Managed Pressure Drilling Modeling & Simulation (a case study)

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Abstract
Drilling with conventional methods in narrow operational mud windows is difficult or even impracticable. The conventional drilling in such mud windows may lead to lots of drilling problems including drill string sticking, kick and lost circulation. In addition, the problems increase the non-productive time (NPT) and costs the oil industry a considerable amount of money.In order to overcome the narrow operational window limits and challenges, managed pressure drilling (MPD) technologies are developed, which are the extension of conventional drilling method.Unlike conventional drilling method, MPD methods use equipment and techniques to control well annular pressure precisely and be able to drill through narrow window safely. There are several MPD variations and methods. In this research, some of famous MPD methods are introduced and a MPD field case simulation is done using OLGA dynamic multiphase flow simulator. Simulated field case is a well drilling into 3 layers with different pore & fracture gradients, so operational mud window is very tight which forces the one to drill with a constant bottomhole pressure. Controlling bottomhole pressure at a constant value was implemented using surface choke back pressure with the help of a PID controller.

Keywords: managed pressure drilling (MPD), dynamic multiphase flow simulator (OLGA), smart drilling, CBHP, choke backpressure, choke opening, PID controller

Introduction
Nowadays, Managed Pressure Drilling (MPD) is one of the evolving technologies in the drilling industry, promising solution for the conventional drilling methods challenges such as [1][2]:

- Deep-water environment
- Depleted reservoirs,
- High pressure high temperature and
- Extended reach wells - Horizontal wells.

One of the keys with MPD technique is that one can precisely control the annular pressure with the help of techniques and tools. Figure 1 shows the operational windows for conventional drilling, MPD and Underbalanced Drilling (UBD). As showon in Figure 1, MPD drill near overpressure, which does not significantly damage the formation as the conventional, and able to drill through narrow drilling window, which is not possible with conventional drilling method. MPD is a relatively recent technology. The main principle of MPD is to manipulate the annular pressure profile accordingly to its needs and this control is made through the hydrostatic fluid column in addition to the application of a surface pressure known as backpressure. The backpressure is normally done by a choke which can vary from manual to semi or automatic, thus maintaining the desired pressure profile during the operation. MPD focuses not simply on the bottomhole pressure but also on the entire pressure profile[1] [2].

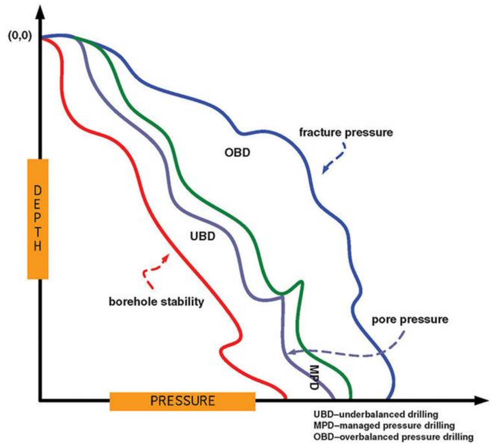

Figure 1-Drilling windows for Conventional, MPD and UBD [3]

According to the International Association of Drilling Contractors (IADC) MPD is defined as: MPD is an adaptive drilling process used to precisely control the annular pressure profile throughout the wellbore.This facilitates faster corrective action when pressure variations occur, as well as enabling drilling of otherwise “undrillable” wells[1].

Some of MPD advantages are as follows:

- Reduced number of casing
- Reduces the number of tripping and cost for cementing operation
- Reduced non-productive time
- Reduced the overall drilling cost
- Drill un-drillable formation, which is challenging for conventional methods
- Allows to drill a highly fractured formation
- Control annular pressure precisely during drilling and connection
- Increase Rate of Penetration (ROP)

To accomplish MPD a combination of techniques is necessary to be applied as follows:

- Backpressure
- A variable fluid density
- The fluid(s) rheology
- Circulation friction factor
- And the hole geometry

Equivalent circulating/static density during MPD can be estimated az Equation 1 for circulating and

$$ESD = MW_{HP} + BP_{SURFACE\ BACKPRESSURE}$$ **Equation 2**

2 for static condistions.(MW) is the drilling fluid density, (AFP) is fluid's frictional annular pressure drop and (BP) is surface back pressure may be enacted by choke[1][2].

$$ECD = MW_{HP} + BP_{SURFACE\ BACKPRESSURE} + AFP$$ **Equation 1**

$$ESD = MW_{HP} + BP_{SURFACE\ BACKPRESSURE}$$ **Equation 2**

MPD equipment package

There are several configurations which are available for MPD equipment. They vary in accordance with the objective of the work and the reservoir characteristics. For an accurate choice of which equipment is necessary for MPD operations, there is a series of relevant inputs and considerations to take into account for each case. Figure 2 shows the surface and subsurface equipment as listed below [2]:

- Rotating Control Devices (RCD)
- Drilling Chokes
- Choke Manifold
- Flowmeter
- Oil/Gas Separators
- Non-return valves, downhole isolation valves, downhole measurement

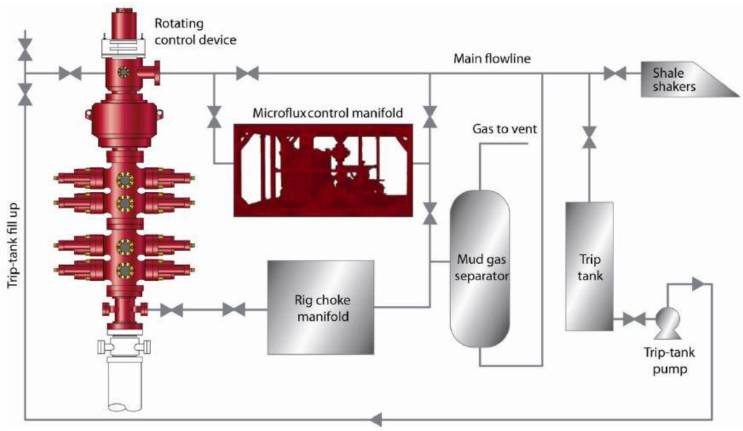

Figure 2- An example of a MPD system [2]

Different kinds of MPD method

MPD can be presented in seven different main variations [2]:

1- Constant bottomhole pressure drilling (CBHP)
2- Pressurized Mud Cap Drilling (PMCD)
3- Dual Gradient Drilling With and without a riser (DGD)
4- Riserless Mud Recovery (RMR)
5- Subsea MudLift Drilling (SMD)
6- Low Riser Return System (LRRS)
7- Returns Flow Control (HSE)

CBHP is used to report actions to reduce or correct the effect of circulation friction loss, or ECD to avoid exceeding the limits of fracture gradient when drilling ahead. This variation is uniquely suited to deal with narrow pressure environments. Normally the fluids program is designed to be at the predetermined depth or nearer balanced than conventional. In practice, the hydrostatic pressure transmitted by the mud, when not circulating, may result in a reasonable disequilibrium, and for that, jointed pipe connections are made with a surface backpressure roughly equivalent to the circulating annulus friction pressure, noted on the last stand of the drill string. The backpressure is applied through a choke manifold system connected to the RCD, hence maintaining the desired overbalance level to avoid an influx from the formation into the well. An adjustable choke is used to control the annular pressure independently if the mud pump is working or not. Even without the pump flow rate, the pressure can be applied in two diverse ways: by circulation through BOP booster line or by circulation through a dedicated pump during connection. In that way, the bottom hole pressure resulted from fluid circulation (ECD) is replaced by the application of surface pressure, in other words, the fluid density is reduced and the hydrostatic pressure loss or friction loss is compensated by the backpressure. This fact allows the bottom pressure to be slightly over than the pore pressure, decreasing the risk of circulation loss and overlap the formation fracture gradient. Nowadays, CBHP is the MPD variation most used in the industry. It allows to extend the shoe casings depth once it's possible to continue drilling even when narrow operation window and possibly reducing the hole sections of the well.[2][3].

MPD simulation Using dynamic multiphase flow simulator (OLGA)

OLGA is a comercial dynamic time dependent multiphase flow simulator, used for networks of wells, flowlines and pipelines and process equipment, covering the production system from bottomhole into the production system. OLGA comes with a steady state pre-processor included which is intended for calculating initial values to the transient simulations, but which also is useful for traditional steady state parameter variations. Modeling a MPD operation in OLGA simulator may be a way to overcome complexity of MPD modeling[4].

Simulation was carried out for a narrow mud window case study.as shown in Figure 3, there exist 3 different layers with different mud windows in open hole region (2 weak zones and a kick zone between them). The the weak zone 3,2 have fracture gradients about 14.9 and 14.8 ppg (lb/gal), however, kick zone 1 has a pore pressure gradient about 13.7 ppg. So drilling these 3 zones in single hole section with a uniform drilling fluid is difficult, because operational mud window is between 13.7 to 14.8 ppg which is a narrow mud window.Following a conventional well control design, a mud weight greater than 13.7 ppg is required to drill Well. However, if this mud weight was used, that would have led to significant frictional pressure losses in the slim annulus and increased the risk of problems such as lost returns and pipe sticking. To overcome these complications, a 13.2 ppg mud weight should be utilized in a MPD CBHP method. The pressure difference between the 13.7 ppg formation and 13.2 mud weight is compensated for by the balanced by the surface backpressure at the choke.choke opening vae adjusted during drilling to hold bottomhole pressure on 10558.912 psi when drilling into the kick zone.Table 1 shows simulation input parameteres. To control choke opening during simulation a parallel PID controller has been used which reads bottomhole pressure variations and changes choke openning related to the readings.Table 2 Contains controller's designed parameters.

Table 1- simualtion input data [4]

Simulation input parameters			
mud weight (ppg)	13.2	Bit Diameter (in)	6
mud flow rate (gpm)	190	bit nozzle size (in)	3* 11/32
Target depth (ft)	17700	choke diameter (in)	3
open hole ID (in)	6	ROP (ft/hr)	23
open hole length (ft)	1832	RPM (rpm)	150

Table 2- PID Controller designed parameters

P	1*10^3
I	1*10^9
D	0
Control variables	Bottomhole Pressure
Manipulated variables	Choke Opening
Control Set Point	10558.912
Min Signal	0
Max signal	1

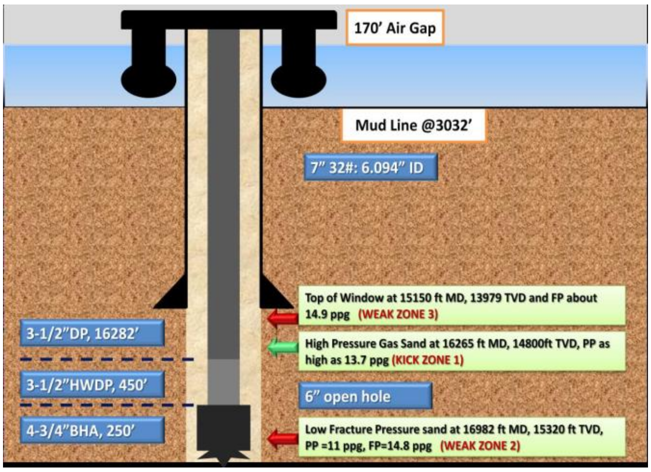

Figure 3- Schematic of simulated offshore well [5]

Results and discussion

Figure 4 shows bottomhole pressure variation during drilling kick zone in OLGA simulation. As mentioned before, bottomhole pressure has been desired at 10558.912 psi. According to Figure 4, simulated botoomhole pressure error related to desired pressure is less than 1% during simulation time which is an acceptable result for controlling bottomhole pressure by choke back pressures caused by changes in choke openning.Figure 5 Shows choke opening changes during simulation caused by designed PID controller output signals.

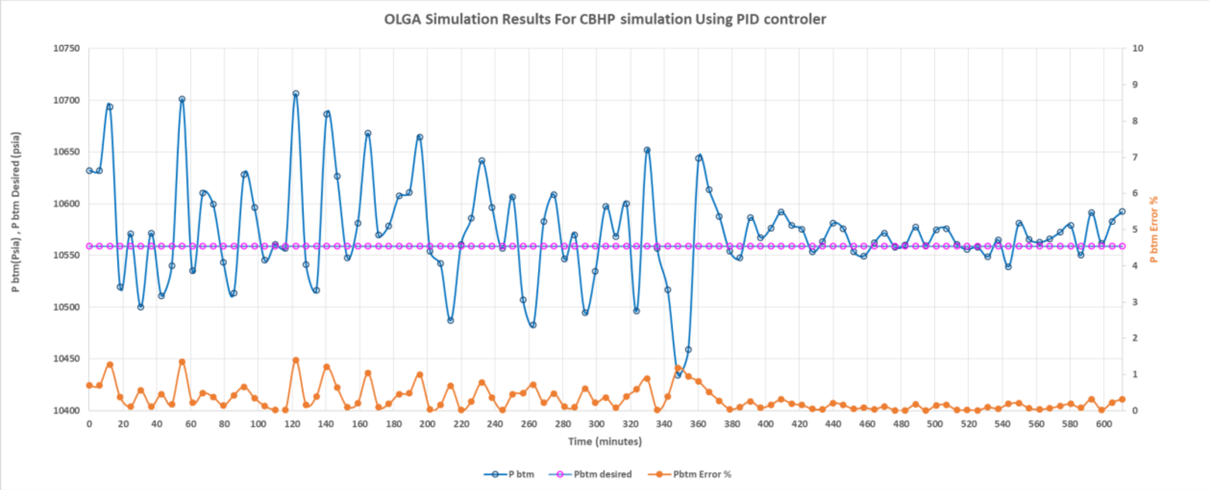

Figure 4- OLGA MPD CBHP results

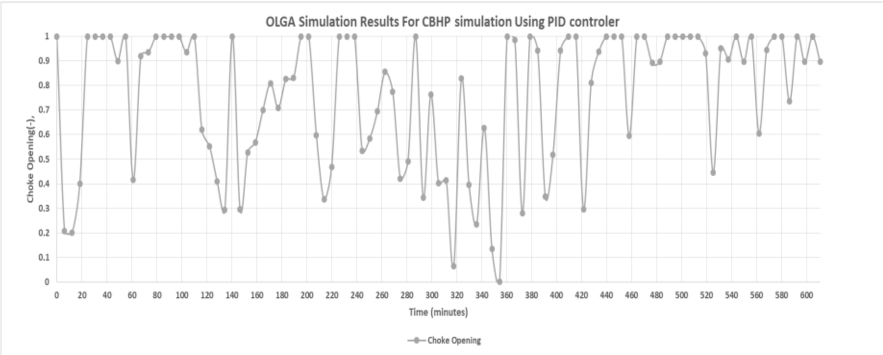

Figure 5- MPD CBHP Choke Opening variation during simulation

Conclusion

Conventional drilling in some cases like narrow mud windows, HPHT, and deep water drilling wells may cause lots of drilling problems such as stuck pipe, loss circulation and formation damage. To avoid these problems, a new drilling method called managed pressure drilling may be useful. One of MPD methods called CBHP is a good choice when drilling in narrow mud windows. In this research, MPD CBHP method modeling and simulation was implemented for a narrow mud window case by OLGA software. Bottomhole pressure has been kept constant by a choke back pressure configuration. Choke Opening during simulation has been estimated by a parallel PID controller. Simulation results showed acceptable bottomhole pressure variations which means MPD CBHP method is a good solution when drilling in narrow mud windows, but needs to be improved and simulated for similar situations before using it in real operations.

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