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Effectiveness of Simulation to Compare Driller's and Engineer's Methods to Control Wells in Highly Deviated Fractured Basement Reservoirs

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Abstract

There are many problems that may occur during drilling, workover, snubbing, and coil tubing. To this extent, occurrence of a kick is considered a serious problem because making a mistake in well control may lead to a catastrophe. Particularly when gas kicks are not properly controlled which eventually can escalate into a blowout. Thus, once a gas kick is detected, it has to be circulated out safely and efficiently to the surface while maintaining bottomhole pressure constant. A quick, appropriate, and an effective response to well control is paramount in order not to end up with a surface or underground blowout. Hence, there are many methods available to kill and control the well such as Driller's method, Engineer's method, concurrent method, bull-heading method, reverse method, lubricate and bleed method. In this research work a multiphase flow Drillbench simulator was used to conduct a comprehensive comparison between the Driller's and Engineer's method to determine the most effective method to kill the well in basement reservoirs. Granitic basement reservoirs are challenging because of the severe shocks, vibrations, heterogeneity, extensive fracture network, high flow rate and unexpected over-pressurized network. Consequently, this shall require proper reaction to kill flowing wells meanwhile avoid affecting other wells within the same network. A case study showed that Engineer's method has better results and more advantages over Driller's method since it would require only one circulation to completely kill the well and no potential for further kicks in highly fractured formation.

***Keywords**: Well control; Basement reservoirs; Driller's method; Engineer's method; Multiphase kick.*

1. Introduction

A blowout disaster has a catastrophic consequence on lives lose, pollution, direct and indirect economic losses. It is very essential to determine the optimum method to respond and circulate the kick out of the wellbore safely without any complications [1]. There are many methods available to control the well. Some of them provide circulation of a fluid to remove the influx from the wellbore up to the surface such as Driller`s method, Engineer's method and reverse circulation [2]. Whereas others provide fluid to be pumped down to the formation without any return to the surface like Bull heading. And in situation where none of them success to kill the well, other methods could be used like volumetric method and lubricate and bleed [3]. Circulating methods require keeping the bottomhole pressure constant while circulating out the kick and replacing the old mud with kill mud weight. Which means after the well is closed, during the time the well is being killed, BHP must be kept more than formation pressure [4]. This needs to be achieved without fracture the formation or cause any equipment failure, henceforth the well should be killed without taking any additional kicks [5].

A kick with high formation permeability could result in a very large pit gain if the kick is not detected and reacted to quickly. It also gives fast well stabilization after well shut in [2]. The mechanism that the gas influx migrates in horizontal wells, is by entrainment or by transporting the gas out as large bubbles depending on the fluid velocity. And depends on critical parameters such as gas dissolution, mass transfer rate gas rise velocity, rate of gas entrainment [6].

1.1. Basement reservoirs

Fractured basement is becoming an important contributor to the petroleum industry. However, drilling into the granitic basement reservoir is challenging because of the severe shocks, vibrations, high flow rate and high network pressure. Fracture would be in a long micro rock separation in micrometer or continental fault until thousands of kilometers [7]. The plane is a weak fragment of rock feature from pressure exchange on earth crust because of fracture from one or more different ways, depends on pressure direction and type of rock [8]. A fracture contains two uncommon rocks surface, and contact each other. Volume between surfaces is called by fracture gap. Naturally fractured reservoirs have been classified according to the relative contribution of the matrix and fractures to the total fluid production [9]. When massive losses occur in formations the well's behavior does not follow the conventional well control scenario. Gains are not seen in pit volumes despite hydrocarbon entry and kicks can go undetected until they have traveled some distance up the annulus [4]. Johnny successfully designed a model for Lost Circulation in fractured formation using RF-Kick simulator that helped to perform planning and anticipation of undesirable situation [10].

2. Well data description

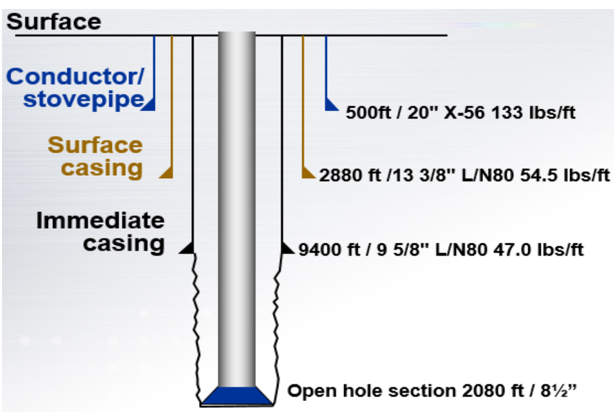

Fig 1. Well X sketch

Well X is located in a Basement field north of Sab'atayn Basin NW-SE. The basin is a late Jurassic. The block started to produce 17 MBOPD since 2005 from fractured basement reservoir. The oil produced is light between 35° to 42° API. Wellbore sketch is shown in Figure 1. Details of the well equipment and components are illustrated in Tables 1 and 2. The length of the open hole section is 2080 ft with 8 1/2" diameter. Simulation will be implemented for the expected kick from this basement reservoir. Additionally, a sensitivity analysis done in order to show the influence of the is kick size and the kick density on controlling well X during exposing to kick from this reservoir.

Table 1. Drillstring and bottomhole assembly description

Drill string components	Section length ft	Inside diameter in	Outside diameter in	Distance from bottom, (ft)
8.5" PDC Smith Bit w float	3.0832	2.81	6.75	0.98
A675XP Motor	25.912	5.5	6 3/4	26.90
8 3/8'' Stabilizer	5.576	2.7	6 1/2	32.47
Float Sub	2.624	2.8	6 1/2	35.10
6 3/4'' Pony NMDC	9.0856	2.8	6 3/4	44.18
MWD	34.112	3.8	6 3/4	78.29
6 3/4'' NMDC	29.52	2.8	6 3/4	107.81
5'' HWDP	30.832	3.875	5.5	138.65
6-1/2" Jars	32.472	2.5	6 1/2	171.12
5'' HWDP	30.832	3	5	201.95
5'' DP	285.36	4.778	5.5	487.31
5'' HWDP	554.32	3.87	5.5	1041.63
DIBPV	2.952	3.875	6 1/4	1044.58
5'' HWDP	30.832	3.875	5.5	1075.41
Drill pipe	10407.44	4.778	5.5	11482.85

Table 2. Casing specifications and properties of well X

Casing	Setting depth, ft	Inside diameter, in	Outside diameter, in	Hole Diameter, in
20" X-56 133.0 lbs/ft	500	18 3/4	20	23
13 3/8" L/N80 54.5 lbs/ft	2880	12 3/5	13 3/8	17 1/2
9 5/8" L/N80 47.0 lbs/ft	9400	8 2/3	9 5/8	12 1/4

3. Methodology

3.1. Driller’s method

The Driller’s method is considered the oldest well killing method and it was developed for shallow vertical wells. With time wells became deeper and went from vertical into horizontal. The method got further developed to overcome the new challenges related to deviated well paths1 [11]. The Driller's method of killing a well kick is accomplished in two circulations [12]. As the well is circulated using mud that was in use when the kick occurred. The pump must be run at constant speed, usually the reduced circulation speed previously selected. The reduced kill circulation speed is usually 1/2 of the regular drilling flow rate.

Kill mud required to contain the formation pressure is circulated to remove and replace the lighter fluid in the well. The pump is run at constant speed, usually the same as employed during the first circulation [13]. More time since Engineer’s method requires only one circulation whereas Driller’s method needs two circulation to kill the well. But need to compare the time required to mix the kill mud and see if it is significant since we may not safe time. Some time it is hard to circulate the gas kick with just one circulation due to hole situation and condition such as when some gas bubbles left over in high pockets, bad mud properties or even due to poor hole cleaning hence additional circulation will be needed to remove all influx [14]. Other issue about the driller’s method it produces maximum on-choke time. As choke operator will have to continuously operate choke for making constant SICP and ICP value and for making constant BHP [15].

3.2. Engineer’s method

The Engineer’s method involves pumping the kill mud and circulate the kick out of the wellbore in only one circulation. It is mandatory to keep the BHP constant during the whole period till the well is completely killed so that the formation will not be fractured neither further influx will not flow to the wellbore. Table 3 break down the field operational procedure for Engineer’s method [16]

Table 3. Field operational procedure for Engineer’s method

1	Once the kill sheet has been completed and the mud weight has been raised to the desired value, prepare to circulate through choke.
2	Open choke manifold valve upstream of choke. Zero stroke counters, and ensure good communication between choke operator, mud pump operator and personnel in the pump room. Hold the casing pressure constant while bringing the pump to kill rate.
3	Once the pump is up to speed and the pressures have stabilized, record the actual circulating drill pipe pressure. If the actual circulating pressure is equal to, or reasonably close to the calculated ICP, continue pumping and follow the standpipe pressure according to the drill pipe pressure schedule.
4	From the moment pumping of the weighted mud begins, until the end of the well kill process, constant BHP must be maintained.
5	When the kill mud enters the annulus, the choke operator then holds drill pipe pressure constant until the kill mud returns at surface.
6	Any time the circulation is interrupted and the well shut-in during the kill operation, it will be necessary to ensure that no pressure has been dynamically trapped and that the BHP is equal to the formation pressure before resuming the kill operation.
7	Once uncontaminated kill mud returns are observed at surface, shut-in the well and monitor the drillpipe and casing pressures.

The overall advantages for Engineer's method [17]

- One circulation to kill the well.
- Less time on choke (less time to remove kick).
- Faster due to kick is circulated out in one circulation.
- The hole and the wellhead equipment are subjected to high pressures for the shortest possible time since the gas kick is circulating out and the well is killed only in one circulation.
- Efficient when modern mixing and pumping facilities are available.
- Kill mud is pumped to wellbore sooner than in Driller's method.

Required equations to kill the well [18]

$$\text{Initial circulating pressure (psi)} = \text{slow circulating rate (psi)} + \text{SIDPP (psi)} \tag{1}$$

$$\text{Final circulating pressure (psi)} = \text{slow circulating rate (psi)} * \frac{\text{kill mud weight(ppg)}}{\text{orginal mud weight (ppg)}} \tag{2}$$

$$\text{Kill mud weight (ppg)} = \text{original mud weight (ppg)} + \frac{\text{SIDPP (psi)}}{\text{True vertical depth (feet)}*0.052} \tag{3}$$

$$\text{MISICP (psi)} = [\text{leak of test (ppg)} - \text{current mud weight (ppg)}] * 0.052 * \text{shoe depth (feet)} \tag{4}$$

$$Strokes = \frac{volume(bbl)}{pump\ output\ (\frac{bbl}{stroke})} \tag{5}$$

$$Pressure\ drop = \frac{ICP-FCP}{surface\ to\ bottom\ strokes} \tag{6}$$

4. Results and discussion

The software results have been graphically presented, analyzed, and discussed. The simulation of a kick for both methods the Driller's and the Engineer's method.

4.1. Driller's methods

After the well was shut-in, the wellbore pressure is allowed to stabilize. The shut-in time is kept until the bottomhole pressure equals the pore pressure and the influx has stopped. This was selected from the shut-in period drop down list. Circulation rate was defining the pump rate when circulating the kick. Table 4 shows the simulation parameters for Driller's method [19]. The flow check continued until volume increases in the pit is achieved. Table 5 summarizes the simulation process for the Driller's method [20].

Table 4. Simulation parameters for Driller's method

Pre-kick circulation time	10 minutes
The pit alarm level	50 bbls
Shut-in period	30 minutes
Circulation rate	100 gallons/min
Circulation mode	Constant bottom hole pressure
Kick intensity	0.50 ppg
Safety margin	100 psi
Simulation method	Driller's method

Table 5. Simulation process for Driller's method

1	Pull out of hole.
2	When kick is detected shut-in the pump.
3	Continue simulation. The simulation activated till the program shows that the pump is off.
4	Close the BOP. Simulation runs till it shows that the BOP is closed.
5	Shut-in time recorded.
6	Open choke.
7	Turn on the pump.
8	Circulate the kick out.

4.1.1. Pit gain

Fig 2 shows the pit gain when its volume increased to 50 bbls as the BOP is close and shut-in the well from 10th minute to 40th minute. Starting to open the choke a small volume of drilling mud will flow to the tank. This due to the gas expansion upward while circulating. The pit gain is increasing as the kick is circulated out and reaches maximum when the top of the gas kick arrives to the surface volume of 66 bbls in 73 minutes. When the pit gain starts to decrease the gas kick is starting to leave the well. The gas circulated out completely at 230 minutes. After that a second circulation is required to kill the well by increasing kill mud it means total time will be 500 minutes.

4.1.2. Pump pressure

Fig 3 describes the pump pressure behaviour. The reduction in the pressure from zero to the 10th minute is due to gas influx flow to the wellbore. From the 10th minute to the 40th minute the well is shut-in. Pressure stabilized at 180 psi. At the 40th minute start pumping the same density of current mud and pump pressure increases to 320 psi. During this region gas bubbles are being circulated out of the hole through the annulus, the drill pipe pressure is constant in the first circulation at 230 minutes. In the second circulation the drill pipe pressure decreases since kill weight mud is pumped. The decrease in drill pipe pressure is due to increase of the hydrostatic pressure caused by the heavier kill mud column. As soon as the drill pipe is full of kill mud, it begins to circulate up the annulus till reaches the surface and this requires 500 minutes.

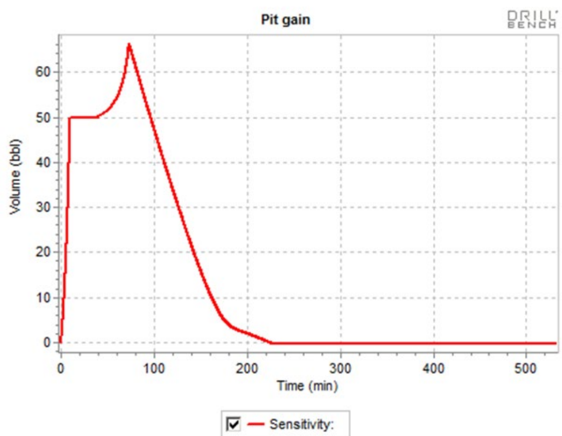

Fig 2. Pit gain profile using Driller’s method

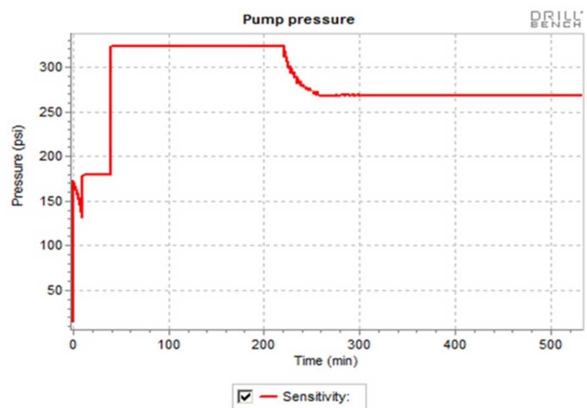

Fig 3. Pump pressure profile using Driller’s method

4.1.3. Choke pressure

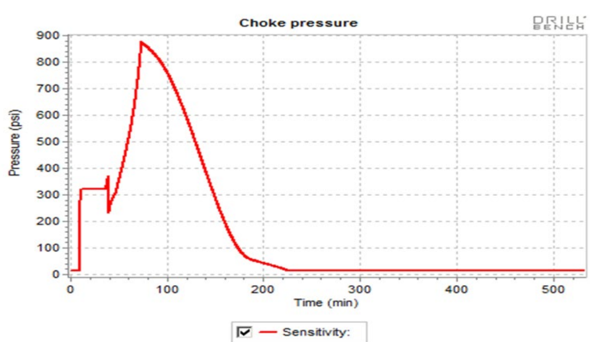

Fig 4. Choke pressure profile using Driller’s method

The choke pressure in Fig 4 illustrates the major increase in choke pressure during circulation the gas kick. The rise in pressure is due to a reduction in hydrostatic pressure in the well as the gas tends to expand. It is necessary to reimburse the lower pressures in the well by increasing the choke pressure to keep a constant bottomhole pressure during circulation. At the 10th minute pit gain is 50 bbls. This is followed by a shut-in period for 30 minutes, shut-in pressure is 320 psi. The gas kick at this point is passing the drill collars, the rapid changes in annular volume create this jagged profile in the casing pressure. At the point where the top of the gas bubble reaches the surface choke pressure reaches maximum value is 890 psi at 73 minutes. After that pressure begins to decrease, the influx is starting to flow out of the well and continue to reduce till the gas is circulated out of the well. The first circulation requires 230 minutes to be accomplished. Hence second circulation commences and kill mud is pumped.

4.1.4. Pressure at casing shoe

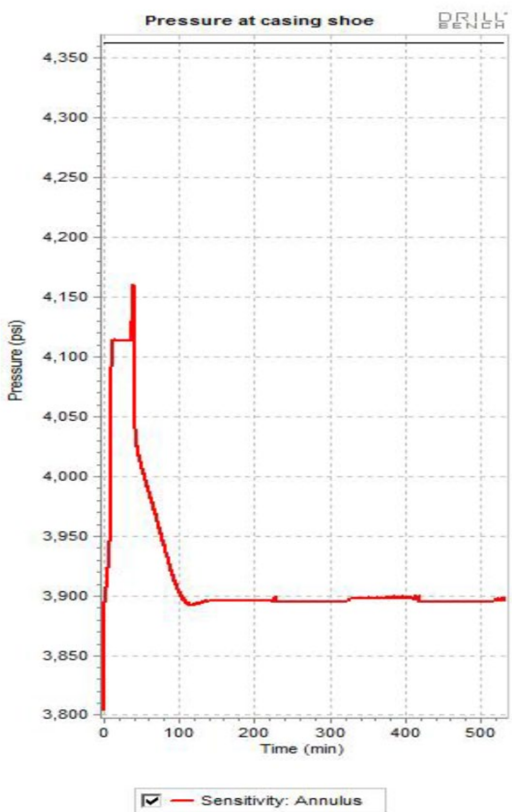

Fig 5. Pressure at casing shoe using Driller's method

Fig 5 represents the behaviour of the pressure while the influx travels in the annulus in the kill procedure. As expected casing shoe pressure rises as soon as the well is shut-in and reaches 4110 psi at 10th minute. Shut-in period is from 10th minute to 40th minute where pressure stabilized. Pressure increases as the influx moves up, the maximum pressure at the shoe is 4160 psi after that pressure reduces when it passes above the shoe and becomes independent from casing.

4.2. Engineer's method

After the well is shut-in, the wellbore pressure is allowed to stabilize. The shut-in time is kept until the bottomhole pressure equals the pore pressure and the influx has stopped. This was selected from the shut-in period drop down list. Circulation rate was defining the pump rate when circulating the kick [5]. Table 6 shows the simulation parameters for Engineer's method. The flow check continued until volume increases in the pit is achieved. Table 7 summarizes the simulation process for the Engineer's method.

Table 6. Simulation parameters for Engineer's method

Pre-kick circulation time	10 minutes
The pit alarm level	50 bbls
Shut-in period	30 minutes
Circulation rate	100 gallons/min
Circulation mode	Constant bottomhole pressure
Kick intensity	0.50 ppg
Safety margin	100 psi
Simulation method	Engineer's method

Table 7 Simulation process for engineers method

1	Pull out of hole.
2	When kick is detected shut-in the pump.
3	Continue simulation. The simulation activated till the program shows that the pump is off.
4	Close the BOP. Simulation runs till it shows that BOP is closed.
5	Shut-in time recorded.
6	Open choke.
7	Turn on the pump.
8	Circulate the kick out.

4.2.1. Pit gain

Fig 6 shows the pit gain when its volume increased to 50 bbls as the BOP is close and shut-in the well from 10th minute to 40th minute. Starting to open the choke a small volume of drilling mud will flow to the tank. As kill mud is pumped from the drill pipe gas expands upward while circulating in a controlled manner. The pit gain is increasing as the kick is circulated out and reaches maximum when the top of the gas kick arrives to the surface with volume of 61 bbls in 77 minutes. When the pit gain decreases the gas kick is starting to leave the well. The gas circulated out completely and kill mud is displace in both drill pipe and annulus in 230 minutes.

4.2.2. Pump pressure

Fig 7 demonstrates the pump pressure, where reduction in pressure at 10th minute is due to influxed gas flow to the wellbore. From the 10th minute to the 40th minute the well is shut-in due to kick influx and pressure stabilized at 180 psi. Starting to pump kill mud at 40th minute when pressure is increased to 540 psi. During this region the gas bubbles are circulated out of the hole through the annulus, hence the drill pipe pressure is falling. The decrease in drill pipe pressure is because of the increase of the hydrostatic pressure caused by the heavier kill mud. As soon as drill pipe is full of kill mud, it would begin to circulate up the annulus till reach the surface with stabilized pressure of 330 psi while time required to kill and control the well is 230 minutes.

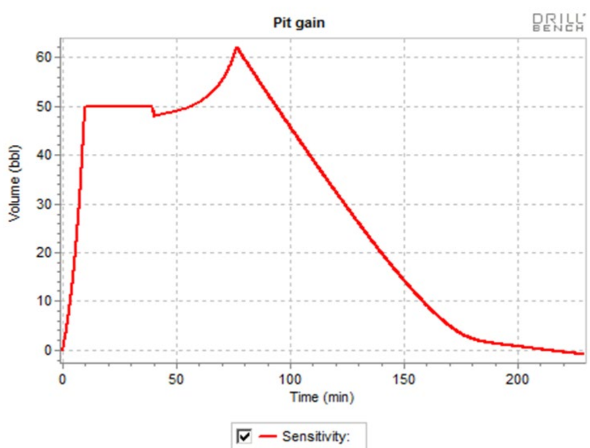

Fig 6. Pit gain profile using Engineer's method

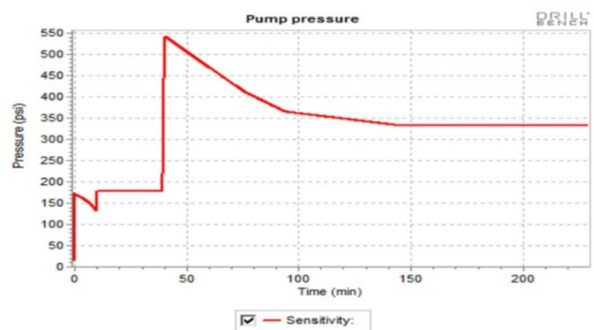

Fig 7. Pump pressure profile using Engineer's method

4.2.3. Choke pressure

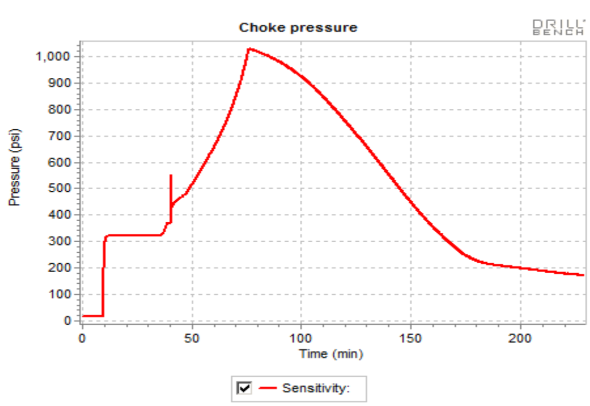

Fig 8. Choke pressure profile using Engineer's method

The choke pressure in Fig 8 shows that at 10th minute pit gain is 50 bbls. From 10 to 40 minutes is the shut-in period and pressure stabilized at 320 psi. Well killing starts at the 40th minute and pump provides 100 psi. The gas kick at this point is passing the drill collars, so the rapid changes in annular volumes create the jagged profile in casing pressure. The rise in choke pressure when we start to circulate the well is due to reduction in hydrostatic pressure caused by gas expansion while circulating. It is required to compensate the lower pressure in the well by increasing the choke pressure to keep a constant bottomhole pressure during circulation. Well killing starts with 100 psi overbalance and top of the influx reaches surface at 77th minute having the highest surface pressure of 1020 psi. Pressure starts to decrease after the influx is flowing to surface and all gas babbles has been circulated out. The well is completely killed and full of kill mud in 230 minutes.

4.2.4. Pressure at casing shoe

Figure 9 shows the behaviour of the pressure while the influx travels in the annulus in the kill procedure. As kick inters the annulus pressure increases till the 10th minute. Shut-in period is from 10th minute to 40th minute. Pressure increase as influx moves up, with maximum pressure at the shoe is 4300 psi. After that pressure reduces as it passes above the shoe. A constant decrease as the kill weight mud is being pumped down the drill pipe. The casing shoe pressure decreases until the kill mud enters the annulus. The casing shoe pressure drops because of the higher static pressure from the kill weight mud in the annulus.

Fig. 9. Pressure at casing shoe using Engineer's method

5. Conclusions

The project has successfully produced a complete swab kick model and proven that well control simulation is a real time powerful tool to assist on choosing the right method to kill the well and evaluate all parameters that may be effected while circulation the influx. Using Engineer's method considered to be effective technique to kill the well for highly fractured basement reservoirs. Results show that the time to kill the well in the Engineer's method is half the time needed if Driller's method is used since Engineer's method requires only one circulation. Simulation time to kill the well and control it by the Engineer's method takes 230 minutes, whereas in Driller's method it takes 500 minutes to kill and control the well. Modern mud mixing facilities can mix up the required weighting agent in a fast time; therefore, time required to weight up the mud is not an issue. Engineer's method results in pumping the kill fluid sooner to the wellbore which it another privilege due to high potential for further kicks to flow in Driller's method at the first circulation particularly in large fractures and high pressure network in Basement reservoirs.

References

[1] WSC Well Control School Manual, International School, Oklahoma city, US, 1991.
[2] Choe J. Advanced Two-Phase Well Control Analysis, PETSOC-01-05-02, (2001) Petroleum Society of Canada.
[3] Grace R. Advanced Blowout and Well Control, Gulf publishing Texas United State of America, 1994.
[4] Dupriest FE. Kick Mechanisms and Unique Well Control Practices in Vugular Deepwater Carbonates, (2012) IPTC 14423.
[5] Brittenham D. Advanced Well Control, Society of Petroleum Engineers, Richardson, Texas, 2003.
[6] Vefring EH, Wang Z, Gaard S, Bach GF, Rogaland RF. An Advanced Kick Simulator for High Angle and Horizontal Wells-Part I. (1995) SPE/ IADC 29345.
[7] Luthi SM. Fractured Reservoir Analysis Using Modern Geophysical Well Techniques. Geological Society, (2005) London, Special Publication, v. 240, p. 95-106.
[8] Whaley J. Hiding in the Basement. Geoscience Geoexpro 2017; 13(6).
[9] Nelson RA. Geologic Analysis of Naturally Fractured Reservoirs. Gulf Professional Publishing Co., Boston2001, 332.
[10] Johnny P, and Rogaland RF. Kick with lost circulation simulation, a tool for design of complex well control situations, (1998) SPE 49956.
[11] Adams N. Workover well control. PennWell publishing, Tulsa, Oklahoma,1981.

[12] Aberdeen Drilling Schools, Well Control for the Rig Site Drilling Team, 50 Union Glen, Aberdeen, AB11 6ER Scotland UK, 2002.
[13] Neal A, Larry K. Kicks and Blowout Control, PennWell Publishing Company, Tulsa, Oklahoma, 1994.
[14] Well Control School, 2600 Moss Lane Harvey, 7OO58 Louisiana USA, 2002.
[15] Fan K, Akgun F, Iddris A. A Different Approach in Handling Well Control Kick Circulation, (2011) SPE/IADC 148514,
[16] Choe J. Dynamic Well Control Simulation Model for water based muds and their computer application. Texas A & M University, 1995.
[17] Recommended Practices for Well Control Operations API (RP 59), American Petroleum Institute Washington DC, 1987.
[18] Wild Well Control Inc., Reference Book of Formulas, Chart, and Tables. Spring, Texas, USA, 2003.
[19] Azar JJ, Robello S. Drilling engineering, PennWell Cooperation, 2007, ISBN 1593700725.
[20] Drillbench dynamic well control user guide, 2016.

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