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Simulation of Gas Kick and Well Control Procedures

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Abstract. Kick refers to uninvited influx flow from the formation into the wellbore during drilling operation. Undesired event such as non-productive time (NPT) and blowout may occur if the engineers ignore the positive indications of kick. The well should be shut-in immediately and well control procedures should take place after the kick is detected. In this study, a base model has been created in the simulation software, Drillbench. Besides, two types of shut-in methods have been evaluated and studied to investigate the relationship of different shut-in methods affecting the volume of pit gain using the software. Both shut-in methods have been simulated in the case with water-based mud and oil-based mud. The results of the studies with the quantitative difference in term of the volume of pit gain between two methods is included in this paper.

Keywords: Simulation; gas kick; well control; shut-in methods; Drillbench

1. Introduction

Well control is a technique used to maintain the hydrostatic pressure of the fluid column in the wellbore to avoid influx flowing into the wellbore from the formation [1]. It is a practice applied in oil and gas operations which include drilling, workover and well completions operation [1]. Well control procedures can be divided into primary well control, secondary and tertiary well control [1], [2]. In primary well control, the hydrostatic pressure in the wellbore is maintaining to be within the pore pressure and fracture pressure [1]. The blowout preventer (BOP) will be used in the case where the primary well control fails [1]. In tertiary well control, it refers to a specific method that can be applied when primary and secondary well control fail [2].

The well need to be shut-in immediately when there are any indications of kick to prevent more influx flowing into the wellbore [2], [3]. Shut-in methods can be divided into hard shut-in method and soft shut-in method [2]. After the well has been shut-in successfully, the influx can be circulated out and kill mud can be pumped into the well before the drilling operation can be resumed [1].

In this study, two types of shut-in methods were being applied in the case with water-based mud and oil-based mud. The pit gain volume, pressure at casing shoe, volume fraction of free gas and dissolved gas have been studied based on the output generated by the simulation software. Results of quantitative analysis between both shut-in methods in water-based mud and oil-based mud have been included in the paper. The aim of this study is to investigate the relationship between the types of shut-in method affecting the amount of influx volume and study on the difference in terms of pit gain in both types of based mud.

2. Background

2.1. Kick

Kick is the influx flow from the formation into the wellbore [1], [4]. It may escalate into a blowout if it is not counteracted properly and will eventually result in environmental contamination, loss of human lives as well as financial losses [4], [5].

The causes of kick include insufficient mud weight in the wellbore, fail to ensure the mud level is full while tripping and fluid losses [3], [6], [7]. Other than that, swabbing and surging are one of the causes of kick [1].

There are many systems have been used to detect kicks or lost circulation in real time by using surface measurement [8]. However, false alarms can happen due to some drilling events such as tripping [9]. Another kick or lost circulation indicators are volume pit gain or reduction as well as unpredicted deviations in pump pressure [10].

2.2. Well Control

There are various well kill methods that can be applied to circulate out the kick [1], [3]. The well kill methods serve the purpose to avoid more influx flowing into the wellbore by circulate out the influx and pump the kill mud [1]. The objective of pumping the kill mud is to ensure the hydrostatic pressure in the wellbore will be higher than the formation pressure [2]. After the kill mud has been fully circulated in the wellbore, the drilling operation can be resumed [2].

Constant bottom-hole pressure kill methods that are commonly used include Wait and Weight method, Driller's method and Concurrent method [2], [11]. These methods are similar in terms of principle just that they are varies in respect of when the kill mud is pumped into the well [2]. Other than that, volumetric method can be applied in a situation where there is no pipe in hole or circulation is not possible [1], [3]. However, this method works only if the influx is gas and there is gas migration [1].

In this study, Driller's method was chosen to be the well control method. Driller's method requires two circulations to circulate out the kick [2]. The kick is circulated out with the original mud weight in the first circulation and the kill mud is pumped into the well after the kick is circulated out [2].

2.3. Shut-in method

There are operators and drilling contractors argue and have debate on the correct way to shut-in the well before the influx can be circulated out [6]. This is due to there will be some issues when it comes to the selection of shut-in method [6].

One of the concern in hard shut-in method is whether the well can withstand the water hammer effect [6]. Water hammer effect or pressure pulse may occur when the blowout preventer is closed directly after turning off the pump without open the choke [6]. Besides, water hammer effect may lead to underground blowout if the pressure at the casing shoe is too weak [6]. Due to this concern, there are operators who have decided to choose soft shut-in method where the choke manifold is opened during the closure of blowout preventer [1], [2], [6]. This will be able to reduce the water hammer effect and prevent underground blowout [6]. However, delay time in closing the choke to ensure the well is shut-in completely may allow additional influx to flow into the wellbore [2], [6]. This would bring issues to the crews when more influx are in the wellbore [6].

3. Methodology

3.1. *Case Study*

The summaries of the input parameters to create the case study are listed in the table below.

Table 1. Input parameter for the case study

Survey section			
Measure depth (ft)	Inclination (°)	Azimuth (°)	Vertical depth (ft)
5577.4	0.00	0.00	5577.4

Casing program				
Name	Hanger depth (ft)	Setting depth (ft)	Inner diameter (in)	Outer diameter (in)
13 3/8" P110 61.0 lbs/ft	0.00	4593.18	12.516	13.374

Component section				
Component	Type	Section length (ft)	Inner diameter (in)	Outer diameter (in)
DC 8" NC 56-80	Drill collar	574.15	3.00	8.00
DP 6 5/8" G105 27.70 lb./ft	Drill pipe	5331.36	5.902	6.626

Drill bit		
Name	Outer diameter (in)	Flow area (ft^2)
Bit 12 ¼"	12.252	0.0066

Choke line	
Length (ft)	Number of line(s)
10.00	1

Pump		
Liquid rate change (US Gal/min^2)	Volumetric output (US Gal/stroke)	Response delay (min)
792.20	3.96	0.17

Blowout preventer	
Closure time (min)	Response delay (min)
0.50	0.17

Fracture pressure			
Depth (ft)	Fracture pressure (psi)	Initiation pressure (psi)	Closing pressure (psi)
4593.18	3593.7940	3585.3329	2737.7774

Drilling fluid #1: Oil-based mud	
Base oil density (lbm/US gal)	7.3022
Water density (lbm/US gal)	8.3454
Solids density (lbm/US gal)	35.0507
Density (lbm/US gal)	10.849
Reference temperature (Fahrenheit)	82.40

Oil-water ratio	75/25
Rheology type	Non-Newtonian
PVT model	Black oil

Fann reading	
Shear rate (rpm)	Shear stress (lbf/100 ft^2)
600	73
300	51
200	42
100	31
6	17
3	16

Drilling fluid #2: Water-based mud	
Base oil density (lbm/US gal)	7.3022
Water density (lbm/US gal)	8.3454
Solids density (lbm/US gal)	35.0507
Density (lbm/US gal)	10.849
Reference temperature (Fahrenheit)	82.40
Oil-water ratio	0/100
Rheology type	Non-Newtonian
PVT model	Black oil

Fann reading	
Shear rate (rpm)	Shear stress (lbf/100 ft^2)
600	73
300	54
200	46
100	33
6	13
3	10

Reservoir lithology				
Top (ft)	Bottom (ft)	Flow model	Top pressure (psi)	Temperature (Fahrenheit)
5905.51	5938.32	Reservoir model	3509.9133	135.86

Temperature properties		
Temperature model	Choke line outlet (Fahrenheit)	Constant mud injection (Fahrenheit)
Measured	77.00	-

Drill string temperature	
Depth (ft)	Temperature (Fahrenheit)
0.00	68.00
4757.22	95.00
5905.51	104.00

Annulus temperature	
Depth (ft)	Temperature
0.00	77.00
3280.84	95.00
4593.18	113.00
5905.51	107.60

4. Results and Discussion

Simulation cases were run with different type of shut-in methods in different mud. The details of the control parameter used in the simulation cases are shown as below.

Table 2. List of control parameters

Control parameters	
Rate of penetration (ft/hr)	35
Pit alarm level (bbl)	3.5
Reservoir pressure (psi)	3622.9573
Kick intensity (ppg)	0.50
Pump rate (US gal/min)	792.5
Circulation mode	Constant bottom hole pressure

4.1. Comparison study of hard shut-in method and soft shut-in method with water-based mud

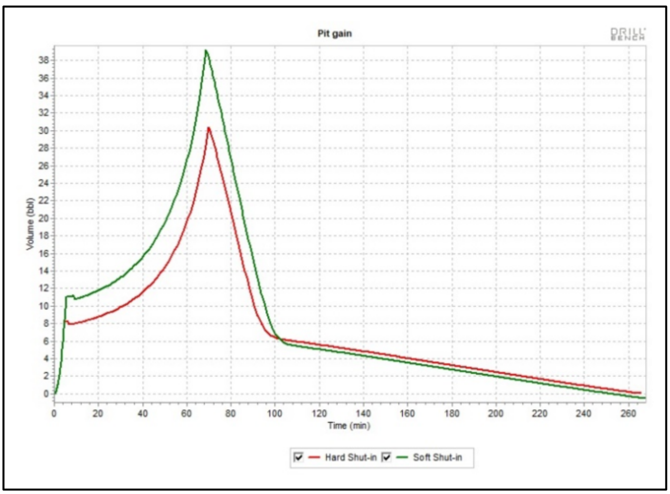

Fig. 1. Volume of pit gain plotted vs time

Drilling operation was stopped when the pit gain volume reached 3.5 barrels. This was due to the setting in the control parameter for pit alarm level was 3.5 barrels. It also means that there was an extra fluid of 3.5 barrels flowed into the wellbore. After the influx was detected, the well was shut-in by the both shut-in method respectively. For hard shut-in method, the blowout preventer and choke valve were closed after the pump was turned off. On the other hand, the choke valve was opened while closing the blowout preventer in the soft shut-in method.

After the pump was turned off, the blowout preventer could be closed to shut the well in. When hard shut-in method was applied, the blowout preventer was closed right after the pump was turned off. This had stopped the increment of the volume of pit gain once the blowout preventer was fully closed. After allowing the pressure to equalize, the kick could be circulated out to the surface. The pump was turned on with a low rate of 100 gallons per minute and choke was opened in order to start the circulation process. The volume of pit gain increased as the kick started to circulate out due to migration and expansion of the kick. Furthermore, maximum volume of pit gain was experienced when the kick reached the surface. The maximum volume of pit gain was approximately 30 barrels when hard shut-in method was applied. When the kick was flowed out to the surface, the pit gain volume was decreased. Then, the kick was fully circulated out when the volume of pit gain returned to zero. After that, the drilling process could be continued after pumping the kill mud into the well.

On the other hand, the volume of pit gain was higher when soft shut-in method was applied after the well was shut-in. This was due to the different steps were applied in soft shut-in method. After the pump was turned off, the choke was opened while closing the blowout preventer. The choke was opened in order to reduce the water hammer effect. After the blowout preventer was closed successfully, the choke was closed. Thus, it resulted in an increment of volume of pit gain when the well was shut-in successfully. The difference between two methods in term of pit gain was approximately 3 barrels. As the kick was circulating up before it reached the surface, there was an increment in the volume of pit gain due to migration and expansion of free gas. This resulted in the higher volume of pit gain when it reached the surface. The difference of the maximum volume of pit gain between two methods was approximately 6 barrels. Moreover, the pit gain volume reduced as the kick was circulating out to the surface. The pit gain volume returned to zero when the kick was fully circulated out.

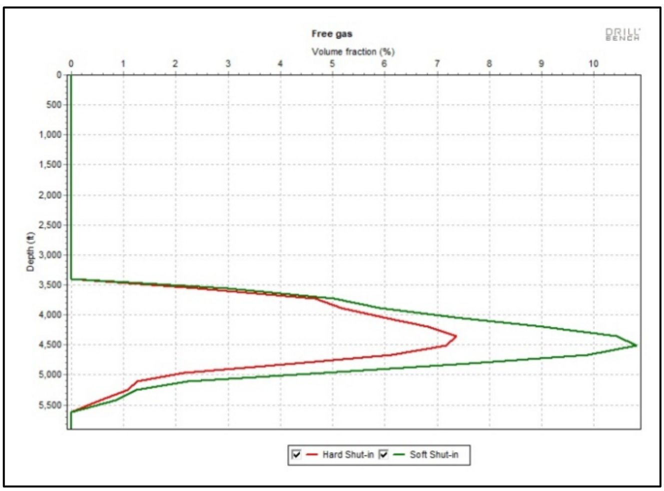

Fig. 2. Volume fraction of free gas

After the well was shut-in, the influx was started to circulate out. Based on the figure above, the red line refers to hard shut-in method while the green line indicates the soft shut-in method. As mentioned earlier, soft shut-in method allowed more influx to flow into the wellbore due to the opening of choke. Therefore, there was some difference in terms of the volume of free gas for both shut-in method. For instance, the volume fraction of gas was 7.1 % at the depth of 4500 ft in hard shut-in method while the volume fraction was 10.8 % at the depth of 4500 ft in soft shut-in method. As the influx was circulating out, the influx migrated and expanded as the gas was flowing up. This caused the increment of the gas fraction for both methods. The volume fraction of free gas returned to 0% when the influx was fully circulated out.

Figure below shows the volume fraction of dissolved gas plotted against depth in water-based mud for two shut-in methods respectively. The volume fraction of dissolved gas remained at 0% all the time from the beginning until the end of the circulation process regardless of which type of shut-in methods were applied. This was because the type of based mud was the factor that would affect the volume of dissolved gas. The influx would not dissolve with water-based mud which caused no increment in terms of the volume of dissolve gas.

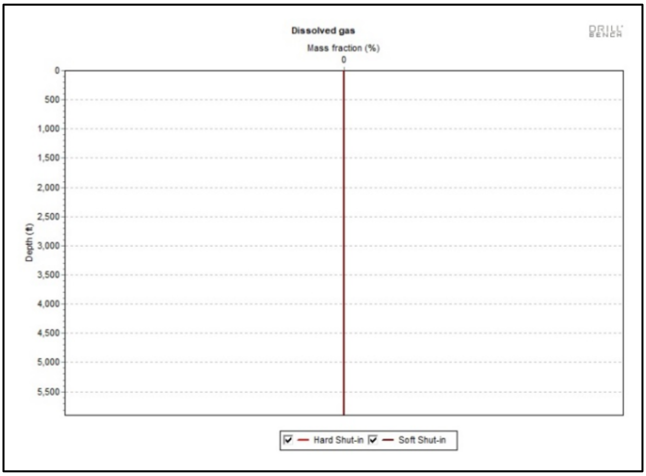

Fig. 3. Volume fraction of dissolved gas

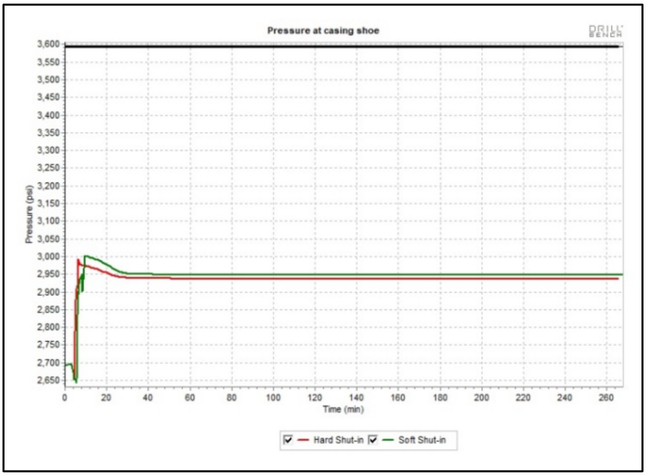

Fig. 4. Pressure at the casing shoe

Figure above shows the graph of pressure at the casing shoe plotted against time. The line in red shows the pressure at the casing shoe when hard shut-in method was applied whereas the line in green shows the pressure at the casing shoe when soft shut-in method was applied. Other than that, the black line shows the fracture pressure of the casing shoe. In this simulation study, the fracture pressure of the casing shoe was at approximately 3600 psi.

The pressure at the casing shoe was higher after the well was being shut-in when hard shut-in method was applied. This was due to the water hammer effect because of direct closure of the blowout preventer after the pump was turned off. However, as the influx was started to circulate out, the pressure at the casing shoe was higher when soft shut-in method was applied. This was due to higher volume of influx in the wellbore. The pressure at the casing shoe would be affected by the column before the casing shoe. Therefore, as the influx was passed through the casing shoe, the pressure at the casing shoe was remained constant throughout the circulation process for both shut-in methods.

4.2. Comparison study of hard shut-in method and soft shut-in method with oil-based mud

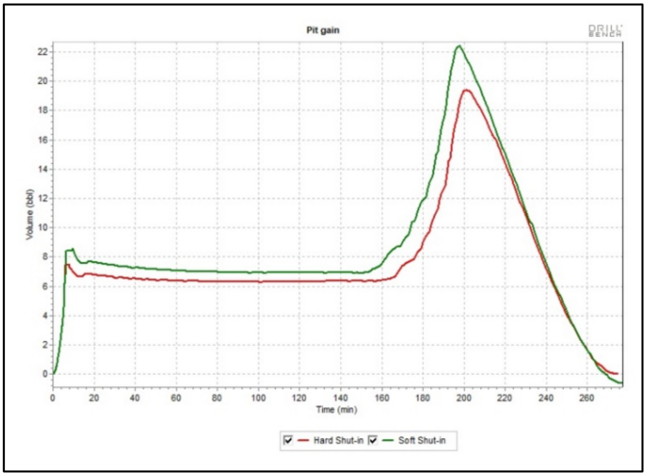

Fig. 5. Volume of pit gain plotted vs time

Figure above shows the pit gain volume plotted against time after the circulation process. The red line indicates hard shut-in method whereas the green line indicates the soft shut-in method. As mentioned in the previous section before, the pump and blowout preventer took times to turn off and close which caused the increment in terms of the pit gain level. The delay in closure time caused more influx to flow into the wellbore. The pit gain stopped to increase when the pump and blowout preventer were fully closed.

When hard shut-in method was applied, the blowout preventer was closed right after the pump was turned off. Therefore, the volume of the pit gain was lower. The difference in terms of the pit gain volume among two methods is approximately 1 barrels. The curve of the graph obtained above was different as compared to the graph obtained when water-based mud was being used. When water-based mud was being used, the pit level increased right after the circulation process started. However, in the cases when the oil-based mud being used, the gas tended to dissolve inside the oil-based mud. Thus, the pit gain level experienced a slightly decrement when the circulation process started. After sometimes, the pit gain volume increased when the bubble point reached. The increment was due to the dissolve gas break through the bubble point from the oil-based mud and exist as free gas. Free gas tended to expand and migrate throughout the circulation process. It resulted in the higher volume of pit gain when it reached the surface. The difference of the maximum pit gain volume between two shut-in method was approximately 3 barrels. The pit gain volume was then decreased when the influx flow out from the wellbore and dropped back to 0 when all the influx had been circulated out successfully.

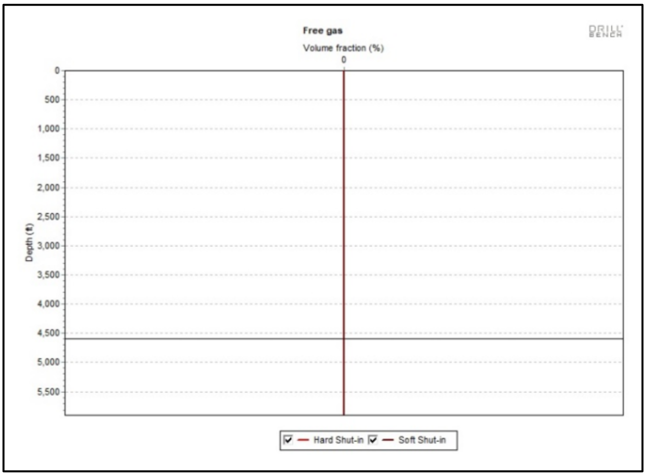

Fig. 6. Volume fraction of free gas before bubble point

Figure above shows the volume fraction of free gas plotted against depth when the influx was first entered the well from the formation. In this simulation, the type of mud was oil-based mud. As mentioned earlier, the influx tended to dissolve in the oil-based mud. This was the reason why it never causes any increment in the volume of pit gain. Therefore, the volume fraction of free gas remained at 0% until it reached the bubble point pressure.

When the bubble point has reached, free gas was detected. This caused the sudden increment in the volume of pit gain. Due to the difference in terms of the influx volume flowed into the wellbore, the volume of free gas detected were different. As stated in the previous case, soft shut-in method tended to allow more influx to flow into the wellbore as compared to hard shut-in method. Therefore, the amount of free gas detected in soft shut-in method was higher. Moreover, the gas volume returned to 0% when the influx was fully circulated out from the well.

As the kick was detected, the volume fraction of free gas increased. In the previous case when water-based mud was being used, there was no increment in the dissolved gas. However, there was an increment in the dissolved gas due to the gas solubility in oil-based mud. Figure below shows the graph of volume of dissolved gas plotted against the depth while circulating the gas out to the surface. The volume of dissolved gas decreased as it was approaching the bubble point. This was due to some of the gas tended to become free gas after it reached the bubble point. As the influx was circulated out successfully, the volume of dissolved gas returned to 0%.

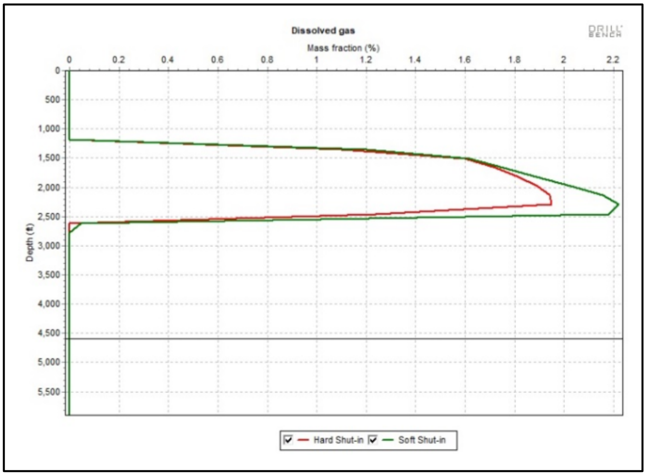

Fig. 7. Volume of dissolved gas while circulating

Figure below shows the pressure at the casing shoe when the pit gain reached 3.5 barrels. The black color horizontal line shows the fracture pressure at the casing shoe which is at 3600 psi. As the pit gain level increased, the pressure at the casing shoe remained constant for both types of shut-in methods. This was due to the gas tended to dissolve inside the mud which did not affect the pressure at the casing shoe. The pressure at the casing shoe can be calculated by the addition of the hydrostatic pressure of the mud column and influx below the casing shoe.

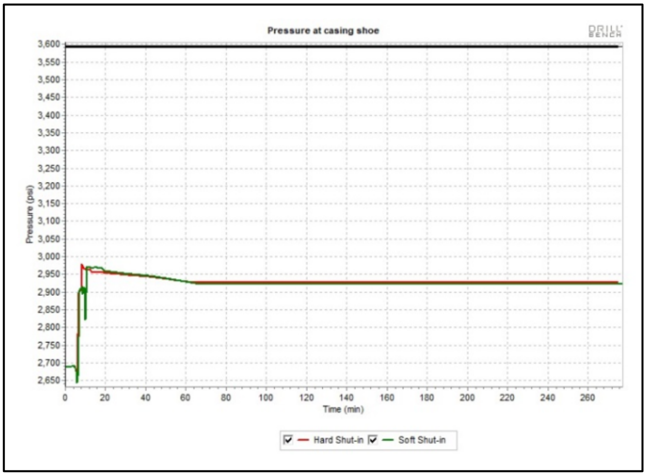

Fig. 8. Pressure at the casing shoe

4.3. Second circulation

In the simulation model, the true vertical depth was 5905.5 ft with the mud weight of 10.849 ppg. Besides, the shut-in drill pipe pressure can be obtained from the output which is 282.83 psi. After applying the equation, the kill mud weight will be 11.77 ppg. The kill mud was circulated into the well after the kill mud weight was calculated. Then, the kill mud was pumped into the wellbore.

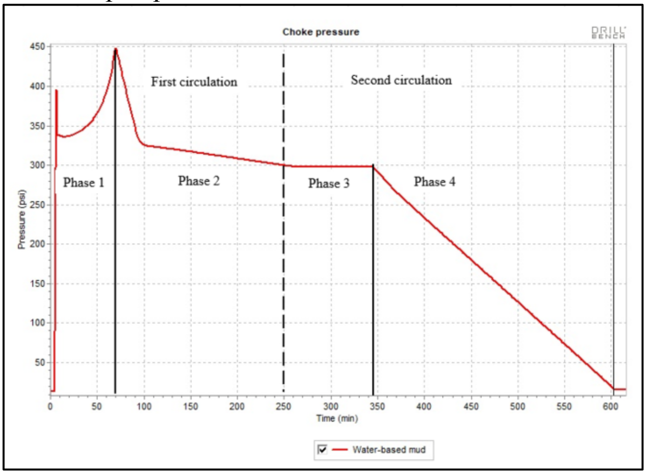

Fig. 9. Choke pressure in water-based mud

In Driller's method, it requires two circulations and there are two phases in each circulation method. Based on the figure above, it shows the choke pressure plotted against time in water-based mud. In the first phase, the kick was travelling to the choke which caused the increment in terms of the choke pressure because more backpressure was needed. The choke pressure decreased when the influx reached the choke. This was due to lesser backpressure was needed as the influx was flowing out from the well. Then, the choke pressure remained constant before the kill mud reached the annulus in the second circulation. The choke pressure experienced reduction when the kill mud started to flow into the annulus until it reached the surface.

Figure below refers to the graph of choke pressure plotted against time in oil-based mud. In phase 1, the kick was travelling from the wellbore to the surface which caused the choke pressure to increase. As the influx was circulating out from the well, the choke pressure reduced because less backpressure was required. First circulation was finished after the influx was fully circulated out. In the second circulation, kill mud was pumped into the well. As the kill mud was pumping down, the casing pressure remained constant because the annulus was still full of the original mud. Then, the choke pressure reduced in phase 4 happened when the kill mud reached the bit and started to flow to the annulus. The kill mud was said to be at the surface when the choke pressure reduced to zero.

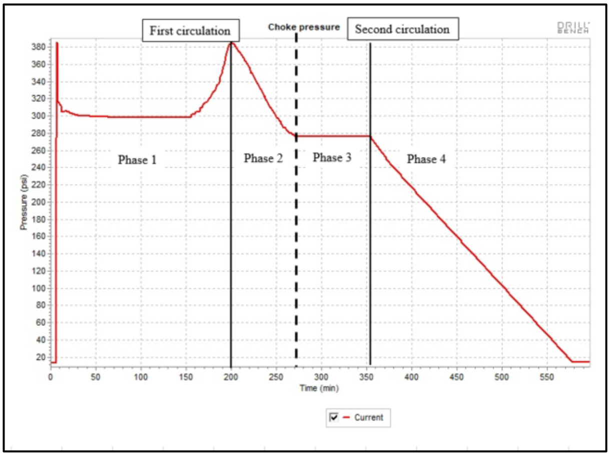

Fig. 10. Choke pressure in oil-based mud

5. Conclusion

Based on the results, the differences of the pit gain volume between two shut-in methods are 3 and 1 barrels in the case of water-based mud and oil-based mud respectively. However, the volume of pit gain increased due to the gas expansion and migration when the influx was circulating up to the surface. In addition, two of the shut-in methods did not cause fracture in the pressure at the casing shoes.

Table 3. Comparison of both shut-in methods in water-based mud

	Hard Shut-in	Soft Shut-in
Pit gain volume after the well was shut-in (bbl)	8	11
Maximum pit gain volume (bbl)	30	38
Presence of free gas?	Yes.	
Presence of dissolved gas?	No. The gas will not dissolve in water-based mud.	

Table 4. Comparison of both shut-in methods in oil-based mud

	Hard Shut-in	Soft Shut-in
Pit gain volume after the well was shut-in (bbl)	7.5	8.5
Maximum pit gain volume (bbl)	19	22
Presence of free gas?	Yes, there will be free gas when the bubble point reaches	
Presence of dissolved gas?	Yes	

Moreover, the pit gain volume in water-based mud will increase directly after the circulation is started regardless of the types of shut-in method. This is due to the gas expansion and migration. On the other hand, pit gain volume in oil-based mud will not increase directly after the circulation process has been started because the gas influx tends to dissolve in the mud. The pit gain volume will increase the bubble point has been reaches. Apart from that, second circulation can be proceeded by pumping the kill mud into the well before the drilling operation can be resumed.

Table below shows the summary of the results obtained from the simulation software for both types of the mud system.

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