PHASE SEPARATION OF TWO-PHASE FLUID IN AN EOR INJECTION WELLBORE

By

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DISSERTATION

Submitted to the Petroleum Engineering Programme
in Partial Fulfilment of the Requirements
for the Bachelor of Engineering (Hons) Degree in Petroleum Engineering

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CERTIFICATION OF APPROVAL

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Approved,

....

(Mr Mohammad Amin Shoushtari)
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
August 2011

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

....

(Kamarul Bin Azahri)

Petroleum Engineering Department,

Universiti Teknologi PETRONAS

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NOMENCLATURE

A = area (ft2)

d = diameter (ft)

E = entrainment fraction

F = dimensionless group

FA = annular flow parameter

f = friction factor

g = acceleration due to gravity (ft/s2)

h = liquid level height (ft)

H = liquid holdup

I = interfacial annular parameter

L = length (ft)

P = pressure (lbf/ft2)

Re = Reynolds number

S = perimeter (ft)

v = velocity (ft/s)

v0¥ = single bubble rise velocity (ft/s)

X = Lockhart and Martinelli parameter

Y = dimensionless group

Greek Letters

a = void fraction

d = film thickness

m = viscosity (lbm/ft s)

p = 3.1415926

f = annular entrainment parameter

q = inclination angle measured from horizontal

r = density (lbm/ft 3)

t = shear stress (lbf/ft2)

s = surface tension (lbf/ft)

ACKNOWLEDGEMENTS

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Last but not least, the author would like to express his gratitude to fellow colleagues who have always provided moral supports and a never-ending assistance in ensuring this final year project is finished within the given time frame.

ABSTRACT

Two phase flow occurs when two phases flow simultaneously in pipes. The fluid may tend to separate because of differences in densities and flow velocities in the pipe. (Dale Beggs, 2003). In this project, flow of a gas-liquid fluid in the injection wellbore is studied. The gas water mixture are injected into multiple perforations or producing zones.

As the two phases have different density, separation of the two phases is likely to occur. We are concern of the phase separation that will occur as this will affect the injection efficiency. Degree of the separation and the factors contributing to the separation will be investigated.

Parameters that are going to be determined are flow pattern, liquid holdup and pressure drop. Different flow patterns give different results and play the most important role in this study. For that reason, flow patterns prediction has been an important aspect in this study.

Computer simulation will be conducted using Mathematica software. The calculation procedure will be coded into the software and a set of data will be used for the simulations

1. PROJECT BACKGROUND

1.1 Background Study

Injection well is a vertical pipe or tubing which water, gases and other liquids are pumped or allowed to flow into the formation. Liquids are pumped into the formation to maintain the reservoir pressure, heat the oil or lower its viscosity, allowing the production oil to flow to a producing well nearby.

Two phase flow occurs when two phases flow simultaneously in pipes. The fluid may tend to separate because of differences in densities and flow velocities in the pipe. (Dale Beggs, 2003). In this project, flow of a gas-liquid fluid in the injection wellbore is studied. The gas water mixture are injected into multiple perforations or producing zones.

As the two phases have different density, separation of the two phases is likely to occur. We are concern of the phase separation that will occur as this will affect the injection efficiency. Degree of the separation and the factors contributing to the separation will be investigated.

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1.2 Problem Statement

Phase separation is a very interesting aspect of a multi phase flow. As liquid and gas have a very large density difference, separation of the two phases is always expected. However, the degree of the separation is dependent on the flow regime or the flow patterns.

The flow regime depends on the flow velocity and the tubing angle. In that case, the tubing and casing size will also be a factor and will be considered during the study. Based on previous studies, the tubing location in reference to the perforations also plays a role in determining the quality of liquids that goes into the perforations.

1.3 Objectives of Project

The objectives that need to be achieved in this study are:

1. Determination of flow pattern.
2. Calculation of liquid holdup.
3. Calculation of pressure loss.
4. Coding the calculation into Mathematica software for running simulation.

Scope of Study

The scope of study includes:

1. Conducting research on the theory and definition of terms related to the topic.

2. Understanding the fluid mechanics involved in the study.

3. Conducting simulations on computer software (Mathematica).

Relevance of Study

This study will be beneficial to the petroleum engineers to get to know more about the wellbore and the effectiveness of their injection methods.

As phase separation can be expected in all multi phase flow in wellbore, this study will be a very important. This study will give better understanding of the phase separation in the injection wellbore and the factors to be considered.

This study also related to the course Petroleum Production Optimization offered in my final year course in Petroleum Engineering. Hence this study shall enhance my knowledge in the subject and act as a practical exercise for the subject.

Feasibility of Study

This study is feasible as research can be done by reading books, journals and research papers. Research will be done in order to understand better on the two phase flows models. The computation software of Mathematica need to be learned and calculation method need to be translated into computer codes.

The process of understanding the model available for downward two phase flow will take time about 1 month and the study of the selected model will take about 2 months and 1 month will be available to study on the software to be used. This is very much within the time constraint of two semesters.

The cost of the study will also be minimal as there will be no experiments involved. All results will be collected using the Mathematica software.

2 LITERATURE REVIEW

Phase Separation of Two Phase Flow

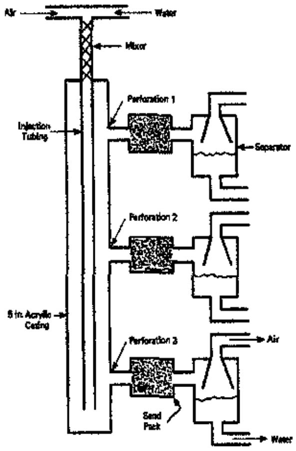
According to T.D Elson of Chevron Oil Field Research Co, when two phase fluid exits the injection tubing in the wellbore, separation of the two phases occur. This will translate into non-uniform steam quality distribution at various points in an interval undergoing steam injection. Phase separation is a major concern because it may affect steam efficiency.

Completion geometry, injection flow rate and down hole quality are also affecting the in-wellbore quality.

The objective of the study was to determine where and when separated flow occurs in the wellbore, to what degree it occurs and to what degree the phase separation can be controlled. Experiments were conduction using a model wellbore and using water and air as injected fluid. Position of tubing was also varied during the experiment.

Result shows that non homogeneous quality exists during injection of a two phase fluid. When tubing is set high above the top perforations, the vapour phase reached the lower perforation only if there is little water in it.

Meanwhile, when the tubing is set low at the bottom perforation, some vapour entered the lower perforations and some liquid phase will be carried upward because of the turbulent slugging action. For the sizes studied, increasing the tubing diameter to reduce annular cross sectional area has caused more liquid to enter the lower perforation.



Flow Regime Prediction for Two Phase Flow

In a journal by Chien, Sze-Foo, E & P Technology Div., Texaco Inc, he stated that all steam EOR projects involve a steam-distribution system. Most steam used in oilfield steam stimulation and steamflood operations is a wet steam, with various levels of quality. It is classified as a two-phase fluid. Many aspects of two-phase flow behavior - such as frictional pressure loss, liquid holdup, and phase splitting at piping tees - are affected by the flow regime existing in the distribution system.

Predicting the flow regime is important to the efficient and effective operation of oil recovery projects. However, the flow regimes are much more complicated for two-phase fluids. To date, no method or chart has been published specifically for the prediction of wet-steam flow regimes.

This problem can be addressed either through experiments or by adapting a general flow-regime prediction technique developed for two-phase flow. The latter approach is used in this study. After several techniques for predicting flow regimes of two-phase flow were reviewed and compared, Taitel and Dukler's Model was selected for steam flow. The flow regimes of wet steam flowing in horizontal pipes are presented here. To facilitate the computation of the flow regimes, a two-phase-flow computer program based on Taitel and Dukler's model was used.

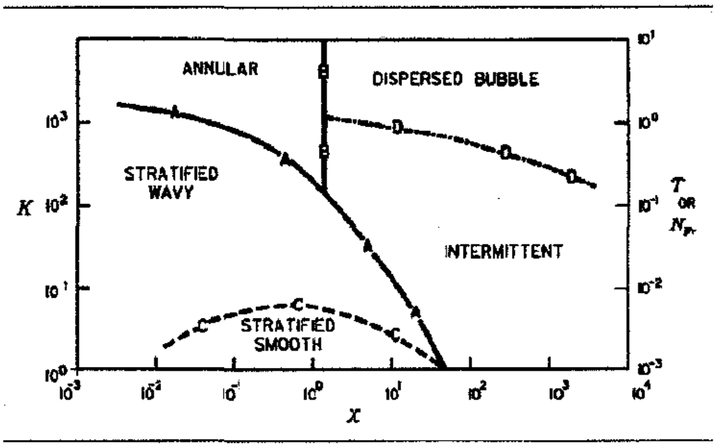


Figure : Flow regime map by Taitel and Dukler

Mechanistic Model for Steady State Two Phase Flow

A team of LE Gomez, O.Shoham and Z Schmidt and others of SPE came up with a unified mechanistic model for the prediction of flow pattern, liquid holdup and pressure drop in wellbore and pipeline. It consists of unified flow pattern prediction model and unified individual model for stratified, slug, bubble, annular, and dispersed bubble flow that is applicable to any inclination angle up to vertical flow.

The model can be applied to vertical wellbores, directional wells, horizontal wells, and pipelines, under normal production operation or artificial lift. The proposed model implements new criteria for eliminating discontinuity problems, providing smooth transitions between the different flow patterns.

The new model has been initially validated against existing, various, elaborated, laboratory and field databases. Following the validation, the model is tested against a new set of field data, from the North Sea and Prudhoe Bay, Alaska, which includes 86 cases.

Example of a unified model is :

Unified Bubble Flow Model

Gas velocity : $v_G = C_0 v_M + v_{0\infty}\, sin\theta\, H_L^{0.5}$

where *vM* is the mixture velocity, *C0* is a velocity distribution coefficient, *v0¥* is the bubble rise velocity and 0.5 *L H* is a correction for bubble swarm. In the present study, the velocity distribution coefficient *C0 = 1.15*, as suggested by Chokshi et al. (1996), and the bubble rise velocity is given by Harmathy (1960) (in SI units), as

$$v_{0\infty} = 1.53\left[\frac{g\sigma(\rho_L - \rho_G)}{\rho_L^2}\right]^{0.25}$$

Substituting for the gas velocity in terms of the superficial velocity results

$$\frac{v_{SG}}{1 - H_L} = C_0 v_M + v_{0\infty}\, sin\theta\, H_L^{0.5}$$

A Study of Multiphase Flow Behaviour In Vertical Wells

by A. Rashid Hasan, U. of North Dakota; C. Shah Kabir, Schlumberger Overseas S.A.

This paper presents a physical model for predicting flow pattern, void fraction, and pressure drop during multiphase flow in vertical wells. The hydrodynamic conditions giving rise to various flow patterns are first analyzed. The method for predicting void fraction and pressure drop is then developed. In the development of the equations for pressure gradient, the contribution of the static head, frictional loss, and kinetic energy loss are examined. Laboratory data from various sources show excellent agreement with the model.

Flow Pattern Transition

The often chaotic nature of multiphase flow makes it difficult to describe and to classify flow patterns and hence to ascribe criteria for flow-pattern transitions correctly. In addition, although flow patterns are strongly influenced by such parameters as phase velocities and densities, other less important variables—such as the method of forming the two-phase flow, the extent of departure from local hydrodynamic equilibrium, the presence of trace contaminants, and various fluid properties—can influence a particular flow pattern. Despite these deficiencies, a number of methods have been proposed to predict flow pattern during gas/liquid two-phase flow. Some of these methods could be extended to liquid/liquid systems with less accuracy.

One method of representing various flow-regime transitions is in the form of flow-pattern maps. Superficial phase velocities or generalized parameters containing these velocities are usually plotted to delineate the boundaries of different flow regimes. Obviously, the effect of secondary variables cannot be represented in a two-dimensional map. Any attempt to generalize the map requires the choice of parameters that would adequately represent various flow-pattern transitions. Because differing hydrodynamic conditions and balance of forces govern different transitions, a truly generalized map is almost impossible. Still, some maps are reasonably accurate. Among these, the map proposed by Govier *et al* has found wide use in the petroleum industry. The flow-pattern map of Hewitt and Roberts[5] has also been widely accepted in academia and the power-generating industry.

An alternative, more flexible approach is to examine each transition individually and to develop criteria valid for that specific transition. Because this approach allows physical modeling of individual flow patterns, it is more reliable than the use of a map.

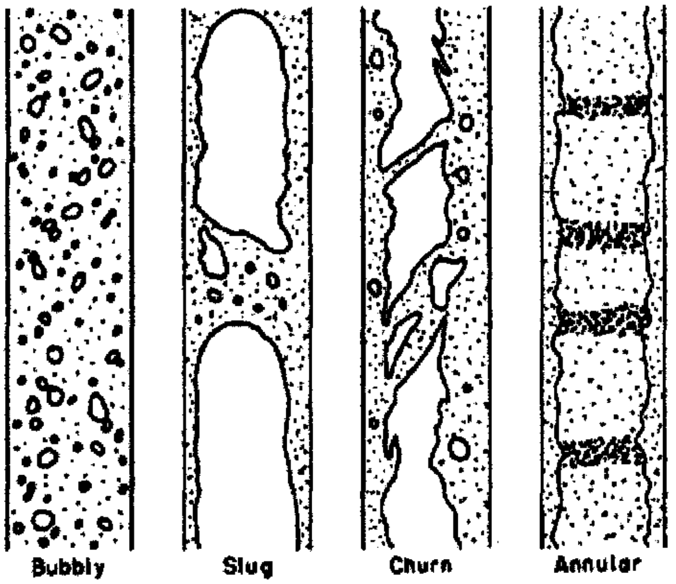


Fig. 1—Flow patterns in vertical cocurrent two-phase flow.[9]

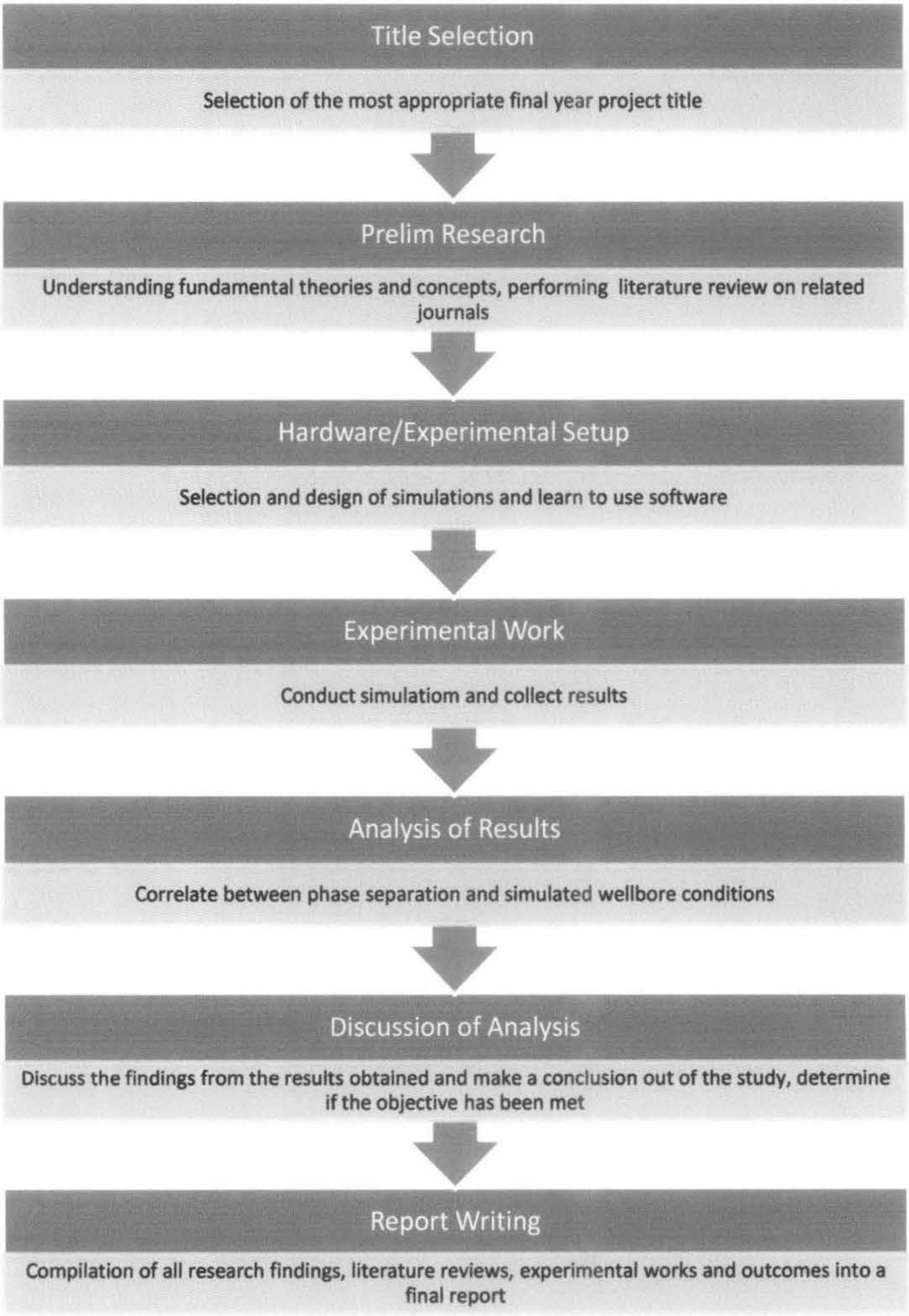
Liquid Holdup

Based on Elemer Bobok (1938) , density and viscosity difference occurs between phases. In this situation, the less dense phase will flow with a higher in-situ velocity. This velocity difference will affect the concentration of the phase along the length of the pipe. In the entrance section of the pipe the less mobile phase concentrates and this concentration gradually decreases in the direction of flow. This phenomenon is called holdup.

Based on H.Dale Beggs (2003), liquid holdup can also be defined as the fraction of an element of pipe that is occupied by liquid at some instant. Liquid holdup is important to determine to calculate such things as mixture density, actual gas and liquid velocities, effective viscosity and heat transfer.

3. METHODOLOGY

3.1 Project Activities



Title Selection

Selection of the most appropriate final year project title

Prelim Research

Understanding fundamental theories and concepts, performing literature review on related journals

Hardware/Experimental Setup

Selection and design of simulations and learn to use software

Experimental Work

Conduct simulatiom and collect results

Analysis of Results

Correlate between phase separation and simulated wellbore conditions

Discussion of Analysis

Discuss the findings from the results obtained and make a conclusion out of the study, determine if the objective has been met

Report Writing

Compilation of all research findings, literature reviews, experimental works and outcomes into a final report

PROJECT ACTIVITIES :

1. Reading journal and published papers on the area of study.
2. Study on the topic of phase separation of two phase flow and flow patterns.
3. Learn to used the simulation software Mathematica.
4. Discussion with supervisor on topic of study.
5. Collect result from simulation runs.

TOOLS REQUIRED :

In order to complete this project, simulations on computer software will be done. There will be no experiments involved therefore negates the need for lab equipments. The software is needed to translate the calculation procedure into computer codes.

The computer software is computation software of Mathematica.
This software was developed by Wolfram Research. This software is the world's only fully integrated environment for technical computing. The calculation method of the model will be changed into codes using this software.

GANTT CHART AND KEY MILESTONES

No	Detail / Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic	■	■						**Mid Semester Break**							
2	Study on Phase Separation and flow regime		■	■	■	■										
3	Submission of Extended Proposal						■									
4	Proposal Defense										■					
5	Study on liquid holdup and pressure gradient											■	■	■		
6	Introduction to Computation Software of Mathematica											■	■	■	■	■
7	Submission of Final Draft Report														■	
8	Submission of Final Report															■

4. RESULTS AND DISCUSSION

FLOW PATTERN PREDICTIONS

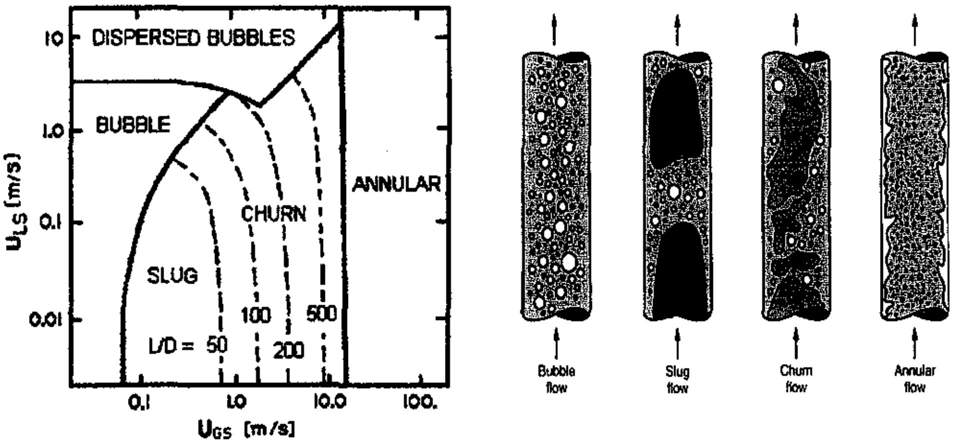


Figure : Flow pattern map for thwo-phase vertical flow

The determination of flow patterns is mostly carried out by direct visual observation, occasionally complemented with high-speed photography or can be determined by considering the superficial velocity. The method of using visual observation is very subjective hence the use of flow pattern diagram which is plotted in terms of superficial velocities of each phase is used. The obtained diagram is called a flow pattern map, in which certain regions correspond to characteristic flow patterns. By inserting gas at progressively increasing flow rate into a homogenous liquid flow, changing flow patterns can be distinguished. The flow pattern that can be identified is the bubble flow, slug flow, froth flow, churn flow and annular flow.

1. Bubble flow

At the lowest gas flow rate, the liquid is continuous and small, spherical gas bubbles move upward near the pipe axis, faster than the liquid. As the gas flow rate is increased the number of bubbles increases, because of coalescence, the average bubble size increases.

2. Slug flow

A further increase in gas flow rate causes an increase in the volume fraction of the bubbles, up to 30 percent, while bubble coalescence leads to the occurrence of large, mushroom-shaped bubbles which nearly span the entire cross-section of the pipe.

These larger mushroom-shaped bubbles are followed by regions containing dispersions of smaller bubbles, and periodical bubble-free liquid plugs. With further increase in the gas flow rate, the larger bubbles become longer having a bullet shape. These bullet-shaped bubbles are called Taylor bubbles. Slug flow pattern is characterized by periodic alternating Taylor bubbles and liquid regions containing a number of smaller spherical bubbles. The liquid phase flows down the outside of the Taylor bubble as a failing film although the resultant flow of both liquid and gas is upward. In these flow patterns liquid phase is always continuous, the gas phase is dispersed.

Taylor bubble is defined as large bubbles of the lighter phase that form by coalescence of small bubbles under certain conditions of fluid flow. The large bubbles occur during slug flow and plug flow. The term is named after G.I. Taylor.

Churn Flow / Froth Flow

Slug flow corresponds to the increase in pressure loss. The increasing pressure gradient now tends to collapse the Taylor bubbles. Surface tension acts against this tendency, but larger gas bubbles become unstable and finally collapse. At this point the interfaces between the phases become highly distorted, both phases become dispersed and froth flow pattern develops. Froth flow is highly unstable; an oscillatory upward-downward motion occurs in the liquid phase, particularly in pipes of larger diameter. This is known as churn flow. In small diameter pipes, the breakdown of the Taylor bubbles is not so abrupt; the transition is more gradual without the occurrence of churn.

3. Annular flow / Mist flow

As the gas flow rate is increased still further an upward moving wavy annular liquid layer develops at the pipe wall, and the gas flows with a substantially greater velocity in the center of the pipe. The gas core flow may carry small fluid droplets ripped from the annular liquid layer. With a further increase of the gas flow rate the liquid film becomes progressively thinner while the number of the droplets in the core flow increases. Finally, the film will be removed from the wall and a pure mist flow occurs.

In this project, the approach proposed by Hasan et al (2007) in determining the pattern transition criteria is used. In this approach, it is assumes that when gas volume fraction exceeds 25% significant increase in collisions amongst bubbles causes transition from bubbly to slug flow.

The following model shows the criteria needed for transition from bubbly flow to slug flow based on the terminal velocity.

$$V_\infty = 1.53\left[g\sigma(\rho L - \rho g)/\rho L^2\right]^{0.25}$$

$$V_{\infty T} = 0.345\left[gd(\rho L - \rho g)/\rho L\right]^{0.5}\sqrt{\sin\theta}\,(1+\cos\theta)^{1.2}$$

Based on the equations above, if $V\infty T < V\infty$, transition to slug flow occurs. While if $V\infty T > V\infty$, bubbly can exist.

Another equation on the basis of superficial gas velocity also can determine the criteria for transition. $V_{sg} = 0.429V_{sL} + 0.357V_\infty \sin\theta$. Based on the equation, slug flow can occur when $Vsg > 0.088m/s$.

Transition from slug to churn flow occurs due to high velocity fluid drag that breaks the Taylor bubbles. Shoham's (1982) suggestion is used in determining the transition criteria.

$$2V_{ms}^{1.2}\left(\frac{f_m}{2d}\right)^{0.4}\left(\frac{\rho_L}{\sigma}\right)^{0.6}\sqrt{\frac{0.4\sigma}{g(\rho_L-\rho_g)}} = 0.725 + 4.15\sqrt{\frac{V_{sg}}{V_m}}$$

The f_m used in the above equation is based on Blassius equation, that suggests $f_m = 0.32(\mathrm{Re}_m)^{-0.25}$. According to Shoham's (1982) suggestion, when $Vm > Vms$, churn flow can occur. In addition to this criteria, it is also suggested that when $V_{sg} > 1.08V_{sL}$, churn flow can exist and dispersed bubbly flow cannot occur.

Transition to annular flow occurs at high gas flow rates. It is because at high gas flow rates, the shear force of the gas on the liquid will pull it upward allowing liquid to flow at the wall of the tube and the gas in the middle of the tube. A model was adopted by Taitel et al. (1989) that examine the drag force needed to keep the entrained liquid droplets in suspension. If the gas velocity is not sufficient to keep the liquid droplets in suspension, the droplets will fall back and form a bridge leading to churn and slug flow. The following equation is based on gas velocity beyond which annular flow is expected.

If $Vsg > 3.1\left[g\sigma(\rho L - \rho g)/\rho g^2\right]^{1/4}$ annular flow will occur, while if $Vsg < 3.1\left[g\sigma(\rho L - \rho g)/\rho g^2\right]^{1/4}$, annular flow cannot occur.

4.2 Gas fraction

For all flow regimes the gas phase moves faster than the liquid because of buoyancy and its tendency to flow close to the channel center, where the velocity is higher than the average mixture velocity. Therefore, the in-situ gas velocity, *Vg* can be expressed as the sum of bubble-rise velocity and *Co* times the average mixture velocity.

$$Vg = CoVm - V\infty$$

…………………………………………………………………………(1)

$$Vg = \frac{Vsg}{fg}$$

…………………………………………………………………………………………(2)

By putting in equation (1) into equation (2), we have a relation between volume fraction and phase velocities.

$$fg = \frac{Vsg}{CoVm - V\infty}$$

…………………………………………………………………………(3)

For each flow pattern, the calculation method and flow parameters have been altered according to the flowing configuration.

4.2.2 Bubbly, Churn and Annular flow

The altered parameter is shown in Table 2.1

Flow Pattern	Flow Parameter, *Co*	Rise Velocity, V_∞
Bubbly	1.2	$V_{\infty b}$
Churn	1.12	$\overline{V}_\infty$
Annular	1.0	0

Table 2.1: Flow parameters and Terminal Velocity Values according to Flow pattern

Below are the equations for Bubble terminal velocity and average terminal velocity.

$$V_{\infty b} = 1.53\left[g\left(\rho_L - \rho_g\right)\sigma / \rho_L^2\right]^{1/4}$$

$$\overline{V}_\infty = V_{\infty b}\left(1 - e^{-0.1 v_{gb}/\left(v_{sg} - v_{gb}\right)}\right) + V_{\infty T}\left(e^{-0.1 v_{gb}/\left(v_{sg} - v_{gb}\right)}\right)$$

4.2.3 Slug flow

Flow configuration in slug flow is quite different then other flows, it is because there are two separate zones during slug flow. One is subjugated by the large Taylor bubble and other consisting of small bubbles in the liquid slug.

Based on Hasan and Kabir's (1988) approach which takes into account for the differing drift velocities in the liquid slug and Taylor bubble, model for calculating slug flow in vertical and inclined annuli for downward flow is following.

The average void fraction is:

$$f_g = \frac{L_T}{L} f_T + \frac{L_s}{L} f_s$$

We use the ideal slug flow calculation for the Taylor bubble portion.

$$f_T = \frac{V_{GS}}{C_o V_m - V_{\infty T}}$$

Based on the data presented by Akagawa and Sakaguchi (1966), it shows that the average volume fraction of gas in the liquid slug is approximately equal to 0.1 when Vgs is greater than 0.4m/s and is equal to 0.25Vgs for lower superficial gas velocities.

$$V_{GS} > 0.4m/s$$

$$f_g = \left(\frac{L_T}{L}\right) f_T + 0.1$$

$$V_{GS} \leq 0.4m/s$$

$$f_g = \left(\frac{L_T}{L}\right) f_T + 0.25Vgs$$

Hasan and Kabir derived the following expression for the fraction $\frac{L_T}{L}$ for gas void fraction in bubbly flow to the liquid slug.

For the condition of $V_{GS} > 0.4m/s$ the following equation is used since $\left(\frac{L_s}{L}\right) fs = 0.1$

$$\frac{L_s}{L} = 0.1\left(\frac{C_o V_m - V_\infty}{V_{GS}}\right)$$

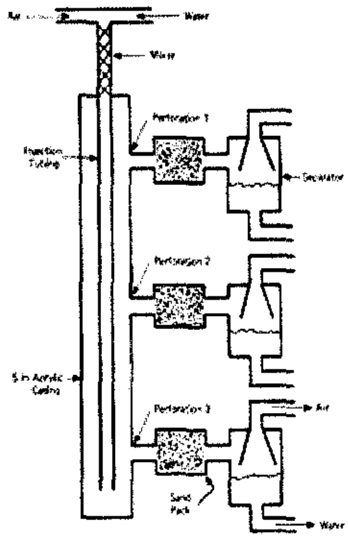
For the condition of $V_{GS} \leq 0.4m/s$ the following equation is used since $\left(\frac{L_s}{L}\right) fs = 0.25Vsg$

$$\frac{L_s}{L} = 0.25\left(C_o V_m - V_\infty\right)$$

Finally the following equation is used to calculate the fraction $\frac{L_T}{L}$

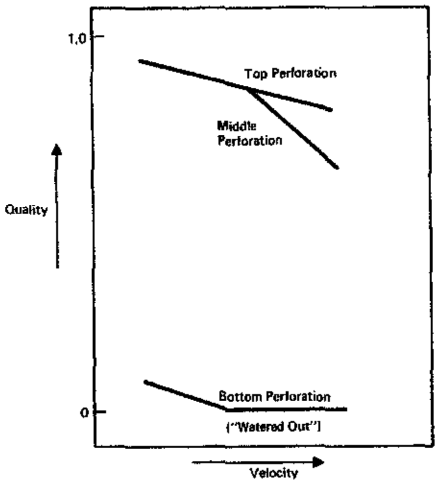
$$\frac{L_T}{L} = 1 - \frac{L_S}{L}$$

EXPERIMENTAL RESULTS

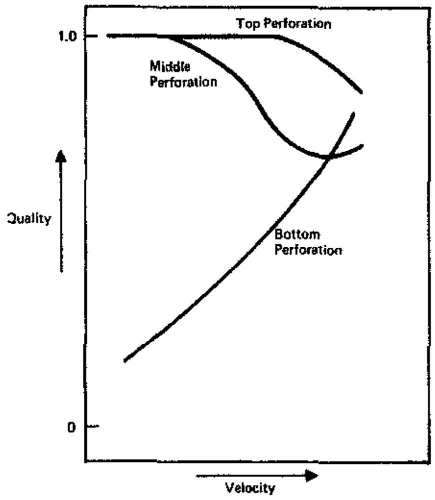


Quality, %

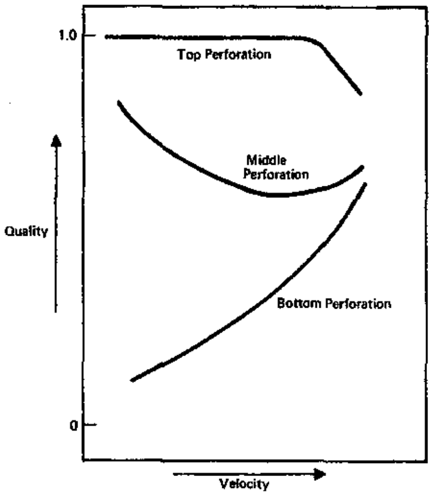
	Case 1	Case 2	Case 3
Perf. 1	88	100	100
Perf. 2	87	43	33
Perf. 3	24	43	56



Case 1 :Tailpipe set above perforations



Case 2 : Tailpipe set below perforations



Case 3 : Larger tailpipe set below perforations

5. CONCLUSIONS AND RECOMMENDATIONS

At the end of this study, the principal flow patterns have been identified which are bubbly flow, slug flow, churn flow and annular flow. These flow patterns are identified using the superficial velocity of gas. Flow patterns are the most important parameter that determines the phase separation during a two phase flow. Other important parameters such as liquid holdup and pressure loss also play a role during the study.

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