UNIVERSITI TEKNOLOGI PETRONAS

# Mathematical Modeling of Wellbore Flow Behavior in Multilateral Wells

by

Farah Amalina Azianti Bt Azmi

Dissertation submitted in partial fulfillment of
The requirement for the
Bachelor of Engineering (Hons)
(Petroleum Engineering)

December 2012

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CERTIFICATE OF APPROVAL

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Approved By,

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Mr Mohammad Amin Shoustari

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

## CERTIFICATE OF ORIGINALITY

This is to certify that we are responsible for the work submitted in this project, that the original work is my own except as specified in the reference and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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FARAH AMALINA AZIANTI BT AZMI

# ABSTRACT

In oil and gas industry, the there is no other way to extract the oil but to drill holes through the earth crust. Since 2550 - 2315 BC, the technology of drilling has been evolved with new techniques and materials parallel to the increasing number of ideas and human population. After the oil become core energy sources for mankind, the world focusing on extracting them even more. In search of newest innovations which could make development projects in mature fields more attractive, multilateral well drilling was identified as the most promising emerging technology. Over the past 20 years, with the rapid evolution of the first horizontal wells and eventually multilateral wells, reservoir-to-well exposure has increased dramatically to orders of magnitude larger than before. Then multilateral wells accomplish both of these tasks, the accessing and the exposure effectively. The multilateral well's exposure is very clear. Also it is expensive to drill other well and thus more laterals within a mother wellbore will give more exposure to the reservoir. The main objective of this project is to develop the computer codes to model the flow behavior in the lateral of multilateral well. Modeling techniques that applied is analytical and numerical approach which implements mathematical software to model the flow behavior in the lateral of multilateral well and perform comparison analysis against different modeling method. The first analysis will consist of the horizontal part of the lateral using no inflow model, Ouyang et al. and Yuan et al. (1998). The analysis will comprise of the model pattern and the effectiveness of each model. The second analysis is done for the build-up section for dual-lateral well. The model used is Beggs and Brill correlation and analysis will be done on two flow conditions which are single phase and multiphase flow. Hypothetical reservoir and well data from research papers and SPE monographs is used to generate the typical well condition for these models. The significance of this study is because the well monitoring especially the flow behavior and pressure drop is one of the key factors in determining the well deliverability and performance. Estimates of well performance assists petroleum engineers to decide the optimum production and reservoir management plan.

## ACKNOWLEDGMENTS

My first gratitude would go to Allah SWT, all praise is due to Allah and this project would not have been possible without His help. My sincere gratitude is extended to my supervisor Mr. Mohammad Amin Shoustari, I am grateful to his commitment and encouragement throughout the project. I would like to thank Miss Raja Rajeshwary Suppiah and Ir. Dr. Mohd Shiraz Aris for their time and valuable advice. I would also like to thank my family for their help and support during my project. Finally, my gratitude goes to my friends for their friendship and help throughout the project.

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## NOMENCLATURES

| Symbol | Description |
|---|---|
| $\Delta p$ | Pressure Difference |
| $g$ | Gravitational Acceleration |
| $g_c$ | Conversion Factor |
| $\rho$ | Density |
| $L_s$ | Segmented Lateral |
| $Ff^*$ | Friction Factor |
| $d$ | Diameter |
| $p_{sc}$ | Pressure in Standard Condition |
| $T_{sc}$ | Temperature in Standard Condition |
| $\gamma_g$ | Oil Specific Gravity |
| $N_{Re}$ | Reynold's Number |
| $N_{Re,w}$ | Inflow Reynold's Number |
| $u$ | Axial Velocity |
| $\bar{q}$ | Average Flow Rate |
| $C_L$ | Liquid Input Volume Fraction |
| D | Inside Pipe Diameter |
| $E_L(0)$ | Horizontal Liquid Holdup |
| $E_L(\theta)$ | Inclined Liquid Holdup |
| $f_{tp}$ | Two Phase Friction Factor |
| $f_{NS}$ | No-Slip Fraction factor |
| $Fr_m$ | Froude Mixture Number |
| L | Length of Pipe |
| $N_{vl}$ | Liquid Velocity Number |
| $V_m$ | Mixture Velocity |
| $V_{sl}$ | Superficial Liquid Velocity |
| $\Delta Z$ | Elevation Change |
| $\mu_{NS}$ | No-Slip Viscosity |
| $\theta$ | Angle of Inclination from the horizontal |
| $\rho_L$ | Liquid Density |
| $\rho_{NS}$ | No-Slip Density |
| $\rho_m$ | Mixture Density |
| $\sigma$ | Gas/Liquid Surface Tension |

# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND OF STUDY

Downhole monitoring is an important process to ensure effective and efficient production process. Every well drilled must be monitored during all the processes involved, drilling, production and etc. It is important to ensure everything is in control and do not lead to any unwanted events like blow out during drilling. During production, downhole monitoring will help the producers estimate the volume of fluid produced and how effective is the process and help them determine the best way to extract the hydrocarbon or which stimulation is the best to be applied.

This project focuses on the flow behaviour of multilateral wells. The definition of multilateral well is a well which has more than one lateral or branch, either inclines or horizontal, connected to a single or mother wellbore. Below is the schematic of the example of various multilateral wells configuration.

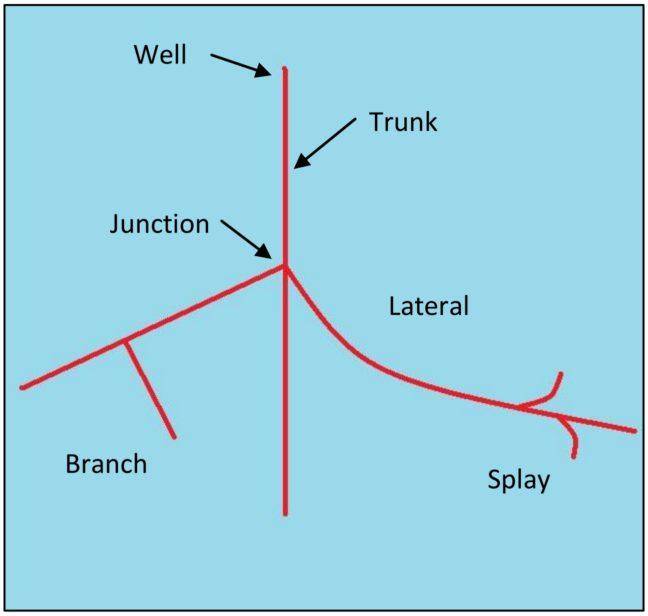



**Figure 1.1: Schematic diagram of a multilateral well**

Many elements involved in downhole monitoring process. For example the temperature, pressure, measuring of multiphase rates downhole and information on water, oil, gas fraction and flow velocity. In multilateral wells, to monitor the well inflow performance, perhaps the most important thing to concern is the pressure drop if fluid inside the wellbore. Since multilateral wells consists of a mother wellbore and laterals, both of them played important role in influencing each other and contribute to more efficient and effective production.

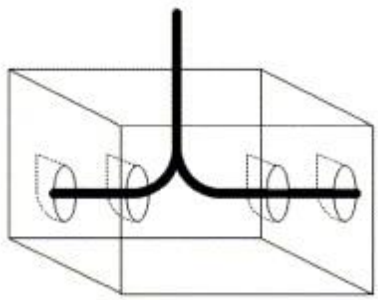
The combination of lateral and conventional vertical wellbore is the build up section, thus its makes it 3 important section in this well system. We have to monitor the pressure drop along the horizontal lateral, the build up section and the vertical mother wellbore.

The objective of this study is to do a mathematical modelling of the flow behaviour in the wellbore of multilateral wells. To narrow it down, we will focus on the pressure drop in the lateral and build up section of the well. Below is the schematic of the example of a multilateral well.

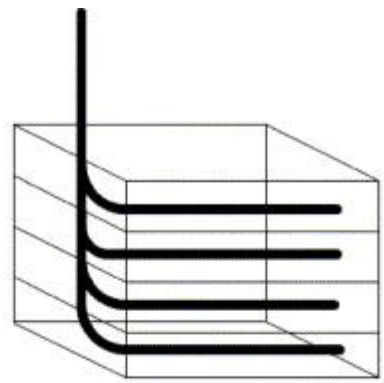
Below are the described benefits of multilateral wells:

a) Increased reserves: The geometry of multilateral wells enabled better reservoir coverage for only 1 well. A single well could only reach limited reservoirs and basically not all reservoirs are well connected to each other. Multilateral helps to reach all the reservoirs available and thus increase the production.
b) Cost reduction and slot conservation: The single wellbore requires fewer production well slots hence reduces cost of rig time, tools, services and equipment. The total cost of a multilateral well could be higher than the cost of a vertical or horizontal completion but the benefits it reaches can possibly overcome the cost. This has been proven by first multilateral well drilled in Russia, the cost is 1.5 times more than conventional wells however the production increases by 17 times more oil per day.

Figure 2 below show the examples of geological settings and the appropriate multilateral well architecture to develop the reservoir:

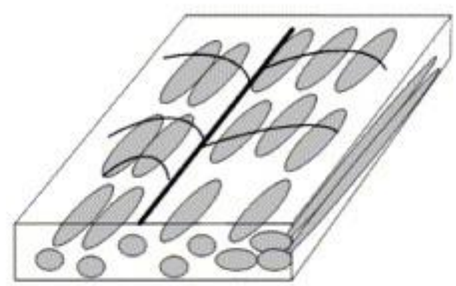


a) Dual opposing laterals for poorly consolidated/thin formations.



b) Multilateral wells for heavy crudes in thick formations.

c) Multibranch well with fractured vertical branches (horizontal parent well is drilled above the reservoir).



d) Multilateral wells for isolated pockets of oil.

**Figure 1.2: Typical multilateral wells for petroleum productions**

## 1.2 PROBLEM STATEMENT

In order to monitor overall well performance of the well and ensuring efficient and effective production process, there are important elements to be taken into account. They are temperature and pressure measurement, multiphase rates downhole and information on water, oil, gas fractions and flow velocity.

In multilateral well, well performance prediction will be more complicated as there are many laterals and build up sections involved and every each of them will influenced the productivity and well performance. The problem consists of predicting the inflow characteristics of each lateral, determining the pressure-drop behavior in both lateral and build up sections between the laterals and main wellbore, and pressure drop in the main wellbore from the lowest junction to the surface.

These parts of the multilateral well system are all connected and influence each other. In this study we will focus on the pressure drop behavior in both lateral and build up sections between the laterals and main wellbore. This pressure drop will affect the laterals inflow behavior which also affects the rest of the multilateral well performance.

As a new technology, the knowledge of the well has to be developed in order to deepen the understanding hence more ideas will be generated for engineers to monitor multilateral type of well. For single well we can use the inflow relationship performance (IPR) to monitor the well inflow capacity but we cannot apply this method to multilateral well. It is because pressure drop in one lateral will affect the other lateral. Thus we must model the pressure drop simultaneously with the reservoir pressure.

## 1.3 OBJECTIVES OF STUDY

The main objective of this study is to develop mathematical codes as an approach to predict the flow behavior in the lateral of multilateral wells. Modeling techniques are applied that is by using numerical and analytical approach. The main objectives can be further refined to the following list below:

- To develop computer codes to determine wellbore flow behavior in multilateral well.
- To assess the pressure drops in lateral and build up parts of multilateral wells.
- Monitor well flow behavior in the wellbore of multilateral well.
- To assess the effect of reservoir permeability and drawdown pressure to the wellbore pressure drop.
- Comparing pressure drops in different lateral lengths and diameter.
- To assess the effect of reservoir inflow to the wellbore pressure drop

## 1.4 SCOPE OF STUDY

For the purpose of this research, 2 parts of the multilateral well will be modeled, which are the horizontal lateral section and the build-up section. We will see the fluid flow behavior and the pressure drop for single phase flow and multiphase flow. To model this, I will use different method and for each method, analysis and comparison will be done. This will serve as the basic modeling of flow behavior in multilateral well. Hypothetical parameters are used in this study. The analysis is done separately by method for horizontal lateral and by flow phase for build-up section.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 NUMERICAL APPROACH

The two modeling techniques that is numerical and analytical approach are elaborated in this section:

For this study purpose, MATLAB software is used to simplify the calculation and produces 2-D graphs that modeled the result. The main reason MATLAB is selected for this project is because of its mathematical capability to execute the calculation effectively.

## 2.2 ANALYTICAL APPROACH

### 2.2.1 Horizontal Lateral

For the first section of the study, only the single phase flow behavior of the horizontal part of the lateral is modeled using 3 methods which are for no inflow well, Ouyang et al. and Yuan et al.

**No Inflow well**: The lateral pressure drop can be calculated using standard pipe flow equations without any explicit consideration of the effects of inflow on the lateral pressure drop. This may be the situation for multilateral applications in heavy-oil reservoirs or in tight gas reservoirs.

If the fluid is incompressible liquid, the pressure drops over a segment of the lateral of length Ls that has an inclination from horizontal of degrees.

$$\Delta p = p_1 - p_2 = \frac{g}{g_c} \rho L_s \sin\theta + \frac{2Ff^* \rho u^2 L_s}{d g_c} \qquad \text{2.1}$$

Compressible fluid (gas), for horizontal segment.

$$p_1^2 - p_2^2 = \frac{32}{\pi^2} \frac{28.97\gamma_g \bar{Z}\bar{T}}{Rg_c d^4} \left(\frac{p_{sc}q}{T_{sc}}\right) \left(\frac{2f_f L_s}{d} + ln \frac{p_1}{p_2}\right) \ldots\ldots 2.2$$

Effect of radial inflow through perforations or slots on the axial pressure drop in horizontal wellbore, considering a section of horizontal wellbore with radial inflow from discrete perforations distributed along,

$$\Delta p = \Delta p_f + \Delta p_{acc} + \Delta p_{perf} + \Delta p_{mix} \ldots\ldots 2.3$$

**Ouyang et al**: Ouyang et al.'s single phase wellbore flow model for pressure drop calculations incorporates frictional, accelerational, and gravitational pressure drops and it accounts for pressure drop caused by inflow and perforation roughness by applying an empirical friction factor correlation.

Pressure drop for a wellbore segment with a uniform inflow per unit length,

$$\Delta p = p_1 - p_2 = \frac{g}{g_c} \rho L_s \sin\theta + \frac{2f_f^* \rho u^2 L_s}{g_c d} + \frac{8\rho u q_1 L_s}{\pi g_c d^2} \ldots\ldots 2.4$$

For laminar flow in wellbore, the friction factor:

$$f_f^* = \frac{16}{N_{Re}} \left[1 + 0.04304 N_{Re,w}^{0.6142}\right] \ldots\ldots 2.5$$

For turbulent flow :

$$f_f^* = f_f \left[1 - 0.0153 N_{Re,w}^{0.3978}\right] \ldots\ldots 2.6$$

Inflow Reynolds number, which is a function of the inflow rate per unit length,

$$N_{Re,w} = \frac{q_1 \rho}{\pi \mu} \quad \text{......2.7}$$

The usual pipe flow Reynolds number,

$$N_{Re} = \frac{du\rho}{\mu} \quad \text{......2.8}$$

Axial velocity used is the mean velocity in the segment,

$$u = \frac{4\bar{q}}{\pi d^2} \quad \text{......2.9}$$

And the average flow rate in the segment defined as,

$$\bar{q} = q + \frac{L_s}{2} q_I \quad \text{......2.10}$$

**Yuan et al. (1998)**: Yuan et al. developed an empirical friction factor correlation based on a large set of experiments with slotted liners and perforated casing. Acceleration and mixing effects were incorporated into the friction factor correlation, yielding

$$\Delta p = p_1 - p_2 = \frac{g}{g_c} \rho L_s \sin\theta + \frac{2 f_f^* \rho u^2 L_s}{g_c d} \quad \text{......2.11}$$

Where the empirical friction factor including all inflow effects given by,

$$f_f^* = a N_{Re}^b + \frac{2 C_n d q_I}{\bar{q}} \quad \text{......2.12}$$

### 2.2.2. Relative Importance of Lateral Pressure Drop

In many cases, horizontal pressure drop is negligible but it depends on the magnitude of the pressure drop in lateral relative to the pressure drop in the reservoir (the drawdown). Using steady state flow equation of Furui et al., the ratio of the lateral pressure drop to the reservoir pressure drop. Here we assume a perfectly horizontal lateral,

$$\frac{\Delta p_f}{\Delta p_r} = \frac{\frac{2f_f \rho u^2 L}{d}}{\frac{q\mu}{2\pi kL}\left[ln\left[\frac{hI_{ani}}{r_w(I_{ani}+1)}\right]+\frac{\pi y_b}{hI_{ani}}-1.224+s\right]} \quad \text{.......2.13}$$

Where velocity in the wellbore can be replaced in terms of volumetric flow rate,

$$u = \frac{4q}{\pi d^2} \quad \text{.......2.14}$$

Ratio of the pressure drop in the wellbore to the pressure drop in the reservoir,

Defining a reservoir geometric factor,

$$F_g = ln\left[\frac{hI_{ani}}{r_w(I_{ani}+1)}\right] + \frac{\pi y_b}{hI_{ani}} - 1.224 + s \quad \text{.......2.15}$$

Next, the pressure drop ratio,

$$\frac{\Delta p_f}{\Delta p_r} = \frac{\frac{8f_f \rho q^2 L}{d}}{\frac{q\mu F_g}{2\pi kL}} \quad \text{.......2.16}$$

Rearrange to,

$$\frac{\Delta p_f}{\Delta p_r} = 4f_f\left(\frac{4q\rho}{\pi d\mu}\right)\left(\frac{kL^2}{d^2 F_g}\right) \quad \text{.......2.17}$$

Yield to, (final equation)

$$\frac{\Delta p_f}{\Delta p_r} = 4 f_f N_{Re} N_H \text{ ……………………………………………………………………………… } 2.18$$

### 2.2.3 Build-up Section

Single Phase Flow

The pressure drop in the build section can be calculated simply by using the total length between two points of interest in the frictional pressure drop calculation and using the difference in elevation to calculate the potential energy pressure drop.

$$\Delta p = p_1 - p_2 = \Delta p_f + \Delta p_{pg} \text{ ……………………………………………………………… } 2.19$$

Where frictional pressure,

$$\Delta p_f = \frac{2 f_f \rho u^2 L_m}{g_c d} \text{ ………………………………………………………………………….. } 2.20$$

And potential pressure,

$$\Delta p_{PE} = \frac{g}{g_c} \rho L_v \text{ ……………………………………………………………………………… } 2.21$$

For a segment of constant inclination the relationship between the pressures at the inlet and outlet ends of the segment is,

$$p_2^2 = e^s p_1^2 + 2.685 \times 10^{-3} \frac{f_f (\overline{Z}\overline{T}q)^2}{\sin\theta d^5} (e^s - 1) \text{ ………………………………………………... } 2.22$$

Where,

$$s = \frac{-0.0375 \gamma_g L \sin\theta}{\overline{Z}\overline{T}} \text{ ……………………………………………………………………….… } 2.23$$

Multiphase Flow

Beggs and Brill Correlation

The Beggs and Brill multiphase correlation deals with both the friction pressure loss and the hydrostatic pressure difference. First the appropriate flow regime for the particular combination of gas and liquid rates is determined, whether they are segregated, intermittent or distributed. After that the liquid holdup, the in-situ density of the gas-liquid mixture is then calculated according to the appropriate flow regime to obtain the hydrostatic pressure difference. To calculate the two-phase friction factor, we use the input gas-liquid ratio and the fanning friction factor. From this the friction pressure loss is calculated using input gas-liquid mixture properties.

The Beggs and Brill correlation requires that a flow pattern be determined. Since the original flow pattern map was created, it has been modified. We have used this modified flow pattern map for our calculations. The transition lines for the modified correlation are defined as follows:

Determining Flow Pattern:

$$L_1^* = 316C_L^{0.302}$$
$$L_2^* = 0.0009252C_L^{-2.4684}$$
$$L_3^* = 0.1C_L^{-1.4516}$$
$$L_4^* = 0.5C_L^{-6.738}$$

The flow type can then be readily determined either from a representative flow pattern map or according to the following conditions, where:

$$Fr_m = \frac{V_m^2}{gD}$$

**Table 2.1: Conditions for Flow Pattern**

| **Flow Pattern** | **Condition 1** | **Condition 2** |
|---|---|---|
| Segregated | $C_L < 0.01$ and $Fr_m < L_1^*$ | $C_L \geq 0.01$ and $Fr_m < L_2^*$ |
| Intermittent | $0.01 \leq C_L < 0.4$ and $L_3^* \leq Fr_m < L_1^*$ | $C_L \geq 0.4$ and $L_3^* < Fr_m \leq L_4^*$ |
| Distributed | $C_L < 0.4$ and $Fr_m \geq L_4^*$ | $C_L \geq 0.4$ and $Fr_m \geq L_4^*$ |
| Transition | $L_2^* < Fr_m < L_3^*$ | |

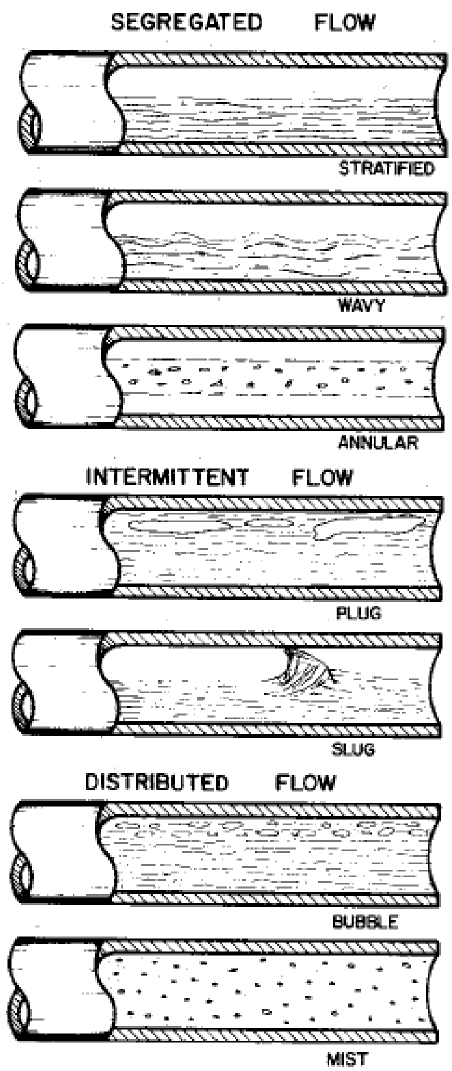



**Figure 2.1: Horizontal Flow Pattern**

Determining Hydrostatic Pressure Difference

Once the flow type has been determined then the liquid holdup can be calculated. Beggs and Brill divided the liquid holdup calculation into two parts.

First the liquid holdup for horizontal flow, $E_L(0)$, is determined, and then this holdup is modified for inclined flow. $E_L(0)$ must be $\geq C_L$ and therefore when $E_L(0)$ is smaller than $C_L$, $E_L(0)$ is assigned a value of $C_L$. There is a separate calculation of liquid holdup ($E_L(0)$) for each flow type.

**Table 2.2: Liquid Holdup for each Flow Type**

| | |
|---|---|
| **SEGREGATED:** $E_L(0) = \frac{0.98\, C_L^{0.4846}}{Fr_m^{0.0868}}$ | **INTERMITTENT:** $E_L(0) = \frac{0.845\, C_L^{0.5351}}{Fr_m^{0.0173}}$ |
| **DISTRIBUTED:** $E_L(0) = \frac{1.065\, C_L^{0.5824}}{Fr_m^{0.0609}}$ | **TRANSITION:** $E_L(0)_{transition} = AE_L(0)_{segregated} + BE_L(0)_{intermittent}$ Where: $A = \frac{L_3^* - Fr_m}{L_3^* - L_2^*}$ and $B = 1 - A$ |

Once the horizontal in situ liquid volume fraction is determined, the actual liquid volume fraction is obtained by multiplying $E_L(0)$ by an inclination factor, $B(\theta)$. i.e.

$$E_L(\theta) = B(\theta) \times E_L(0)$$

Where:

$$B(\theta) = 1 + \beta\left[\sin(1.8\,\theta) - \frac{1}{3}\sin^3(1.8\theta)\right]$$

**Note**: $\beta$ is a function of flow type, the direction of inclination of the pipe (uphill flow or downhill flow), the liquid velocity number ($N_{vl}$), and the mixture Froude Number ($Fr_m$).

The liquid velocity number ($N_{vl}$) is defined as:

$$N_{vl} = 1.938\, V_{sl}\left(\frac{\rho_L}{g\sigma}\right)^{1/4}$$

For **UPHILL** flow:

SEGREGATED

$$\beta = (1 - C_L)\ln\left[\frac{0.011\ N_{vl}^{3.539}}{C_L^{3.768}Fr_m^{1.614}}\right]$$

INTERMITTENT

$$\beta = (1 - C_L)\ln\left[\frac{2.96\ C_L^{0.305}Fr_m^{0.0978}}{N_{vl}^{0.4473}}\right]$$

DISTRIBUTED

$$\beta = 0$$

For **DOWNHILL** flow:

All flow types:

$$\beta = (1 - C_L)\ln\left[\frac{4.70\ N_{vl}^{0.1244}}{C_L^{0.3692}Fr_m^{0.5056}}\right]$$

**Note**: β must always be ≥ 0. Therefore, if a negative value is calculated for β, β = 0.

Once the liquid holdup ($E_L(\theta)$) is calculated, it is used to calculate the mixture density ($\rho_m$). The mixture density is, in turn, used to calculate the pressure change due to the hydrostatic head of the vertical component of the pipe or well.

$$\Delta P_{HH} = \frac{p_m g \Delta z}{144\ g_c}$$

Friction Pressure Loss

The first step to calculating the pressure drop due to friction is to calculate the empirical parameter S. The value of S is governed by the following conditions:

if 1 < y < 1.2, then

$$S = \ln(2.2y - 1.2)$$

Otherwise,

$$S = \frac{y}{-0.0523 + 3.18y - 0.872y^2 + 0.01853y^4}$$

Where:

$$y = \ln \frac{C_L}{E_L^2}$$

**Note**: Severe instabilities have been observed when these equations are used as published. Our implementation has modified them so that the instabilities have been eliminated.

A ratio of friction factors is then defined as follows:

$$\frac{f_{tp}}{f_{NS}} = e^S$$

$$\therefore f_{tp} = f_{NS} e^S$$

**Notes**: $f_{NS}$ is the no-slip friction factor. We use the Fanning friction factor, calculated using the Chen equation. The no-slip Reynolds Number is also used, and it is defined as follows:

$$Re_{NS} = \frac{p_{NS} V_M D}{\mu_{NS}}$$

Finally, the expression for the pressure loss due to friction is:

$$\Delta P_f = \frac{2f_{tp} V_m^2 p_{NS} L}{144\ g_c D}$$

## Beggs and Brill Correlation Flow Map

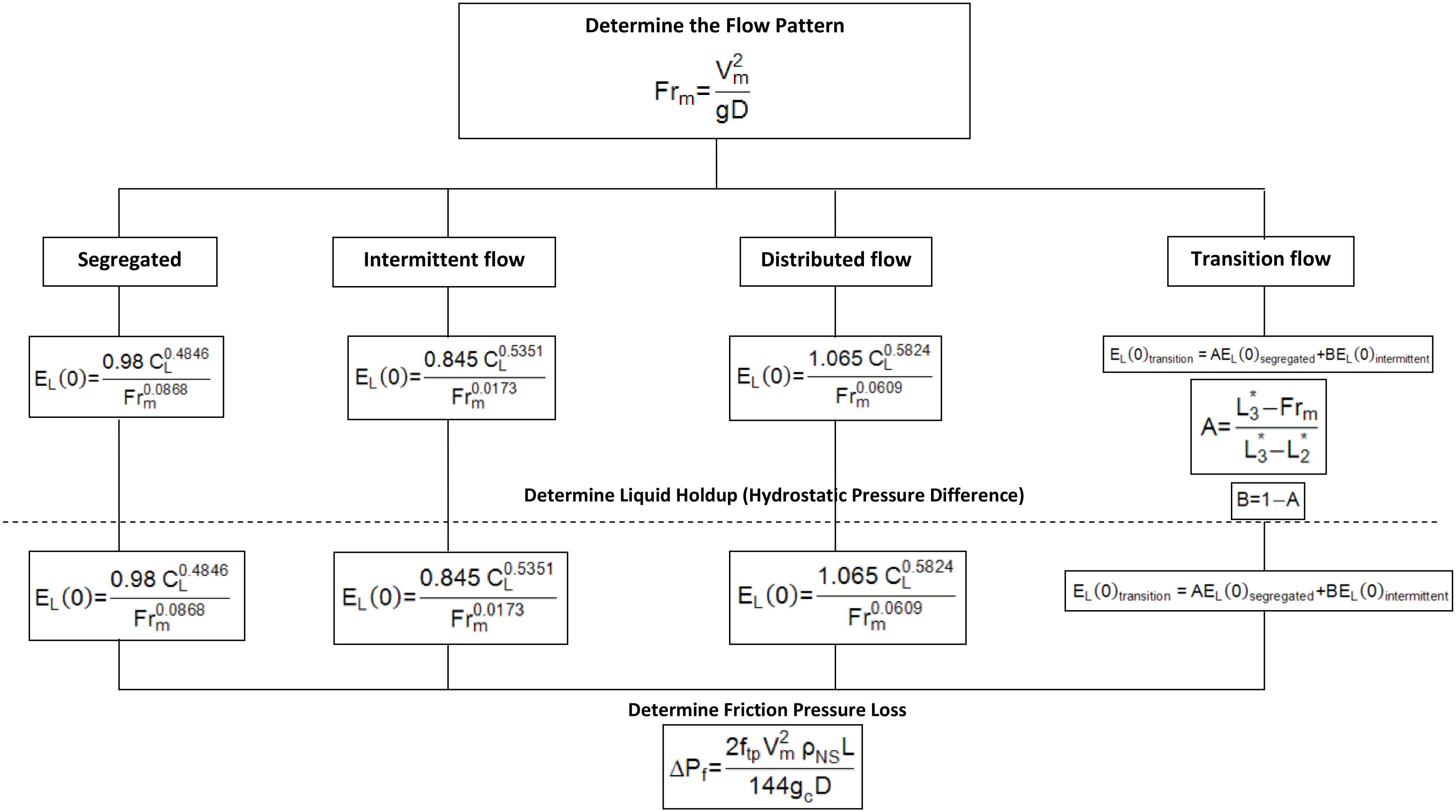



**Figure 2.2: Beggs and Brill Correlation Flow Map**

# CHAPTER 3

# METHODOLOGY

This section elaborates on the modeling procedure of the flow behavior in the lateral of multilateral well. The analysis is divided into two sections that is the horizontal lateral and builds up section of the lateral which consists of single phase and multiphase fluid.

Research Flow

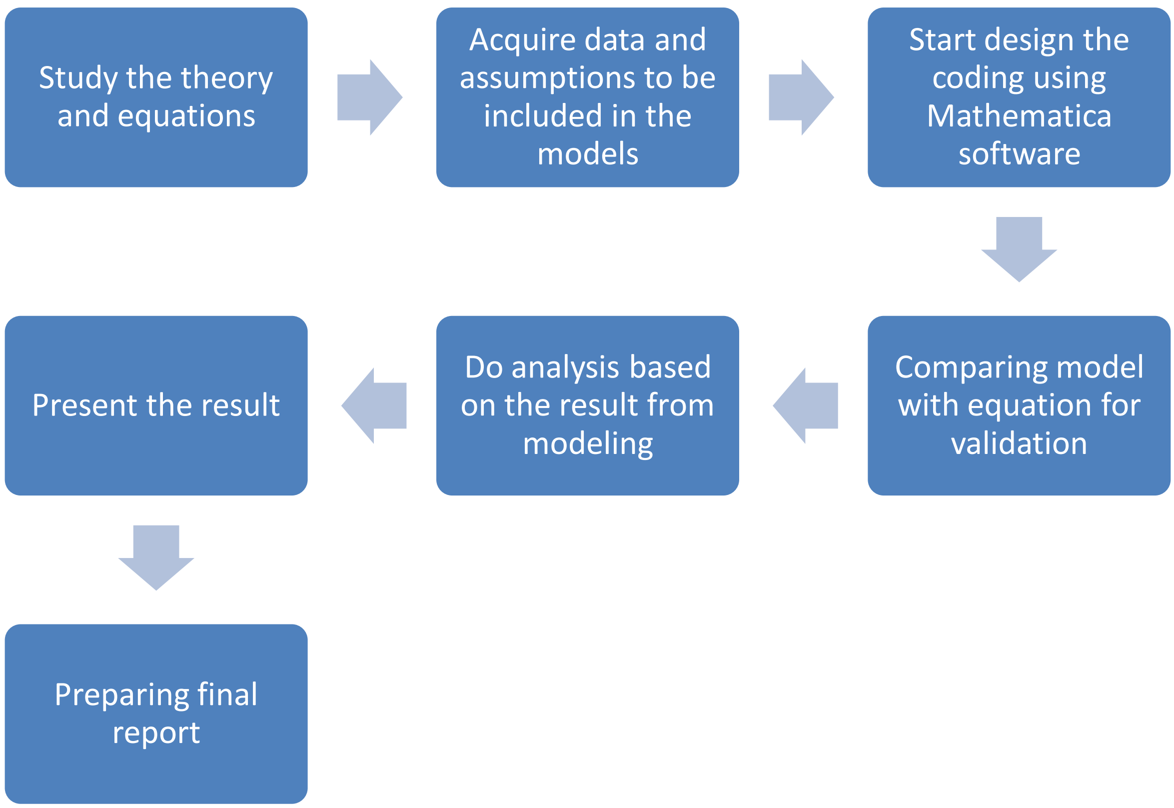



**Figure 3.1: Research Flow**

## 3.1 HORIZONTAL LATERAL

### a) Data Availability

Table below shows the hypothetical reservoir and well data taken from SPE Monograph and research papers. This data was used for the same purpose that is to assess the flow behaviour in the lateral of multilateral well.

**Table 3.1: Reservoir and well data**

| Description | Units | Value |
|---|---|---|
| Horizontal lateral length | ft | 1000 |
| Flow rate | B/D | 10 000 |
| Reservoir inflow rate | B/D/F | 4 |
| Total Lateral Flow Rate | B/D | 14 000 |
| Oil density | lbm/ft3 | 58 |
| Oil viscosity | cp | 1 |

**Table 3.2: Constant in Yuan's Model**

| Slot perforation/ Configuration | a | b | $C_n$ |
|---|---|---|---|
| Perforated with 20 shots/ft and $90^0$ phasing | 1.297 | -0.421 | 2.2 |

**b) Model Assumptions**

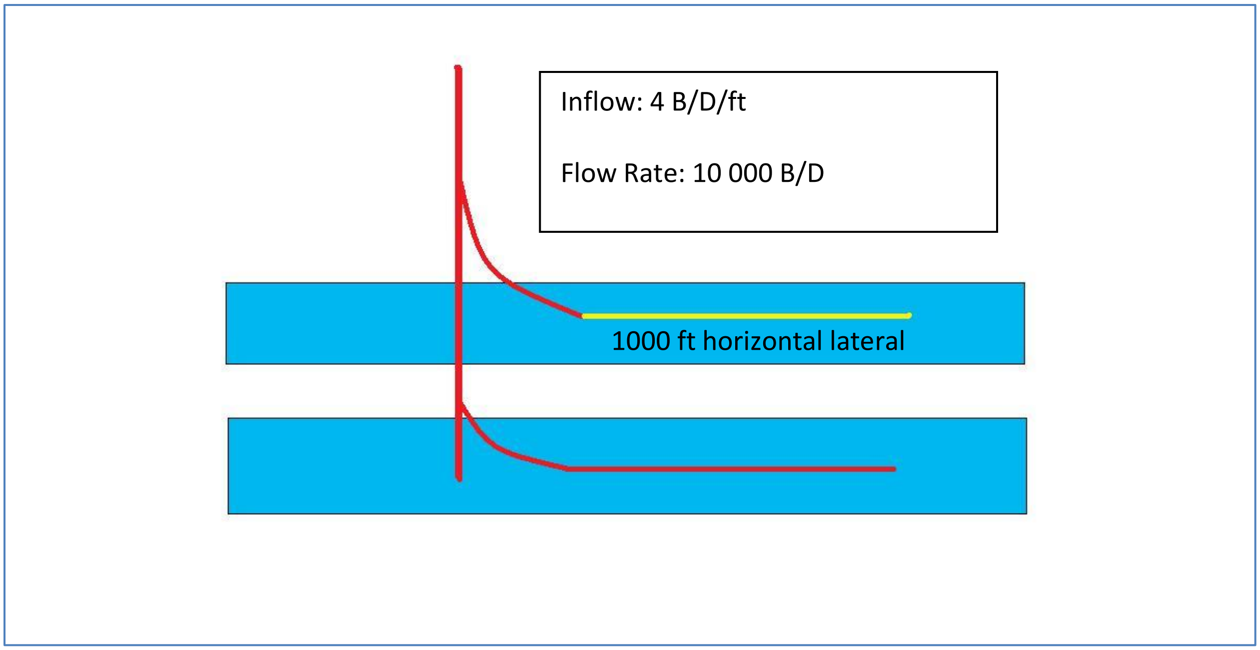



**Figure 3.2: Model assumption for horizontal lateral**

## 3.2 BUILD UP LATERAL

### a) Data Availability

Single-phase flow

**Table 3.3: Well, Reservoir and PVT Data**

| Description | Units | Value |
|---|---|---|
| Oil Gravity | API | 20 |
| Gas Oil Ratio | Scf/bbl | 150 |
| Lateral 1 Flow Rate | B/D | 2000 |
| Lateral 2 Flow Rate | B/D | 3000 |
| Tubing Diameter | In | 3 |
| Tubing Roughness | | 0.0006 |
| Bottomhole Temperature | F | 120 |
| Oil Density | lbm/ft3 | 58.8 |
| Oil Viscosity | Cp | 5 |
| Bubblepoint Pressure | psi | 1241 |

Multiphase Flow

**Table 3.4: Well, Reservoir and PVT Data**

| Description | Units | Value |
|---|---|---|
| Oil Gravity | API | 30 |
| Gas Gravity | API | 0.71 |
| Solution Gas Ratio | scf/bbl | 500 |
| Bottomhole Temperature | F | 150 |
| Bubblepoint Pressure | psia | 2652 |
| Angle of Lateral 1 | Degree | 29 |
| Angle of Lateral 2 | degree | 50 |

**b) Model Assumptions**

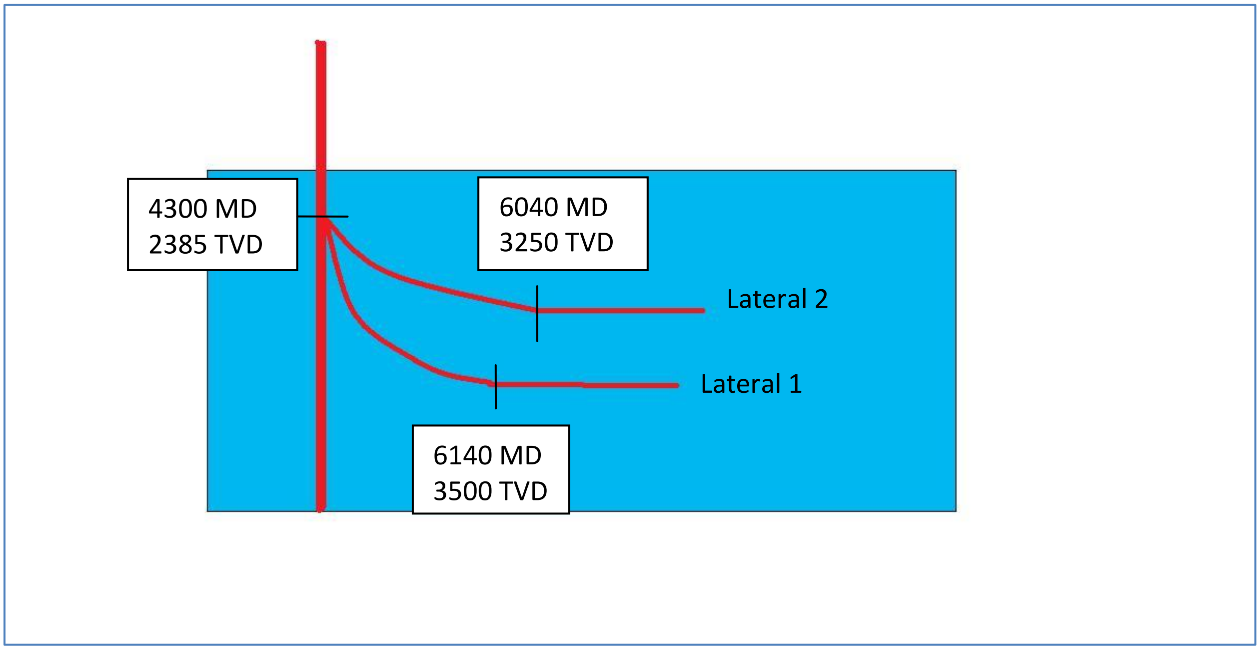



**Figure 3.3: Model Assumption for build-up lateral**

## 3.3 MODELLING PREOCEDURES

a) First modeling is for horizontal part of the lateral

b) Data needed is collected from SPE papers and SPE monographs

c) Manual calculation is done to test the validity of data

d) Computer codes are designed to produce the model.

e) Repeat the process for different tubing diameter.

f) Do analysis of the model and comparison between the methods used.

g) Repeat step b) until f) for build-up section of the lateral.

h) Do analysis for single phase flow and multiphase flow for the build-up section models.

## 3.4 WORKFLOW SUMMARY

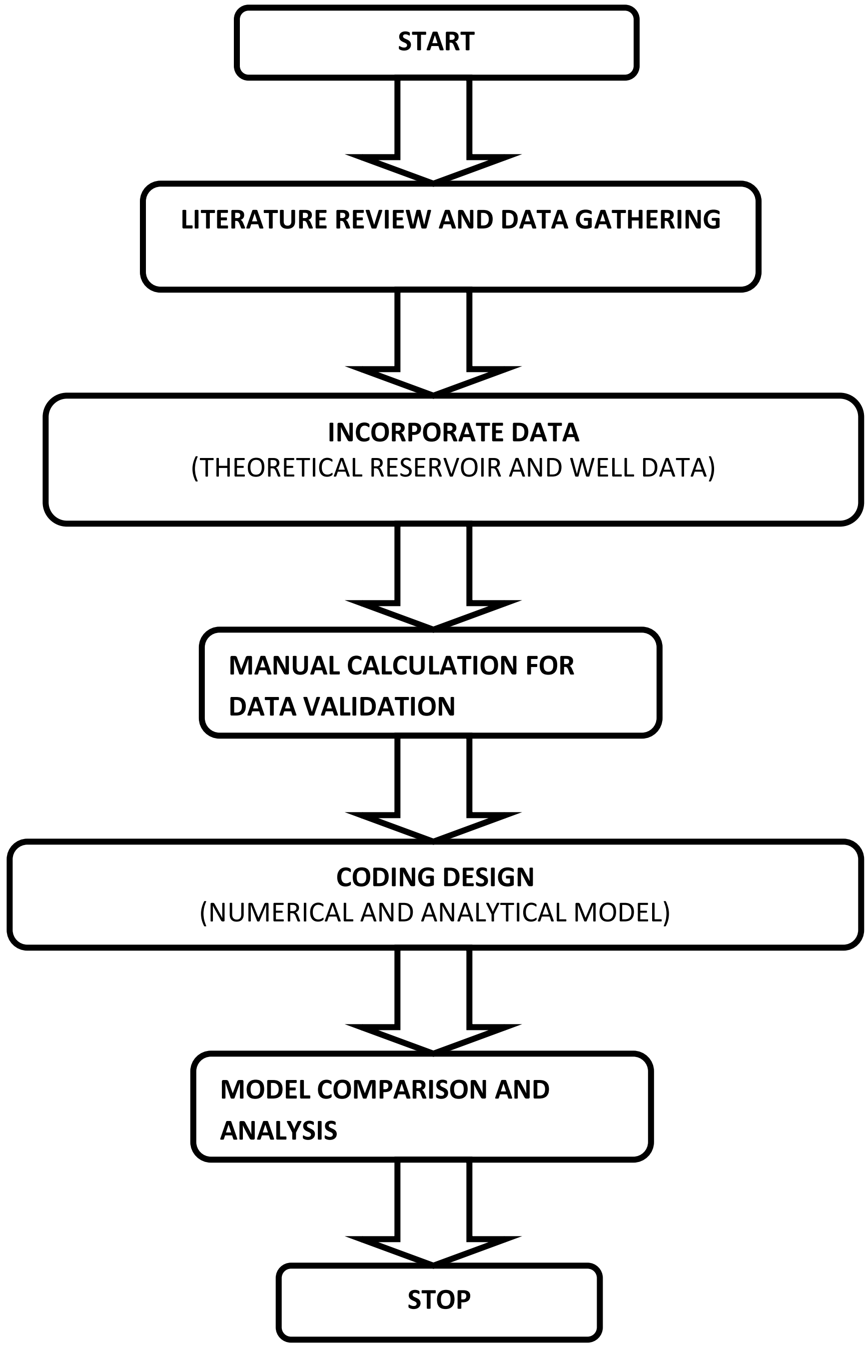



**Figure 3.4: Workflow Summary**

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 HORIZONTAL LATERAL

Estimating wellbore performance in multilateral well is vastly different than in single well. For single well we can use the IPR (inflow performance relationship) to predict the well performance. However flow rate in multilateral wells couple in the main wellbore after producing from different lateral. This is the tricky part, where we have to consider the pressure drawdown in the reservoir relative to the pressure drop in the lateral.

Fluid flow pattern in horizontal well is quite similar to pipe flow with mass transfer through its porous wall. The main differences are:

- In horizontal well, the mass transfer is normally through perforations. And by it the effective perforation density is very large for the porous-pipe flow case. However if the well is open hole completion, then the horizontal and porous-pipe flow problems are conceptually identical.
- Injection rate usually small in porous-pipe flow, but not necessarily the case for wellbore flow.
- For horizontal well, when there is no mass transfer through the wall the effective pipe roughness may be very different from the actual pipe roughness, but in porous-pipe flow case, its changes only slightly.

In this study we will observe 3 methods of defining the pressure drop pattern in horizontal lateral.

### 4.1.1 Pressure Drop in Horizontal Lateral

a) Figure 4.1 shows the pressure drop model evaluated by numerical approach in 4 inches tubing using no inflow, Ouyang's and Yuan's method.

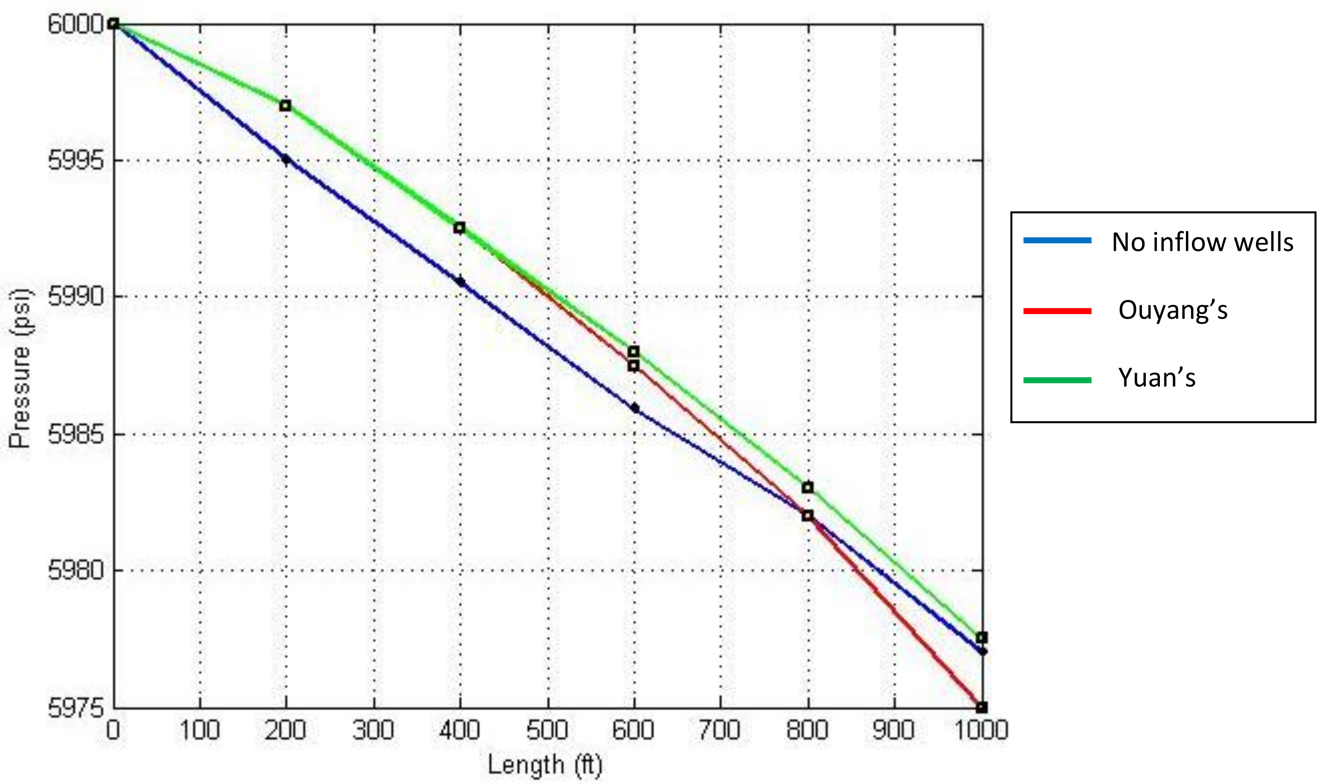



**Figure 4.1: Pressure drop analytical model for 4 in Tubing**

**Discussion**: In 4 in tubing, the total pressure drop for all 3 methods is approximately 23 psia. Using the standard pipe flow where there is no inflow into the wellbore produces almost straight line graph. The pressure drop is uniform when not disturbed by well inflows and other possible elements. For Ouyang's, we've taken into account additional elements which are the pressure drop caused by inflow and perforation roughness. Yuan's method considering the acceleration and mixing effects into the friction correlation. The pressure profile obtained by Ouyang's is slightly different from that obtained by other 2 with the gradient increasing toward the heel of the section which means pressure drop here experiencing higher rate than other part of the lateral.

b) Figure 4.2 shows the pressure drop model evaluated by numerical approach in 5 inches tubing using no inflow, Ouyang's and Yuan's method.

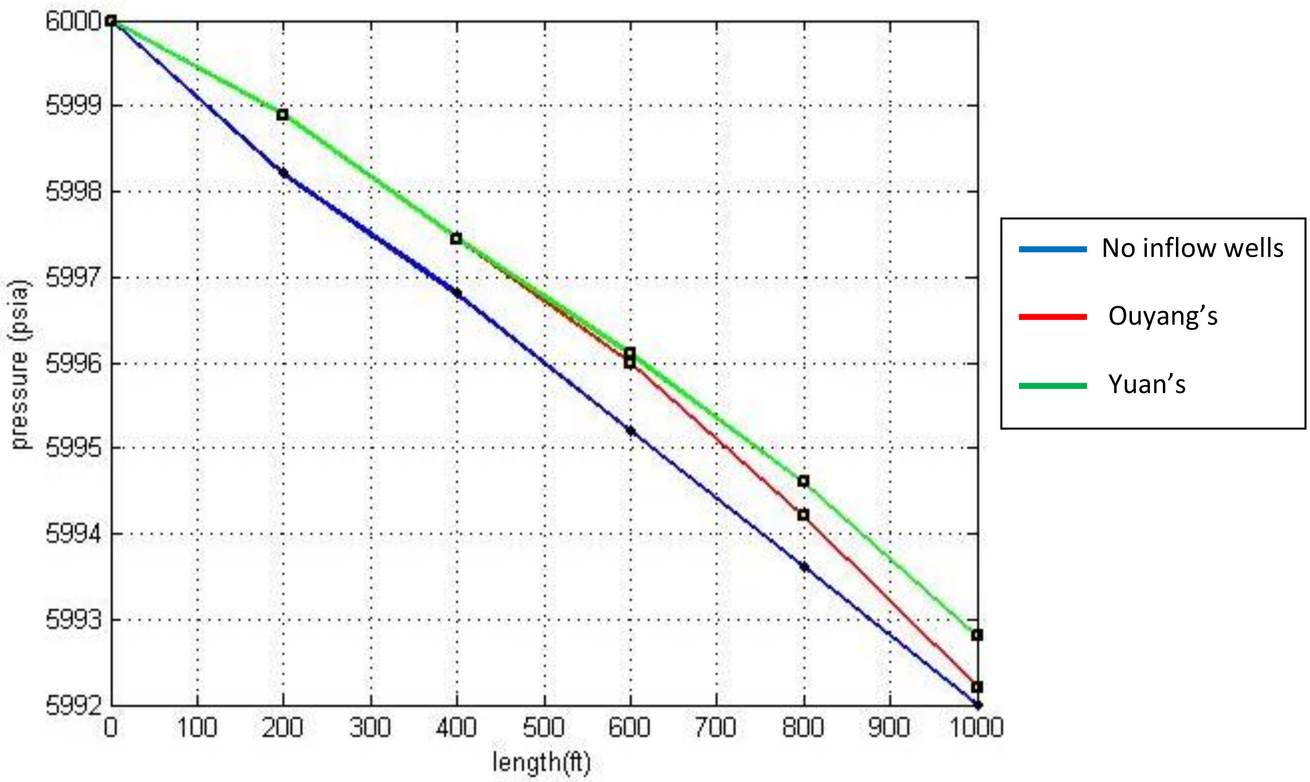



**Figure 4.2: Pressure drop analytical model for 5 in Tubing**

**Discussion**: In 5 in tubing, the total pressure drop for all 3 methods is approximately 8 psia. This graph mainly shows that when the diameter is higher, than the effects of pressure drop will be less. We can see that from methods above, the gradient is the same except for Ouyang's where its gradient is still higher at the heel of the section but the overall gradient is lower than in 4 in tubing.

c) Figure 4.3 shows the pressure drop model evaluated by numerical approach in 6 inches tubing using no inflow, Ouyang's and Yuan's method.

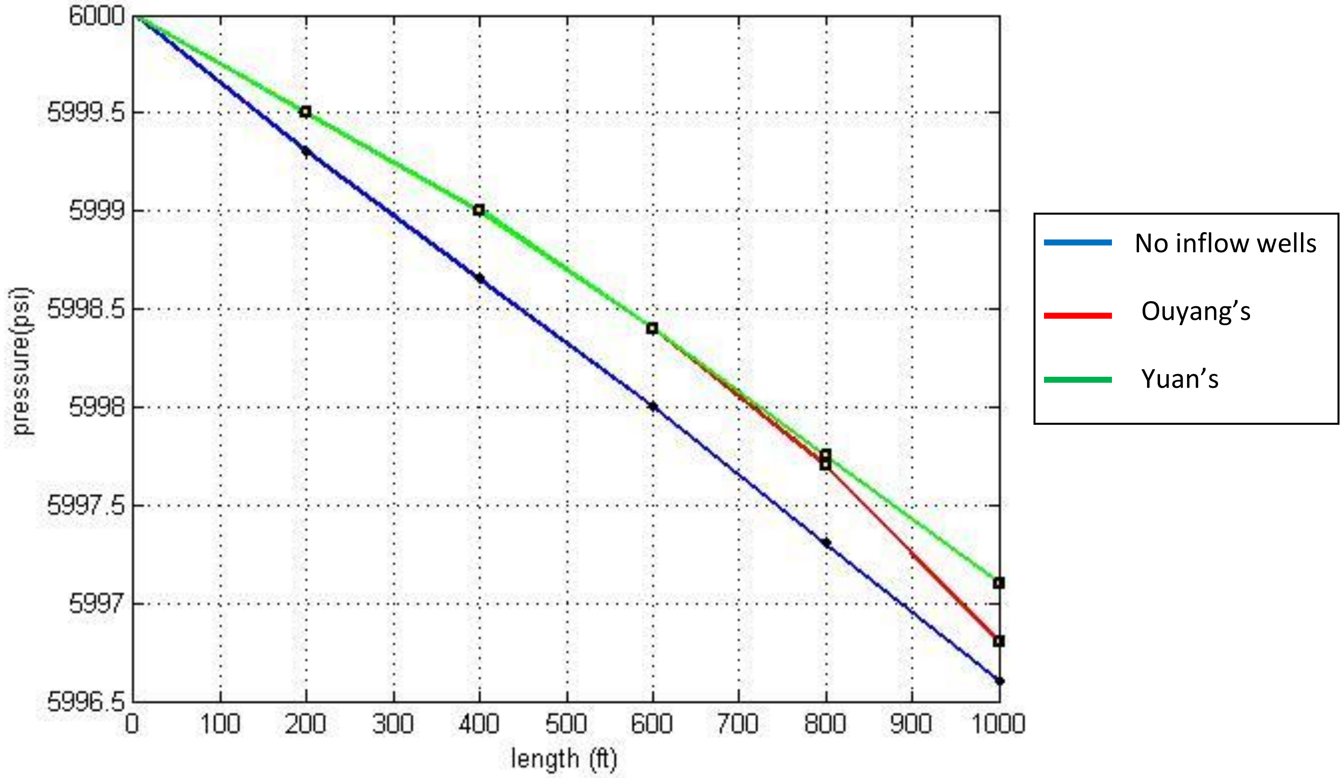



**Figure 4.3: Pressure analytical model for 6 in Tubing**

**Discussion**: Last but not leats, In 5 in tubing, the total pressure drop for all 3 methods is approximately 3 psia only. These lines have the less steep gradient for all 3 methods because of its high diameter. Ouyang's still has the highest gradient at the heel but the less gradient compared to 4 and 5 in tubing. This proves that tubing diameter favors in every pressure drop in the tubing.

### 4.1.2 Comparison and Analysis Process

Blue lines: Where there is no inflow along the lateral, flow behavior is the same as in the standard horizontal pipe flow. For all 3 cases, pressure drop almost in straight line.

Red lines: (Ouyang et al.'s single-phase) Ouyang's model for pressure drop calculations incorporates frictional,  accelerational and gravitational pressure drops, and it accounts for pressure drop caused by inflow and perforation roughness by applying an empirical friction factor correlation.

Green lines: (Yuan et al. 1998). It gives an empirical friction factor correlation based on large set of experiments with slotted liners and perforated casing. Acceleration and mixing effects were incorporated into the friction factor correlation.

Basically in the graph above, the longer the lateral section, the higher pressure drop occurred. We can saw that the pressure drop over a 1000 ft section was only 3 psi in a 6 in ID liner and only 23 psi in a 4 in ID liner.

How important this pressure drops depend on its ratio to the reservoir drawdown. To calculate this we use Furui et al. to see the ratio of the lateral pressure drop to the reservoir pressure drop for horizontal lateral.

In many cases, pressure drop in the lateral is negligible when compared to the reservoir drawdown. But there are certain cases where the relative pressure drop to the reservoir drawdown becomes significant.

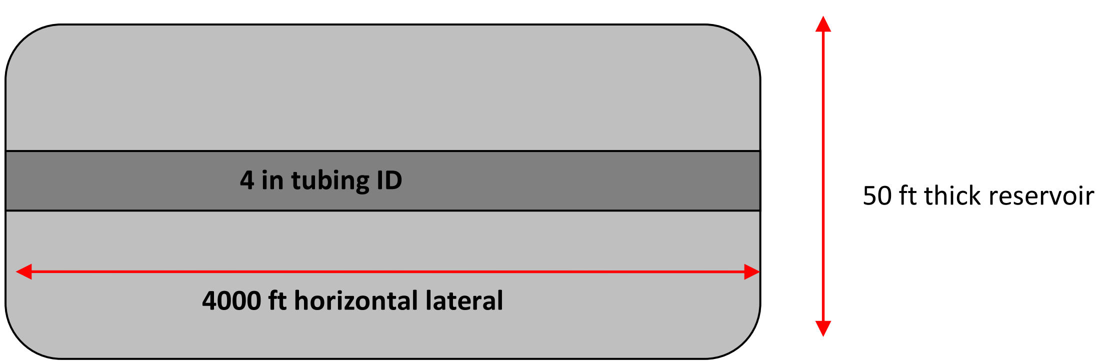



**Figure 4.4: Example of tubing setting in the formation**

**Table 4.1: Change in Pressure Ratio due to Change in Reservoir Drawdown**

| K (md) | Reservoir Drawdown (psi) | Ratio $(\Delta p_f/\Delta p_r)$ |
|---|---|---|
| 50 | 500 | 0.01 |
| 50 | 1000 | 0.02 |

**Table 4.2: Change in Pressure Ratio due to Change in Reservoir Permeability**

| K (md) | Reservoir Drawdown (psi) | Ratio $(\Delta p_f/\Delta p_r)$ |
|---|---|---|
| 500 | 100 | 0.21 |
| 1000 | 100 | 0.78 |

From the table above, we can see that when reservoir drawdown is changed, the ration difference is very small. For a constant permeability, 500 psi of reservoir drawdown gives 1% ratio and when reservoir drawdown is doubled to 1000 psi, the ratio is 2%. Hence we can conclude that reservoir drawdown doesn't affect the effect of pressure drop in the lateral towards the overall system.

However, referring to table 4.2, it shows that changes in permeability give a great impact on the pressure ratio. With constant reservoir drawdown, 500 md reservoir gives 21% and 1000 md reservoir gives 78% which is tripled the 1$^{st}$ value. Here we can conclude that reservoir permeability gives significant impact on the wellbore pressure drop.

Eventhough the value seems very unsupportive to the well performance, engineers still can change other elements in order to reduce this wellbore pressure drops effects on the well production such a using large diameter wellbore or shorter lateral.

## 4.2 PRESSURE DROP IN BUILD UP SECTION OF LATERAL

For the build-up section, the result is divided into 2, one where there is single phase flow, and the other is multiphase flow. Basically when there is an inclination in the pipe, pressure drop will be higher, thus it is important to carefully modeled is so that every elements is taken into account.

### 4.2.1 Single Phase Flow

Assuming that the fluid properties are constant throughout the build sections, we can calculate the potential energy and frictional components of the pressure drops using equation directly.

**Table 4.3: Result summary for single flow in Build up Section**

| Lateral | Angle | TVD (ft) | Pressure Drop (psi) |
|---|---|---|---|
| **1** | **29 degrees** | **1115** | **464** |
| **2** | **50 degrees** | **860** | **344.5** |

We don't consider the well elevation as in angle, I use TVD of the heel section to differentiate the well elevation. For lateral 1, the total measured distance along the build up section from the heel of the lateral to the junction is 1840 ft, using equation, the frictional pressure drop is 10.1 psi. Using the TVD difference which is 1115ft, the potential energy drop is 454 psi. Adding these 2 pressures yield the total pressure loss which is 464 psi.

Whereas in lateral 2, the frictional pressure is 19.5 psi. For the elevation of 860 ft, the potential energy drop is 352 psi and yields 344.5 psi for total pressure drop.

### 4.2.2 Multiphase Flow

There are many ways to calculate pressure drop of multiphase flow in inclination well. For this study purpose, I choose to sue Beggs and Brill Correlation. In multiphase flow, the fluid hold up is depending strongly on pipe inclination, and the inclination is varying through the build section. Because of that, the build section has to be divided into smaller segment and each segment is assumed to have constant angle.

a) Figure 4.5 shows the pressure drop trend in the build-up section with multiphase flow in lateral 1.

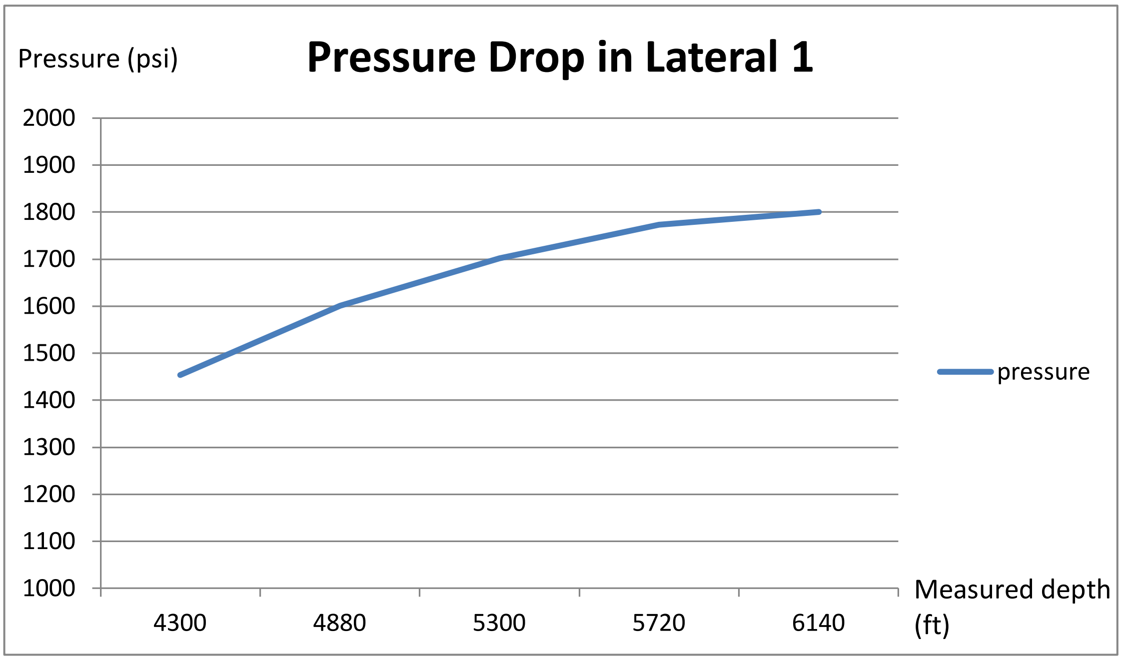



**Figure 4.5: Pressure drop analytical model in Lateral 1**

As the lateral extended from the starting of horizontal part to the mother wellbore, the difference in measured depth is about 1840 ft with $29^o$ inclination from vertical. The total pressure drop of the lateral is 346 psi.

b) Figure 4.6 shows the pressure drop trend in the build-up section with multiphase flow in lateral 2.

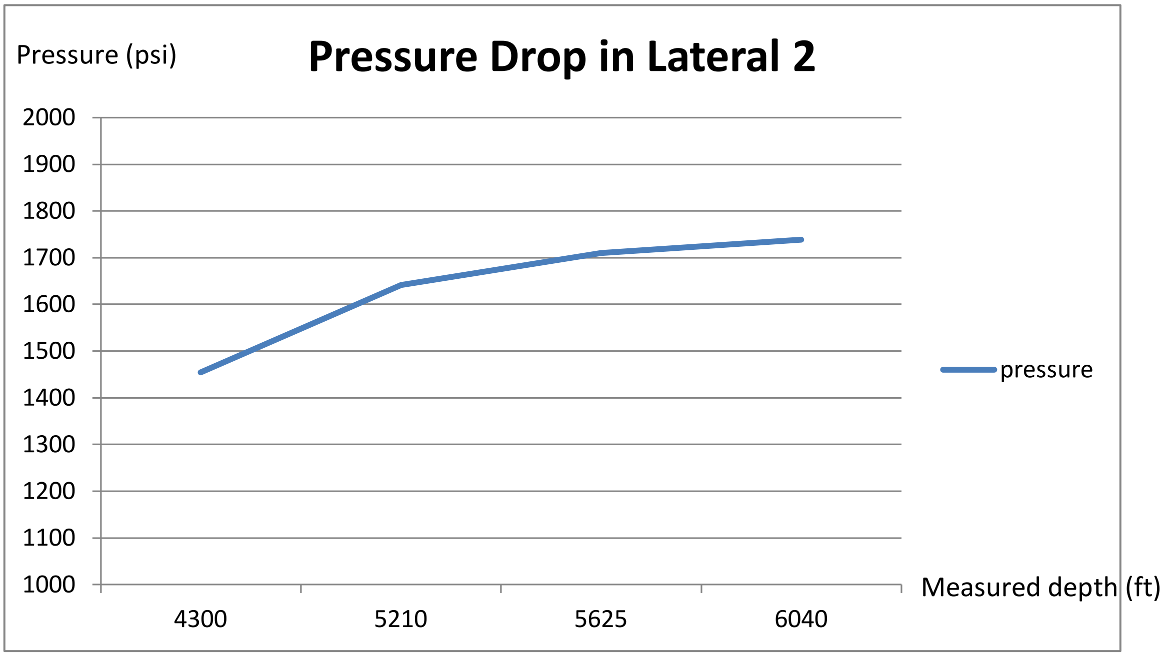



**Figure 4.6: Pressure drop analytical model in Lateral 2**

As for lateral 2 which also extended from the starting of horizontal part to the mother wellbore, the difference in measured depth is about 1740 ft with $50^o$ inclination from vertical. The total pressure drop of the lateral is 285 psi.

Discussion:

From the results above, basically we can conclude that the steeper the inclination is, the higher is the pressure drop. Between the differences in flow phase, multiphase flow seems to have lower pressure drop than the single phase flow. Mainly because of the all fluid form in single phase flow, then the frictional pressure drop will be higher than the one that has less, and aided by gas which changes the properties of the fluid itself.

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATION

## 5.1 CONCLUSIONS

As a result of an analysis of flow behavior inside the lateral of multilateral well the following conclusions can be drawn:

The general trend of pressure drop models simulated from numerical and analytical approach for horizontal lateral and build up section is identical. However, not all the methods will produce the accurate result. For the horizontal lateral, the Ouyang's method is the most accurate to model pressure drop in horizontal lateral since it is considering the well inflow into the pressure drop. For the buildup section, the fluid properties and inclination angle are other parameters that influence the pressure drop.

It is important to determine the pressure drop in the lateral because it will determine the well performance and well deliverability eventually. Although the pressure drop is likely to be negligible in most wells, but the effect can be severe in certain cases for example in high permeability well.

Still, there are ways to reduce this effect by changing the perimeters of the well itself such as the tubing diameter and lateral length so that the well performance won't be affected.

## 5.1 RECOMMENDATION

Recommendation:

For the future study, we could consider other methods to develop more accurate and flexible models. Other mathematical method such as Finite Difference can be utilized to model the multiphase flow in the tubing. When more parameters are taken into account, the model should be very reliable and accurate. It is exactly what we needed in order to understand the pressure for well monitoring thus will lead to better well development.

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