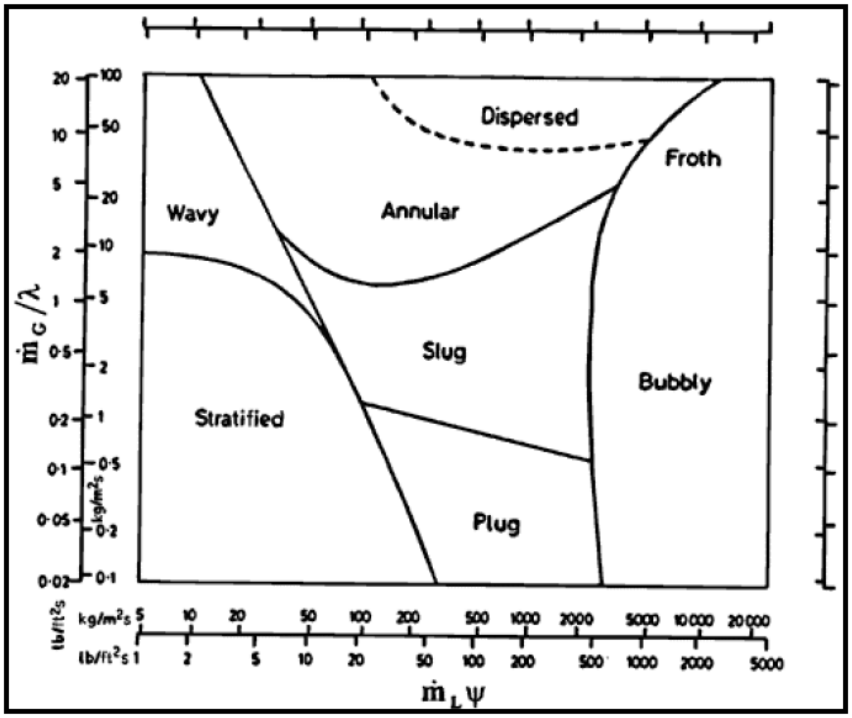

Figure 2.3: Two-phase flow pattern map of Baker (1954) for horizontal tube (Thome, 2004)

The Baker (1954) map pattern for horizontal two-phase flow in pipe shown in **Figure 2.3** shows that the boundaries of the different flow patterns as the functions of $\dot{m}_G$, the mass flow rates of the gas phase and $\dot{m}_L$, the mass flow rates of the liquid phase that are presented in both Si and English Units.. The dimensionless parameters of λ and Ψ were added to modify the chart and could be used for prediction of any liquid-gas phase combination at other pressures and temperatures apart from the standard condition which just allowed the water and air phase flow under atmospheric pressure and room temperature been used for this particular equation. Firstly, the mass flow rates of the liquid and gas must be determined in order to interpret the map pattern.

The gas phase parameter, λ is:

$$\lambda = \left(\frac{\rho_G}{\rho_{air}}\frac{\rho_L}{\rho_{water}}\right)^{1/2} \tag{2.4.1}$$

The liquid phase parameter, Ψ is:

$$\Psi = \left(\frac{\sigma_{water}}{\sigma}\right)\left[\left(\frac{\mu}{\mu_{water}}\right)\left(\frac{\rho_{water}}{\rho}\right)^2\right]^{1/3} \tag{2.4.2}$$

Where the properties of liquid are:

ρ_{water} = 998.2 kg/m^3;

ρ_{air} = 1.225 kg/m^3;

μ_{water} = 0.001003 Ns/m^2;

σ_{water} = 0.0719404 N/m.

Table 2.1: Physical Properties of gasoil liquid, gasoil vapor, water and air at (T=298 K, P= 101,325 Pa)

Properties	Gasoil-Liquid	Gasoil-Vapor	Water
Density, ρ (kg/m^3)	830	9.4	998.2
Viscosity, μ (kg/m-s)	0.00332	-	0.001003
Surface Tension, α (N/m)	0.0190355	-	0.0719404

According to the John R. Thome (2004), the flow pattern maps develop by Taitel and Dukler (1976) as shown in **figure 2.4**. It is based on their methodical analysis that was specifically for adiabatic two-phase flows but often been extrapolated to be use with