Hittite Journal of Science and Engineering, 2018, 5 (3) 239-247
ISSN NUMBER: 2148-4171
DOI: 10.17350/HJSE19030000103

Drilling of Horizontal Wells in Carbonate Reservoirs of Middle East for Petroleum Production – Investigation of Hydraulics for the Effect of Tool Joints

Tuna Eren
Izmir Katip Celebi University, Petroleum and Natural Gas Engineering Department, İzmir, TURKEY

Article History:
Received: 2018/01/22
Accepted: 2018/03/21
Online: 2018/04/06

***Correspondence to**: Tuna Eren, Izmir Katip Celebi University, Petroleum and Natural Gas Engineering Department, Cigli Ana Yerleskesi, Merkezi Ofisler 1 Binasi, 35620, Cigli, Izmir, Turkey,*
E-mail: tuna.eren@ikc.edu.tr,
Phone: +905325437217,
Fax: +90(232) 386 08 88

ABSTRACT

Drilling of a horizontal well to produce petroleum is a task which needs careful planning. The foremost advantage of an openhole horizontal well completion is having the pay zone with the least drilling damage. The first task whether a well can be completed in open hole is by knowing if the formation once drilled is competent enough so that it can remain intact or not. Once the formation is declared and/or proofed to be competent and drilling of the horizontal well is approved there should be enough time to ensure that all equipment and services are going to be available. This study synopsises a brief literature review regarding effects of tool joints during drilling. A diligently planned horizontal well design for Middle East formations is given in this study. The effects of tool joints on the drillpipes are taken into consideration for the calculation of frictional pressure losses in annulus and equivalent circulating density itself. The operational steps while drilling the horizontal well are synopsised in this manuscript, which can be a useful guide for future applications in various petroleum and gas fields. The study also includes frictional pressure calculations for non-newtonian fluids used in drilling operations. The results indicate whether while drilling a horizontal well the fracture gradient of the petroleum reservoir formation is exceeded or not. The study can be improved further by means of considering the effects of temperature on the behaviour of the drilling fluids.

Keywords:
Open hole; Horizontal well; Completion; Limestone reservoir; Pressure depletion; Drilling; Tool joint; Equivalent circulating density

INTRODUCTION

It is known that Middle East oil fields are dominated by carbonate reservoirs inside which the big majority of the oil and gas reserves are located. It is to the knowledge of reservoir engineers that carbonate reservoirs can have significantly varying rock properties such as porosity, permeability. This property of carbonates makes them a challenging reservoir type to exploit hydrocarbons. One solution to penetrate through the best quality reservoir sections is to drill horizontal wells, and even completing the wells in open hole. Horizontal wells in unknown oil/gas fields would require drilling of a pilot hole. Pilot hole is a wellbore trajectory that is drilled and abandoned once the landing point formation details have been acquired. In some mature oil fields located in southern Iraq; recently introduced High Angle Wells allowed drilling horizontally into a seam and under infrastructure with substantially improved results.

Not only for horizontal wells with relatively long drainages, the margin between pore and fracture gradients are getting critical also for the ultra deep and deepwater applications. One factor that influences the ECD (Equivalent Circulating Density) which is effected by the drilling fluid's hydrostatic column and the frictional pressure losses along the flow circuit. The frictional pressure losses are the term that depends on the flow geometry, fluid rheological properties and last but not the least the flow rates. What industry approaches have considered so far, are based on the fact that the effects of the tool joints of the drillpipes are not necessarily taken into the consideration when the frictional pressure losses are calculated. An experienced drilling engineer in the field should always bear in mind that a single segment of a tool joint may not result in excessive frictional pressure loss individually. However knowing that there are hundreds of tool joints in a wellbore at a depth of

3000 m, the sum of the frictional pressure losses for all of the tool joint segments could result in additional substantial frictional pressure loss. It is that additional substantial frictional pressure loss which would increase the ECD and could be the very main reason for well to encounter drilling troubles.

LITERATURE REVIEW

Plenty of researches worked on horizontal drilling planning and openhole completions respectively. One of the most significant findings of the previous researchers is importance of paying attention to the to the details regarding geology, hydraulics and strength of materials when dealing with high angle wells and particularly horizontal wells Aguilera et. al. [1]. Horizontal drilling is only successful if everyone understands the objectives of different operations. It is known and as stated in API RP 13D [2] that in case of deviated wells there is no simple method that exists to calculate the contribution of the cuttings over the ECD (Equivalent Circulating Density). Hole inclinations between 30 degrees to 60 degrees are the most difficult holes to clean. This fact is due to the existence of unstable solid beds on the low side of the wellbore. The problem is the risk of having these unstable solids bed avalanching towards the bottom of the hole. However, downhole annular pressure measurements can be monitored to estimate the contribution of the cuttings over the static drilling fluid density.

Azar and Samuel [3], stated that a number of mathematical models have been derived from a combination of experimental flow-loops to model hole cleaning. It is important to keep in consideration that the derived empirical equations are valid for the size configuration that their respective data has been acquired from. Scaling up the correlations to different hole geometries may introduce significant errors.

Viloria [4] conducted a research study on the analysis of drilling fluid rheology and tool joint effect to reduce the errors in hydraulics calculations. It has been indicated that the current API recommended drilling hydraulics calculation techniques do not include tool joint parameters. Thus the API calculations can be deemed as inaccurate. Their study revealed that the frictional pressure losses being affected by the tool joints of the drill pipes can be corrected by means of implementing appropriate practical methods.

Even though the equations in use of the industry does not account for the effect of the tool joints in hydraulic pressure loss calculations, it is known that effects of the tool joints are significantly important when it comes to observe the annular frictional pressure losses. Enfis et. al. [5] performed extensive experiments to study the effects of the tool joints of drill pipes on frictional pressure losses in annulus. They concluded that the presence of tool-joints in a wellbore substantially increases the annular pressure losses (up to 30 %).

Simoes et. al. [6] performed Computational Fluid Dynamics analysis to investigate the effects of tool joints on the annular frictional pressure losses. Their findings revealed that the presence of tool joints significantly increased the pressure gradient.

Jeong and Shah [7] analysed the tool joint effects for accurate frictional pressure loss calculations. Their research study composed of gathering experimental data conducted with three different fluids. They concluded that presence of tool joints on the annular frictional pressure losses is significant and an accurate prediction method has been proposed.

Previous research studies indicate that a sound planning is the key to success and the effects of tool joints is a requirement that has got to be considered to ensure a trouble free drilling activity for horizontal wells.

HORIZONTAL WELL DRILLING PRACTICES

Horizontal well drilling planning is a joint task. The planning is based on following trajectory definition and determination of drilling engineering related decisions. The subsurface team and drilling team is required to work in collaboration. A work flow for a horizontal well planning is given in Fig. 1. The initial proposal originates from sub surface team as to where to drill the well. The directional plan is worked out jointly by the drilling team with the fine tuning until the formation tops are acceptable by the sub surface team. The casing points, drill string, hydraulics program and eventually the time estimate is prepared by the drilling team. The key to success in drilling operations is to keep things as simple as possible.

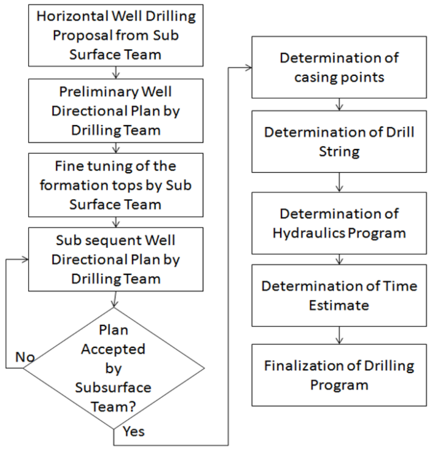

Figure 1. Horizontal well planning work flow

Most of the subsurface formations in Middle East Geomarket are relatively flat for a considerable subsurface extend. This results in having similar drilling cases in significant number of wells. Fig. 2 gives the Stratigraphic column for Rumaila and Zubair Oilfields, Al-Ameri et al. [8]. The critical drilling planning requirement depends on knowing the specifications of the formations to be encountered. Widespread assumption in the Middle East Geomarket especially for vertical wells is that they could be drilled without many troubles. However this assumption is recommended to be addressed carefully not only for vertical wells, but especially for highly deviated and horizontal wells. The critical aspects for a selected list of formations which are deemed important are as listed as follows:

Dammam Formation (Dominating lithology Limestone): Dammam formation is fragile for this reason tripping best practices are required to be implemented. Generally the surface casing string is set to the top of this formation. Running speed of the casing is required to be calculated not to exceed surge pressures to prevent the breakage of the formation which can induce downhole losses.

Tayarat Formation (Dominating lithology Limestone): Tayarat is known to be containing sulphurous water if kicks into the wellbore are going to result in a well control event. Within the Middle East formations the Tayarat Formation is required to be drilled with a drilling fluid having a density of approximately 8.68 ppg.

Tanuma Formation (Dominating lithology Shale): Tanuma Formation is one of the most challenging formations especially if drilling at inclinations in excess of 60 degrees. Tanuma formation is highly unstable and is required to be drilled as fast as practically possible. The drilling fluid properties are required to be kept with the necessary ranges outlined in the program. If KCl (Potassium Chloride) drilling fluid is being used, the KCl concentration is to be monitored and accordingly kept as necessary. Back reaming and elongated circulations with BHA is to be prevented while in Tanuma.

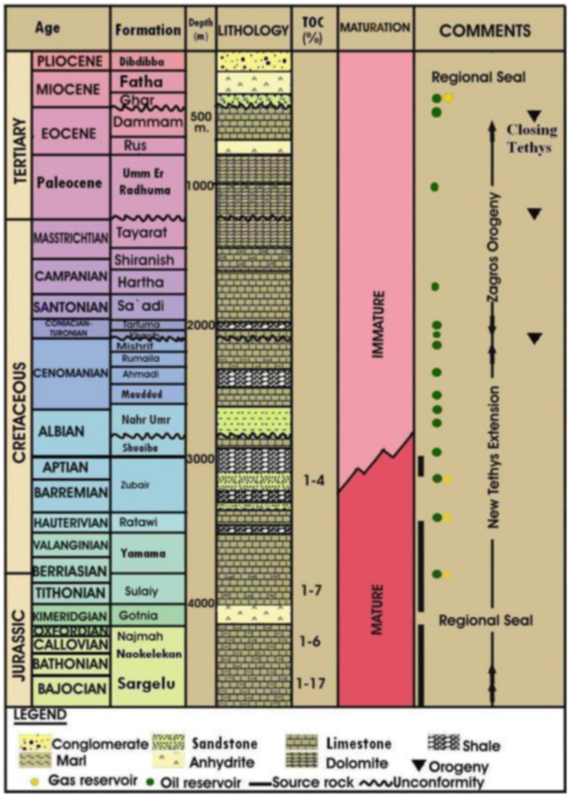

Figure 2. Stratigraphic column of South Iraq, Basrah region (Rumaila and Zubair oil fields), Al-Ameri et al., [8]

An example geological prognosis including formation depths is as given in Table 1. When planning a horizontal well to Mishrif Formation (Middle Cretaceous) porous formation, the overlying formations should be studied very carefully. In given formation top depths the thickness of Tanuma formation is 40 m. However since the penetration of the trajectory across this zone is going to be at a specific angle the course of penetration is going to be more than 40 m.

Table 1. Geological prognosis of Rumaila field, after Arshad et. al., [9].

Formation Name	*Depth, m*	*Thickness, m*	*Age*	*Lithology Description*
Dibdiba	*Surface*	*997*	*Late Mio-Plio*	*Thicj sand and pebbles*
Lower Fars	*997.12*	*558*	*Early Middle Miocene*	*Interbedded argillaceos limestone, qnhydrite, claystone and gypsum*
Ghar	*1554.72*	*351*	*Early Middle Miocene*	*Thick sand and pebbles*
Dammam	*1905.68*	*813*	*Middle - Late Eocene*	*Thin limestone overlying thick karstic dolomite/limestone*
Rus	*2719.12*	*485*	*Paleocene-Early Eocene*	*Thich anhydrite interbedded with dolomite*
Umm Er-Radhuma	*3204.56*	*1492*	*Paleocene-Early Eocene*	*Dolomite with thin anhydrite interbeds*
Tayarat	*4696.96*	*712*	*Late Cretaceous*	*Bituminous shale overlying dolomite*
Shiranish	*5408.72*	*499*	*Late Cretaceous*	*Thick argillaceous marly limestone*
Hartha	*5907.28*	*731*	*Late Cretaceous*	*Dolomite and argillaceous limestone*
Sadi	*6638.72*	*689*	*Late Cretaceous*	*Thick interval of chalky, argilaceous limestone*
Tanuma	*7327.52*	*131*	*Late Cretaceous*	*Shale with localised limestone stringers*
Khasib	*7458.72*	*148*	*Late Cretaceous*	*Limestone with thin shale interbeds*
Mishrif	*7606.32*	*594*	*Middle Cretaceous*	*Limestone: white, brown, detrital, rudist, porous*
Rumaila	*8200*	*-*	*Middle Cretaceous*	*Thick sequence of marly and argillaceous limestone*

Directional Drilling Planning

The planning of a horizontal well necessitates a very careful study. The casing points are required to be appropriately selected, so that the casing shoes are placed into impermeable layers at the exit of which a competent seal is going to be achieved. Also it is very important that the exit of the casing shoe points for highly deviated and especially horizontal wells is strong enough. Under normal circumstances and especially in an unknown oil or gas field the casing points are required to be chosen by mean of kick tolerance calculations. Devereux [10] study indicated that the casing points should be selected so that the selected depths are going to allow kick tolerances to be maintained. The casing exit is required to be strong so that no problems such as washed formation are not going to be formed along the immediate exit of the casing shoe.

Planning of a horizontal well in 2-dimension is carried out by means of ensuring that build sections are planned in the manner that the downhole tools to be used are going to be able to perform the drilling activity. Fig. 3 gives the sketch of a 2-dimensional horizontal well.

The geometrical equations for the planning are mainly based on build up radius (R) as given in Equation 1;

$$R = 180 / (B \times \pi) \tag{1}$$

where B is the build up rate. The length of the hole is calculated by L, which is given in Equation 2;

$$L_{hole} = 100 \times (\beta_{ii} - \beta_i) / B \tag{2}$$

where β_{ii} and β_i are the final and initial wellbore inclinations respectively. The vertical section of the wellbore is calculated by means of Equation 3:

$$V = R \times (\mathrm{Sin}(\beta_{ii}) - \mathrm{Sin}(\beta_i)) \tag{3}$$

The wellbore displacements are calculated using Equation 4:

$$D = R \times (\mathrm{Cos}(\beta_i) - \mathrm{Cos}(\beta_{ii})) \tag{4}$$

The segment length of the build curve section is calculated using Equation 5:

$$\text{Build Curve} = (\beta_{ii} - \beta_i)/B \tag{5}$$

The tangent section length of the wellbore where the inclination is not changing is calculated by using Equation 6:

$$MD(_{\text{Tangent Length}}) = D/ \mathrm{Sin}(\beta_i) \tag{6}$$

The Kick off, is the depth from which the wellbore deviates from vertical is calculated by means of Equation 7:

$$KOP = TVD - (H_3 + H_2 + H_1) \tag{7}$$

where H_2 can be calculated using Equation 8:

$$H_2 = MD_2/ \mathrm{Cos}(\beta_i) \tag{8}$$

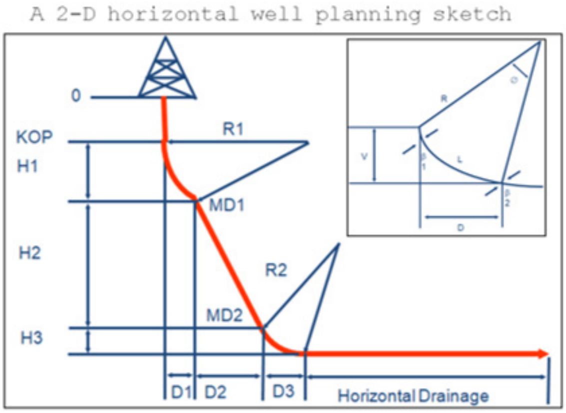

Figure 3. A 2-D horizontal well planning sketch.

A 2-D directional plan to drill the horizontal well in the carbonate formations is as given in Table 2. The depths are referenced to the formation tops given in Table 1. The planning of a directional well is required to respect the casing depths. The kick off point in order to deviate the well is selected to be at 6120 ft within Hartha Formation; a depth at which no more downhole losses are expected. The hole section that the well is kicked off is 12 1/4". The kick off for a directional well is strongly suggested to be selected at a depth after which circulation losses are not expected. The wellbore is planned to be drilled with a build of 4 deg /100 ft until the wellbore penetrates Sadi Formation at 6639 ft TVD. The 9 5/8" casing depth is planned to be 50 ft beneath the Sadi Formation. One of the most critical sections of the wellbore is the section to be built in 8 1/2" hole section. The field practices show that the Tanuma formation is suggested to be penetrated with a maximum inclination of 55 degrees. For this reason starting from the 9 5/8" casing shoe the trajectory is planned to be built to 55 degrees with a rate of 4.38 deg/100 ft in 8 1/2" hole section. For this reason once the wellbore inclination is 55 degrees, the wellbore is drilled tangent down to the top of the Mishrif formation. The wellbore is deepened to accommodate the 7" liner at a depth that is 50 ft below the top of Mishrif formation. Once the 7" liner is safely set in place, the last wellbore section is 6". The planned build rate is 5 deg/100 ft so that the inclination can be brought up to almost 90 degrees. Once the horizontal section commenced to be drilled the section is planned to be drilled almost 2300 ft, so that the well drilling operations can be finalized.

Table 2. 2D directional plan for horizontal well.

No	Command	Limit	Depth, ftMD	Depth, ftTVD	Horizontal Displacement, ft	Inclination, degree
1	0	0	0	0	0	0
2	Hold 0 degrees	Drill to Measured Depth 6120 ft	6120	6120	0	0
3	Build with 4 deg/100 ft	Drill to Vertical Depth 6639 ft	6651	6639	98	21.6
4	Hold at 21.6 degrees	Drill only 50 ft of additional hole	6701	6685	118	21.6
5	Build with 4.38 deg/100 ft	Drill to Vertical Depth 7265 ft	7452	7265	574	55
6	Hold at 55 degrees	Drill to Vertical Depth 7606 ft	8046	7606	1063	55
7	Hold at 55 degrees	Drill only 50 ft of additional hole	8095	7636	1102	55
8	Build with 5 deg/100 ft	Drill to 89.5 degrees	8774	7839	1738	89.5
9	Hold at 89.5 degrees	Drill only 2296 ft of additional hole	11070	7859	4034	89.5

The well sketch f the planned 2D directional trajectory is depicted in Fig. 4. The drawing gives the casing depths, formations, and well trajectory.

Calculation of Frictional Pressure Loss in Annulus

The frictional pressure loss equations presented by Adams and Charrier [11] are summarized in Fig. 5. The given equations are observed to give reasonable results when compared with actual pressure readings. Eren et. al., [12] performed a comparison of actual and theoretical pressures in wellbores, and concluded that the frictional pressure losses along wellbores could be predicted at an accuracy of ±25%. The details of the equations are as explained in the following section.

The velocity across the annulus is calculated using the below Equation 9:

$$V_{annulus} = q/(2.448 \times (d_2^2 - d_1^2)) \qquad (9)$$

where q is the flow rate of the fluid. Plastic viscosity (μp) is the difference in between 600 rpm and 300 rpm readings of variable speed rheometer as presented in Equation 10;

$$\mu_p = \theta_{600} - \theta_{300} \qquad (10)$$

The yield point (τ_y) is calculated using the relation given in Equation 11;

$$\tau_y = \theta_{300} - \mu_p \qquad (11)$$

For each wellbore section a critical velocity (v_c) is required to be calculated using Equation 12;

$$v_c = [1.08\mu_p + 1.08\,(\mu_p^2 + 9.26(d_2 - d_1)2(\mu_p)\rho)^{0.5}]/[\rho(d_2 - d_1)] \qquad (12)$$

where ρ is the density of the drilling fluid.

The pressure loss in the annulus is calculated by means of comparing the critical velocity with the actual velocity of the drilling fluid in the annulus.

If vannulus < vc the pressure loss is calculated for the frictional losses attributed to laminar flow as given in Equation 13;

$$\Delta P_{annulus\text{-}Laminar\ flow} = (\mu_p v_{annulus} L)/(1000(d_2 - d_1)^2) + (\tau_y L)/(200(d_2 - d_1)) \qquad (13)$$

where L is the interval length.

If $v_{annulus} > v_c$ the pressure loss is calculated for the frictional losses attributed to turbulent flow as given in Equation 14;

$$\Delta P_{annulus\text{-}Turbulent\ flow} = [\rho^{0.75}\, v_{annulus}^{1.75}\, \mu_p^2 L]\ /[4901(d_2 - d_1)^{1.25}] \qquad (14)$$

where $v_{annulus}$ is with a “ft/s” in terms of unit of measure.

In the scope of this study the drilling fluid behaviour is assumed to be Bingham Plastic. In order to calculate the frictional pressure losses in the annular sections of a wellbore the first equation to be solved is the annular velocity. The flow behavior parameters; plastic viscosity and yield point parameters are also required to be calculated using the rheometer readings. The successive step is the calculation of critical velocity. The critical velocity is going to be compared in reference to the annular velocity, and depending on either being greater or less, the flow regime type is going to dictate which frictional pressure loss equation to be used. Having a critical velocity greater than the annular velocity would mean that the flow regime is turbulent and therefore the respective annular frictional pressure loss equation given for turbulent regimes is required to be used. The same logic is valid for critical velocities less than the annular velocities in the case of which laminar flow pressure loss equations are to be used.

In this study the last two wellbore sections of the planned horizontal well namely 8 1/2" and 6" sections are studied for the frictional pressure loss calculations. In today's information technology machinery it is possible to conduct complex calculations very quickly. Even though quick calculations are easy to be performed, not all frictional pressure calculation studies take into account the tool joint (TJ) sections of the drill pipes in use. A generalized drillpipe drawing is given in Fig. 6. The drawing of a drillpipe depicts the tool joint sections at the top and bottom parts of a drillpipe. The tool joint segments of a drillpipe are larger in diameter. API Specification 7 [13] gives the details of tool joint dimensions for drill pipe grades. In a single drillpipe joint, a total of 17 inches is the sum of pin and box tong space sections. The length of the geometrically enlarged tool joint sections contributes to the generation of additional frictional pressure loss along the annulus.

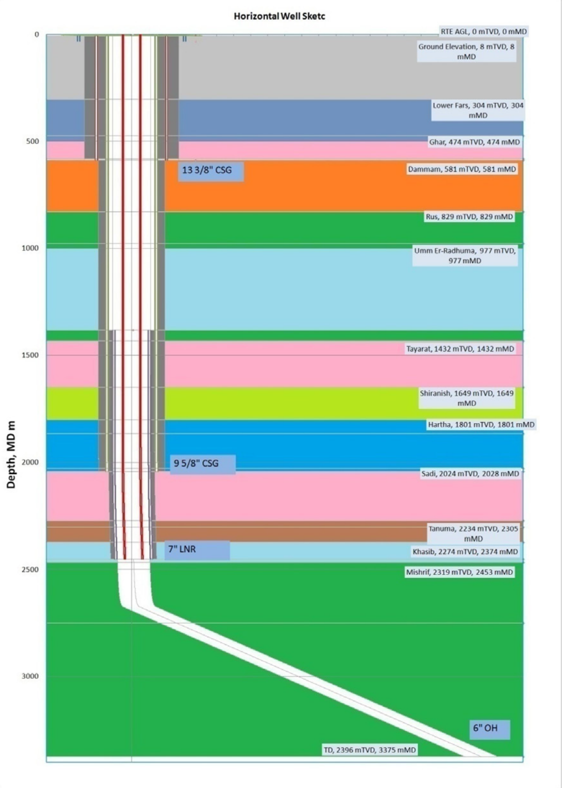

Figure 4. Planned horizontal well sketch.

While circulating in a wellbore which includes joints of drill pipes, the drilling fluid initially after having gone through the Bottom Hole Assembly; flows through the tool Joint of the pin end, then flows through the body section of the drillpipe, and flows through the tool joint of the box end for each and every drillpipe in the drillstring. For a geometry combination in an 8 1/2" wellbore, 5" nominal OD drillpipe, and 6 5/8" OD tool joint, the scaled drawing is as given in Fig. 7.

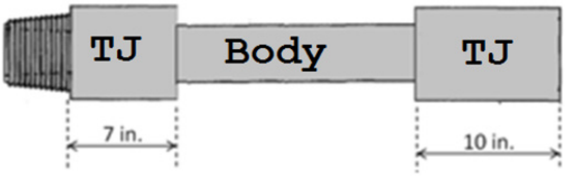

Figure 6. Schematics of a drillpipe joint.

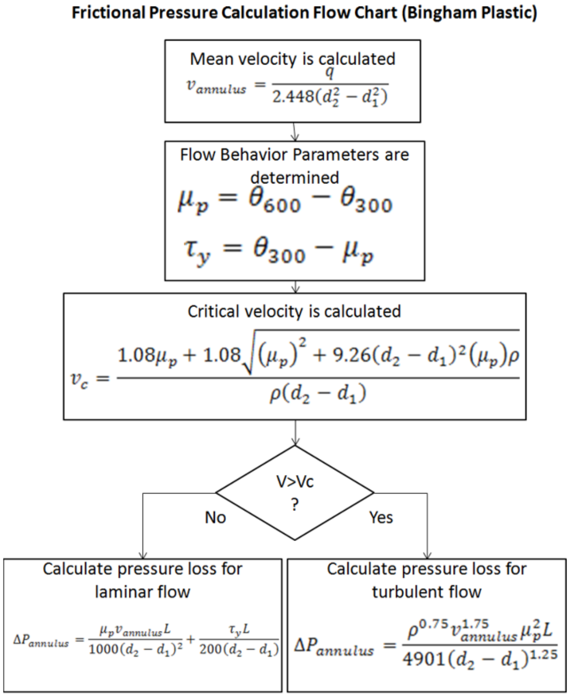

Figure 5. Frictional pressure calculation chart for annular flow by Adams and Charrier (1985).

The flow area gets restricted to the brown color shaded area, when the fluid element passes across the tool joints. Under normal circumstances the frictional pressure loss calculations mostly assumed that the flow area across the drillpipe elements is the area between the 5" nominal OD of the pipe and wellbore diameter itself. Fig. 8 depicts the ideal versus actual drillstring in a wellbore. The BHA (Bottom Hole Assembly) is composed of the following subsurface items: 8 1/2" PDC bit, 7" mud motor, float sub, 6 3/4" float sub, 8 1/8" Integral blade Stabilizer, 6 3/4" NMDC, 6 3/4" NM Hang-off sub. The rest of the workstring is composed of 5” HWDP and 5” DP to surface. The plain workstring drawing (given as the top drawing of Fig. 8) depicts

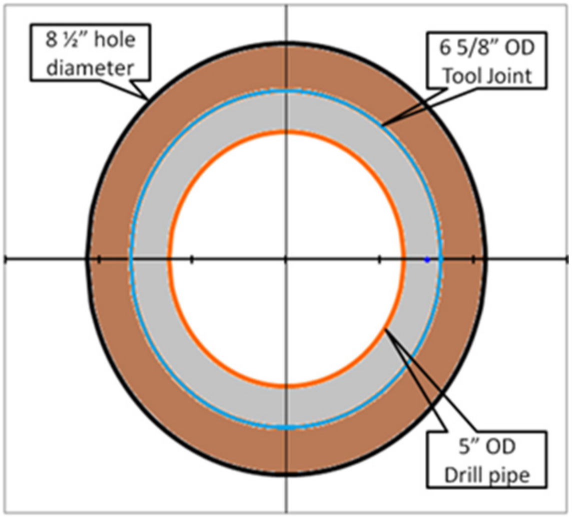

Figure 7. Scaled drawing of a tool joint section view in a wellbore.

the workstring with no tool joint upsets along the well bore. Whereas the workstring on which the tooljoint upsets are depicted (given as the lower drawing of Fig. 8) indicates the actual case of the string in the wellbore. The scaled drawing for a 3280 ft long drillstring clearly gives how the tool joints appear in a wellbore.

Figure 8. Ideal versus actual drill string in a wellbore.

Representation of the Calculated Frictional Pressure Losses

The frictional pressure loss and the respective Equivalent Circulating Density (ECD) are calculated for three different combinations of flow behaviors and flow rates. The flow rates taken into account are 340, 382.5, 425 and eventually 500 gpm (gal/min). The scaled drawing of the drillstring for which the calculations are made is as depicted in Fig. 9. The hydraulics analysis is conducted for the interval covering the previous (or otherwise the existing) casing shoe and targeted TD for the 8 1/2" wellbore section.

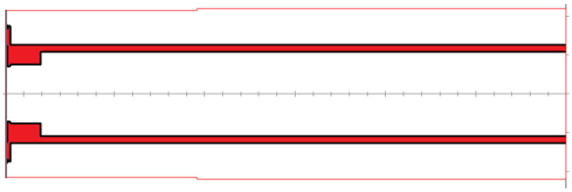

Figure 9. Scaled drawing of the 8 1/2" drillstring.

The first flow behavior group is PV=10 cp, and YP= 20 lbf/100ft^2. The results of the first flow analysis, which can be considered as mild from the rheological properties perspective is as presented in Fig. 10 and Fig. 11 respectively for annular pressure drop and ECD. It is observed that for each of the four different flow rates, the influence of the tool joints is observed to have increased the frictional pressure loss in the annulus. Consequently the ECD for the case of tool joints is showing elevated magnitudes. Assuming a depleted pore gradient of 7.51 ppg as indicated in the PPFG (Pore Pressure Fracture Gradient) of South of Iraq in the study presented by Eren et. al., (2013), it can be concluded that the loss of circulation is imminent.

The second group analysed is with the mild flow behaviors of a PV= 15 cp and YP= 25 lbf/100ft^2. Fig. 12 and Fig. 13 respectively present annular pressure drop and ECD. The results indicate that both the frictional pressure loss in the annulus and ECD magnitudes are further increased.

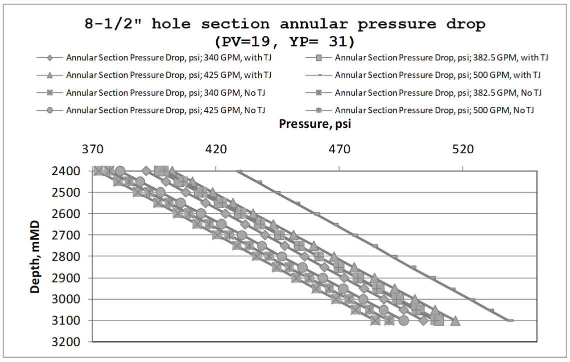

Figure 10. Annular pressure drop with PV=10 cp, and YP= 20 lbf/100ft^2.

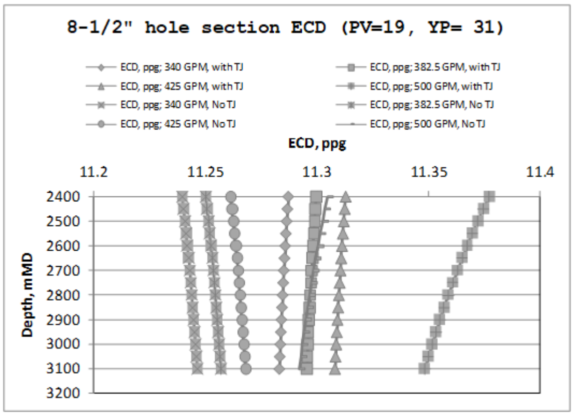

Figure 11. ECD with PV=10 cp, and YP= 20 lbf/100ft^2.

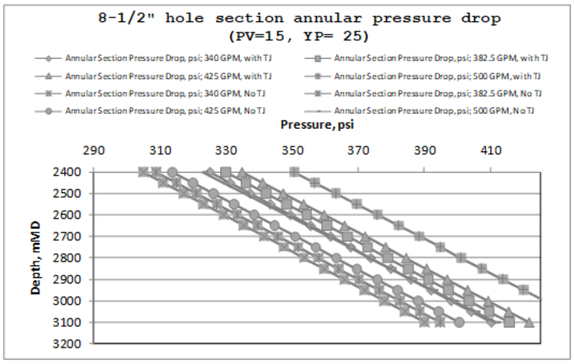

Figure 12. Annular pressure drop with PV=15 cp, and YP= 25 lbf/100ft^2.

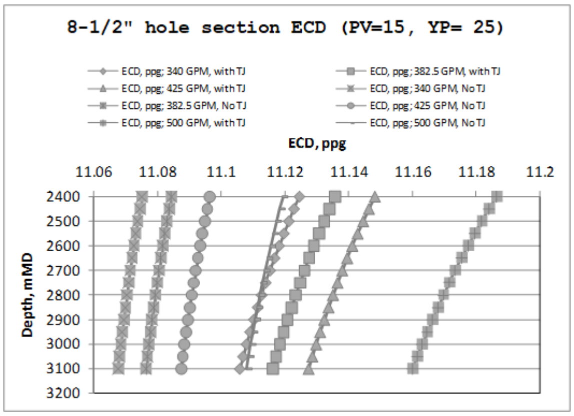

Figure 13. ECD with PV=15 cp, and YP= 25 lbf/100ft^2.

The third group analysed is with the high flow behaviors of a PV= 19 cp and YP= 31 lbf/100ft^2. Fig. 14 and Fig. 15 respectively present annular pressure drop and ECD. It is observed that the frictional pressure loss, and ECD magnitudes especially for a flow rate of 500 gpm can be extremely high approaching to Leak Off values (11.6 ppg), reported in the study of Eren et. al., (2007).

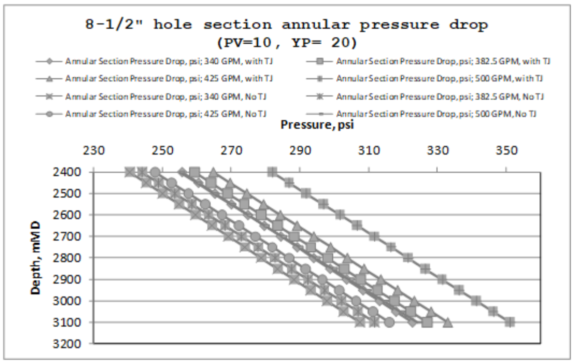

Figure 14. Annular pressure drop with PV=19 cp, and YP= 31 lbf/100ft^2.

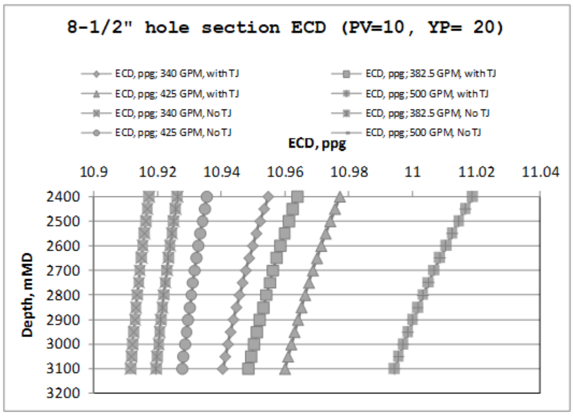

Figure 15. ECD with PV=19 cp, and YP= 31 lbf/100ft^2.

CONCLUSION

The planning of horizontal wells requires a very delicate study. In this research study the investigated aspects of horizontal well planning is presented. The geological prognosis of a well located in Iraq's Rumaila oil field is used for the planning of a horizontal well. Directional planning of the well is built on the formation details of the field. The selected build rates are based on practically applicable build rates for the similar oilfields.

The annular frictional pressure losses in the annulus are calculated using Non-Newtonian drilling fluid theoretical pressure loss equations. The tool joint sections of the drillpipes are also used as inputs in the calculations. The additional frictional pressure that is being generated is due to the restriction at each and every tool joint segment of a drillpipe. Calculation methodology is a novelty performed in the scope of this research study. It is can be observed that the ECD magnitudes being observed can be greater than the fracture gradients of the horizontal wells. The findings reveal that the annular frictional pressure losses, and ECD magnitudes especially for a flow rate of 500 gpm can be extremely high approaching to Leak Off values reported in the literature.

RECOMMENDATIONS

Here in this study the frictional pressure losses and ECD magnitudes are studied. What is recommended is to simulate a real case dataset and compare with the results. Effects of temperature as well as the effects of tool joints if incorporated are going to improve the accuracy of the hydraulics calculations. The contraction and expansion of the flow across the tool joint sections can also be incorporated for a further accurate study.

NOMENCLATURE

B = Build-Up Rate, deg/100 ft

d_1 = casing or open hole diameter, inches

d_2 = outer diameter of the drillstring member, inches

D_1, D_2, D_3 = Displacements of respective wellbore sections 1,2 and 3, ft

H_1, H_2, H_3 = Vertical lengths of respective wellbore sections 1,2 and 3, ft

L_{hole} = Length of hole, ft

L = pipe length, ft

q = flow rate, gpm

R = Build-Up Radius, ft

V = Vertical Height, ft

$v_{critical}$ = critical velocity, ft/s

$v_{annulus}$ = velocity of drilling fluid in annulus, ft/s

$\Delta P_{annulus}$ = pressure loss, psi

μ_p = (PV) plastic viscosity, cp

ρ = drilling fluid density, ppg

τ_y = (YP) yield point, blf/100ft^2

β_1 = Initial Inclination, deg

β_2 = Final Inclination, deg

References

1. Aguilera. R., Cordell. G.M., Nicholl. G.W. Contributions in Petroleum Geology and Engineering Volume 9: Horizontal Wells, Gulf Publishing Company, Calgary, Alberta, 1991.
2. API Recommended Practice 13D. Recommended Practice on Rheology and Hydraulics of Oil–well Fluids, 6th edition, Washington, 2010.
3. Azar, J.J. and Samuel, G.R. Drilling Engineering, PennWell Books, Tulsa, OK, 2007.
4. Viloria O.M. Analysis of drilling fluid rheology and tool joint effect to reduce errors in hydraulics calculations. PhD diss., Texas A&M University, 2006.
5. Enfis, M.S., Ahmed, R.M. and Saasen, A. The hydraulic effect of tool–joint on annular pressure loss. Paper presented at the SPE Production and Operations Symposium, Oklahoma City, Oklahoma, USA, 27–29 March. Society of Petroleum Engineers, Richardson, TX, pp. 1–11, 2011.
6. Simoes, S. Q., Miska, S. Z., Takach, N. E., & Yu, M. The Effect of Tool Joints on ECD While Drilling. Paper presented at the Production and Operations Symposium, Oklahoma City, Oklahoma, USA, 31 March–3 April. Society of Petroleum Engineers, Richardson, TX, pp. 1–8, 2007.
7. Jeong, Y.T., & Shah, S. N. Analysis of Tool Joint Effects for Accurate Friction Pressure Loss Calculations. Paper presented at the IADC/SPE Drilling Conference, Dallas, Texas, USA, 2–4 March. Society of Petroleum Engineers, Richardson, TX, pp. 1–8, 2004.
8. Al–Ameri, T.K., Jafar M.S.A., Pitman J. Hydrocarbon Generation Modeling of the Basrah Oil Fields, Southern Iraq. http://www.searchanddiscovery.com/documents/2011/20116alameri/ndx_alameri.pdf. Search and Discovery Article No 20116. Retrieved on 2016–03–30. 2011.
9. Arshad, U., Jain, B., Ramzan, M., Alward, W., Diaz, L., Hasan, I., Ali, A., Riji, C. Engineered Solution to Reduce the Impact of Lost Circulation During Drilling and Cementing in Rumaila Field, Iraq. Presented at the International Petroleum Technology Conference, Qatar, 6–9 December. Society of Petroleum Engineers, Richardson, TX, pp. 1–17, 2015.
10. Devereux, S. Practical well planning and drilling manual. PennWell Books, Tulsa, OK, 1998.
11. Adams, N. and Charrier, T. Drilling engineering: a complete well planning approach. Pennwell Corp., Tulsa, OK, 1985.
12. Eren T., Ozkale A., Ozer C., Kirbiyik S. A Case Study: Comparison of the Theoretical and Actual Drilling Hydraulic Pressures for Wells in Turkey. Presented at the 17th International Petroleum and Natural Gas Congress and Exhibition, Ankara, Turkey, 29 May, pp. 1–6, 2007.
13. API Specification 7. Specification for Rotary Dril Stem Elements, 40th edition, Washington, 2002.