PRESSURE DROP OF DIFFERENT FLOW PATTERN IN MULTIPHASE FLOW SYSTEM

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PRESSURE DROP OF DIFFERENT FLOW PATTERN IN MULTIPHASE FLOW SYSTEM

MOHAMMAD HAFIZEZAZMI BIN AJAMAIN

Thesis submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Chemical Engineering

Faculty of Chemical & Natural Resources Engineering
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JUNE 2015

SUPERVISOR’S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Chemical Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Dedication

I dedicate this thesis to my parents Ajamain bin Abdul Mujib and Amidah binti Ambia.

ACKNOWLEDGEMENT

First of all, my appreciation and thanks to the almighty Allah S.W.T for allowing me to and giving me the strength completing this thesis. Appreciation goes out to all my family especially my parents Ajamain bin Abdul Mujib and Amidah Binti Ambiafor endless support and motivation which has given me the push to complete this thesis. Thanks also to my frieds which has given their support whenever I needed it. Lust but not least, a very big thank you to my supervisor Professor Dr. Zulkefli Yaacob for the teaching and guidance throughout the progress of the thesis.

ABSTRACT

Multiphase flow is not an old issue to be discussed. Pressure drop and heat transfer under multiphase flow are very complicated to predict. Lots of empirical correlations have been made to predict pressure drop in pipelines under multiphase condition. Example of correlation used to predict pressure drop is Petalas-Aziz correlation, Begss-Brill correlation and Flannigan correlation. Under multiphase condition, different types of flow pattern can happen. In predicting pressure drop flow pattern is considered because different flow pattern will give a different pressure drop. In this study flow pattern is consider to determine the flow pattern. Flow pattern used is intermittent, stratified, annular and bubble flow. After determining the flow pattern, three empirical correlations used to predict the pressure drop which is Petalas-Aziz correlation, Beggs and Brill correlation and Flannigan correlation. Thus, to determine the flow pattern and pressure drop mathematical programming software is used which is FORTRAN. Using the programming code, predicting the pressure drop and determining flow pattern user can use it to design a better pipeline to encounter pressure loss.

ABSTRAK

Aliran berbilang bukan isu lama yang akan dibincangkan. Kejatuhan tekanan dan pemindahan haba di bawah aliran berbilang fasa yang sangat rumit untuk diramalkan. Banyak korelasi empirik telah dibuat untuk meramal kejatuhan tekanan dalam saluran paip dalam keadaan aliran yang berbeza. Contoh korelasi digunakan untuk meramalkan kejatuhan tekanan adalah korelasi Petalas-Aziz, korelasi Begss-Brill dan korelasi Flannigan. Di bawah keadaan berbilang fasa, pelbagai jenis corak aliran boleh berlaku. Aliran yang. Dalam pola ini aliran pengajian adalah mempertimbangkan untuk menentukan corak aliran. Corak aliran yang digunakan adalah terputus-putus, berlapis, anulus dan aliran gelembung. Aliran yang berbeza akan menghasilkan penuruan tekanan yang berbeza. Tiga korelasi empirikal digunakan untuk meramalkan kejatuhan tekanan yang Petalas-Aziz, Beggs dan Brill dan Flannigan. Oleh itu, untuk menentukan corak aliran dan penurunan tekanan satu perisian pengaturcaraan matematik digunakan iaitu FORTRAN. Kod pengaturcaraan digunakan meramalkan kejatuhan tekanan dan menentukan corak aliran. Pengguna boleh menggunakannya untuk mereka bentuk saluran paip yang lebih baik untuk menghadapi kehilangan tekanan.

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LIST OF ABBREVIATIONS

D	Pipe diameter
k	Wall roughness
u_{SL}	Superficial liquid viscosity
u_{SG}	Superficial gas viscosity
ρ_L	Liquid density
ρ_G	Gas density
ρ_m	Mixture density
μ_L	Liquid viscosity
μ_G	Gas viscosity
u_m	Mixture viscosity
Re_{SL}	Superficial liquid Reynolds number
Re_{SG}	Superficial gas Reynolds number
f	Fanning friction factor
f_m	Mixture Fanning friction factor
F_L	Liquid Froude number
F_G	Gas Froude number
g	Acceleration of gravity
Y	Inclination or gravity parameter
X	Lockhart Martinelli parameter
Kh	Kelvin-Helmholtz instability
$Kh_{critical}$	Kelvin-Helmholtz instability critical
α_L	Liquid holdup
α_G	Gas holdup
d_{max}	Maximum bubble size
d_{def}	Critical bubble size for deformation
d_{migr}	Bubble migration to the upper part of the pipe
σ	Surface tension
E_L	In-situ liquid volume fraction
L_1, L_2	Length of pipe
A	Surface area
F_{rm}	Froude mixture number

F_{NS}	No-slip friction factor
F_{tp}	Two phase friction factor
P_f	Friction pressure
P_{HH}	Hydrostatic pressure
C_0	Velocity distribution coefficient

1 INTRODUCTION

1.1 Motivation and statement of problem

Single phase is defined when one of the matter exist as one states such as a liquid, a solid or a gas. While multiphase flow defined as simultaneous flow of several phases. It can exist as two phase flow or three phase flow. Examples of two phase flow are solid-solid flow, solid-liquid flow, liquid-liquid flow or gas-liquid flow. Flow of mud and slurries is an example of two phase flow. Three phase flow is solid, liquid and gas flow simultaneously. Oil and gas transportation through pipelines always experience multiphase flow. (Awad, 2012)

Multiphase is very important oil and gas transportation and it is not unique in oil and gas industry. In the past three decades, researcher have do some efforts to understand multiphase flow. Different empirical correlations had been made to predict flow pattern liquid holdup, friction factor and pressure-gradient equation in pipelines under multiphase flow condition (Brill, 2010).

In this study the problem statements is programming the prediction of pressure drop in pipelines under multiphase condition. A programme will be developed using FORTRAN software to ease the prediction. Different correlation will be used to compare the pressure drop under certain condition. Since flow pattern is considered in this study thus the correlation that will be used is Petalas and Aziz correlation and Beggs and Brill correlation. Other correlation that not refers to the flow also will be used to compare the results. The correlation is Flannigan Correlation.

N. Petalas and K. Aziz have developed their model to improve previous pressure drop correlation. The correlation is applicable for all types of pipe geometries, fluid properties and flow in all direction. It is improved with a mechanistic approach mixed with empirical closure relationships. With this combination the pressure drop prediction and holdup in pipes can be calculated in more extensive range and conditions. (Petalas & Aziz, 2000)

H. Dale Beggs and James P.Brill has developed their own correlation for pressure drop in two phase system. They developed an air-water system by testing it in 1 to 1 1/5 inch pipes. Furthermore, different angle of pipes are tested to measure the pressure drop (James & H., 1973).

Flannigan correlation (1985) is the extension of Panhandle single-phase correlation. The correlation is good for a horizontal pipelines but it cannot used more or less 10 degrees from the horizontal.

Flow pattern will give a different result of pressure drop. Up until now there’s no correlation that can predict the entire flow pattern accurately. Few assumptions will be made in order the programme can work. The flow patterns are based on Madhane et, al. horizontal flow regime map.

Different flow pattern will result a different pressure drop. Petalas-Aziz correlation and Beggs-Brill correlation refer to the flow pattern before calculating the pressure drop. Thus, in this studies flow pattern will be determined first either it is stratified, intermittent, dispersed and bubble flow pattern. The pressure drop is calculated based on the types of flow pattern.

.

1.2 Objectives

Two objectives are set in order to achieve these studies. First is to develop a program to identify the flow pattern of multiphase flow. There are 4 types flow patterns which are bubble, stratified, annular and intermittent flow pattern. The flow pattern is based on Mandhane et al. horizontal flow regime map.

A second objective is to calculate and compare the pressure drop based on the flow pattern by using different correlations. The calculation will be determined automatically by programming software which is FORTRAN.

1.3 Scope of this research

The correlations that will be used are Petalas-Aziz, Beggs-Brill and Flannigan correlations. The angle of the pipe is horizontal thus Madhane et, al. horizontal flow regime map is considered.

Furthermore, type of multiphase flow is liquid and gas. Last but not least the flow patterns that will be calculated in this studies are bubble, annular, stratified and intermittent flow pattern.

1.4 Main contribution of this work

Main contribution of this study is to understand the concept of flow pattern as well as pressure drop in multiphase flow system. Furthermore the programming code can be used in academic field to determine the pressure drop of different flow pattern in multiphase flow system Thus, designing a pipeline can be easier by using the programming code. I thank you from the bottom of my heart to Professor Dr. Zulkefli Yaacob for helping me doing this study.

1.5 Organisation of this thesis

The structure of the reminder of the thesis is outlined as follow:

Chapter 1 involves the overview of this thesis. It includes general introduction of pressure drop of different flow pattern in multiphase flow system. Furthermore it contains the problem statement, objectives and scopes.

Chapter 2 will give a detailed reviews on pressure drop as well as multiphase flow. A detailed work on flow pattern also included where all types of flow pattern in horizontal work are included. Furthermore the types of correlation also listed.

Chapter 3 is where methodology of this projects. It shows how the software will run through the formula to calculate pressure drop. Some of assumptions are made to make the software to run as well as the parameter that will be used.

Chapter 4 is the most important part where results based on the calculation are discussed.

Chapter 5 is the final part of this thesis it concluded overall studies.

2 LITERATURE REVIEW

2.1 *Pressure drop*

Pressure drop can be defined as the reduction in mixture pressure from one point to one point. It occurs when there are obstacles in the pipelines. Tremendous pressure drop will affect low system performance and high energy consumption. High operating pressure drop means higher energy consumptions. (Compressed air challenge)

2.2 *Multiphase flow*

Multiphase flow system is the flow of mixture such as liquid in gas, liquid and solid and more. Multiphase is so important in oil and gas industries but along with it comes with a problem such as pressure drop. This problem does not unique in the industries, thus many researcher have done some experiments to encounter the problem by introducing a correlation. These correlations help the ability of engineer to predict pressure drop in pipelines more accurate. (T.Crowe, 2006)

2.3 *Flow pattern*

First and foremost flow pattern determination one of the most important element in calculating pressure loss. Pipe corrosion and erosion depends on the system flow pattern. Beggs-Brill correlation and Petalas-Aziz correlation depends on the flow pattern in their calculation. Basically there are few types of flow pattern. Beggs and Brill correlation divide the flow pattern into four groups which are segregated, intermittent, transition and distributed whilst Petalas-Aziz correlation divide into 6 major groups dispersed, stratified, annular, bubble and intermittent. This issue will be discussed more in other sections.

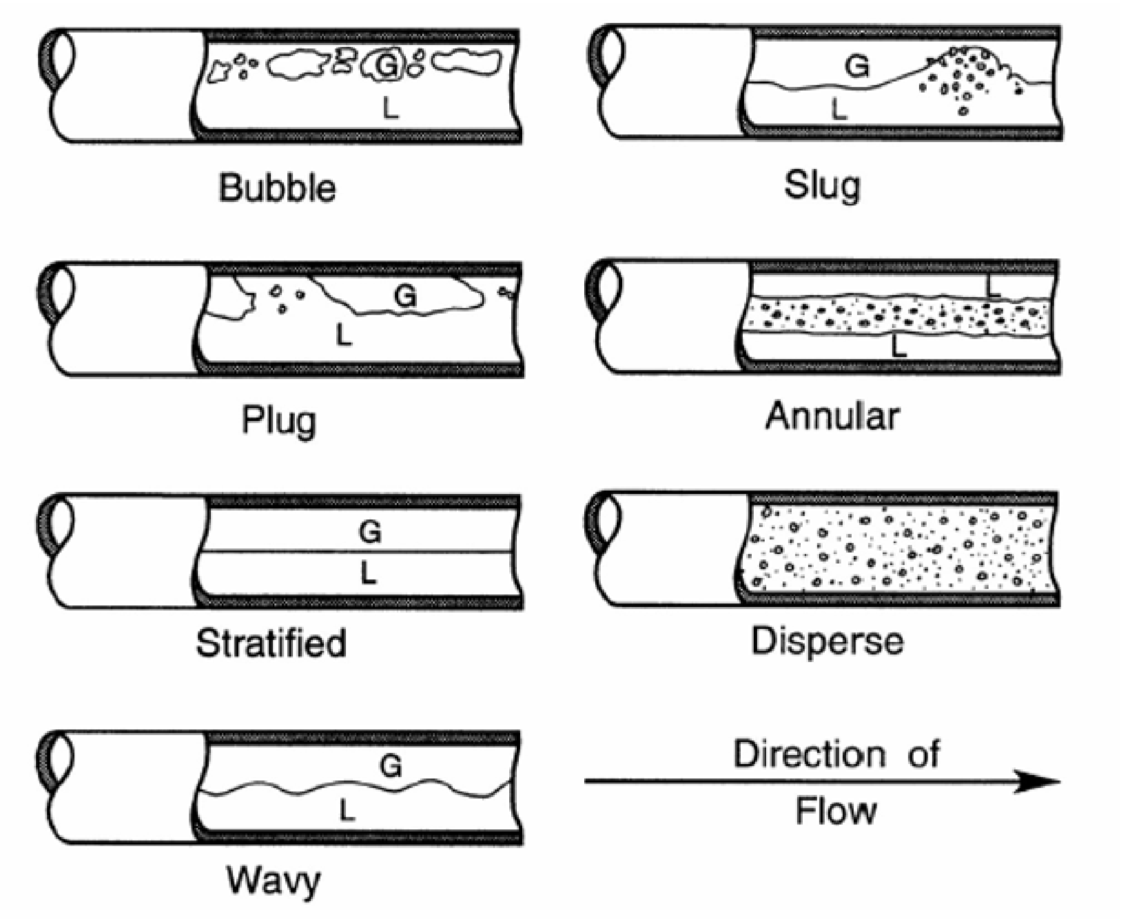


Figure 2-1 Flow pattern in horizontal pipes

Since this study only focus on horizontal pipelines thus Mandhane et al. horizontal flow regime is used to determine the flow pattern regime (Mandhane, G.A, & K, 1974). There are 7 types of flow pattern which is;

a) Bubble
b) Plug
c) Slug
d) Annular
e) Stratified
f) Disperse
g) Wavy

2.3.1 Bubble

High concentration of bubble is formed in the upper half of the tube because of the buoyancy of the bubble. The gas bubbles dispersed when shear forces are bigger, thus the bubbles tend to disperse uniformly. This regime happens at high mass flow rate. (Wolverine Tube,Inc)

2.3.2 Plug

Plug flow has a separated by elongated gas bubbles. The diameter of the elongated bubbles is smaller than the pipelines itself. The liquid phase is continuous along the bottom of the tube below the elongated bubbles. Plug flow regime sometimes called as elongated bubble flow. (Wolverine Tube,Inc)

2.3.3 Slug

Increasing the gas velocities, the elongated bubbles diameter will be same as the pipelines. The liquid slugs that separated the elongated bubbles also described as large amplitude waves. (Wolverine Tube,Inc)

2.3.4 Stratified

Complete separation of the mixture will happen when the gas and liquid in low velocities. Gas exist at top of the pipe while liquid is at the bottom. The mixture completely stratified undisturbed horizontal interface. (Wolverine Tube,Inc)

2.3.5 Wavy

Waves are formed on the interface of the mixture when the gas and liquid velocity is increased. The wave is notable and depends on the relative velocity of the two phase. But the amplitude or top of the waves do not reach the pipelines. Thin films of the liquid are stained on the wall because of the behaviour of the waves. (Wolverine Tube,Inc)

2.3.6 *Annular*

Continuous annular film is forms around the pipelines. All of this happens when the gas flow rate is increased. The liquid at the bottom is thicker than the top, the surface between the liquid annulus and the vapour core is disturbed by small amplitude waves and droplets. The top of the pipelines with thinner liquid film will dry first because of the high gas fractions. (Wolverine Tube,Inc)

2.3.7 *Dispersed*

The mixture will be in continuous gas phase at very high gas velocities. The liquid might be striped and become small droplets. (Wolverine Tube,Inc)

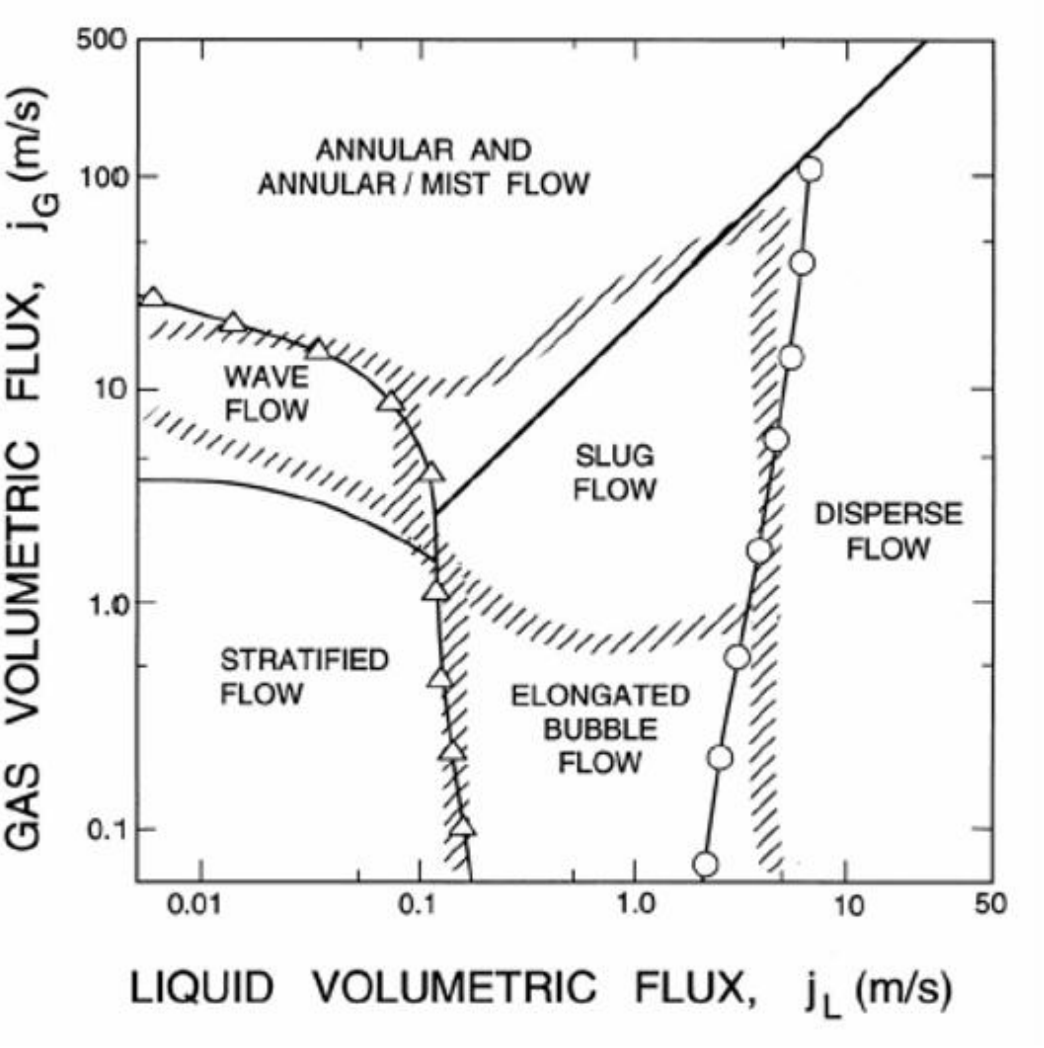


Figure 2-2 Mandhane et al. horizontal flow pattern

2.4 *Pressure drop correlation*

2.4.1 *Beggs and Brill correlation*

Beggs and Brill correlation is one of the oldest correlations that have been used up until now. It can predict the pressure drop in all types of angle. Based on figure there 4 types of flow pattern has been mentioned in previous section. For distributed it specified for bubble flow. Stratified, wavy and annular is categorized as segregated. Intermittent stand for plug and slug flow. Segregated is define as annular and stratified flow. Distributed is for bubble flow and transition is for other than the other flow. For this research transition is not determined.

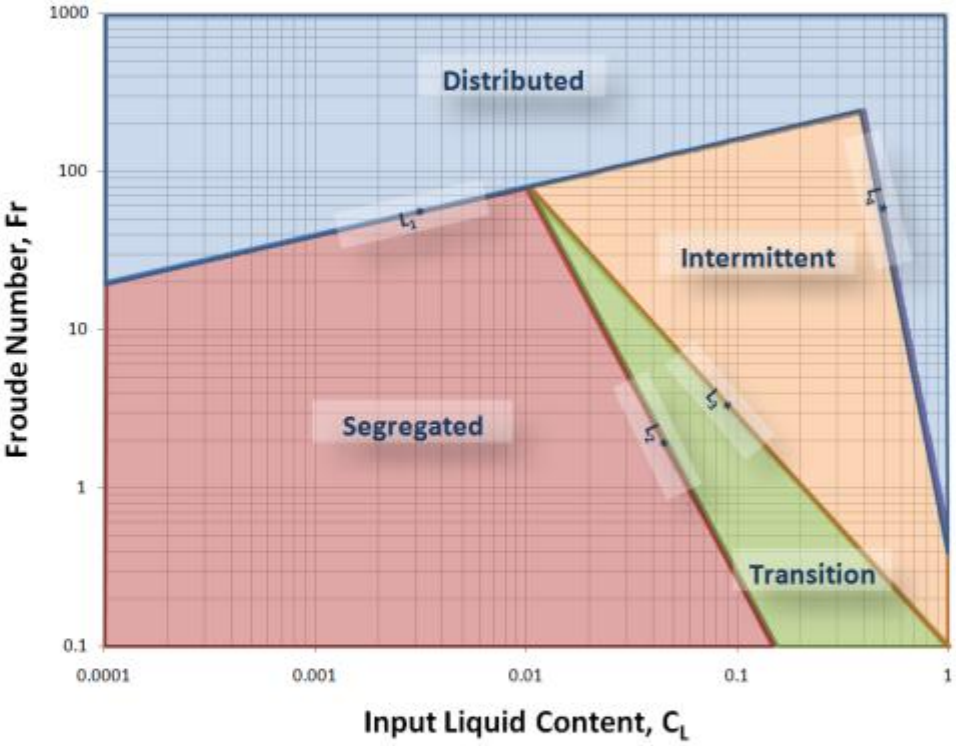


Figure 2-3 Beggs and Brill flow pattern

2.4.2 *Petalas Aziz correlation*

Petalas-Aziz is one of the newest correlation to predict pressure drop. Same as Beggs and Brill correlation, this correlation can calculate any pipe inclinations and all types of fluid. Moreover, this model also uses database more than 20,000 laboratory measurement and data from 18000 wells. Figure shows that for Petalas Aziz consider disperse, bubble, intermittent, stratified, annular and froth. Froth stand for any types of flow pattern mentioned in Petalas-Aziz correlation.

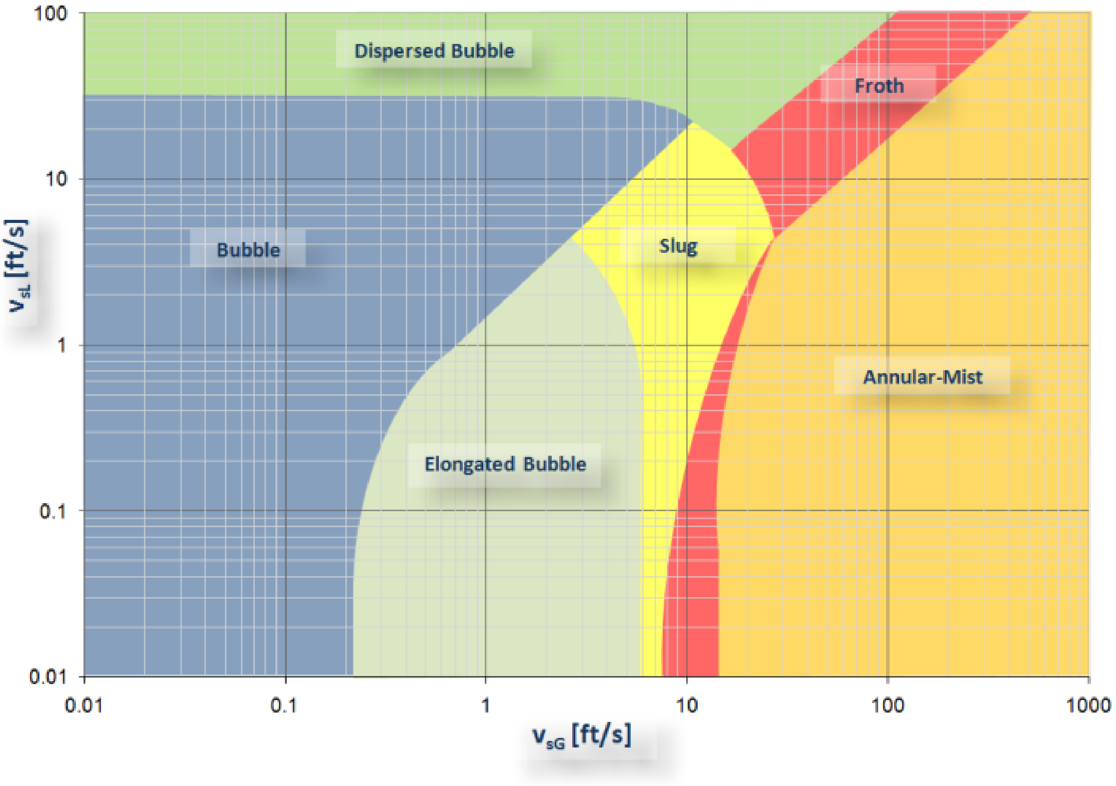


Figure 2-4 Petalas and Aziz flow patern map

2.5 *Software*

FORTRAN stands for FORmula TRANslation. The purpose of the software is for mathematical computations in engineering. This software is the high level programming language. It was developed by Salford Software Limited a company owned by University of Salford.

3 METHODOLOGY

3.1 Overview

In order to predict the pressure drop under multiphase flow conditions, two correlations will be used which is Petalas-Aziz correlation (2000) and Beggs-Brill correlation (1973). Both correlations will consider the flow pattern. Flannigan (1985) does not consider the flow pattern in the correlation but it will be used to compare with other correlation.

Figure 3-1 shows the methodology to solve the pressure loss under multiphase condition. First of all the input parameters are inserted. Natural gas and water properties are used for the input parameters. The diameter of pipes will be varies since different diameter will give a different results in flow pattern and pressure drop. After inserting the input parameters, dimensional parameters are calculated.

After calculating the dimensionless parameters, the flow pattern will be determined. Figure 3-2 shows the methodology to determine the flow pattern. Last but not least is the determination of pressure drop using Beggs-Brill (1985) and Petalas-Aziz (2000) correlations. For Flannigan (1985) the pressure drop is directly calculated based on the input parameters this is because the correlation does not refer the flow pattern.

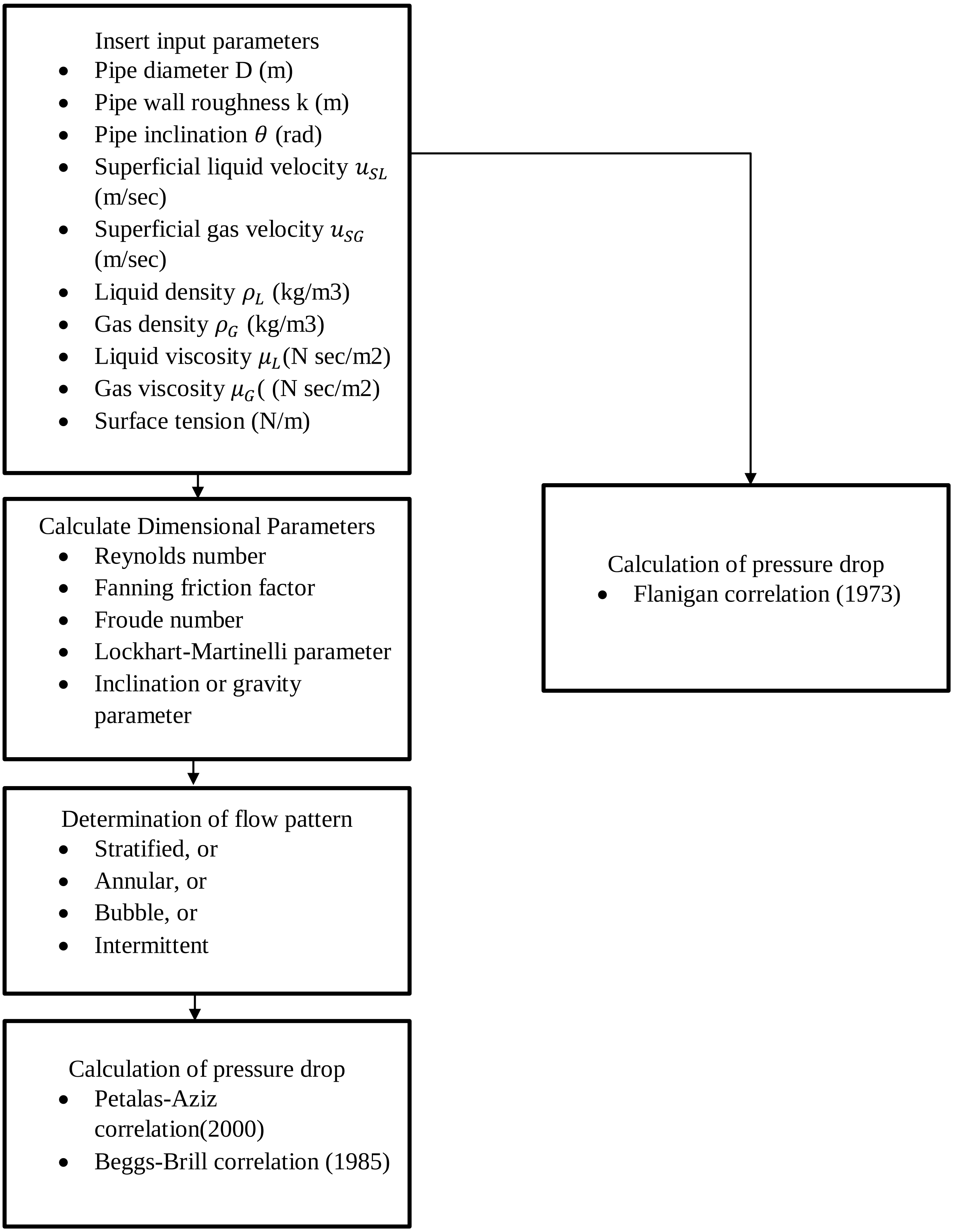


Figure 3-1 Pressure determination methodology

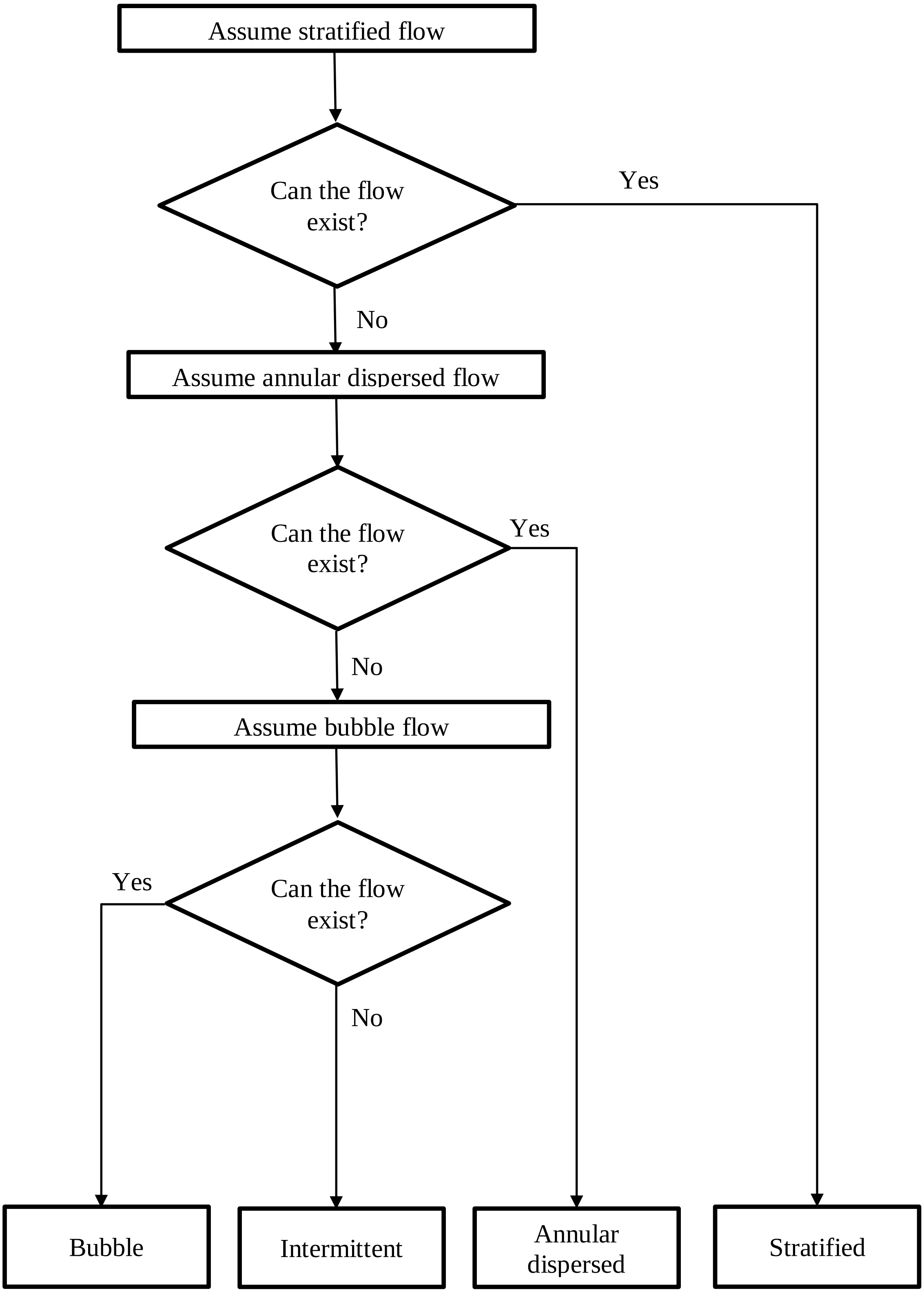


Figure 3-2 Flow pattern determination methodology

3.2 *Determination of flow pattern*

First step to determine the flow pattern some input parameters need to be inserted. First is the diameter of the pipe, D and wall roughness, k. Second is the pipe inclination. But since this studies assume that it will consider horizontal pipe only thus the inclination set to 180^o. Next is the properties of the natural gas and crude oil which is superficial liquid velocity u_{SL} (m/sec), superficial gas velocity u_{SG} (m/sec), liquid density ρ_L (kg/m3), gas density ρ_G (kg/m3), liquid viscosity μ_L(N sec/m2) and gas viscosity μ_G((N sec/m2). Last but not least is the surface tension. The value of superficial velocity will be used as in

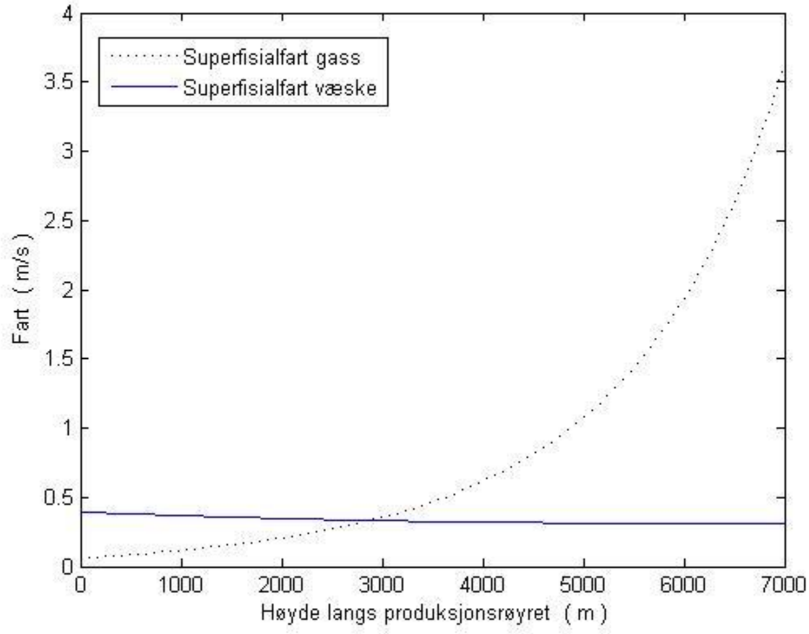


Figure 3-3 Superficial velocity along the pipe

After inserting the input parameters, the second step is calculation dimensionless parameter. First is superficial Reynolds number for gas and liquid. Reynolds number used to determine whether the mixture flow as turbulent, laminar or transition. If the value of Reynolds number is greater than 4100 the command window will show “The flow is laminar” and if the Reynolds number calculated is more less than 2300 the command window will show “The flow is turbulent”. But if the value of is between 2300 and 4100 the program will not run since this study only consider laminar and turbulent flow.

$$Re_{SL} = \frac{\rho_L u_{SL} D}{\mu_L} \tag{1}$$

$$Re_{SG} = \frac{\rho_G u_{SG} D}{\mu_G} \tag{2}$$

Results from calculating the Reynolds number will be used to determine the superficial fanning friction. Superficial fanning friction is named after John Thomas Fanning (1837-1911), it is an element to calculate the pressure drop due to friction occurred in pipelines for both laminar and turbulent flow.

If neither the liquid nor the gas is a laminar flow Superficial Fanning friction will be calculated as in equation (3). Besides that, if the data shows the system exist as turbulent flow both liquid and gas Superficial Fanning friction calculated as shown in equation (4).

$$f = \frac{16}{Re} \tag{3}$$

$$\frac{1}{\sqrt{f}} = -4\log(\frac{2k}{D} + \frac{9.35}{Re\sqrt{f}} + 3.48) \tag{4}$$

Froude number both for liquid and gas are calculated as in equation (5) and (6)

$$F_L = u_{SL}(\frac{\rho_L}{\Delta\rho g D})^{\frac{1}{2}}\ , where\ \Delta\rho = \ \rho_L - \rho_G\ and\ g = 9.81\, m/s^2 \tag{5}$$

$$F_G = u_{SG}(\frac{\rho_G}{\Delta\rho g D})^{\frac{1}{2}}\ , where\ \Delta\rho = \ \rho_L - \rho_G\ and\ g = 9.81\, m/s^2 \tag{6}$$

Inclination or gravity parameter is calculated by referring to the gas Froude number and gas Fanning friction.

$$Y = \frac{\sin\theta}{2 f_{SG} F_G^2} \tag{7}$$

Lockhart-Martinelli is one of the oldest correlations used for two phase friction in horizontal pipes. Furthermore, it is the simplest parameter to use. On the other hand the parameter is not very accurate.

$$X = (\frac{F_L}{F_G})(\frac{f_{SL}}{f_{SG}})^{\frac{1}{2}} \tag{8}$$

After succeeding calculating the dimensionless parameter, next step is assuming the mixtures flow as stratified flow. Referring to the value of Lockhart Martinelli and inclination or gravity parameter, the value of Kelvin Helmholtz instability is taken from Figure 3-4.

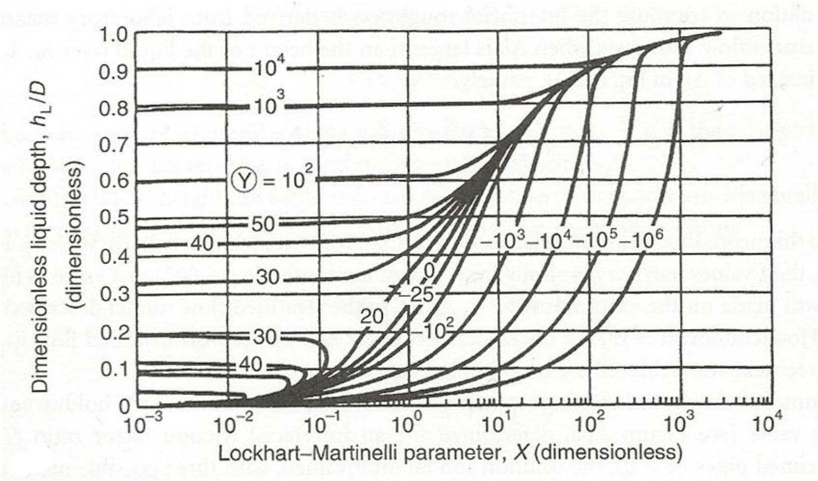


Figure 3-4 Liquid Level in stratified two-phase flow

On the other hand, Kelvin-Helmholtz instability will be calculated using equation (9).99

$$Kh = \frac{F_G}{(\cos\theta)^{\frac{1}{2}}} \tag{9}$$

The value of Kelvin Helmholtz instability will be compared with Kelvin Helmholtz instability critical. If the calculated value is lower than the value from the Figure 3-4, thus the flow will be determined as stratified. Conversely, if Kelvin Helmholtz instability critical bigger than Kelvin Helmholtz instability then program will test for liquid holdup.

In this step the, liquid holdup, α_L is specified from X and Y from Figure 3-5.

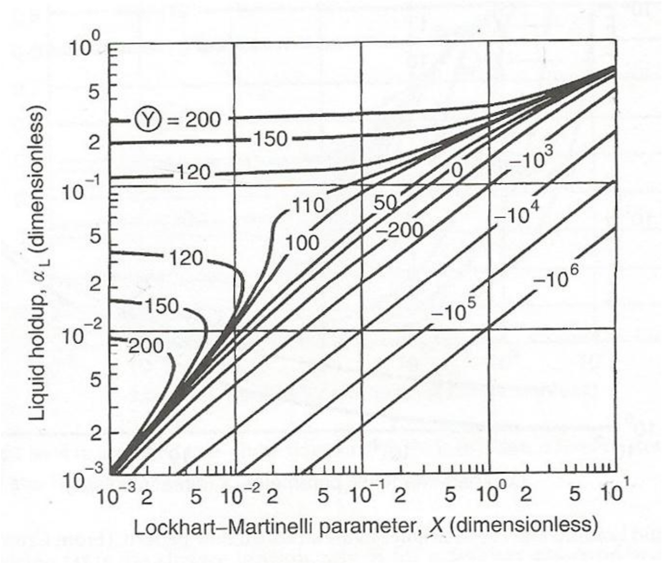


Figure 3-5 Liquid holdup in annular two phase flow

Then mixtures liquid holdup is tested. If $\alpha_L < 0.35$, then the mixtures flow pattern is annular. Contrarily, the mixtures will be test for bubble and intermittent flow. First gas holdup will be calculated using equation

$$\alpha_G = \frac{u_{SG}}{u_G} \tag{10}$$

If $\alpha_G > 0.52$, the mixtures is intermittent flow whilst $\alpha_G < 0.25$ it exist as bubble flow. Meanwhile, if the value of gas holdup is between 0.52 and 0.25 bubble size need to be calculated.

$$d_{max} = \left[0.725 + 4.15\left(\frac{u_{SG}}{u_m}\right)^{1/2}\right]\left(\frac{\sigma}{\rho_L}\right)^{\frac{3}{5}}\left(\frac{2f_m u_m^3}{D}\right)^{\frac{-2}{5}} \tag{11}$$

$$d_{def} = \left(\frac{0.4\sigma}{\Delta\rho g}\right)^{\frac{1}{2}} \tag{12}$$

$$d_{migr} = \frac{3}{8}\frac{\sigma}{\rho_L}\frac{2f_m u_m^2}{g\cos\theta} \tag{13}$$

Based on the bubble size calculation result, they will be compared to determine whether the mixture is bubbly flow or intermittent. If $d_{max} < d_{def}$ and $d_{max} < d_{migr}$ thus the mixture flow pattern is Bubbly flow otherwise the flow pattern is intermittent.

3.3 Determination of pressure drop

As mention in this study three correlations will be used to calculate pressure drop. After getting the type of flow pattern, the program will continue to calculate the pressure drop based on the flow pattern.

First and foremost is the pressure drop determination by using Beggs and Brill correlation. Referring to the flow pattern from Figure 2-3, Beggs and Brill correlation consider four types of flow pattern which is segregated, distributed, and intermittent and transition. Equation (14) is used to calculate stratified and annular flow. On the other hand, equation (15) and (16) are used to calculate bubble and intermittent flow respectively.

$$E_L = \frac{0.98\alpha_L^{0.4846}}{Fr_m^{0.0868}} \tag{14}$$

$$E_L = \frac{0.845\alpha_L^{0.5351}}{Fr_m^{0.0173}} \tag{15}$$

$$E_L = \frac{1.065\alpha_L^{0.5824}}{Fr_m^{0.0609}} \tag{16}$$

$$Fr_m = \frac{F_L + F_G}{2} \tag{17}$$

To calculate the pressure as in equation (19) mixture density need to be defined. Liquid density is multiplied with horizontal liquid hold up and gas density is multiplied with one minus horizontal liquid holdup. Last but not least is the calculation of hydrostatic pressure drop. g_c, is the gravity level of the place that will be examined. Each sea level or place has different gravitational pull.

$$\rho_m = \rho_L E_L + \rho_G (1 - E_L) \tag{18}$$

$$P_{HH@Beggs-Brill} = \frac{9.81\rho_m}{144 g_c} \cdot L sin\theta \tag{19}$$

Last but not least is the calculation of friction loss, P_f.

$$F_{NS} = \left(\frac{F_{SL} + F_{SG}}{2}\right) \tag{20}$$

$$F_{tp} = 1.22 F_{NS} \tag{21}$$

$$P_f = \frac{2LF_{tp}\left(\frac{\rho_L + \rho_G}{2}\right)(u_{SL} + u_{SG})^2}{144 D g_c} \tag{22}$$

Second correlation is Petalas-Aziz correlation. Since there are six types of flow pattern in Petalas-Aziz correlation based on Figure 2-4, thus only four are selected based on the characteristic and the scope of this work. The concept of calculation is same as Beggs and Brill correlation, because it needs to define mixture density to calculate the pressure drop.

For stratified flow the in situ liquid holdup need to be calculated by referring to the area of liquid divided by the area of gas. But it is assume that the area ratio of gas and liquid is 1:1. After getting the liquid in situ liquid holdup, mixture density will be calculated as in equation (35).

$$E_L = \frac{A_L}{A_i} \tag{23}$$

Same as annular flow, but the difference is it needs to define the liquid friction entrained, FE as in equation (24). Furthermore the in situ liquid holdup will use surface tension in its calculation.

$$\frac{FE}{1-FE} = 0.735N_B^{0.074} \tag{24}$$

$$E_L = 1 - (1-2\sigma)^2 \frac{\mu_{SG}}{\mu_{SG} + (FE\ x\ \mu_{SL})} \tag{25}$$

Next, is the computation of bubble flow. The calculation is much complex than the other flows because it needs to calculate velocity distribution coefficient. The velocity distribution will be used to compute the translational bubble velocity, μ_t which leads to calculate the in situ gas holdup. Since bubble flow almost exists as gas, in situ gas holdup is used.

$$E_G = \frac{\mu_{SG}}{\mu_t} \tag{26}$$

$$\mu_t = C_0\mu_{SM} + \mu_b \tag{27}$$

$$\mu_b = 1.41\left(\frac{g(\rho_L - \rho_G)\sigma}{\rho_L^2}\right)^{1/4} sin\theta \tag{28}$$

$$C_0 = (1.64 + 0.12\ sin\theta)Re_{mL}^{-0.031} \tag{29}$$

$$Re_{mL} = \frac{\rho_L\mu_{SM}D}{\mu_L} \tag{30}$$

Last but not least is the calculation for intermittent flow. The calculation is nearly same as bubble flow. In this flow, the velocity distribution, C_0 is calculated as in equation (29).

$$E_L = \frac{E_{LS}\mu_t + \mu_{Gdb}(1-E_{LS}) - \mu_{SG}}{\mu_t} \tag{31}$$

$$E_{LS} = \frac{1}{1 + \left(\frac{\mu_m}{8.66}\right)^{1.39}} \tag{32}$$

$$\mu_{Gdb} = C_0\mu_{SM} + \mu_b \tag{33}$$

$$\mu_b = 1.53\left(\frac{g(\rho_L - \rho_G)\sigma}{\rho_L^2}\right)^{1/4} sin\theta \tag{34}$$

Last but least is to define the mixture density which leads to compute the pressure drop determination for Petalas-Aziz correlation. For stratified, annular and intermittent, the formula used for mixture density is in equation (35) whilst for bubble flow is in equation (36). Equation (37) shows the final computation for Petalas-Aziz pressure drop calculation.

$$\rho_m = \rho_L E_L + \rho_G(1 - E_L) \tag{35}$$

$$\rho_m = \rho_L(1 - E_G) + \rho_G E_G \tag{36}$$

$$P_{HH@Petalas-Aziz} = \frac{9.81\rho_m}{g_c} \cdot sin\theta \tag{37}$$

Third correlation used is Flannigan correlation. This correlation does not consider the flow pattern. Thus in this study it used to compare the pressure drop with Beggs-Brill correlation and Petalas-Aziz correlation.

$$P_{HH@Flannigan} = (\rho_L E_L + \rho_G(1 - E_L))\left(\frac{g}{144gc}\right)$$

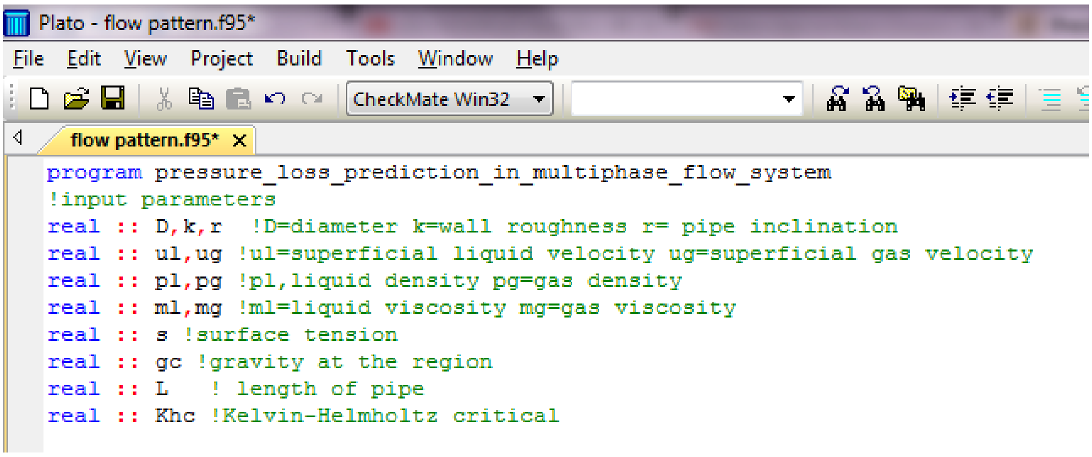
$$E_{L@Flannigan} = \frac{1}{1 + 0.3264u_{SG}^{1.006}}$$

4 Result and Discussion

4.1 Introduction

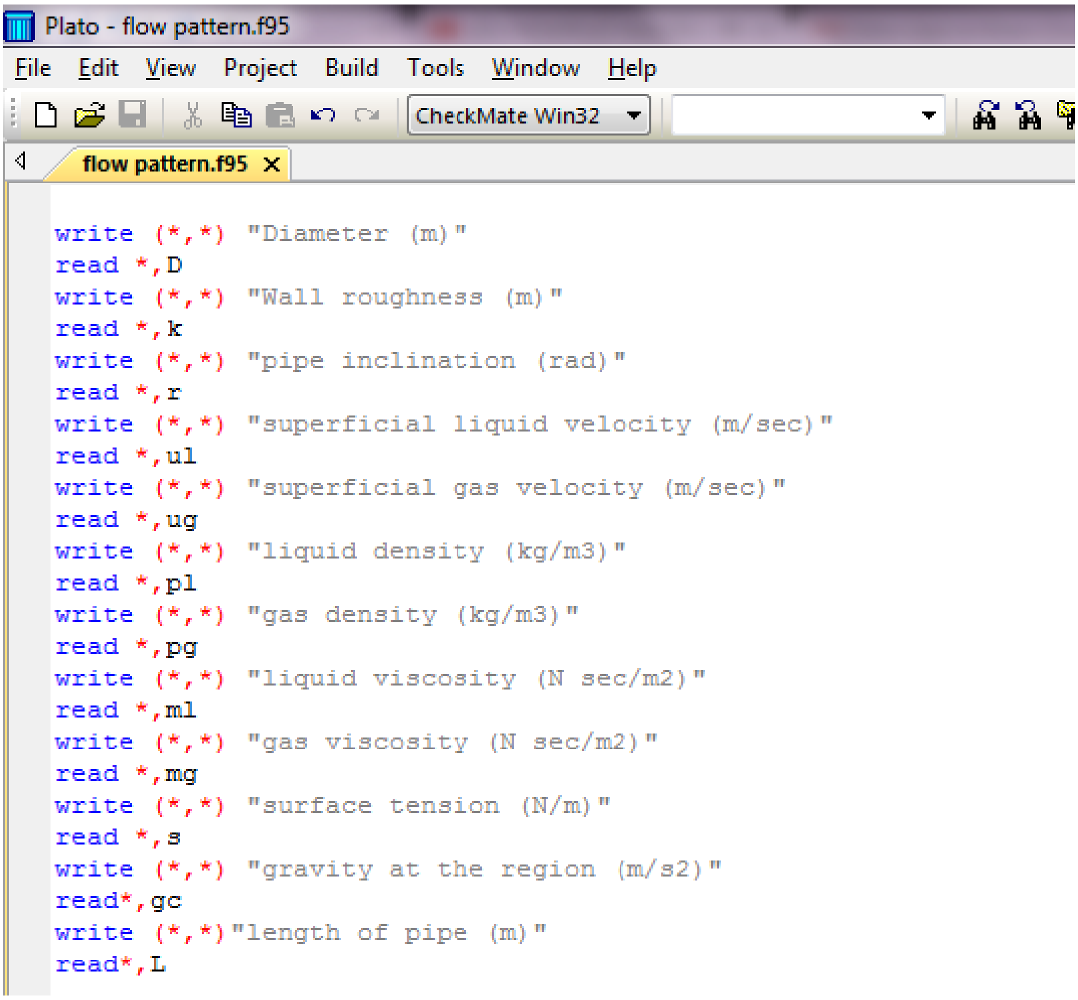
In this section, result of how the program works will be shown. At the same time, a few tests will be run to show which parameters will affect the flow pattern changes. Two parameters are selected which is diameters of the pipe and the length of pipe. The discussion on the result also included in this section.

4.2 Programming



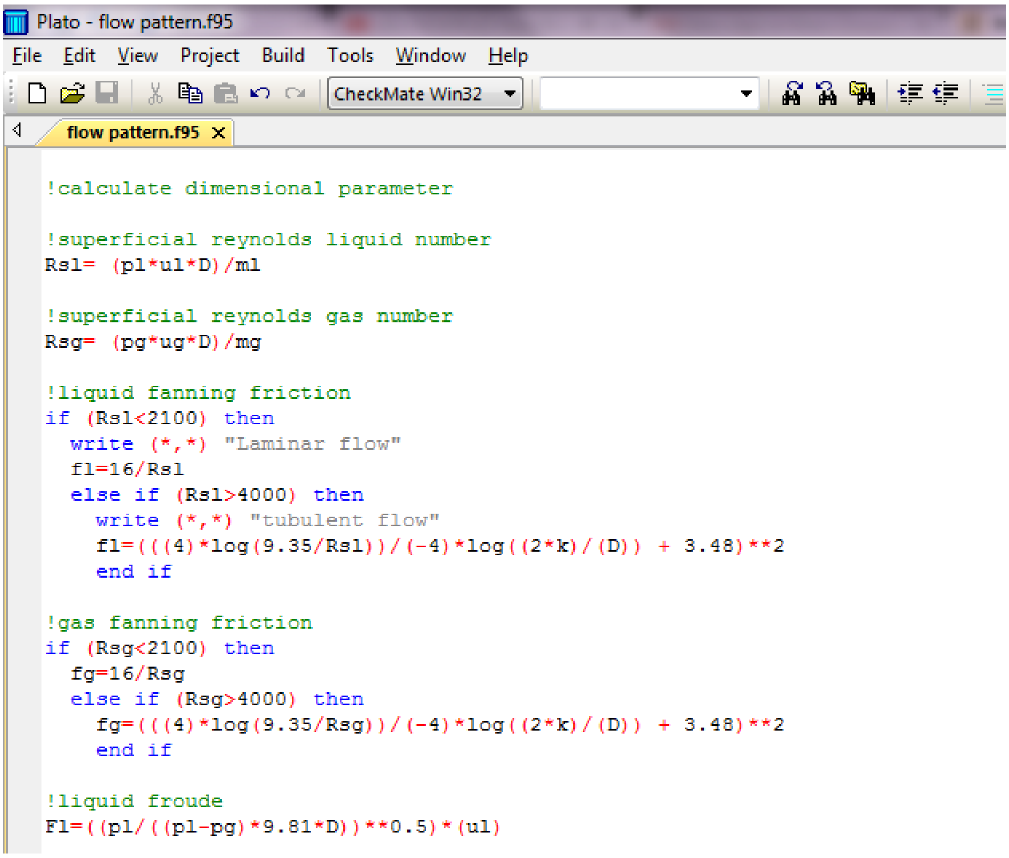
```
program pressure_loss_prediction_in_multiphase_flow_system
!input parameters
real :: D,k,r  !D=diameter k=wall roughness r= pipe inclination
real :: ul,ug !ul=superficial liquid velocity ug=superficial gas velocity
real :: pl,pg !pl,liquid density pg=gas density
real :: ml,mg !ml=liquid viscosity mg=gas viscosity
real :: s !surface tension
real :: gc !gravity at the region
real :: L   ! length of pipe
real :: Khc !Kelvin-Helmholtz critical
```

To start the program some pareters need to be defined as real as all the parameters might exist in decimals form.



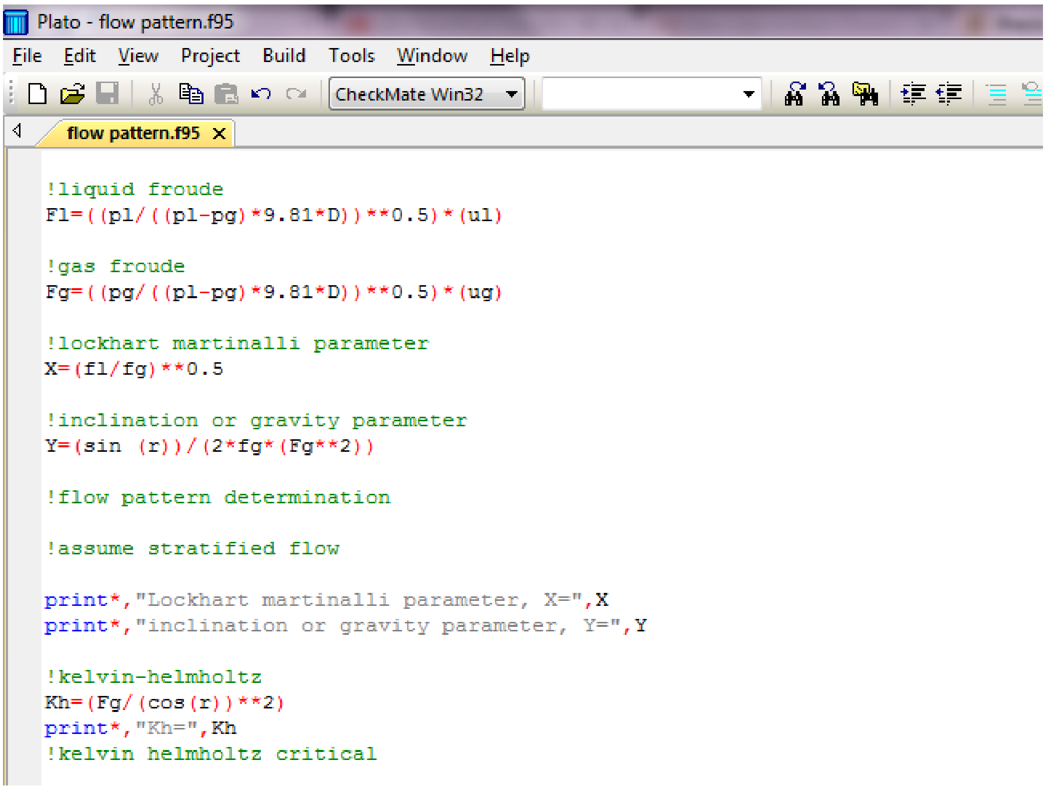
```
write (*,*) "Diameter (m)"
read *,D
write (*,*) "Wall roughness (m)"
read *,k
write (*,*) "pipe inclination (rad)"
read *,r
write (*,*) "superficial liquid velocity (m/sec)"
read *,ul
write (*,*) "superficial gas velocity (m/sec)"
read *,ug
write (*,*) "liquid density (kg/m3)"
read *,pl
write (*,*) "gas density (kg/m3)"
read *,pg
write (*,*) "liquid viscosity (N sec/m2)"
read *,ml
write (*,*) "gas viscosity (N sec/m2)"
read *,mg
write (*,*) "surface tension (N/m)"
read *,s
write (*,*) "gravity at the region (m/s2)"
read*,gc
write (*,*)"length of pipe (m)"
read*,L
```

The parameters are inserted.



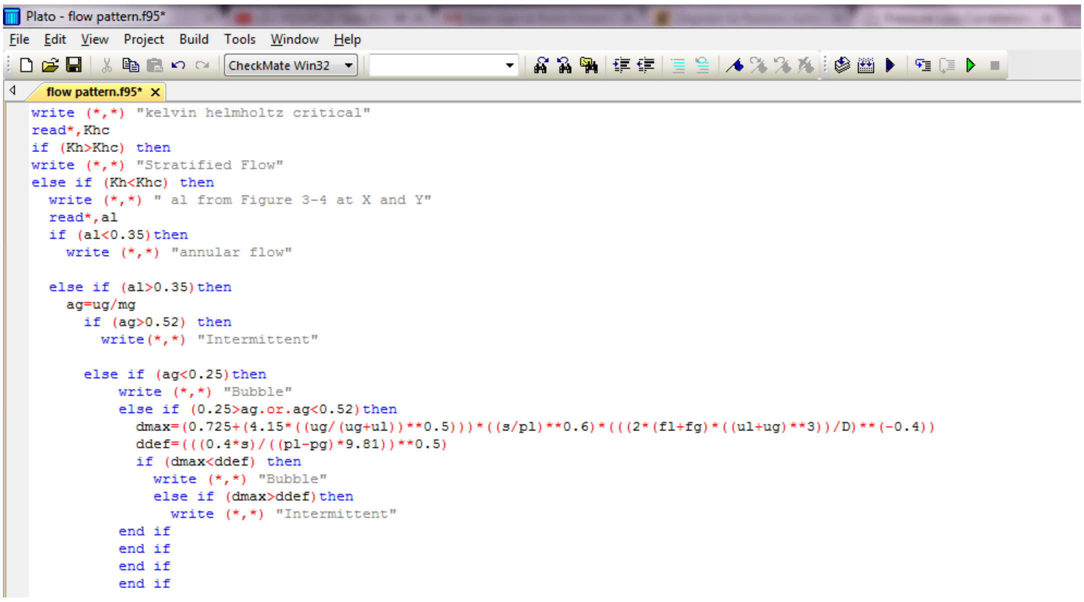
```
!calculate dimensional parameter

!superficial reynolds liquid number
Rsl= (pl*ul*D)/ml

!superficial reynolds gas number
Rsg= (pg*ug*D)/mg

!liquid fanning friction
if (Rsl<2100) then
  write (*,*) "Laminar flow"
  fl=16/Rsl
  else if (Rsl>4000) then
    write (*,*) "tubulent flow"
    fl=(((4)*log(9.35/Rsl))/(-4)*log((2*k)/(D)) + 3.48)**2
    end if

!gas fanning friction
if (Rsg<2100) then
  fg=16/Rsg
  else if (Rsg>4000) then
    fg=(((4)*log(9.35/Rsg))/(-4)*log((2*k)/(D)) + 3.48)**2
    end if

!liquid froude
Fl=((pl/((pl-pg)*9.81*D))**0.5)*(ul)
```

After the parameters is inserted, dimensionless parameters such Reynolds number, Fanning friction, Froude number, Lockhart-Martinelli and Inclination or gravity parameter is calculated.



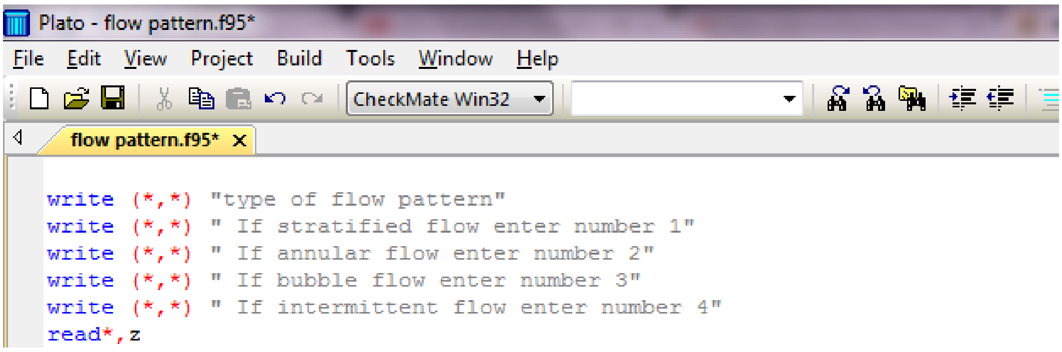
```
!liquid froude
Fl=((pl/((pl-pg)*9.81*D))**0.5)*(ul)

!gas froude
Fg=((pg/((pl-pg)*9.81*D))**0.5)*(ug)

!lockhart martinalli parameter
X=(fl/fg)**0.5

!inclination or gravity parameter
Y=(sin (r))/(2*fg*(Fg**2))

!flow pattern determination

!assume stratified flow

print*,"Lockhart martinalli parameter, X=",X
print*,"inclination or gravity parameter, Y=",Y

!kelvin-helmholtz
Kh=(Fg/(cos(r))**2)
print*,"Kh=",Kh
!kelvin helmholtz critical
```

Lockhart-Martinelli, X and Inclination or gravity parameter, Y is shown. This is because the values will be used to read Kelvin Helmholtz critical and liquid holdup.



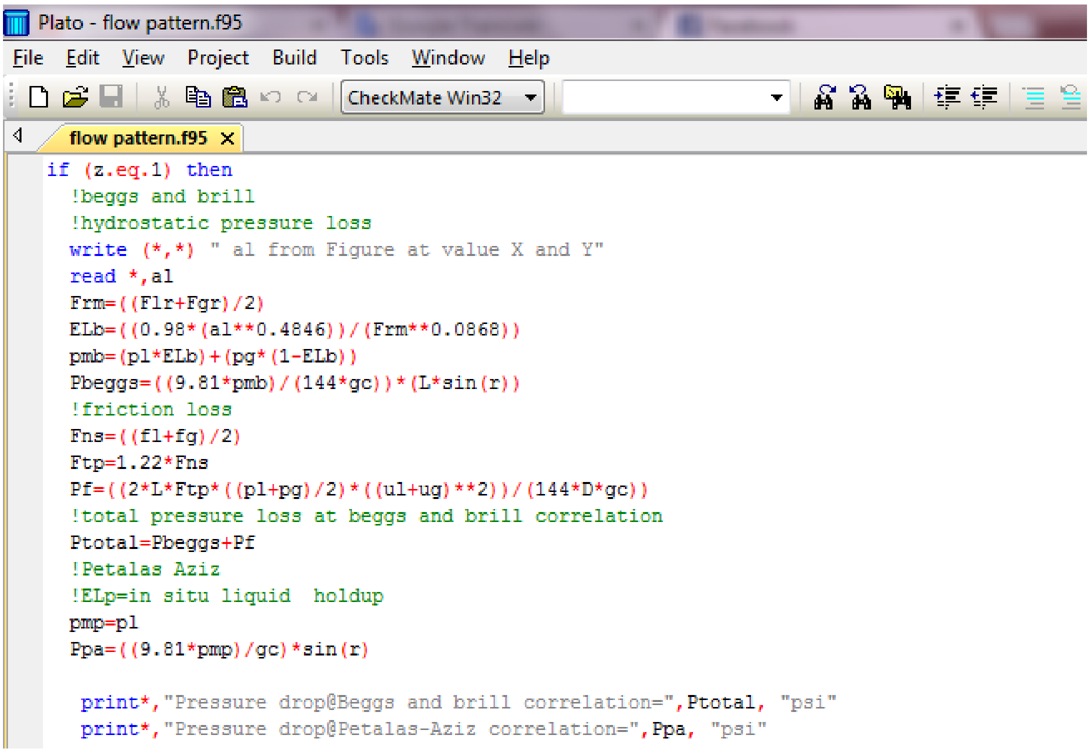
```
write (*,*) "kelvin helmholtz critical"
read*,Khc
if (Kh>Khc) then
write (*,*) "Stratified Flow"
else if (Kh<Khc) then
  write (*,*) " al from Figure 3-4 at X and Y"
  read*,al
  if (al<0.35)then
    write (*,*) "annular flow"

  else if (al>0.35)then
    ag=ug/mg
      if (ag>0.52) then
        write(*,*) "Intermittent"

      else if (ag<0.25)then
          write (*,*) "Bubble"
          else if (0.25>ag.or.ag<0.52)then
            dmax=(0.725+(4.15*((ug/(ug+ul))**0.5)))*((s/pl)**0.6)*(((2*(fl+fg)*((ul+ug)**3))/D)**(-0.4))
            ddef=(((0.4*s)/((pl-pg)*9.81))**0.5)
            if (dmax<ddef) then
              write (*,*) "Bubble"
              else if (dmax>ddef)then
                write (*,*) "Intermittent"
          end if
          end if
          end if
          end if
```

After reading the Kelvin Helmholtz critical the system will perform flow pattern identification. At the end of the system it will shows the types of flow pattern.



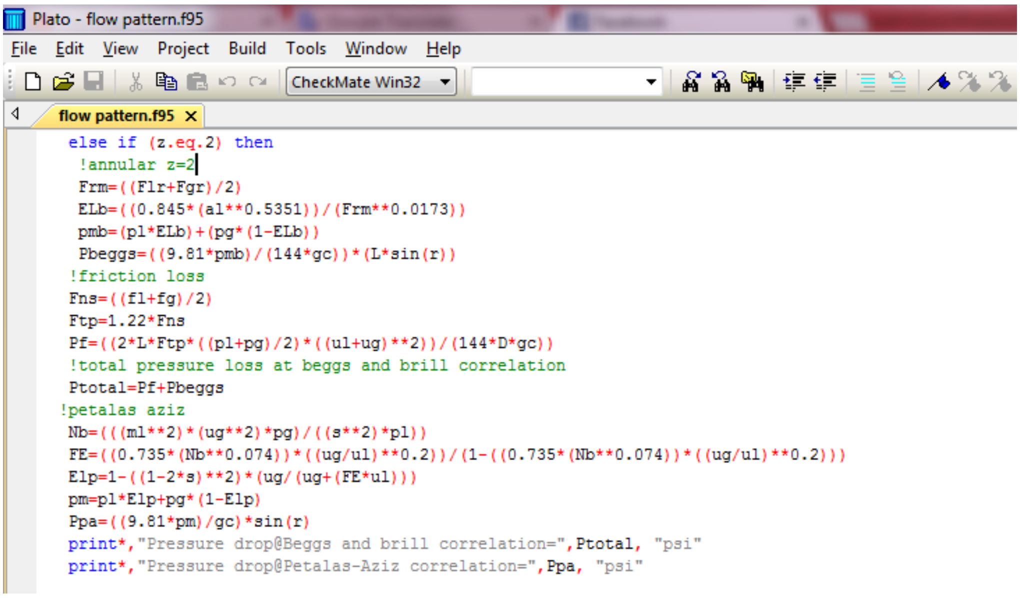
```
write (*,*) "type of flow pattern"
write (*,*) " If stratified flow enter number 1"
write (*,*) " If annular flow enter number 2"
write (*,*) " If bubble flow enter number 3"
write (*,*) " If intermittent flow enter number 4"
read*,z
```

Since the result is in word the system cannot recognize it. Thus as an alternative the type of flow pattern is change to number and inserted to the system.



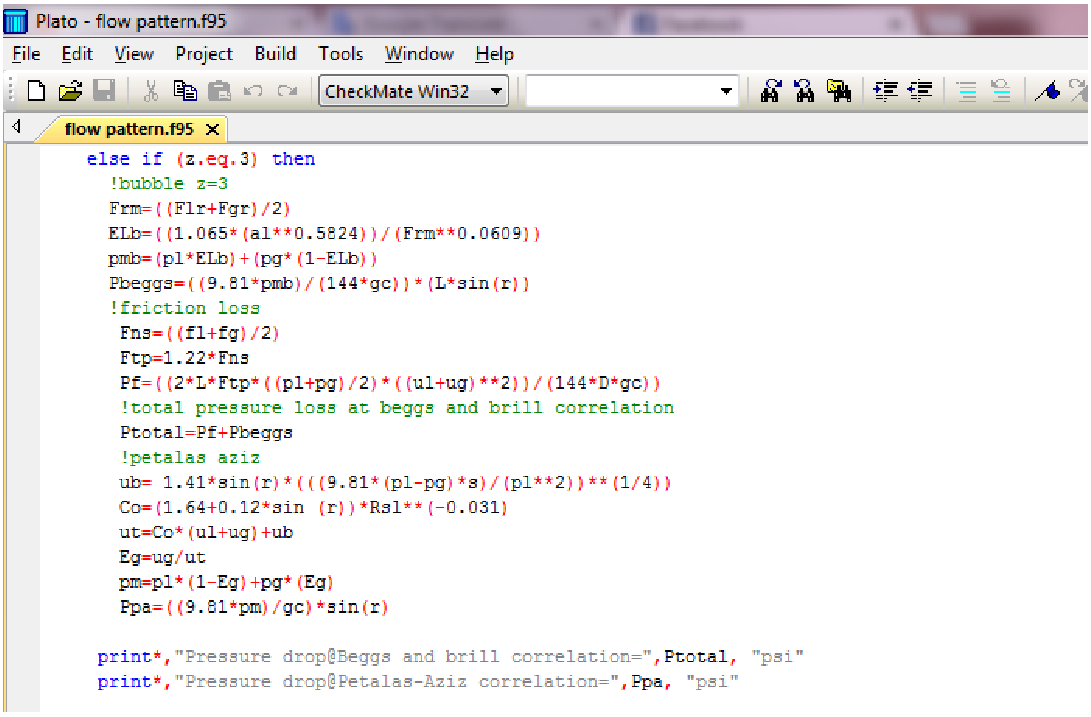
```
if (z.eq.1) then
  !beggs and brill
  !hydrostatic pressure loss
  write (*,*) " al from Figure at value X and Y"
  read *,al
  Frm=((Flr+Fgr)/2)
  ELb=((0.98*(al**0.4846))/(Frm**0.0868))
  pmb=(pl*ELb)+(pg*(1-ELb))
  Pbeggs=((9.81*pmb)/(144*gc))*(L*sin(r))
  !friction loss
  Fns=((fl+fg)/2)
  Ftp=1.22*Fns
  Pf=((2*L*Ftp*((pl+pg)/2)*((ul+ug)**2))/(144*D*gc))
  !total pressure loss at beggs and brill correlation
  Ptotal=Pbeggs+Pf
  !Petalas Aziz
  !ELp=in situ liquid  holdup
  pmp=pl
  Ppa=((9.81*pmp)/gc)*sin(r)

   print*,"Pressure drop@Beggs and brill correlation=",Ptotal, "psi"
   print*,"Pressure drop@Petalas-Aziz correlation=",Ppa, "psi"
```

If the number 1 is inserted the system will calculate pressure drop for stratified flow.



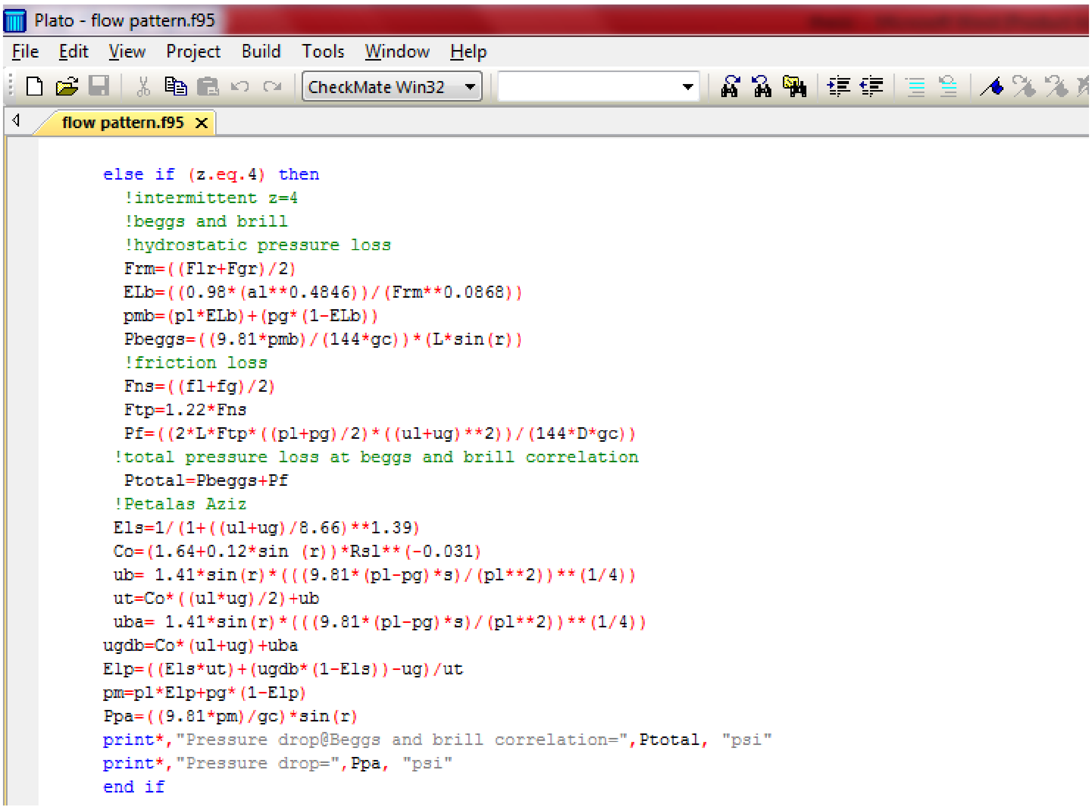
```
  else if (z.eq.2) then
   !annular z=2
   Frm=((Flr+Fgr)/2)
   ELb=((0.845*(al**0.5351))/(Frm**0.0173))
   pmb=(pl*ELb)+(pg*(1-ELb))
   Pbeggs=((9.81*pmb)/(144*gc))*(L*sin(r))
  !friction loss
  Fns=((fl+fg)/2)
  Ftp=1.22*Fns
  Pf=((2*L*Ftp*((pl+pg)/2)*((ul+ug)**2))/(144*D*gc))
  !total pressure loss at beggs and brill correlation
  Ptotal=Pf+Pbeggs
 !petalas aziz
  Nb=(((ml**2)*(ug**2)*pg)/((s**2)*pl))
  FE=((0.735*(Nb**0.074))*((ug/ul)**0.2))/(1-((0.735*(Nb**0.074))*((ug/ul)**0.2)))
  Elp=1-((1-2*s)**2)*(ug/(ug+(FE*ul)))
  pm=pl*Elp+pg*(1-Elp)
  Ppa=((9.81*pm)/gc)*sin(r)
  print*,"Pressure drop@Beggs and brill correlation=",Ptotal, "psi"
  print*,"Pressure drop@Petalas-Aziz correlation=",Ppa, "psi"
```

If the number 2 is inserted the system will calculate pressure drop for annular.



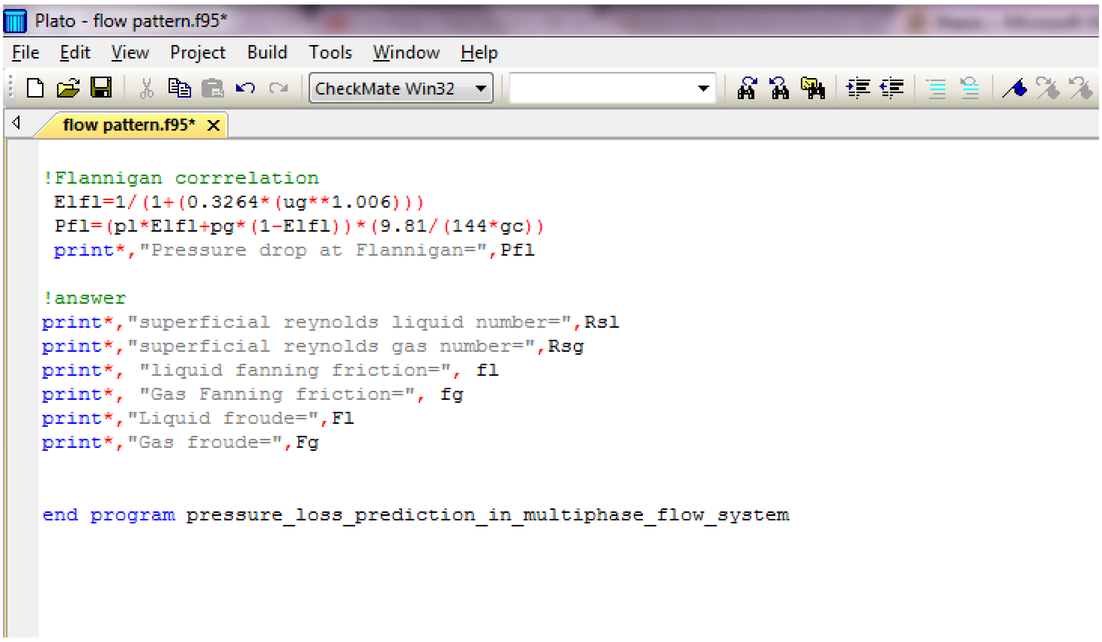
```
    else if (z.eq.3) then
      !bubble z=3
      Frm=((Flr+Fgr)/2)
      ELb=((1.065*(al**0.5824))/(Frm**0.0609))
      pmb=(pl*ELb)+(pg*(1-ELb))
      Pbeggs=((9.81*pmb)/(144*gc))*(L*sin(r))
      !friction loss
       Fns=((fl+fg)/2)
       Ftp=1.22*Fns
       Pf=((2*L*Ftp*((pl+pg)/2)*((ul+ug)**2))/(144*D*gc))
       !total pressure loss at beggs and brill correlation
       Ptotal=Pf+Pbeggs
       !petalas aziz
       ub= 1.41*sin(r)*(((9.81*(pl-pg)*s)/(pl**2))**(1/4))
       Co=(1.64+0.12*sin (r))*Rsl**(-0.031)
       ut=Co*(ul+ug)+ub
       Eg=ug/ut
       pm=pl*(1-Eg)+pg*(Eg)
       Ppa=((9.81*pm)/gc)*sin(r)

     print*,"Pressure drop@Beggs and brill correlation=",Ptotal, "psi"
     print*,"Pressure drop@Petalas-Aziz correlation=",Ppa, "psi"
```

If the number 3 is inserted the system will calculate pressure drop for bubble flow.



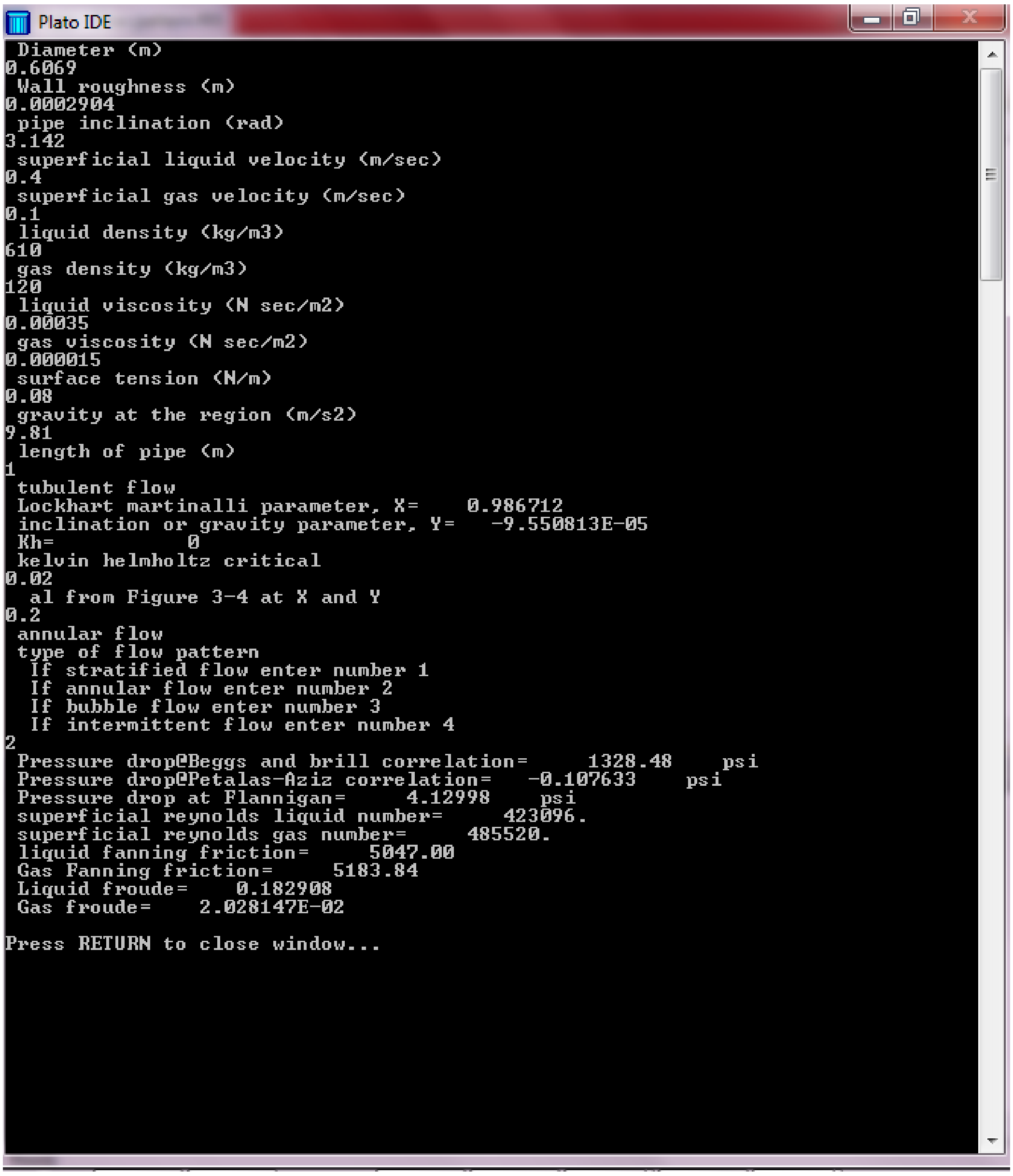
```
    else if (z.eq.4) then
      !intermittent z=4
      !beggs and brill
      !hydrostatic pressure loss
      Frm=((Flr+Fgr)/2)
      ELb=((0.98*(al**0.4846))/(Frm**0.0868))
      pmb=(pl*ELb)+(pg*(1-ELb))
      Pbeggs=((9.81*pmb)/(144*gc))*(L*sin(r))
      !friction loss
      Fns=((fl+fg)/2)
      Ftp=1.22*Fns
      Pf=((2*L*Ftp*((pl+pg)/2)*((ul+ug)**2))/(144*D*gc))
     !total pressure loss at beggs and brill correlation
      Ptotal=Pbeggs+Pf
     !Petalas Aziz
     Els=1/(1+((ul+ug)/8.66)**1.39)
     Co=(1.64+0.12*sin (r))*Rsl**(-0.031)
     ub= 1.41*sin(r)*(((9.81*(pl-pg)*s)/(pl**2))**(1/4))
     ut=Co*((ul*ug)/2)+ub
     uba= 1.41*sin(r)*(((9.81*(pl-pg)*s)/(pl**2))**(1/4))
    ugdb=Co*(ul+ug)+uba
    Elp=((Els*ut)+(ugdb*(1-Els))-ug)/ut
    pm=pl*Elp+pg*(1-Elp)
    Ppa=((9.81*pm)/gc)*sin(r)
    print*,"Pressure drop@Beggs and brill correlation=",Ptotal, "psi"
    print*,"Pressure drop=",Ppa, "psi"
    end if
```

If the number 4 is inserted the system will calculate pressure drop for intermittent.



```
!Flannigan corrrelation
 Elfl=1/(1+(0.3264*(ug**1.006)))
 Pfl=(pl*Elfl+pg*(1-Elfl))*(9.81/(144*gc))
 print*,"Pressure drop at Flannigan=",Pfl

!answer
print*,"superficial reynolds liquid number=",Rsl
print*,"superficial reynolds gas number=",Rsg
print*, "liquid fanning friction=", fl
print*, "Gas Fanning friction=", fg
print*,"Liquid froude=",Fl
print*,"Gas froude=",Fg


end program pressure_loss_prediction_in_multiphase_flow_system
```

Last but not least Flannigan correlation is calculated and all the result will be shown at the bottom of the system.



```
 Diameter (m)
0.6069
 Wall roughness (m)
0.0002904
 pipe inclination (rad)
3.142
 superficial liquid velocity (m/sec)
0.4
 superficial gas velocity (m/sec)
0.1
 liquid density (kg/m3)
610
 gas density (kg/m3)
120
 liquid viscosity (N sec/m2)
0.00035
 gas viscosity (N sec/m2)
0.000015
 surface tension (N/m)
0.08
 gravity at the region (m/s2)
9.81
 length of pipe (m)
1
 tubulent flow
 Lockhart martinalli parameter, X=     0.986712
 inclination or gravity parameter, Y=    -9.550813E-05
 Kh=             0
 kelvin helmholtz critical
0.02
  al from Figure 3-4 at X and Y
0.2
 annular flow
 type of flow pattern
  If stratified flow enter number 1
  If annular flow enter number 2
  If bubble flow enter number 3
  If intermittent flow enter number 4
2
 Pressure drop@Beggs and brill correlation=      1328.48     psi
 Pressure drop@Petalas-Aziz correlation=    -0.107633     psi
 Pressure drop at Flannigan=      4.12998     psi
 superficial reynolds liquid number=      423096.
 superficial reynolds gas number=      485520.
 liquid fanning friction=      5047.00
 Gas Fanning friction=      5183.84
 Liquid froude=     0.182908
 Gas froude=     2.028147E-02

Press RETURN to close window...
```

The system will start if there is no error. It will immediately show the result.

4.3 Flow pattern determination

Extending the knowledge of this research a few sets of data is tested. The purpose is to see which parameters will affect the changes of flow pattern. The two parameters are pipe diameter and length. The diameters obviously will change the Reynolds number which will be used for the entire structure of flow pattern determination. The length also affecting the Reynolds number since the viscosity change due to the length based on Figure 4-1. Based on the program input parameters, some of the data are set to constant as shown in Table 4-1. The pipe is set to horizontal and the pipe used is cast iron. In the end of data testing, an analysis will be made based on the result.

Viscosity of Gas	$0.015\text{x}10^{-3}$ N.s/m^2
Viscosity of Liquid	$0.35\text{x}10^{-3}$ N.s/m^2
Gravity at the region	9.81 m/s^{-2}
Liquid density	610 kg/m^3
Gas density	120 kg/m^3
Surface tension (below 20^o)	0.08 N/m
Wall roughness (cast iron)	2.904 x 10^{-4} m

Table 4-1 Constant value for flow pattern determination

4.3.1 Diameter

Table 4-2 shows the result from the programme by changing the diameter of pipe. The data start from 2 inch to 36 inch. Based on equation (1) and (2) changing the diameter absolutely will change the superficial Reynolds number. Based on (Cheng, 2009) flow pattern changes are observed by changing the system superficial Reynolds number and heat flux. Thus, to check the changes of flow pattern the length of pipe is set to 1 meter while the superficial velocity for liquid is set to 0.4 and superficial gas velocity set to 0.1. Both values are taken from Figure 3-3.

First and foremost, based on the result it shows that both superficial Reynolds numbers as in Figure 4-1 increased steadily by changing the diameter. Same as Fanning friction for gas and liquid where the number increased as the superficial Reynolds number increased. Inversely, referring to Figure 4-6 it shows Froude number for gas and liquid decrease responding to the increasing pipe diameter. Gas Froude number only shows a slight decrease. These three parameters will affect the Lockhart Martinelli and Inclination or gravity parameter. Due to the increasing of superficial Reynolds number it shows that Lockhart Martinelli also increasing while the inclination or gravity parameter decreased. On the other hand it shows that in Figure 4-4 the Kelvin Helmholtz and liquid holdup increased at one point which is at the 28 inch diameter. Start from the changes the flow pattern start to change from annular to intermittent.

For pressure drop, only Beggs and Brill shows an obviously changes in pressure drop. For 2 inches pipes in annular flow it shows that the pressure drop from Beggs and Brill pressure drop is at 3517.32 psi. The pressure still decreases steadily even though the flow pattern changes from annular to intermittent. Besides that, Petlas Aziz correlation does not shows any changes at same flow pattern. The pressure drop only show -0.107633 at annular flow, but the pressure start to show at intermittent flow. At 28 inch diameter the pressure drop is 0.59828 psi and continues to increase as the diameter increase. Flannigan correlation does not show any changes of pressure drop. From the equation the diameter of pipe does not affecting its calculation value of pressure drop.

Diameter (inch)	2	4	6	8	10
Diameter (m)	0.0508	0.1016	0.1524	0.2032	0.2540
Superficial Reynolds liquid number	35414.9	70829.7	106245	141659	177074
Superficial Reynolds gas number	40640	81280	121920	162560	203200
Lockhart Martinalli parameter	0.981889	0.983609	0.984451	0.98491	0.985382
Inclination or gravity parameter	$-3.589955x10^{-5}$	$-3.589955x10^{-5}$	$-5.115544x10^{-5}$	$-5.746377x10^{-5}$	$-6.323116x10^{-5}$
Kelvin Helmholtz Instability critical	0.02	0.02	0.02	0.02	0.02
Liquid Holdup	0.2	0.2	0.2	0.2	0.2
Liquid Fanning friction	1112.95	1819.17	2355.36	2798.78	3181.90
Gas Fanning friction	1154.38	1880.30	2430.35	2884.73	3277.01
Liquid Froude	0.632209	0.447039	0.365006	0.316104	0.282732
Gas Froude	$7.010132x10^{-2}$	$4.956912x10^{-2}$	$4.047302x10^{-2}$	$3.50506x10^{-2}$	$3.135027x10^{-2}$
Flow pattern	Annular	Annular	Annular	Annular	Annular
Pressure drop, psi					
Beggs and Brill	3517.32	2869.51	2474.70	2204.22	2003.95
Petalas-Aziz	-0.107633	-0.107633	-0.107633	-0.107633	-0.107633
Flannigan	4.12998	4.12998	4.12998	4.12998	4.12998

Table 4-2 Tabulated data for different pipe diameter

Diameter (inch)	12	14	16	18	20
Diameter (m)	0.3048	0.3556	0.4064	0.4572	0.5080
Superficial Reynolds liquid number	212489	247904	283319	318734	354149
Superficial Reynolds gas number	203200	284480	325120	365760	406400
Lockhart Martinalli parameter	0.985382	0.985929	0.986134	0.986310	0.986463
Inclination or gravity parameter	-6.323116×10^{-5}	-7.36898×10^{-5}	-7.842689×10^{-5}	-8.300054×10^{-5}	-8.739209×10^{-5}
Kelvin Helmholtz Instability critical	0.02	0.02	0.02	0.02	0.02
Liquid Holdup	0.2	0.2	0.2	0.2	0.2
Liquid Fanning friction	3181.90	3829.31	4110.09	4371.046	4614.53
Gas Fanning friction	3277.01	3939.39	4227.31	4493.66	4742.06
Liquid Froude	0.282732	0.238952	0.223520	0.210736	0.199922
Gas Froude	3.135027×10^{-2}	2.649581×10^{-2}	2.478456×10^{-2}	2.336711×10^{-2}	2.216798×10^{-2}
Flow pattern	Annular	Annular	Annular	Annular	Annular
Pressure drop, psi					
Beggs and Brill	1847.84	1721.66	1616.89	1528.06	1451.49
Petalas-Aziz	-0.107633	-0.107633	-0.107633	-0.107633	-0.107633
Flannigan	4.12998	4.12998	4.12998	4.12998	4.12998

Diameter (inch)	22	24	26	28	30
Diameter (m)	0.5588	0.6096	0.6604	0.7112	0.7620
Superficial Reynolds liquid number	389563	424978	460393	495808	531223
Superficial Reynolds gas number	447040	487680	528320	568960	609600
Lockhart Martinalli parameter	0.986597	0.986718	0.986827	0.986927	0.987017
Inclination or gravity parameter	-9.162624x10^{-5}	-9.57226x10^{-5}	-9.969699x10^{-5}	-1.035622x10^{-4}	-1.073291x10^{-4}
Kelvin Helmholtz Instability critical	0.02	0.02	0.02	0.19	0.19
Liquid Holdup	0.2	0.2	0.2	0.4	0.4
Liquid Fanning friction	4842.74	5058.15	5262.38	5456.76	5642.38
Gas Fanning friction	4975.21	5195.24	5403.81	5602.29	5791.79
Liquid Froude	0.190618	0.182503	0.175343	0.168965	0.163236
Gas Froude	2.113635x10^{-2}	2.023651x10^{-2}	1.844261x10^{-2}	1.873537x10^{-2}	1.810008x10^{-2}
Flow pattern	Annular	Annular	Annular	Intermittent	Intermittent
Pressure drop, psi					
Beggs and Brill	1384.60	1325.51	1272.81	1225.43	1182.52
Petalas-Aziz	-0.107633	-0.107633	-0.107633	0.59828	0.600336
Flannigan	4.12998	4.12998	4.12998	4.12998	4.12998

Diameter (inch)	32	34	36
Diameter (m)	0.8128	0.8636	0.9144
Superficial Reynolds liquid number	566638	602053	637467
Superficial Reynolds gas number	650240	690880	731520
Lockhart Martinalli parameter	0.987101	0.987179	0.987251
Inclination or gravity parameter	$-7.36898\text{x}10^{-5}$	$-1.146026\text{x}10^{-4}$	$-1.181237\text{x}10^{-4}$
Kelvin Helmholtz Instability critical	0.19	0.19	0.19
Liquid Holdup	0.4	0.4	0.4
Liquid Fanning friction	5820.14	5990.80	6155.02
Gas Fanning friction	5973.24	6147.42	6315.01
Liquid Froude	0.158052	0.153333	0.149013
Gas Froude	$1.752533\text{x}10^{-2}$	$1.700207\text{x}10^{-2}$	$1.652304\text{x}10^{-2}$
Flow pattern	Intermittent	Intermittent	Intermittent
Pressure drop, psi			
Beggs and Brill	1143.44	1107.65	1074.71
Petalas-Aziz	0.60265	0.605797	-0.107633
Flannigan	4.12998	4.12998	4.12998

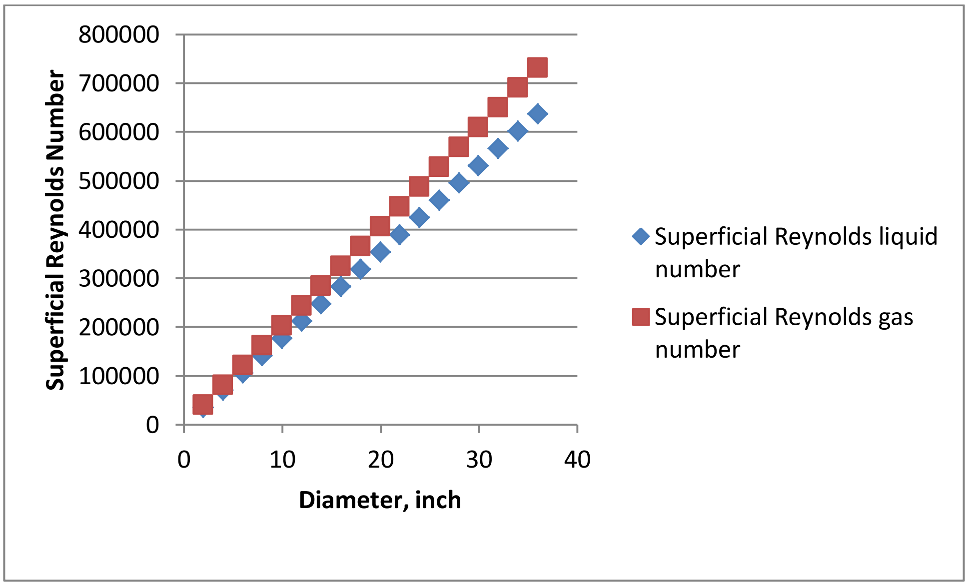


Figure 4-1Superficial Reynolds number for different pipe diameter

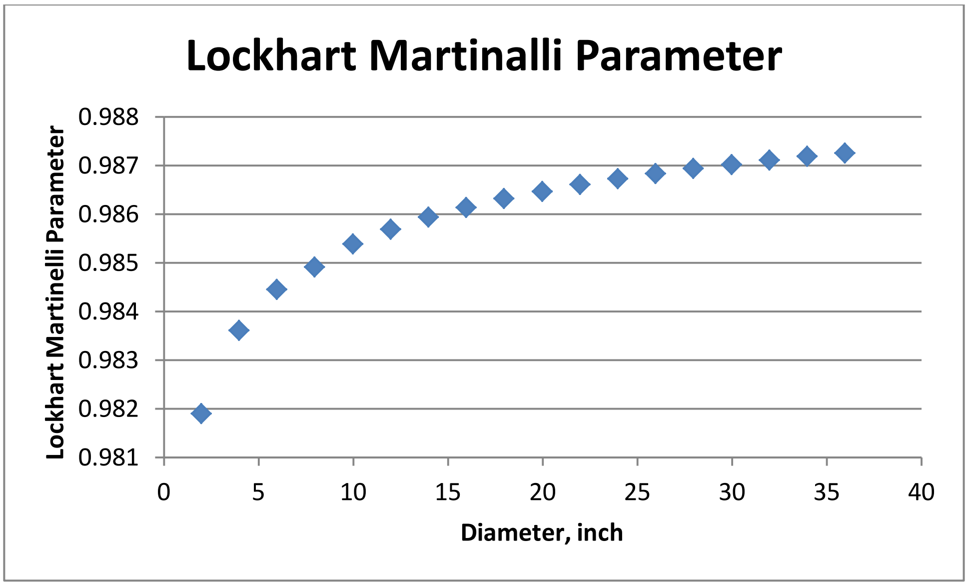


Figure 4-2Lockhart Martinalli parameter of for different pipe diameter

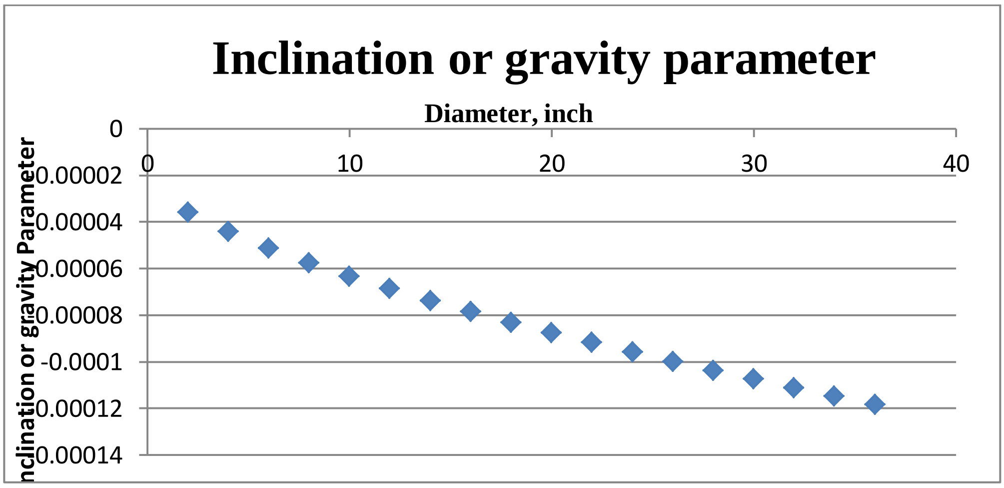


Figure 4-3Inclination or gravity parameter for different pipe diameter

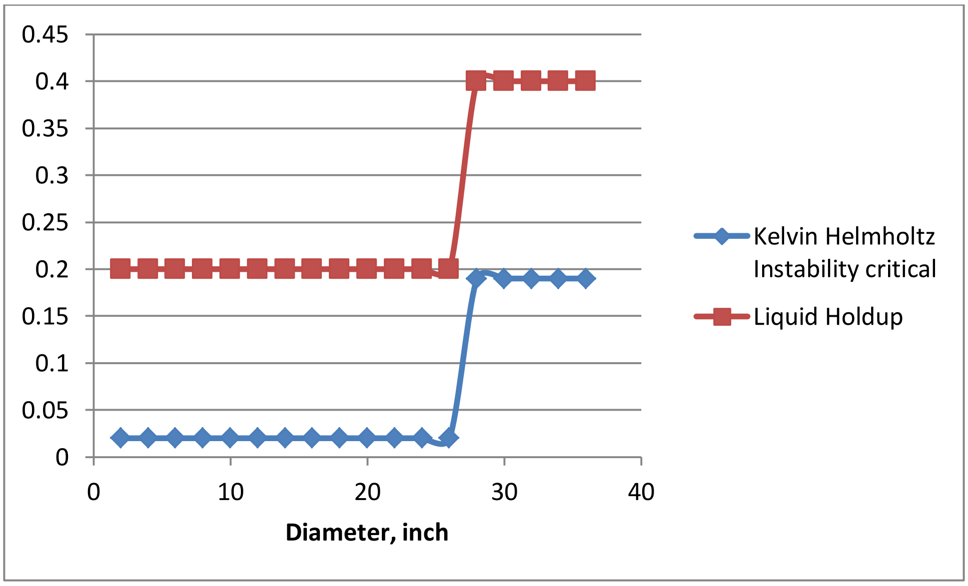


Figure 4-4Kelvin Helmholtz instability critical and liquid holdup for different pipe diameter

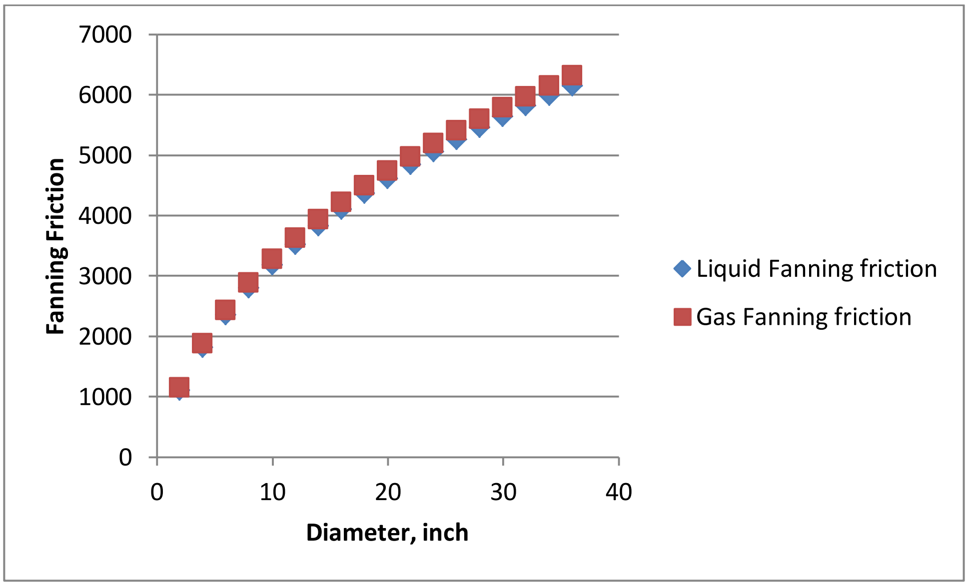


Figure 4-5Fanning Friction for different pipe diameter

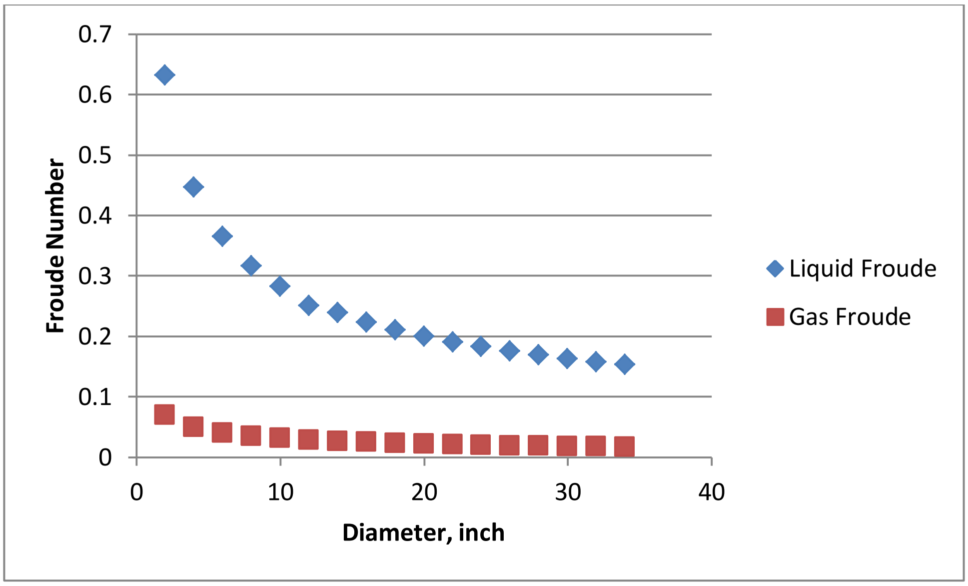


Figure 4-6 Froude number for different pipe diameter

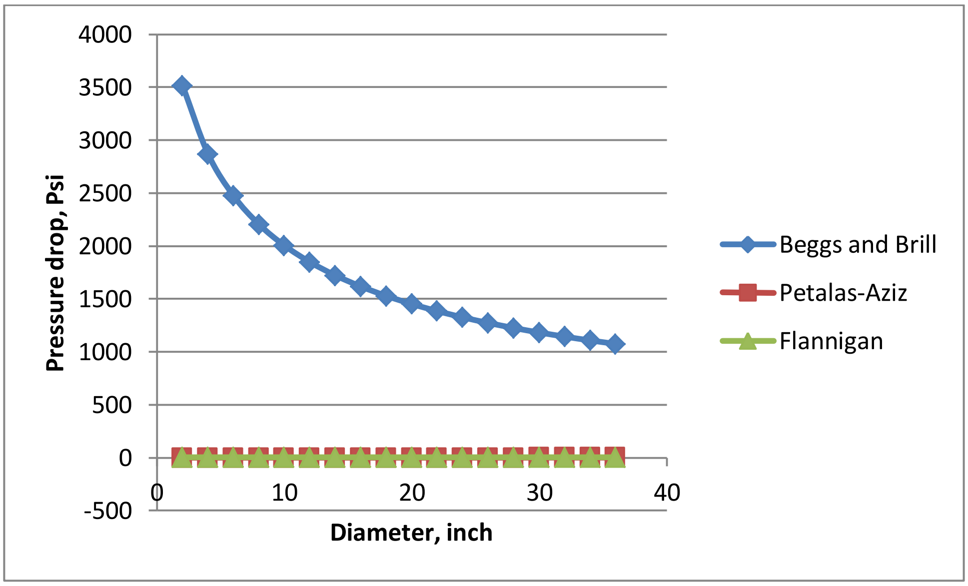


Figure 4-7Pressure for different pipe diameter

4.3.2 Length

Table 4-3 shows the overall calculation by differentiating the length of pipe. From Figure 3-3 it shows that by changing the length of pipe the superficial also change. Superficial is very crucial in calculating the pressure drop as well as determining the flow pattern. In (Lawrence C., 2013) an experiment was conducted by ranging the superficial velocity to observe flow pattern changes for liquid-liquid flows. Using the programme developed in this research length of pipe is varied to see the changes of flow pattern. The diameter of pipe is set to 18 inches.

Figure 4-8 display the superficial Reynolds number for gas and liquid. Since the superficial liquid velocity are same at some point thus the superficial liquid Reynolds number are same. From the trend the superficial Reynolds liquid number are decreasing since the superficial liquid velocity are also decreasing. Meanwhile the superficial Reynolds gas number keeps rising. Due the trend of the superficial Reynolds number the Fanning friction in Figure 4-5 also changes. The liquid Fanning friction keeps declining whilst the gas Fanning friction increasing as the length of pipe increasing. On the other hand, the Froude number also changes same as the Fanning friction. The liquid Froude keeps decreasing and the gas Froude keeps surging. At point the Fanning friction for gas and liquid are intersect and then after that the value of liquid Fanning friction is lower than the value for gas. Referring to Figure 4-11the Kelvin Helmholtz is constant for the entire calculation while liquid holdup changes at 1800 meters. Even though there is changes in the liquid holdup there are still no flow pattern changes observed.

Pressure drop calculation can be for each correlation can be observed from Figure 4-14. Beggs and Brill still show an interesting value. The pressure drop rosing as the length of pipe increasing. Unfortunately Petalas Aziz does not show any changes since there are no flow pattern changes. Flannigan correlation shows positive changes since there are changes in superficial gas velocity.

Length (m)	200	400	600	800	1000
Superficial Liquid Velocity	0.4	0.4	0.4	0.38	0.38
Superficial Gas Velocity	0.10	0.12	0.14	0.16	0.2
Superficial Reynolds liquid number	318734	318734	318734	302797	302797
Superficial Reynolds gas number	365760	438912	512064	585216	731520
Lockhart Martinalli	0.986310	0.968740	0.954366	0.937380	0.91791
Inclination or gravity parameter	-8.300054×10^{-5}	-5.560401×10^{-5}	-3.964860×10^{-5}	-2.959041×10^{-5}	-1.815950×10^{-5}
Kelvin Helmholtz Instability critical	0.02	0.018	0.018	0.018	0.018
Liquid Holdup	0.2	0.2	0.2	0.2	0.2
Liquid Fanning friction	4371.46	4371.46	4371.46	4923.69	4326.35
Gas Fanning friction	4493.66	4658.14	4799.52	4923.69	5134.73
Liquid Froude	0.210736	0.210736	0.210736	0.200199	0.200199
Gas Froude	2.336711×10^{-2}	2.804053×10^{-2}	3.271395×10^{-2}	3.738737×10^{-2}	4.673422×10^{-2}
Flow pattern	Annular	Annular	Annular	Annular	Annular
Pressure drop, psi					
Beggs and Brill	305611	673365	1206291	1487770	2194378
Petalas-Aziz	-0.107633	-0.107633	-0.107633	-0.107633	-0.107633
Flannigan	4.12998	4.12998	4.12998		

Table 4-3Tabulated data for different pipe length

Length (m)	1200	1400	1600	1800	2000
Superficial Liquid Velocity	0.38	0.38	0.38	0.38	0.38
Superficial Gas Velocity	0.22	0.25	0.26	0.28	0.3
Superficial Reynolds liquid number	302797	302797	302797	302797	302797
Superficial Reynolds gas number	804672	950400	988416	1064448	1140480
Lockhart Martinalli parameter	0.909844	0.899622	0.896429	0.890456	0.884968
Inclination or gravity parameter	$-1.474513\text{x}10^{-5}$	$-1.137358\text{x}10^{-5}$	$-1.044100\text{x}10^{-5}$	$-8.883138\text{x}10^{-6}$	$-7.643097\text{x}10^{-6}$
Kelvin Helmholtz Instability critical	0.016	0.016	0.016	0.014	0.014
Liquid Holdup	0.2	0.2	0.2	0.01	0.01
Liquid Fanning friction	4326.35	4413.61	4412.61	4413.61	4413.61
Gas Fanning friction	5226.22	5453.49	5492.41	5566.33	5635.59
Liquid Froude	0.200199	0.196371	0.196371	0.196371	0.196371
Gas Froude	$5.14076\text{x}10^{-2}$	$5.73006\text{x}10^{-2}$	$5.959272\text{x}10^{-2}$	$6.417678\text{x}10^{-2}$	$6.876083\text{x}10^{-2}$
Flow pattern	Annular	Annular	Annular	Annular	Annular
Pressure drop, psi					
Beggs and Brill	2845239	3637000	4306494	5190786	6164874
Petalas-Aziz	-0.107633	-0.107633	-0.107633	-0.107633	-0.107633
Flannigan	4.12998	4.12998	4.12998	3.95315	3.93462

Length (m)	2200	2400	2600	2800	3000
Superficial Liquid Velocity	0.36	0.36	0.36	0.36	0.36
Superficial Gas Velocity	0.32	0.34	0.36	0.38	0.4
Superficial Reynolds liquid number	298154	298154	286860	286860	286860
Superficial Reynolds gas number	1216512	1292544	1316736	1389888	1463040
Lockhart Martinalli parameter	0.876545	0.870404	0.865538	0.861428	0.857566
Inclination or gravity parameter		-5.819624×10^{-6}	-5.038497×10^{-6}	-4.479248×10^{-6}	-4.006347×10^{-6}
Kelvin Helmholtz Instability critical	0.014	0.014	0.012	0.012	0.012
Liquid Holdup	0.01	0.01	0.01	0.01	0.01
Liquid Fanning friction	4400.12	4365.56	4279.05	4279.05	4279.05
Gas Fanning friction	5682.31	5762.34	5711.83	5766.46	5818.52
Liquid Froude	0.186036	0.186036	0.189663	0.189663	0.189663
Gas Froude	7.334489×10^{-2}	7.792895×10^{-2}	8.412159×10^{-2}	8.879501×10^{-2}	9.346844×10^{-2}
Flow pattern	Annular	Annular	Annular	Annular	Annular
Pressure drop, psi					
Beggs and Brill		7900806	9284470	1061960	1206370
Petalas-Aziz	-0.107633	-0.107633	-0.107633	-0.107633	-0.107633
Flannigan	3.91630	4.12998	3.88027	3.86256	3.84506

Length (m)	3200	3400	3600	3800	4000
Superficial Liquid Velocity	0.34	0.34	0.34	0.34	0.32
Superficial Gas Velocity	0.45	0.50	0.6	0.75	0.8
Superficial Reynolds liquid number	270924	270924	270924	270924	254987
Superficial Reynolds gas number	1645920	1828800	2194560	2743000	2926080
Lockhart Martinalli parameter	0.843879	0.836255	0.823383	0.808157	0.798861
Inclination or gravity parameter	-3.101313x10^{-6}	-2.4668785x10^{-6}	-1.660775x10^{-6}	-1.023951x10-^{6}	-8.904067x10-^{7}
Kelvin Helmholtz Instability critical	0.012	0.012	0.012	0.012	0.012
Liquid Holdup	0.01	0.01	0.01	0.01	0.01
Liquid Fanning friction	4229.33	4229.23	4229.23	4229.33	4176.91
Gas Fanning friction	5938.96	6047.75	6238.33	6475.60	65645.05
Liquid Froude	0.179126	0.179126	0.179126	0.179126	0.168589
Gas Froude	1.05152x10^{-1}	1.16836x10^{-2}	1.40203x10^{-2}	1.75253x10^{-1}	1.86937x10^{-1}
Flow pattern	Annular	Annular	Annular	Annular	Annular
Pressure drop, psi					
Beggs and Brill	1400126	1699895	21681980	3332232	3709242
Petalas-Aziz	-0.107633	-0.107633	-0.107633	-0.107633	-0.107633
Flannigan	3.80214	3.68027	3.68027	3.56785	3.53230

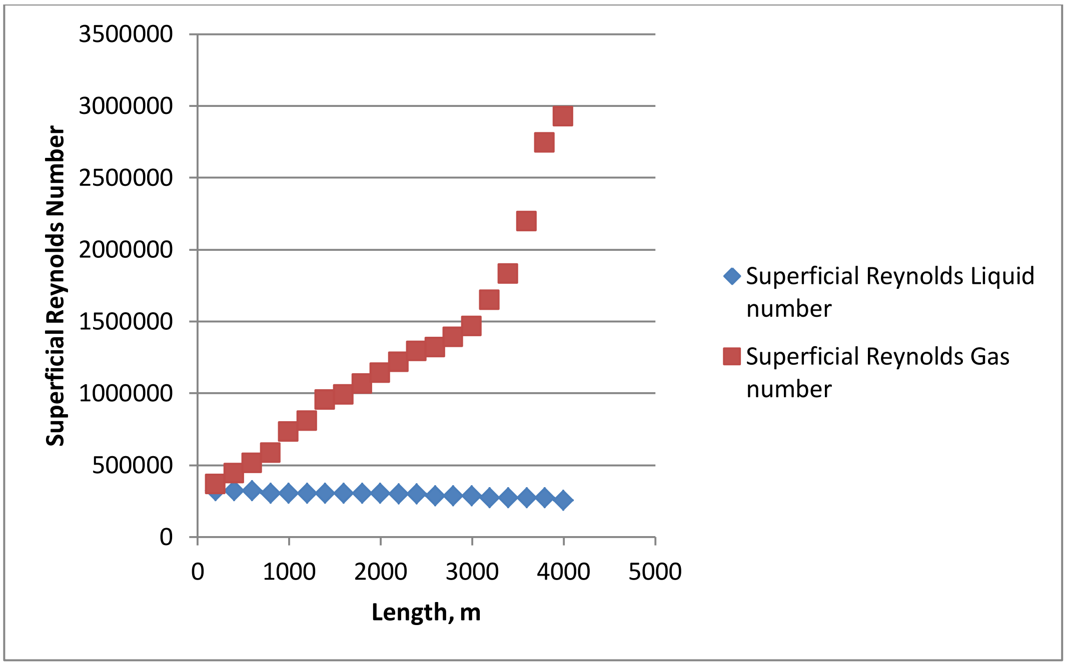


Figure 4-8 Superficial Reynolds number for different pipe length

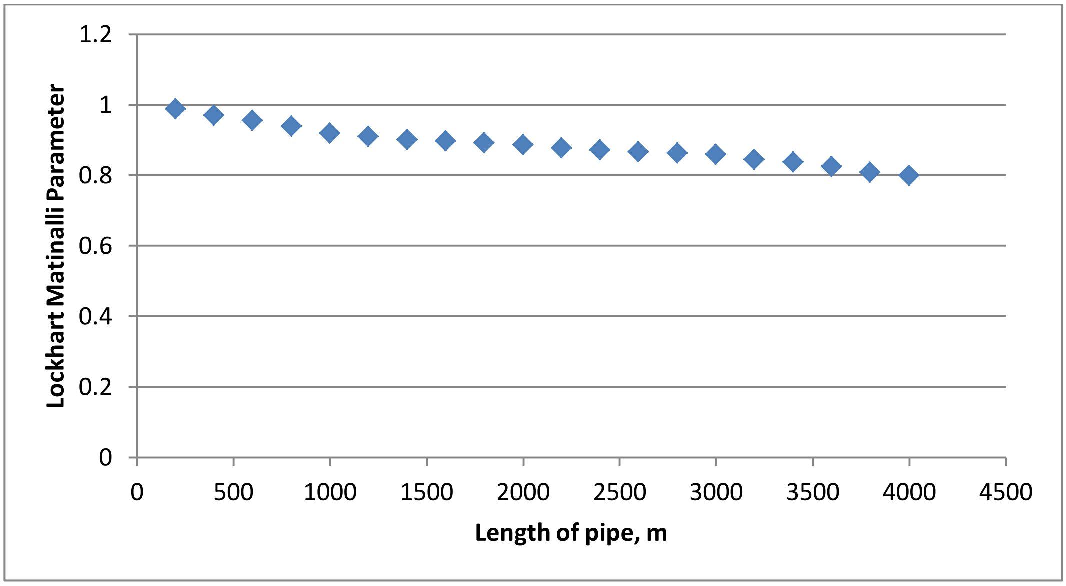


Figure 4-9 Lockhart Martinelli parameter for different pipe length

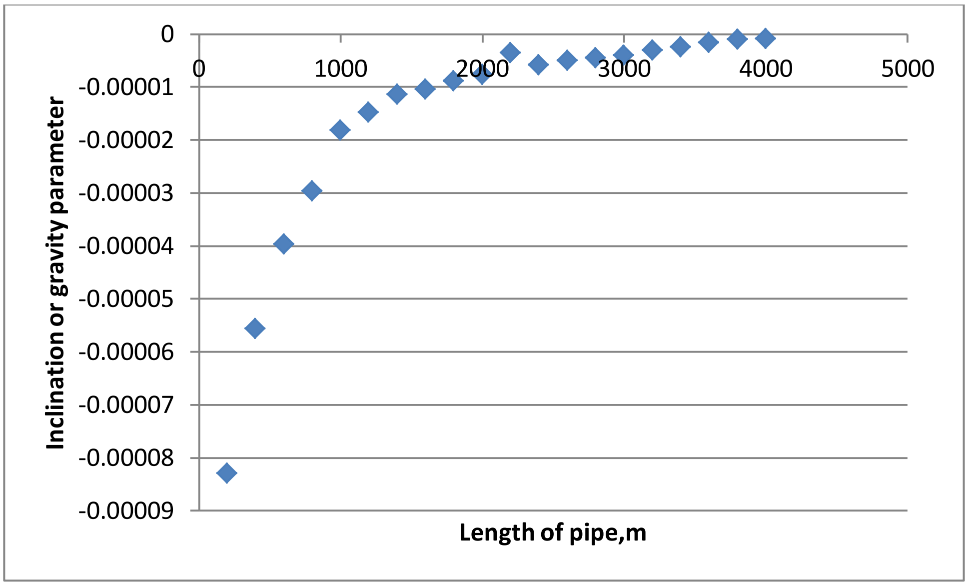


Figure 4-10 Inclination or gravity parameter for different pipe length

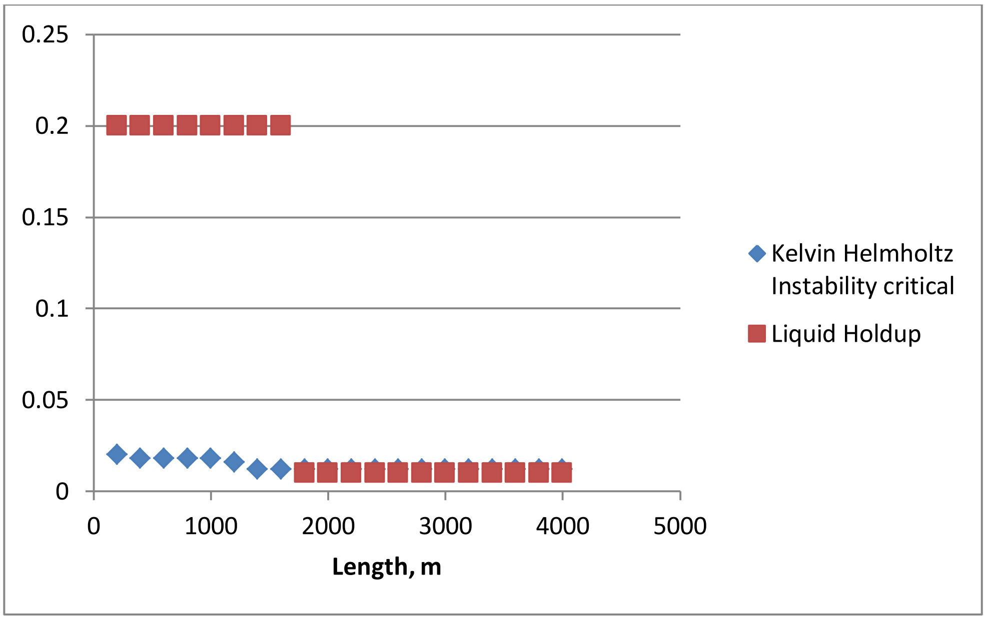


Figure 4-11 Kelvin Helmholtz and liquid holdup for different length of pipe

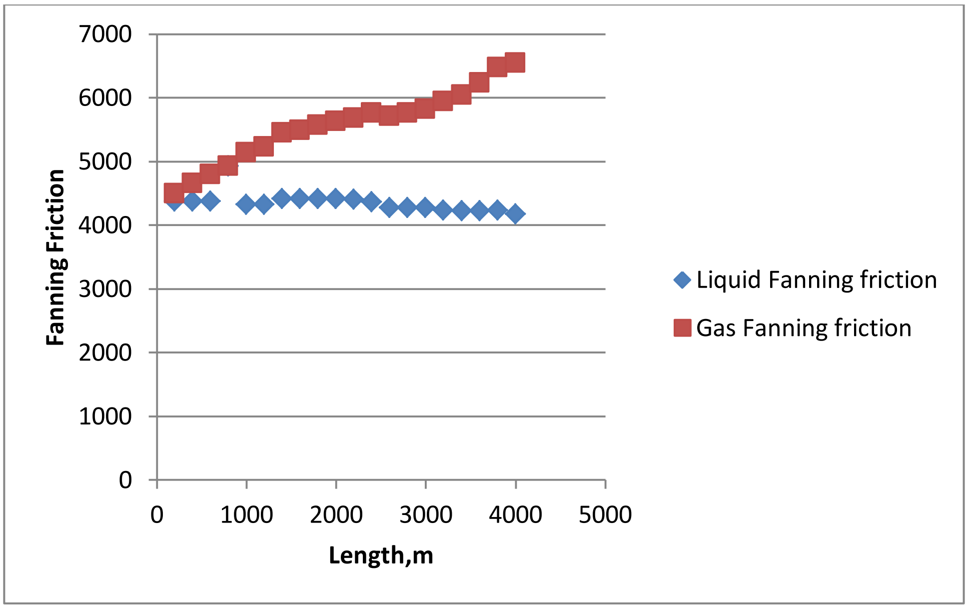


Figure 4-12 Fanning friction for different pipe length

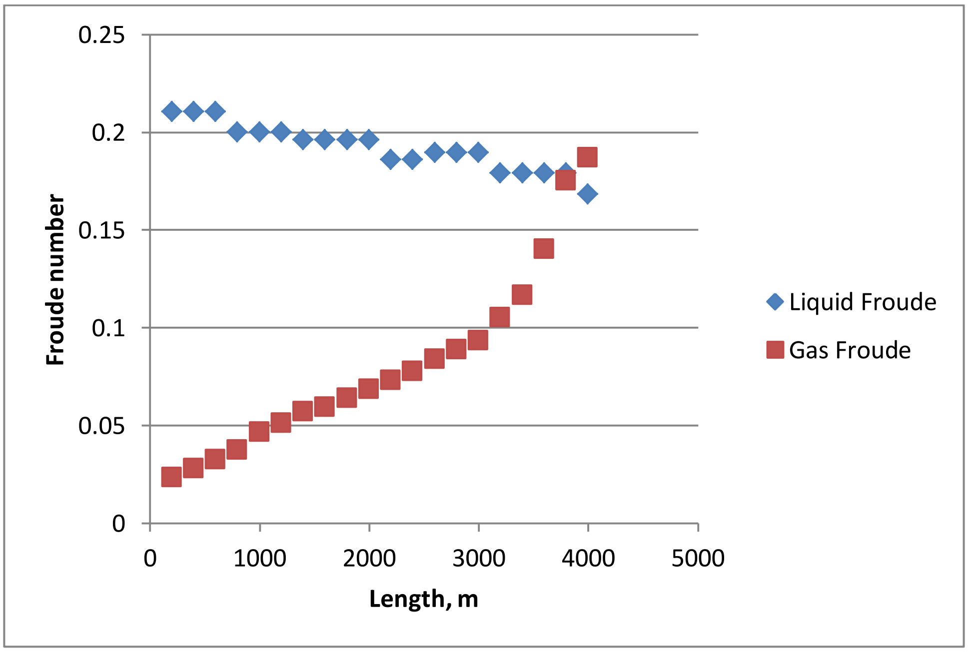


Figure 4-13Froude number of different pipe length

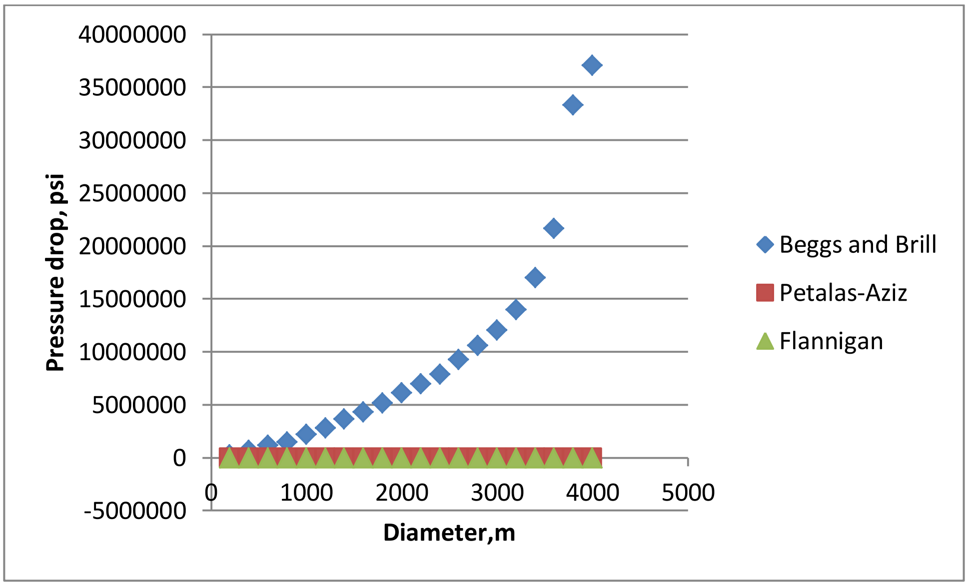


Figure 4-14Pressure drop of different pipe length

4.4 Discussion

From the analysis, only the diameter of pipe give a positive result on the changes in flow pattern. The changes occur on the 28 inch diameter. The changes start when the liquid holdup and Kelvin Helmholtz fluctuate at 28 inch. Both parameters are influenced by the increasing of superficial Reynolds number. On the other side theirs is no changes of flow pattern when the length of pipe are changed. Eventhough the liquid holdup is drop to 0.01 from 0.2 between 1600 meters and 1800 meters there is still flow pattern changes. The value of liquid holdup does not meet the condition for changes. If the liquid holdup are bigger 0.35 theere are possibilities for flow changes from annular to bubble flow or annular flow.

An experiment has been conducted, by (Cheng, 2009) 208 point of data are measured in horizontal pipeline. The experiment is set to check the effect of heat flux on the transformation of flow pattern. Figure 4-15 shows the tabulated data from the experiment. The data shows that at superficial liquid Reynolds number more than 200000, annular flow and intermittent (plug and slug) are exist. Thus the result from the tabulated data are exepted.

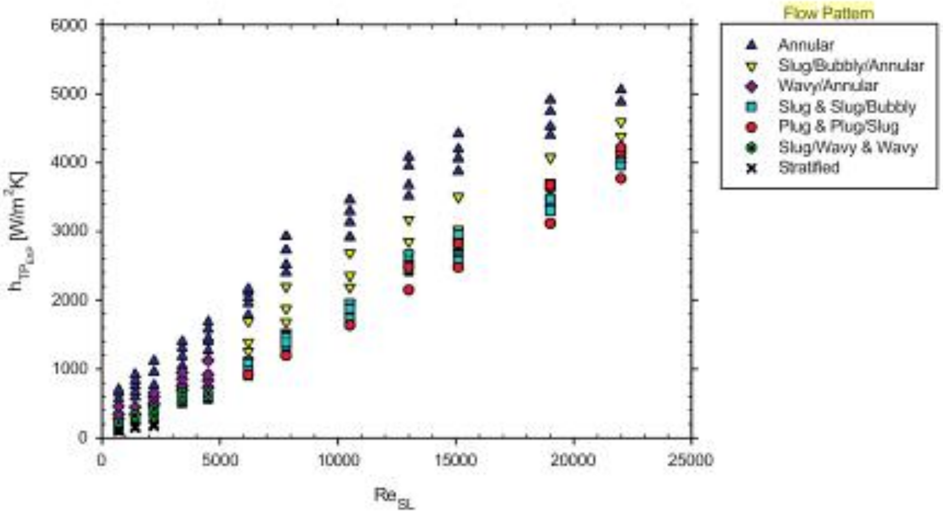


Figure 4-15 Variation of two phase heat transfer coefficient with superficial liquid Reynolds number in horizontal pipe

However, the data for length of pipe still need to be discussed. From (Lawrence C., 2013) different superficial liquid and gas velocity should change the flow pattern. From the data, superficial velocity of water lower than 0.34 and superficial velocity of oil more than 0.15 will give annular flow. At superficial velocity of water more than 0.336 and superficial velocity of oils more than 0.017 the flow that is observed dual continuous flow or bubble flow. But since the experiment use liquid-liquid flow thus the difference between the substance properties or the system setup the data from this research and from (Lawrence C., 2013) are differ. But from (Das, 2010) annular flow are observed in his experiment. The system nearly same thus even though there changes in superficial velocity, other factor might affect why the system does not change the flow pattern such as the properties of substance in the system or type of pipe used.

Pressure prediction is analysed based on both tests. For the first test which changing the diameter of pipe. Only Beggs and Brill show the best result. It responds to the changes in diameter or length of pipe. For Flannigan it only respond when the superficial liquid velocity. When length of pipe is varied the pressure drop for Flannigan also changes. The higher the superficial gas velocity the higher the value of pressure drop for Flannigan correlation. Meanwhile Petalas Aziz gives a negative respond. There are no changes in pressure even though the length or diameter of pipe increases. There are few reason why the result not so good compared to Beggs and Brill. From one of the website which is (Pressure loss correlation) each of the correlation has its own flow pattern determination. From Figure 2-4 the flow pattern of Petalas Aziz are based on the superficial gas and liquid velocity. The computation is difference than what is stated in this research. Thus there will be error occurred in computing the value of pressure drop for Petalas Aziz correlation.

5 Recommendation and Conclusion

5.1 Conclusion

As a conclusion the program can run with no error during the processing. The program can determine the flow pattern and pressure drop. The pressure drop calculation is based on three correlations which are Beggs and Brill correlation, Petalas Aziz correlation and Flannigan correlation. Two parameters are tested in this programme to see which one of the parameters will show the changes in flow pattern.

Based on the result only the diameter shows a changes of flow pattern at 28 inch and the length of pipe does not affecting the changes in flow pattern. Superficial Reynolds one of the most important in changing the flow pattern.

For pressure drop, the result display that for Beggs and Brill the pressure drop keep increasing by changing the length of pipe. Inversely the pressure drop decreasing with the changes of pipe diameter. The pressure still decreasing even there are changes in flow pattern at point 28 inch. Petalas Aziz correlation only shows changes when the flow pattern changes from annular to intermittent. Meanwhile, Flannigan correlation change when there are changes on superficial gas velocity. The value does not change when the diameter are changed since there no changes superficial gas velocity.

5.2 Recommendation

There is little recommendation that can be made to improve this thesis. First and foremost, surveying pipeline agencies, from this surveying student can understand extensively about pressure drop in multiphase flow in reality. Thus from the observation student can use the knowledge to improve pressure drop prediction. Data from agencies also can be used in the program to predict a real situation of pressure drop activity.

Secondly, this research focussing only on horizontal pipelines. What if the angle of the pipelines is change? In reality the pipelines won't stay horizontal. Does the flow pattern is affected by angle changing. Since the inclination or gravity parameter is determine by the angle does the flow pattern will be change. Other than that Flannigan only can determine horizontal pipelines. Thus, by changing the angle the pressure drop calculation and flow pattern might differ.

Every correlation such as Petalas-Aziz and Beggs-Brill correlations have their own flow pattern map. Rather using Madhane et. al. flow pattern map, use the original flow pattern determination for every correlation. The result might different with this research flow pattern determination. The parameters also easy to calculate by using the original flow pattern map.

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