PRESSURE DROP PREDICTION FOR STRATIFIED OIL-WATER FLOW IN HORIZONTAL PIPE

ADIB ZULHILMI BIN MOHD ALIAS

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Marine Technology)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

JANUARY 2015

DEDICATION

To the people who have encouraged me to grow professionally and spiritually over the semester, especially my family. Included also are my great fellow educators, supervisor, co-supervisor, friends and people that I am indebted to.

ACKNOWLEDGEMENT

All praises and thanks are due to Allah, who guided and helped me throughout my Master journey. Glory be to Allah who has given me the strength, patience and knowledge to continue and complete my study.

I would like to express my deepest gratitude to mu supervisor, Dr Jaswar Koto and Dr Yasser Mohamed Ahmed for their constant guidance, encouragement and patience. I owe them heartfelt thanks for their time and effort in providing me assistance throughout my Master project undertaking. I would also like to express my thanks to the Government of Malaysia and the Universiti Teknologi Malaysia (UTM) for providing the financial support and facilities throughout this project work.

I would like to express my sincere thanks to all Computational Fluid Mechanic (CFM) Lab members, especially to Ikhwan, Nofrizal, Hakim, Ubaidullah and Shahrizal for his open-handed helping me during simulation sets up. Special thanks to Dr Zahran, Badruzzaman and all my friends who always stay close to me along of my Master journey. They are place for me to ask for advice and support when I was deadlocked.

Finally, continuous gratitude to my mother, father, and my family for their endless support and prayers. They provided me with love, care, and motivation, without which, I cannot survive to undertake all the challenges in my study.

ABSTRACT

Immiscible liquid-liquid flow of oil-water is common phenomenon in many industrial processes; amongst them is crude oil transportation in oil and gas industry. Produced water with oil has complex interfacial structure which complicates the hydrodynamic predictions of the fluid flow. Due to the complexity of liquid-liquid flow, development of reliable analysis tool is difficult. Computational Fluid Dynamics (CFD) has been an established tool for flow analysis in the field of single phase flow but has only started becomes established in multiphase field. Therefore, this thesis attempts to model stratified oil-water flow in horizontal pipe using ANSYS software Fluent. Since pressure drop is an important consideration in liquid-liquid flow, the modelled flow is then used to predict pressure drop base on the factor of superficial velocity at each liquid phase. The results were compared against the established experimental data available in the literature for reliableness. Base on the simulation, it was evident that the Volume of Fluid (VOF) modelling approach is able to model stratified oil-water flow and possible to predict for pressure drop. Generally the predicted pressure drop was in quite good consistency with experimental data for low superficial velocities but predicted low agreement for higher superficial velocities. However, the simulation can be improved as the turbulence model adopted for this simulation could be modified to obtain better pressure predictions.

ABSTRAK

Aliran cecair-cecair yang tidak bercampur seperti minyak-air merupakan fenomena biasa dalam banyak proses perindustrian antaranya ialah pengangkutan minyak mentah menggunakan saluran paip dalam industri minyak dan gas. Air yang terhasil bersama minyak mempunyai struktur permukaan yang kompleks. Hal ini merumitkan ramalan aliran hidrodinamik cecair-cecair tersebut. *Computational Fluid Dynamics (CFD)* ialah perisian yang biasa digunakan untuk menjalankan analisis dalam bidang bendalir mekanik khususnya untuk keadaan aliran satu fasa, tetapi masih kurang untuk aliran multifasa. Tujuan tesis ini adalah untuk melakukan simulasi aliran minyak-air berstrata dalam paip mendatar menggunakan perisian *ANSYS Fluent*. Aliran yang disimulasikan kemudiannya digunakan untuk mengenalpasti perubahan tekanan pada jarak paip yang tertentu. Perubahan tekanan dinilai berdasarkan kepada faktor halaju setiap fasa cecair. Keputusan yang diperoleh semasa simulasi kemdudian dibandingkan dengan hasil daripada eksperimen yang dijalankan dalam kajian yang lalu. Berdasarkan simulasi pilihan *Volume of Fluid (VOF)* sebagai model multifasa dilihat dapat menghasilkan simulasi aliran minyak-air berstrata dengan baik. Secara umumnya, perubahan tekanan yang diramalkan mempunyai konsistensi agak baik dengan data eksperimen untuk halaju rendah tetapi meramalkan perbandingan yang kurang memberangsangkan untuk halaju cecair lebih tinggi. Walau bagaimanapun, simulasi ini boleh diperbaiki dengan mengubahsuai model pergolakan serta meningkatkan kualiti element untuk mendapatkan ramalan perubahan tekanan yang lebih baik.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

CFD	-	Computational Fluid Dynamics
VOF	-	Volume of Fluid
RNG	-	Re-normalized Group
RANS	-	Reynolds-averaged Navier-Stokes
ST	-	Stratified Flow
ST & MI	-	Stratified with mixing interface flow
Do/w	-	Oil in water emulsion
Dw/o	-	Water in Oil Emulsion
SW	-	Stratified wavy flow
SWD	-	Stratified wavy/drop
SMW	-	Stratified mixed / water layer
SMO	-	Stratified mixed / oil layer
GIT	-	Grid Independent Test
CAD	-	Computer Aided Design
DM	-	Design Modeler

LIST OF SYMBOLS

A – Flow cross-sectional area

A' – Actual area of phase

F – Surface tension

G – Generation of turbulence kinetic energy

g – Gravity vector

k – Turbulence kinetic energy

$\dot{M}$- Mass flow rate

n – unit normal vector

P – Pressure

Q – Input volumetric flow rate

Re – Reynolds number

S – Slip ratio

t – Time

U – Velocity vector

u – Velocity in the x direction

υ – velocity in the y direction

X – Martinelli parameter (single phase pressure gradient)

x, y, z – Descartes coordinates, m

Greek symbols

Φ – Martinelli parameter (two-phase pressure gradient)

ρ – Density

τ – Viscous tensor

θ – Local volume fraction

μ – Dynamic viscosity

σ – Surface tension coefficient

κ – Curvature

α – holdup of phases

β – Volume fraction of phases

υ – Kinematic viscosity

ε – turbulence dissipation

Ø – ration of superficial velocity

η – normal distance vector from the wall at the cell centers

σ_k, σ_ε – coefficient in low-Reynold k-ε model

Subscripts

o – oil phase

s – Surface

so – superficial for oil phase

sw – superficial for water phase

T – Turbulence

w – water phase

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Immiscible liquid-liquid flow is a common occurrence encountered in various industrial processes amongst them is in petroleum industry where oil-water appears in the wellbore as well as during oil transportation. The presence of water in the well either as formation water or from water breakthrough in later years of production often delivered simultaneously with the crude oil through subsea pipeline. Starting from the wellhead to the processing facilities located either offshore or onshore, the pipeline lies on the seabed horizontally or near horizontal orientation and over relatively long distances. Fraction of water in the output stream will increase as the producing life of a well increase. However the production is considered economic even the water fraction is as high as 90% [1].

The presence of water during the transportation of oil can no longer be treated as a single-phase flow. Oil-water has complex interfacial structure which complicates the hydrodynamic prediction of the fluid flow. During the simultaneous concurrent flow of oil and water, several configurations are formed which are generally grouped into separated flow where both phases retain their continuity and dispersed flow where one phase is continuous and the other is in the form of dispersed flow [2,3]. Even though there are other flow configurations observed such as slug flow, core annularflow, stratified wavy flow and three layer flow, [6,7,14] however these two are the main flow configurations in oil-water system.

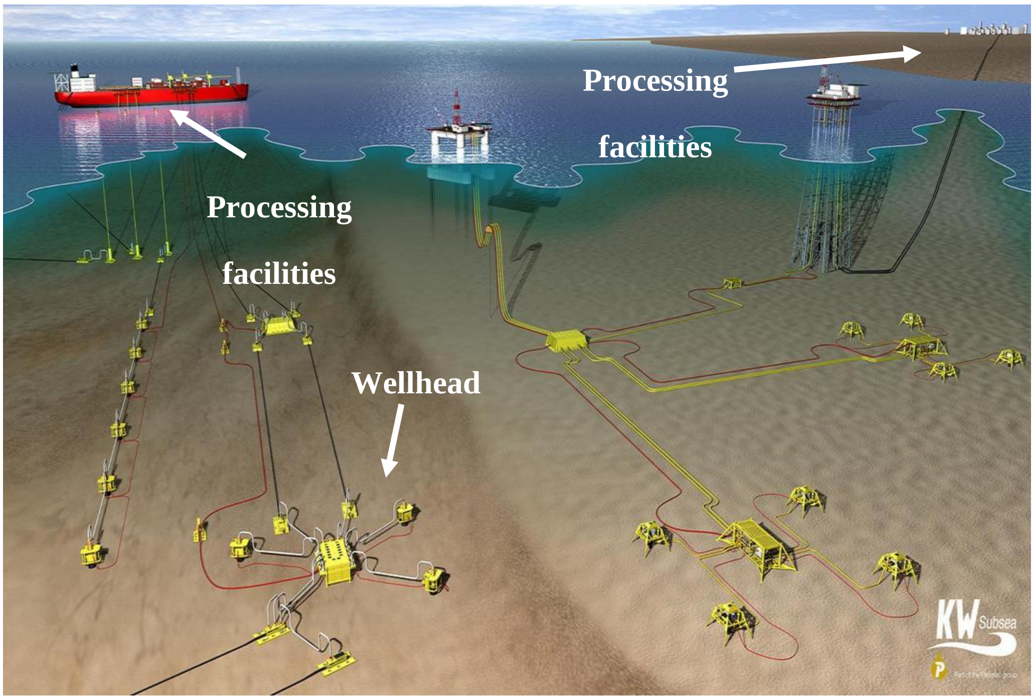

Figure 1.1: Pipeline distribution network for oil transportation from wellhead to the processing facilities. *(Source: www.offshoreenergytoday.com)*

In principle, the flow inside a pipe is governed by the difference of pressure between the upper stream and lower stream i.e. pressure at wellhead was usually set higher than at processing facilities. However, since oil-water being transported over long distances, the pressure will drops and requires additional support to maintain continuous flow until it reaches the processing facilities. Common practice is using pump to push the flow and it needs sufficient power requirements which relates to operational costs. That is why the importance of initial prediction on pressure drop in order to help in optimizing the use of pump is beneficial to reduce power consumption. Slight enhancement in transportation efficiency will have significant influence on revenues for companies in the oil and gas industry. Hence, finding reliable analysis tools for understanding and optimization of multiphase flows is a priority for these companies.

Computational Fluid Dynamics (CFD) was developed during the second half of the 20th century and became an established analysis tool for single-phase flow calculations during 90ies with the appearance of commercial CFD software such as ANSYS Fluent and ANSYS CFX. However, the use of CFD in the area of multiphase flow is not well established such as single phase field. Not much published work has been done on simulating oil-water flow using ANSYS CFD. Nowadays, the development of computer resources, making more complex analyses possible, along with the combination of multiphase flow models in commercial codes such as those previously mentioned, CFD is now gaining more importance also in this field.

CFD Models and codes may be intended and developed for a certain multiphase area, but what is accurate and applicable for one business area might be unsuitable to use for another area. Therefore, proper selection for the models available need to do wisely and results obtained need to be compared with established experimental data for validation. This will create a knowledge base for multiphase flow simulations using commercial software in the oil and gas industry.

1.2 Problem Statement

An oil-water system presents a unique and complex problem for pipeline transportation of crude oils in the petroleum industry due to its complicated rheological behavior. Type of flow pattern is a common observation in this field of studies because even slight differences in flow conditions will exhibit different flow configurations. In multiphase flow system even more important thing to discuss is about pressure. Both flow pattern and pressure were actually directly related since both are dependent under the same factors such as mixture flow rate, density ratio, viscosity ratio, wetting properties, surface tension and etc.

Another phenomenon that further complicates an oil-water dispersion system is the phase inversion phenomenon, in which the dispersed phase switches to the continuous phase. It is highly desirable in the pipeline design to be able to accurately predict this phase inversion point for the flowing oil-water system, since the pressure drop in the pipeline could differ greatly between an oil-in-water and water-in-oil systems. Furthermore, since there have been some published results indicating that the oil-water mixture viscosity could increase dramatically at this inversion point, it is highly recommended that the operator should avoid operating an oil-water pipeline at these flow conditions.

1.3 Objectives

The primary objectives of the project are:

1. simulate oil-water stratified flow in horizontal pipe using Computational Fluid Dynamic (CFD) with commercial code ANSYS-FLUENT
2. use the simulated flow to predict pressure drop base on the factor of superficial velocity at each liquid phase
3. compare the results obtained from simulation with established experiment data for reliableness

1.4 Scope of Project

The scopes of the project are as follow:

1. The study is carried out for two-phase oil-water flowing in horizontal pipe.
2. The flow pattern is stratified by considering the two phases is completely separated and occupying the top and bottom of the pipe due to difference in density.
3. Prediction on pressure drop is based on variation of superficial velocity at each liquid phase. Other parameters which also influence the pressure drop

such as inner pipe surface roughness and wettability, pipe diameter and flow temperature are maintained.

4. Friction between the fluid particles in a pipe which cause a slight rise in fluid temperature as a result of the mechanical energy being converted to sensible thermal energy is consider negligible.

1.5 Significance of the Project

At present, economic consideration on offshore oil fields exploitation requires a shift towards lower cost options in subsea production. Changes in water fraction in the pipe can have a significant influence on power required to pump the fluid due to corresponding changes in pipeline pressure drop [14]. Significant savings in the pumping power required for oil transportation can be attained when water flows in the pipeline together with the oil especially when the viscous phase [6,13]. Knowledge of the pressure drop is required for the prediction and design of an energy efficient transportation system. [4]. That is why the importance of initial prediction on pressure drop in order to help in optimizing the use of pump is beneficial. Slight enhancement in transportation efficiency will have significant influence on revenues for companies in the oil and gas industry.

1.6 Thesis Organization

This dissertation is organized in seven chapters. After the introduction, Chapter 2 list out literature review relates to previous work on stratified oil-water flow base on empirical correlation, experimental and simulation.

Chapter 3 contains basic theory about fluid flow in general, multiphase flow and the most common modelling approaches for multiphase flow. In addition, some basic theory about CFD is given.

In Chapter 4 the methodology is described. Geometry, mesh, simulation settings and boundary conditions are presented and convergence and evaluation criteria are discussed.

The results are presented in Chapter 5 and discussed in Chapter 6. Finally, Chapter 7 conclusions from the study are drawn.

REFERENCES

[1] Soleimani, A., Phase distribution and associated phenomenon in oil-water flows in horizontal tube, PhD Thesis, Imperial College, University of London; 1999.

[2] Al-Wahaibi, T., Pressure gradient correlation for oil-water separated flow in horizontal pipes, Experimental Thermal and Fluid Sciences, 2012, 42:196-203.

[3] Xuan Xu, X., Study on oil-water two-phase flow in horizontal pipelines, Journal of Petroleum Science and Engineering, 2007, 59:43-58.

[4] Chakrabarti, D.P., Das, G., Ray, S., Pressure drop in liquid-liquid two phase horizontal flow: Experiment and prediction, Chem. Eng. Technol., 2005, 28:No. 9.

[5] Elseth, G., An Experimental Study of Oil / Water Flow in Horizontal Pipes, PhD Thesis, The Norwegian University of Science and Technology (NTNU); 2001.

[6] Sotgia, G., Tartarini, P., Stalio, E., Experimental analysis of flow regimes and pressure drop reduction in oil-water mixtures, Int. J. Multiphase Flow, 2008, 34:1161-1174.

[7] Angeli, P., Hewitt, G.F., Pressure gradient in horizontal liquid-liquid flows, Int. J. Multiphase Flow, 1998, 24:1183-1203.

[8] Prof. Rune W. Time, Flow assurance and multiphase flow, May 31st 2011, Department of Petroleum Engineering, University of Stavanger, Seminar at Aker Solutions, Stavanger.

[9] Russell, T.W.F., Hodgson, G.W., Govier, G.W., Horizontal pipeline flow of mixtures of oil and water, Can. J. Chem. Eng. 1959, 37:9-17.

[10] Charles, M.E., Redberger, P.J., The reduction of pressure gradients in oil pipelines by the addition of water: numerical analysis of stratified flow, Can. J. Chem. Eng., 1962, 40:70-75.

[11] Arirachakaran, S., Oglesby, K.D., Malinowsky, M.S., Shoham, O., Brill, J.P., An analysis of oil/water flow phenomena in horizontal pipes, SPE Paper 18836, SPE Prod. Operating Symp., Oklahoma, March 13-14, 1989, pp. 155-167.

[12] Trallero J.L., Cem Sarica, Brill J.P., A study of oil/water flow patterns in horizontal pipes, SPE production & facilities, August 1997.

[13] Nadler, M., Mewes, D., 1995, The effect of gas injection on the flow of two immiscible liquids in horizontal pipes. Chem. Eng. Technol., 1995, 18:156-165.

[14] Al-Yaari, M., Abu-Sharkh, CFD Prediction of stratified oil-water flow in a horizontal pipe, Asian Transactions on Engineering, November 2011, Volume 01 Issue 05.

[15] Russell, T.W.F., Charles, M.E., The effect of the less viscous liquid in the laminar flow of two immiscible liquids. Can. J. Chem. Eng., 1959, 37:18-24.

[16] Charles, M.E., Lilleleht, L.U., Correlation of pressure gradients for the stratified laminar-turbulent pipeline flow of two immiscible liquids, Can. J. Chem. Eng., 1966, 44:47-49.

[17] Lockhart, R.W., Martinelli, R.C., Proposed correlation of data for isothermal two-phase, two-component flow in pipes, Chem. Eng., 1949, 45:39-48.

[18] Theissing, P., A generally valid method for calculating frictional pressure drop in multiphase flow, Chem. Ing. Techn. 1980, 52:344-345 (In German).

[19] Stapelberg, H.H., Mewes, D., The pressure loss and slug frequency of liquid-liquid gas slug flow in horizontal pipes, Int. J. Multiphase Flow, 1994, 20:285-303.

[20] Yuan, H.Y, Ping, Q.L, Wang, T., An experimental investigation on pressure gradients in horizontal heavy oil-water pipe flows, International Offshore and Polar Engineering Conference Osaka, Japan, 2009, June 21-26.

[21] Awal, Mohammad R., Zughbi, Habib D., Razzak, Shaikh A., Al-Majed, Abdulaziz A., Al-Yousef, Hasan Y., Liquids phase holdup and separation characteristics as a function of well inclination and flowrate, SPE SA, 2005, 14-16 May.

[22] Elseth, G., Kvandal, H.K., Melaaen, M.C., Measurement of velocity and phase fraction in stratified oil-water flow, International Symposium on Multiphase Flow and Transport Phenomena, Antalya, Turkey, 2000, pp.206-210.

[23] Brackbill, J.U., Kothe, D.B., Zemach, C., A continuum method for modeling surface tension, Journal Comp. Phys., 1992, 100:335-354.

[24] Rashmi G., Walvaker, Thomas S.Y., Choong, S.A., Hussain, M. Khalid, Chuah, T.G., Numerical study of dispersed oil-water turbulent flow in horizontal tube, Journal of Petroleum Science and Engineering, 2009, 65:123-128.

[25] Carlos F. Modelling of oil-water flow in horizontal and near horizontal pipes, PhD Thesis, Tulsa University; 2006.

[26] Gao, H., Gu, H.Y, Guo, L.J., Numerical study of stratified oil-water two-phase turbulent flow in a horizontal tube, International Journal Heat Mass Transfer, 2003, 46:749-754.

[27] Lam, C.K.Y., Bremhost, K., A modified form of the k-ε model for prediction wall temperature, ASME. J. Fluids Eng., 1981, 103 (2):456-460.

[28] Andersson, Andersson, Hakansson, Mortensen, Sudiyo, and van Wachem, Computational fluid dynamics for engineers, Cambridge university press, 2011.

[29] Lovick. J., Angeli. P., Experimental studies on the dual continuos flow pattern in oil-water flows, Int. J. Multiphase Flow, 2004, 30:139-157.

[30] W.P. Jones, B.E. launder, The prediction of laminarization with a two-equation model of turbulence, Int. J. Heat Mass Transfer, 1972, 15(4).