A STUDY OF THE EFFECT OF LIQUID FLOW RATE, PIPE SIZE AND PIPE ORIENTATION ON THE LIQUID HOLD-UP USING BEGGS AND BRILL CORRELATION

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ABSTRACT

The effect of liquid flow rate, pipe size (diameter) and pipe orientation (inclination) on liquid hold-up was investigated. Liquid flow rate between 500 STB/day and 5000 STB/day was studied. An oil of 25˚API at an average temperature of 175˚F, a gas gravity of 0.65, water cut of 25% with water gravity of 1.07 and containing no free gas was used in this study. The correlations given by Standing, Culberson and Maketta, Vasquez, Dodson and Standing, Papay, Beggs and Robinson, and Lee et al correlations were employed to calculate the fluid properties. Beggs and Brill correlation was used to predict the liquid hold-up. A step by step procedure was developed using Microsoft excel to generate results for various combination of the variables under consideration.

The hold-up recorded for flow in pipes of negative angle of inclination was less than that for positive angle of inclination for the same fluid properties and flow parameters. It was evident, from the result of the study that the liquid hold-up increase with increase in the liquid flow rate. As the pipe inclination changes from -90˚ to 90˚, there is an increase in the liquid hold-up recorded, for each liquid flow rate.

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What shall I say unto the Lord? All I've got to say is "thank you Lord". I am forever grateful to the Lord God almighty for his mercy and divine wisdom which he has granted me from the beginning of my academic life till this day.

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DEDICATION

I dedicate this work to my parents, Mr & Mrs Kporngor, my brother Strong Julius and my five sisters Brainy Dilys, Independent Cynthia, Humorous Irene, Caring Josephine and Pretty Isabella.

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CHAPTER 1

1.0 Introduction

The simultaneous flow of oil, water and gas in pipe is encountered in many engineering installations. In petroleum, chemical process, nuclear engineering and many other industries, problems associated with simultaneous flow of two or more phases through vertical and inclined pipes have been of interest for a long time [1]. This interest has increased considerably during recent years due to the applications of new processes in petroleum production and refining. One prominent example of vertical two phase flow is provided by the gas lift process where liquid (oil and water) and gas flow simultaneously [1, 3]. If the pressure profile in a gas-lift well can be predicted within reasonable accuracy, it would be possible to get good estimates of the power required to lift the oil, the optimum depth pressure and the rate at which to inject gas [1].

1.1 Problem Statement

Reservoir bottom hole flowing Pressure plays a very important role as the primary driving force that 'lifts' the hydrocarbons and transport them from the reservoir to the surface gathering facilities. As the pressure declines below the bubble point, gas comes out of solution, resulting in liquid and gas flowing simultaneously.

The simultaneous flow of two phase fluid is very common in the oil industry [2]. It occurs in oil wells, gas wells, injection wells and production lines. The spatial distribution of the phases inside the pipe and the pipe inclination plays an extremely important role in the accurate determination of the pressure drop and flow characteristics [2].

There are a number of correlations like Duns and Ros, Hagedon and Brown, and Orkiszewski for multiphase flow in pipes at various angles of inclination that enable the calculation of the pressure gradient in the pipe. The pressure gradient is a local measure of the pressure changes with depth and can be applied at any location in the tubing string.

The purpose of this study is to determine the effect of liquid flow rate, pipe size (diameter) and pipe orientation (angle of inclination) on liquid holdup using Beggs and Brill correlations. The choice of Beggs and Brill correlation is informed by the fact that this correlation considers slip between flowing faces and flow regimes and also give relatively accurate results for liquid hold-up for various pipe inclination for both upward and down wards flow [2].

1.2 **Expected Outcome**

The ability to accurately predict the liquid hold-up for various liquid flow rate, pipe size (diameter) and pipe orientation (angle of inclination) will provide the producer a tool to estimate productivity. The accurate prediction of the pressure drop can help in the determination of the required horse power in the well. This information will help in the economic analysis of the well. This piece of information will help the producer in deciding on any activity to engage in, like artificial lift method where necessary to improve production.

1.3 Project Organisation

Chapter one of this write up gives an introduction of the problem being studied in this project and the expected outcome. Chapter two gives a general literature review of challenges that multiphase flow in pipes pose during production and transportation of oil. It presents some of the common correlations used in the oil and gas industry for predicting pressure gradient along the length of pipes during multiphase flow of fluids.

Chapter three gives an outline of the various correlations that is used in the calculation of the fluid properties. These fluid properties were then used to determine the liquid hold-up in a step by step procedure in Microsoft Excel using Beggs and Brill correlation at various locations along the length of the pipe. The results obtained are analysed in chapter four and the conclusion and recommendations are laid out in chapter five. Appendices A through C contain the plots of the results obtained from the Beggs and Brill correlation.

CHAPTER 2

2.0 Literature Review

2.1 Multiphase Fluid Flow Concepts

In the exploration of a hydrocarbon reservoir, liquids and gases flow simultaneously. This flow of liquids and gases, which may be in any direction or pattern, is called multiphase flow. The liquids are oil and water whilst the gases are a composition of hydrocarbon gases and non-hydrocarbon gases. Among the hydrocarbon gases are methane, ethane, propane, butanes, pentanes, and hexanes plus and some of the non-hydrocarbon gases are CO_2, N_2, and H_2S.

The petroleum and chemical industries are interested in accurately calculating the Pressure losses that occur for multiphase flow in tubing and pipe lines [7]. The importance of accurate calculations of pressure losses in pipes is as the result of the fact that practically all oil well production design involves multiphase flow [7]. Accurate predictions of pressure losses in pipes ensure good well design [4]. Some parts of the well design are the selection of completion strings, the prediction of flow rates, and the design of artificial lift installations.

Because the pressure in a well decreases from the sand face to the wellhead, some of the dissolved gas in the oil comes out of solution as free gas whilst being transported to the wellhead, causing a decrease in the specific volume of oil. The free gas that enters into the tubing string also starts to expand due to the reduction in the flowing pressure, resulting in an increase in the amount of free gas as the mixture flows from the producing formation to the wellhead.

The simultaneous flow of liquids and gases in pipes is not as simple as the flow of a single phase [8]. An interface between gases and liquids may exist and the interface may be smooth or not, depending on the regime and on the flow pattern. Sometimes the gases slip and pass the liquids. These slips involve transfer of energy from gases to liquids and to the surroundings. As a result, there are major pressure losses in the system compared with single phase flow [7].

Two phase flow may occur in vertical pipes, horizontal pipes and in inclined pipes. The flow of gas-liquid mixture is of great importance to the production of oil and gas [1]. It has received continuous and strong attention by many investigators from the early days of the invention of the air-lift principle in the late 1920's, stimulated further interest in the area of vertical two phase flow and resulted in a large number of theoretical as well as experimental studies [4]. The main difficulties in analysing gas-liquid flow are the variety of flow patterns possible and the existence of slip between the phases [4]. In a very short pipe, only one flow pattern will exist for a given pair of liquid and gas flow rates. However, in long risers, long horizontal wells and in the tubing of vertical oil wells, usually two or three flow patterns can exist at different locations along the pipe.

2.2 Flow Patterns

The distribution of liquids and gases tends to vary whenever the two phases flow together through a pipe. This distribution depends on factors like the flow velocity of the mixture, the pipe inclination and the respective amount of each fluid phase present. Flow patterns can be considered as the distribution of each phase with respect to the other in a pipe. The determination of the flow pattern is easier in a vertical pipe than in a horizontal pipe, because in the horizontal flow the phases tend to separate due to gravity [7]. The complex interaction between the phases in two phase flow forms an overall outlook of the flow at each time, which is categorized into different flow regimes. The concept of a flow regime is a subjective and qualitative concept and is not possible to incorporate it into mathematical equations as a parameter [8]. Predicted results usually show some discontinuity between different regimes which is related to uncertain prediction [1].

Most investigators that consider flow regimes define four main regimes which may occur in a vertical pipe, though different names are given to these regimes by different investigators. Brief descriptions of the manner in which the fluids are distributed in the pipe for each flow regime, as given by Orkiszewski are bubble flow, slug flow, transition flow and mist flow.

Bubble flow is characterised by the pipe being almost completely filled with liquid and the free gas phase is present as small bubbles. The bubbles move at different velocities and except for their density, have little effect on the pressure gradient. The wall of the pipe is always contacted by the liquid phase in this type of flow.

The gas phase is more pronounced in slug flow. Although the liquid phase is still continuous, the gas bubbles coalesce and form plugs or slugs which almost fill the pipe cross section. The gas bubble velocity is greater than that of the liquid and the liquid in the film around the bubble may move downward at low velocities. Both phases have significant effects on the pressure gradient in this flow regime.

The change from a continuous liquid phase to a continuous gas phase occurs in transition Flow. The gas bubbles may join and liquid may be entrained in the bubbles. Even though the liquid effects are significant, the gas phase effects are predominant.

In mist flows the gas phase is continuous and the bulk of the liquid is entrained as droplets in the gas phase. The pipe wall is coated with a liquid film but the gas phase predominantly controls the pressure gradient.

2.3 Flow Behaviour Prediction Models

The general energy equation is the basis for the development of the equations that are used to solve many problems associated with multiphase flow [8]. Different multiphase flow investigators have used this equation in one form or the other. Authors like Duns and Ros expressed it in a pressure balance form, while Poettmann and Carpenter and Hagedom and Brown used it in an energy balance form [7].

The general energy balance equation simply states that the energy of a fluid entering a control volume, plus any shaft work done on or by the fluid, plus any heat energy added to or taken from the fluid, plus any change of energy with time in the control volume must be equal to the energy leaving the control volume.

The total pressure gradient is composed of three distinct components which are friction, gravitation and acceleration.

The gravitational component is the component due to potential energy or change in elevation. It is also referred to as the hydrostatic component, as it is the only component which applies at conditions of no flow. This term is zero for horizontal flow applicable to both compressible and incompressible fluids in steady state or transient flow in both vertical and inclined flow.

The frictional component is the component due to friction losses which exists in any type of flow at any pipe angle. Pressure drop is recorded in the direction of flow for this component. The friction loss term has been determined analytically only in single phase laminar flow but for multiphase flow, it is determined by an analogy with the single phase or by experimental means.

The acceleration component is the component due to kinetic energy change and holds for all transient flow conditions. For any flow condition that records velocity change, such as in compressible flow, a pressure drop will occur in the direction of the velocity increase. The acceleration component may account appreciably for the pressure losses near the top of the well where low tubing pressures are encountered.

Many correlations [7] have been developed for predicting two-phase flowing pressure gradients which differ in the manner in which the friction loss, elevation and acceleration components of the total pressure gradient is calculated. Some investigators, according to Carrascal [7], chose to assume that gas and liquid phases travel at the same velocity when evaluating the mixture density, liquid holdup and friction factor and also develop separate correlations for each flow regime.

2.4 Variables Used in Two-Phase Flow Pressure Gradient

Two phase flow pressure drop depends on a large number of independent parameters like geometric configuration of the pipe, mass and volume fractions of the individual phases, pressure, fluid properties, mass flux, liquid hold-up, orientation of the pipe and flow patterns.

2.4.1. Liquid Hold-up

The presence of gas flowing with liquid is a phenomenon that occurs frequently in natural gas gathering and transmission pipelines for both onshore and offshore operations [8]. The liquid usually contain the heavy hydrocarbon fractions and water [8]. The fraction of the volume of pipe that is occupied by the liquid is the liquid hold-up. Liquid holdup is contained in the gravity component of the pressure gradient term. The hold-up, as used by Beggs and Brill [9], is a correction for gas slippage. If the variation of liquid hold-up is known, it is possible to calculate the average velocity of each phase and their relative difference, which is known as slip velocity. This would result in the accurate prediction of the pressure loss due to gravitational component. This information will help in the economic evaluation of the system.

2.4.2 Superficial Velocity

Many two-phase flow pressure gradient correlations are based this variable. [7]. The superficial velocity of a fluid phase is the velocity which that particular phase would exhibit if it flowed through the total cross section of the pipe alone whilst the in-situ velocity is the actual velocity of the phase when the two phases travel together.

2.5 Empirical Correlations for Pressure Prediction

A large number of two phase flow pressure drop correlations are reported in literature [2]. Many of these correlations being empirical in nature are applicable only for limited parameter ranges [2]. For many practical situations, designers and analysts often require some guidance to choose the appropriate correlation. Some of the popular empirical correlations used in the oil and gas industry [5] are “Poettmann and Carpenter (1952)”, “Baxendell and Thomas (1965)”, “Eaton et al. (1967)”, “Duns and Ros (1963)”, “Orkiszewski (1967)”, “Aziz et al. (1972)”, “Beggs and Brill (1973)” and “Dukler et al. (1969)”.

The range of applicability of the multiphase flow models is dependent on several factors such as tubing diameter, oil gravity, gas-liquid ratio and two-phase flow with or without water-cut.

2.5.1 Duns & Ros [10] Correlation

The Duns and Ros correlation is the result of laboratory experiments that considered slippage between the flowing phases and the flow regimes. The general energy equation was expressed as a pressure balance equation by Duns & Ros [10] in which three terms were distinguished, namely the static gradient term, the wall friction gradient term, and the acceleration gradient term. 20, 000 data points were used in the development of this correlation. This correlation distinguished three different flow types which three equations for slippage and friction each were developed. The flow types are

a. Type I- where the liquid phase is the continuous one, covering bubble flow, plug flow and part of the froth -flow regime.
b. Type II- where the phases of liquid and gas alternate, covering the slug flow and the remainder of the froth flow regime.
c. Type III- where the gas phase is the continuous one, covering the mist flow regime

2.5.2 Hagedon & Brown [11] Correlation

The Hagedon and Brown correlation is the result of experimental work done by Hagedon and Brown, and Fancher and Brown [2]. Hagedon and Brown used data collected from 475 tests run in 1500 ft well and another 106 data which was previous work done by Fancher and Brown [11]. This test involved the use of water and 10, 35 and 110 cp viscose oil. The fluid production was controlled from the surface, allowing the investigators to test these fluids in different tubing sizes. 1, 1 ¼ and 1 ½ in. pipes were used for the test. A total of 2,905 pressure points were collected for a wide range of conditions, producing the liquids at different flow rates whilst injecting air in different quantities. This made the study of the effect of pipe diameter and the flow parameters on the pressure gradients with four different pipes and for various flow conditions possible.

The liquid and gas were in contact for a short period of time during the period of the test and the pressure range studied was narrow. The different composition of oil and air did not allow much air to go into solution which implies that there is not much effect of pressure on the viscosity of the oils. This formed the basis of the assumption that the amount of air that went into solution was negligible by Hagedon and Brown [11]. In the application of the correlation however, the solubility effects were considered.

2.5.3 Orkiszewski [12] Correlation

Orkiszewski based his study on test results from 148 wells, with a large part of this data gotten from literature [12] from which he showed that no single correlation was accurate enough to predict the pressure gradient in a well for a set of different flow conditions. The Orkiszewski [12] grouped the correlation into three categories according to theoretical concepts.

In the first category, the liquid holdup was accounted for in the calculation of the density. The composition of the produced fluids (top hole) which was corrected for temperature and pressure changes was used in this calculation. The liquid holdup and the wall frictional losses were correlated in the empirical friction factor but the flow regimes were not considered.

In the second category, the liquid hold-up was also used in the calculation of the density. The liquid hold-up, in this category however can be correlated separately or combined with the wall friction losses. The friction losses were also calculated using the composite properties of the fluids. Like the first category, the second category did not consider flow regimes.

The calculation of the density was based on the liquid holdup which was determined using the concept of slip velocity in the third category. The wall friction losses were based on the fluid properties of the continuous phase.

Orkiszewski [12] distinguished four types of flow patterns and for each, he developed relations to establish the slippage velocity and the friction losses. The flow patterns were bubble, slug, transition, and mist. In a similar way as Duns and Ros [10] stated, Orkiszewski [12] postulated the matching of the calculations of the regions with the flow patterns. With this, Orkiszewski [12] selected different theories and choose the most appropriate for each regime. He then discovered that no method was accurate enough for the prediction of the pressure gradient for a wide set of flow conditions.

2.5.4 Beggs and Brill [9] Correlation

The Beggs & Brill Correlation was developed based on 584 measured tests results [9]. A small test facility which consisted of 1 and 1 ½ in. sections of acrylic pipe, 90 ft long was used for the experiment from which the 584 results were obtained. The pressure gradient and the liquid holdup were then measured for different angles with the horizontal as the base.

Whilst the angle of inclination of the pipe was varied, the flow rate was kept constant so the effects of the flow patterns and liquid holdup on the pressure gradient could be studied. The test was conducted for turbulent flow using water and air. For a transition zone between the segregated and intermittent flow regimes to be included, the original flow pattern map was slightly modified. The friction factor used in the calculation of the pressure gradient is independent of the flow regime but dependent on the holdup.

CHAPTER 3

3.0 Application of Beggs and Brill Correlation and Sample Calculation for Liquid Hold-up and Pressure Gradient.

The Beggs and Brill correlation enables the calculation of the pressure gradient as a function of other production variables like pipe diameter, GLR and gas and oil flow rates. These parameters also affect the liquid holdup at every location in the pipe.

The liquid holdup in a long pipe will vary with location long the length of the pipe [10]. Over such long distances, the local liquid holdup will change depending on the flow rates and the flow conditions occurring at each location of the pipe [10]. This phenomenon is observed because the fluid properties, amount of gas in solution, amount of free gas and in-situ volumetric gas and liquid flow rates are functions of pressure and temperature. Thus the liquid holdup is also a function of pressure and temperature.

3.1 Properties of the Produced Fluid

3.1.1The Gas Solubility in Oil (R_{so})

Standing [13] published a correlation for estimating bubble-point pressure in 1947. This correlation was developed with field values of reservoir temperature, solution gas-oil-ratio at the bubble point, and the oil and gas gravities. 105 experimentally determined data points from 22 different crude-oil/natural-gas mixtures from California fields was used by Standing [13] in developing this correlation. Rearranging Standing [13] correlation yields the equation for the gas solubility in oil, as is given by equation 3.1

3.1

3.1.2 The Gas Solubility in Water (R_{sw})

The amount of gas that is able to dissolve in water is a function of pressure and temperature, as is outlined by Culberson and Maketta [6]. The empirical correlation developed by Culberson and Maketta is given by equation 3.2.

3.2

Where;

3.3

3.4

3.5

3.1.3 Free Gas-Liquid Ratio

The free gas produced as a ratio of the produced liquid is determined by performing mass balance on the produced fluids. The free gas-liquid-ratio, from mass balance performed on the gas, (GLR_{free}) is given by equation 3.6 or 3.7 depending on the reservoir pressure.

3.6

3.7

3.1.4 The Isothermal Oil Compressibility C_o

Vasquez and Beggs [14] in 1976 used laboratory results from more than 600 crude oil systems to develop empirical correlations for several oil properties like the solution gas-oil ratio and the oil formation volume factor both at the bubble point. Vasquez and Beggs [14] correlation, when rearranged gives the compressibility of the oil as a single-phase liquid with some amount of gas in solution. The isothermal oil compressibility, as developed by Vasquez and Beggs [14] is given by equation 3.8

3.8

.

3.1.5 The Oil Formation Volume Factor B_o

The oil formation volume factor is calculated from Standing Correlation [13] as outlined in equations 3.9 and 3.10 for pressure below the bubble point and above the bubble point respectively.

3.9

3.10

3.1.6 The Water Formation Volume Factor (B_w)

The water formation volume factor, B_w for the fluid pressure below and above the bubble point is calculated from Gould Correlation [6] as outlined in equations 3.11 and 3.12, respectively.

3.11

and

3.12

3.1.7 Gas Deviation Factor Z

Using Papay Correlation [15], the gas deviation factor Z is calculated from equation 3.13

3.13

Where

3.14

3.15

3.16

and

3.17

3.1.8 The Mixture Froude Number, N_{FR}

The Froude number, N_{FR} is a dimensionless number that describes different flow regimes of open channel flow. Named after William Froude, the Froude number is a ratio of inertial and gravitational forces. It is given by equation 3.18

3.18

3.1.9 Flow Regime Correlating Parameters

Beggs and Brill correlation considers the flow regime that the fluid flowing in the pipe would be in if the pipe were horizontally inclined. This flow regime is a correlating parameter and gives no information about the actual flow regime unless the pipe is horizontal. Equations 3.19 through 3.23 give the correlating parameters.

3.19

3.20

3.21

3.22

and

3.23

3.2 Flow regimes.

The flow regimes considered by Beggs and Brill are segregated flow, transition flow, intermittent flow, and distributed flow. The flow regime of the fluid is obtained by determining the set of limits which is satisfied. The limits of the horizontal flow regimes are as outlined below.

3.2.1 Segregated Flow Regime

3.24

and

3.25

3.2.2 Transition Flow Regime

3.26

3.2.3 Intermittent Flow Regime

3.27

and

3.28

3.2.4 Distributed Flow Regime

3.29

and

3.30

3.3 Gravitational component of the pressure gradient

The liquid holdup is used to calculate the slip density of the flowing fluid once the flow regime has been determined. The same equations are used to calculate liquid holdup for all flow regimes but the coefficients and exponents used in the equations are different for each flow regime. The liquid holdup for a flow in the transition regime is calculated by interpolating the calculated liquid holdup in the segregated and the intermittent flow regime. The weighting factor used for the interpolation is;

3.31

Where

3.32

3.33

The liquid hold-up for any angle, ($H_{L(\theta)}$) can be obtained from equation 3.34

3.34

Where is the liquid holdup which would exist at the same conditions in a horizontal pipe and is calculated from equation 3.35

3.35

Where a, b, and c are determined for each flow pattern from Table 3.1

Table 3.1-Flow regimes defined for Beggs and Brill Correlation

Flow pattern	A	B	C
Segregated flow	0.98	0.4868	0.0868
Intermittent flow	0.845	0.5351	0.0173
Distributed flow	1.065	0.5824	0.0609

The correction factor for the holdup for the effect of pipe inclination, Ψ is given by

3.36

is the actual angle of the pipe measured from horizontal.

and

3.37

Where the liquid velocity number N_{LV} is given by equation 3.38

3.38

and

3.39

Each flow regime has a set of values corresponding to d’, e, f and g in equation 3.37 and these values are given in Table 3.2

Table 3.2-Flow regime correction coefficients.

Flow pattern	d’	e	f	G
Segregated uphill	0.011	-3.768	3.539	-1.614
Intermittent uphill	2.96	0.305	-0.4473	0.0978
Distributed uphill	No correction		C=0, Ψ=1, H_L	$f(\theta)$
All downhill flow patterns	4.70	-0.3692	0.1244	-0.5056

The gravitational component of the pressure gradient is given by equation 3.40

3.40

where

3.41

3.4 Friction component of the pressure gradient

The frictional component of the pressure gradient is given by equation 3.42

3.42

Where

The two phase friction factor is given by equation 3.43

3.43

where

3.44

and

3.45

The no-slip mixture density is given by equation 3.46

3.46

and the no-slip mixture viscosity is also given by equation 3.47

3.47

Where the no-slip liquid viscosity is given by equation 3.48

3.48

The no-slip friction factor is given by equation 3.49

3.49

where

3.50

3.51

and the Reynolds number is given by

3.52

The mixture flow rate is given by

3.53

3.5 Acceleration component of the pressure gradient

The acceleration term in the pressure gradient is very small except for high velocity flow. Thus it is not included in this calculation.

3.6The total pressure gradient

The total pressure gradient is calculated from equation 3.54

3.54

3.7. Sample Calculation.

The data used in this calculation is presented in Appendix A. This calculation is for liquid flowing at a rate of 4000 STB/day through a pipe of diameter 1.995 in. inclined at an angle of 70˚. The temperature of the produced fluid is assumed to be 175˚F. This computation is for fluid at atmospheric pressure.

The gas solubility in oil is given by equation 3.1

The gas solubility in water, R_{sw} is given by equation 3.2

From by equation 3.2,

Since the pressure under consideration is lower than the bubble pressure, then the free gas-liquid-ratio, GLR_{free}, is given by equation 3.6

The isothermal oil compressibility C_o as given by Vasquez and Beggs [14] in equation 3.8 is valid only for pressure above the bubble point, thus it is not applicable at this stage of the computation since the pressure under consideration is below the bubble pressure.
The oil formation volume factor B_o is given by equation 3.9 since the pressure is below the bubble point pressure.

Since the fluid pressure is lower than the bubble point pressure, the isothermal compressibility becomes negligible.
The water formation volume factor, B_w is given by equation 3.11since $P<P_b$

The gas deviation factor, Z is gotten from equation 3.13
The pseudo critical pressure and temperature are gotten from equations 3.16 and 3.17 respectively.

and

The pseudo reduced pressure and temperature are given by equations 3.15 and 3.14

and

The gas deviation factor is thus given by equation 3.13

At standard condition of temperature and pressure, the pseudo reduced temperature and pressure are calculated in the same way as was done for the fluid pressure as follows;

and

The gas deviation factor at standard temperature and pressure thus is

Gas formation volume factor B_g is given by

The gas density in Ibm/ ft^3 is given by

The oil density is given by

The water density is given by

The fluid flow rates are calculated as follows
The oil flow rate is given by

The water flow rate is given

And the gas flow rate is also given by

The superficial fluid velocities are given
Superficial oil velocity is

and

The mixture velocity thus is

The no-slip liquid and gas phase fractions are

The dead oil viscosity is given by

The oil viscosity is given by

The gas viscosity is calculated as follows.

Water viscosity

No slip liquid velocity

The mixture Froude number is given by equation 3.18

Flow pattern transition Froude numbers are given by equation 3.19 through 3.23

then the flow is distributed flow if it were in the horizontal direction. The liquid hold-up which would exist if the pipe were in horizontal direction is given by equation 3.35

From Table 3.1, the coefficients are; a = 1.065, b = 0.5824 and c = 0.0609

The liquid density is given by

The liquid velocity number is given by equation 3.52

The liquid holdup correction factor for the effect of pipe inclination, Ψ is unity for upward distributed flow, thus

The specific gravity of the mixture is

Gravitational component of the pressure gradient is given by equation 3.40

Frictional component of the pressure gradient is given by equation 3.42

Where

The no-slip mixture density is as follows

The no-slip mixture viscosity is given by

Reynolds number is given by

The mixture flow rate is given by

Total pressure drop is given by equation 3.54

The length of pipe in which the initial pressure step will be depleted is

The pipe length is the used to calculate the liquid hold-up and its corresponding pressure gradient for the next pressure increment of 5 psi.

CHAPTER 4

4.0 Analysis of Results

The Beggs and Brill correlation was programmed in Microsoft Excel and the result is plots of liquid hold-up against pipe length. These plots are presented in Appendices C, D and E. The data used for this work is presented in Appendix A whilst sample results are presented in Appendix B. A pressure increment of 5 psi was used to calculate the bottom hole flowing pressure until the pressure exceed 100 psi where it is changed to pressure steps of 50 psi.

The liquid flow rate used in the study range from 500 STB/day to 5000 STB/day in steps of 500 and the pipe inclination varied from -90˚ to 90˚. Three different pipe sizes were used for the study, namely 1.995, 2.441 and 2.992 inches.

A sample calculation is presented in Chapter 3 of this work with the following variables;

Pipe diameter	1.995 in
Liquid flow rate	4000 STB/day
Pipe inclination	70˚

4.1 Effect of Liquid Flow Rate on Liquid Hold-up

Fig 4.1.1 through Fig 4.1.7 in Appendix C are graphical presentation of the results of the computation for the upward flow of fluid at rate ranging from 500 to 5000STB/day through a 1.995 in. pipe. It is seen from these plots that the liquid hold-up increase with length for the entire range of flow rate studied. The graphs in this group exhibit a few disturbances between pipe lengths of 800 to 1200 ft.

Fig. 4.1.8 through Fig. 4.1.12 show graphically the results for the calculations for the downward flow through a pipe of diameter 1.995 in. for the entire range of liquid flow rates under consideration. This set of graphs show the liquid hold-up increase with pipe length but these plots do not exhibit the disturbances that was observed in the upward fluid flow plots in Fig. 4.1.8 through Fig. 4.1.12

Fig. 4.1.13 through Fig. 4.1.19 show the result of the calculation for the upward flow of fluid through a 2.992 in pipe for the range of flow rate being studied. The plots in this group exhibit similar trend as is seen in the plots in Fig. 4.1.1 through Fig. 4.1.7 for flow through the 1.995 in. pipe discussed earlier on but can be seen that the liquid hold-up recorded for the 2.992 in pipe flow is lower than the liquid flow rate recorded for the 1.995 in pipe flow.

Fig. 4.1.20 through Fig. 4.1.24 show the results of calculations for downward flow through 2.992 in. pipe for liquid flow rate spanning the range under consideration. This set of plots also exhibit trends that are very similar to the plots in Fig.4.1.8 through Fig. 4.1.12 for flow through 1.995 in pipe. It is observed that flow through the 1.995 in pipe record a higher liquid flow rate compared to the flow through the 2.992 in. pipe.

Fig.4.1.25 through Fig.4.1.31 and Fig.4.1.32 through Fig.4.1.36 show the plots of the results of the calculations for upward and downward flow of fluid at a rate ranging from 500 to 5000 STB/day through 2.441 in. pipe respectively. These plots exhibit the same trend as is observed in the flow through 1.995 and 2.992 in. pipes.

The liquid hold-up for each flow rate considered is observed to decrease at each pipe location as the pipe size increase from 1.995 in. through 2.441 in. to 2.992 in.

4.2 Effect of Pipe Inclination on Liquid Hold-up

Fig.4.2.1 through Fig. 4.2.10 show graphically, the result of computations for fluid flow ranging from 500 to 5000 STB/day through a 1.995 in. pipe of inclination ranging from downward 90˚ flow to upward 90˚ flow. It can be observed from this set of plots that the hold-up increase linearly with pipe length. The upward fluid flow records a higher liquid hold-up than the downward fluid flow at all locations in the pipe. The liquid hold-up at each pipe location for all pipe inclination considered is also observed to increase with increase in liquid flow rate. The curves for the various downward fluid flow studied tend to converge at low flow rates, but this correlation is broken as the liquid flow rate increase. This set of plots reveal that the upward 90˚ flow recorded the highest liquid hold-up whilst downward 90˚ fluid flow recorded the least liquid hold-up at every pipe location.

Fig.4.2.11 through Fig.4.2.20 show the result of the computation for flow through a 2.992 in. pipe at various inclination. The features observed in this set of plots are very similar to those in Fig.4.2.1 through Fig.4.2.10. The liquid hold-up at every pipe location is observed to increase with increase in liquid flow rate.

Fig. 4.2.21 through Fig.4.2.30, which is the result of computations for fluid flow through 2.441 in pipe for the range of pipe inclination and liquid flow rate under consideration also exhibit the same features that are observed in the result of the fluid flow through 1.995 and 2.992 in. pipes discussed earlier on.

It can be seen from these three set of plots that as the pipe size increase from 1.995 through 2.441 to 2.992 inches, the curves for the various pipe inclination tend to converge. At low flow rates, the liquid hold-up recorded for the three pipe sizes under consideration, at all locations along the pipe length is the same but at high flow rates, the liquid hold-up recorded decrease with increase in pipe size at all locations along the length of the pipe.

4.3 Effect of Pipe Diameter on Hold-up

Fig.4.3.1 through Fig.4.3.12 is graphical presentation of the result of computations for liquid flow rate of 500 STB/day and pipe inclinations ranging from downward 90˚ to upward 90˚ fluid flow, each plot showing the curves for the three pipe sizes under consideration. It is seen from this set of plots that as the pipe size increase from 1.995 to 2.992 in. the liquid hold-up decrease at each pipe location. It is also observed that the liquid hold-up increase as the pipe inclination increase from downward 90˚ to upward 90˚. The three curves for each plot tend to converge as the pipe inclination change from -90˚ to 90˚.

Fig.4.3.13 through Fig.4.3.24 is the plot of the result of computations for fluid flow at 1000 STB/day through the three pipe sizes being studied for the range of pipe inclination being studied. This set of graphs exhibit the same features as is seen Fig.4.3.1 through Fig.4.3.12 but the degree of convergence is observed to decrease in this set as compared to the previous.

Fig.4.3.25 through Fig.4.3.36 are the results for fluid flow at 1500 STB/day with all other variables same as is in the previous set discussed. Fig.4.3.37 through Fig.4.3.48 whilst Fig.4.3.49 through Fig.4.3.60 are the results of computations for flow at 2000 and 2500 STB/day spanning the entire range of pipe inclination and pipe size being studied.

The common trend observed in this last three set of graphs is an increase in the liquid hold-up recorded as the pipe orientation change from downward 90˚ to upward 90˚ for all three pipe size studied. The liquid hold-up is also observed to increase for the same liquid flow rate and pipe size as the pipe orientation change from downward 90˚ to upward 90˚. The convergence of the curves for the three pipe sizes being studied observed as the pie orientation approaches upward vertical for low fluid flow rates is not observed in these three set of plots.

Fig.4.3.61 through Fig.4.3.120 show plots of liquid flow rates ranging from 3000 to 5000 STB/day in steps of 500 for the three pipe sizes under consideration and for the entire range of pipe inclination being studied.

The liquid hold-up is observed to increase with increase in liquid flow rate at every pipe inclination and for all pipe sizes studied.

CHAPTER 5

5.0 Conclusions and Recommendations

5.1 Conclusions

Increasing liquid hold-up and flow velocity increase the gravitational and frictional components of the total pressure drop respectively, therefore;

1. The hold-up calculated from Beggs and Brill correlations for downward flow is less than for upward flow for same flowing conditions hence downward flow records a lower pressure drop compared to upward flow for the same flow conditions.
2. The total pressure loss increase with increasing liquid flow rate since liquid hold-up is observed to increase with increasing liquid flow rate for all flow conditions studied.
3. An increase in the pipe diameter is observed to result in a decrease in the liquid hold-up calculated and the total pressure loss.

5.2 Recommendations

This study should be expanded and refined to generate results for the pipe sizes between 2 7/8 to 4 ½ in. that were not included in this study. Laboratory experiments should be conducted considering slippage and for various flow regimes. The results of the experiment should be compared with the generated results from Beggs and Brill correlation. The accuracy of the Beggs and Brill correlation can then be established for various combinations of liquid flow rate, pipe size and pipe inclination studied.

REFERENCE

1. Zhao Xiadong.: “Mechanistic-based models for slug flow in vertical pipes,” PhD thesis, Texas Tech University, 2005.
2. *Rao Bharath.:”*Multiphase Flow Models Range of Applicability,*”* CTES, L.C, (May 18, 1998).
3. Zabaras G.J..: “Physical Modelling of Vertical Multiphase Flow: Prediction of Pressure Gradients in Oil and Gas Wells,” 28th Annual OTC in Houston, Texas, OTC 7515, (2-5 May 1994).
4. Olufemi Adekomaya, Fadairo A.S. Adesina and Falode Olugbenga.: “Predictive tool for bottom-hole pressure in multiphase flowing wells,” Petroleum & Coal ISSN 1337-7027(September 5, 2008).
5. Brill J.P. and H. Mukherjee.:”Multiphase Flow in Wells,” Monograph Volume 17, SPE Henry L. Doherty Series, (1999).
6. Prado M..: “Two Phase Flow,” Lecture delivered at African University of Science and Technology, Nigeria (2008).
7. Carrascal J. F..: “Multiphase Flow Application to ESP Pump Design Program,” MS Thesis, Texas Tech University, (May 1996).
8. Brown K.E. and H.D. Beggs.: “The Technology of Artificial Lift Methods,” Volume I, Penn Well Publishing Company, Tulsa, Oklahoma (1977).
9. Beggs H.D and P.P Brill.:”A Study of Two Phase Flow in Inclined Pipes,” SPE 4007, JPT, May 1973.
10. Duns, H., Jr. and Ros, N. C. J.: “Vertical Flow of Gas and Liquid Mixtures in Wells”,. Proc. Sixth World Pet. Congress, Frankfurt (Jun. 19-26, 1963) Section II, Paper 22-PD6.
11. Hagedorn, A. R. and Brown, K. E.: “Experimental Study of Pressure Gradients Occurring During Continuous Two-Phase Flow in Small Diameter Vertical Conduits”, J. Pet. Tech. (Apr. 1965) 475-484.
12. Orkiszewski, J.: “Predicting Two-Phase Pressure Drops in Vertical Pipe”, J. Pet. Tech. (Jun. 1967) 829-838.
13. Standing, M.B.:”A Pressure-Volume-Temperature Correlation for Mixtures of Califonia Oil and Gas”, Drilling and Production Practice, API (1947) 275-87.
14. Vasquez, M.E. and Beggs, H.D.:”Correlations for Fluid Physical Property Prediction,” JPT (June 1980), 968-70.

15. Ahmed Tarek,:"Reservoir Engineering Handbook", Second Edition, Gulf Publishing Company, Houston (2000).
16. Hernandez F. and J.P. Brill.:"Comparison of friction factor correlations for gas-liquid flow in horizontal pipes," SPE 4691, AIME, 1973.
17. Chierici G.L., G.M. Ciucci and G. Sclocchi.:"Two Phase Flow in Oil Wells-Prediction of Pressure Drop," SPE 4316, JPT,August 1974.
18. Messulam S.A.G.:"Comparison of Correlations for Predicting Multiphase Flowing Pressure Losses in Vertical Pipes," MS Thesis, The University of Tulsa (1970)
19. Payne G.A., C.M. Palmer, J.P. Brill and H.D. Beggs.:"Evaluation of Inclined-Pipe, Two-Phase Liquid Holdup and Pressure-Loss Correlations Using Experimental Data," SPE 6874, JPT September 1979, pages 1198-1208.
20. Camacho C.A..''Comparison of Correlations for Predicting Pressure Losses in High Gas-Liquid Ratio Vertical Wells," MS Thesis, the University of Tulsa (1970).
21. Espanol Jose H..:"Comparison of Three Methods for Calculating A Pressure Traverse in Vertical Multiphase Flow," MS Thesis The University of Tulsa (1968).
22. Hasan A. Rashid and C. Shah Kabir.:"A Study of Multiphase Flow Behaviour in Vertical Wells," SPE 15138, SPE Production Engineering, May 1988.
23. Hasan A. Rashid and C. Shah Kabir,.:"Predicting Multiphase Flow Behaviour in Deviated Wells," SPE 15449, SPE Production Engineering, November 1988.
24. Fuentes Alvaro J..: "A Study of the Multiphase-Flow Phenomena in Directional Wells," MS Thesis, The University of Tulsa (1968)
25. Baxendell P.B..: "The Calculation of Pressure Gradients in High-Rate Flowing Wells," SPE 2, JPT, October 1961, pages 1023-1028.
26. Aziz Khalid, G.W Govier and M.Fogarasi.: "Pressure Drop in Wells Producing Oil and Gas," JCPT, July-September 1972, Montreal, pages 38-45.
27. Salim P.H and J.F Stanislav.: "Evaluation of Methods Describing the Flow of Gas-Liquid Mixture in Wells," JCPT, February 1994, Vol 33, No. 2
28. Yuan H. and D. Zhou,: "Evaluation of two-phase flow correlations and Mechanistic models for pipelines at inclined downward flow," SPE 117395, SPE Eastern Region, October 2008.

NOMENCLATURE

= in-situ liquid flow rate

= the in-situ gas flow rate

A_p = flow area of pipe

ρ = average fluid density

ΔP = pressure drop

p = average pressure

W_t = total mass flow rate

X_f = friction loss gradient

q_g = gas volumetric flow rate

q_t = total volumetric flow rate

Δh= depth change

θ = the angle of the pipe from the horizontal,

d_z = the axial distance moved,

G_m = mixture mass flow rate

G_G= gas mass flow rate

G_L= liquid mass flow rate

V_m = the mixture velocity

q_L = in-situ liquid velocity

q_g = in-situ gas velocity

f_{tp}= Friction factor for two phase flow

H_L= liquid hold-up

H_G= gas hold-up

V_{SL}= superficial liquid velocity

V_{SG}= superficial gas velocity

dp= pipe diameter

APPENDIX A

The data used in this work.

Table 3.1.1 Data used for this study [12]

APPENDIX B

Table of Sample results.

Table 3.2.1 Sample result for dp=1.995 in and GLR=500 STB/day

θ= -90	θ= -70	θ= -50	θ= -30				
Length (ft)	Hold-up	Length (ft)	Hold-up	Length (ft)	Hold-up	Length (ft)	Hold-up
0	0.004799	0	0.004799	0	0.004799	0	0.004799
5.593453	0.006433	5.59264	0.006433	5.5903	0.006433	5.586718	0.006433
12.21991	0.008069	12.21756	0.008069	12.21082	0.008069	12.20051	0.008069
19.782	0.009706	19.77716	0.009706	19.76324	0.009706	19.74194	0.009706
28.25754	0.011345	28.24893	0.011345	28.22415	0.011345	28.18629	0.011345
37.66666	0.012985	37.65261	0.012985	37.61222	0.012985	37.55053	0.012985
48.05351	0.014626	48.03188	0.014626	47.96972	0.014626	47.87487	0.014626
59.47584	0.016268	59.44389	0.016268	59.35213	0.016268	59.2122	0.016268
71.99917	0.017912	71.95342	0.017912	71.8221	0.017912	71.62206	0.017912
85.69336	0.019557	85.62945	0.019557	85.44612	0.019557	85.16716	0.019557
100.6308	0.021204	100.5433	0.021204	100.2925	0.021204	99.91133	0.021204
116.8854	0.022852	116.7677	0.022852	116.4304	0.022852	115.9185	0.022852
134.5323	0.024501	134.3762	0.024501	133.9292	0.024501	133.2518	0.024501
153.6477	0.026152	153.4432	0.026152	152.8584	0.026152	151.9739	0.026152
174.3087	0.027804	174.044	0.027804	173.2879	0.027804	172.1462	0.027804
196.5943	0.029458	196.2552	0.029458	195.2875	0.029458	193.8293	0.029458
220.5852	0.031113	220.1547	0.031113	218.9279	0.031113	217.0834	0.031113
246.3643	0.032769	245.8226	0.032769	244.2805	0.032769	241.9678	0.032769
274.0176	0.034427	273.3411	0.034427	271.4181	0.034427	268.5419	0.034427
303.6346	0.036086	302.7957	0.036086	300.415	0.036086	296.8646	0.036086
335.3086	0.037747	334.2753	0.037747	331.3478	0.037747	326.9955	0.037747
369.1383	0.039409	367.8731	0.039409	364.2955	0.039409	358.9945	0.039409

730.0306	0.056105	726.0133	0.056105	714.7408	0.056105	698.2715	0.056105
1230.031	0.068763	1226.013	0.069018	1214.741	0.069753	1198.271	0.07088
1730.031	0.076712	1726.013	0.077204	1714.741	0.078634	1698.271	0.080873
2230.031	0.082414	2226.013	0.083132	2214.741	0.085244	2198.271	0.088612
2730.031	0.086724	2726.013	0.087657	2714.741	0.090431	2698.271	0.094935
3230.031	0.090076	3226.013	0.091213	3214.741	0.094622	3198.271	0.100254
3730.031	0.09273	3726.013	0.094057	3714.741	0.098071	3698.271	0.104813
4230.031	0.094858	4226.013	0.09636	4214.741	0.100945	4198.271	0.108771
4730.031	0.096577	4726.013	0.098242	4714.741	0.103362	4698.271	0.11224
5230.031	0.097976	5226.013	0.099788	5214.741	0.105408	5198.271	0.115302
5730.031	0.09912	5726.013	0.101066	5714.741	0.10715	5698.271	0.11802
6230.031	0.100058	6226.013	0.102127	6214.741	0.108638	6198.271	0.120445
6730.031	0.10083	6726.013	0.103009	6714.741	0.109915	6698.271	0.122615

Table 3.2.2 Sample result for dp=1.995 in and GLR=1000 STB/day

θ= -90	θ= -70	θ= -50	θ= -30				
Length (ft)	Hold-up	Length (ft)	Hold-up	Length (ft)	Hold-up	Length (ft)	Hold-up
0	0.004799	0	0.004799	0	0.004799	0	0.004799
1.413599	0.006433	1.413547	0.006433	1.413397	0.006433	1.413168	0.006433
3.090042	0.008069	3.089892	0.008069	3.089461	0.008069	3.0888	0.008069
5.004707	0.009706	5.004397	0.009706	5.003504	0.009706	5.002137	0.009706
7.151743	0.011345	7.15119	0.011345	7.1496	0.011345	7.147166	0.011345
9.535792	0.012985	9.534891	0.012985	9.532296	0.012985	9.528324	0.012985
12.16733	0.014626	12.16594	0.014626	12.16194	0.014626	12.15583	0.014626
15.05997	0.016268	15.05792	0.016268	15.05202	0.016268	15.04299	0.016268
18.22898	0.017912	18.22604	0.017912	18.2176	0.017912	18.20468	0.017912
21.69028	0.019557	21.68619	0.019557	21.67441	0.019557	21.65639	0.019557
25.46003	0.021204	25.45443	0.021204	25.43833	0.021204	25.4137	0.021204
29.55422	0.022852	29.5467	0.022852	29.52507	0.022852	29.49201	0.022852
33.98856	0.024501	33.97861	0.024501	33.94999	0.024501	33.90628	0.024501
38.77836	0.026152	38.76537	0.026152	38.72803	0.026152	38.671	0.026152
43.93851	0.027804	43.92176	0.027804	43.87361	0.027804	43.80012	0.027804
49.48349	0.029458	49.46212	0.029458	49.40071	0.029458	49.30703	0.029458
55.42735	0.031113	55.40036	0.031113	55.32282	0.031113	55.20459	0.031113
61.78376	0.032769	61.74998	0.032769	61.65298	0.032769	61.50515	0.032769
68.56606	0.034427	68.52414	0.034427	68.40381	0.034427	68.22056	0.034427
75.78728	0.036086	75.73566	0.036086	75.58757	0.036086	75.3622	0.036086
83.46018	0.037747	83.3971	0.037747	83.21619	0.037747	82.94108	0.037747
91.59734	0.039409	91.52078	0.039409	91.30129	0.039409	90.96778	0.039409
177.7354	0.056105	177.5012	0.056105	176.8308	0.056105	175.8156	0.056105
318.2999	0.072937	317.47	0.072937	315.1127	0.072937	311.5903	0.072937
526.954	0.089899	524.4275	0.089899	517.3352	0.089899	506.9645	0.089899

822.5821	0.106981	815.8893	0.106981	797.4311	0.106981	771.2694	0.106981
1235.252	0.124173	1219.003	0.124173	1175.346	0.124173	1116.155	0.124173
1735.252	0.138989	1719.003	0.139565	1675.346	0.141226	1557.394	0.141462
2235.252	0.14966	2219.003	0.150738	2175.346	0.153881	2057.394	0.156968
2735.252	0.157758	2719.003	0.159293	2675.346	0.163816	2557.394	0.16952
3235.252	0.164079	3219.003	0.166034	3175.346	0.171852	3057.394	0.180031
3735.252	0.169102	3719.003	0.171443	3675.346	0.178476	3557.394	0.189017
4235.252	0.17314	4219.003	0.175835	4175.346	0.184005	4057.394	0.196809
4735.252	0.176416	4719.003	0.179433	4675.346	0.188665	4557.394	0.203633
5235.252	0.179089	5219.003	0.182401	5175.346	0.192618	5057.394	0.209657
5735.252	0.181281	5719.003	0.18486	5675.346	0.195991	5557.394	0.215006
6235.252	0.183086	6219.003	0.186906	6175.346	0.198881	6057.394	0.219779
6735.252	0.184575	6719.003	0.188613	6675.346	0.201365	6557.394	0.224055
7235.252	0.185808	7219.003	0.190042	7175.346	0.203506	7057.394	0.227898
7735.252	0.186831	7719.003	0.191239	7675.346	0.205357	7557.394	0.231362
8235.252	0.187679	8219.003	0.192245	8175.346	0.206959	8057.394	0.234491
8735.252	0.188385	8719.003	0.19309	8675.346	0.208349	8557.394	0.237323

Table 3.2.3 Sample result for dp=1.995 in and GLR=1500 STB/day

θ= -90	θ= -70	θ= -50	θ= -30				
Length (ft)	Hold-up	Length (ft)	Hold-up	Length (ft)	Hold-up	Length (ft)	Hold-up
0	0.004799	0	0.004799	0	0.004799	0	0.004799
0.630952	0.006433	0.630941	0.006433	0.630912	0.006433	0.630866	0.006433
1.379672	0.008069	1.379642	0.008069	1.379556	0.008069	1.379425	0.008069
2.235245	0.009706	2.235183	0.009706	2.235005	0.009706	2.234732	0.009706
3.195107	0.011345	3.194997	0.011345	3.19468	0.011345	3.194193	0.011345
4.261366	0.012985	4.261186	0.012985	4.260667	0.012985	4.259873	0.012985
5.438	0.014	5.438	0.014	5.437	0.014	5.436	0.014

711	626	434	626	635	626	411	626
6.733227	0.016268	6.732817	0.016268	6.731636	0.016268	6.729828	0.016268
8.151695	0.017912	8.151108	0.017912	8.149417	0.017912	8.146828	0.017912
9.701184	0.019557	9.700364	0.019557	9.698004	0.019557	9.69439	0.019557
11.38881	0.021204	11.38769	0.021204	11.38446	0.021204	11.37952	0.021204
13.22161	0.022852	13.2201	0.022852	13.21576	0.022852	13.20913	0.022852
15.20642	0.024501	15.20442	0.024501	15.19868	0.024501	15.18991	0.024501
17.34986	0.026152	17.34726	0.026152	17.33977	0.026152	17.32832	0.026152
19.65834	0.027804	19.65499	0.027804	19.64533	0.027804	19.63056	0.027804
22.13799	0.029458	22.13371	0.029458	22.1214	0.029458	22.10257	0.029458
24.79471	0.031113	24.7893	0.031113	24.77376	0.031113	24.75	0.031113
27.63415	0.032769	27.62739	0.032769	27.60795	0.032769	27.57824	0.032769
30.66177	0.034427	30.65339	0.034427	30.62929	0.034427	30.59246	0.034427
33.88279	0.036086	33.87248	0.036086	33.84283	0.036086	33.79755	0.036086
37.30225	0.037747	37.28966	0.037747	37.25347	0.037747	37.19821	0.037747
40.92503	0.039409	40.90976	0.039409	40.86589	0.039409	40.79892	0.039409
79.23289	0.056105	79.1864	0.056105	79.05291	0.056105	78.84946	0.056105
140.6807	0.072937	140.5201	0.072937	140.0605	0.072937	139.3641	0.072937
229.1779	0.089899	228.7106	0.089899	227.3798	0.089899	225.3814	0.089899
348.8233	0.106981	347.6679	0.106981	344.399	0.106981	339.5509	0.106981
504.6035	0.124173	502.0664	0.124173	494.9526	0.124173	484.5716	0.124173
703.1077	0.141462	697.9821	0.141462	683.7781	0.141462	663.4775	0.141462
953.5133	0.158836	943.7296	0.158836	917.032	0.158836	879.8759	0.158836
1269.199	0.176281	1251.181	0.176281	1203.005	0.176281	1138.2	0.176281
1670.699	0.193782	1638.082	0.193782	1553.237	0.193782	1444.024	0.193782
2170.699	0.210614	2132.554	0.211323	1984.405	0.211323	1804.491	0.211323
2670.699	0.223297	2632.554	0.224828	2484.405	0.227667	2228.938	0.22889
3170.699	0.233168	3132.554	0.235423	2984.405	0.240737	2728.938	0.246433
3670.699	0.241005	3632.554	0.243909	3484.405	0.251439	3228.938	0.261213
4170.699	0.247312	4132.554	0.2508	3984.405	0.260341	3728.938	0.273903

4670.699	0.252436	4632.554	0.256452	4484.405	0.267827	4228.938	0.284944
5170.699	0.256629	5132.554	0.261122	4984.405	0.274176	4728.938	0.294644
5670.699	0.260078	5632.554	0.265002	5484.405	0.279595	5228.938	0.303231
6170.699	0.262927	6132.554	0.268241	5984.405	0.284243	5728.938	0.310876
6670.699	0.265289	6632.554	0.270953	6484.405	0.288247	6228.938	0.317718
7170.699	0.267251	7132.554	0.273231	6984.405	0.291708	6728.938	0.323864

Table 3.2.4 Sample result for dp=2.992 in and GLR=500 STB/day

θ= -90	θ= -70	θ= -50	θ= -30				
Length (ft)	Hold-up	Length (ft)	Hold-up	Length (ft)	Hold-up	Length (ft)	Hold-up
0	0.004799	0	0.004799	0	0.004799	0	0.004799
42.62371	0.006433	42.57653	0.006433	42.44127	0.006433	42.2357	0.006433
93.50057	0.008069	93.36335	0.008069	92.97059	0.008069	92.37554	0.008069
152.101	0.009706	151.8141	0.009706	150.9945	0.009706	149.7575	0.009706
218.5178	0.011345	217.9998	0.011345	216.5238	0.011345	214.3059	0.011345
293.243	0.012985	292.3835	0.012985	289.9416	0.012985	286.2914	0.012985
377.0561	0.014626	375.7057	0.014626	371.8816	0.014626	366.2008	0.014626
470.9765	0.016268	468.9328	0.016268	463.1685	0.016268	454.6668	0.016268
576.258	0.017912	573.2472	0.017912	564.7948	0.017912	552.4334	0.017912
694.4141	0.019557	690.0652	0.019557	677.9238	0.019557	660.3415	0.019557
827.272	0.021204	821.0808	0.021204	803.9093	0.021204	779.3279	0.021204
977.0581	0.022852	968.3362	0.022852	944.3333	0.022852	910.4336	0.022852
1146.526	0.024501	1134.327	0.024501	1101.062	0.024501	1054.82	0.024501
1339.149	0.026152	1322.154	0.026152	1276.326	0.026152	1213.793	0.026152
1559.401	0.027804	1535.752	0.027804	1472.829	0.027804	1388.832	0.027804
1813.208	0.029458	1780.227	0.029458	1693.903	0.029458	1581.632	0.029458
2108.658	0.031113	2062.398	0.031113	1943.74	0.031113	1794.157	0.031113
2457.	0.032	2391.	0.032	2227.	0.032	2028.	0.032

235	769	667	769	718	769	706	769
2876.032	0.034427	2781.539	0.034427	2552.918	0.034427	2288.007	0.034427
3376.032	0.036034	3252.437	0.036086	2928.94	0.036086	2575.336	0.036086
3876.032	0.037302	3752.437	0.037505	3369.269	0.037747	2894.682	0.037747
4376.032	0.038315	4252.437	0.038647	3869.269	0.039331	3250.986	0.039409
4876.032	0.039133	4752.437	0.039576	4369.269	0.040644	3750.986	0.041491
5376.032	0.039797	5252.437	0.040337	4869.269	0.041744	4250.986	0.043281
5876.032	0.04034	5752.437	0.040963	5369.269	0.042672	4750.986	0.044837
6376.032	0.040785	6252.437	0.041482	5869.269	0.043459	5250.986	0.046202
6876.032	0.041151	6752.437	0.041913	6369.269	0.04413	5750.986	0.047406
7376.032	0.041453	7252.437	0.042272	6869.269	0.044704	6250.986	0.048474
7876.032	0.041702	7752.437	0.042572	7369.269	0.045196	6750.986	0.049426
8376.032	0.041909	8252.437	0.042822	7869.269	0.04562	7250.986	0.050277
8876.032	0.04208	8752.437	0.043032	8369.269	0.045985	7750.986	0.05104
9376.032	0.042222	9252.437	0.043208	8869.269	0.0463	8250.986	0.051726
9876.032	0.04234	9752.437	0.043356	9369.269	0.046573	8750.986	0.052344
10376.03	0.042438	10252.44	0.04348	9869.269	0.046808	9250.986	0.052902
10876.03	0.04252	10752.44	0.043584	10369.27	0.047013	9750.986	0.053406
11376.03	0.042587	11252.44	0.043672	10869.27	0.04719	10250.99	0.053863
11876.03	0.042644	11752.44	0.043746	11369.27	0.047344	10750.99	0.054277
12376.03	0.042691	12252.44	0.043808	11869.27	0.047478	11250.99	0.054652
12876.03	0.04273	12752.44	0.043861	12369.27	0.047594	11750.99	0.054993
13376.03	0.042763	13252.44	0.043905	12869.27	0.047695	12250.99	0.054941
13876.03	0.04279	13752.44	0.043942	13369.27	0.047783	12750.99	0.054792
14376.03	0.042812	14252.44	0.043973	13869.27	0.047859	13250.99	0.054644
16876.03	0.04288	16752.44	0.04407	16369.27	0.048116	15750.99	0.053893

Table 3.2.5 Sample result for dp=2.992 in and GLR=1000 STB/day

θ= -90	θ= -70	θ= -50	θ= -30

Length (ft)	Hold-up	Length (ft)	Hold-up	Length (ft)	Hold-up	Length (ft)	Hold-up
0	0.004799	0	0.004799	0	0.004799	0	0.004799
10.69875	0.006433	10.69578	0.006433	10.68722	0.006433	10.67414	0.006433
23.40271	0.008069	23.39412	0.008069	23.3694	0.008069	23.33164	0.008069
37.93649	0.009706	37.91867	0.009706	37.86745	0.009706	37.78928	0.009706
54.26951	0.011345	54.23768	0.011345	54.14626	0.011345	54.00686	0.011345
72.45451	0.012985	72.40239	0.012985	72.25278	0.012985	72.02498	0.012985
92.59327	0.014626	92.51267	0.014626	92.28153	0.014626	91.93008	0.014626
114.8175	0.016268	114.6979	0.016268	114.3551	0.016268	113.8347	0.016268
139.2782	0.017912	139.106	0.017912	138.6131	0.017912	137.8663	0.017912
166.1402	0.019557	165.8982	0.019557	165.2064	0.019557	164.1606	0.019557
195.5791	0.021204	195.2457	0.021204	194.2938	0.021204	192.8582	0.021204
227.7807	0.022852	227.3288	0.022852	226.0404	0.022852	224.1027	0.022852
262.9411	0.024501	262.3369	0.024501	260.6176	0.024501	258.0399	0.024501
301.2675	0.026152	300.4697	0.026152	298.2033	0.026152	294.8174	0.026152
342.9807	0.027804	341.9382	0.027804	338.9831	0.027804	334.5852	0.027804
388.3167	0.029458	386.9672	0.029458	383.1509	0.029458	377.4958	0.029458
437.5295	0.031113	435.7972	0.031113	430.9113	0.031113	423.7053	0.031113
490.8952	0.032769	488.6881	0.032769	482.4811	0.032769	473.3742	0.032769
548.7151	0.034427	545.9217	0.034427	538.0912	0.034427	526.6683	0.034427
611.321	0.036086	607.8066	0.036086	597.9899	0.036086	583.7597	0.036086
679.0807	0.037747	674.6826	0.037747	662.4452	0.037747	644.8284	0.037747
752.4049	0.039409	746.9263	0.039409	731.7484	0.039409	710.0635	0.039409
1252.405	0.049913	1246.926	0.050091	1231.748	0.050604	1210.063	0.051389
1752.405	0.056198	1746.926	0.056545	1731.748	0.057554	1710.063	0.059133
2252.405	0.060624	2246.926	0.061135	2231.748	0.062636	2210.063	0.065028
2752.405	0.063933	2746.926	0.0646	2731.748	0.066581	2710.063	0.069795
3252.405	0.066486	3246.926	0.067301	3231.748	0.069744	3210.063	0.073774
3752.405	0.068494	3746.926	0.069448	3731.748	0.072331	3710.063	0.077166
4252.	0.070	4246.	0.071	4231.	0.074	4210.	0.080

405	095	926	177	748	476	063	097
4752.405	0.071383	4746.926	0.072583	4731.748	0.076271	4710.063	0.082655
5252.405	0.072426	5246.926	0.073734	5231.748	0.077785	5210.063	0.084905
5752.405	0.073275	5746.926	0.074681	5731.748	0.079069	5710.063	0.086897
6252.405	0.07397	6246.926	0.075464	6231.748	0.080163	6210.063	0.088668
6752.405	0.074539	6746.926	0.076113	6731.748	0.081098	6710.063	0.090248
7252.405	0.075007	7246.926	0.076652	7231.748	0.0819	7210.063	0.091664
7752.405	0.075392	7746.926	0.077102	7731.748	0.082589	7710.063	0.092936
8252.405	0.07571	8246.926	0.077476	8231.748	0.083182	8210.063	0.09408
8752.405	0.075972	8746.926	0.07779	8731.748	0.083693	8710.063	0.095112
9252.405	0.076189	9246.926	0.078051	9231.748	0.084135	9210.063	0.096045
9752.405	0.076368	9746.926	0.078271	9731.748	0.084517	9710.063	0.096889
10252.4	0.076517	10246.93	0.078454	10231.75	0.084848	10210.06	0.097654

Table 3.2.6 Sample result for dp=2.992 in and GLR=1500 STB/day

θ= -90	θ= -70	θ= -50	θ= -30				
Length (ft)	Hold-up	Length (ft)	Hold-up	Length (ft)	Hold-up	Length (ft)	Hold-up
0	0.004799	0	0.004799	0	0.004799	0	0.004799
4.773823	0.006433	4.773231	0.006433	4.771526	0.006433	4.768917	0.006433
10.44013	0.008069	10.43842	0.008069	10.4335	0.008069	10.42596	0.008069
16.91807	0.009706	16.91452	0.009706	16.90433	0.009706	16.88873	0.009706
24.19057	0.011345	24.18425	0.011345	24.16606	0.011345	24.13826	0.011345
32.27663	0.012985	32.26629	0.012985	32.23657	0.012985	32.19115	0.012985
41.21573	0.014626	41.19978	0.014626	41.15393	0.014626	41.08391	0.014626
51.05898	0.016268	51.03536	0.016268	50.96751	0.016268	50.86397	0.016268
61.86409	0.017912	61.8302	0.017912	61.73288	0.017912	61.58451	0.017912
73.69244	0.019557	73.645	0.019557	73.50884	0.019557	73.30146	0.019557
86.60746	0.021204	86.54239	0.021204	86.35574	0.021204	86.07176	0.021204
100.6738	0.022852	100.5861	0.022852	100.3346	0.022852	99.95236	0.022852
115.9568	0.024501	115.8403	0.024501	115.5064	0.024501	114.9997	0.024501
132.5227	0.026152	132.3698	0.026152	131.9323	0.026152	131.2694	0.026152
150.4382	0.027804	150.24	0.027804	149.6734	0.027804	148.8162	0.027804
169.7711	0.029458	169.5169	0.029458	168.7907	0.029458	167.694	0.029458
190.5903	0.031113	190.2673	0.031113	189.3455	0.031113	187.9562	0.031113
212.9666	0.032769	212.5597	0.032769	211.3997	0.032769	209.6553	0.032769
236.9725	0.034427	236.4639	0.034427	235.016	0.034427	232.8436	0.034427
262.6829	0.036086	262.0519	0.036086	260.2579	0.036086	257.5731	0.036086
290.1758	0.037747	289.3982	0.037747	287.1906	0.037747	283.8958	0.037747
319.5327	0.039409	318.5803	0.039409	315.881	0.039409	311.8641	0.039409
632.5942	0.056105	629.5688	0.056105	621.0509	0.056105	608.53	0.056105
1132.594	0.070881	1129.569	0.071137	1121.051	0.071873	1106.657	0.072937
1632.594	0.079685	1629.569	0.080183	1621.051	0.081631	1606.657	0.083852

2132.594	0.085897	2129.569	0.08663	2121.051	0.088784	2106.657	0.092184
2632.594	0.090551	2629.569	0.091508	2621.051	0.094352	2606.657	0.098938
3132.594	0.094148	3129.569	0.095318	3121.051	0.098826	3106.657	0.104592
3632.594	0.096983	3629.569	0.098352	3621.051	0.102492	3606.657	0.109419
4132.594	0.099246	4129.569	0.100799	4121.051	0.105536	4106.657	0.113599
4632.594	0.10107	4629.569	0.102792	4621.051	0.108089	4606.657	0.117253
5132.594	0.102548	5129.569	0.104425	5121.051	0.110245	5106.657	0.120471
5632.594	0.103754	5629.569	0.105772	5621.051	0.112076	5606.657	0.123324
6132.594	0.10474	6129.569	0.106885	6121.051	0.113637	6106.657	0.125863
6632.594	0.10555	6629.569	0.10781	6621.051	0.114973	6606.657	0.128132
7132.594	0.106216	7129.569	0.108579	7121.051	0.116121	7106.657	0.130167
7632.594	0.106765	7629.569	0.10922	7621.051	0.117107	7606.657	0.131996
8132.594	0.107218	8129.569	0.109756	8121.051	0.117958	8106.657	0.133645
8632.594	0.107593	8629.569	0.110204	8621.051	0.118692	8606.657	0.135133
9132.594	0.107903	9129.569	0.110579	9121.051	0.119327	9106.657	0.136478
9632.594	0.10816	9629.569	0.110893	9621.051	0.119876	9606.657	0.137697

Table 3.2.7 Sample result for dp=2.441 in and GLR=500 STB/day

θ= -90	θ= -70	θ= -50	θ= -30				
Length (ft)	Hold-up	Length (ft)	Hold-up	Length (ft)	Hold-up	Length (ft)	Hold-up
0	0.004799	0	0.004799	0	0.004799	0	0.004799
15.32279	0.006433	15.31669	0.006433	15.29915	0.006433	15.27235	0.006433
33.50459	0.008069	33.48697	0.008069	33.43637	0.008069	33.35914	0.008069
54.29647	0.009706	54.25998	0.009706	54.15521	0.009706	53.99555	0.009706
77.65942	0.011345	77.59428	0.011345	77.40738	0.011345	77.12302	0.011345
103.6764	0.012985	103.5698	0.012985	103.2641	0.012985	102.7998	0.012985
132.5039	0.014626	132.3389	0.014626	131.8667	0.014626	131.1509	0.014626
164.3452	0.016268	164.1001	0.016268	163.3995	0.016268	162.3402	0.016268
199.4361	0.017912	199.083	0.017912	198.0748	0.017912	196.5546	0.017912
238.0384	0.019557	237.5413	0.019557	236.1246	0.019557	233.9952	0.019557
280.4364	0.021204	279.75	0.021204	277.7973	0.021204	274.8724	0.021204
326.9381	0.022852	326.0049	0.022852	323.356	0.022852	319.4043	0.022852
377.8767	0.024501	376.6246	0.024501	373.0797	0.024501	367.8151	0.024501
433.6146	0.026152	431.9538	0.026152	427.2647	0.026152	420.3361	0.026152
494.549	0.027804	492.3674	0.027804	486.2275	0.027804	477.2064	0.027804
561.118	0.029458	558.2767	0.029458	550.3081	0.029458	538.6741	0.029458
633.8096	0.031113	630.1363	0.031113	619.8748	0.031113	604.9985	0.031113
713.1718	0.032769	708.4529	0.032769	695.3291	0.032769	676.4519	0.032769
799.8254	0.034427	793.7964	0.034427	777.1124	0.034427	753.3221	0.034427
894.4803	0.036086	886.8129	0.036086	865.713	0.036086	835.9154	0.036086
997.9557	0.037747	988.2415	0.037747	961.6757	0.037747	924.5594	0.037747
1111.207	0.039409	1098.935	0.039409	1065.612	0.039409	1019.607	0.039409
1611.207	0.046116	1598.935	0.046294	1565.612	0.046805	1519.607	0.047589
2111.207	0.050633	2098.935	0.050969	2065.612	0.051947	2019.607	0.053476
2611.207	0.053945	2598.935	0.054428	2565.612	0.05585	2519.607	0.058117

3111.207	0.056472	3098.935	0.057093	3065.612	0.058939	3019.607	0.061936
3611.207	0.058448	3598.935	0.059197	3565.612	0.061445	3519.607	0.06516
4111.207	0.060016	4098.935	0.060885	4065.612	0.063512	4019.607	0.067928
4611.207	0.061275	4598.935	0.062253	4565.612	0.065236	4519.607	0.070332
5111.207	0.062293	5098.935	0.06337	5065.612	0.066686	5019.607	0.07244
5611.207	0.063121	5598.935	0.064289	5565.612	0.067914	5519.607	0.0743
6111.207	0.063797	6098.935	0.065048	6065.612	0.068958	6019.607	0.07595
6611.207	0.064352	6598.935	0.065677	6565.612	0.069849	6519.607	0.07742
7111.207	0.064808	7098.935	0.0662	7065.612	0.070613	7019.607	0.078736
7611.207	0.065184	7598.935	0.066635	7565.612	0.07127	7519.607	0.079916
8111.207	0.065494	8098.935	0.066999	8065.612	0.071835	8019.607	0.080977
8611.207	0.06575	8598.935	0.067302	8565.612	0.072322	8519.607	0.081933
9111.207	0.065962	9098.935	0.067557	9065.612	0.072743	9019.607	0.082797
9611.207	0.066137	9598.935	0.06777	9565.612	0.073107	9519.607	0.083578
10111.21	0.066283	10098.94	0.067948	10065.61	0.073422	10019.61	0.084285
10611.21	0.066404	10598.94	0.068098	10565.61	0.073695	10519.61	0.084927

Table 3.2.8 Sample result for dp=2.441 in and GLR=1000 STB/day

θ= -90	θ= -70	θ= -50	θ= -30				
Length (ft)	Hold-up	Length (ft)	Hold-up	Length (ft)	Hold-up	Length (ft)	Hold-up
0	0.004799	0	0.004799	0	0.004799	0	0.004799
3.869241	0.006433	3.868852	0.006433	3.867732	0.006433	3.866017	0.006433
8.458466	0.008069	8.457343	0.008069	8.454111	0.008069	8.449165	0.008069
13.70109	0.009706	13.69876	0.009706	13.69207	0.009706	13.68184	0.009706
19.58217	0.011345	19.57803	0.011345	19.56611	0.011345	19.54789	0.011345
26.11586	0.012985	26.10909	0.012985	26.08964	0.012985	26.05991	0.012985
33.33268	0.014626	33.32226	0.014626	33.29229	0.014626	33.2465	0.014626
41.27233	0.016268	41.25692	0.016268	41.21263	0.016268	41.14499	0.016268
49.97954	0.017912	49.95746	0.017912	49.89401	0.017912	49.79719	0.017912
59.50166	0.019557	59.4708	0.019557	59.38215	0.019557	59.24699	0.019557
69.88735	0.021204	69.84508	0.021204	69.72374	0.021204	69.53888	0.021204
81.18579	0.022852	81.12889	0.022852	80.96565	0.022852	80.71718	0.022852
93.44633	0.024501	93.37088	0.024501	93.15451	0.024501	92.82555	0.024501
106.7183	0.026152	106.6196	0.026152	106.3366	0.026152	105.9068	0.026152
121.0512	0.027804	120.9235	0.027804	120.5576	0.027804	120.0027	0.027804
136.4945	0.029458	136.331	0.029458	135.863	0.029458	135.1543	0.029458
153.0981	0.031113	152.8908	0.031113	152.298	0.031113	151.4016	0.031113
170.9122	0.032769	170.6516	0.032769	169.9073	0.032769	168.7838	0.032769
189.9879	0.034427	189.6631	0.034427	188.7362	0.034427	187.3397	0.034427
210.3773	0.036086	209.9754	0.036086	208.8298	0.036086	207.1072	0.036086
232.1337	0.037747	231.6399	0.037747	230.2339	0.037747	228.1242	0.037747
255.3119	0.039409	254.7091	0.039409	252.9947	0.039409	250.4283	0.039409
501.8817	0.056105	499.9911	0.056105	494.6428	0.056105	486.713	0.056105
934.4614	0.072937	926.9797	0.072937	906.3106	0.072937	876.9296	0.072937
1434.461	0.084489	1426.98	0.084822	1406.311	0.085783	1376.93	0.087257

1934.461	0.09233	1926.98	0.092959	1906.311	0.09479	1876.93	0.097657
2434.461	0.098111	2426.98	0.099014	2406.311	0.101672	2376.93	0.105916
2934.461	0.102544	2926.98	0.103702	2906.311	0.107148	2876.93	0.112752
3434.461	0.106021	3426.98	0.107417	3406.311	0.111608	3376.93	0.118549
3934.461	0.108789	3926.98	0.110404	3906.311	0.115299	3876.93	0.123544
4434.461	0.111016	4426.98	0.112833	4406.311	0.118387	4376.93	0.127898
4934.461	0.112821	4926.98	0.114821	4906.311	0.12099	4876.93	0.131724
5434.461	0.114291	5426.98	0.11646	5406.311	0.123199	5376.93	0.13511
5934.461	0.115495	5926.98	0.117815	5906.311	0.125082	5876.93	0.13812
6434.461	0.116483	6426.98	0.11894	6406.311	0.126693	6376.93	0.140808
6934.461	0.117297	6926.98	0.119877	6906.311	0.128076	6876.93	0.143217
7434.461	0.117969	7426.98	0.120659	7406.311	0.129266	7376.93	0.145382
7934.461	0.118524	7926.98	0.121312	7906.311	0.130293	7876.93	0.147332
8434.461	0.118983	8426.98	0.121859	8406.311	0.131179	8376.93	0.149093
8934.461	0.119363	8926.98	0.122317	8906.311	0.131946	8876.93	0.150685
9434.461	0.119679	9426.98	0.122702	9406.311	0.13261	9376.93	0.152127
12434.46	0.120717	12426.98	0.124012	12406.31	0.135109	12376.93	0.158396

Table 3.2.9 Sample result for dp=2.441 in and GLR=1500 STB/day

θ= -90	θ= -70	θ= -50	θ= -30				
Length (ft)	Hold-up	Length (ft)	Hold-up	Length (ft)	Hold-up	Length (ft)	Hold-up
0	0.004799	0	0.004799	0	0.004799	0	0.004799
1.727499	0.006433	1.727421	0.006433	1.727198	0.006433	1.726856	0.006433
3.777263	0.008069	3.777039	0.008069	3.776395	0.008069	3.775407	0.008069
6.119494	0.009706	6.11903	0.009706	6.117695	0.009706	6.115651	0.009706
8.747326	0.011345	8.7465	0.011345	8.74412	0.011345	8.740478	0.011345
11.66675	0.012985	11.66539	0.012985	11.66151	0.012985	11.65556	0.012985
14.8909	0.014626	14.88882	0.014626	14.88283	0.014626	14.87367	0.014626
18.43683	0.016268	18.43376	0.016268	18.42491	0.016268	18.41137	0.016268
22.32364	0.017912	22.31923	0.017912	22.30656	0.017912	22.28717	0.017912
26.57131	0.019557	26.56515	0.019557	26.54745	0.019557	26.52039	0.019557
31.20013	0.021204	31.19171	0.021204	31.1675	0.021204	31.13049	0.021204
36.2303	0.022852	36.21898	0.022852	36.18643	0.022852	36.13671	0.022852
41.68172	0.024501	41.66672	0.024501	41.62363	0.024501	41.55783	0.024501
47.57386	0.026152	47.55427	0.026152	47.49798	0.026152	47.41207	0.026152
53.92579	0.027804	53.9005	0.027804	53.82784	0.027804	53.71703	0.027804
60.75611	0.029458	60.72381	0.029458	60.63106	0.029458	60.48968	0.029458
68.08302	0.031113	68.04217	0.031113	67.92494	0.031113	67.74636	0.031113
75.92432	0.032769	75.87314	0.032769	75.72632	0.032769	75.50284	0.032769
84.29751	0.034427	84.23393	0.034427	84.0516	0.034427	83.77431	0.034427
93.21981	0.036086	93.14144	0.036086	92.9168	0.036086	92.57545	0.036086
102.7082	0.037747	102.6123	0.037747	102.3376	0.037747	101.9205	0.037747
112.7797	0.039409	112.6631	0.039409	112.3294	0.039409	111.8233	0.039409
219.4919	0.056105	219.1334	0.056105	218.1092	0.056105	216.5624	0.056105
395.6823	0.072937	394.3892	0.072937	390.7281	0.072937	385.2919	0.072937
661.889	0.089899	657.8402	0.089899	646.554	0.089899	630.2552	0.089899

1049.307	0.106981	1038.134	0.106981	1007.725	0.106981	965.5921	0.106981
1549.307	0.122218	1538.134	0.122713	1507.725	0.124139	1410.137	0.124173
2049.307	0.132839	2038.134	0.133769	2007.725	0.136479	1910.137	0.139047
2549.307	0.140769	2538.134	0.1421	2507.725	0.146021	2410.137	0.150911
3049.307	0.146897	3038.134	0.148601	3007.725	0.15367	2910.137	0.160761
3549.307	0.151732	3538.134	0.153781	3507.725	0.159934	3410.137	0.169133
4049.307	0.155599	4038.134	0.157965	4007.725	0.165138	3910.137	0.176362
4549.307	0.158721	4538.134	0.161379	4507.725	0.169507	4410.137	0.182672
5049.307	0.16126	5038.134	0.164184	5007.725	0.173201	4910.137	0.188227
5549.307	0.163336	5538.134	0.166502	5507.725	0.176344	5410.137	0.193148
6049.307	0.165039	6038.134	0.168424	6007.725	0.179029	5910.137	0.19753
6549.307	0.166442	6538.134	0.170024	6507.725	0.181333	6410.137	0.201448
7049.307	0.1676	7038.134	0.17136	7007.725	0.183314	6910.137	0.204964
7549.307	0.168557	7538.134	0.172477	7507.725	0.185023	7410.137	0.208127
8049.307	0.16935	8038.134	0.173413	8007.725	0.1865	7910.137	0.210981
8549.307	0.170009	8538.134	0.174198	8507.725	0.187778	8410.137	0.21356

Table 3.2.10 Sample result for GLR=500 STB/day and θ= -90˚

GLR=500, θ= -90					
d	d	dp=2.441			
[illegible]	[illegible]H	L	H	L	H
[illegible]	0	[illegible]	0	[illegible]	0
5	0	4	0	1	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	3	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	3	0
[illegible]	0	[illegible]	0	6	0
8	0	[illegible]	0	[illegible]	0
5	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
1	0	[illegible]	0	[illegible]	0
3	0	1	0	[illegible]	0
5	0	3	0	[illegible]	0
7	0	5	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	2	0	[illegible]	0
[illegible]	0	[illegible]	0	7	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	9	0
[illegible]	0	[illegible]	0	1	0
3	0	[illegible]	0	[illegible]	0
2	0	[illegible]	0	2	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	3	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	4	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	5	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	6	0
[illegible]	0	8	0	[illegible]	0
[illegible]	0	0	0	7	0
7	0	0	0	[illegible]	0
2	0	1	0	8	0
[illegible]	0	1	0	[illegible]	0
[illegible]	0	2	0	9	0
[illegible]	0	2	0	6	0

2 . 3 . 0 .

Table 3.2.11 Sample result for GLR=500 STB/day and θ= -70˚

GLR=500, θ= -70					
d	d	dp=2.441			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0	[illegible]	0	[illegible]	0
5	0	4	0	1	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	2	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	3	0
[illegible]	0	[illegible]	0	[illegible]	0
8	0	[illegible]	0	[illegible]	0
5	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
1	0	6	0	[illegible]	0
3	0	1	0	[illegible]	0
5	0	3	0	[illegible]	0
7	0	5	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	8	0
[illegible]	0	[illegible]	0	[illegible]	0
2	0	[illegible]	0	[illegible]	0
2	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	7	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	7	0	[illegible]	0
[illegible]	0	0	0	[illegible]	0
7	0	0	0	[illegible]	0
[illegible]	0	1	0	[illegible]	0
[illegible]	0	1	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	5	0
[illegible]	0	3	0	[illegible]	0
7	.	3	.	0	.

Table 3.2.12 Sample result for GLR=500 STB/day and θ= -50˚

GLR=500, θ= -50					
d	d	dp=2.441			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0	[illegible]	0	[illegible]	0
5	0	4	0	1	0
[illegible]	0	[illegible]	0	[illegible]	0
2	0	2	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	2	0	7	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	3	0
[illegible]	0	[illegible]	0	6	0
8	0	[illegible]	0	[illegible]	0
5	0	[illegible]	0	[illegible]	0
0	0	[illegible]	0	[illegible]	0
1	0	4	0	[illegible]	0
3	0	1	0	[illegible]	0
5	0	2	0	[illegible]	0
7	0	4	0	[illegible]	0
[illegible]	0	6	0	[illegible]	0
2	0	[illegible]	0	6	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	6	0
[illegible]	0	[illegible]	0	0	0
1	0	[illegible]	0	[illegible]	0
2	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
7	0	0	0	[illegible]	0
2	0	0	0	[illegible]	0
[illegible]	0	1	0	[illegible]	0
[illegible]	0	1	0	[illegible]	0
[illegible]	0	2	0	5	0
[illegible]	0	2	0	0	0
7	0	3	0	0	0
0	0	3	0	1	0
0	.	4	.	1	.

Table 3.2.13 Sample result for GLR=500 STB/day and θ= -30˚

GLR=500, θ= -30					
dp	dp	dp=2.441			
[illegible]	[illegible]	L	H	L	H
0	0	0	0	0	0
5	0	4	0	1	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	2	0	[illegible]	0
[illegible]	0	[illegible]	0	0	0
[illegible]	0	[illegible]	0	3	0
[illegible]	0	[illegible]	0	6	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
9	0	[illegible]	0	[illegible]	0
1	0	1	0	3	0
3	0	0	0	[illegible]	0
5	0	[illegible]	0	[illegible]	0
7	0	3	0	[illegible]	0
[illegible]	0	5	0	[illegible]	0
2	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	7	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	2	0
[illegible]	0	[illegible]	0	0	0
9	0	[illegible]	0	[illegible]	0
1	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
2	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
3	0	[illegible]	0	[illegible]	0
[illegible]	0	7	0	[illegible]	0
4	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
5	0	[illegible]	0	[illegible]	0
[illegible]	0	[illegible]	0	[illegible]	0
6	0	[illegible]	0	[illegible]	0
[illegible]	0	7	0	[illegible]	0
7	0	0	0	[illegible]	0
[illegible]	0	0	0	[illegible]	0
8	0	1	0	[illegible]	0
[illegible]	0	1	0	5	0
9	0	[illegible]	0	0	0
6	0	[illegible]	0	0	0
0	0	3	0	1	0
0	.	3	.	1	.

Table 3.2.14 Sample result for GLR=1000 STB/day and θ= -90˚

GLR=1000, θ= -90					
d	d	dp=2.441			
p	p H	L	H	L	H
0	0	0	0	0	0
1	0	1	0	3	0
3	0	2	0	8	0
5	0	3	0	.1	0
7	0	5	0	3	0
9	0	7	0	2	0
.1	0	2	0	3	0
4	0	2	0	4	0
5	0	1	0	4	0
2	0	3	0	5	0
2	0	6	0	8	0
2	0	2	0	8	0
3	0	2	0	9	0
3	0	3	0	3	0
4	0	3	0	0	0
4	0	3	0	2	0
3	0	4	0	3	0
6	0	4	0	5	0
6	0	3	0	7	0
7	0	6	0	2	0
3	0	6	0	2	0
9	0	7	0	2	0
1	0	5	0	5	0
3	0	2	0	9	0
5	0	2	0	3	0
8	0	2	0	4	0
2	0	3	0	2	0
2	0	3	0	2	0
2	0	4	0	3	0
2	0	4	0	3	0
3	0	5	0	4	0
3	0	3	0	4	0
4	0	6	0	3	0
4	0	6	0	5	0
5	0	7	0	8	0
3	0	2	0	6	0
6	0	8	0	7	0
6	0	8	0	7	0
7	0	9	0	8	0
2	0	8	0	8	0
8	0	7	0	9	0

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Table 3.2.15 Sample result for GLR=1000 STB/day and θ= -70˚

GLR=1000, θ= -70					
d	d	dp=2.441			
p	p	HL	H	L	H
0	0	0	0	0	0
1	0	1	0	3	0
3	0	2	0	8	0
5	0	3	0	1	0
7	0	5	0	3	0
9	0	7	0	2	0
1	0	9	0	6	0
2	0	2	0	4	0
5	0	1	0	4	0
8	0	3	0	9	0
2	0	6	0	8	0
5	0	9	0	8	0
9	0	2	0	9	0
3	0	6	0	3	0
8	0	0	0	0	0
4	0	4	0	2	0
9	0	8	0	3	0
6	0	4	0	5	0
6	0	8	0	7	0
8	0	6	0	8	0
8	0	0	0	0	0
9	0	7	0	3	0
1	0	4	0	5	0
3	0	2	0	9	0
5	0	7	0	2	0
8	0	2	0	4	0
1	0	3	0	2	0
2	0	3	0	4	0
7	0	4	0	9	0
2	0	4	0	3	0
3	0	5	0	4	0
3	0	8	0	4	0
4	0	6	0	9	0
4	0	6	0	5	0
5	0	7	0	8	0
8	0	2	0	6	0
6	0	8	0	9	0
8	0	8	0	7	0
7	0	9	0	8	0
2	0	9	0	8	0
8	0	7	0	9	0
2	.	0	.	4	.

Table 3.2.16 Sample result for GLR=1000 STB/day and θ= -50˚

GLR=1000, θ= -50					
d	d	dp=2.441			
p	pH	L	H	L	H
0	0	0	0	0	0
1	0	1	0	3	0
3	0	2	0	8	0
5	0	3	0	1	0
7	0	5	0	3	0
9	0	7	0	2	0
1	0	8	0	6	0
2	0	2	0	4	0
5	0	1	0	4	0
2	0	3	0	5	0
2	0	6	0	8	0
5	0	2	0	8	0
9	0	2	0	9	0
3	0	2	0	3	0
4	0	9	0	0	0
4	0	3	0	2	0
9	0	8	0	3	0
6	0	4	0	5	0
6	0	8	0	6	0
8	0	5	0	2	0
5	0	8	0	2	0
9	0	6	0	2	0
1	0	3	0	5	0
3	0	2	0	9	0
5	0	2	0	0	0
7	0	2	0	4	0
9	0	3	0	2	0
1	0	3	0	4	0
2	0	4	0	9	0
2	0	4	0	5	0
6	0	5	0	4	0
3	0	8	0	4	0
4	0	6	0	9	0
4	0	6	0	5	0
6	0	7	0	8	0
5	0	2	0	6	0
6	0	3	0	9	0
6	0	8	0	7	0
6	0	9	0	8	0
7	0	8	0	8	0
6	0	7	0	9	0
1	.	0	.	4	.

Table 3.2.17 Sample result for GLR=4500 STB/day and θ= -90˚

GLR=4500, θ= -90					
d	d	dp=2.441			
p	H	L	H	L	H
0	0	0	0	0	0
0	0	0	0	0	0
0	0	1	0	0	0
0	0	1	0	0	0
0	0	2	0	0	0
0	0	3	0	1	0
0	0	4	0	1	0
0	0	5	0	2	0
0	0	6	0	2	0
1	0	8	0	2	0
1	0	9	0	3	0
1	0	1	0	4	0
1	0	1	0	4	0
1	0	2	0	5	0
2	0	4	0	6	0
2	0	6	0	6	0
2	0	2	0	7	0
3	0	2	0	8	0
3	0	2	0	9	0
3	0	2	0	1	0
4	0	3	0	0	0
4	0	3	0	1	0
8	0	6	0	2	0
1	0	7	0	4	0
2	0	2	0	3	0
3	0	2	0	0	0
8	0	4	0	0	0
7	0	6	0	2	0
9	0	8	0	2	0
6	0	1	0	3	0
2	0	0	0	4	0
5	0	4	0	5	0
2	0	2	0	6	0
2	0	2	0	6	0
3	0	3	0	9	0
3	0	3	0	6	0
4	0	4	0	1	0
4	0	4	0	3	0
9	0	8	0	5	0
6	0	5	0	2	0
7	0	6	0	2	0
1	.	3	.	5	.

Table 3.2.18 Sample result for GLR=4500 STB/day and θ= -70˚

GLR=4500, θ= -70					
d	d	dp=2.441			
p	p	L	H	L	H
0	0	0	0	0	0
0	0	0	0	0	0
0	0	1	0	0	0
0	0	1	0	0	0
0	0	2	0	0	0
0	0	3	0	1	0
0	0	4	0	1	0
0	0	5	0	2	0
0	0	6	0	2	0
1	0	8	0	2	0
1	0	9	0	3	0
1	0	1	0	4	0
1	0	1	0	4	0
1	0	2	0	5	0
2	0	4	0	6	0
2	0	6	0	6	0
2	0	8	0	7	0
3	0	2	0	8	0
3	0	3	0	9	0
3	0	6	0	1	0
4	0	8	0	0	0
4	0	3	0	1	0
8	0	6	0	2	0
1	0	7	0	4	0
5	0	2	0	7	0
5	0	9	0	0	0
8	0	9	0	0	0
7	0	3	0	5	0
9	0	8	0	0	0
6	0	0	0	7	0
2	0	0	0	4	0
5	0	3	0	3	0
8	0	7	0	6	0
2	0	2	0	6	0
6	0	7	0	9	0
3	0	2	0	4	0
6	0	4	0	1	0
4	0	2	0	3	0
8	0	5	0	5	0
5	0	3	0	8	0
2	0	6	0	2	0
0	0	8	0	4	0
9	.	7	.	8	.

Table 3.2.19 Sample result for GLR=4500 STB/day and θ= -50˚

GLR=4500, θ= -50					
d	d	dp=2.441			
dp	dP	HL	H	L	H
0	0	0	0	0	0
0	0	0	0	0	0
0	0	1	0	0	0
0	0	1	0	0	0
0	0	2	0	0	0
0	0	3	0	1	0
0	0	4	0	1	0
0	0	5	0	2	0
0	0	6	0	2	0
1	0	8	0	2	0
1	0	9	0	3	0
1	0	1	0	4	0
1	0	1	0	4	0
1	0	2	0	5	0
2	0	4	0	6	0
2	0	6	0	6	0
2	0	2	0	7	0
3	0	2	0	8	0
3	0	2	0	9	0
3	0	2	0	1	0
4	0	3	0	0	0
4	0	3	0	1	0
8	0	6	0	2	0
1	0	7	0	4	0
2	0	2	0	3	0
3	0	2	0	0	0
5	0	4	0	0	0
7	0	3	0	2	0
9	0	8	0	2	0
6	0	8	0	3	0
2	0	0	0	4	0
5	0	3	0	8	0
2	0	2	0	3	0
2	0	2	0	7	0
3	0	3	0	9	0
3	0	3	0	2	0
4	0	4	0	0	0
2	0	4	0	2	0
8	0	5	0	4	0
4	0	5	0	7	0
6	0	6	0	2	0
7	0	6	0	2	0
7	.	6	.	5	.

Table 3.2.20 Sample result for GLR=4500 STB/day and θ= -30˚

GLR=4500, θ= -30					
d	d	dp=2.441			
p	p	H L	H	L	H
0	0	0	0	0	0
0	0	0	0	0	0
0	0	1	0	0	0
0	0	1	0	0	0
0	0	2	0	0	0
0	0	3	0	1	0
0	0	4	0	1	0
0	0	5	0	2	0
0	0	6	0	2	0
1	0	8	0	2	0
1	0	9	0	3	0
1	0	1	0	4	0
1	0	1	0	4	0
1	0	2	0	5	0
2	0	4	0	6	0
2	0	6	0	6	0
2	0	8	0	7	0
3	0	2	0	8	0
3	0	3	0	9	0
3	0	6	0	1	0
4	0	8	0	0	0
4	0	3	0	1	0
8	0	6	0	2	0
1	0	7	0	4	0
5	0	1	0	6	0
5	0	9	0	9	0
6	0	4	0	0	0
7	0	5	0	4	0
9	0	7	0	2	0
6	0	6	0	6	0
2	0	8	0	3	0
5	0	2	0	8	0
8	0	5	0	6	0
2	0	9	0	7	0
6	0	3	0	4	0
3	0	8	0	8	0
5	0	3	0	0	0
4	0	8	0	1	0
7	0	4	0	3	0
3	0	8	0	5	0
8	0	5	0	7	0
7	0	6	0	2	0
4	.	3	.	2	.

Table 3.2.21 Sample result for GLR=5000 STB/day and θ= -90˚

GLR=5000, θ= -90					
d	d	dp=2.441			
p	p H	L	H	L	H
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	1	0	0	0
0	0	2	0	0	0
0	0	2	0	1	0
0	0	3	0	1	0
0	0	4	0	1	0
0	0	5	0	2	0
0	0	6	0	2	0
1	0	7	0	2	0
1	0	9	0	3	0
1	0	1	0	3	0
1	0	0	0	4	0
1	0	1	0	4	0
2	0	3	0	5	0
2	0	5	0	6	0
2	0	7	0	6	0
2	0	9	0	7	0
3	0	2	0	8	0
3	0	3	0	9	0
3	0	5	0	1	0
7	0	8	0	0	0
1	0	9	0	9	0
2	0	7	0	5	0
3	0	5	0	6	0
4	0	3	0	5	0
5	0	4	0	2	0
9	0	6	0	6	0
8	0	8	0	2	0
0	0	4	0	3	0
2	0	0	0	5	0
5	0	3	0	3	0
3	0	7	0	6	0
2	0	2	0	7	0
5	0	7	0	5	0
9	0	3	0	9	0
3	0	7	0	0	0
9	0	2	0	2	0
5	0	7	0	4	0
8	0	8	0	6	0
6	0	7	0	8	0
7	0	8	0	2	0
0	.	7	.	4	.

Table 3.2.22 Sample result for GLR=5000 STB/day and θ= -70˚

GLR=5000, θ= -70					
d	d	dp=2.441			
p	H	L	H	L	H
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	1	0	0	0
0	0	2	0	0	0
0	0	2	0	1	0
0	0	3	0	1	0
0	0	4	0	1	0
0	0	5	0	2	0
0	0	6	0	2	0
1	0	7	0	2	0
1	0	9	0	3	0
1	0	1	0	3	0
1	0	0	0	4	0
1	0	1	0	4	0
2	0	3	0	5	0
2	0	5	0	6	0
2	0	7	0	6	0
2	0	9	0	7	0
3	0	2	0	8	0
3	0	3	0	9	0
3	0	5	0	1	0
7	0	8	0	0	0
1	0	9	0	9	0
2	0	7	0	5	0
9	0	5	0	6	0
4	0	3	0	5	0
5	0	4	0	2	0
9	0	6	0	2	0
8	0	8	0	2	0
9	0	3	0	8	0
2	0	0	0	4	0
5	0	3	0	3	0
2	0	7	0	6	0
2	0	2	0	7	0
2	0	6	0	5	0
9	0	3	0	8	0
3	0	6	0	0	0
4	0	4	0	2	0
5	0	5	0	3	0
6	0	5	0	5	0
6	0	6	0	2	0
2	.	1	.	1	.

Table 3.2.23 Sample result for GLR=5000 STB/day and θ= -50˚

GLR=5000, θ= -50					
d	d	dp=2.441			
p	p	H L	H	L	H
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	1	0	0	0
0	0	2	0	0	0
0	0	2	0	1	0
0	0	3	0	1	0
0	0	4	0	1	0
0	0	5	0	2	0
0	0	6	0	2	0
1	0	7	0	2	0
1	0	9	0	3	0
1	0	1	0	3	0
1	0	0	0	4	0
1	0	1	0	4	0
2	0	3	0	5	0
2	0	5	0	6	0
2	0	7	0	6	0
2	0	9	0	7	0
3	0	2	0	8	0
3	0	3	0	9	0
3	0	5	0	1	0
7	0	8	0	0	0
1	0	9	0	9	0
2	0	7	0	5	0
9	0	5	0	6	0
4	0	3	0	5	0
5	0	4	0	2	0
9	0	6	0	2	0
9	0	8	0	2	0
9	0	1	0	3	0
2	0	0	0	4	0
5	0	3	0	3	0
2	0	2	0	6	0
2	0	2	0	7	0
2	0	4	0	8	0
9	0	9	0	5	0
3	0	4	0	9	0
8	0	9	0	1	0
4	0	4	0	3	0
9	0	9	0	5	0
6	0	5	0	7	0
6	0	8	0	2	0
8	.	4	.	2	.

Table 3.2.24 Sample result for GLR=5000 STB/day and θ= -30˚

GLR=5000, θ= -30					
d	d	dp=2.441			
p	P	H L	H	L	H
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	1	0	0	0
0	0	2	0	0	0
0	0	2	0	1	0
0	0	3	0	1	0
0	0	4	0	1	0
0	0	5	0	2	0
0	0	6	0	2	0
1	0	7	0	2	0
1	0	9	0	3	0
1	0	1	0	3	0
1	0	0	0	4	0
1	0	1	0	4	0
2	0	3	0	5	0
2	0	5	0	6	0
2	0	7	0	6	0
2	0	9	0	7	0
3	0	2	0	8	0
3	0	3	0	9	0
3	0	5	0	1	0
7	0	8	0	0	0
1	0	9	0	9	0
2	0	7	0	5	0
3	0	5	0	6	0
4	0	3	0	5	0
8	0	4	0	2	0
9	0	6	0	2	0
9	0	7	0	2	0
9	0	8	0	3	0
2	0	9	0	4	0
5	0	2	0	5	0
2	0	5	0	6	0
2	0	8	0	7	0
5	0	2	0	8	0
9	0	6	0	9	0
3	0	0	0	5	0
4	0	5	0	0	0
4	0	4	0	2	0
8	0	5	0	4	0

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APPENDIX C
Effect of liquid flow rate on liquid hold-up

Figure 4.1.1 Effect of liquid flow rate on liquid hold-up for dp=1.995 in and θ=90˚

Figure 4.1.2 Effect of liquid flow rate on liquid hold-up for dp=1.995 in and θ=80˚

Figure 4.1.3 Effect of liquid flow rate on liquid hold-up for dp=1.995 in and θ=70˚

Figure 4.1.4 Effect of liquid flow rate on liquid hold-up for dp=1.995 in and θ=50˚

Figure 4.1.5 Effect of liquid flow rate on liquid hold-up for dp=1.995 in and θ=30˚

Figure 4.1.6 Effect of liquid flow rate on liquid hold-up for dp=1.995 in and θ=10˚

Figure 4.1.7 Effect of liquid flow rate on liquid hold-up for dp=1.995 in and θ=0˚

Figure 4.1.8 Effect of liquid flow rate on liquid hold-up for dp=1.995 in and θ=-10˚

Figure 4.1.9 Effect of liquid flow rate on liquid hold-up for dp=1.995 in and θ=-30˚

Figure 4.1.10 Effect of liquid flow rate on liquid hold-up for dp=1.995 in and θ=-50˚

Figure 4.1.11 Effect of liquid flow rate on liquid hold-up for dp=1.995 in and θ=-70˚

Figure 4.1.12 Effect of liquid flow rate on liquid hold-up for dp=1.995 in and θ=-90˚

Figure 4.1.13 Effect of liquid flow rate on liquid hold-up for dp=2.992 in and θ=90˚

Figure 4.1.14 Effect of liquid flow rate on liquid hold-up for dp=2.992 in and θ=80˚

Figure 4.1.15 Effect of liquid flow rate on liquid hold-up for dp=2.992 in and θ=70˚

Figure 4.1.16 Effect of liquid flow rate on liquid hold-up for dp=2.992 in and θ=50˚

Figure 4.1.17 Effect of liquid flow rate on liquid hold-up for dp=2.992 in and θ=30˚

Figure 4.1.35 Effect of liquid flow rate on liquid hold-up for dp=2.441 in and θ=-70˚

Figure 4.1.36 Effect of liquid flow rate on liquid hold-up for dp=2.441 in and θ=-90˚

APPENDIX D
Effect of pipe inclination on liquid hold-up

Figure 4.2.1 Effect of pipe inclination on liquid hold-up for dp=1.995 in and ql=500

Figure 4.2.2 Effect of pipe inclination on liquid hold-up for dp=1.995 in and ql=1000

Figure 4.2.3 Effect of pipe inclination on liquid hold-up for dp=1.995 in and ql=1500

Figure 4.2.4 Effect of pipe inclination on liquid hold-up for dp=1.995 in and ql=2000

Figure 4.2.5 Effect of pipe inclination on liquid hold-up for dp=1.995 in and ql=2500

Figure 4.2.6 Effect of pipe inclination on liquid hold-up for dp=1.995 in and ql=3000

Figure 4.2.7 Effect of pipe inclination on liquid hold-up for dp=1.995 in and ql=3500

Figure 4.2.8 Effect of pipe inclination on liquid hold-up for dp=1.995 in and ql=4000

Figure 4.2.9 Effect of pipe inclination on liquid hold-up for dp=1.995 in and ql=4500

Figure 4.2.10 Effect of pipe inclination on liquid hold-up for dp=1.995 in and ql=5000

Figure 4.2.11 Effect of pipe inclination on liquid hold-up for dp=2.992 in and ql=500

Figure 4.2.12 Effect of pipe inclination on liquid hold-up for dp=2.992 in and ql=1000

Figure 4.2.13 Effect of pipe inclination on liquid hold-up for dp=2.992 in and ql=1500

Figure 4.2.14 Effect of pipe inclination on liquid hold-up for dp=2.992 in and ql=2000

Figure 4.2.15 Effect of pipe inclination on liquid hold-up for dp=2.992 in and ql=2500

Figure 4.2.16 Effect of pipe inclination on liquid hold-up for dp=2.992 in and ql=3000

Figure 4.2.17 Effect of pipe inclination on liquid hold-up for dp=2.992 in and ql=3500

Figure 4.2.18 Effect of pipe inclination on liquid hold-up for dp=2.992 in and ql=4000

Figure 4.2.19 Effect of pipe inclination on liquid hold-up for dp=2.992 in and ql=4500

Figure 4.2.20 Effect of pipe inclination on liquid hold-up for dp=2.992 in and ql=5000

Figure 4.2.21 Effect of pipe inclination on liquid hold-up for dp=2.441 in and ql=500

Figure 4.2.22 Effect of pipe inclination on liquid hold-up for dp=2.441 in and ql=1000

Figure 4.2.23 Effect of pipe inclination on liquid hold-up for dp=2.441 in and ql=1500

Figure 4.2.24 Effect of pipe inclination on liquid hold-up for dp=2.441 in and ql=2000

Figure 4.2.25 Effect of pipe inclination on liquid hold-up for dp=2.441 in and ql=2500

Figure 4.2.26 Effect of pipe inclination on liquid hold-up for dp=2.441 in and ql=3000

Figure 4.2.27 Effect of pipe inclination on liquid hold-up for dp=2.441 in and ql=3500

Figure 4.2.28 Effect of pipe inclination on liquid hold-up for dp=2.441 in and ql=4000

Figure 4.2.29 Effect of pipe inclination on liquid hold-up for dp=2.441 in and ql=4500

Figure 4.2.30 Effect of pipe inclination on liquid hold-up for dp=2.441 in and ql=5000

APPENDIX E

Effect of pipe diameter on liquid hold-up

Figure 4.3.1 Effect of pipe diameter on liquid hold-up for ql=500 and θ=-90˚

Figure 4.3.2 Effect of pipe diameter on liquid hold-up for ql=500 and θ=-70˚

Figure 4.3.3 Effect of pipe diameter on liquid hold-up for ql=500 and θ=-50˚

Figure 4.3.4 Effect of pipe diameter on liquid hold-up for ql=500 and θ=-30˚

Figure 4.3.5 Effect of pipe diameter on liquid hold-up for ql=500 and θ=-10˚

Figure 4.3.6 Effect of pipe diameter on liquid hold-up for ql=500 and θ=0˚

Figure 4.3.7 Effect of pipe diameter on liquid hold-up for ql=500 and θ=-10˚

Figure 4.3.8 Effect of pipe diameter on liquid hold-up for ql=500 and θ=-30˚

Figure 4.3.8 Effect of pipe diameter on liquid hold-up for ql=500 and θ=50˚

Figure 4.3.10 Effect of pipe diameter on liquid hold-up for ql=500 and θ=70˚

Figure 4.3.11 Effect of pipe diameter on liquid hold-up for ql=500 and θ=80˚

Figure 4.3.12 Effect of pipe diameter on liquid hold-up for ql=500 and θ=90˚

Figure 4.3.13 Effect of pipe diameter on liquid hold-up for ql=1000 and θ=-90˚

Figure 4.3.14 Effect of pipe diameter on liquid hold-up for ql=1000 and θ=-70˚

Figure 4.3.15 Effect of pipe diameter on liquid hold-up for ql=1000 and θ=-50˚

Figure 4.3.16 Effect of pipe diameter on liquid hold-up for ql=1000 and θ=-30˚

Figure 4.3.17 Effect of pipe diameter on liquid hold-up for ql=1000 and θ=-10˚

Figure 4.3.18 Effect of pipe diameter on liquid hold-up for ql=1000 and θ=0˚

Figure 4.3.19 Effect of pipe diameter on liquid hold-up for ql=1000 and θ=10˚

Figure 4.3.20 Effect of pipe diameter on liquid hold-up for ql=1000 and θ=30˚

Figure 4.3.21 Effect of pipe diameter on liquid hold-up for ql=1000 and θ=50˚

Figure 4.3.22 Effect of pipe diameter on liquid hold-up for ql=1000 and θ=70˚

Figure 4.3.23 Effect of pipe diameter on liquid hold-up for ql=1000 and θ=80˚

Figure 4.3.24 Effect of pipe diameter on liquid hold-up for ql=1000 and θ=90˚

Figure 4.3.25 Effect of pipe diameter on liquid hold-up for ql=1500 and θ=-90˚

Figure 4.3.26 Effect of pipe diameter on liquid hold-up for ql=1500 and θ=-70˚

Figure 4.3.27 Effect of pipe diameter on liquid hold-up for ql=1500 and θ=-50˚

Figure 4.3.28 Effect of pipe diameter on liquid hold-up for ql=1500 and θ=-30˚

Figure 4.3.29 Effect of pipe diameter on liquid hold-up for ql=1500 and θ=-10˚

Figure 4.3.30 Effect of pipe diameter on liquid hold-up for ql=1500 and θ=0˚

Figure 4.3.31 Effect of pipe diameter on liquid hold-up for ql=1500 and θ=10˚

Figure 4.3.32 Effect of pipe diameter on liquid hold-up for ql=1500 and θ=30˚

Figure 4.3.33 Effect of pipe diameter on liquid hold-up for ql=1500 and θ=50˚

Figure 4.3.34 Effect of pipe diameter on liquid hold-up for ql=1500 and θ=70˚

Figure 4.3.35 Effect of pipe diameter on liquid hold-up for ql=1500 and θ=80˚

Figure 4.3.36 Effect of pipe diameter on liquid hold-up for ql=1500 and θ=90˚

Figure 4.3.112 Effect of pipe diameter on liquid hold-up for ql=5000 and θ=-30˚

Figure 4.3.113 Effect of pipe diameter on liquid hold-up for ql=5000 and θ=-10˚

Figure 4.3.114 Effect of pipe diameter on liquid hold-up for ql=5000 and θ=0˚

Figure 4.3.115 Effect of pipe diameter on liquid hold-up for ql=5000 and θ=10˚

Figure 4.3.116 Effect of pipe diameter on liquid hold-up for ql=5000 and θ=30˚

Figure 4.3.117 Effect of pipe diameter on liquid hold-up for ql=5000 and θ=50˚

Figure 4.3.118 Effect of pipe diameter on liquid hold-up for ql=5000 and θ=70˚

Figure 4.3.119 Effect of pipe diameter on liquid hold-up for ql=5000 and θ=80˚

Figure 4.3.120 Effect of pipe diameter on liquid hold-up for ql=5000 and θ=90˚