A SIMULATION OF MANAGED PRESSURE DRILLING IN IRANIAN DARQUAIN OIL FIELD

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ABSTRACT

The narrow operating window between pore pressure and fracture pressure makes drilling difficult in some operations. A feasibility study of managed pressure drilling (MPD) is carried out on Iran Darquain oil field. The previous wells drilled in this field showed that mud returns were lost during drilling Gadvan formation. The present work addresses this problem by means of surface back pressure application in Darquain oil field. The methodology employed in this study is based on hydraulic analysis calculations and comparative drilling operation pressures. The DZxION MPD software performs hydraulic analysis using the API RP 13D rheological model and calculates the annular pressure drop to compare the pressures and the required back pressure, if needed. Using a mud weight of 14.31 ppg and exerting 100 psi static back pressure, the wellbore pressure profile got slightly overbalanced. When the mud pumps are in service, no back pressure is required. The problem is resolved and no kick or loss is observed using a MW of 14.31 ppg and a static back pressure of 100 psi. As a result, the managed pressure drilling technology is useful in Iran Darquian oil field through using a lower mud weight in order to overcome the circulation loss in Sarvak formation. This study is based on hydraulic analysis calculations and comparing the drilling operation pressures in Darquain oil field. For analyzing the pressure regimes throughout the well, DZxION managed pressure drilling software performs hydraulic analysis. This software calculates annular pressure drop and equivalent circulating density to compare the pressures and required back pressure, if needed. By using this method to drill the well, some advantages were gained: the mud weights used to drill the well, the number of casing strings, and the number of changing mud weights were reduced.

Keywords: Equivalent Circulating Density, Back Pressure, Annular Frictional Pressure, Constant Bottom Hole Pressure, Darquain Oil Field

INTRODUCTION

Several MPD wells have been drilled onshore and offshore worldwide so far and the range of application of MPD has enormously increased since the past few years. MPD technology has four major variations and some of them have many different methods to attain MPD, while some have just one method. These variations

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are constant bottom hole pressure, pressurized mud cap drilling, dual gradient drilling, and HSE. MPD has been used in the USA, Canada, Mexico, South America, North-Sea, Europe, Africa, the Middle East, Australia, South East Asia, China, India, and several other parts of the world. According to some accounts and information available in the public domain, more than 350 MPD wells have been drilled offshore by the end of 2008 [7]. In 2006, drilling time and cost in Puguang province of China were reduced by half through managed pressure drilling. The use of MPD in the non-reservoir sections also provides the following advantages [2]: 1) increased ROPs and shortened drilling curves; 2) reduced bit usage; and 3) the enhancement of overall drilling performance through the reduction of vibration, drill string-related problems, and sticking potential. In 2008, the CBHP variation of MPD technique was applied in an exploratory well in Saudi Arabia. In previously drilled wells in the area, many drilling problems and wellbore stability issues were experienced. One of the possible causes of the mechanical instability could be attributed to the large fluctuations in the bottom hole pressure found in conventional drilling practices. These fluctuations are originnated from the stopping and starting of drilling fluid circulation during jointed pipe connections; specifically, they result from the fluctuations in the ECD, which occur when the pumps are turned on and off. The main problems during drilling in this area were associated with either increases in high nonproductive time and drilling cost caused by the partial/total loss of circulation, sloughing hole, pipe stuck, H_2S, water/oil/gas influx, and an increase in chlorides in the mud through contact with salt water formations or unsafe situations which were evident if the hydrostatic pressure exerted by the drilling fluid was not enough to control unexpected pressurized gas zones [14]. Based on these drilling problems events, CBHP was applicable and recommended as a MPD technique in this research. The MPD operation was successful and the ECD was maintained in the dynamic and static conditions between pore pressure and fracture pressure window in terms of onsite drilling, MPD software (to input data in real time such as pump rate), MW, standpipe pressure, and required choke manifold pressure. Such software can provide both early kick/loss detection, and lead time in the process to increase/decrease mud weight and circulation rate without any interruption to drilling ahead. Such services are provided by companies like Secure Drilling and AtBalance [11]. A number of studies have been involved in the feasibility study of MPD with offline hydraulic calculations. Almost all of them are done onsite [14]. Some process control methods have been utilized in many control problems [1], but a disadvantage of such methods for drilling purposes was the need to determine the control parameters in all stages (fluid rheology, cuttings loading, and temperature effects). The manipulations of cuttings loading and temperature effects make the process onerous [8]. However, for the preliminary candidate selection process, this level of accuracy is not necessary.

EXPERIMENTAL

Methodology

The Darquain oil field lies in the western banks of the Karun river in an area about 40 km of the northeast of Abadan, Iran. It is 24 km long and 10 km wide, elongated in northern-southern direction. For the scope of this study, the main source of offset data will be well DQ No. 4 and all the wells in the field, in particular, well DQ No. 2. The target reservoir was the carbonate sequence of Fahliyan formation within the so called Khami group (lower Cretaceous) found oil bearing by the exploration well DQ No. 2 and the first appraisal well DQ No. 4. The top of the reservoir is at 13290 ft TVD. The high reservoir pressures and the sour nature of some of the fluids dictate special care and attention during drilling through the cap rock and reservoir sequences to avoid potential drilling hazards [4]. It is decided to use the constant bottom hole pressure variation of managed pressure drilling technique to stay close to an agreeable pressure profile using surface backpressure. This variation is closely related to the enhanced kick and loss detection category of MPD. DZxION MPD CSM was used in order to perform offline hydraulic analysis and calculations [11]. The software can act as a preliminary screen to determine the utility of MPD for the potential MPD candidate wells. For calculating the annular and pipe pressure drop, it follows API RP 13D rheological model. Essential input parameters for this software are as follows:

1. Pp and PF data;
2. Drill string and BHA-OD's lengths;
3. Set of rheology data;
4. Mud weight, circulation rate;
5. Wellbore profile (if the well is directional);
6. Casing and open hole details (IDs and ODs).

The hydraulic calculations cannot be performed without the required input parameters mentioned above. Following the basic hydraulic analysis and calculations, it would help the user to make a better engineering decision in deciding whether to use MPD or not for a given prospect. In the method selected to perform the feasibility study of the DQ No. 5 well of Darquain field, the hydraulic calculations using API RP 13D model are performed. This can determine the ECD of each mud weight. By determining ECD and having pore pressure and fracture pressure in hand, it is possible to choose which technology is suitable for drilling the well, namely conventional drilling or managed pressure drilling.

So the first input data is the casing and drill pipe data set. The drill pipe length depends on which section of the well is to be simulated. The next step is to enter the formation pressure regime. By using overburden pressure gradient, pore pressure gradient, and Poisson's ratio in Eaton's equations, the fracture pressure gradient is obtained. The obtained fracture pressure gradient and pore pressure gradient are input to the software in pound per gallon unit. The calculated equivalent circulating density by the software is compared with the pore pressure/ fracture pressure window. Drilling fluid properties, mud rheology data, and the BHA details are next.

This is how the software determines whether this window is acceptable or not. If both the hydrostatic and dynamic pressures in the well are between the pore pressure and fracture pressures, the well does not need the MPD. If these pressures (hydrostatic of mud and dynamic pressure when pumps are on) fall below the pore pressure or exceed the fracture pressure, the software calculates the required mud weight and amount of back pressure. Afterwards, the software decides whether the MPD is applicable or not. The next section refers to the pressure gradients using the actual drilling data from well DQ No. 4 and all the important and valuable information from the offset wells. Well DQ No. 4 still remains as the reference well, though.

Fracture Pressure and Pore Pressure

The overburden gradient was calculated using the sonic log data of well DQ No. 4. The bulk density has been calculated using AGIP default formulas. The default values in the formula such as matrix bulk density, pore fluid density, and average matrix transit time were modified according to the local conditions, although there was no sufficient data. The bulk density was then integrated to calculate the overburden gradient. The fracture gradient is calculated as a function in the estimated pore and overburden gradient of the area. Depending on lithological type encountered, the K constant (a function in

Poisson's ratio) has been defined maintaining ENI AGIP strict policy operating in an unknown new area. In well DQ No. 4, all the tests were conducted as formation integrity test (FIT). Therefore, the fracture gradient curve illustrated in the gradient forecast graph was constructed using the theoretical formula using the basic rules as stated in ENI AGIP policies and manuals. The fracture pressure prediction strategy was also developed by Ben Eaton in 1975. The data required are formation overburden stress, pore pressure, and Poisson's ratio of the formation. The fracture gradient prediction equation is given by:

$$\frac{P_{frac}}{D} = \frac{\nu}{1-\nu}\left(\frac{\sigma_{ob}}{D} - \frac{P_{pore}}{D}\right) + \frac{P_{pore}}{D} \quad (1)$$

The resulting overburden pressure gradient is integrated from the bulk density of the well DQ No. 5 and is represented in pound per gallon unit of depth. The main source of the actual pore pressure data above the reservoir section is the well DQ No. 4. In the reservoir section, the actual bottom hole formation pressure from the DST tests has been used to update the pressure gradient data from the offset wells.

Drilling Operation Window

As it can be seen in Figure 1, from surface to Pabdeh formation at about 7382 ft TVD and in the whole Fahliyan formation, there is no serious drilling problem (through the 24", 17 ½", and 8 ½" hole section) due to the wide pressure margin. Figure 1 illustrates the drilling operation window of Darquain field. A significant loss has been observed during drilling lower 12 ¼" hole that has marginal pressure. Thus, the focus of this study is only on this section.

Steps of the Study

The steps involved either candidate selection or a feasibility study that can be divided into the following main categories: defining the purpose, procuring information, performing hydraulic analysis, and selecting the method [10]. First of all, establishing the purpose of the study has a higher precedence compared to the remaining steps. Heavy losses occur during drilling the lower 12 ¼" hole section; thus suggesting a way solving this drilling problem seems satisfactory. Therefore, curing the loss of circulation through that way provides advantages, including cost effectiveness (due to less mud loss) and eliminating excess casing string and saving time (because of fewer drilling problems and less rig cost).

All available data from the well being drilled (such as pressure regimes, drill string and BHA details, mud weight and rheology, and well bore geometry) are used in this study. Tables 1 to 7 are the input data of the software.

By using API RP 13D rheological model, the annular frictional pressure, ECD changes, and the required mud weight are calculated. The feasibility of the option, hydraulic analysis, constraints of the rig, and availability of the equipment assist choosing the best method along the different MPD variation.

RESULTS AND DISCUSSION

All the data mentioned above were input to the software. After running casing 13 3/8" to 7382 ft TVD and cementing, drilling continued with a 12 ¼" bit without major kick or loss problems according to the planned mud weight (ENI AGIP, 2005) [4]. When the bit reaches 13181 ft TVD (lower 12 ¼" hole section), the operator changes the MW from 13.34 ppg to 14.68 ppg because of high pore pressure expected in Gadvan. This is continued to the planned 9 5⁄8 " casing setting depth (13304 ft TVD). Figure 2 illustrates this procedure. According to the Figure 2, the pore pressure at 13304 ft TVD is about 9983 psi, and the column pressure of 14.68 ppg of mud is 10156 psi. When circulating the mud at 767 gpm, the BHP increases to 10259 psi. Although the well does not flow, as it generates positive differential pressures of 173 psi and 276 psi in static and dynamic conditions respectively, mud returns are lost throughout the Sarvak formation during drilling and making connection. It is critical to reduce the mud weight so as to possibly cure the problem. The minimum mud weigh that can be used to drill this interval (about last 123 ft of Gadvan formation) is an EMW of 14.43 ppg. For safety reasons, a mud weight of 14.45 ppg was used to drill this section. Hence a little overbalanced was expected at the bottom of the hole; however, when the pump turned on at 767 gpm, the mud returns could be found in Sarvak formation.

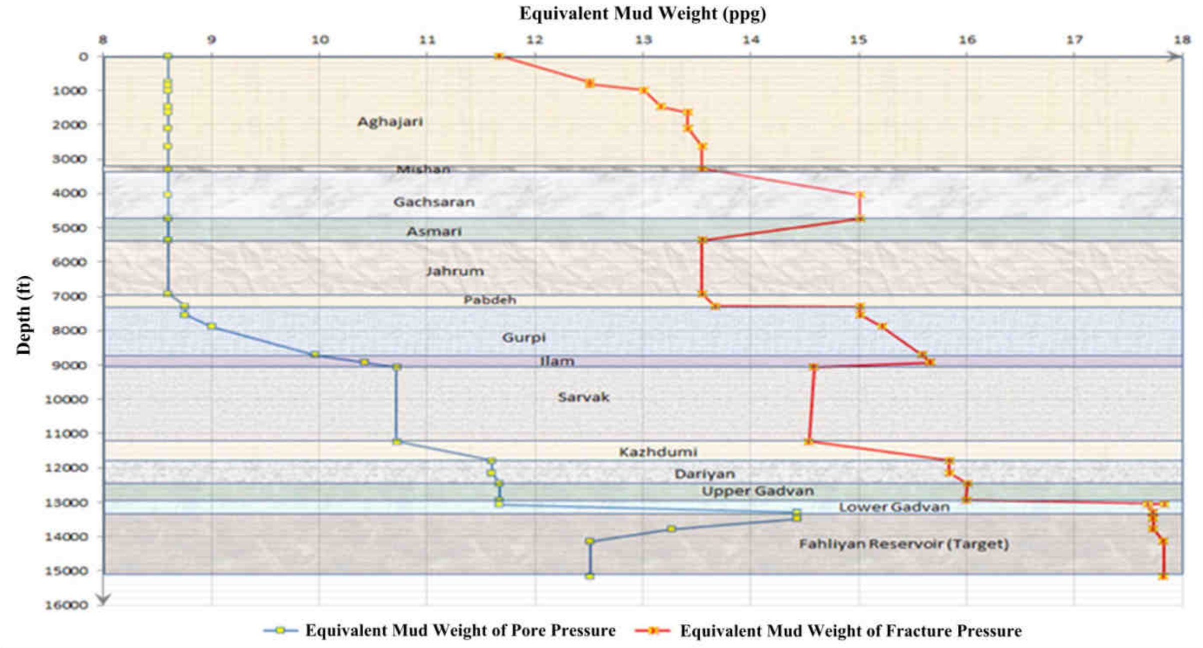

Figure 1: Pore pressure and fracture pressure profile of Well DQ No. 5

Table 1: Input data, drill string and BHA details, used in Fahliyan formation

Drill String Description (From Bit to Top)	ID (in)	OD (in)	Length (ft)	Distance from Bit (ft)
DC	2.81	8.00	30.80	30.80
St. Stab	2.81	12.25	4.82	35.62
DC	2.81	8.00	62.73	98.35
St. Stab	2.81	12.25	5.41	103.76
DC	2.81	8.00	180.90	284.66
Jar	2.81	8.00	16.53	301.19
DC	2.81	8.00	30.80	331.99
HWDP	3.00	5.00	460.78	792.77
DP	4.27	5.00	12511.00	13304.50

Table 2: Input data, casing design data

Description (Go From Bottom to Top)	Hole Dia. (in)	Casing OD (in)	Casing ID (in)	Depth From (ft)	Depth To (ft)
Open Hole	12.25	9.625	8.535	7382.25	13304.45
Surface Casing	17.50	13.375	12.415	0.00	7382.25
Conductor	24.00	18.625	17.755	0.00	820.25

Table 3: Input data, drilling fluid and circulation data

Rotational Speeds	Fann Viscometer Dial Readings		
θ_3	2		
θ_6	3		
θ_{100}	20		
θ_{200}	30		
θ_{300}	40		
θ_{600}	60		
Parameter	**Min**	**Increment**	**Max**
Circulation Rate (gpm)	707.0	10.0	767
Mud weight (ppg) used in lower 12 ¼” hole	14.22	0.03	14.31

Table 4: Input data, formation data

Formation Description	TVD (ft)	Pore Pressure (ppg)	Fracture Pressure (ppg)
Aghajari	0.00	8.60	11.67
Aghajari	820.2	8.60	12.51
Mishan	3281.0	8.60	13.55
Gachsaran	4035.6	8.60	15.01
Gachsaran	4727.9	8.60	15.01
Asmari	5367.7	8.60	13.55
Jahrum	6922.9	8.60	13.55
Jahrum	7287.1	8.75	13.67
Pabdeh	7290.0	8.75	15.01
Pabdeh	7533.1	8.75	15.01
Gurpi	7874.0	9.00	15.22
Gurpi	8697.9	9.96	15.59
Ilam	8924.3	10.42	15.67
Ilam	9058.8	10.72	14.59
Sarvak	11224.3	10.72	14.54
Kazhdumi	11782.0	11.60	15.84
Dariyan	12139.7	11.60	15.84
Upper Gadvan Lower Gadvan	12943.5 13051.0	11.67 11.67	16.00 17.84
Lower Gadvan	13288.0	14.43	17.73
Fahliyan Reservoir	13304.4	14.43	17.73
Fahliyan Reservoir	13780.2	13.26	17.73
Fahliyan Reservoir	15151.6	12.51	17.83

Table 5: Input data, used mud systems (ENI AGIP, 2005)

	Mud system	Density range (ppg)	Mud volume (ft^3)
24" hole section at 820 ft	Fresh water, bentonite (FW-GE)	8.75 -9.17	17700
17½" hole at 7382 ft	Salt water, polymer-lignosulfonate system (SW-PO-LS)	9.17-11.5	77700
12¼" hole at 13304 ft	Salt water, polymer-lignosulfonate system (SW-PO-LS)	12.5-14.7	47700

Table 6: Input data, mud characteristics (ENI AGIP, 2005)

		Hole Phases		
		24”	**17 ½”**	**12 ¼”**
Mud Type	Units	FW-GE	SW-PO-LS	SW-PO-LS
From	ft	0	820	7382
To	ft	820	7382	13304
Mud Density	ppg	8.75 -9.17	9.17-11.5	12.5-14.7
Viscosity	sec^{-1}	70	50-60	50-60
PV	cps	15-20	15-20	15-20
YP	lb/100 ft^2	61	18-22	19-25
Gel 10”	lb/100 ft^2	NA	2-4	2-4
Gel 10’	lb/100 ft^2	NA	4-6	4-6
PH	-	9.5-10	9-10	9-10
Filtrate API	cc/30’	NA	< 8	4-6
Pm	cm^3 0.02N H_2SO_4	NA	1	1
Pf	cm^3 0.02N H_2SO_4	NA	0.7	0.7

Table 7: Hydraulic program, 17 ½” section from 820 to 7382 ft RKB

		Pump data						**Bit Data**				
Depth (ft)	Mud Weight (ppg)	Flow Rate (gpm)	Pressure (psi)	Force (HHP)	Annular Velocity (ft/sec)	Nozzles (1/32 in.)	TFA (in^2)	Pressure at bit (psi)	% pressure at bit	Jet velocity (ft/sec)	Pressure (HHP/in^2)	Impact Force (kg)
1640	9.2	898	1251	662	1.306	3*18+1*16	0.941	793	61.0	305	1.7	594
3821	10.1	898	1507	792	1.306	3*18+1*16	0.941	867	55.0	305	1.8	648
4921	10.2	898	1678	886	1.306	3*18+1*16	0.941	867	49.6	305	1.8	648
7218	10.2	898	2361	1241	1.306	3*18	0.745	1381	56.0	387	2.9	820
7382	10.2	898	2446	1288	1.306	3*18	0.745	1381	54.0	387	2.9	820

Conventional Drilling

When a MW of 14.68 ppg is used, there is no other way to reduce loss amount and stop it, even if the pump is turned off. Thus this mud weight is rejected. By using a MW of 14.45 ppg, the circulation is lost under dynamic conditions using a pump rate of 767 gpm (see Figure 3). The only way to eliminate the problem in this situation is to reduce the pump rate to about 545 gpm; nevertheless, this rate might increase the risk of undesirable hole cleaning. It generates excessive frictional pressure of the cuttings, compensates for the pump rate reducing action, and might increase the ECD greater than that of the 767 gpm condition. Therefore, this mud weight could not treat loss of returns. These results make the use of a lower mud weight and the application of surface back pressure by choke manifold or back pressure pump inevitable in order to compensate for the bottom hole pressure due to a lower mud weight.

Constant Bottom Hole Pressure Solution

In the simulator, a MW of 14.31 ppg is used to drill this section. It is obvious that this mud is about 0.12 ppg lower than the pore pressure of the Gadvan formation at 13304 ft TVD. The static BHP of this mud is 9900 psi, while the pore pressure is about 9983 psi (see Figure 4). The well will certainly flow during drilling and connection, and thus the minimum 83 psi back pressure should be exerted at surface through choke manifold to compensate for the BHP. When the bit is reaming the formation at a pump rate of 767 gpm, the pressure throughout the wellbore is in a margin of safety and kick or loss scenario does not happen. The main issue is when a connection is to be made and the mud pumps are to be turned off. This is called the transition from dynamic to static condition.

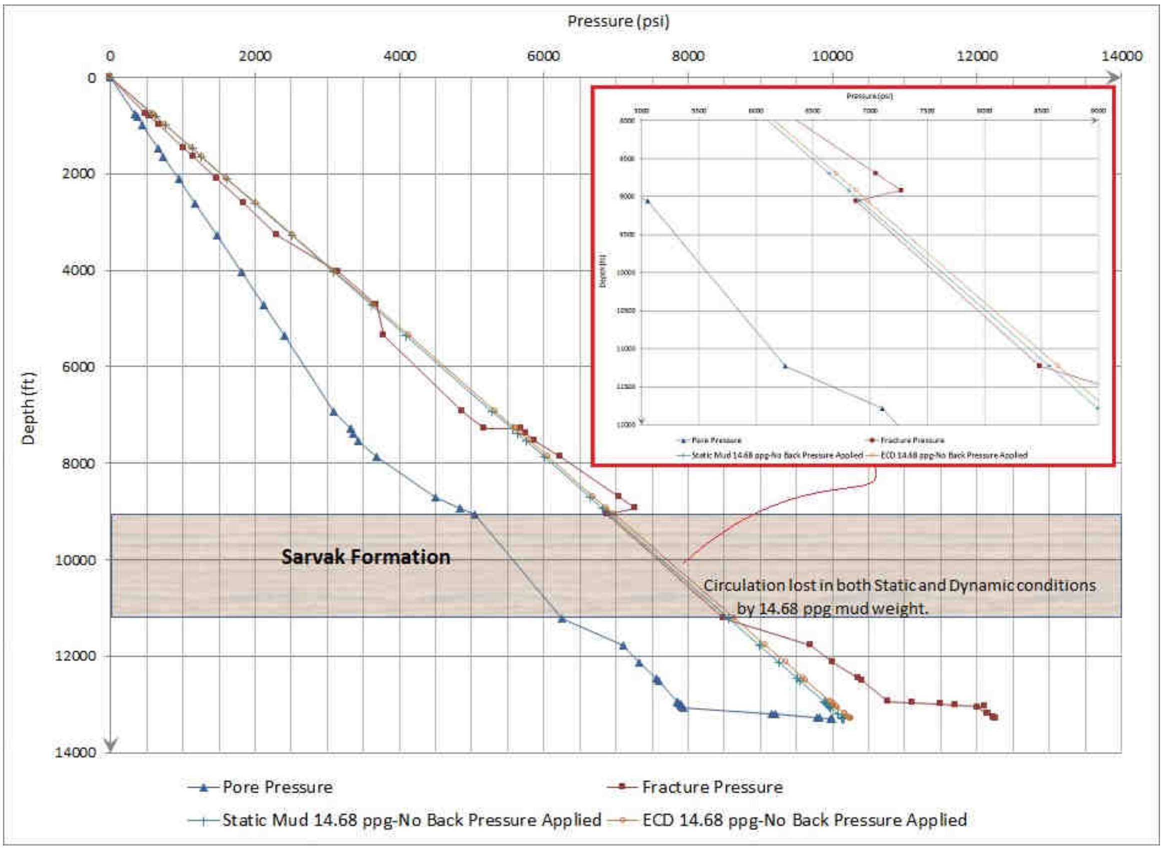

Figure 2: Operation window, static and dynamic BHP using a MW of 14.68 ppg at a pump rate of 767 gpm

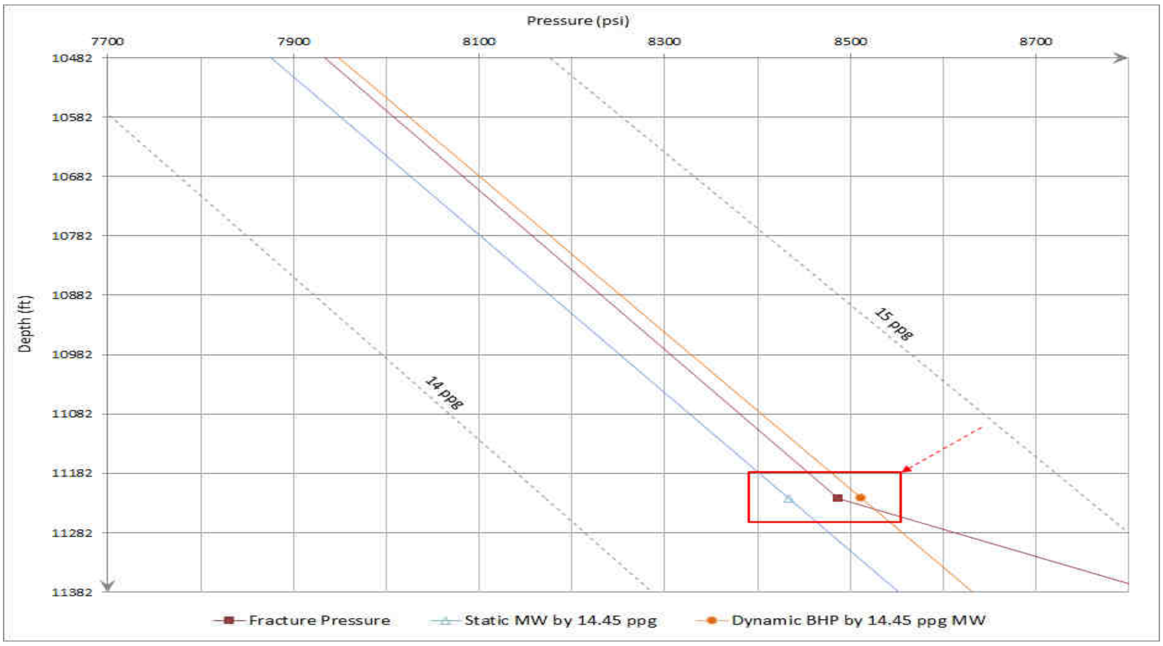

Figure 3: Static and dynamic BHP using a MW of 14.45 ppg at a pump rate of 767 gpm

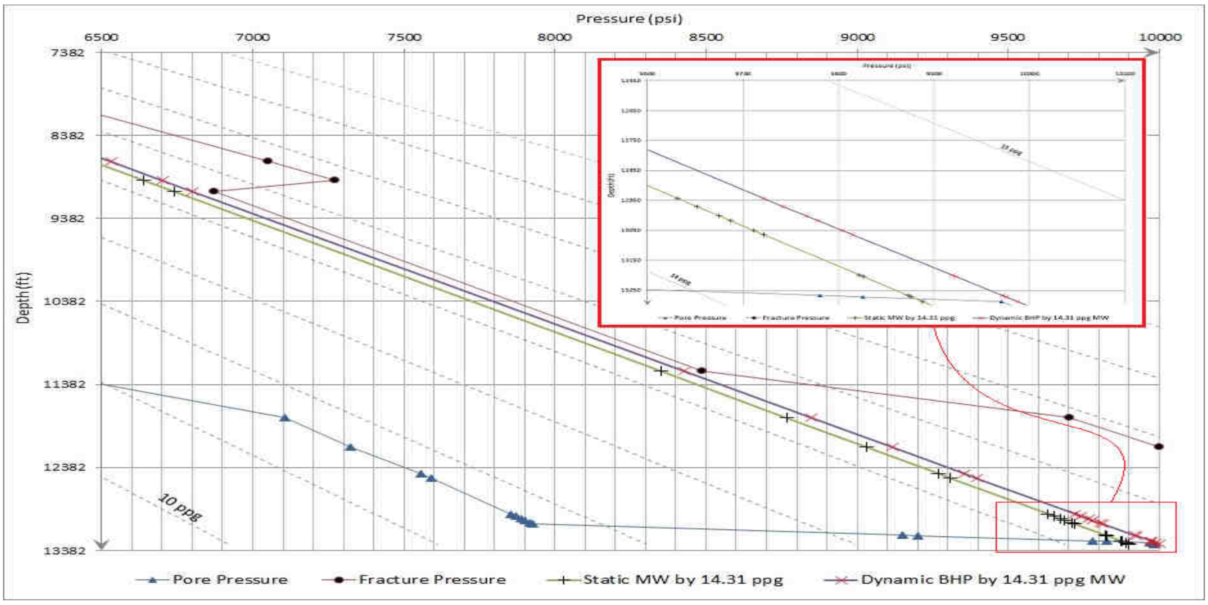

Figure 4: Static and dynamic BHP using a MW of 14.31 ppg at a pump rate of 767 gpm

Choke Opening Design

To shut down the pump for any reasons or if the pump is shut down suddenly, the BHP falls down the formation pressure and the well flows. Then, transition from dynamic to static conditions should follow a scheduled process to overcome the problem. Imagine that the pump rate is reduced; thus the BHP decreases stepwise until the pump is shut down. To avoid flow while the pump rate is reduced, the back pressure should slowly be exerted to the surface simultaneously to compensate for BHP. The choke opening is reduced until the annular pressure reaches the desired pressure at the next pump rate on the schedule; then, the pump rate is reduced to the one matching that annular pressure. Table 8 and Figure 5 show the design of the reducing pump rate while increasing choke back pressure to maintain the bottom hole pressure constant. It can be deduced from the bottom part of Figure 6 that the well flows if the pump is suddenly shut down from 767 gpm to a static condition. However, if the back pressure schedule is followed, the colored lines between “static-no BP” (green dotted line) and “static-100 psi BP” (red dotted line) are obtained. The result is that all of the stages from dynamic to static conditions are accompanied with a reduction in choke opening (means BP applied) and simultaneously pump rate is reduced; as a consequence, the bottom hole pressure is always constant.

Tripping in and Tripping out

Due to the marginal pressure window while drilling the last 123 ft of Gadvan formation, the surge and swab pressures should be taken into consideration. The lowest and highest criteria of allowable pressures while tripping are pore pressure in Gadvan and fracture pressure in Sarvak respectively. Since the BHP under both static and dynamic conditions are nearly equal to Gadvan pore pressure (about 17 psi over-balanced), the maximum pipe velocity while tripping out the hole should be simulated. The fracture pressure at bottom Sarvak is 8487 psi and should not exceed a maximum of 35 psi during tripping in. The mud clinging constant for annulus between 5" drill pipe and 12 ¼" open hole is equal to 0.36. The maximum allowable downward pipe velocity to have no returns loss to Sarvak is simulated to be about 1.75 ft/s. Also, the maximum allowable upward pipe velocity to avoid well flow is simulated to be about 0.58 ft/s. It is recommended that a good condition bit be selected for drilling this interval to avoid any bit problem in pulling out of hole.

Thus when a MW of 14.68 ppg is used and there is return loss in Sarvak formation, two ways are available to continue the operation:

1-Casing the bottom Sarvak and then using a higher MW will be possible;

2-Using the lowest possible MW to drill the Gadvan formation safely by choking the outlet of the wellbore to generate a pressure drop over a surface choke.

Each of these ways has a series of disadvantages and benefits. The first way requires a higher budget for casing and cementing excessive casing string, and as a consequence reduces borehole size. Therefore, it places some constraints on completion and production operations. The risk of stuck pipe due to high differential pressure is also high. The NPT increases and the total project cost per foot rises. In the second way, with an initial fixed cost of implementing MPD process, the need for excessive casing string is eliminated. Casing setting depth is extended and the wellbore reaches the reservoir with a higher hole size; this is suitable for performing completion and production operations. The risks of kick, loss, and differential stuck pipe are reduced due to a lower MW and controlled back pressure. The number of mud weight changes throughout the process is also reduced. All of these advantages can reduce NPT with no drilling problems, and eventually lower cost per foot is needed. The biggest disadvantage of this method is surge/ swab problem. By using a velocity of 1.75 ft/s and 0.58 ft/s in tripping in and tripping out respectively, it take a longer time to complete the operation. About 2 hours to trip in and 6 and half hours to trip out, which is too much high and can increase the total cost per foot of project.

Table 8: Schedule of reducing choke opening in shutting down the mud pump process with a mud weight of 14.31 ppg

Pump rate (gpm)	767	677	587	497	407	317	137	0
Applied Back pressure (psi)	0	17	37	52	67	78	94	100

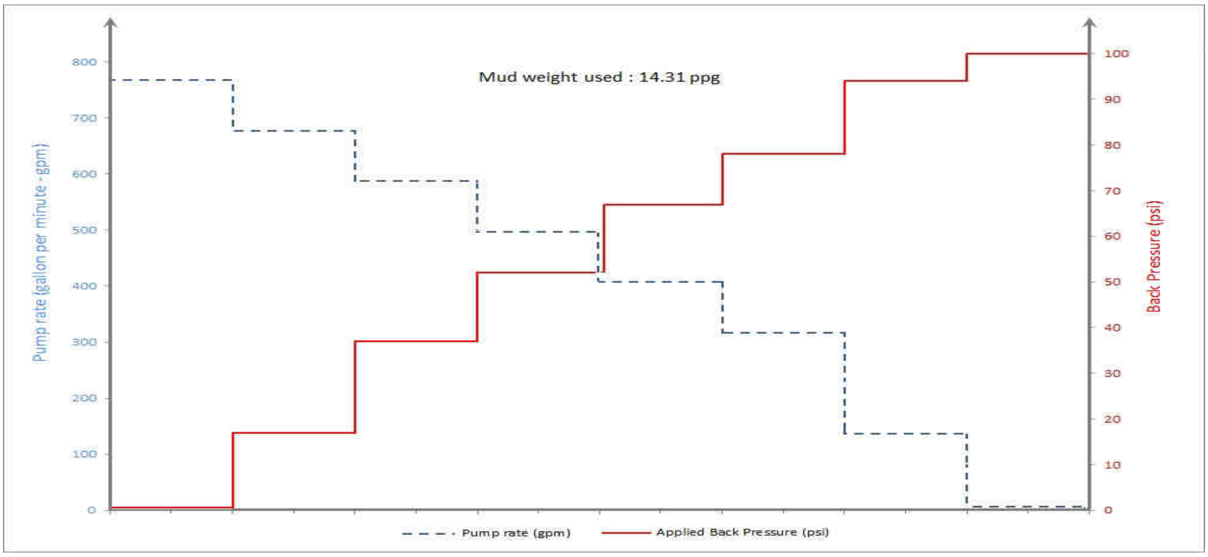

Figure 5: Pump rate and back pressure schedule to maintain constant BHP

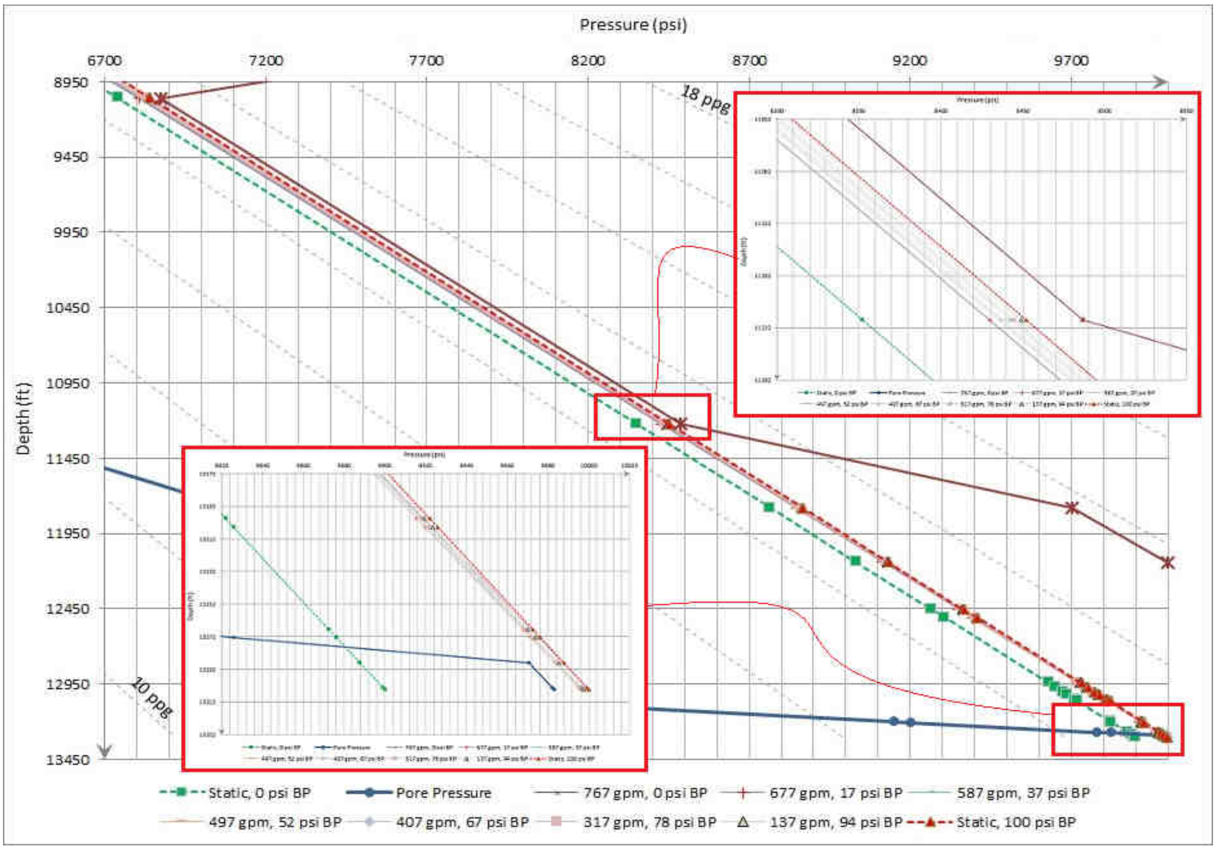

Figure 6: Pressure profile by following scheduled choke opening to maintain constant BHP

CONCLUSIONS

The feasibility study of implementing CBHP variation in Darquain oil field was done;

It was more challenging when the hole was simultaneously exposed to Gadvan formation with a pore pressure very close to the fracture pressure of the other exposed formation (Sarvak). A MW of 14.68 ppg induced circulation loss in Sarvak;

A MW of 14.45 ppg lowered the differential pressure and possibly brought formation fluid into the wellbore when the mud pumps were on;

By using the MPD software, a MW of 14.31 ppg was selected to drill the bottom 12 ¼" hole section;

Under static conditions, applying a surface back pressure of 100 psi by following the scheduled pump rate-choke opening eliminated the problem.

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NOMENCLATURE

AFP : Annular frictional pressure
BHP : Bottom hole pressure
BP : Back pressure
CBHP : Constant bottom hole pressure
ECD : Equivalent circulating density
EMW : Equivalent mud weight
Fp : Fracture pressure
gpm : Gallon per minute
MW : Mud weight
NPT : Nonproductive time
Pp : Pore pressure
ppg : Pound per gallon
TVD : True vertical depth

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