Well Control in Extended Reach Drilling (ERD) Well by Using WELLPLAN Software

By

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Dissertation report submitted in partial fulfillment of the requirements for the Bachelor of Engineering (Hons) Petroleum Engineering

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CERTIFICATION OF APPROVAL

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A project dissertation report submitted to the
Petroleum Engineering Programme
Universiti Teknologi PETRONAS
In partial fulfillment of the requirements for the
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Approved

……………………………..
(Dr. Reza Ettehadi Osgouei)
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2012

CERTIFICATION OF ORIGINALITY

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

……………………………….

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ABSTRACT

The oil and gas industry has developed rapidly by introduced new various technologies. Directional, horizontal, Extended Reach Drilling (ERD) and multilateral wells has been used in the industry for economical and technical reasons. Even though technologies are well developed in the last decade, but these wells still have high levels of risk in drilling and completion. Well control is one of the important issues because improper well control will lead to a blowout which is the most feared operational hazards and expensive cost. The key elements for the success and further development of ERD projects are the ability to continue developing new technology while at the same time adopting a technical limit approach to performance delivery.

For this study, the project focused on well control in ERD well by using Halliburton's software, WELLPLAN. WELLPAN is very useful software which is provides various functionalities such as torque drag analysis, analyze hydraulics, analyze surge/swab pressures and ECD's, investigate well control and etc. This project is focused on investigate well control using the Well Control Analysis Module. The Well Control module can be used to determined predicted kick type, estimate influx volume and kick tolerance, evaluate pressure and generate kill sheet.

Besides, the theoretical calculations also were performed to compare the results with WELLPLAN. Two equations are identical to find the suitable kill rate. Based on this study with literature review, well control procedures for extended-reach wells are as follows:

- Once a kick is detected and confirmed, perform a "hard" shut-in of the well.
- When the pressure is stabilized, record SIDPP, SICP and pit gain and start circulate immediately using the Driller's Method.
- In order to remove the gas from the horizontal section, the kill rate should be 1/3 to ½ of the rate in drilling circulation flowrate.

- However, for high inclination angle, high kill rate should be performed for a short time to displace the gas kick.
- Once the choke pressure starts to increase rapidly, slow down the kill circulation rate to 1/3 to ½ of the rate in drilling mode.

Keywords: Well Control, ERD Well, WELLPLAN Software, Macro Visual Basic (VBA), Kill Rate

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NOMENCLATURE

ERD = Extended Reach Drilling

TVD = True vertical depth, ft

HD = Horizontal depth, ft

MD = Measured depth, ft

ROP = Rate of penetration

BOP = Blow-out preventer

CP = Circulating pressure, psi

ICP = Initial circulating pressure, psi

FCP = Final circulating pressure, psi

SPR = System pressure loss at kill rate, psi

MW = Mud weight, ppg

KMW = Kill mud weight, ppg

ECD = Equivalent circulating density, ppg

SIDPP = Shut-in drillpipe pressure, psi

SICP = Shut-in casing pressure, psi

Q = Flow rate, gpm

V = Fluid velocity, ft/sec

V_a = Annular fluid velocity, ft/sec

sg = Specific gravity

ppg = Pound per gallon

P_f = Formation pressure, psi

P_p = Surface pump pressure, psi

P_{bh} = Bottom-hole pressure, psi

P_f = Formation pressure, psi

P_b = Pressure drop throught the bit, psi

P_h = Hydrostatic pressure, psi

P_{dph} = Drillpipe hydrostatic pressure, psi

P_{ah} = Annular-hydrostatic pressure, psi

P_i = Influx-hydrostatic pressure, psi

ρ_{mud} = Mud density, ppg

ρ_{kick} = Kick density, ppg

L_k = Length of the kick fluid, ft

L_{dc} = Drill collar length, ft

DP_a = Pressure change over time interval / time interval, hr

D_1 = Hole diameter, in.

D_2 = Drillpipe diameter, in.

V_g = Rate of gas migration, ft/hr

CHAPTER 1

INTRODUCTION

1.1 Project Background

Extended Reach Drilling (ERD) wells has change from simple directional drilling to horizontal, lateral and multi-lateral steps-outs. ERD is directional wells with long horizontal departure. ERD can be defined as a well with a measured depth to true vertical depth (TVD) ratios.

The purpose of well control systems theory is to prevent the uncontrolled flow of formation fluids into the wellbore. In other words, it is to manage the formation pressure which the wellbore pressure has to higher than formation pressure. If the wellbore pressure less than formation pressure, the greater formation pressure has a tendency to force formation fluids into the wellbore and will begin displacing the drilling fluid from the well.

Figure 1: Loss of well control in the Gulf of Mexico

The entry of formation fluids into the wellbore in the presence of drilling fluid is called a kick. Kicks may occur during drilling operations such as drilling, tripping or other procedures. A blowout might occur when the well control systems fail to controlled flow of formations fluids.

In order to prevent the incident happen, kick must be detected and killing the kick immediately. One of the solutions is by using the Halliburton's software which is WELLPLAN. WELLPLAN offers integrated, scalable and configurable technology solutions that require pore pressure prediction, analysis and interpretation. This software can improved the drilling performance through reduction of kicks, stuck pipe, lost circulation and blowouts for significant reductions in non-productive time.

For this study, actual well data which is UTP-2 well was used because this well is an ERD well and this well is located at offshore Terengganu, Malaysia. The measured depth (MD) for this well is 15652.9 ft and true vertical depth (TVD) is 5257.1 ft. The horizontal depth (HD) / TVD ratio is 2.465.

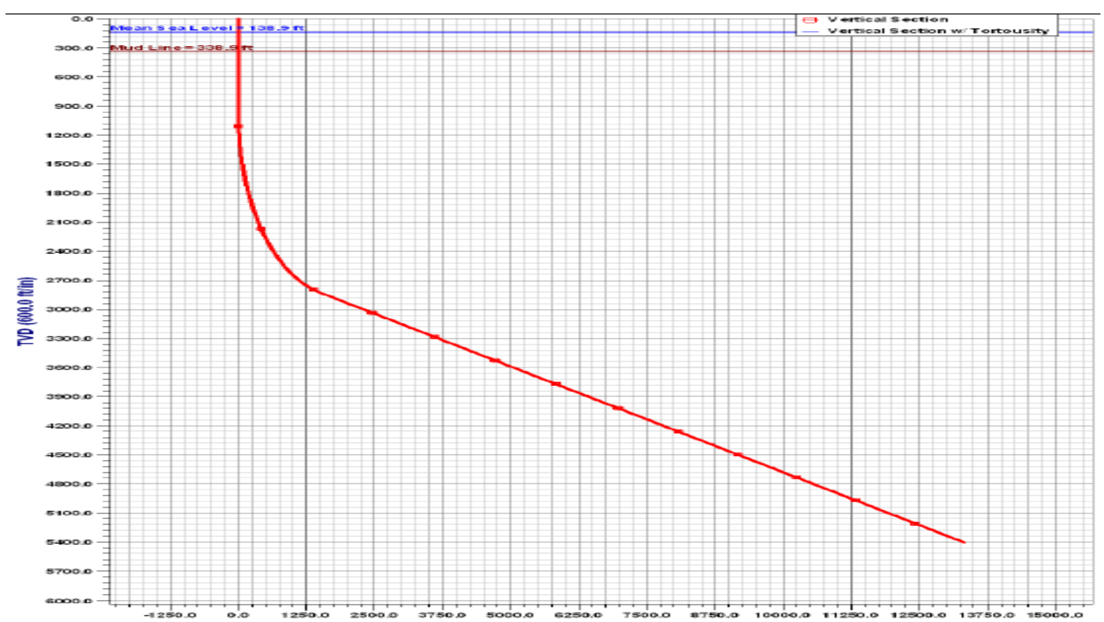

Figure 2: TVD vs. Vertical Section

1.2 Problem Statement

If the well control system couldn't detect the kick (the formation pressure higher than wellbore pressure) and killing the kick immediately and properly, blowout will occur. In ERD, the well control system is different from conventional drilling or vertical drilling. One of the examples is gas kicks accumulated and trapped (buoyancy of the gas) at the end of the well if that section inclined upwards. Besides, the gas can also get trapped in gas pockets in the high-lying parts of an undulating well trajectory and washouts. This gas kicks problem is not present in conventional vertical wells. The problem is the method on how to remove the gas kicks in ERD wells.

Moreover, kill procedures in conventional wellbores usually are conducted at a pump rate between 1/3 and ½ of the normal drilling rate. The reasons for this procedure are to lower the annulus friction pressure loss and less pressure fluctuation in response to a change in choke setting. In addition, the supervisor has more time to analyze the pressures and make wiser decisions (Advanced Well Control, Watson, et al. 2003). So, this project was performed to see whether the kill procedures in ERD well is same with conventional well or not.

1.3 Objectives

1.3.1 To use WELLPLAN to simulate well control in ERD well

In WELLPLAN, the Well Control Analysis Module is used to investigate the well control. The module provides various functions such as:

- Determine predicted kick type
- Estimate influx volume and kick tolerance
- Evaluate pressures as a kick is circulated out
- Predict a safe drilling depth
- Generate kill sheet

1.3.2 To use the theoretical calculations in macro visual basic (VBA)

The purpose of this objective is to compare the results from WELLPLAN with the theoretical calculations. In order to use anytime and can put any values, the student have to create a coding in macro visual basic.

1.4 Scope of Study

The work scopes involved in this project is simulating the WELLPLAN software that is related to well control in lab. Well Control Analysis Module in WELLPLAN provides investigate well control, determine predicted kick type and; estimate influx volume and kick tolerance. Besides, it also has evaluated pressures as a kick is circulated out, predict a safe drilling depth and lastly generate a kill sheet. The kick can be detected by studying the differential pressure between the formation and wellbore, sudden increase in rate of penetration (ROP), insufficient mud weight and etc.

The student also should have study and understand the well control procedures and the concept of removal gas in ERD wells. It is because in conventional wells, there is no accumulated and trapped gas at the end of the wellbore. Theoretical calculations were performed and were developed in VBA in order to compare the results with WELLPLAN.

CHAPTER 2

LITERATURE REVIEW

Directional drilling is drill the wellbore vertically to a located at a given distance. ERD means directional drilling of very long horizontal wells or the horizontal departure (HD) has at least twice the TVD of the well. Kick is known as when flow of formation fluids into the well in the presence of drilling fluid. (Applied Drilling Engineering, 2005). In this situation, kick occur when the higher formation pressure greater than mud hydrostatic pressure. The early detection of kicks is very important because blowout might occur if the kick is not controlled properly. Figure 3 below shows an ERD well pattern.

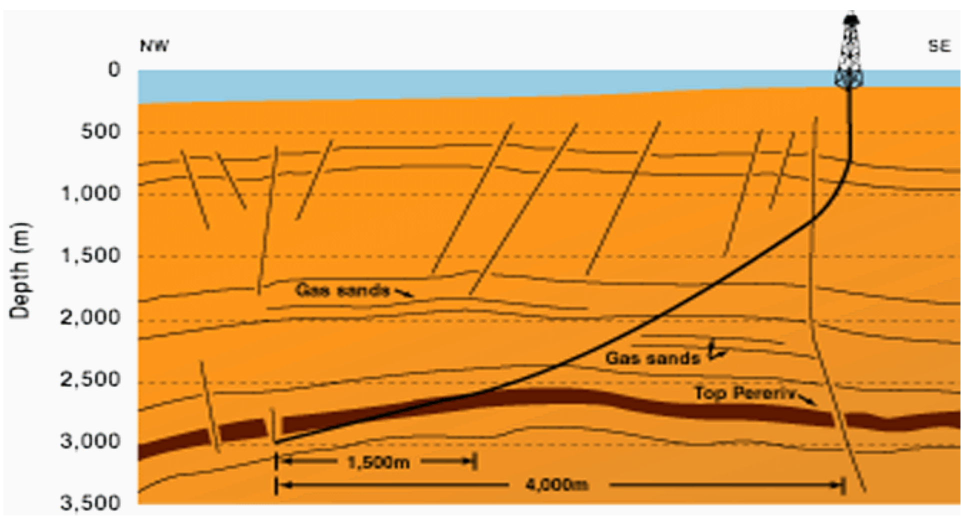

Figure 3: ERD well pattern

There are some factors affecting kick severity which are permeability, porosity and differential pressure. Higher permeability and porosity in a rock has higher potential for kick occur. Meanwhile, the causes of kicks in the well are insufficient mud weight, improper hole fill-up during trips, and swabbing. Other causes are cut mud and lost circulation.

During drilling operations at conventional wells, the well control is easier than well control in ERD wells. The well control operation for ERD wells is different from conventional wells because of several reasons. The reasons are the effect of swabbing during tripping out of the hole, shut-in pressure, remove the gas kick and mud density design.

During well control procedure in ERD wells, the maximum casing-shoe pressure is usually smaller and the choke pressures stay in low value for a long time than in conventional vertical well. This is because the TVD at casing shoe is frequently near to the TVD of the influx zone. The SIDPP and SCIP are same because the hydrostatic pressures on both sides of the U-tube are the same. Figure 4 below shows an ERD well that has taken a kick and is shut-in.

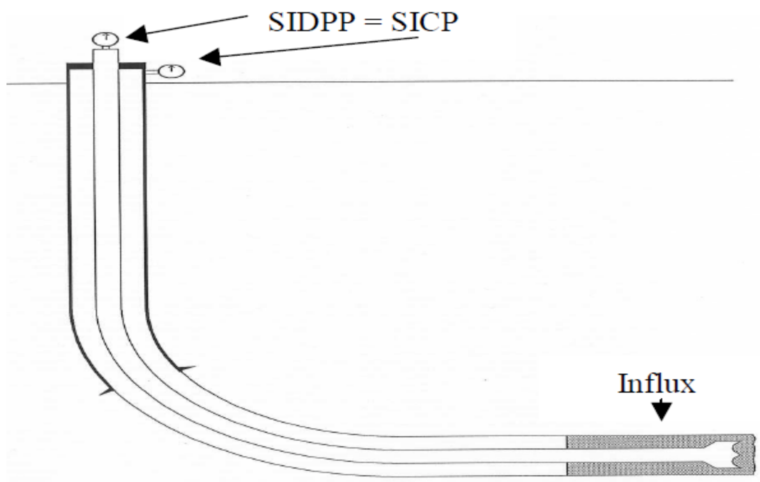

Figure 4: Shut-in of the well after taken a kick in ERD well

In ERD wells, the gas kick occur some unique problems which it is not present in conventional wells. Three potential traps have been identified that the buoyancy of the gas may trap at the upward inclined section, local tops in the lateral trajectory and washout called out of gauge sections.

In order to investigate well control problems, the author using the Well Control Analysis Module to calculate the expected influx volume, assist with casing design in terms of shoe setting depths and calculate expected conditions resulting from an influx. In addition, the module can be used to generate kill sheets and determine maximum safe drilling depths and maximum allowable influx volumes.

2.1 Kick Detection

Detecting a kick early is the most critical factor because from that we can know whether the kick is manageable to control or not. Warning signs and possible kick indicators can be observed at the surface by crew members. Not all positive signs show a kick because some of the indications just warn of potential kick situations. There are primary or secondary warning sign, relative to its importance in kick detection.

One of the indications of the kick to occur is abrupt increase in rate of penetration (ROP), called a drilling break. Increase in bit-penetration rate is an abnormal pressure indicator and should not be misinterpreted as an abrupt rate increase. The bit cuts the rock more easily and faster when high pressure gas may be breaking apart the rock in front of the drill bit, causing an increase in ROP or rate or penetration. An increase in ROP does not mean that a kick is occurring but it could just indicate that the rock type has changed.

Another kick indicator is increasing in flow rate. If the return flow rate from the wellbore increases higher than what is pumped at a constant rate into the wellbore, it means there is an influx formation fluids into the wellbore. This excessive volume of mud that the influx displaces over a period of time at the flow line, resulting pit gain. The well inflow and outflow of the well must be balance with constantly monitoring to prevent late kick detection.

Moreover, another indication of kick is cut mud weight. Obviously reducing the mud weight at the wellbore caused a kick to occur. The lower mud weights from cuttings effect are found near the surface, generally because of gas expansion and do not significantly reduced mud density throughout the hole.

Besides, the changing of string weight is also a kick indication. The drilling fluid provides a buoyant effect to the drillstring and reduces the actual pipe weight supported by the derrick. For example, the drillstring is removed from the wellbore when tripping out of the hole. In order to prevent the bottom-hole pressure less than pore pressure, the volume of drillstring has to be replaced with mud to make sure that the hydrostatic pressure in the wellbore is balanced.

Nowadays, there is a new technology that is really important to detect the kick early which is measurement while drilling (MWD). Although the functions of MWD are to monitor mud properties, formation parameters, bottom-hole location, and orientation of directional drilling systems, it also can be used for well control applications. The advantage of using MWD is it delivers the required information in real time while drilling. MWD also can provide early detection of kicks and potential influx.

2.2 Kick Identification

In case after the kick is detected and a kick occurrence, the type of the influx type that enters the wellbore is required to be determined. The equation for the determination of the density of kick is as follow:

$$\rho_{kick} = \rho_{mud} - \left(\frac{SICP - SIDPP}{0.052 \times L_k}\right) \quad (1)$$

The influx gradient can be evaluated using the given ranges as table below:

Table 1: Influx gradient table

Gradient, psi/ft			Gradient, sg			Gradient, ppg			Influx Type
0.05	**-**	**0.2**	0.115	-	0.461	**0.96**	**-**	**3.85**	**Gas**
0.2	**-**	**0.4**	0.461	-	0.923	**3.85**	**-**	**7.70**	Probable **combination of gas, oil**, and/or **salt** water
0.4	**-**	**0.5**	0.923	-	1.153	**7.70**	**-**	**9.63**	Probable **oil** or **salt water**

2.3 Shut-in procedures

Before killing the kick, the well shut-in procedures must be performed as soon as one or more warning signs is detected and confirmed. The main reason to have the shut-in procedure is to minimize kick volume entering into a wellbore when well control situation occurs. Basically, the faster kick is recognized and shut in a well, the better well control situation is manage.

The amount of wellbore influx that enters the wellbore are minimized when personnel respond quickly to shut the well in. It is the fact that a small amount of kick entering into the wellbore will result in lower initial shut-in casing pressure and lower casing pressure while circulating. Shutting in the well is not an option even though it is shallow gas kicks and the surface casing has not been set yet because it can very quickly turn into a big blowout. If the well is shut-in, the result is almost certainly to be a combination of underground and surface blowout, where the well is fractured and the blowout breaks through the formation up to the surface.

There are two types of shut-in procedures in the well which are “soft” shut-in and “hard” shut-in. In the “soft” shut-in procedure, it is done by closing the BOP with open the choke valve and once the preventers are closed, then closing the valve slowly. The problem of delay in closing the valve to obtain complete shut-in of the well is the additional influx from the formation into the wellbore.

For the “hard” shut-in procedure, it is accomplished by immediately closing the blow-out preventer (BOP) with close the choke valve after the pumps are shut down. By performing the “hard” shut-in, the fluid flow is stop abruptly and this procedure produce a pressure wave, called a “water hammer” through the mud. It was believed that the pressure in the wellbore could damage the formation and underground blowout may occur. But until now the “water hammer” effect has no proven substance.

Based on the experimental and theoretical study, it can conclude that the “hard” shut-in procedures a better than the “soft” shut-in procedures. The reason is the “soft” shut-in procedures permit continuous influx into the wellbore while the procedures are executed. Another reason is longer closing time and human error associated with closing and opening the valves will increase the risk by taking a larger kick. This is why the “hard” shut-in is the preferred method.

The shut-in pressure can be used in the following equations:

Drillpipe pressure,

$$P_f = SIDPP + P_{dph} \tag{2}$$

Casing pressure,

$$P_f = SICP + P_{ah} + P_i \tag{3}$$

In the shut-in procedure, when the well is shut-in, gas will migrate from bottom to the top of the well. The estimated and actual gas migration rate in a shut-in well can be calculated with these following equations:

Estimated rate of gas migration,

$$V_g = 12e^{(-0.37 \times MW)} \tag{4}$$

Actual rate of gas migration,

$$V_g = \left(\frac{Increasing\ in\ casing\ pressure, psi/hr}{MW\ gradient, psi/ft}\right) \tag{5}$$

2.4 Killing kick

After the well is shut-in, the pit gain is recorded. Then pressure on the drillpipe and on the casing is recorded when the pressures have stabilized. The values of pressure are then used to identify kick fluid, estimate the height of the kick column and calculate the new kill-mud weight needed to stabilize the formation pressure.

The most common kill procedures have been developed are the Driller's Method and the Engineer's Method (Wait-and-Weight Method). There are some differences, but both methods are used to maintaining the formation pressure constant while the kick is circulating out and replacing the old mud with kill-weight mud.

The Driller's Method uses the old mud to circulate out the influx and it requires two circulations to kill the well. The first circulation of the Driller's Method is performed using the original mud. The original mud from the pits displaces the influx and then second circulation takes place where the old mud replaced with new kill mud.

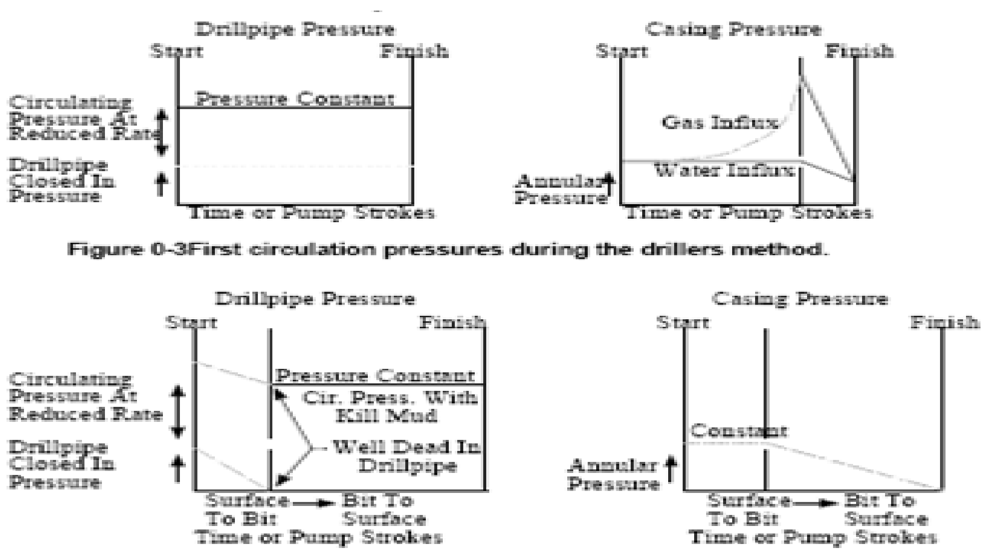

Figure 5: Driller's Method, pressure behaviour of first and second circulation

The Engineer's Method uses only one circulation to kill the well. The mud weight is increased to kill density in the suction pit. Before starting to circulate out the influx, the crew members have to wait the kill-weight mud is weighted up and then replacing the old mud with new kill mud, all in just one circulation.

Before starting of a kill operation, a kill sheet should be filled out completely. During planning and executing a well kill, kill sheets are really helpful. For the new method of well kill procedure, only calculated surface casing pressure has been modified in the kill sheet. By generating the kill sheets, it would draw charts and graphs, calculate the critical well control parameters, and estimate maximum surface and pit gain volumetric. A standard kill sheets will show a straight line on the graph of pump pressure vs. pump strokes.

It is important to calculate pump strokes from surface to bit and from bit to surface in order to get total time of the pump to kill the well.

Surface to bit strokes,

$$Strokes\ (stk) = \frac{Drill\ string\ volume\ (bbl)}{Pump\ Output\ (bbl/stk)} \tag{6}$$

Bit to surface strokes,

$$Strokes\ (stk) = \frac{Annular\ volume\ (bbl)}{Pump\ Output\ (bbl/stk)} \tag{7}$$

Total stokes,

$$Total\ strokes\ (stk) = \left[\frac{Drill\ string\ vol.(bbl) + Annular\ vol.(bbl)}{Pump\ output\ (bbl/stk)}\right] \tag{8}$$

Total time to pump from surface to bit and from bit to surface,

$$Total\ time\ (mins) = \frac{Total\ strokes}{Stokes\ per\ minute} \tag{9}$$

The velocity of the fluid is also another parameter that has to calculate. From this calculation also the time can be known for a particular depth.

Inside drillpipe or drill collar,

$$V = \left[\frac{Q}{2.448 \times ID^2}\right] \tag{10}$$

Annular (between casing and drillpipe or drill collar),

$$V_a = \left[\frac{Q}{2.448 \times (OD^2 - ID^2)}\right] \tag{11}$$

Once the SIDPP and SICP and pit gain are recorded, start immediately to circulate the well using the Driller's Method. In an ERD well, the choice of kill methods is not a big issue because the casing shoe is close to TVD. In ERD well, there are three different sections to kill the well. Firstly, the kill mud weight is start circulating at a high rate for a short time to remove gas from the horizontal section of the wellbore. After that, slowly reduce the pump speed when the choke pressure starts increase rapidly.

When the gas is expected to be circulated out of the horizontal section and into the hold section, the kill rate can be reduced to a normal rate, usually 1/3 to ½ of normal drilling rate. In the hold section, the gas will remove and flow co-currently and to circulate the gas out of the well, the normal kill rate should be sufficient.

The drillpipe pressure decline schedules are prepared for one pre-determined kill circulation rate. If various circulation rates are used, pressure decline schedules have to be made for each circulation rate. The reason for this is the friction pressure loss which increases with circulation rate.

Recommended procedures of well control in ERD well are as follow:

1. Kick is detected by warning signs such as increase in ROP, increase in flow rate, cut mud weight, changing of string weight, and MWD.

2. The type of influx can be determined by using the Equation 1:
   After get the gradient of influx, the influx type can be referred from Table 1.

3. Once a kick and the influx type is detected and confirmed, performed the "hard" shut-in of the well.

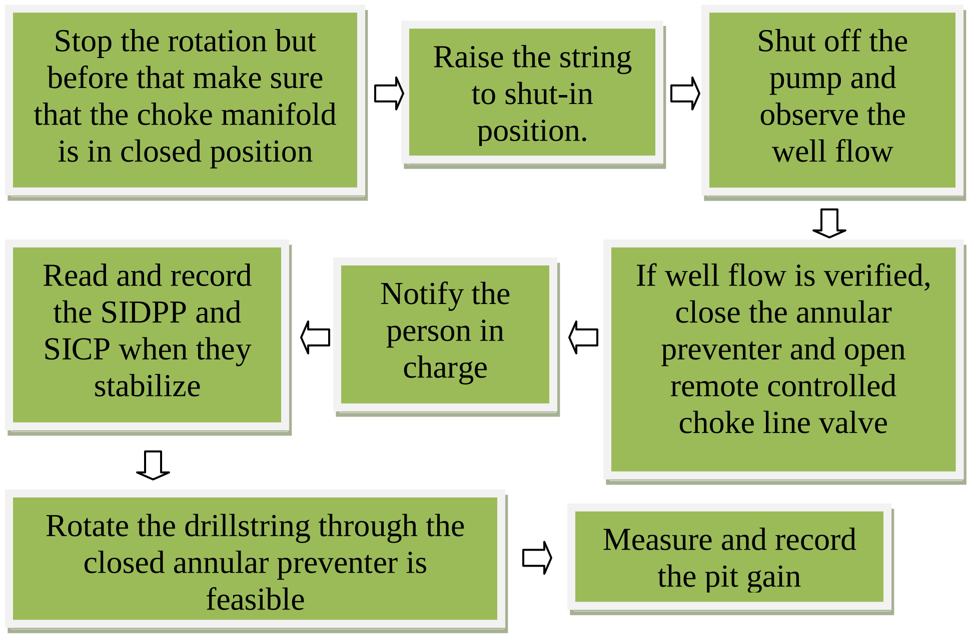

Figure 6: "Hard" shut-in procedure

"Soft" shut-in is not preferred in ERD well because the delay in closing the choke to obtain the well completely shut-in caused additional influx from formation into the wellbore.

4. Once the well is shut-in, it is necessary to generate the kill sheet for planning and executing a well kill. The kill sheet examples as in Appendix A, Figures 23, 24 and 25. The formulas used in kick and kill procedures are presented in Appendix B.

5. After made the calculations as in step (2), start directly to circulate using the Driller's Method. The reason of the Engineer's Method is not preferable is the mixing kill weight mud is expected to take a longer period of time and hole cleaning problem is another concern.

6. The first circulation is performed using the original mud to kill the mud density. The kill mud is starting to circulate when the kill mud volume has been achieved.

7. The choke is opened slightly and the pump speed increased to the kill rate while the annulus pressure is kept constant by controlling the choke until the kill mud has reached the bit.

8. Next, kill the well at a high kill rate for a short time just to remove the gas from the horizontal section of the wellbore. In order to get high kill rate, the flow rate of the mud have to increase by increasing the pump rate control. The mud also must be used heavy mud or in other word increase the density of the mud.

9. Then the kill rate reduced to normal rate which is usually 1/3 to ½ of normal drilling rate. This reduction of kill rate is performed when the gas is expected to be circulated out of the horizontal section and into the hold section.

10. For the last section which at the hold section, the gas will migrate to the surface and again normal kill rate is performed to circulate the gas out of the well.

11. When all the influx and original mud have been displaced from the wellbore, open widely the choke and the pump should be shut down. At this time, SIDPP and SICP should be zero. If so, the well should then be observed for flow.

12. The kick is now killed and the wellbore save from blowout.

13. After that, pump the new mud into the wellbore to be circulated to condition the hole, and at the same time the trip margin (if any) should be added.

CHAPTER 3
METHODOLOGY

3.1 Research Methodology

In the process of preliminary works, first of all, the student should has a better understanding the well control procedure in conventional well and also in ERD well. In order to get the information, the student has to refer various good books and journals that related to the well control procedure. Then, the student should learn the Landmark's software by using WELLPLAN software training manual. The training for the students who are using the Landmark's software is provided. The training was given from Halliburton's staffs and it was two weeks course. For this study, the student have to focus only in Drilling chapter that contain investigate well control using the Well Control Analysis Module.

Two sections were focused in this project which vertical section (Section 1) and horizontal section (Section 2). For the Final Year Project 2 (FYP 2), research methodologies are divided into two parts:

1. Run the WELLPLAN software.
2. Determine kill rate and kill results using VBA.

3.1.1 Run the WELLPLAN software

Procedure

Procedure 1: Filled up the basic information

a) Wellpath editor (wellbore trajectory).
   - Kick off well with 3˚/100 ft, Azimuth at 61˚ at 1082.7 ft. Build angle from 0˚ to 78˚ from 1082.7 ft to 3608.9 ft at 61˚ Azimuth. Then hold at 78˚ Tangent at 61˚ Azimuth to well MD at 15652.9 ft.

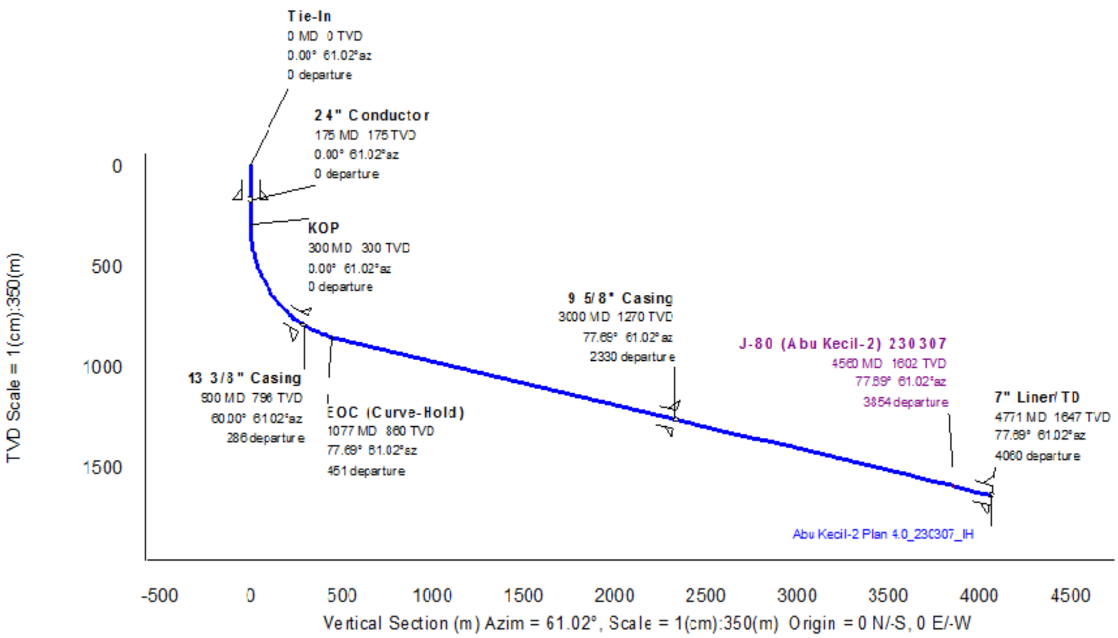

Figure 7: UTP-2 well trajectory

b) Pore pressure and fracture pressure.

Table 2: Pore pressure and fracture pressure

TVD (ft)	Pore Pressure (psi)	EMW (ppg)	Fracture Pressure (psi)	EMW (ppg)
338.9	147.68	8.38	236.15	13.40
574.2	250.20	8.38	400.09	13.40
2611.7	1138.06	8.38	1833.40	13.50
4166.9	1815.76	8.38	3076.82	14.20
4364.7	1901.97	8.38	3222.91	14.20
4459.9	1943.43	8.38	3293.16	14.20
4499.0	1960.48	8.38	3322.06	14.20
4538.6	1975.38	8.37	3351.31	14.20
4902.8	2131.34	8.36	3620.23	14.20
5155.4	2238.49	8.35	3806.77	14.20
5237.5	2271.38	8.34	3894.58	14.30
5257.1	2299.06	8.41	3881.88	14.20

c) Hole section editor and string section editor.

- The vertical section of this well is with conductor casing, 24" at 574.1 ft and open hole (OH) section, 16" at 1476.4 ft. The last section of this well for this study is intermediate casing, 9 5/8" at 9842.5 ft and the open hole section, 8 ½" at 15652.9 ft.
- The string as in Appendix, Figures 26 and 36.

d) Fluid editor.

- Mud density, mud type, rheology model, rheology data, temperature, plastic viscosity, and yield point.

e) Geothermal gradient.

- Surface ambient temperature, mudline temperature and temperature at well TVD.

f) Circulating system.

- Surface equipment and mud pump.

Next step is using the Well Control Analysis module. The Well Control Analysis has three modes which are Expected Influx Volume, Kick Tolerance and Kill Sheet. The processes involve in Well Control Analysis firstly determine the kick type. After that estimate the influx volume and detection time of the expected kick volume also known. Next step is analyzing the kick tolerance and evaluate pressures as a kick is circulated out. Then generate the kill sheet and lastly the report is generated from the kill sheet information.

Procedure 2: Run the Well Control Analysis

a) Expected Influx Volume mode.

i) Kick Class Determination

- It is used to calculate the bottom-hole pressure (BHP) and kick type at the moment an influx occurs.
- The gradient of the initial mud is specified in Setup field.

- The circulation flowrate and kick interval gradient is specified in Input fields.
- Kick class, circulating BHP, static BHP, kick interval pressure and underbalanced kick interval is automatic calculated by the software.

ii) Influx Volume Estimation

- There are Setup, Kick Detection Method, Reservoir, Reaction Times and Results tab in this parameter.
- Kick Detection Method, the Flowrate Variation field detects flow-out increase and Volume Variation detects pit volume increases. The Flowrate Variation is used in this study.
- Reaction Times is tab for estimation of crew reaction when kick occur.
- Results tab is use to displays the results of total influx volume, influx volume at detection and detection time.

iii) Temperature Distribution

b) Kick Tolerance mode.

- Type of influx, kill rate, total influx volume, kill mud gradient and depth interval to check are specified in the Kick Tolerance mode.
- From this analysis mode:
    - Wellbore pressures for depth of interests while circulating a kick can be determined.
    - The maximum pressure at each point in the wellbore can be determined.
    - The allowable influx volume based on formation breakdown pressure can be determined.
    - The maximum pressure for various influx sizes at several wellbore depths can be calculated.
    - Shoe setting depth can be estimated based on formation breakdown gradients.
    - The wellbore pressures in the well assuming all mud in the well was displaced by gas can be calculated.

- The results can be viewed by using the animation. The schematic showed animated simulation of the process for circulating the influx to the surface.

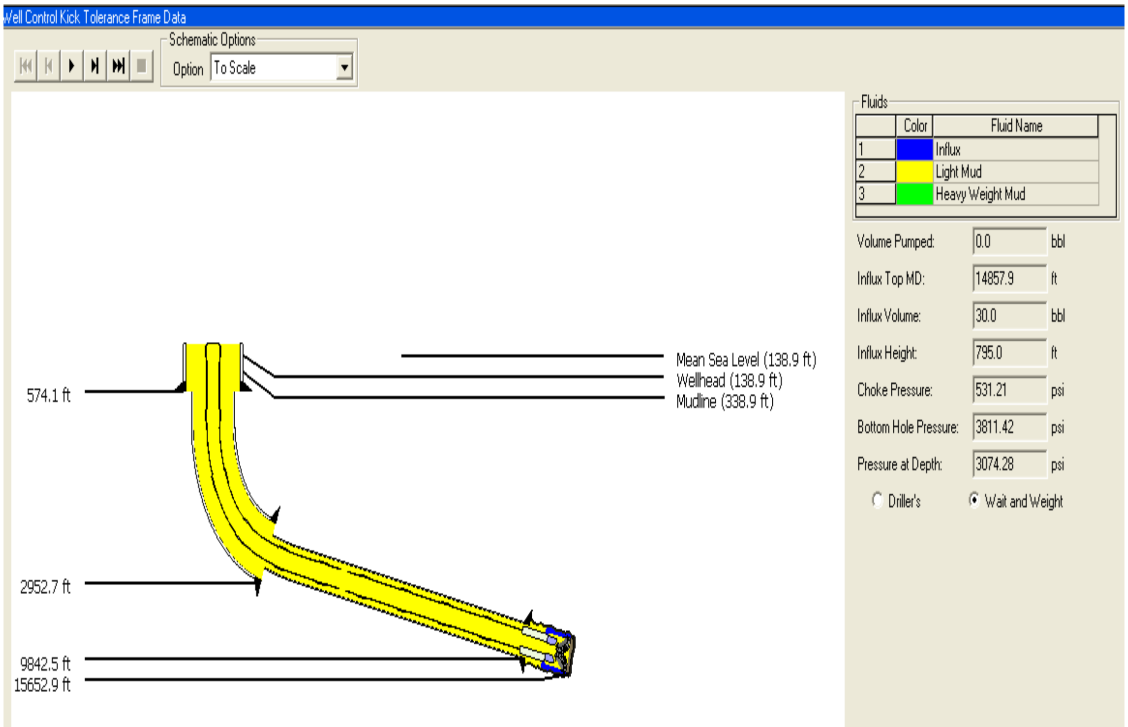

Figure 8: Animation before kill the well

c) Kill Sheet mode.

i) Well Control Setup

- Slow pump information is reviewed.

ii) Kill Sheet dialog

- Kick Parameters part (MD of kick, pit gain, SIDPP, SICP), Weight Up part (mud tank volume, weighting material, weighting material specific gravity, weighting material weight per sack, weighting material mixing capacity) and Pump Details part (pump name, volume/stroke, speed, pressure, volumetric efficiency) is filled up.
- String Annulus Volumes part, String Volume part and Kill Mud Weight Details are specified by the software.

iii) Kill Graph

- Kill graph is reviewed.

iv) Kill Sheet Report

- Kill sheet report is generated to review the summary of the information specified in the Kill Sheet dialog. It also reports the summary of weak links, weight-up requirement for kill mud and trip margin, pump stroke schedule, and volume and capacities.

3.1.2 Determine kill rate and kill result from theoretical calculations using VBA.

Procedure

Procedure 1: Determine the suitable kill rate

a) ECD is taken from the maximum fracture pressure.
b) New ECD is determined by minus 0.5 safety margin.
c) Friction pressure loss, P_f is determined by using the following equation:

$$ECD = EMW + \left(\frac{P_f}{0.052 \times TVD}\right) \quad (12)$$

d) From the study, the kill rate, Q can be calculated by using the following equation, Eq. 13 and 14:

Assume the flow regime is turbulent flow.

$$P_{\mathrm{f1}} = \frac{8.91 \times 10^{-5} \times MW^{0.8} \times Q^{1.8} \times PV^{0.2} \times L_{\mathrm{dp}}}{(D_{\mathrm{h}} - D_{\mathrm{p}})^3 \times (D_{\mathrm{h}} + D_{\mathrm{p}})^{1.8}} \quad (13)$$

$$P_{\mathrm{f2}} = \frac{8.91 \times 10^{-5} \times MW^{0.8} \times Q^{1.8} \times PV^{0.2} \times L_{\mathrm{dc}}}{(D_{\mathrm{h}} - D_{\mathrm{c}})^3 \times (D_{\mathrm{h}} + D_{\mathrm{c}})^{1.8}} \quad (14)$$

Procedure 2: Determine the kill result

a) Figure 9 shows the process of getting the kill result.

b) The calculations are presented in Appendix C.

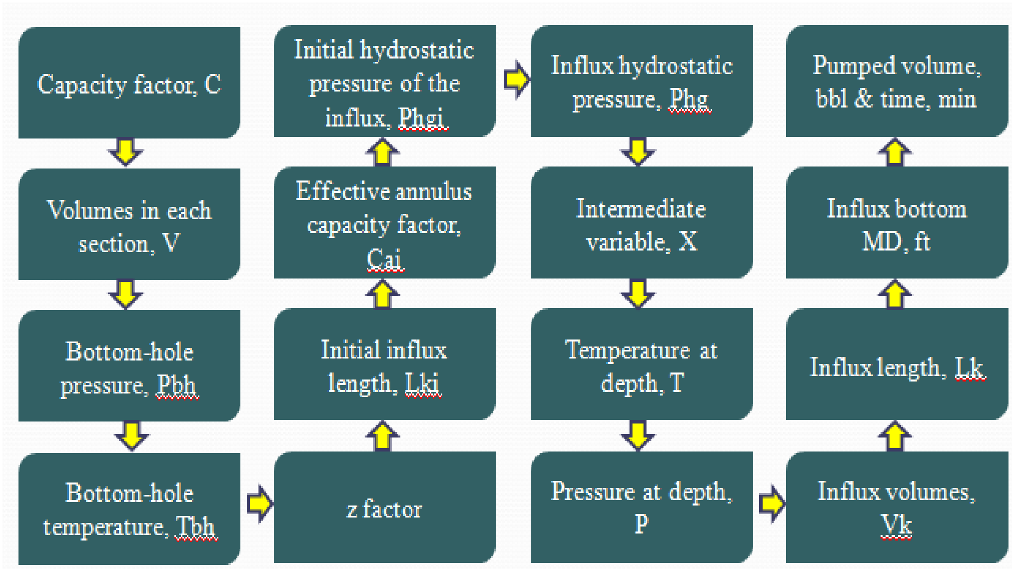

Figure 9: Determination of kill result

Procedure 3: Develop the VBA by using Procedure 1 and 2

a) Coding is written in the VBA.

b) The results are compared with WELLPLAN software.

3.2 Project Work Flow

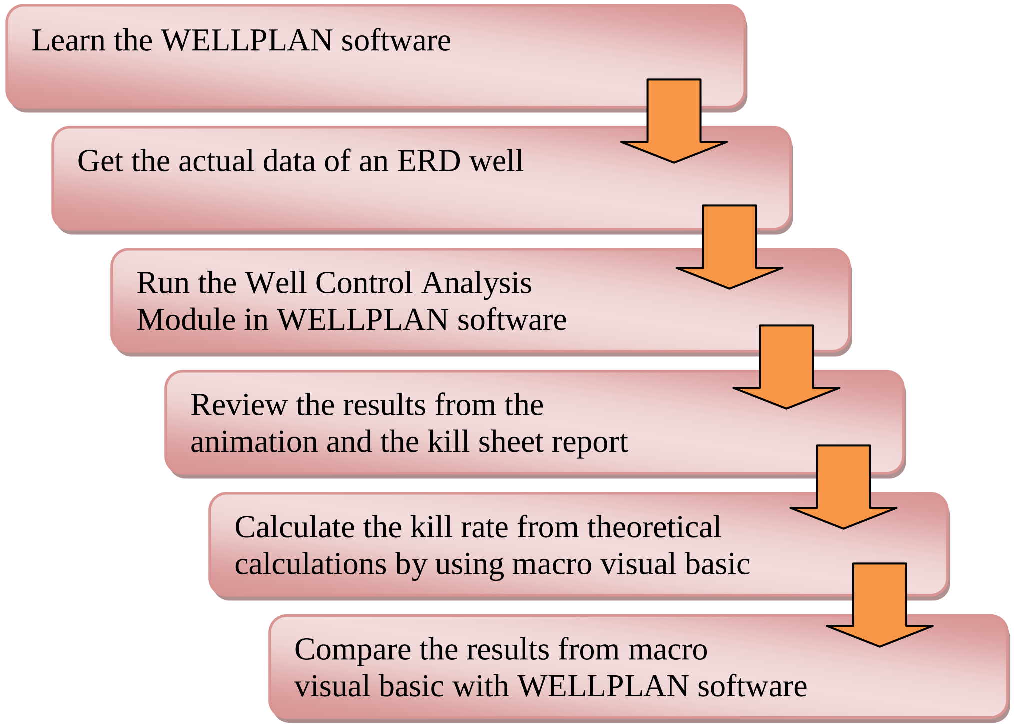

Figure 10: Flow diagram of Project Work Flow

3.3 Equipment and Tools

This project is is not dealing with equipment but only use tools which are two softwares. The project is divided into two parts, first run the WELLPLAN software. For the second part, macro visual basic is used to compare the results with WELLPLAN.

3.4 Project Activities

Below are the activities for this project:

a) Get the actual data from lecturer
b) Run the WELLPLAN
c) Fill up the basic information fields as Procedure 1 in 3.1.3.

d) Make sure the kick class is kick while drilling by changing the kick interval gradient value

e) Changing parameters in kick tolerance with different values such as kill rate and total influx volume

f) Determine the maximum allowable volume of kick

g) Evaluate the annulus pressure, and safe drilling depth

h) Evaluate the performance of Driller's Method in animation

i) Generate kill sheet

j) Review the summary of the well control

k) Design coding of theoretical calculations in VBA

l) Compare some the results obtained from the WELLPLAN with the theoretical calculations in VBA.

3.5 Gantt chart

Below is the Gantt chart for FYP 2.

Table 3: Gantt chart for FYP2

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Project Work Continues	■	■	■	■	■	■	■	Mid-Semester Break								
2	Submission of Progress Report									●							
3	Project Work Continues									■	■	■	■	■			
4	Pre-EDX												●				
5	Submission of Draft Report													●			
6	Submission of Dissertation (soft bound)														●		
7	Submission of Technical Paper														●		
8	Oral Presentation															●	
9	Submission of Project Dissertation (Hard Bound)																●

● Suggested milestone

■ Process

CHAPTER 4
RESULTS AND DISCUSSION

The information and basic data that are used as follows:

Table 4: UTP-2 Well data

	Section 1 (Vertical Section)	Section 2 (ERD)
MD (ft)	1476.4	15652.9
TVD (ft)	1470.9	5257.1
Casing Size (in)	24	9 5/8
Open Hole Size (in)	16	8 ½
MW (ppg)	10.1	10.8
Initial Mud Gradient (psi/ft)	0.525	0.561
Rheology Model	Bingham Plastic	Bingham Plastic
Rheology Data	PV and YP	PV and YP
Temperature (˚F)	88.0	88.0
Plastic Viscosity (cp)	18.0	18.0
Yield Point (lbf/100 ft^2)	22.0	18.0
Kick Interval Gradient (psi/ft)	0.535	0.641
Kick Class	Kick While Drilling	Kick While Drilling
Influx Volume (bbl)	18.0	30.0
Kill Mud Gradient (psi/ft)	0.540	0.650
Circulation Flowrate (gpm)	900	620
Kill Rate (gpm)	450	350
SIDPP (psi)	100	300
SICP (psi)	300	500

4.1 Effect of varying total influx volume in kick tolerance and geometry of the wellbore

4.1.1 Introduction

For this investigation, UTP-2 well data was used as the base case for the typical ERD well profile. Assuming that varying total influx volume in kick tolerance would have the most effect on annulus pressure during kick occur. The experiment was performed with several simulation runs for different total influx volume with the ERD section and vertical section in the same well. All of the experiment was performed with gas is the type of influx.

Example of experiment:

Table 5: Range variables of total influx volume

	Section 1	Section 2
Total influx volume (bbl)	15, 30, 50	15, 30, 50

4.1.2 Results

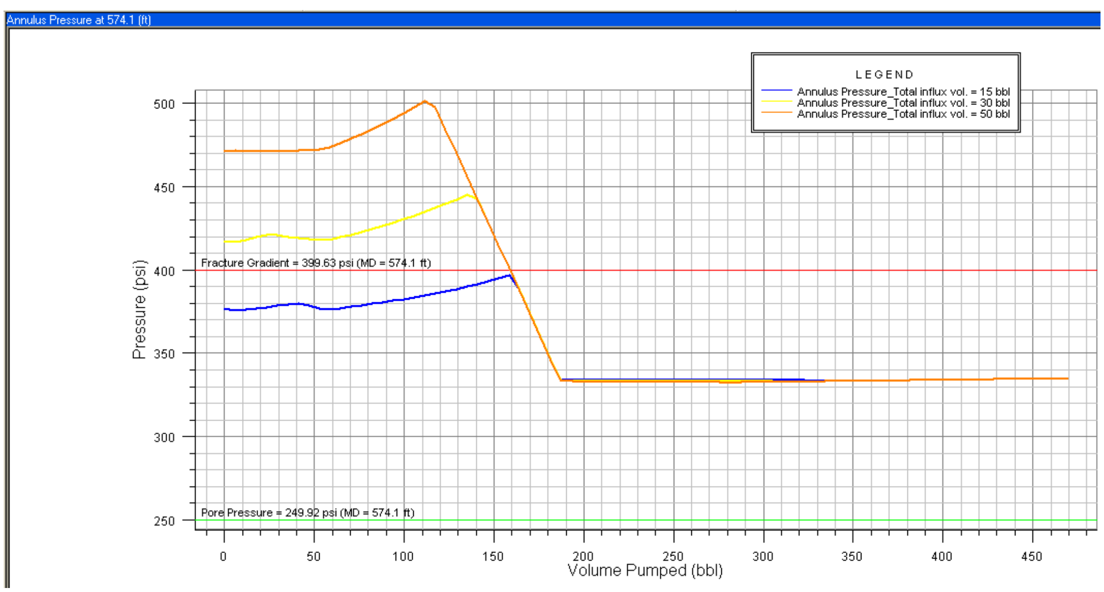

Figure 11: Annulus pressure for various total influx volume (Section 1)

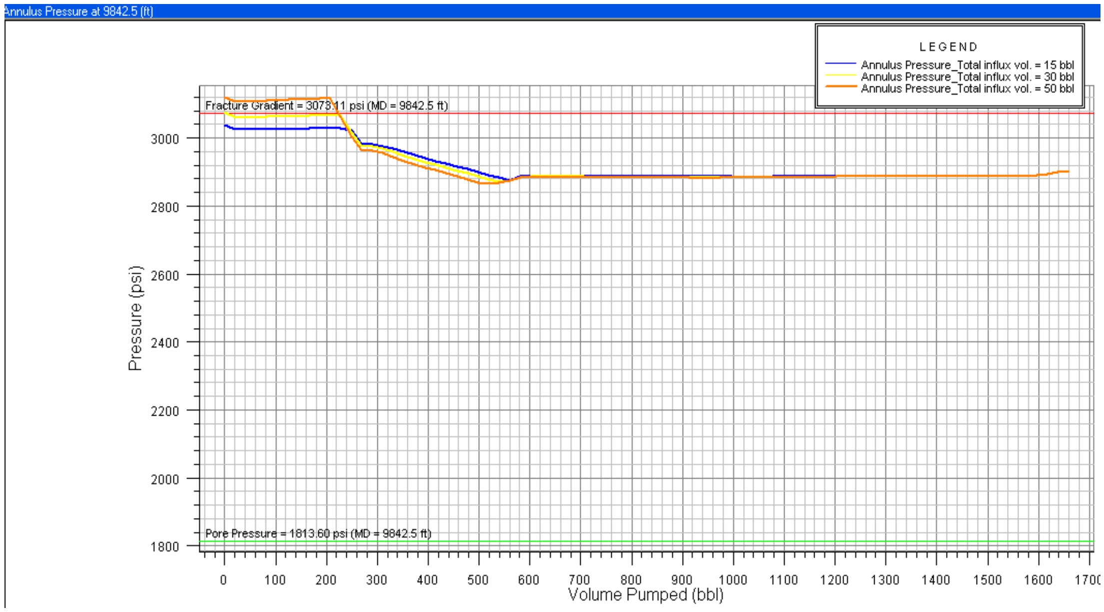

Figure 12: Annulus pressure for various total influx volume (Section 2)

4.1.3 Discussions

From Figures 11 and 12, the increasing in total influx volume causes an increase in the annulus pressure. Besides, the annulus pressure increase with TVD of the well is higher. For the Section 1, a 15 bbl influx volume is the only acceptable influx volume for the Section 1 because the annulus pressure is not exceeds the fracture pressure. The highest annulus pressure for 15 bbl kick is 397 psi and the fracture pressure is 399.62 psi. 30 bbl and 50 bbl are not acceptable because their pressure too high. However, the results show the annulus pressure of 30 bbl influx volume is not exceeds the fracture pressure for Section 2. It is because the Section 2 has longer open holes section and it is allowable more additional influx in the wellbore. The fracture pressure at MD 9842.5 ft is 3073.1 psi and annulus pressure for 50 bbl is 3120 psi.

The maximum allowable influx volumes for both sections are presented in Appendix, Figures 37 and 38.

4.2 Kill rate

4.2.1 Introduction

For this project, one of the objectives is to see the results from both WELLPLAN and theoretical calculations. The high kill rate must be performed in ERD well in order to remove gas kick from horizontal section. Table 6 shows the range variables of kill rate for this project.

Example of experiment:

Table 6: Range variables of kill rate

	Section 1	Section 2
Kill Rate (gpm)	300, 450, 500	210, 310, 350

4.2.2 Results

WELLPLAN, Section 1 (450 gpm).

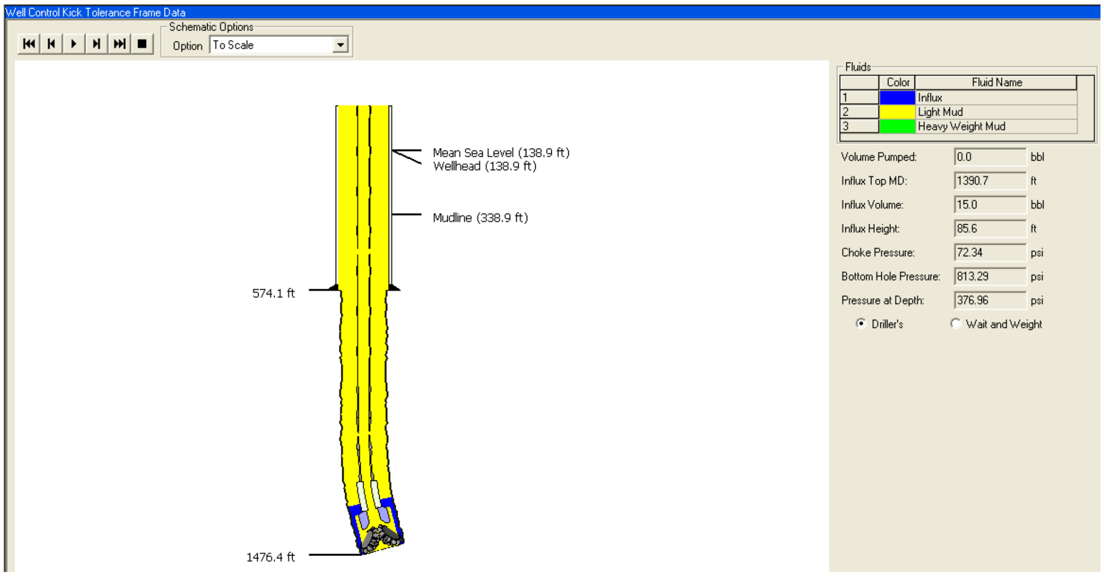

Figure 13: Animation of schematic before kill the well (Section 1)

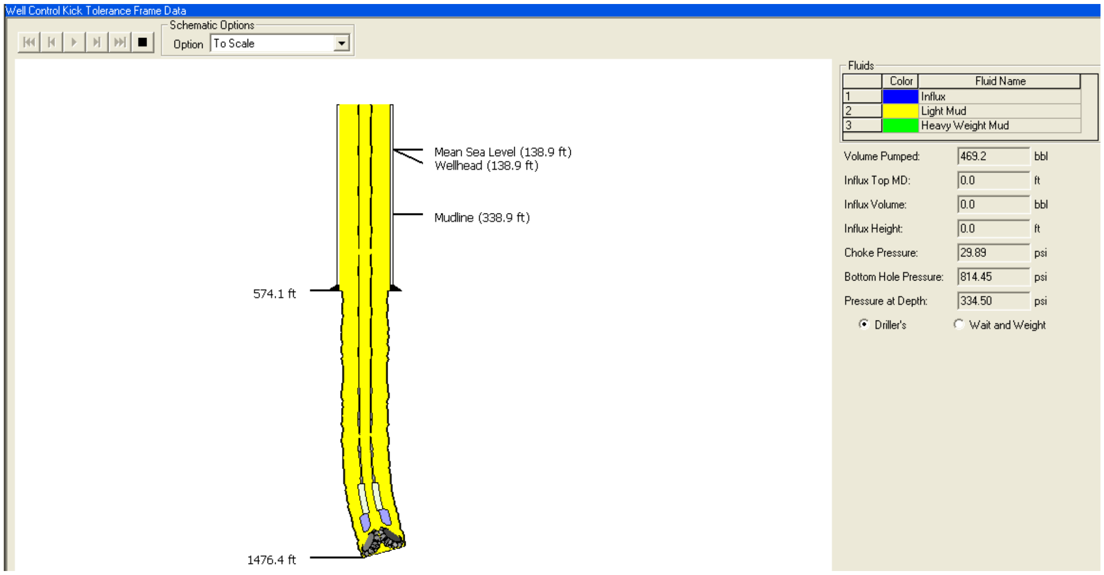

Figure 14: Animation of schematic after completely kill the well (Section 1)

WELLPLAN, Section 2 (350 gpm).

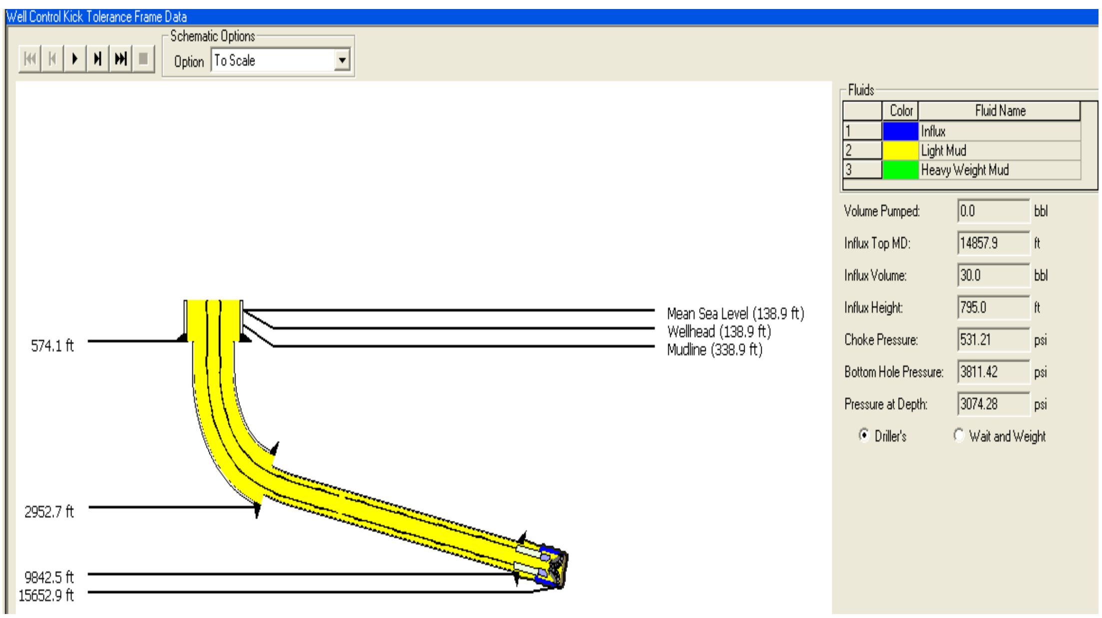

Figure 15: Animation of schematic before kill the well (Section 2)

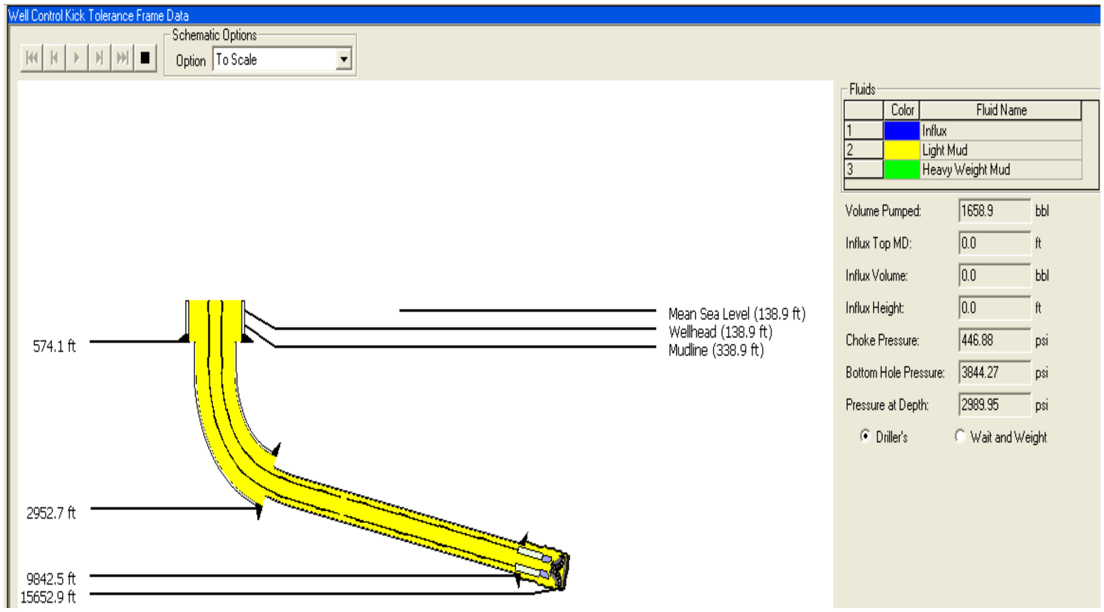

Figure 16: Animation of schematic after completely kill the well (Section 2)

Theoretical calculations.

The theoretical calculations were performed with using Procedure 1 in 3.1.2.

Section 1:

a) Max ECD = 13.5 ppg.

b) ECD = 13.0 ppg.

c) P_f = 221.8 psi

d)

$$P_{f1} = \frac{8.91 \times 10^{-5} \times 10.1^{0.8} \times Q^{1.8} \times 18^{0.2} \times 1167.2}{(16.0 - 5.43)^3 \times (16.0 + 5.43)^{1.8}}$$

$$= 4.013 \times 10^{-6} \times Q^{1.8}$$

$$P_{f2} = \frac{8.91 \times 10^{-5} \times 10.1^{0.8} \times Q^{1.8} \times 18^{0.2} \times 309.2}{(16.0 - 8.0)^3 \times (16.0 + 8.0)^{1.8}}$$

$$= 2.000 \times 10^{-7} \times Q^{1.8}$$

$$P_{f1} + P_{f2} = 6.013 \times 10^{-6} Q^{1.8} = 221.8 \text{ psi}$$

$$Q = 15989.6 \text{ gpm}$$

Table 7: Max Q calculations using VBA (Section 1)

	B	C	D	E	F	G
3	MD (ft)	1476.4	TVD (ft)	1470.9		
4	Temp (˚F)	88.0	Temp Gradient (˚F/100 ft)	2.20	Compressibility Factor, z	1
5	Plastic Viscosity (cp)	18.0	Yield Point (lbs/100 ft2)	22.0	SG	0.6
6	1. Conductor Csg MD (ft)	574.1	1. Conductor Csg TVD (ft)	574.1	ID Csg 1 (in)	22.000
7	2. Intermediate Csg MD (ft)	0.0	2. Intermediate Csg TVD (ft)	0.0	ID Csg 2 (in)	0.000
8	3. Production Csg MD (ft)	0.0	3. Production Csg TVD (ft)	0.0	ID Csg 3 (in)	0.000
9	OH Length (ft)	902.3	Open Hole (in)	16.000		
10	Drillpipe Length (ft)	1167.2	OD Drillpipe (in)	5.430	ID dp (in)	4.780
11	Drill collar Lentgh (ft)	309.2	OD Drill collar (in)	8.000	ID dc (in)	3.000
12	MW (ft)	10.1	MW Gradient (psi/ft)	0.525	Kick Interval Gradient (psi/ft)	0.530
13	Pit Gain (bbl)	15.0	SIDPP (psi)	100.0	SICP (psi)	300.0
14	Max ECD (ppg)	13.5	ECD (ppg)	13.0		
15	Friction Pressure Loss (psi)	221.8	Kill Rate (gpm)	15989.6	Lk (ft)	80.4
16						
17	A	4.013E-06				
18	B	1.9998E-06			Calculate	

Section 2:

Maximum ECD, ECD, and P_f are as in Table 8.

a) P_{f1} $= 4.938 \times 10^{-3} Q^{1.8}$

P_{f2} $= 4.329 \times 10^{-4} Q^{1.8}$

$P_{f1} + P_{f2}$ $= 5.371 \times 10^{-3} Q^{1.8} = 815.0$ psi

Q $= 755.8$ gpm

Table 8: Max Q calculations using VBA (Section 2)

	B	C	D	E	F	G
3	MD (ft)	15652.9	TVD (ft)	5404.6		
4	Temp (˚F)	88.0	Temp Gradient (˚F/100 ft)	2.20	Compressibility Factor, z	1
5	Plastic Viscosity (cp)	18.0	Yield Point (lbs/100 ft2)	18.0	SG	0.6
6	1. Conductor Csg MD (ft)	574.1	1. Conductor Csg TVD (ft)	574.1	ID Csg 1 (in)	22.000
7	2. Intermediate Csg MD (ft)	2952.7	2. Intermediate Csg TVD (ft)	2612.2	ID Csg 2 (in)	12.400
8	3. Production Csg MD (ft)	9842.5	3. Production Csg TVD (ft)	4165.9	ID Csg 3 (in)	8.681
9	OH Length (ft)	5810.4	Open Hole (in)	8.500		
10	Drillpipe Length (ft)	15359.3	OD Drillpipe (in)	5.430	ID dp (in)	4.780
11	Drill collar Lentgh (ft)	293.6	OD Drill collar (in)	6.750	ID dc (in)	3.000
12	MW (ft)	10.8	MW Gradient (psi/ft)	0.562	Kick Interval Gradient (psi/ft)	0.600
13	Pit Gain (bbl)	30.0	SIDPP (psi)	300.0	SICP (psi)	500.0
14	Max ECD (ppg)	14.2	ECD (ppg)	13.7		
15	Friction Pressure Loss (psi)	815.0	Kill Rate (gpm)	755.8	Lk (ft)	832.5
16						
17	A	0.0049376				
18	B	0.00043294			Calculate	

4.2.3 Discussion

For the Section 1 and Section 2 in WELLPLAN, all the experiment kill rates are enough to completely remove the gas kick from the wellbore. From the researches that have been done by reading books and journals, the kill rate should be high rate for Section 2 to remove the gas kick. However, all the tested kill rates are enough to displace the kick. The influx volume and influx height are 15 bbl and 85.6 ft for Section 1 with 450 gpm kill rate. The required KMW to displaced gas volume is 469.2 bbl. Meanwhile in Section 2 with kill rate of 350 gpm, the influx height is 795 ft and 30 bbl of influx volume. The pumped volume kill mud is 1658.9 bbl to completely remove the gas kick. The differences in kill rate effects the P_{wf}. By increasing the Q, the P_{wf} will increase. Other kill rate results are presented in Appendix, Figures 27, 29, 31 and 33.

Next, for the theoretical calculations, by using the Equation X, the calculated kill rate for Section 1 is 15988.8 gpm and 755.8 gpm for Section 2. The result for Section 1 is too high and not realistic. One of the reasons the result too high is because the flow regimes in the annulus of drillpipe and drill collar are assumed to be turbulent flow. If the flow regime is laminar, the calculations would be different. The student assumed turbulent flow because there is not enough data to use in friction pressure loss formula for laminar flow.

Meanwhile as Table 8, the maximum Q is realistic and the result is suitable to remove the gas kick at the end of the well. It is because the value is higher than 1/3 and ½ of normal drilling circulation rate. Once the gas kick is removed at the end of the well, the kill rate is reduced between 1/3 and ½ of drilling circulation rate. The process is the user has to fill the required data in green field and the macro visual basic will made the calculations when click the “Calculate” button. Then the results appear in the yellow field.

4.3 Kill Result

4.3.1 Results

WELLPLAN.

Table 9: WELLPLAN kill result table (Section 1)

	A	B	C	D	E	F	G	H	I	J
4–5	Pumped Volume (bbl)	Influx Top Measured Depth (ft)	Influx Bottom Measured Depth (ft)	Influx Height (ft)	Influx Volume (bbl)	Influx Press (psi)	Influx Press Grad (psi/ft)	Choke Pressure (psi)	Bottom-hole Pressure (psi)	Pressure at Depth (psi)
6	0.0	1390.7	1476.4	85.6	15.0	801.56	0.014	72.34	813.29	376.96
7	5.9	1357.9	1440.7	82.8	15.2	783.43	0.014	71.12	813.41	375.74
8	11.7	1325.1	1408.5	83.4	15.5	767.02	0.014	71.59	813.42	376.21
9	17.6	1292.3	1376.7	84.4	15.7	750.74	0.014	72.27	813.41	376.89
10	23.5	1259.5	1345.3	85.8	16.0	734.57	0.013	73.13	813.39	377.74
11	29.3	1226.5	1313.8	87.3	16.3	718.34	0.013	74.02	813.37	378.63
12	35.2	1193.5	1282.4	88.9	16.6	702.07	0.013	74.94	813.36	379.55
13	41.1	1161.4	1250.9	89.5	16.9	685.76	0.013	75.37	813.36	379.99

Cont.

	A	B	C	D	E	F	G	H	I	J
4–5	Pumped Volume (bbl)	Influx Top Measured Depth (ft)	Influx Bottom Measured Depth (ft)	Influx Height (ft)	Influx Volume (bbl)	Influx Press (psi)	Influx Press Grad (psi/ft)	Choke Pressure (psi)	Bottom-hole Pressure (psi)	Pressure at Depth (psi)
72	387.1	0.0	120.8	120.8	53.3	93.27	0.002	93.04	813.74	333.78
73	393.0	0.0	107.5	107.5	47.5	86.30	0.002	86.11	813.82	333.86
74	398.8	0.0	94.2	94.2	41.6	79.33	0.002	79.18	813.9	333.94
75	404.7	0.0	81.0	81.0	35.7	72.36	0.001	72.24	813.98	334.02
76	410.6	0.0	67.7	67.7	29.9	65.39	0.001	65.3	814.05	334.1
77	416.4	0.0	54.4	54.4	24.0	58.42	0.001	58.36	814.13	334.18
78	422.3	0.0	41.1	41.1	18.2	51.45	0.001	51.41	814.21	334.26
79	428.2	0.0	27.8	27.8	12.3	44.48	0.001	44.46	814.29	334.33
80	434.0	0.0	14.5	14.5	6.4	37.51	0.001	37.5	814.37	334.41
81	439.9	0.0	1.3	1.3	0.6	30.54	0.001	30.54	814.45	334.49
82	445.7	0.0	0.0	0.0	0.0	29.89	0.001	29.89	814.45	334.5
83	451.6	0.0	0.0	0.0	0.0	29.89	0.001	29.89	814.45	334.5

Table 10: WELLPLAN kill result table (Section 2)

	A	B	C	D	E	F	G	H	I	J
3–4	Pumped Volume (bbl)	Influx Top Measured Depth (ft)	Influx Bottom Measured Depth (ft)	Influx Height (ft)	Influx Volume (bbl)	Influx Press (psi)	Influx Press Grad (psi/ft)	Choke Pressure (psi)	Bottom-hole Pressure (psi)	Pressure at Depth (psi)
5	0.0	14857.9	15652.9	795.0	30.0	3479.22	0.063	531.21	3811.42	3074.28
6	20.7	14405.5	15056.7	651.3	30.3	3407.91	0.063	516.06	3828.41	3059.48
7	41.5	13953.9	14611.5	657.6	30.6	3354.65	0.062	516.81	3828.17	3060.2
8	62.2	13503.0	14166.3	663.3	30.9	3301.4	0.062	517.49	3827.96	3060.85
9	82.9	13051.8	13721.1	669.3	31.2	3248.14	0.061	518.21	3827.81	3061.57
10	103.7	12600.4	13275.8	675.5	31.5	3194.89	0.061	518.95	3827.65	3062.32
11	124.4	12148.7	12830.6	681.9	31.8	3141.63	0.06	519.72	3827.49	3063.1
12	145.2	11696.8	12385.4	688.6	32.1	3088.38	0.059	520.52	3827.32	3063.92
13	165.9	11244.6	11940.2	695.6	32.4	3035.12	0.059	521.35	3827.14	3064.77

Cont.

	A	B	C	D	E	F	G	H	I	J
3/4	Pumped Volume (bbl)	Influx Top Measured Depth (ft)	Influx Bottom Measured Depth (ft)	Influx Height (ft)	Influx Volume (bbl)	Influx Press (psi)	Influx Press Grad (psi/ft)	Choke Pressure (psi)	Bottom-hole Pressure (psi)	Pressure at Depth (psi)
62	1182.0	119.8	398.5	278.7	123.1	670.46	0.015	598.93	3842.92	2988.6
63	1202.7	61.1	351.5	290.5	128.3	644.11	0.015	605.54	3842.86	2988.54
64	1223.4	0.0	304.6	304.6	134.5	617.76	0.014	613.49	3842.8	2988.47
65	1244.2	0.0	257.6	257.6	113.7	591.41	0.013	588.03	3843.02	2988.7
66	1264.9	0.0	210.6	210.6	93.0	565.06	0.012	562.47	3843.25	2988.93
67	1285.7	0.0	163.7	163.7	72.3	538.71	0.011	536.83	3843.48	2989.15
68	1306.4	0.0	116.7	116.7	51.5	512.36	0.011	511.11	3843.71	2989.38
69	1327.1	0.0	69.8	69.8	30.8	486.01	0.01	485.31	3843.93	2989.61
70	1347.9	0.0	22.8	22.8	10.1	459.66	0.009	459.45	3844.16	2989.84
71	1368.6	0.0	0.0	0.0	0.0	446.88	0.009	446.88	3844.27	2989.95
72	1389.3	0.0	0.0	0.0	0.0	446.88	0.009	446.88	3844.27	2989.95
73	1410.1	0.0	0.0	0.0	0.0	446.88	0.009	446.88	3844.27	2989.95
74	1430.8	0.0	0.0	0.0	0.0	446.88	0.009	446.88	3844.27	2989.95

VBA

Table 11: VBA kill result table (Section 1)

	I	J	K	L	M	N	O	P	Q
4	Pumped vol. (bbl)	Time (min)	TVD (ft)	Influx Vol. (bbl)	Influx Length (ft)	Influx Top MD (ft)	Influx Bottom Measured	Bottom-Hole Pressure (psi)	Pressure at Depth (psi)
5	0.0	0.0	1470.9	15.0	80.4	1396.0	1476.4	872.5	905.8
6	20.7	3.8	1370.9	15.2	69.3	1313.0	1382.3	872.5	855.2
7	41.4	7.6	1270.9	16.1	73.3	1214.9	1288.3	872.5	804.8
8	62.1	11.4	1170.9	17.1	77.9	1116.3	1194.2	872.5	754.7
9	82.8	15.3	1070.9	18.3	83.1	1017.0	1100.1	872.5	704.9
10	103.5	19.1	970.9	19.6	89.0	917.0	1006.0	872.5	655.5
11	124.2	22.9	870.9	21.1	95.8	816.1	912.0	872.5	606.6
12	144.9	26.7	770.9	22.8	103.7	714.2	817.9	872.5	558.2
13	165.6	30.5	670.9	24.9	113.0	610.9	723.8	872.5	510.5
14	186.3	34.3	570.9	27.3	123.9	505.9	629.8	872.5	463.7
15	207.0	38.1	470.9	30.1	136.9	398.8	535.7	872.5	418.1
16	227.7	42.0	370.9	33.6	152.5	289.1	441.6	872.5	373.7
17	248.4	45.8	270.9	37.7	171.4	176.1	347.5	872.5	331.2
18	269.1	49.6	170.9	42.8	194.5	59.0	253.5	872.5	290.7
19	289.8	53.4	70.9	49.0	222.6	0.0	159.4	872.5	253.0
20	310.5	57.2	0.0	54.1	122.5		112.5	872.5	228.5

Table 12: VBA kill result table (Section 2)

	I	J	K	L	M	N	O	P	Q
4	Pumped vol. (bbl)	Time (min)	TVD (ft)	Influx Vol. (bbl)	Influx Length (ft)	Influx Top MD (ft)	Influx Bottom Measured	Bottom-Hole Pressure (psi)	Pressure at Depth (psi)
5	0.0	0.0	5404.6	30.0	832.5	14820.4	15652.9	3335.2	3663.7
6	20.7	3.8	5304.6	27.6	664.7	14490.0	15154.6	3335.2	3611.7
7	41.4	7.6	5204.6	27.9	672.1	13984.2	14656.4	3335.2	3559.7
8	62.1	11.4	5104.6	28.2	679.8	13478.3	14158.1	3335.2	3507.9
9	82.8	15.3	5004.6	28.6	687.7	12972.1	13659.8	3335.2	3456.1
10	103.5	19.1	4904.6	28.9	695.8	12465.8	13161.5	3335.2	3404.5

Cont.

	I	J	K	L	M	N	O	P	Q
4	Pumped vol. (bbl)	Time (min)	TVD (ft)	Influx Vol. (bbl)	Influx Length (ft)	Influx Top MD (ft)	Influx Bottom Measured	Bottom-Hole Pressure (psi)	Pressure at Depth (psi)
43	786.6	144.9	1604.6	47.8	395.5	424.6	820.2	3335.2	1832.7
44	807.3	148.8	1504.6	48.7	403.5	245.2	648.7	3335.2	1789.6
45	828.0	152.6	1404.6	49.7	411.8	65.4	477.2	3335.2	1746.9
46	848.7	156.4	1304.6	50.8	420.4	0.0	305.8	3335.2	1704.8
47	869.4	160.2	1204.6	51.8	429.3	0.0	134.3	3335.2	1663.1
48	890.1	164.0	1104.6	52.9	438.5	0.0	0.0	3335.2	1622.0
49	910.8	167.8	1004.6	54.1	448.0	0.0	0.0	3335.2	1581.4
50	931.5	171.6	904.6	55.3	457.9	0.0	0.0	3335.2	1541.3
51	952.2	175.5	804.6	56.5	468.1	0.0	0.0	3335.2	1501.8
52	972.9	179.3	704.6	57.8	478.7	0.0	0.0	3335.2	1462.9

4.3.2 Discussions

The initial influx height for Sections 1 and 2 in WELLPLAN are 85.6 ft and 795.0 ft. Meanwhile results in VBA show the influx height is 80.4 ft for Section 1 and 832.5 ft. The percentage error of VBA result for Section 1 is about 6.1% and Section 2 is 4.7%. Reason for the error is because the bottom-hole assembly (BHA) components. VBA is only considering the drillpipe and drill collar but in WELLPLAN it takes other BHA components such as stabilizer, crossover, jar and etc.

Next, the results of volume pumped to completely remove the influx are comparing. Results in WELLPLAN show the kill mud volume pumped are 445.7 bbl for Section 1 and 1368.6 bbl for Section 2 as showed in Tables 9 and 10. VBA results show for Section 1 is around 320 bbl and 890.1 bbl for Section 2. For this comparison, the percentage errors are 28.2% for Section 1 and for Section 2 is about 35%. The explanation for this error is because the inclination of the well. VBA are not developing in taking consideration of the well inclination. Other reasons are the bottom-hole pressure was assumed constant for all TVD and the choke pressure was neglected.

4.4 Kill Sheet

4.4.1 Introduction

WELLPLAN provides its own kill sheet to ease the user to review the summary of well control. The kill mud weight is calculated by the software.

4.4.2 Results

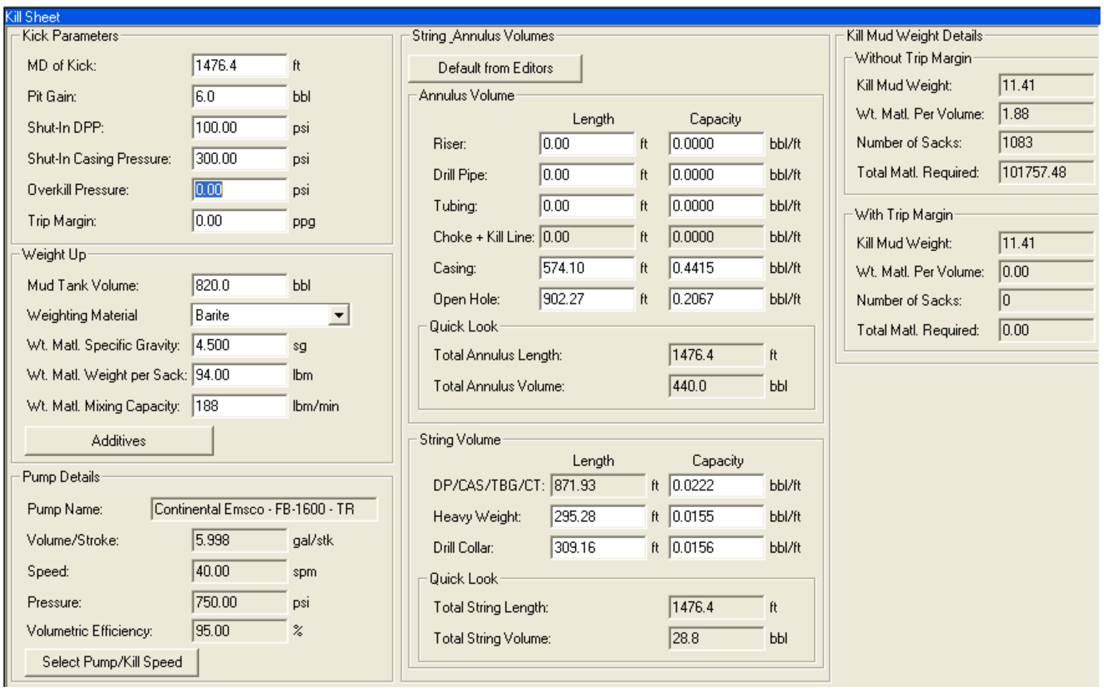

Figure 17: Kill sheet for Section 1

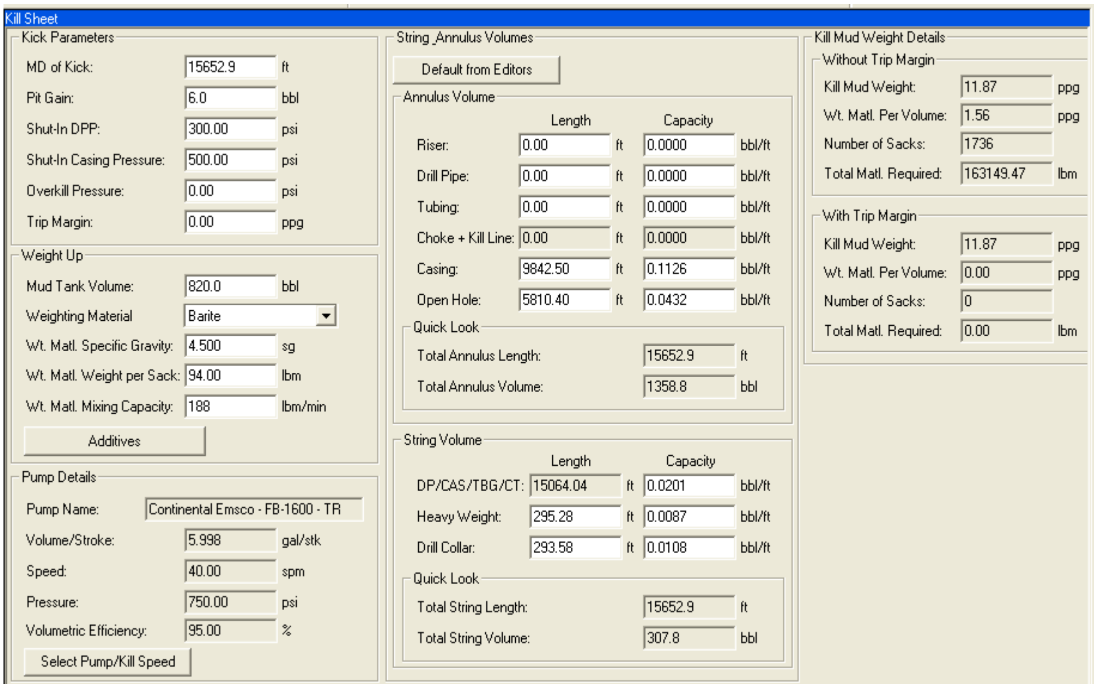

Figure 18: Kill sheet for Section 2

4.4.3 Discussion

The values in kick parameters, weight up and pump details are set to be constant for both sections. The string annulus volumes are specified by the software when click the ‘Default from Editors’ button. The value of string annulus volumes are taken from the String Editor. Then the KMW details also are specified by the software.

The KMW for Section 1 is 11.41 ppg and the number of sacks required to pump into the well is 1083. If the assumption of SIDPP is high for example 300 psi, KMW will increase as in Appendix, Figure 35. Thus, the number of sacks and total material required also increase.

For the Section 2, the calculated KMW to kill the well is 11.87 ppg. The mud weight increases 1.07 ppg and the number of sacks required is 1736. The total material required to pump from surface to the target depth is 163149.47 lbm and the value of it depends on the number of sacks. Meanwhile the weight material per volume is depends on the KMW and MW.

4.5 Kill Graph and Well Control Summary

4.5.1 Introduction

Kill graph is one of the important things in well control. It shows the standpipe pressure as the kill mud is pumped down the string until it hits the annulus. Well control summary shows pumping schedule and pump stroke summary. The pump stroke can be used in well control operations to use drillpipe pressure schedules for maintaining the bottom-hole pressure at a proper value. During well control operations, the bottom-hole pressure must be maintained at a value slightly higher than the formation pressure during kill operations.

4.5.2 Results

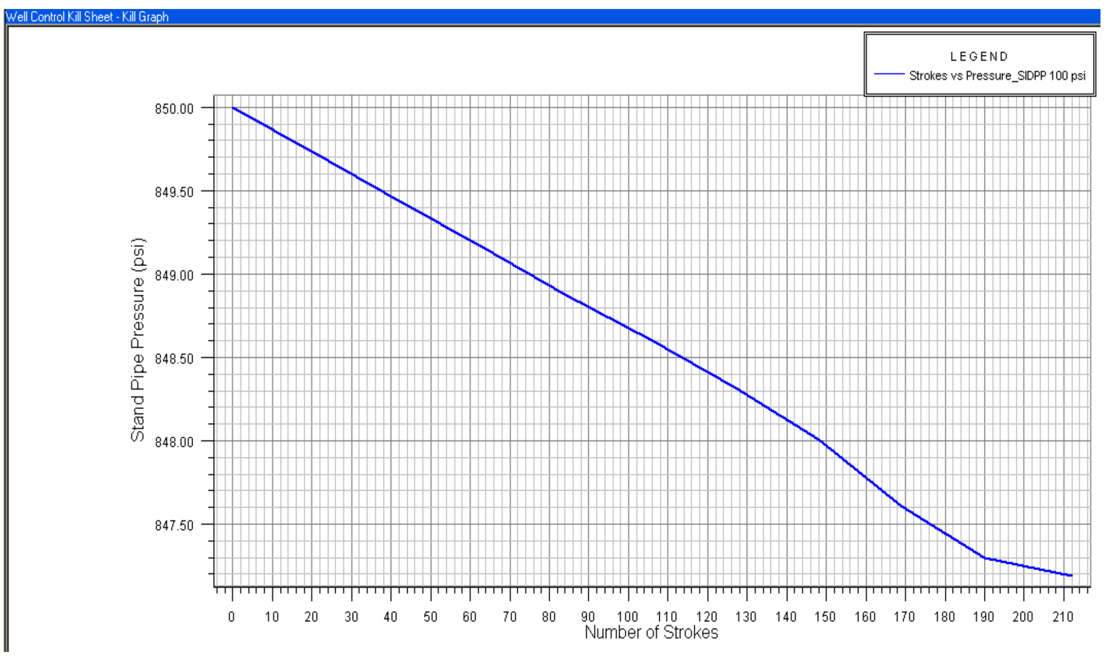

Figure 19: Kill graph for Section 1 with kill rate 450 gpm and 40 spm (Section 1)

Table 13: Pumping schedule (Section 1)

Measured Depth (MD) (ft)	True Vertical Depth (TVD) (ft)	Time (min)	No. of Strokes	Stand Pipe Pressure (psi)
0.0	0.0	0.0	0	850.00
129.7	129.7	0.5	21	849.72
259.3	259.3	1.1	42	849.44
389.0	389.0	1.6	63	849.16
518.6	518.6	2.1	84	848.88
648.3	648.3	2.7	106	848.60
777.9	777.9	3.2	127	848.32
922.8	922.8	3.7	148	848.01
1,107.9	1,107.9	4.2	169	847.61
1,292.3	1,291.0	4.8	190	847.30
1,476.4	1,470.8	5.3	212	847.19

Table 14: Pump strokes summary (Section 1)

	Strokes	Volume (bbl)	Time (min)
Fill String	212	28.8	5.3
Fill Open Hole	1,375	186.5	34.4
Fill Casing	1,868	253.5	46.7
Fill Annular Drill Pipe	0	0.0	0.0
Fill Annular Tubing	0	0.0	0.0
Fill Riser	0	0.0	0.0
Fill Choke / Kill Line	0	0.0	0.0
Fill Annulus	3,243	440.0	81.1
Total	3,455	468.8	86.4

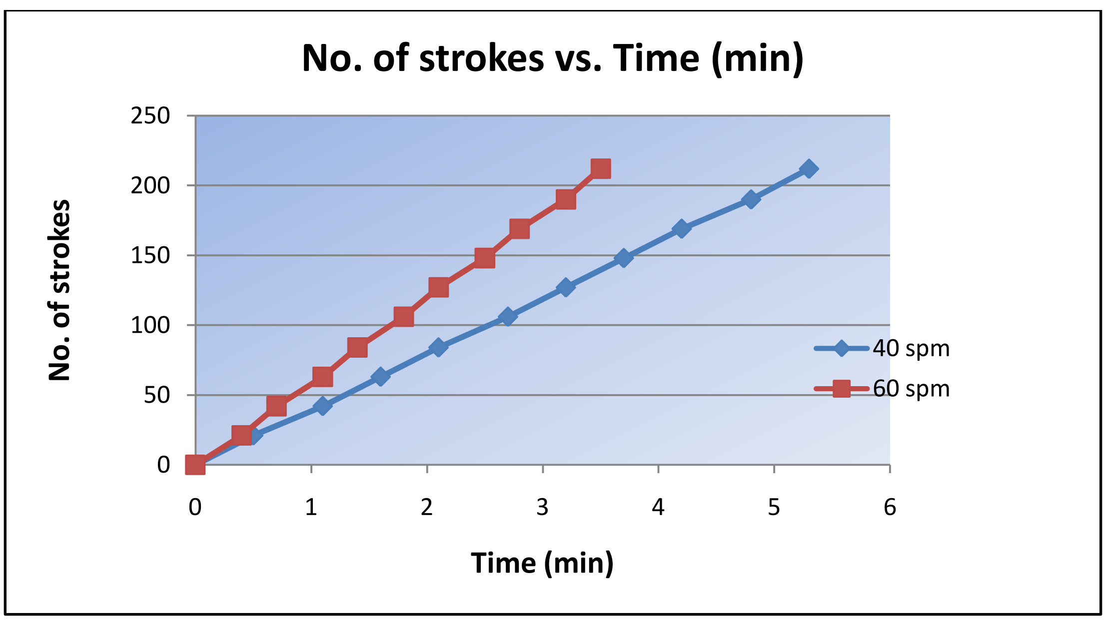

Figure 20: No. of strokes vs. Time (Section 1)

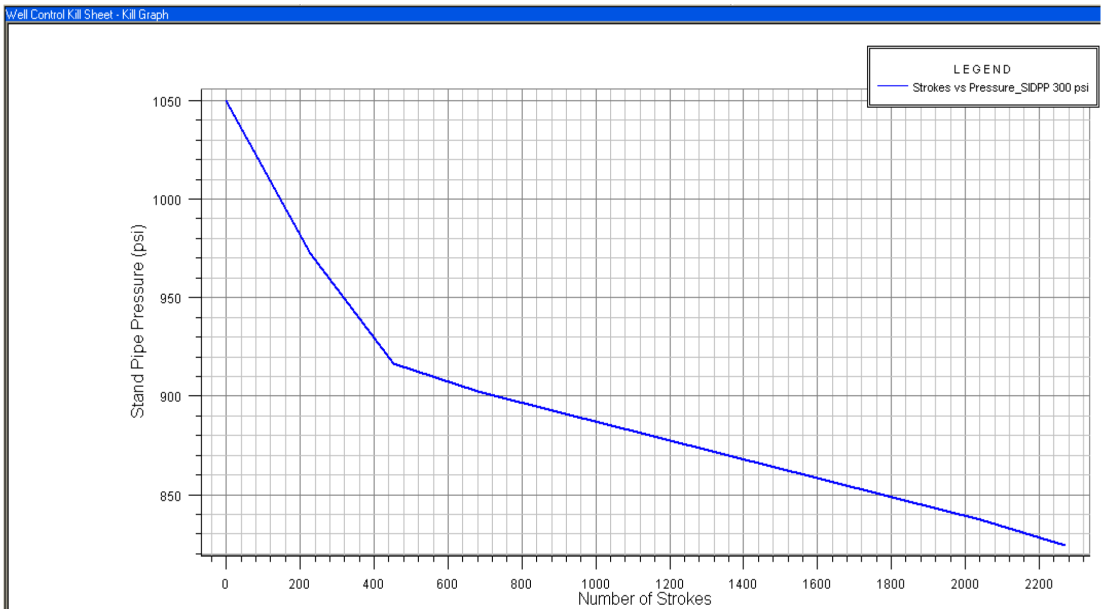

Figure 21: Kill graph for Section 2 with kill rate 350 gpm and 40 spm (Section 2)

Table 15: Pumping schedule (Section 2)

Measured Depth (MD) (ft)	True Vertical Depth (TVD) (ft)	Time (min)	No. of Strokes	Stand Pipe Pressure (psi)
0.0	0.0	0.0	0	1,050.00
1,535.1	1,527.3	5.7	226	972.50
3,070.3	2,667.8	11.3	453	916.48
4,605.4	3,049.5	17.0	680	902.57
6,140.6	3,376.8	22.7	907	891.68
7,675.7	3,704.1	28.4	1,134	880.79
9,210.8	4,031.4	34.0	1,361	869.90
10,746.0	4,358.7	39.7	1,588	859.01
12,281.1	4,686.0	45.4	1,815	848.12
13,816.3	5,013.3	51.1	2,042	837.23
15,652.9	5,404.9	56.7	2,269	824.20

Table 16: Pump strokes summary (Section 2)

	Strokes	Volume (bbl)	Time (min)
Fill String	2,269	307.8	56.7
Fill Open Hole	1,849	250.8	46.2
Fill Casing	8,167	1,107.9	204.2
Fill Annular Drill Pipe	0	0.0	0.0
Fill Annular Tubing	0	0.0	0.0
Fill Riser	0	0.0	0.0
Fill Choke / Kill Line	0	0.0	0.0
Fill Annulus	10,016	1,358.8	250.4
Total	12,285	1,666.6	307.1

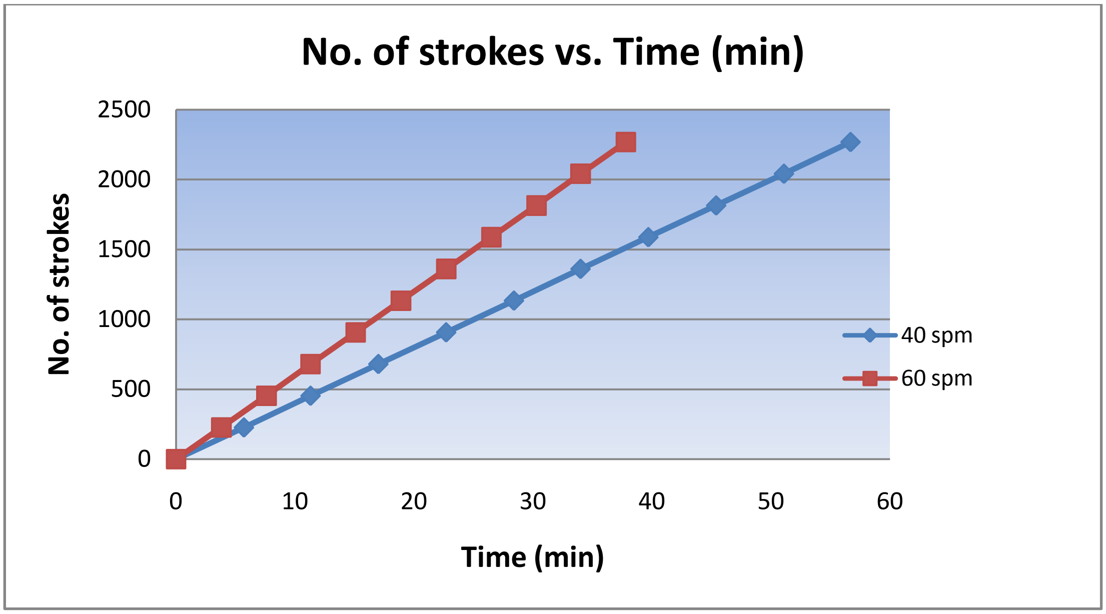

Figure 22: No. of strokes vs. Time (Section 2)

4.5.3 Discussion

From the above results, in order to kill the well for Section 1, 212 strokes needed to fill the KMW inside the drill string. The total strokes for the well control operations is 3455 and it takes 86.4 minutes. The standpipe pressure is start at 850.00 psi at 0 strokes and during the last stroke, the standpipe pressure reduce to 847.20 psi. The reduction of standpipe pressure is too small which is about 3 psi. The factor of this situation is because it takes only a few minutes just to transport the KMW to the end of the well. If the strokes per min high, time taken for the well control operations is less as presented in Figures 20 and 22.

Next, Figure 21 illustrate 2269 strokes are required in Section 2 to kill the well and it takes 56.7 minutes and 307.8 bbl from the surface to the target depth. Before starts kill the well, the standpipe pressure is 1050 psi and it reduces to 824.2 psi when the MW reaches the target depth. The total time for the well control operation is 307.1 minutes and the number of strokes is 12285 from the surface to the target depth and from the target depth to the surface. Besides, the total volumes of kill mud to pumped to whole well is 1666.6 bbl.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The conclusion of this study is the well control procedures in ERD wells are different from the conventional wells. For the kick detection, there are no difference between conventional wells and ERD wells. But for the killing kick, it is difference between both wells.

In ERD wells, the Driller's Method is the preferred method to kill the well because the Engineer's Method takes a long time to wait until the pressure stabilized. Kill procedures in conventional wells are usually 1/3 and ½ of the normal drilling rate. In ERD wells, the kill rate is high at the horizontal section then normal kill rate is performed between horizontal section and into the hold section, and in the hold section.

But for this study, the gas kick still can be displaced at the end of the well by using 1/3 or ½ of the circulation rate. One of the reasons is maybe the inclination angle of this well is not high. Besides, for the theoretical calculations, the flow regime is assumed to be turbulent in the annulus. That is the reason why the value of flowrate in Equation X is not realistic. In addition, the data is not enough for example the $\theta600$ and $\theta300$ data is unknown.

From this study, the procedure of kill the well is as follows:

1. Performed "hard" shut-in of the well once a kick is detected and confirmed.
2. Read the SIDPP, SICP and pit gain when the pressures have stabilized.
3. Verify the KMW using the current the SIDPP and increase the density of the mud in the pits.
4. Start circulates by using the Driller's Method.

5. Use high rate for a short time to displace the gas kick from the horizontal section of the wellbore.
6. When the choke pressure starts to increase to increase rapidly, the pumps have to slow down. Then continue with a kill rate which 1/3 or ½ of the normal circulation rate.
7. Continue holding the constant casing pressure until the strokes reach the no. of strokes that fill the drillstring.
8. Observe the drillpipe pressure and maintain constant until the KMW circulates the whole well which is referring to the total no. of strokes.
9. After complete the circulations, shut off the pump and close the well in.

WELLPLAN is really useful software in analyzing the drilling operations and it is friendly user. This software can improved the drilling performance through reduction of kicks, stuck pipe, lost circulation and blowouts for significant reductions in non-productive time. It will reduce the time to analyze the problem when using the WELLPLAN. By having proper well control procedures, we can avoid losses of valuable natural resources, increased drilling costs, environmental damages, increased regulations, injuries to personnel and the vast consequence is loss of life.

5.2 Recommendation

For the recommendation, the next step would be to investigate the factors that have effect on valve pressures and gas-return rates for different kick scenarios. The factors are the effect of kick size, water depth, circulation kill rate, holes size and also kick intensity. This research also can use the WELLPLAN software to run and get the better result.

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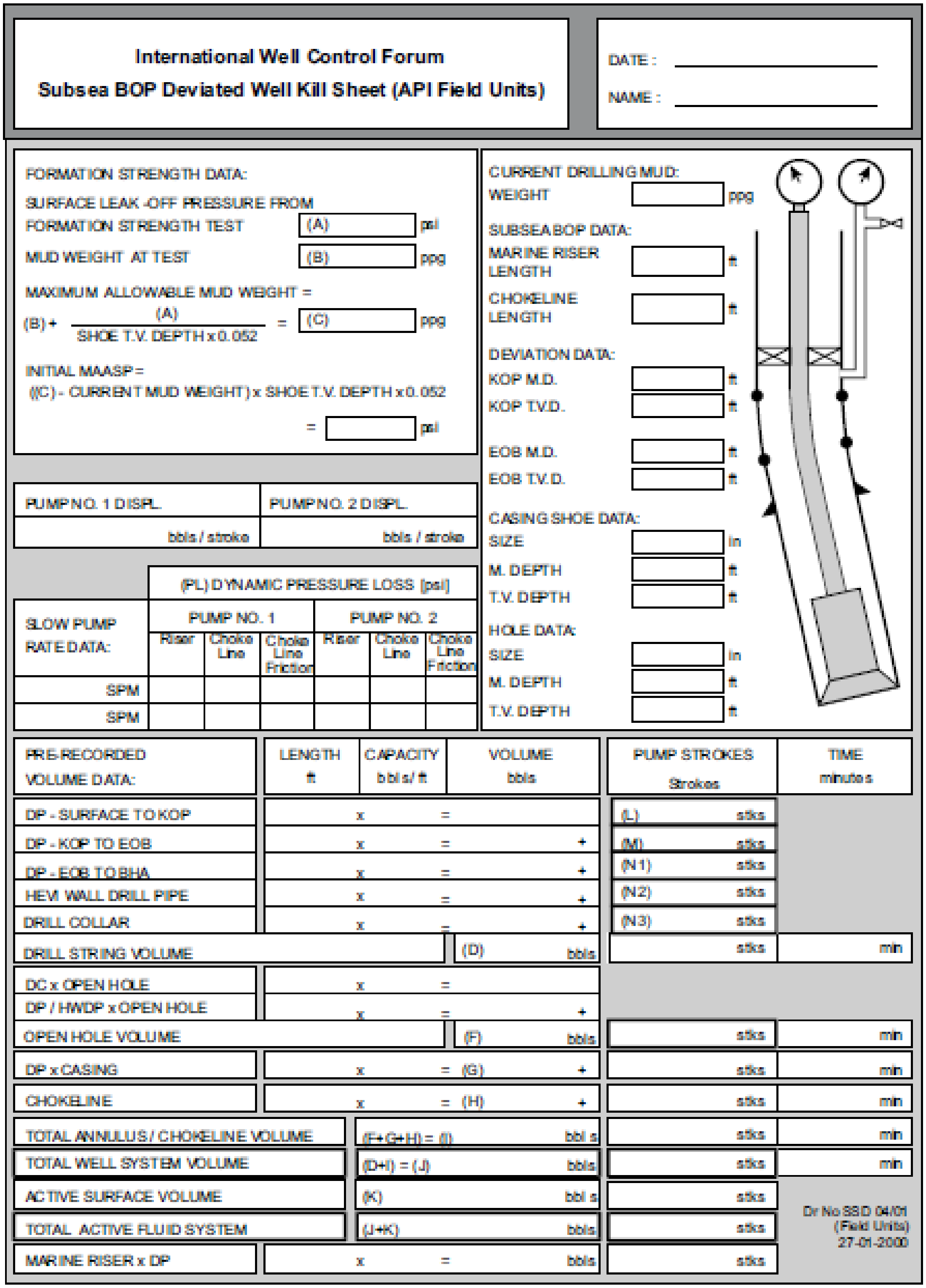
APPENDIX A



International Well Control Forum
Subsea BOP Deviated Well Kill Sheet (API Field Units)

DATE : ____________

NAME : ____________

FORMATION STRENGTH DATA:

SURFACE LEAK -OFF PRESSURE FROM FORMATION STRENGTH TEST (A) psi

MUD WEIGHT AT TEST (B) ppg

MAXIMUM ALLOWABLE MUD WEIGHT =

(B) + (A) / SHOE T.V. DEPTH x 0.052 = (C) ppg

INITIAL MAASP =
((C) - CURRENT MUD WEIGHT) x SHOE T.V. DEPTH x 0.052
= psi

PUMP NO. 1 DISPL.	PUMP NO. 2 DISPL.
bbls / stroke	bbls / stroke

SLOW PUMP RATE DATA:	(PL) DYNAMIC PRESSURE LOSS [psi]					
	PUMP NO. 1			PUMP NO. 2		
	Riser	Choke Line	Choke Line Friction	Riser	Choke Line	Choke Line Friction
SPM						
SPM						

CURRENT DRILLING MUD:
WEIGHT ppg

SUBSEA BOP DATA:
MARINE RISER LENGTH ft
CHOKELINE LENGTH ft

DEVIATION DATA:
KOP M.D. ft
KOP T.V.D. ft
EOB M.D. ft
EOB T.V.D. ft

CASING SHOE DATA:
SIZE in
M. DEPTH ft
T.V. DEPTH ft

HOLE DATA:
SIZE in
M. DEPTH ft
T.V. DEPTH ft

PRE-RECORDED VOLUME DATA:	LENGTH ft	CAPACITY bbls / ft	VOLUME bbls	PUMP STROKES Strokes	TIME minutes
DP - SURFACE TO KOP		x	=	(L) stks	
DP - KOP TO EOB		x	= +	(M) stks	
DP - EOB TO BHA		x	= +	(N1) stks	
HEVI WALL DRILL PIPE		x	= +	(N2) stks	
DRILL COLLAR		x	= +	(N3) stks	
DRILL STRING VOLUME			(D) bbls	stks	min
DC x OPEN HOLE		x	=		
DP / HWDP x OPEN HOLE		x	= +		
OPEN HOLE VOLUME			(F) bbls	stks	min
DP x CASING		x	= (G) +	stks	min
CHOKELINE		x	= (H) +	stks	min
TOTAL ANNULUS / CHOKELINE VOLUME			(F+G+H) = (I) bbls	stks	min
TOTAL WELL SYSTEM VOLUME			(D+I) = (J) bbls	stks	min
ACTIVE SURFACE VOLUME			(K) bbls	stks	
TOTAL ACTIVE FLUID SYSTEM			(J+K) bbls	stks	
MARINE RISER x DP		x	= bbls	stks	

Dr No SSD 04/01
(Field Units)
27-01-2000

Figure 23: Kill sheet sample 1

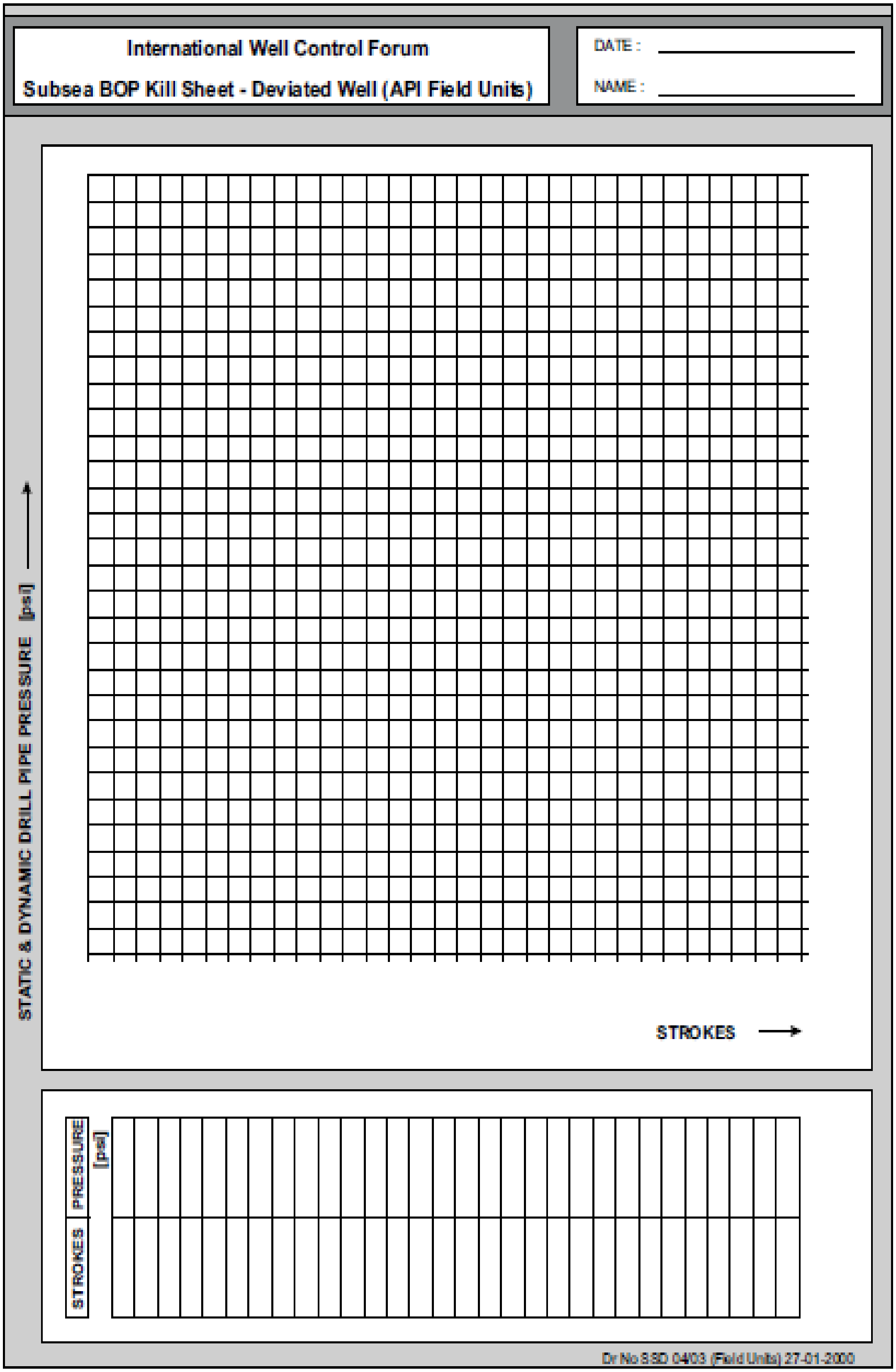
International Well Control Forum Subsea BOP Kill Sheet - Deviated Well (API Field Units)	DATE : ______ NAME : ______

KICK DATA :	SIDPP ______ psi SICP ______ psi PIT GAIN ______ bbl
KILL MUD WEIGHT KMW	CURRENT MUD WEIGHT + SIDPP / (TVD x 0.052) ______ + ______ / X 0.052 = ______ ppg
INITIAL CIRC. PRESSURE ICP	DYNAMIC PRESSURE LOSS + SIDPP ______ + ______ = ______ psi
INITIAL DYNAMIC CASING PRESS AT KILL PUMP RATE	SICP - CHOKE LINE FRICTION = ______ - ______ = ______ psi
FINAL CIRCULATING PRESSURE FCP	KILL MUD WEIGHT / CURRENT MUD WEIGHT x DYNAMIC PRESSURE LOSS ______ / ______ x ______ = ______ psi
DYNAMIC PRESSURE LOSS AT KOP (O)	PL + [(FCP-PL) x KOPMD / TDMD] = ______ + [(______ - ______) x ______ / ______] = ______ psi
REMAINING SIDPP AT KOP (P)	SIDPP - [(KMW - CMW) x KOPTVD x 0.052] = ______ - [(______ - ______) x 0.052 x ______] = ______ psi
CIRCULATING PRESS. AT KOP (KOP CP)	(O) + (P) = ______ + ______ = ______ psi
DYNAMIC PRESS. LOSS AT EOB (R)	PL + [(FCP-PL) x EOBMD / TDMD] = ______ + [(______ - ______) x ______ / ______] = ______ psi
REMAINING SIDPP AT EOB (S)	SIDPP - [(KMW - CMW) x EOBTVD x 0.052] = ______ - [(______ - ______) x 0.052 x ______] = ______ psi
CIRCULATING PRESS. AT EOB (EOB CP)	(R) + (S) = ______ + ______ = ______ psi

(T) = ICP - KOP CP = ______ - ______ = ______ psi	(T) x 100 / (L) = ______ X 100 / ______ = ______ psi / 100 strokes
(U) = KOP CP - EOB CP = ______ - ______ = ______ psi	(U) x 100 / (M) = ______ X 100 / ______ = ______ psi / 100 strokes
(W) = EOB CP - FCP = ______ - ______ = ______ psi	(W) x 100 / (N1+N2+N3) = ______ X 100 / ______ = ______ psi / 100 strokes

Dr.No.SSD.04/02 (Field Units) 27-01-2000

Figure 24: Kill sheet sample 2



International Well Control Forum

Subsea BOP Kill Sheet - Deviated Well (API Field Units)

DATE :

NAME :

STATIC & DYNAMIC DRILL PIPE PRESSURE [psi]

STROKES

PRESSURE [psi]

STROKES

Dr No SSD 04/03 (Field Units) 27-01-2000

Figure 25: Kill sheet sample 3

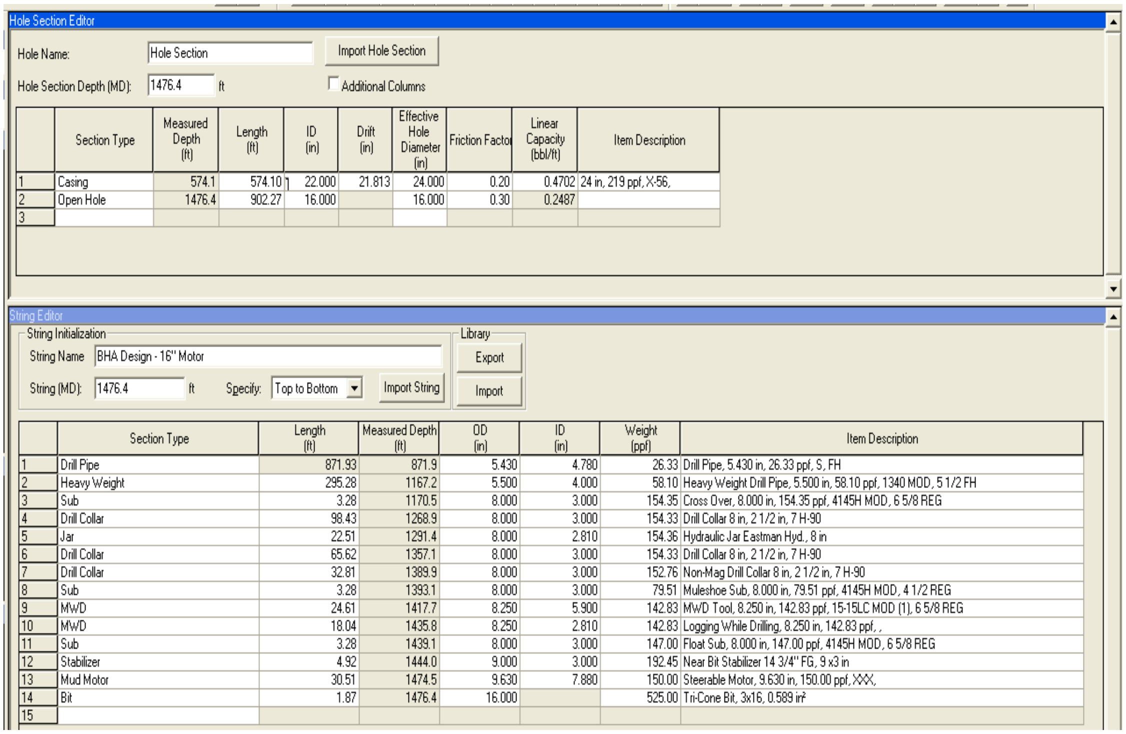


Figure 26: Hole section and string editor

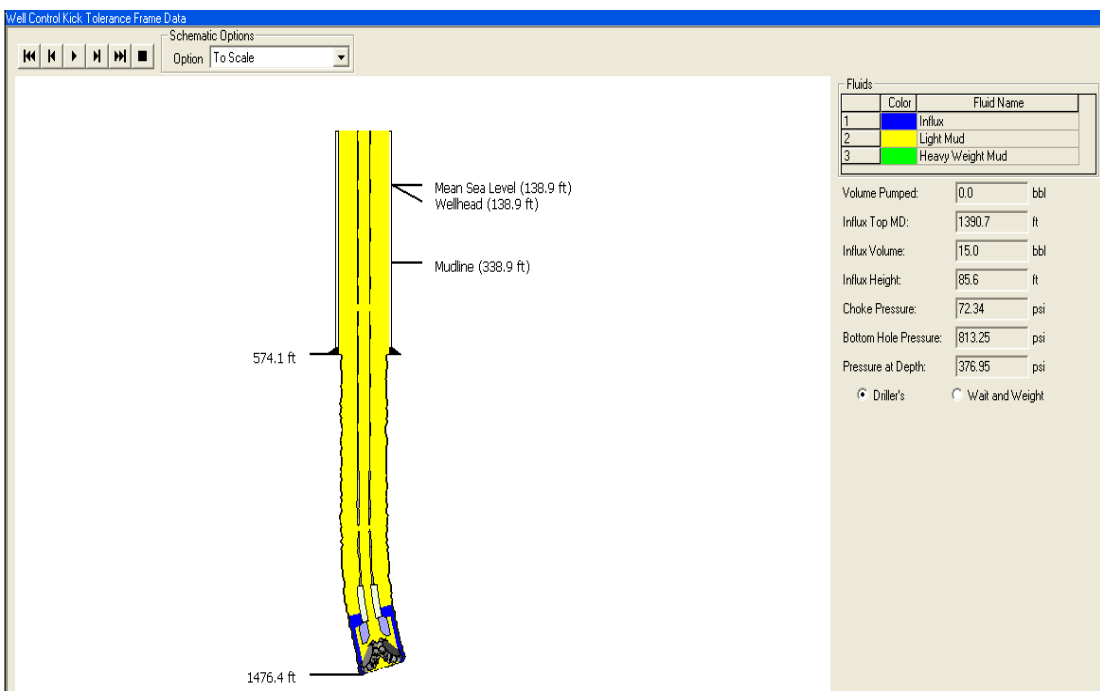


Figure 27: Animation of schematic before kill the well, kill rate 300 gpm (Section 1)

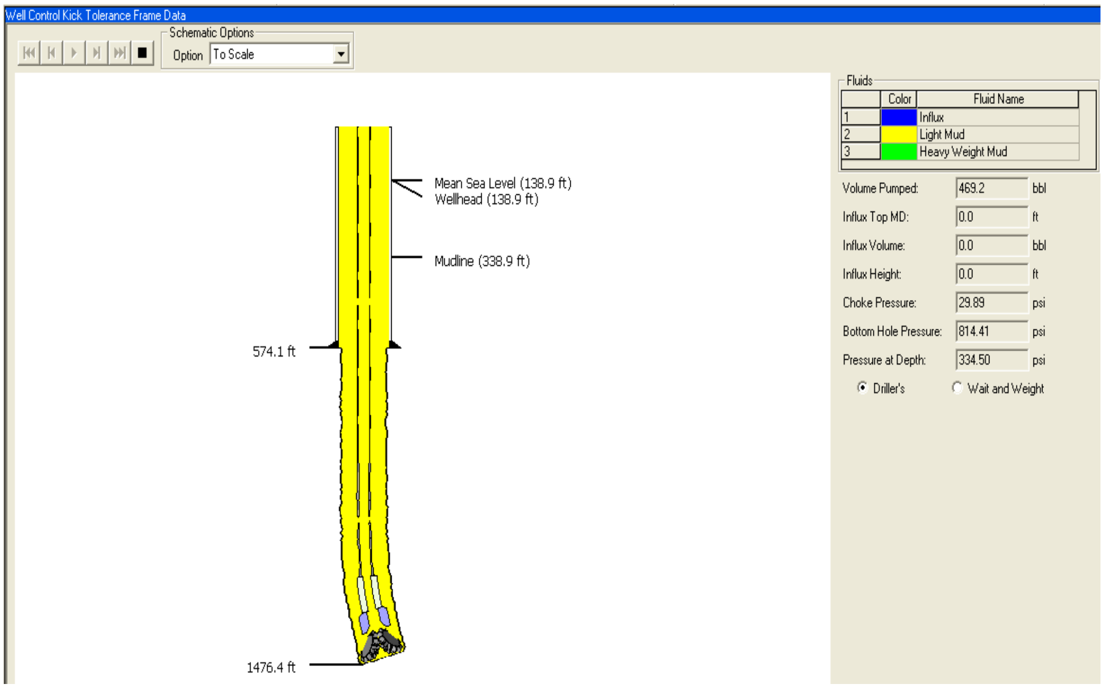


Figure 28: Animation of schematic after completely kill the well, kill rate 300 gpm (Section 1)

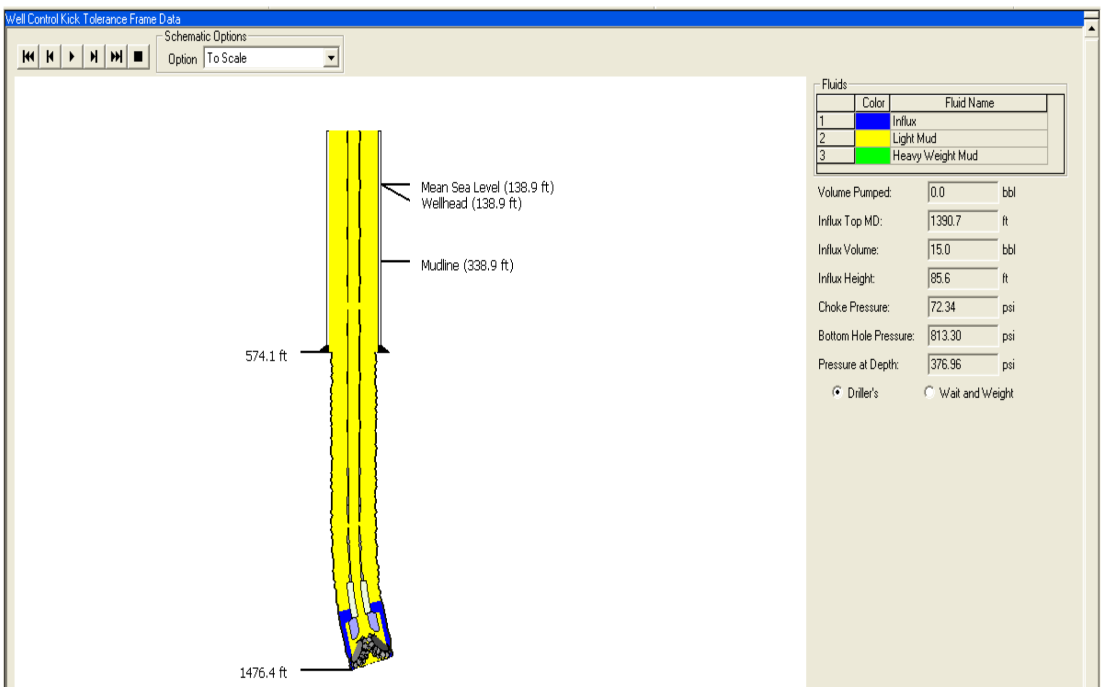


Figure 29: Animation of schematic before kill the well, kill rate 500 gpm (Section 1)

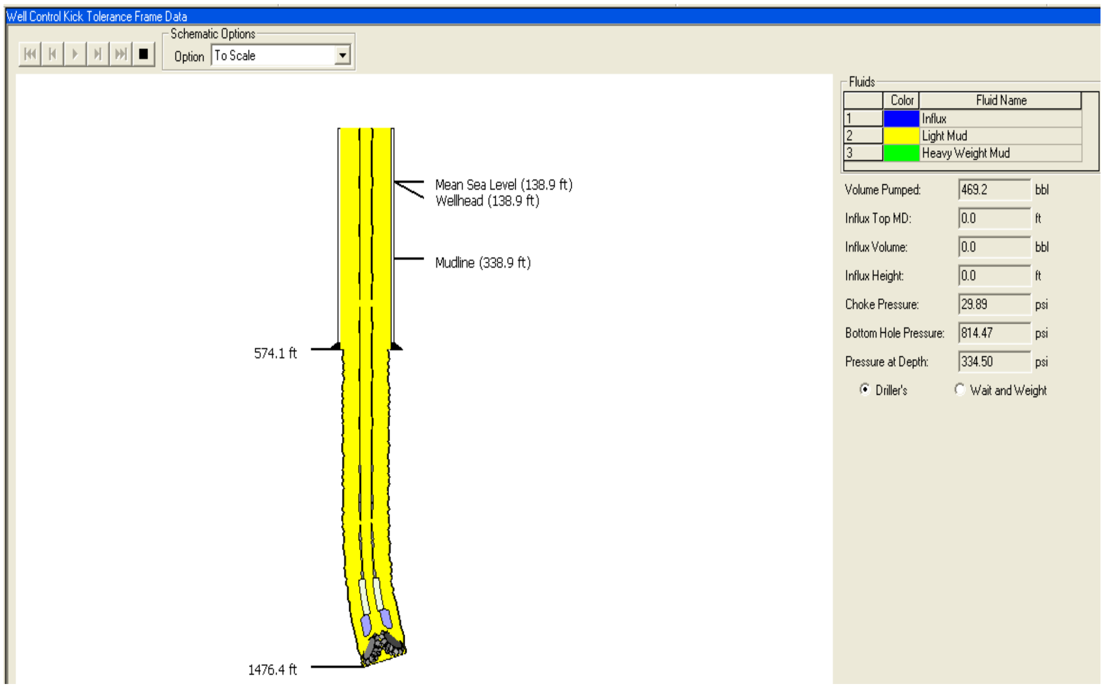


Figure 30: Animation of schematic after completely kill the well, kill rate 500 gpm (Section 1)

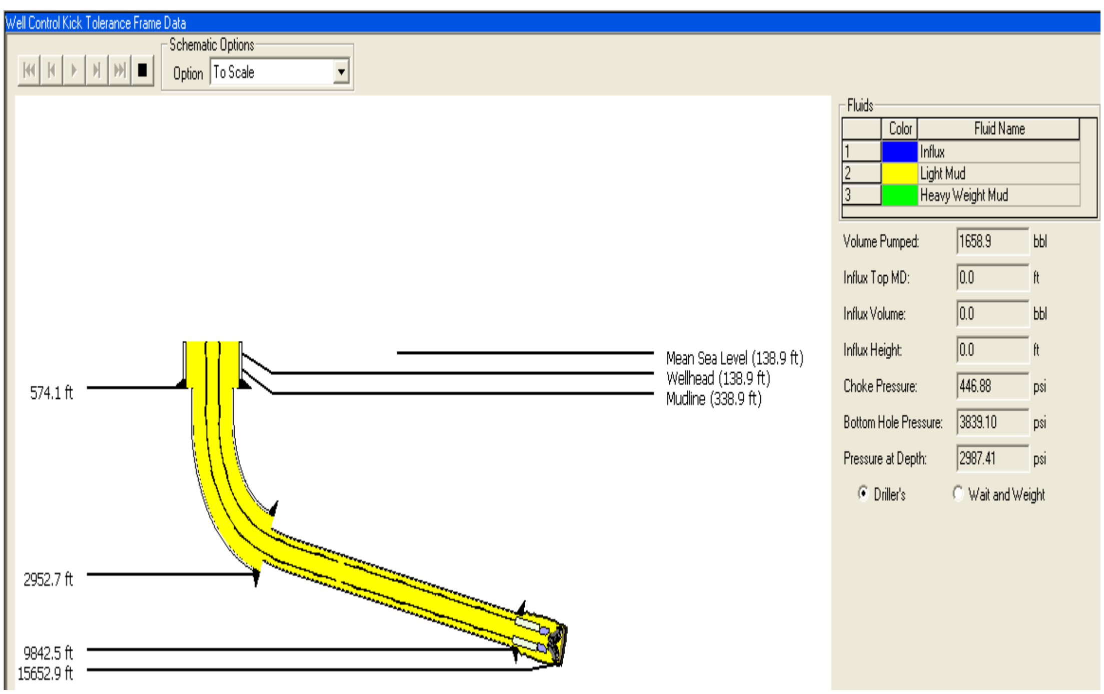


Figure 31: Animation of schematic before kill the well, kill rate 310 gpm (Section 2)

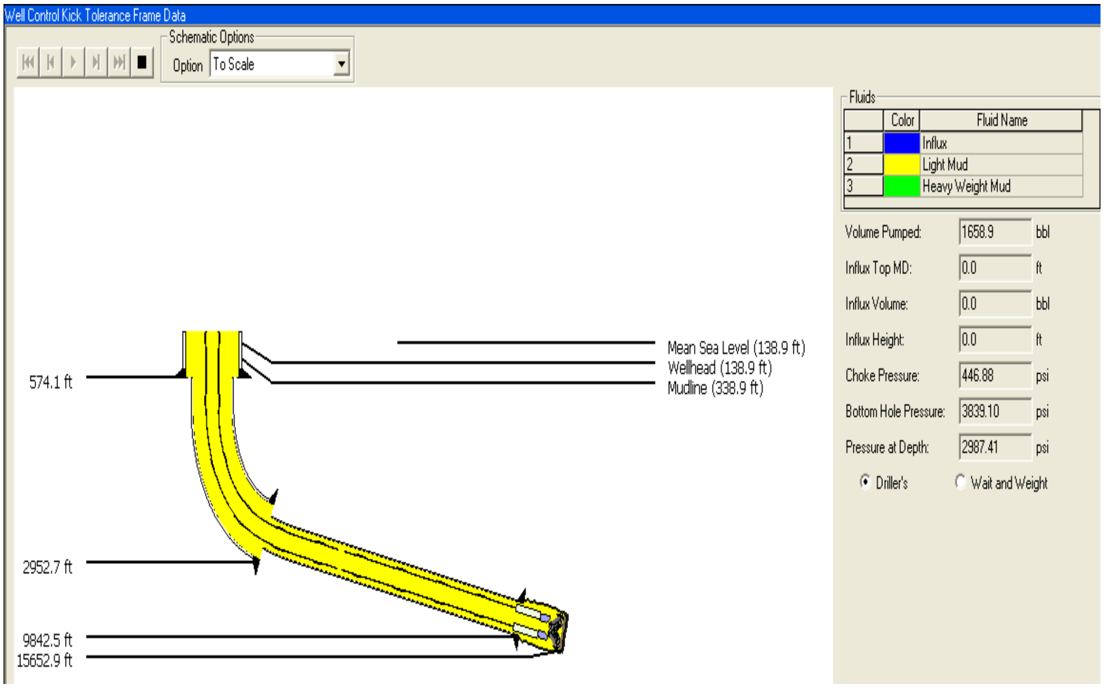


Figure 32: Animation of schematic after completely kill the well, kill rate 310 gpm (Section 2)

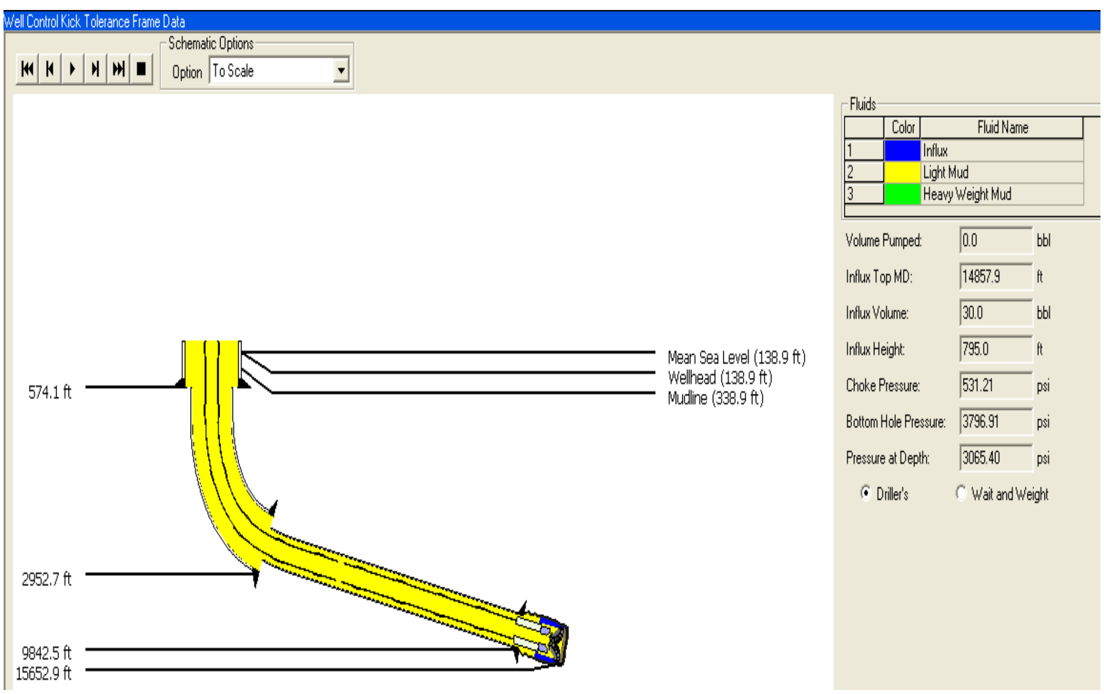


Figure 33: Animation of schematic before kill the well, kill rate 210 gpm (Section 2)

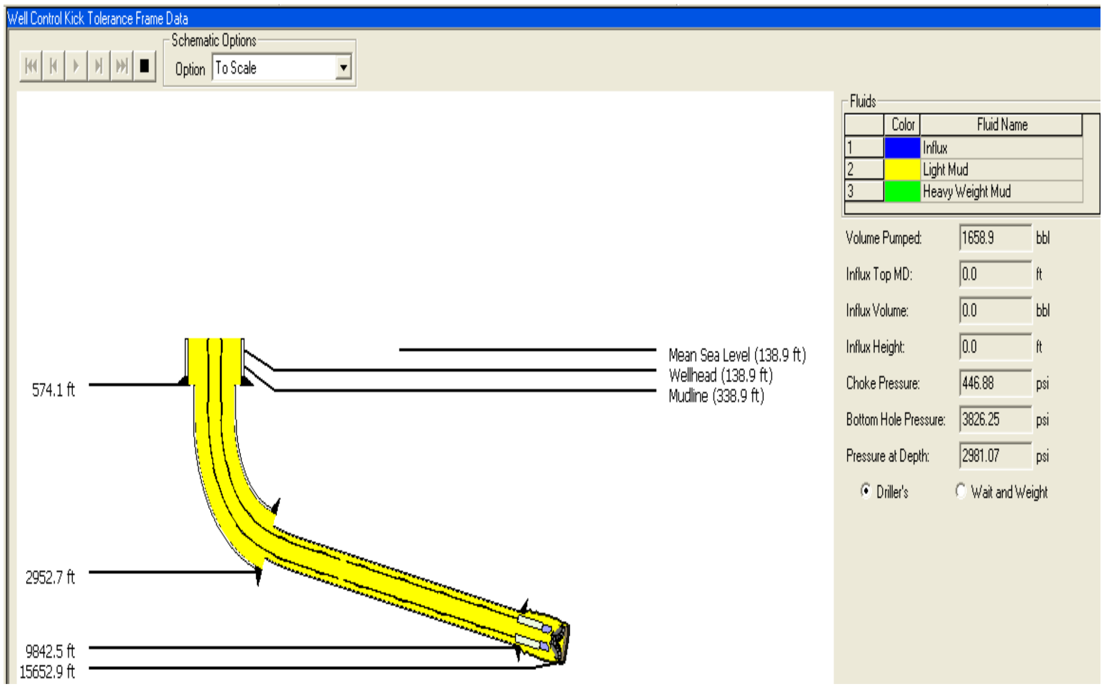


Figure 34: Animation of schematic after completely kill the well, kill rate 210 gpm (Section 2)

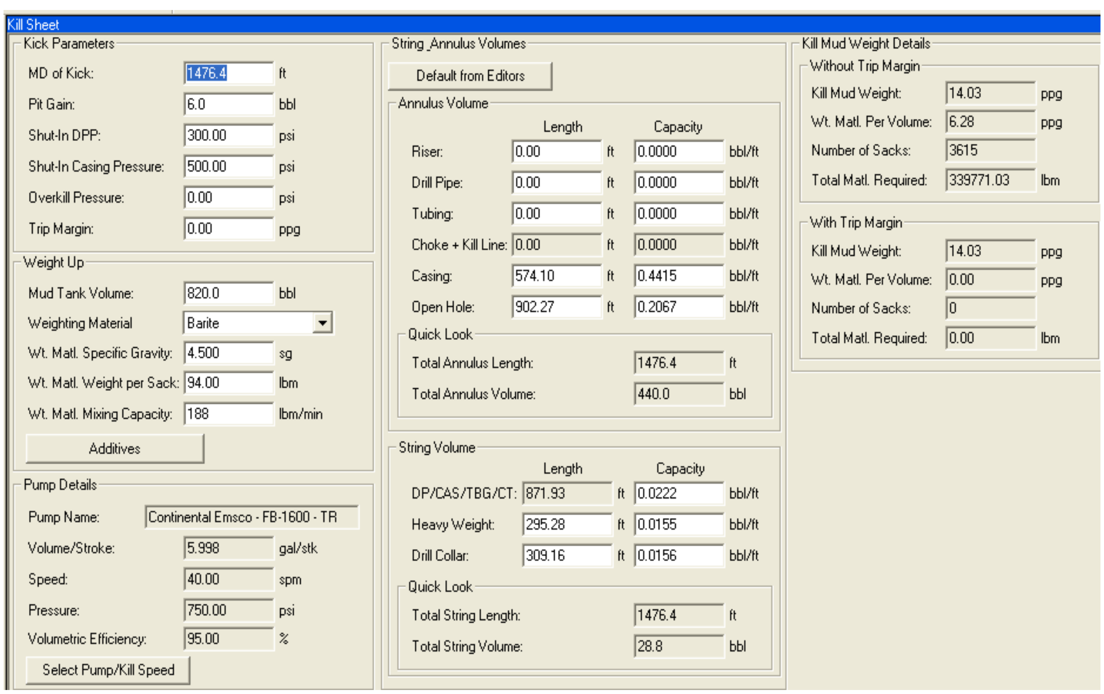
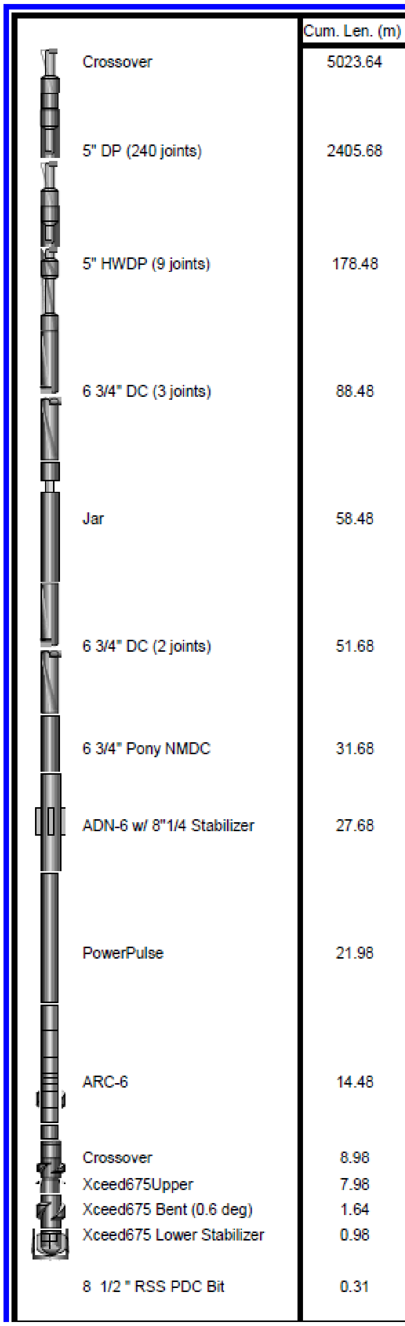


Figure 35: Kill sheet with SIDPP 300 psi (Section 1)



BHA DESCRIPTION

ELEMENT	LENGTH (m)	OD (in)	ID (in)	MAX OD (in)
8 1/2 " RSS PDC Bit	0.31	8.50	2.25	8.50
Xceed675 Lower Stabilizer	0.67	6.75	3.00	8.38
Xceed675 Bent (0.6 deg)	0.66	7.60	5.00	7.60
Xceed675Upper	6.34	6.85	5.16	8.25
Crossover	1.00	6.75	3.00	6.75
ARC-6	5.50	6.75	2.81	7.50
PowerPulse	7.50	6.75	5.11	6.89
ADN-6 w/ 8"1/4 Stabilizer	5.70	6.75	2.25	8.25
6 3/4" Pony NMDC	4.00	6.75	3.00	6.75
6 3/4" DC (2 joints)	20.00	6.75	3.00	6.75
Jar	6.80	6.50	2.25	6.63
6 3/4" DC (3 joints)	30.00	6.75	3.00	6.75
5" HWDP (9 joints)	90.00	5.00	3.00	6.50
5" DP (240 joints)	2227.20	4.93	4.28	6.63
Crossover	1.00	6.75	3.00	6.75
5-1/2 " DP (94 Stands)	2616.96	5.43	4.78	7.50

Bit to Direction & Inclination Sensor = 18.0858 m

DRILLING OVERVIEW

Depth in:	3000.00 m	Depth out:	4797.00 m
Inclination in:	78.00°	To:	78.00°
Direction in:	61.00°	To:	61.00°
Total Drilled	1797.00 m	Dogleg:	0

Figure 36: BHA design for MD 15652.9 ft

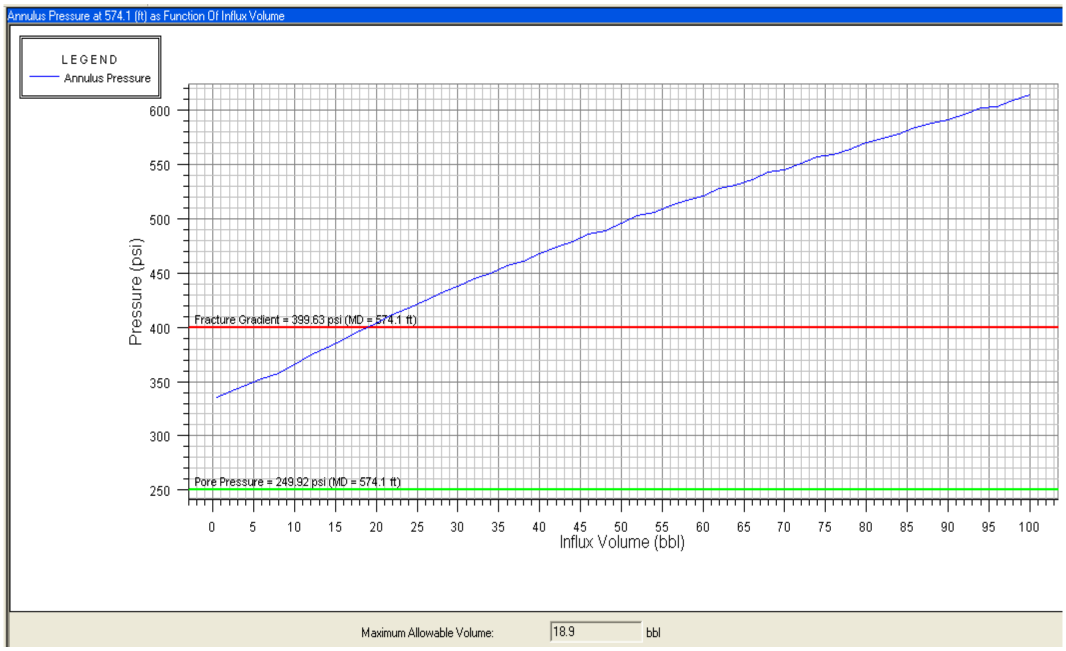


Figure 37: Maximum allowable volume (Section 1)

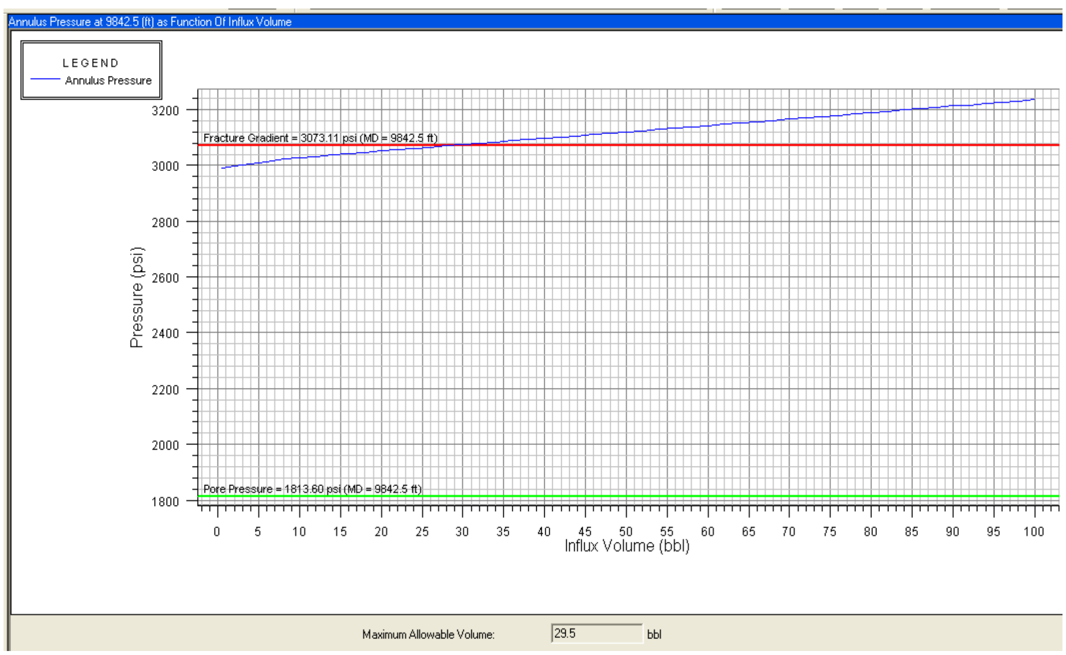


Figure 38: Maximum allowable volume (Section 2)

APPENDIX B

$$P_{\mathrm{h}} = MW \times 0.052 \times TVD \tag{15}$$

$$P_{\mathrm{p}} = P_{\mathrm{bh}} - \Delta P_{\mathrm{hyd,DS}} + \Delta P_{\mathrm{f,DS}} + \Delta P_{\mathrm{b}} \tag{16}$$

$$CP = P_{\mathrm{h}} + P_{\mathrm{af}} \tag{17}$$

$$ICP = SIDPP + SPR \tag{18}$$

$$FCP = SPR + \left(\frac{KMW}{MW}\right) \tag{19}$$

$$KMW = MW + \left(\frac{SIDPP}{0.052 \times TVD}\right) \tag{20}$$

$$P_{\mathrm{f}} = SIDPP + (MW \times 0.052 \times TVD) \tag{21}$$

$$Gas\ bubble\ migration\ rate = \frac{DP_{\mathrm{a}}}{0.052 \times MW} \tag{22}$$

$$Barite\ required\ \left(\frac{sk}{100\ bbl\ mud}\right) = 1490 \times \frac{KMW - MW}{35.8 - KMW} \tag{23}$$

$$Volume\ increase\ caused\ by\ weighting\ up = 100 \times \frac{KMW - MW}{35.8 - KMW} \tag{24}$$

APPENDIX C

$$C_i = \frac{ID^2}{1029.4} \tag{25}$$

$$C_i = \frac{ID^2 - OD^2}{1029.4} \tag{26}$$

$$V = L \times C \tag{27}$$

$$P_{bh} = SIDPP + (MW \times 0.052 \times TVD) \tag{28}$$

$$T_{bh} = Temp. + (MW \times 0.052 \times TVD) \tag{29}$$

$$L_{ki} = \frac{V_{ki}}{C_a} \tag{30}$$

$$C_{ai} = \frac{V_{ki}}{L_{ki}} \tag{31}$$

$$P_{hgi} = \frac{\gamma_g P L_k}{53.29 zT} \tag{32}$$

$$P_{hg} = \frac{P_{hgi} C_{ai}}{C_a} \tag{33}$$

$$X = P_{bh} - g_{om}(D - D_k) - P_{hg} \tag{34}$$

$$T_{@D} = Temp. + (MW \times 0.052 \times TVD_{@D}) \tag{35}$$

$$P_{@D} = \frac{X}{2} + \left(\frac{X^2}{4} + \frac{g_{om} P_{bh} L_{ki} z T C_{ai}}{z_{bh} T_{bh} C_a}\right)^{0.5} \tag{36}$$

$$V_k = \frac{P_{bh} V_{ki} z T}{P z_{bh} T_{bh}} \tag{37}$$

$$L_k = \frac{V_k}{C_a} \tag{38}$$

$$Time = \frac{\left(\frac{V}{\frac{V}{stk}} \times 0.02381 \times V_{eff}\right)}{Speed} \tag{39}$$