Archives of Petroleum & Environmental Biotechnology

Saad MA and El-Sayed AAH. Arch Pet Environ Biotechnol: APEB-125.

Research Article

DOI: 10.29011/ 2574-7614. 100025

How to Optimize Well Hydraulics of MPD Under HPHT Environment

Mohanad Aly Saad*, **Abdel-Alim Hashem El-Sayed**

Department of Petroleum, Cairo University, Egypt

***Corresponding author:** Mohanad Aly Saad, Department of petroleum, Cairo University, Egypt. Tel: +201271321573; Email: petroeng.mohanadaly@gmail.com

Citation: Saad MA, El-Saye AAH (2018) How to Optimize Well Hydraulics of MPD Under HPHT Environment. Arch Pet Environ Biotechnol: APEB-125. DOI: 10.29011/ 2574-7614. 100025

Received Date: 01 January, 2018; **Accepted Date:** 11 January, 2018; **Published Date:** 17 January, 2018

Abstract

As exploring for oil and gas traps becomes more extreme in term of depths, the companies start to search for modern technologies and equipment for drilling under HPHT conditions. One of the challenges of HPHT deep water well is narrow margin between the fracture pressure gradient and pore pressure gradient, therefore prediction and control of well hydraulics is indeed vital. The solution for the HPHT deep water challenges is a technology of Managed Pressure Drilling (MPD). Riser less drilling is one of the types of MPD. It uses two different annular pressure gradients for maintaining required bottom hole pressure to drill a well

This study presents a new approach for accurate determination and optimization of well hydraulics for MPD (Riser less drilling) under HPHT conditions. This approach depends on accurate prediction and determination of borehole temperature, mud density and pressure, mud rheology and hydraulics profiles inside wellbore under HPHT conditions. This work shows the comparison between well hydraulics that calculated by constant fluid properties (i.e independent on pressure and temperature conditions) and well hydraulics that calculated by taking into account the effect of pressure and temperature on fluid properties. This paper also shows the effect of drill pipe tool-joint, drilled cutting, annular eccentricity and drill string rotation pressure losses on well hydraulics for MPD. The objectives were achieved by designing computer simulator called ''HPHT MAT''. A case study by using ''HPHT MAT'' simulator to show the correct procedure for optimization the well hydraulics of MPD is introduced.

The results show that accurate prediction and determination of temperature and mud rheology modelling is highly required for accurate planning and designing of MPD hydraulics. The pressure difference between the drill pipe and annulus in Riser less drilling must be taken into consideration during the calculation of the density, plastic viscosity, yield point and ECD profiles inside wellbore. Neglecting the effect of pressure and temperature on mud properties in the well hydraulics calculation will lead to erroneous results which may lead to a kick or a loss of circulation. Pressure losses due to drill pipe tool-joint, drilled cutting, annular eccentricity and drill string rotation have significant effect on well hydraulics of MPD. New technique for calculating the well hydraulics of MPD by using finite difference calculation is developed.

Keywords: Dual Gradient Drilling; High Pressure and High Temperature Condition; Managed Pressure Drilling; Riser Less Drilling

Abbreviations:

G	:	**acceleration of gravity, m/s^2**
Θ	:	**angle of divergence or convergence, degrees**
E	:	**annular eccentricity, dimensionless**
ΔP_a	:	**annulus pressure loss, psi**
$\tilde{v}$	:	**average velocity in pipe or annulus, m/s**

μ_o	:	**base oil plastic viscosity at reference conditions, cp**
µTP	:	**base oil plastic viscosity at (T,P) pressure P,cp**
C_a	:	**cutting concentration, %**
D_b	:	**diameter of drill bit, m**
ρm1	:	**density of mud phase at reference condition** (P_1, T_1)
ρ01	:	**density of oil phase at** (P_1, T_1)**, ppg**
ρ02	:	**density of oil phase at** (P_2, T_2)**, ppg**
ρs	:	**density of solid content, kg/m3**
ρw1	:	**density of water phase at** (P_1, T_1)
ρw2	:	**density of water phase at** (P_2, T_2)
D_i	:	**drill pipe diameter**
P_{Vo}	:	**drilling fluid plastic viscosity at standard conditions, cp**
PV_{TP}	:	**drilling fluid plastic viscosity at (T, P), cp**
X	:	**depth of well, ft**
Ψ	:	**diameter ratio Di/Do, dimension less**
F_e	:	**eccentricity coefficient, dimensionless**
N	:	**generalized flow behaviour index, dimensionless**
G	:	**geothermal gradient** ^{O}**F/ft**
k_c	:	**gradual contraction coefficient, dimensionless**
k_e	:	**gradual enlargement coefficient, dimensionless**
T_{pi}	:	**inlet temperature of mud in drillpipe,** ^{O}**F**
K	:	**local resistance factor**
M	:	**mass flow rate, Ib/hr**
C_p	:	**mud heat capacity, BTU/(Ib.°F)**
T_a	:	**mud temperature in annulus, °F**
T_p	:	**mud temperature in drillpipe, °F**
ρm	:	**mud weight, ppg**
U	:	**overall heat transfer coefficient across wellbore face, BTU/ (sqft.**^{O}**F hr)**
h_p	:	**overall heat transfer coefficient across drillpipe BTU/(**ft^2**.°F hr)**

μp	:	**plastic viscosity,** cp
ΔP_E	:	**pressure drop of annulus eccentricity and pipe rotation, Pa**
ΔP_S	:	**pressure drop of cutting concentration, Pa**
P	:	**pressure, psi**
R	:	**radius, ft**
R_{op}	:	**rate of penetration, m/s**
r_p	:	**radius of drillpipe, ft**
r_p	:	**radius of drillpipe, ft**
σ	:	**ratio of diameters of small to large pipes, dimensionless.**
F_r	:	**rotation coefficient, dimensionless**
F_w	:	**salt water volume fraction**
T_0	:	**standard temperature, 60 ^oF**
V_S	:	**slip velocity of cuttings, m**
γ	:	shear rate, 1/sec
τ	:	shear stress, $lb_f/100\ ft^2$
H	:	**true vertical depth of well, Ft**
T	:	**temperature, ^OF**
T_s	:	**temperature of formation's surface, ^oF**
ΔP_J	:	**tool joint pressure loss, Pa**
K'	:	**velocity profile correction factor, dimensionless**
D_o	:	**wellbore diameter, m**
τy	:	**yield point at elevated temperature,** $lb_f/100\ ft^2$
τy_o	:	**yield point at reference temperature,** $lb_f/100\ ft^2$

Introduction

HPHT well is defined as the well have bottom hole temperature exceeds 300 ^oF and bottom hole pressure greater than 0.8 psi/ft. Nowadays, companies try to find petroleum in unconventional areas such as HPHT deep water, to decrease the gap between the demand and supply. Drilling of HPHT deep water wells involves high risk and cost; therefore, effective methods are required to solve these issues. Oil and gas industry offer advanced drilling technologies to reach HPHT deep water reservoir targets safely [1].

The margin between pore pressure and fracture pressure in HPHT deep water well is narrow, therefore accurate determination and optimization of well hydraulics is highly required. Managed Pressure Drilling (MPD) has been developed for overcoming the HPHT deep water well challenges. In MPD techniques, there is a method defined as Riser less drilling. The Riser less method uses two different annular fluid pressure gradients for well drilling. In the technique of Riser less drilling, the riser is completely filled with sea water and returned mud along with the cuttings is pumped by additional subsea mud pump to surface through small return line 6”, (Figure 1) [2].

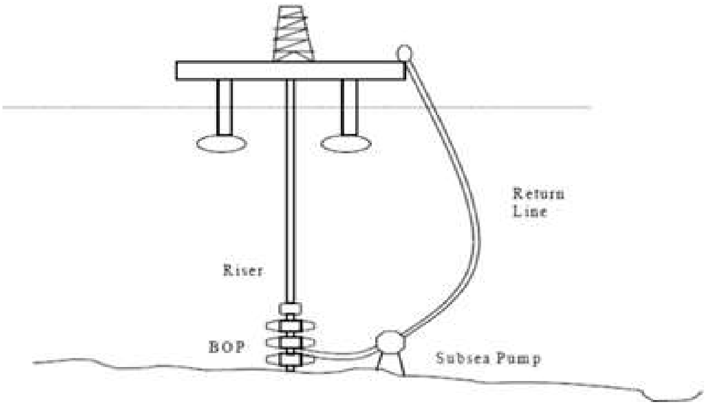

Figure 1: Riser less drilling schematic [2].

There are pressure and temperature variations across wellbore during drilling by Riser less drilling technique; above seabed there is low temperature condition which will lead to increase in mud rheology, however below seabed there is opposite effect. Well hydraulics planning depends on how drilling fluid rheology is influenced by pressure and temperature effects inside wellbore; therefore, ignoring these effects in the well hydraulics calculations will give erroneous result [3]. Accurate well hydraulics planning for HPHT wells is needed to avoid drilling problems such as kick and loss of circulation. This paper presents a new approach for accurate determination and optimization well hydraulics of MPD (Riser less drilling) under HPHT conditions. This work shows the comparison between well hydraulics calculated by constant fluid properties (i.e independent on pressure and temperature conditions) and well hydraulics calculated by taking into account the effect of pressure and temperature on fluid properties. This research also shows the effect of tool joint, cutting, annular eccentricity and drill string rotation pressure losses on well hydraulics of MPD.

Theoretical Background

Temperature modelling, mud density and pressure modelling, plastic viscosity and yield point modelling and rheological hydraulic modelling are indeed important for accurate determination and optimization for well hydraulics of MPD under HPHT conditions.

Drilling Fluid Temperature Modelling

Temperature modelling inside the wellbore is necessary for determining well hydraulics. Wellbore temperature has great impact on mud properties such as density, hydrostatic pressure, yield point and viscosity, therefore it will influence on the determination of pressure losses and Equivalent Circulating Density (ECD) [4]. The Holmes and Swift model 5 assumes steady-state linear heat transfer between annulus fluid and the formation. The model is described in three steps [5].

Step 1: Calculation of A and B parameters, Equation1 and Equation 2 [5].

$$A=\frac{mCp}{2\,\pi\, rp\, hp} \quad (1) \qquad B=\frac{rU}{rp\, hp} \quad (2)$$

Step 2: Calculation of C1, C2, C3, and C4 parameters, from Equation 3 to E Equation 6 [5].

These equations represent the analytical solution of the wellbore temperature profiles inside the drill pipe and annulus

$$C_1=\left(\frac{B}{2A}\right)\left[1+\left(1+\frac{4}{B}\right)^{1/2}\right] \quad (3) \qquad C_2=\left(\frac{B}{2A}\right)\left[1-\left(1+\frac{4}{B}\right)^{1/2}\right] \quad (4)$$

$$C_3=1+\frac{B}{2}\left[1+\left(1+\left(1+\frac{4}{B}\right)^{1/2}\right]\right. \quad (5) \qquad C_4=1+\frac{B}{2}\left[1-\left(1+\left(1+\frac{4}{B}\right)^{1/2}\right]\right. \quad (6)$$

Step 3: Calculation of temperature in drill pipe and annulus. For the temperature of the mud in the drill pipe and annulus (Equations 7, 8, 9, 10) [5].

$$T_p=K_1 e^{c_1 x}+K_2 e^{c_2 x}+GX+T_s-GA \quad (7) \qquad T_a=K_1 C_3 e^{c_1 x}+K_2 C_4 e^{c_2 x}+GX+T_s \quad (8)$$

$$K_1=T_{pi}-K_2-T_s+G*A \quad (9) \qquad K_2=\frac{G*A-[Tpi-Ts+G*A]\, e^{c_3 H}(1-C_3)}{e^{c_2 H}(1-C_4)-e^{c_1 H}(1-C_3)} \quad (10)$$

Density Behaviour Modelling

Drilling fluid density is affected by temperature and pressure [6]. The Hobe rock [7] Model assumes that drilling fluid density variations as a result of pressure and temperature changes occur due to liquid constituent’s volumetric behaviour such as water and/or oil.

Density of oil based drilling fluid can be described mathematically as follows: [7]

$$\rho_m=\frac{\rho_{m1}}{1+f_o\left(\frac{\rho_{o1}}{\rho_{o2}}-1\right)+f_w\left(\frac{\rho_{w1}}{\rho_{w2}}-1\right)} \quad (11)$$

Plastic Viscosity and Yield Point Modelling

Politte [8] studied rheological data for oil based mud and concluded that the plastic viscosity follows the base oil behaviour. Therefore, the plastic viscosity can be normalized with the base oil viscosity [9]. The Politte [8] equation is described as follows.

$$PV_{T,P}=PV_o\,\frac{\mu_{T,P}}{\mu_0} \qquad 12$$

Procedure of Politte correlation [8] can be used with any base oil. He established the following formula as a function of temperature and pressure for viscosity of base oil (Equation13) from analysis of diesel oil No. 2 [8].

$$\mu(T,P) = P\times(T\times P)^{A_o}\times 10^{\left(A_1+A_2T+A_3T\,P+A_4P+A_5\rho_o+\frac{A_6}{\rho_o}\right)} \qquad 13$$

A0 = -23.18 A1 = -0.00148 A2 = -0.950 A3 = -1.9776×10-8 A4 =3.3416×10-5 A5 = 14.67

Politte8 gives the following equation for yield point determination.

$$\tau_y=\tau_{yo}\frac{B_o+B_1T^{-1}+B_2T^{-2}}{B_o+B_1T_o^{-1}+B_2T_o^{-2}} \qquad 14$$

B0 = -0.186 B1 = 145.054 B2 = -3410.322

Rheological Hydraulic Modelling

First two-parameter model is Power law model. The model is the most popular one in drilling engineering and it is used inside the simulator, Equation15 [10].

$$\tau = K\,\gamma n15$$

Factors Influencing Pressure Losses

Influence factors of pressure drop are drill pipe tool-joint, drilled cuttings, annular eccentricity and drill string rotation

Drill pipe Tool- Joints

When mud moves inside pipe with uniform diameter, it will take a certain flow pattern. Any change in the diameter of pipe will change flow pattern, this will lead to turbulence and loss of energy. This turbulence will create an additional pressure loss. This additional pressure loss can be calculated by: [11].

$$\Delta P_j=K\left(\frac{1}{2}\rho_m\,\tilde{v}^2\right) \qquad 16$$

This K is factor of local resistance. This factor includes gradual enlargement and contraction factor [11].

Gradual enlargement factor (Eq. 17) Gradual contraction factor (Eq. 18)

$$K_e=\begin{cases} 2.6\,\mathrm{Sin}\left(\frac{\theta}{2}\right)(1-\sigma^2)^2 & (\theta\le 45^0) \\ (1-\sigma^2)^2 & (45^o<\theta\le 180^0)\end{cases} \qquad 17$$

$$K_C=\begin{cases} 0.8\sin\left(\frac{\theta}{2}\right)(1-\sigma^2) & (\theta\le 45^0) \\ 0.5\sqrt{\sin\left(\frac{\theta}{2}\right)}(1-\sigma^2) & (45^o<\theta\le 180^0)\end{cases} \qquad 18$$

Drill String Rotation and Annular Eccentricity

Annular eccentricity and drill pipe rotation must be considered during calculation pressure losses. Annular eccentricity and drill pipe rotation pressure losses can be defined as follows: [12]

$\Delta PE= fe\times fr\times\Delta Pa$ 19

fe is the coefficient of eccentricity, fr is coefficient of rotation. Haciislamoglu [13] developed a correlation for determining the two coefficients (Equation 20 & 21), thus:

$$f_e=1-0.072\,\frac{\epsilon}{N}(\Psi)^{0.8454}-1.5\,\varepsilon^2\sqrt{N}\,(\Psi)^{0.1852}+0.96\,\varepsilon^3\sqrt{N}\,(\Psi)^{0.2527} \qquad 20$$

$$f_r=\left[1+\frac{3}{2}\,\varepsilon^2\right]^{0.5} \qquad 21$$

For concentric annuli ε = 0, and for fully eccentric conditions ε =1.

Drilled Cuttings Pressure Drop

Flow inside annulus considered two-phase flow (solid-liquid). Cuttings will create additional pressure losses. Cutting pressure loss is function of drilled cutting concentration. Cutting pressure loss is given by Equation 22 [14]. Bhattacharya [14] determined the cutting concentration by using the two-phase flow theory (solid-liquid) and it can be determined by using the Equation 23:

$$\Delta P_S=g\,H\,(\rho_s-\rho_m)\,C_a \qquad 22$$

$$C_a=\frac{D_b^2\,R_{op}}{(D_O^2-D_i^2)(\tilde{v}-K'\,V_S)} \qquad 23$$

Methodology

Main objective of this study is designing simulator that can optimize the wellbore hydraulics of Riser less drilling by taking into account the effect of HPHT on mud flow properties. Methodology based on designing simulator that can simulate the temperature profile, density and pressure profile, plastic viscosity and yield point profile, pressure losses and ECD profile

The correct procedures for optimization well hydraulics of MPD under HPHT condition:

1. Simulate temperature profile inside drill string and annulus, taking into consideration heat transfer between drill string and

annulus and also between annulus and formation.

2. Study the density and volumetric behavior of mud under HPHT. Calculate the density of drilling fluid by taking into consideration the two effects of the temperature and pressure. Calculate the pressure by two methods; first method is assuming constant fluid density and second method is taking into account temperature-pressure dependence of fluid density.

3. Study the effect of HPHT on rheology of mud. As yield value and viscosity will be used in pressure loss calculation, so that understanding rheological behaviour of drilling fluid under HPHT is indeed important

4. Determine the relationship between mud flow properties and pressure/temperature conditions, so that this relation can be used in well hydraulics calculation

5. Determine the appropriate hydraulics model to simulate the pressure losses of mud at HPHT environment

6. By using finite difference calculation, it possible to determine the hydrostatic pressure, density profile, mud rheology profile, ECD and total pressure losses inside wellbore

7. Optimize bit hydraulics, by using either impact force or max hydraulic horsepower criteria

Combining the above seven steps will optimize the wellbore hydraulics of MPD under HPHT.

The ‘’HPHT MAT’’ simulator is menu-driven, easy to use, and runs on a personal computer and compatible system. The simulator was developed using MATLAB. After opening the computer program, the input data sheet is displayed. A picture of the input data sheet can be seen in (Figure 2). The computer program contains 5 MATLAB files. The program can export data to excel sheets.

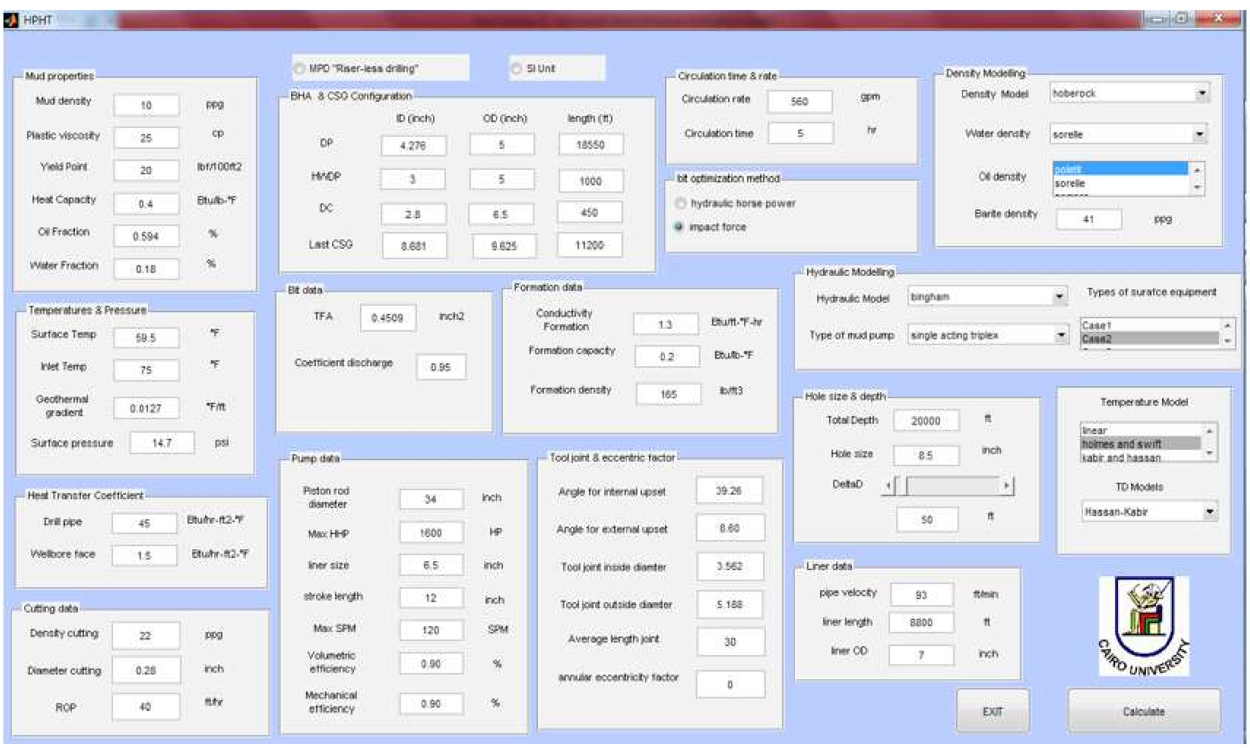

Figure 2: Graphical user interface of input data.

(Table 1) shows well and mud circulating properties for well that has been drilled by a Riser less drilling technique. ''HPHT MAT'' simulator is used to simulate this case study.

Depth of bottom of well , ft	30000
Outside diameter of drill pipe, inch	5
Inside diameter of drill pipe , inch	4.276
Inside diameter of tool joint ,inch	3.562
Outside diameter of tool joint ,inch	5.188
Angle for internal upset (drill pipe),degree	39.26
Angle for external upset (annulus),degree	8.6
Average joint length ,ft	30
Outside diameter of HWDP , inch	5
Inside diameter of HWDP, inch	3
Length of HWDP,ft	600
Outside diameter of DC, inch	8
Inside diameter of DC, inch	3.25
Length of DC, ft	300
Inside diameter of last casing ,inch	10.05
Last casing shoe,ft	25000
Diameter of well, inch	9.5
Circulation rate, bbl/hr	800
Geothermal gradient , ^{o}F/ft	0.0127
Sea water gradient , ^{o}F/ft	-0.004
Surface sea temperature, ^{o}F	85
Water depth, ft	10000
Mud heat capacity, BTU/(Ib-^{o}F)	0.4
Mud density ,Ib/gal	13
Plastic Viscosity, cp	20
Yield Point , Ibf/100ft^{2}	14
Over-all heat transfer coefficient across drill pipe , BTU/(sqft-^{o}F-hour)	45
Over-all heat transfer coefficient across well bore face , BTU/(sqft-^{o}F-	1.5
hour)	
Oil fraction	0.591
Water fraction	0.18
Surface pressure, psi	14.7
Nozzle sizes , 1/32 inch	14 14 14
Coefficient of discharge	0.95
Liner size , inch	6.5
Max HHP, HHP	1600
Stroke length, inch	12
Max SPM	120
Volumetric efficiency	0.9
Mechanical efficiency	0.9
Type of pump	Single acting triplex pump
Type of surface equipment	Type 2
Annular eccentricity(dimensionless)	0
Density of rock , ppg	22
Average cutting size, inch	0.28
ROP , ft/hr	40

Table 1: Riser less drilling case study.

Results and Discussion

A case study (Table 1) had been simulated to analyse the correct procedure for accurate determination and optimization of MPD well hydraulics under HPHT. After all, input data has been entered into input sheet of ''HPHT MAT'' simulator, the user is required to press the calculate button for simulator to run. Once simulator is executed properly output results and graphs can be viewed.

Temperature Modelling

The simulation of temperature profile inside the drill pipe and annulus is shown in Figure 3. Temperature of mud inside drill pipe at seabed is 45^{o}F and returned temperature of mud at seabed is 65.2 ^{o}F. Temperature at bit is 151.4 ^{o}F and max downhole temperature is 155.3 ^{o}F at depth 27450 ft. Temperature difference between the drill pipe and annulus is due to heat transfer from the formation to annulus then drill pipe. Difference in bottom hole temperature between the linear method and Holmes method is 147.6 ^{o}F

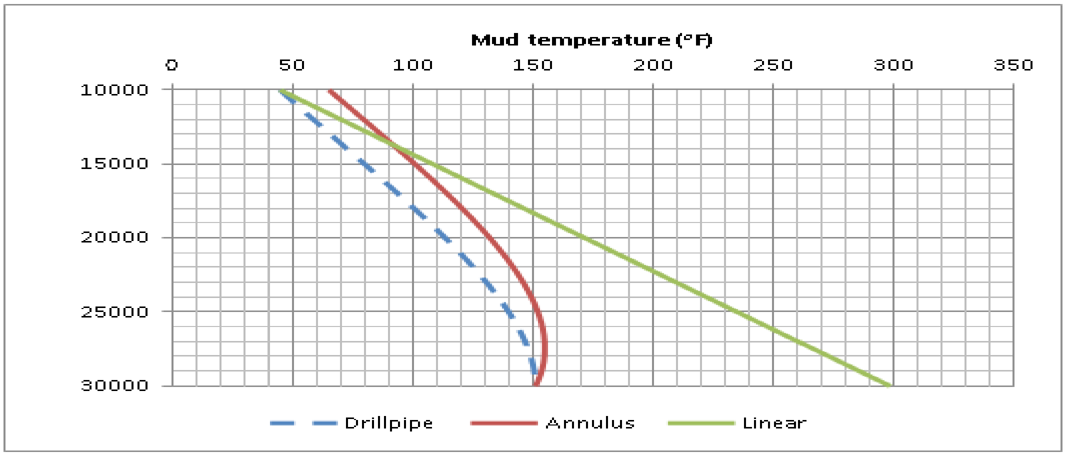

Figure 3: Mud temperature inside wellbore.

Density and Pressure Modelling

Simulation of density profile is shown in (Figure 4). Bottom hole mud density inside drill pipe is 13.5 ppg and inside annulus is 13.4ppg. Bottom hole density inside annulus calculated by constant fluid density (i.e independent of pressure and temperature conditions) is 0.4 ppg less than bottom hole density inside annulus calculated by temperature-pressure dependence of fluid density.

Pressure/temperature dominant depth for drill pipe density profile is 16350 ft, before this depth the temperature becomes more dominant than pressure leading to mud weight decrease and after this depth the pressure becomes more dominant than temperature leading to mud weight increase. For annulus density profile, pressure/temperature dominant depth is 17550 ft. From simulator output, total hydrostatic pressure inside the drill pipe is 20,762 psi and total hydrostatic pressure inside the annulus is 18,138 psi. Annulus hydrostatic pressure calculated by constant fluid density is 276 psi less than annulus hydrostatic pressure calculated by temperature-pressure dependence of fluid density. Drill pipe hydrostatic pressure calculated by constant fluid density is 482 psi less than drill pipe hydrostatic pressure calculated by temperature-pressure dependence of fluid density.

Difference in density profiles between the drill pipe and annulus is due to two factors. First factor is the pressure difference between the dill pipe and annulus in Riser less drilling; the pressure inside drill pipe is higher than inside annulus. Second factor is temperature difference between the dill pipe and annulus; temperature inside the drill pipe is less than inside annulus.

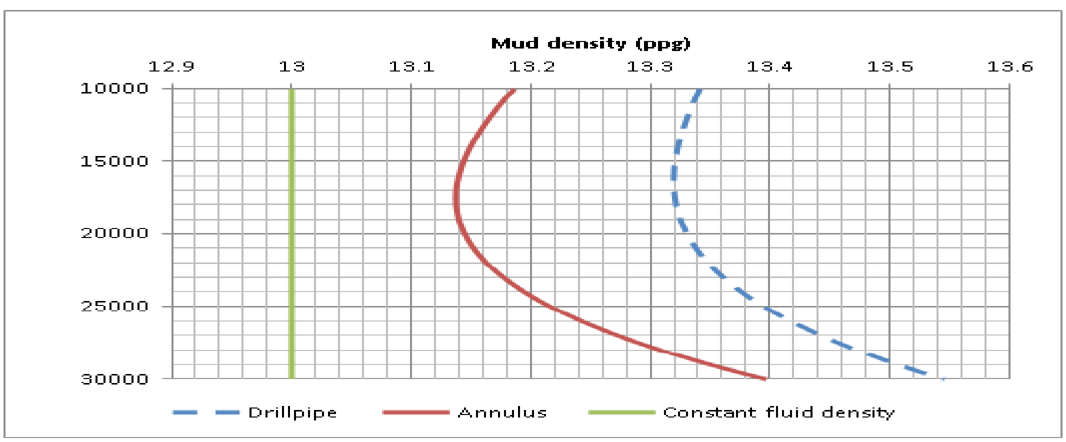

Figure 4: Mud density inside wellbore.

Plastic Viscosity and Yield Point Modelling

Simulations of plastic viscosity and yield point profile are made by Politte model. Bottom hole plastic viscosity inside drill pipe is 59 cp and inside annulus is 47 cp. Annulus bottom hole plastic viscosity calculated by constant fluid property is 27 cp less than bottom hole plastic viscosity calculated by temperature-pressure dependence of fluid property, (Figure 5).

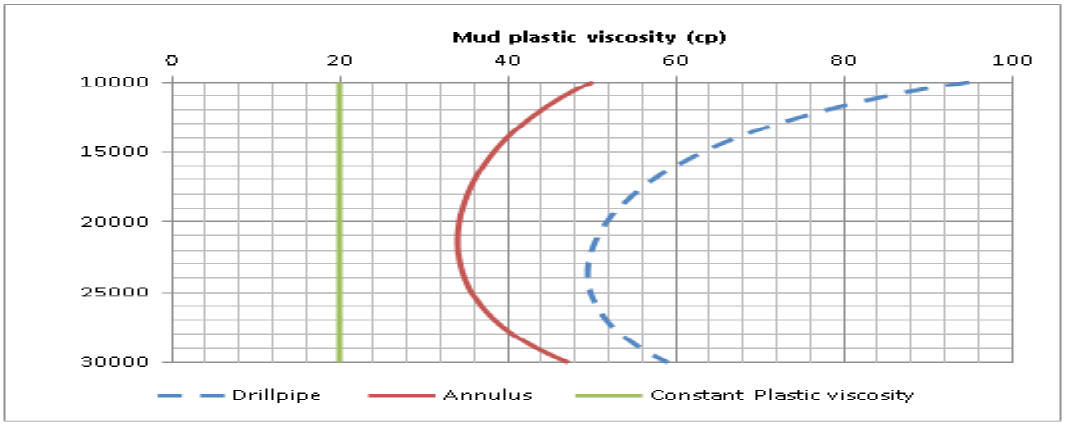

Figure 5: Mud plastic viscosity profile inside wellbore.

Pressure/temperature dominant depth for drill pipe profile is 23650 ft, before this depth the temperature becomes more dominant than pressure leading to plastic viscosity decrease and after this depth the pressure becomes more dominant than temperature leading to plastic viscosity increase. For annulus profile, pressure/temperature dominant depth is 21350 ft.

Plastic viscosity inside the drill pipe is higher than inside annulus. This is due to temperature inside the drill pipe is less than inside annulus and also the pressure inside the drill pipe is higher than inside annulus. Bottom hole plastic viscosity calculated by constant fluid property is 27.26 cp less than bottom hole plastic viscosity calculated by temperature-pressure dependence of fluid property. As seen in Figure 6, the yield point decreases with depth. For drill pipe yield point profile, minimum yield point is 8.32 Ibf/100ft^2 at depth 30000 ft. For annulus yield point profile, minimum yield point is 8.10 Ibf/100ft^2 at depth 27450 ft. Yield point inside annulus is less than inside drill pipe because the temperature inside the annulus is higher than inside drill pipe. Bottom hole yield point calculated by constant fluid property is 5.6 Ibf/100ft^2 higher than bottom hole yield point calculated by temperature-pressure dependence of fluid property.

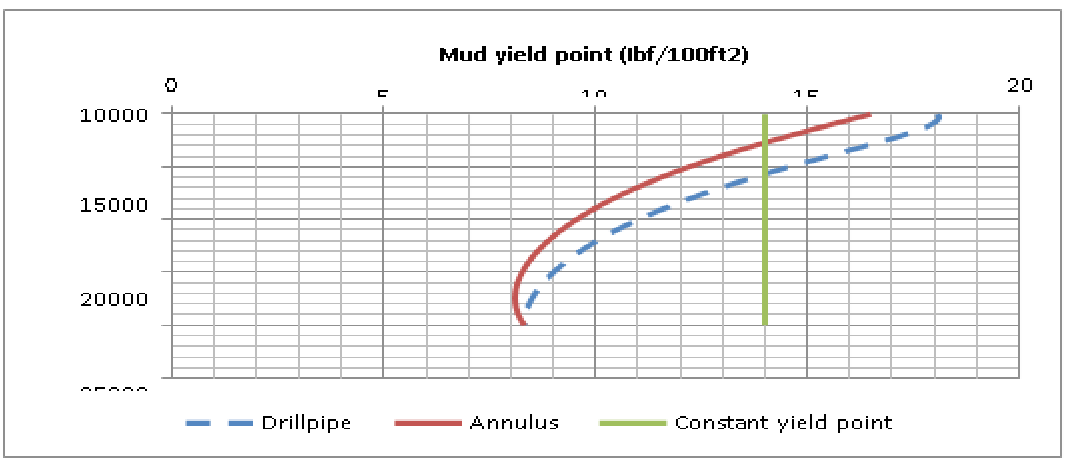

Figure 6: Mud yield point profile inside wellbore.

ECD Modelling, Pressure Losses and Bit Optimization Plan

Simulation of ECD profile is shown in (Figure 7). Bottom hole ECD calculated by the temperature-pressure dependence of fluid properties is 0.4 ppg higher than bottom hole ECD calculated by constant fluid properties; (Table 2). For equivalent circulating density profile, pressure/temperature dominant depth is 17800 ft. Bottom hole ECD taking into account tool joint, cutting, drill string rotation and eccentricity pressures losses is 13.7 ppg; (Table 3).

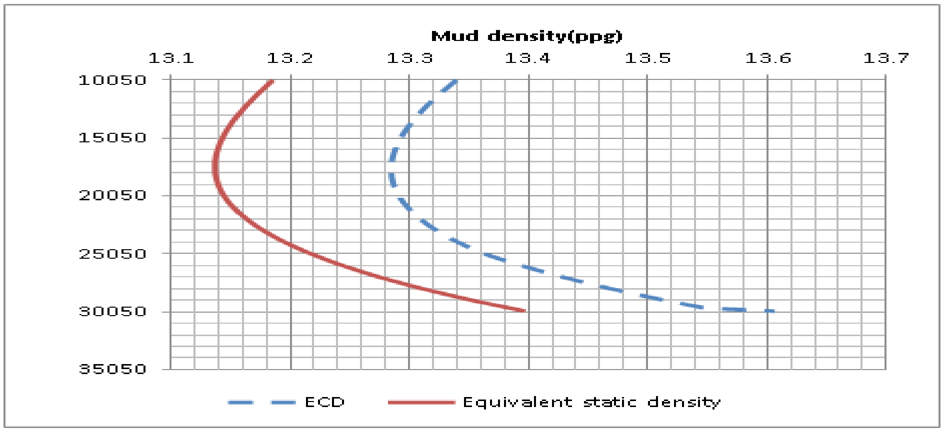

Figure 7: ECD profile under HPHT.

Well hydraulics	Case 1 : Fluid properties depend on temperature and pressure	Case 2: Constant fluid properties	Difference between two cases
Total pressure loss(psi)	3985	3295	690
Bottom hole ECD (ppg)	13.6	13.2	0.4

Table 2: Effect of constant fluid properties on bottom hole ECD and total pressure losses.

Well hydraulics	Case 1: Without influence factors of	Case 2: With influence factor of	Difference between two cases
	pressure loss	pressure loss	
Total pressure loss (psi)	3295	4580	1285
Bottom hole ECD (ppg)	13.2	13.7	0.5

Table 3: Effect of pipe rotation, tool joint and cutting concentration on total pressure losses and bottom hole ECD.

The total system pressure loss calculated by temperature-pressure dependence of fluid properties is 3985 psi. Difference between total pressure loss calculated by temperature- pressure dependence of fluid properties and total pressure loss calculated by constant fluid properties is 690 psi. As seen in Table 3, ignoring the influence factor of pressure losses (tool joint, cutting, annular eccentricity and drill pipe rotation) will lead to inaccurate well hydraulics modelling. Bit optimization plan of Riser less drilling is done by bit hydraulic horsepower criteria; (Table 4). Optimum flow rate and optimum nozzle area calculated by temperature-pressure dependence of fluid properties are 315 gpm and 0.21 $inch^2$ respectively. Bit optimization plan that based on temperature-pressure dependence of fluid properties will result in good drilling progress and effective hole cleaning.

Bit optimization	First method : Bit optimization calculated by temperature-pressure dependence of the fluid properties	Second method : Bit optimization calculated by constant fluid properties
Optimum flow rate (gpm)	315	346
Optimum nozzle area (in) 2	0.21	0.23
Hydraulic horsepower (hhp)	534	572

Table 4: Effect of constant fluid properties on hydraulic bit optimization (Bit hydraulic horsepower criteria).

Conclusion

Based on the results from this study, the conclusions are:

1. A ''HPHT MAT'' simulator for optimizing well hydraulics in MPD was designed. The simulator can be used to predict temperature, density, plastic viscosity and yield point profiles under HPHT conditions. The program can be also used by drilling personnel to plan bit optimization operations and simulate ECD and pressure losses under HPHT environment

2. Well hydraulics optimization of Riser less drilling is divided into four main steps

- Prediction of temperature profile inside wellbore
- Simulation of density and pressure profile under HPHT conditions
- Plastic viscosity and yield point modelling
- Determination of ECD and pressure losses in drilling system

3. Neglecting the effects of pressure and temperature on fluid properties in the calculation of total pressure loss, ECD, bit optimization, and bottom hole pressure will lead to erroneous results. This may lead to loss of circulation or kick.

4. Influence factor of pressure losses (tool-joint, cutting concentration and drill pipe rotation) are needed to be calculated for optimization the well hydraulics of MPD

References

1. Dhameliya, JD, Jain S, Gupta V (2013) Liquid Lift Dual Gradient Drilling in Deep Water: Early Kick Detection and Control. Paper SPE 165372 presented at the SPE Western Regional & AAPG Pacific Section Meeting, California 19-25.

2. Choe J, Schubert JJ, Juvkam-Wold HC (2007) Analyses and Procedures for Kick Detection in Subsea Mud lift Drilling. Paper SPE-87114 presented at the IADC/SPE Drilling Conference, Dallas, USA 22: 2-4.

3. Marbun BH, Kurnia HA (2012) The Effect of High Pressure and Temperature Variation to the Hydraulic of Dual Gradient Drilling Operation. Paper IADC/SPE 156373 presented at the IADC/SPE Asia Pacific Drilling Technology Conference and Exhibition, Tianjin, china 9-11.

4. Hasan AR, Kabir CS (1996) Determining Circulating Fluid Temperature in Drilling, Workover, and Well-control Operation. Paper SPE-24581 presented at the SPE Annual Technical Conference & Exhibition, Washington DC, USA 11: 4-7.

5. Holmes CS, Swift SC (1970) "Calculation of Circuiting Mud Temperatures''. Journal of Petroleum Technology 670-674.

6. Zamora M, Roy S, Slater K, Troncoso J (2012) Study on the Volumetric Behavior of Base Oils, Brines, and Drilling Fluids Under Extreme Temperatures and Pressures. Paper SPE-160029-MS presented at SPE Annual Technical Conference and Exhibition, San Antonio, Texas, USA 28: 8-10.

7. Hoberock LL, Thomas DC, and Nickens HV (1982) Bottom-Hole Mud Pressure Variations Due to Compressibility and Temperature Effects. Paper SPE-11050 presented at Drilling Technology Conference of the International Association of Drilling Contractors, Pittsburgh, Pennsylvania USA, 9-11 March 1982.

8. Politte MD (1985) Invert Oil Mud Rheology as a Function of Temperature. Paper SPE-13458 presented at the SPE Annual Technical Conference and Exhibition, New Orleans LA, USA 6-8.

9. Methven NE, Baumann R (1972) Performance of Oil Muds at High Temperatures. Paper SPE-3743 presented at SPE-European Spring Meeting, Amsterdam, Netherlands, 16-18.

10. 10. Bourgoyne AT, Millhcim KK, Chenevert ME, Young FS (1991) Applied Drilling Engineering. second edition, SPE Textbook Series - Drilling Series, Society of Petroleum Engineers.

11. Yeon-Tae J, Subhash S (2004) "Analysis of Tool Joint Effects for Accurate Friction Pressure Loss Calculations,". Paper SPE 87182 presented at the SPE Drilling Conference, Dallas 2-4.

12. Singhai N, Shah SN, Jain S (2005) Friction pressure correlation for Newtonian and non-Newtonian fluids in concentric annuli. R. Paper SPE 94280 presented SPE Annual Technical Conference and Exhibition, New Orleans LA, USA, 10-13.

13. Haciislamoglu M (1990) Non-Newtonian flow in eccentric annuli. Journal of Energy Resources Technology 112: 163-169.

14. Bhattacharya A (1995) Flow of solid-liquid suspensions in vertical columns. Journal of Industrial and Engineering Chemistry 268-274.

15. Ziegler R, Ashley P, Malt R. Stave R, Toftevag KR (2013) Successful Application of Deep Water Dual Gradient Drilling. Paper IADC/SPE164561 presented at IADC/SPE Managed Pressure Drilling and Underbalanced Operations Conference and Exhibition, San Antonio, Texas, USA 17-18.

16. Ziegler R, Sabri MSA, Idris MRB, Malt R, Stave R (2013) First Successful Commercial Application of Dual Gradient Drilling in Ultra Deepwater GOM. Paper SPE-166272 presented at SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, USA 30.