SIMULATION OF A RE-ENTRY WITH CASING DRILLING UNDER HPHT CONDITIONS

Gabriella Federer-Kovacs

1. Introduction

Due to the ongoing depletion of available hydrocarbon reserves, the petroleum and oil industry is impelled to explore more daring depths and complex geological formations recently. This study aims at providing information about hydraulics and the importance of mud selection when drilling into unusual depths and formation structures, particularly in high temperature high pressure (HTHP) conditions.

HTHP wells are defined as follows[1]: the "undisturbed" bottomhole temperature is higher than 300° F (149 °C) and/or the pore pressure exceeds 0.8 psi/ft.

Since most HTHP wells contain condensates or gas under extreme pressure and temperature, special attention should be paid to planning the casing process. The following factors should be considered when planning the casing tube of a HTHP well[1]:

- the $13^{3/8}$" casing tube should be able to yield annular temperature effects.
- the $9^{5/8}$"section should not be inclined by high temperature.
- the $9^{5/8}$" and 7" sections should resist CO_2 and H_2S effects, while their nominal values are expected to be lower (due to the temperature effect).

However, despite all the precautions and proper geo-technical planning, unanticipated problems may arise, so the application of non-conventional methods may be necessary to make a well productive.

Published data show that deepening of an existing well requires half the cost of drilling a new well.[2] Drilling with casing might further reduce costs.

By simulating the sidetracking operation of a HTHP ultra deep well, this study aims to demonstrate the hydraulics and formation damage deriving from extreme conditions.

2. Problems arising

Due to the high value of the geothermal gradient, which this region is well-known for, the deep-level underground temperature is very high in Hungary. This causes the production fluid (formation fluid) in the casing to heat up the fluid entrapped between the production and the intermediate casing columns. As a result of thermal expansion, pressure will grow in the annular space between the two respective casings. If the fluid or the pressure is not released on a regular base, overpressure will occur. It may exceed the critical value defined for the pipe, which leads to its deformation or the collapse.

3. Re-entry examples

When simulating new methods, it is important to ascertain that there is a need for the modeled solution. Considering this fact, I gathered examples where this application has been used.

3.1. The Texas re-entries.[2] Re-entries usually target partially depleted reservoirs with an anticipated pressure lower than 7,000 psi. The respective wells have a 5 or $5^{1/2}$"

production casing with a premium connection that provided a second barrier in case of a leak. The drilling-with-casing(DWC) connection selected for the re-entries was a $2^{7/8}$" RTS 6 which has been used successfully as both work string and production tubing in south - Texas wells.

In this typical re-entry, the existing production equipment was recovered to the point of casting failure. A whipstock was set and a window was cut in the 5" or $5^{1/2}$" casing. A modified drilling assembly was used for DWC and work underbalanced. Using a $3^{3/8}$" or $4^{1/8}$" drill bit makes it possible to drill the entire interval (500 ft-1,800 ft) without tripping. A back pressure valve was installed in the bit sub, and a landing nipple was run above the bottomhole assembly, so that an additional back-pressure valve could be run on wireline as backup. A watermelon mill was used for cutting the window and elongating it.

The (casing) drillstring was not centralised and was rotated during cementing. The BHA was shortened to 100 ft. A surface stripper was used to divert the well returns and hold pressure while making connections to minimise inflow from underbalanced zones.

The first three re-entries DWC can be considered representative of the entire program and demonstrate the advantages of underbalanced drilling with casing. One case, Well D, is described in detail in this study as a sample model for the following simulation experiments.

Well D was the first new well where underbalanced (UB) DWC was used. After setting a $7^{5/8}$" liner, drilling continued with reduced mud weight (from 17 to 15 lbm/gal) until a zone of unexpectedly high pressure was reached. At total depth, the mud weight was increased to 16 lbm/gal, but complete returns were lost in one of the upper zones, and the fluid level dropped 2,600 ft. The openhole was squeezed with LCM cement. Normally, at this point a $5^{1/2}$" drilling liner would be run across the depleted zones; instead, an attempt was made to ream out the cement squeeze with the production casing and cement it at total depth. A rotating head was installed and a $6^{1/2}$" PDC bit and conventional double-valve float collar were run on $3^{1/2}$", 12.7 lbm/ft, L80 casing with a premium connection. The mud weight was reduced to 15 lbm/gal. Gas inflow was handled by a rotating head and a large gas separator. The cemented section was drilled out in 24 hours; then a mandrel hanger was positioned above the casing bowl, with the string rotated while cementing. The $3^{1/2}$" casing was finally cemented with full returns.

3.2. Kuwait.[3] In the Kuwait region in 2004, a 22,094 ft exploration well was the second deepest, to target, through the perforation of Paleozoic and Trias strata, the exploration of hydrocarbon reserves at 18,500 to 21,500 ft. The re-perforation of the well was completed underbalanced, with a $3^{1/2}$" drillstring at 16,260 ft.

The results of these completed projects are taken as a basis for the hydraulic data discussed. Since DWC is potentially applicable in Hungary in the future, it is reasonable to use in-place temperature and pressure data for modeling the potential outcomes. Considering these data, a 12,000 ft depth level was assumed for the sidetrack simulation and associated calculations presented in this paper.

4. Formation properties

Ultra deep wells are unique not only regarding depth, but also other characteristics like special properties of the targeted formation. While drilling these wells, one or more production zones have to be penetrated to reach the targeted sedimental stratum. In

Hungary, the respective average storage temperature is 200- 250°C (390-490°F) and the average storage pressure is approximately 10,000 psi (700 bar). Besides HT and HP, low porosity and permeability rates of the targeted zone can cause complications.

5. Simulating hydraulic conditions during re-entry

Due to high surface pressure and HTHP conditions, the re-entry of ultra deep wells is challenging. Since special drilling operations have to be executed under harsh conditions, uncertainties are involved in both the testing and the implementation of these projects.

Expected difficulties and issues to consider include:[3]

- high pressure and, high temperature of the well
- wall thickness of the casing and cement tubes separating the targeted formation
- extraordinary diameter of production casing
- careful selection of the drilling mud, with respect to formation properties.

Deepening and sidetracking usually target partially depleted reservoirs (for reasons of recovery). Less frequently, such operations are performed to eliminate failures resulting from casing damage or a defective cement column.

In the case of sidetracking, it is advisable to conduct wireline logging in order to detect potential damage to the casting and/or cement column and determine the exact depth. After placing a whipstock above the potential defect or at the planned depth of sidetracking, a window is cut in the 7” casing. A $4^{1/2}$” tube is selected for casing drilling, equipped with a PDC bit and 6” underreamer and a bottomhole motor. The back pressure valve is installed in the bit sub, and the landing nipple is run above the bottomhole assembly. A watermelon drill is necessary for cutting the window. In an optimal case, this assembly makes it possible to drill a 500- 1,800 ft section (~150 to 550 m) without tripping.

Sidetracking with the specified casing size is often combined with underbalanced drilling, basically in order to reduce losses. A critical point of practice is the control of formation pressure, where static and dynamic fluid pressures are used to maintain sidewall stability. If the fluid pressure is too high, the differential pressure between pore pressure and fracture pressure will drastically fall, which in an extreme case might lead to total fluid loss. Bottomhole pressure during circulating is determined as the sum of hydrostatic pressure and annular pressure loss.[4] This is called total pressure or dynamic pressure.

$$p_{din} = p_h + \Delta p_a \quad (1)$$

$$\rho_e * g * h = p_h + \Delta p_a \quad (2)$$

$$\mathrm{ECD} = \frac{p_h + \Delta p_a}{g * h} \quad (3)$$

where ρ_e is equivalent circulating density and h is depth.

Hydrostatic pressure is defined by average mud density and cutting concentration in the annulus. DWC makes it possible to attain a good cutting carry index even at lower flow rates.

$$p_h = g * (\rho_m * (1 - C_v) + \rho_c * C_v) * h \quad (4)$$

where ρ_c is cutting density and C_v is the concentration of annular cutting.

Annular pressure loss depends on sidewall geometry, flow regime and rotated casing and drillstring dynamics.

In addition to the fact that well geometry differs significantly for a sidetracked well and for a conventionally drilled one, other irregularities are also considered in this paper. Due to the (joint) effect of smaller annular diameter and increased annular pressure losses, the equivalent circulating density (ECD) will be higher when drilling-with-casing is conducted. This might turn an otherwise underbalanced state/assembly overbalanced while flushing.

Let us assume that the simulated well section is drilled with 1.8 SG (15 lbm/gal) mud, supposing that this weight is enough to balance formation pressure at 12,000 to 13,800 ft (3,660 m to 4,200 m) under static conditions/in static position. The Drilling Formulas™ Excel table is used for the calculations. Tables I and II show comparative data for rotary and casing drilling under the assumed circumstances.

Perhaps one of the most relevant parameters concerning drilling at this depth and casing size is proper cutting transport. This is given by the cutting carry index calculated as below:

$$CCI = \frac{K * v_a * MW}{4 * 10^5} \quad (5)$$

where K is the power law constant (consistency factor), V_a is annular velocity (ft/min) and MW is mud weight (lbm/gal)

$$K = 511^{1-n} * (PV + YP) \quad (6)$$

$$n = 3{,}322 * \log \frac{(2PV + YP)}{(PV + YP)} \quad (7)$$

where n is the flow behavior index, PV is plastic viscosity and YP is yield point.

In case the cutting carry index is ≥0.5, it denotes inappropriate cutting transport. Transport is considered good if the value is between 0.5 and 1. If it exceeds 1, cutting transport is considered excellent.

Accordingly, a value of optimal cutting carry index has been considered for the calculations. As seen, drilling-with-casing allows lower flow rates to obtain this optimal value. Due to irregular/complex hole geometry, however, annular pressure loss will be still higher (than normal). As a result, ECD is also higher.

Proper cutting carry and minimal and maximal flow rates specified for the given bottomhole assembly will limit the pump rate. However, it is important to minimise the damage made to the formation and to avoid potential mud loss.

6. Formation damage effects

If properly cemented and perforated, a 400-500 m long section could be enough to actuate production from the given well. Assuming optimal conditions and drilling without tripping, attention should be paid to the selection of mud weight. Besides avoiding unanticipated problems, the careful selection of mud weight should ensure that the potential production zone, characterized by low permeability and low porosity, will not be contaminated so that formation damage will not cause a problem when starting production.

Table I. Well Data

	Rotary drilling	**Casing Drilling**	
Well depth (ft)	13,800		13,800
Casing size (in)	7		7
Casing shoe depth (ft)	12,000		12,000
Bit size (in)	6		6
Drill pipe (in)	3.5	Casing (in)	4.5
Drill Collar (in)	4 3/4		-
Length of drill collar (m)	183		-
Bottomhole assembly (m)	30		30
	-	Drilling Motor	3.5
Mud properties			
Mud weight (kg/m^3)	1,800		1,800
Plastic viscosity (cP)	15		15
YP (Pa)	10		10
Cutting properties			
Cutting density (kg/l)	2,600		2,600
Cutting size (mm)	19.05		19.05

Table II. Comparison of circulation properties when cutting carry index is equal

	Rotary drilling	**Casing drilling**
Pump rate (liter/min)	**460**	**300**
ECD (kg/m3)	**1,820**	**1,840**
Static bottom hole pressure (bar)	**760**	**760**
Dynamic bottom hole pressure (bar)	**770**	**773**
Annular pressure loss (bar)	**10**	**13**
Cuttings velocity (m/min)	**23**	**23**
Annular velocity (m/min)	**38**	**38**
Cutting carry index	**0.87**	**0.87**

Most mud contains weighting additives. However, differential pressure might allow these substances to enter in the formation and destroy it. Common types of destruction are a negative effect on relative permeability, too high capillary pressure and particle migration.

All have negative effects on actuating production. In case re-entry is planned a relatively high-cost technique it is worth considering that formation damage would cause extra costs.

Proposed solutions: (1) mud and mud cake analyses, (2) underbalancing, (3) decreasing ECD: by decreasing plastic viscosity and yield point a practically acceptable small amount of bottom-hole pressure decrement can be obtained.[5]

Gabriella Federer-Kovacs, associate research scientist
Research Institute of Applied Earth Sciences, University of Miskolc
3515 Miskolc, Egyetemváros, federer@afki.hu

Among the listed solutions, underbalancing is proved effective by the published data. Therefore, we propose the application of this technique to the simulated well data published in this paper. The results obtained are summarised in Table III.

Table III. Circulation properties underbalanced

	Casing drilling	
Pump rate (liter/min)	**300**	**460**
MW (kg/m^3)	**1,680**	**1,680**
ECD (kg/m^3)	**1,700**	**1,750**
Static bottom hole pressure (bar)	**706**	**706**
Dynamic bottom hole pressure (bar)	**720**	**734**
Annular pressure loss (bar)	**13.4**	**28**
Cuttings velocity (m/min)	**23**	**41**
Annular velocity (m/min)	**40**	**57**
Cutting carry index	**0.85**	**1.23**

7. Conclusions

If a re-entry is necessary in extra deep HPHT wells, such exist even in Hungary, we frequently meet with unpredictable conditions where the benefits of casing drilling can be advantageous. Although using this technique causes elevated ECD and therefore damage the formations that may have already been problematic to produce.

For this reason calculations were made to find a solution for cases where the reservoir characteristics require casing drilling but the hydraulic conditions does not allow to drill with regularly calculated balancing mud parameters. Calculations results indicate that using a low mud weight compared to formation pressure (which means underbalanced condition) can be a solution for re-entry under the above mentioned hydraulic conditions.

Acknowledgement

The described work was carried out as part of the Tlution for cases where the reservoir characteristics require casing drilling Development Plan. The realisation of this project is supported by the European Union, co-financed by the European Social Fund.

References

[1] H. Rabia: Oilwell Drilling Engineering-Mud Engineering and Rig Hydraulics, ISBN 0860107140
[2] D. Gordon, R. Billa, M. Weissman: Underbalanced Drilling With Casing in South Texas, JPT March 2004, p. 55
[3] H. Al-Bader, Y. Zaid Al-Salali, V.S. Duggiral,: Successful Discovery of Light Oil from an Unsuccessful Paleozoic Well Through Re-entry-A Case Study of HPHT Well SPE 147247
[4] H. Diaz, S. Miska: "Modeling of ECD in Casing Drilling Operations and Comparison with Experimental and Field Data" , University of Tulsa 2004 IADC/SPE 87149
[5] G. Federer: Evaluation of well hydraulics in relation with casing drilling, Freiberger Forschungsforum, 16. bis 18. Juni 2004