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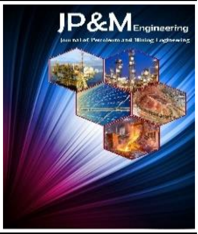

An Optimum Model for Slim Hole Well Kill

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Abstract

The slim hole drilling technology satisfies the oil and gas industry demands todays. As it offers not only a significant cost reduction but also minimize the environmental impact generated from the drilling operation. The cost reduction is realized from using smaller rigs and tubulars and less cement, drilling fluid and drilling cutting disposal1. In general slim hole wells reduce costs by 40-60% for remote exploration wells and 25-40% of development wells compared to the conventional wells2. The second main advantage of the slim hole drilling technology is the minimization of waste and improvement general environmental impact. If the size of the slim hole is half of a conventional one, the cuttings and mud volume will be 25% of a conventional volume2. Slim hole drilling technology has been impeded by the lack of documentation of well control methods for small annulus drilling3. One of the major barriers to the introduction of slim hole drilling technology to oil field operations was perceived to be the maintenance of safe standards of well control4. This paper will introduce a simple analysis of the pressures undergone by the well bore during killing operation so as to drive the optimum killing model for the slim hole wells.

Keywords

Slim hole; well control; reservoir optimum model

Introduction

Slim hole technology has been applied in the petroleum industry as an economical alternative to the conventional drilling technology, which considers only standard well bore diameters1.There are two main problems faces the slim hole drilling regarding the well control issues. First, the small annular capacity at the slim hole well dictates smaller kick tolerances so that the kick detection system should be able to detect a kick volume of one barrel otherwise a blowout is potential2,3,4.

Second, the killing techniques used to kill the slim hole wells, the conventional techniques such as the driller's method and wait and weight method depend on the annular pressure losses to be a small fraction of the total circulation system pressure loss and can be neglected 2,4,5. This assumption is valid for the conventional wells and represents a safety factor while using these killing techniques. But the neglection of the annular pressure loss while killing slim hole well may lead to losses or even underground blowout4,5.

The earlier trials to produce suitable killing techniques for slim hole wells was made by modifying the conventional techniques such as the driller's and wait and weight methods to take into account the annular pressure losses4. These efforts are continued through this paper to produce the optimum well control method or technique for safely killing slim hole wells.

Well kill theory

The objectives of any killing method are to remove the kick from the well bore then to replace the original mud by the kill mud to be able to bring the well back to the primary well control status4,5,7. To perform a good killing operation a basic concept should be followed during the killing process that is the constant bottom hole pressure concept. A great many operators agree that the safest well control procedure is the constant bottom hole pressure method6.

Constant bottom hole pressure concept

The two common and conventional killing methods "Driller's method and wait and weight method" follow the constant bottom hole pressure concept6. The idea of the technique is to keep the bottom hole pressure while killing operation constant at or slightly above the formation pressure so as not to induce any extra pressures at the open hole section. These extra pressures if exist with large values would lead to down hole losses or even an underground blowout.

U-tube analysis

For good understanding the killing process basis, a simple analysis of the pressures undergone by the well bore during killing operation is made using the u- tube theory, one side represents the drill string side and the other side of the u-tube represents the annulus side.

When the well is first shut in on a kick and the pressures have stabilized then the bottom hole pressure equal the formation pressure providing no other pressures trapped in the well.

From the drill pipe side

$$BHP = FP = SIDPP + H_{mDp} \quad (1)$$

And from the annulus side

$$BHP = FP = SICP + H_{ia} + H_{ma} \quad (2)$$

Figure (1) shows this situation where the drill pipe and annulus sides are represented as a u-tube system

From Equations (1) & (2), it is obvious that the formation pressure is more easily to be calculated from the drill pipe side as the annulus side contains two different fluids with different densities "mud and the kick".

In order to kill this well while achieving the general concept of constant bottom hole pressure, it is necessary to circulate the kill mud around the well and maintain the bottom hole circulating pressure equal the formation pressure.

To do that let us take a general vision for the well bore pressures distribution during circulating the kill mud around the well.

Figure (2) shows the situation when the kill mud is circulated through the drill string.

$$BHCP = P_{circ} + H_{mDp_c} - DSPL_c \quad (3)$$

Rearranging the Equation for the circulation pressure

$$P_{circ} = BHCP + DSPL_c - H_{mDp_c} \quad (4)$$

Equation (4) represents the general equation that governs the drill pipe pressure while circulating the kill mud from the surface to the bit.

To achieve the general concept of the constant bottom hole pressure, the bottom hole pressure while circulation will be replaced by a constant value equal the formation pressure.

Substituting from Equation (1) into Equation (4)

$$P_{circ} = SIDPP + H_{mdp} + DSPL_c - H_{mDp_c} \quad (5)$$

If the dynamic pressure loss and the hydrostatic pressure of the mud inside the drill string can be determined when the kill mud progresses from the surface to the bit through the drill string, then Equation (5) can be used to determine the circulation pressure that must be kept on the drill pipe to keep the bottom hole circulating pressure constant at a value equal to the formation pressure during the killing operation.

The choke on the annulus side is used to keep certain pressure value on the drill pipe in other words is used to make the drill pipe follows a certain pressure schedule named step down so as to keep the bottom hole circulating pressure constant.

The conventional approach

Applying the general Equation (5) when the kill mud is just at the rig floor as shown in Figure (3)

$$P_{circ} = ICP \quad (6)$$

$$DSPL_c = DSPL \quad (7)$$

$$H_{mDp_c} = H_{mDp} \quad (8)$$

Substituting from Equations (6), (7) & (8) into Equation (5)

$$ICP = SIDPP + DSPL \quad (9)$$

Applying the general Equation (5) when the kill mud just at the bit as shown in Figure (4)

$$P_{circ} = FCP_{sh} \quad (10)$$

$$DSPL_c = DSPL\ x\ (\frac{KMW}{OMW}) \quad (11)$$

$$H_{mDp_c} = SIDPP + H_{mDp} \quad (12)$$

Substituting from Equations (10), (11) & (12) into Equation (5)

$$FCP_{sh} = DSPL\ x\ \left(\frac{KMW}{OMW}\right) \quad (13)$$

The conventional procedure is as following: First, calculate the pressure drop per 100 stk of kill mud pumped as following

$$\Delta P/100\,stk = \frac{(ICP - FCP_{sh})}{String\ Vol.stk} x\ 100 \quad (14)$$

Second, form the step down graph according to Table (1) as shown in Figure (5).

From Equation (14) as noticed in Figure (5), the pressure drop per stroke all over the drill string is constant that is not true as the pressure drop per stroke through the drill pipe not equal the pressure drop per stroke through the bottom hole assembly due to the different capacity. This defect in this approach is fixed by adding a safety factor for the circulation pressure.

Materials and Methods

The optimum model is obtained by developing the general Equation (5) to be able to calculate the circulating pressure when the kill mud at any depth from the rig floor to the bit.

$$P_{circ} = SIDPP + H_{mdp} + DSPL_c - H_{mDp_c} \quad (5)$$

Solving for $DSPL_c$ and H_{mDpc}

$$DSPL_c = DSPL + \left[DSPL\ x\ \frac{KMW}{OMW} - DSPL\right] x\ \frac{MD}{TMD}$$

$$DSPL_c = DSPL + [FCP_{sh} - DSPL]\ x\ \frac{MD}{TMD} \quad (15)$$

$$H_{mDp_c} = H_{mDp} + (KMW - OMW) x\ VD\ x\ 0.052$$

$$H_{mDp_c} = H_{mDp} + SIDPP\ x\ \frac{VD}{TVD} \quad (16)$$

Substituting from Equations (15) & (16) into Equation (5)

$$P_{circ} = ICP + (FCP_{sh} - DSPL) x\ \frac{MD}{TMD} - SIDPP\ x\ \frac{VD}{TVD} \quad (17)$$

Equation (17) is valid for calculating the drill pipe circulating pressure that keeps the bottom hole circulating pressure constant at a value equal the formation pressure and it is valid for the vertical, deviated and horizontal slim hole wells.

Simplification for vertical wells

$$P_{circ} = ICP + (FCP_{sh} - ICP)x\,\frac{MD}{TMD} \quad (18)$$

Work strategy

To use the optimum model for killing: first, use Equation (17) or its modification Equation (18) upon the well type vertical or deviated to calculate the circulating pressures at critical depths then depths in between each 100 stk.

The critical depths contain depths at which the inside diameter of the drill string changes also the kick off point depth, end of build depth,……., and total depth as shown in Table (2).

Second, demonstrate the step down graph as shown in Figure (6)

From Figure (6) and the way of calculation, the relationship between the circulation pressure and the volume of kill mud pumped into the drill string is a group of straight segments connected to each other that form a curve bent up.

Constant bottom hole pressure concept

To judge the validity and the preference of any well control model, the constant bottom hole pressure concept is used. The best model will generate a bottom hole circulating pressure constant at or slightly above a value equal to the formation pressure

From the u-tube analysis

$$BHCP = P_{circ} + H_{mDp_c} - DSPL_c \quad (3)$$

Substituting from Equations (15) & (16) into Equation (3)

$$BHCP = P_{circ} + H_{mDp} + SIDPPx\,\frac{VD}{TVD} - DSPL - [FCP_{sh} - DSPL]x\,\frac{MD}{TMD} \quad (19)$$

The Equation (19) will be used to judge the validity and to compare between the conventional and optimum models.

Results and discussions

In order to ascertain the validity of the optimum model for the slim holes and compare its results with the conventional approach, a vertical well with tapered drill string is used as an example, the well data are as in Table (3).

Solution using the conventional approach

- Use Equations (9) & (13) to calculate the ICP & FCPsh then Equation (14) to demonstrate Table (4)
- Draw step down graph as per Figure (7)

Solution using the optimum model

- Use Equation (18) to calculate the circulation pressure at the critical depths and at depths in between corresponding to increments of 100 stk then tabulates the results in Table (5)
- Draw step down graph as per Figure (7)

For comparison

- Use Equation (19) to calculate the relevant BHCP of the conventional model then tabulates in Table (4)
- Use Equation (19) to calculate the relevant BHCP of the optimum model then tabulates in Table (5)
- Use data of the relevant BHCP from the two models and compare same with the formation pressure as per Figure (8)
- Draw the variation of the relevant bottom hole circulation pressures of the two models from the formation pressure as per Figure (9).

Although each model forms a step down graph but Figure (7) contains the circulating pressures from the two models just for comparison

As in Figure (7) the two models coincide at the initial and final pressures but differ in between.

As observed, the conventional model is represented by a straight line because it assumes an average internal capacity all over the drill string that resulted in an equal pressure drop per stroke from the surface to the bit.

On the other hand, the optimum model is represented by a curve bent upward because it takes into consideration the inside diameter of the drill string. The pressure drop per stroke depends on the internal diameter, the lowest value of pressure drop per stroke occurs at the largest internal diameter and vice versa. The smallest pressure drop per stroke at the example well occurs in the first drill pipe and the largest value of pressure drop per stroke occurs at the drill collar.

Figure (8) shows the relevant bottom hole circulating pressure from the two models.

The relevant bottom hole circulating pressure from the conventional model is lower than the formation pressure and the maximum under balance occurs at the end of the 5” drill pipe about 100 psi. An extra pressure called a safety factor must be added to the circulating pressure using the choke otherwise this under balance will generate a secondary kick. Two defects here: first, the safety factors will not be equal at all points, second, if the safety factor is not enough, a secondary kick is expected that will complicate the situation and may cause harmful consequences.

On the other hand, the relevant bottom hole circulating pressure from the optimum model exactly equals the formation pressure.

Figure (9) shows that the variation of the relevant BHCP of the optimum model from the formation pressure is zero during the progress of the kill mud from the surface to the bit. Also in case of the conventional model, the variation reaches to -100 psi that will result in a secondary kick during the progress of kill mud from the surface to the bit.

Conclusions

The main conclusions drawn from this research are listed below

- The optimum model is simple and can be used easily to demonstrate the step down graph for kill sheet for slim hole wells.

- The optimum model produces bottom hole circulating pressure exactly equal the formation pressure.
- The optimum model removes the effect of change in drill string diameter or the reduction in internal diameter through the bottom hole assembly.
- The optimum model is valid for all wells profiles, vertical, directional, horizontal wells.
- The optimum model removes the effect of the annular pressure losses that increase the bottom hole circulating pressure, so it also can be used for killing the conventional wells that are sensitive for the extra pressures applied while killing process in other words, the optimum model can be used with wells that had low fracture pressures.

Conflicts of interest

There are no conflicts to declare.

References

[1] Azari, M., Soliman, M., Wendler, C. :" Testing and Production Performance of Slim-Hole wells" paper SPE 29630 presented at the Western Regional Meeting held in Bakersfield, CA, U.S.A., March 1995.

[2] Tao Zhu, Carroll, H.B. :" TOPICAL REPORT SLIMHOLE DRILLING : APPLICATION AND IMPROVEMENTS" August 1995.

[3] Bode, D.J., Noffke, R.B., Nickens, H.V. : "Well Control Methods and Practices in Small Diameter Wellbores" paper SPE 19526 presented at the SPE Annual Technical Conference and Exhibition held in San Antonio, October 1989.

[4] Prince, P.K., Cowell, E.E. :"Slimhole Well Kill : A Modified Conventional Approach" paper SPE 25707 presented at SPE/IADC Drilling Conference held in Amsterdam February 1993.

[5] Schlumberger Well Control Manual," HQS-PO-OPT-01 rev 0", 1999.

[6] Kastor, R.L., Letbetter, S.C. :"Extra Increments of Pressure or Mud weight Safety Factors Added During Well Killing Procedures Can Be Unsafe" paper SPE 4973 presented at the 49th Annual Fall Meeting of SPE of AIME held in Houston, Texas, October 1974.

[7] Institute of Petroleum Engineering, Heriot Watt University - Drilling Module, Chapter 6 "Well control".

Nomenclature

BHP = Bottom hole pressure, psi

FP = formation pressure, psi

$SIDPP$= Shut in drill pipe pressure, psi

H_{mDp} = Hydrostatic head of original mud in drill pipe side, psi

$SICP$ = Shut in casing pressure, psi

H_{ia}= Hydrostatic head of influx in the annulus, psi

H_{ma} = Hydrostatic head of original mud in casing side, psi

$BHCP$ = Bottom hole circulating pressure, psi

P_{circ} = Circulating pressure at the drill pipe during replacing original mud by kill mud, psi

H_{mDp_c}= hydrostatic pressure in drill pipe during replacing original mud by kill mud, psi

$DSPL_c$= Dynamic pressure loss in drill string during replacing original mud by kill mud, psi

ICP = Initial circulating pressure, psi

$DSPL$ = Dynamic pressure loss in drill string during circulation of original mud, psi

FCP_{sh}= Final circulation pressure when the kill mud reaches the bit, psi

KMW = Kill mud weight, ppg

OMW= Original mud weight, ppg

VD = Vertical depth, ft

TVD = Total vertical depth, ft

MD = Measured depth, ft

TMD = Total measured depth, ft

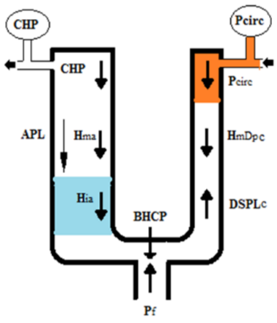

Figure 1 First shut in pressures

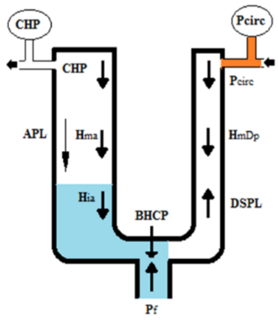

Figure 2 When the kill mud at bit

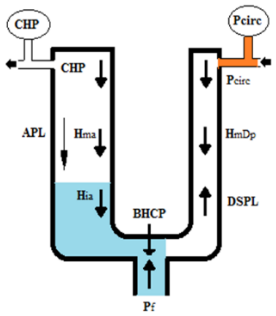

Figure 3 When the kill mud at surface

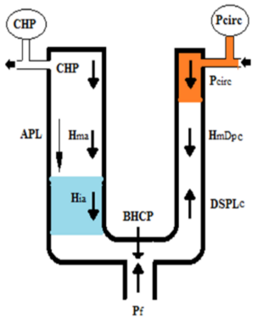

Figure 4 Well pressures while circulation

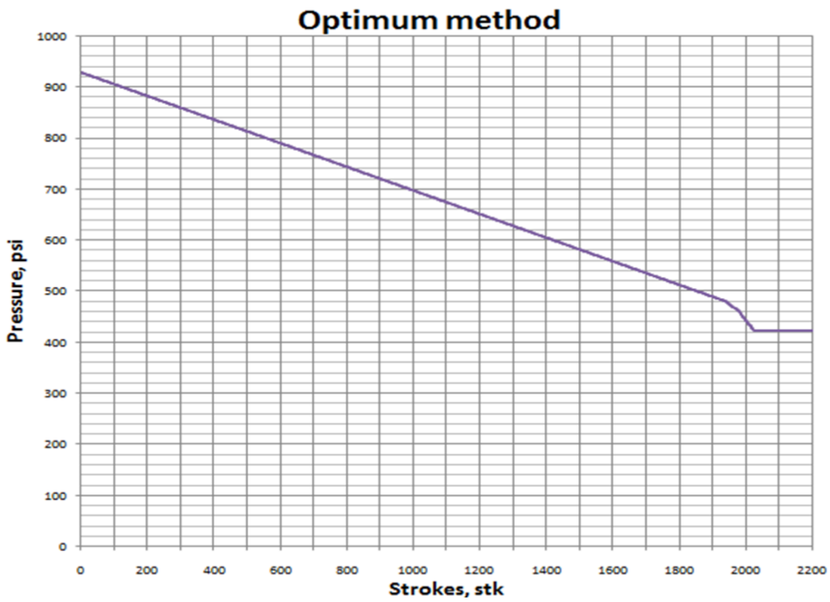

Figure 5 Step down graph as per optimum model

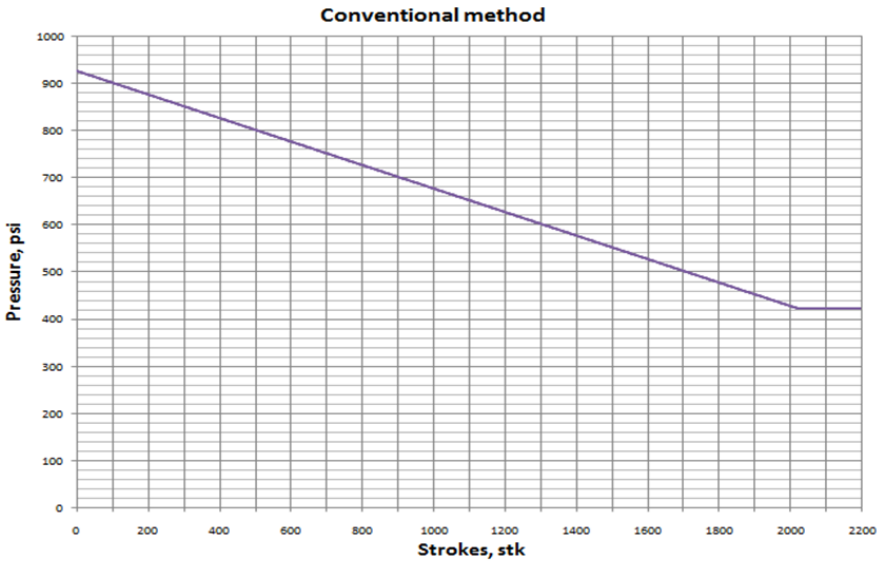

Figure 6 Step down graph as per conventional approach

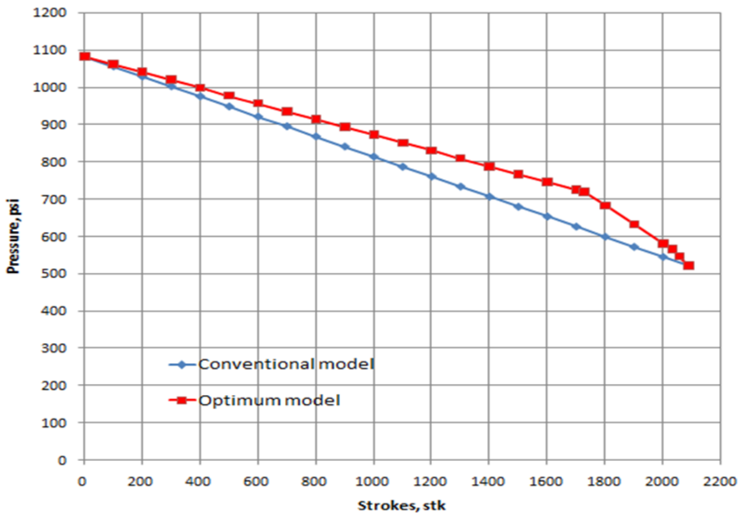

Figure 7 The circulation pressure of the conventional and optimum models

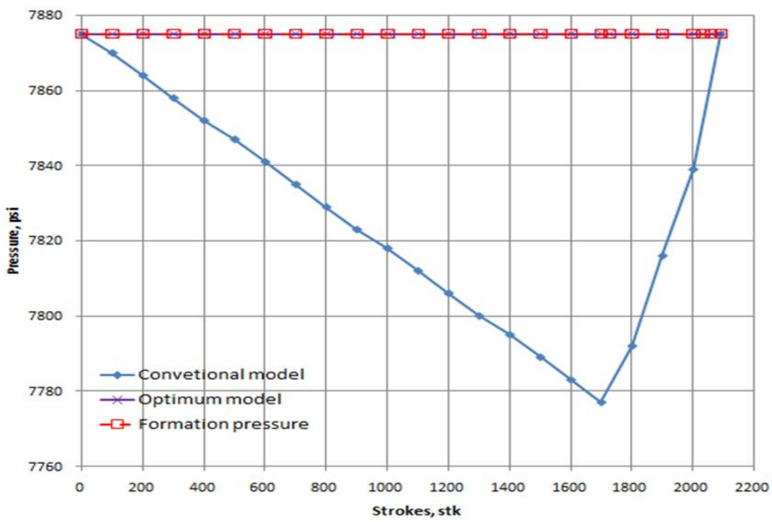

Figure 8 The relevant bottom hole circulation pressure of the conventional and optimum models compared with the formation pressure

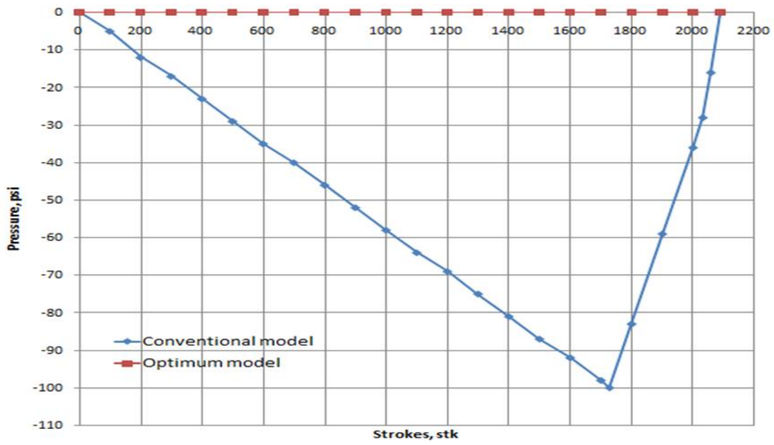

Figure 9 Variation of the two models from the formation pressure

Table 1 Pressure drop schedule for conventional step down graph

Pressure, psi	Vol. of kill mud pumped, stk
ICP	0
Icp -Δp	100
ICP-2Δp	200
……	……..
……	……..
FCPsh	Total string vol., stk

Table 2 Pressure drop schedule for optimum step down graph

Critical point	Vol. of kill mud pumped, stk	Measured depth, ft	Vertical depth, ft	Pcirc, psi
Start	0	0	0	ICP
…..	100	…..	…..	…..
…..	200	…..	…..	…..
…..	…..	…..	…..	…..
KOP	STK @KOP	…..	…..	…..
…..	STK @KOP+100	…..	…..	…..
…..	STK @kop +200	…..	…..	…..
…..	…..	……..	……	……
EOB	STK@ EOB	……..	……	……
…	STK @ EOB+100	…..	…..	…..
…..	STK @ EOB+200	…….	……..	……
…..	…….	……..	……..	……
…..	…..	…..	…..	…..
Top of HWDP	…..	…..	…..	…..
Top of DC	…..	…..	…..	…..
End	Total STK	TMD	TVD	FCPsh

Table 3 Example well data

Vertical well with tapered drill string		
Hole data		
Hole size	6	in
Hole depth TVD	12836	ft
Hole depth TMD	12836	ft
Casing (9 5/8” 43.5 lb/ft) VD	8693	ft
Casing 9 5/8” MD	8693	ft
7” liner (29 lb/ft) top	8386	ft
7” liner shoe	11478	ft
Drill string data		
Drill pipe 5” capacity	0.01776	bbl/ft
Drill pipe 3.5”	3501	ft
Drill pipe 3.5” capacity	0.0074	bbl/ft
Heavy weight drill pipe 3.5”	454	ft
Heavy weight drill pipe capacity	0.00492	bbl/ft
Drill collar 4 3/4”	561	ft
Drill collar capacity	0.00492	bbl/ft
Bit nozzles TFA	0.6628	in^2
Capacity open hole x drill collars	0.0131	bbl/ft
Capacity open hole x drill pipe / HWDP	0.0231	bbl/ft
Capacity liner x drill pipe 3.5”	0.0252	bbl/ft
Capacity csg x drill pipe 3.5”	0.0626	bbl/ft
Capacity csg x drill pipe 5”	0.0502	bbl/ft
Kick data		
Pit gain	10	bbl
SIDPP	600	psi
SICP	750	psi
Mud data		
Original mud weight, OMW	10.9	ppg
Yield point, YP	26	lb/100 ft2
Plastic viscosity, PV	27	cp
Initial gel or viscometer reading at speed ϴ3	7	lb/100 ft2
Other data		
Fracture fluid density at the casing shoe	13	ppg
Slow circulating rate pressure, SCR at 30 SM	890	psi
Mud pump displacement, PO	0.0855	bbl/stk
Annular pressure loss APL	408	psi
Drill string pressure loss DSPL	482	psi
Calculated data		
Formation pressure, PF	7875	psi
Kill mud weight KMW	11.8	ppg
Strokes to end of drill pipe 5”	1728	stk
Strokes to end of drill pipe 3.5”	2032	stk
Strokes to end of HWDP	2058	stk
Strokes to bit	2090	stk
Step down for the conventional approach	25	psi/100stk

Table 4 Step down Table as per conventional approach with the relevant BHCP

Conventional approach			
Vol., stk	**Pcirc, psi**	**BHCP, psi**	**Variation from PF, psi**
0	1082	7875	0
100	1055	7870	-5
200	1028	7864	-12
300	1002	7858	-17
400	975	7852	-23
500	948	7847	-29
600	921	7841	-35
700	895	7835	-40
800	868	7829	-46
900	841	7823	-52
1000	814	7818	-58
1100	787	7812	-64
1200	761	7806	-69
1300	734	7800	-75
1400	707	7795	-81
1500	680	7789	-87
1600	654	7783	-92
1700	627	7777	-98
1800	600	7792	-83
1900	573	7816	-59
2000	546	7839	-36
2090	522	7875	0

Table 5 Step down Table as per optimum relevant BHCP model with the relevant BHCP

Optimum model				
Vol., stk	**MD, ft**	**VD, ft**	**Pcirc, psi**	**BHCP, psi**
0	0	0	1082	7875
100	481	481	1061	7875
200	963	963	1040	7875
300	1444	1444	1019	7875
400	1925	1925	998	7875
500	2407	2407	977	7875
600	2889	2889	956	7875
700	3370	3370	935	7875
800	3851	3851	914	7875
900	4333	4333	893	7875
1000	4814	4814	872	7875
1100	5296	5296	851	7875
1200	5777	5777	830	7875
1300	6258	6258	809	7875
1400	6740	6740	788	7875
1500	7221	7221	767	7875
1600	7703	7703	746	7875
1700	8184	8184	725	7875
1728	8319	8319	719	7875
1800	9147	9147	683	7875
1900	10299	10299	633	7875
2000	11452	11452	582	7875
2032	11820	11820	566	7875
2058	11273	11273	547	7875
2090	12836	12836	522	7875