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A Comparative Study Between the Driller's Method and the Reverse Driller's Method Used in Drilling Operations

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Abstract

Maintaining pressure within the wellbore to avoid the uncontrolled flow of formation fluids is essential, and this process is known as well control. When there is an influx during drilling, different techniques are employed to maintain well control. The Driller's Method and Wait and Weight Method are common conventional methods used in the drilling industry due to their effectiveness and adaptability. One of the limitations of these two methods is when having a kick size exceeding the kick tolerance. In order to ensure the safety and integrity of a well in such conditions, it is imperative to explore alternative methods for managing large influxes of formation fluids that may occur during drilling operations. One promising approach involves implementing a reverse well control operation, which would enable the circulation of such influxes from the wellbore without compromising the integrity of the well. By reversing the flow of fluids from the wellbore and diverting them inside the strongest pipe from the beginning, the annulus pressures will be lower. This method can effectively manage and control huge influx sizes without exposing the annulus to high pressures. This paper does a detailed comparison between the Driller's Method and Reverse Driller's Method.

Keywords: *Well Control; Reverse Driller's Method; Driller's Method; Kick; Blowout.*

1. Introduction

Well control is a crucial aspect of drilling operations that involves managing the pressure inside the wellbore to prevent uncontrolled releases of formation fluids. In the event of an influx of formation fluids, it is necessary to implement effective killing methods to control the well and prevent blowouts that can pose a significant risk to human life, equipment, and the environment [1].

Killing methods involve techniques that enable the safe and controlled circulation of formation fluids from the wellbore, preventing the fluids from escaping uncontrollably. Proper implementation of killing methods ensures the integrity and safety of the well, as well as the personnel and equipment involved in drilling operations. Therefore, understanding and utilizing effective killing methods is essential to mitigating the risks associated with well control and conducting safe, sustainable, and efficient drilling operations [2].

1.1. Driller's method

The Driller's method is a conventional well control technique widely used in the drilling industry to control the pressure inside the wellbore. This method involves carefully monitoring and adjusting the weight of the drilling fluid to balance the pressure inside the wellbore with that of the formation being drilled [3].

The Driller's method is a well-established well control technique that involves two distinct and complete circulations of drilling fluid within the well [4]. During the first circulation, the influx is expelled from the annulus using the mud density that was present in the well at the onset of the kick. The casing pressure is maintained at a constant level until the pump reaches the kill rate, at which point the drillpipe pressure is stabilized to ensure that the bottomhole pressure remains either equal to or slightly greater than the formation pressure [5].

The second circulation involves the maintenance of a constant choke pressure during the displacement of the drillstring with kill mud. Finally, the standpipe pressure is maintained at a constant level until the annulus is filled with kill mud. By following these procedures, the Driller's Method can effectively manage wellbore pressure during drilling operations and prevent uncontrolled releases of formation fluids [6].

1.2. Wait and weight method

The Wait and Weight method is a widely used well control technique that involves a single and complete circulation of kill mud within the well. This method is also called "Engineer's Method" [3,7].

Following a kick in a well, the well must be shut-in until the kill mud can be weighted up to the required density in the mud pits. Subsequently, the kill mud is circulated into the well, thus displacing the influx. Throughout this process, it is crucial to maintain the bottomhole pressure slightly greater than the pore pressure. The casing pressure is maintained at a constant level until the pump reaches the kill rate. This method involves the maintenance of a stepdown to standpipe pressure during the displacement of the drillstring with kill mud. Finally, the standpipe pressure is maintained at a constant level until the annulus is filled with kill mud [8].

The Wait and Weight method has the advantages of lower annulus pressures. It reduces the chance of fracturing the shoe in case of the drillstring volume is smaller than the open hole annulus volume [9-10].

Conventional well control techniques, such as the Driller's method or the Wait and Weight method, have gained significant traction in the drilling industry due to their efficacy and adaptability. These methods have become widely accepted and are utilized to manage a variety of well control scenarios [11].

1.3. Modified Wait and Weight method

One of the disadvantages of the Wait and Weight Method is that the increase in mud weight necessitates adjustment of the drill pipe pressure to maintain a constant bottom-hole pressure. Thus, it is crucial to perform calculations to determine the pumping schedule required for this purpose. To minimize the number of calculations involved, a modified version of the Wait and Weight method, called the "Modified Wait and Weight method" or "Constant Casing Pressure, Constant Drill Pipe Pressure Wait and Weight method," has gained popularity. The only difference between this method and the original one is that the casing pressure is maintained at a constant level until the weighted mud reaches the bit, which is equal to the initial shut-in casing pressure plus the hydrostatic pressure of the drillstring volume when it is in the annulus. Once the weighted mud reaches the bit, the drill pipe pressure is recorded and maintained at a constant level until the influx has been entirely displaced [8,12].

1.4. Overkill Wait and Weight method

The overkill Wait and Weight method is another modified version of the Wait and Weight method that involves using a mud density greater than the calculated kill mud weight, which reduces the casing shoe pressure by the difference between the two weights. However, it is crucial to consider the maximum practical density that can be used to avoid a vacuum on the drill pipe [13].

Despite the use of higher mud densities, both the Driller's Method and the Wait and Weight method have the same effect on the annulus pressure during the displacement of the drill string, regardless of the density of the kill mud weight used in the overkill Wait and Weight method. After the displacement of the drill string volume, this casing shoe pressure is the maximum pressure it can face during the killing operation. Then casing shoe pressure decreases [14].

One of the most common causes of failure of the overkill Wait and Weight method is the improper consideration of the reduction in drill pipe pressure resulting from the increased density. However, despite this potential danger, the overkill Wait and Weight method can be a viable and effective alternative in situations where casing shoe pressures approach fracture pressures and the risk of an underground blowout exists. By carefully monitoring and adjusting the drill pipe pressure, this method can help regain control of the well, prevent further influxes, and minimize the risk of safety hazards and environmental impact [15-16].

1.5. Reverse circulation method

During the reverse circulation technique, when the bubble is reversed out, the pressure profiles for the drill pipe and annulus are reversed as well. The result is a reduction in annulus pressure compared with the Driller's method and the Wait-and-Weight method. While there are potential hazards associated with this technique, such as bridging the annulus or plugging the bit or drill pipe, industry experience has shown that it can be successful. The industry has not experienced none of these problems when utilizing this new technique [6,8].

2. Mathematical model

The following equations were used for well control calculations:
Pressure at any point (P):

$$P = P_{surface} + P_h \tag{1}$$

Hydrostatic pressure:

$$P_h = \sum_{j=1}^{n} 0.052 * Fluid\ Weight_j * TVD_j \tag{2}$$

Formation pressure (P_f):

$$P_f = SIDPP + 0.052 * OMW * TVD \tag{3}$$

$$P_f = SICP + 0.052 * OMW * TVD_{mud} + influx\ gradient * TVD_{influx} \tag{4}$$

Kill mud weight (KMW): by dividing Equation (3) by $(0.052 * TVD)$

$$KMW = \frac{SIDPP}{0.052 * TVD} + OMW \tag{5}$$

Initial circulating pressure (ICP) in normal circulation:

$$ICP = SIDPP + RRCP \tag{6}$$

Final circulating pressure (FCP) in normal circulation:

$$FCP = RRCP * \frac{KMW}{OMW} \tag{7}$$

Initial circulating pressure (ICP) in reverse circulation:

$$ICP = SICP_i + 100 \tag{8}$$

Median circulating pressure (MCP) in reverse circulation:

$$MCP = SIDPP_i + 100 \tag{9}$$

Final circulating pressure (FCP) in reverse circulation:

$$FCP = 100 * \frac{KMW}{OMW} \tag{10}$$

3. Methods

3.1. Circulation path

3.1.1. Normal circulation killing methods

Conventional well control methods involve pumping mud down the drill pipe and up the annulus to circulate the well, as shown in Figure 1.

3.1.2. Reverse circulation killing methods

Reverse circulation is a Killing technique that involves pumping the drilling fluid in the opposite direction of normal drilling. This technique entails pumping the drilling fluid through the annulus down to the bottom of the hole. From there, the mud bypasses the bit and enters the drillstring through a circulating sub located just above the bit. Finally, the mud travels back to the surface through the drillstring, as illustrated in Fig. 2.

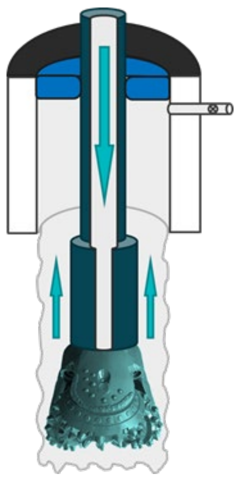


Fig. 1. Conventional well control methods.

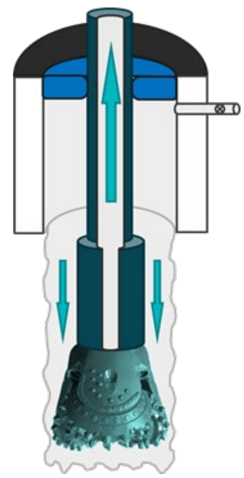


Fig. 2. Reverse circulation well control method

3.2. The line-up of the standpipe manifold

3.2.1. Normal circulation killing methods

During normal circulation through the drillstring, the standpipe should be connected to the mud pumps, as illustrated in Fig. 3. When taking a kick and starting to kill the well with conventional methods, the lineup of the standpipe manifold should not be altered.

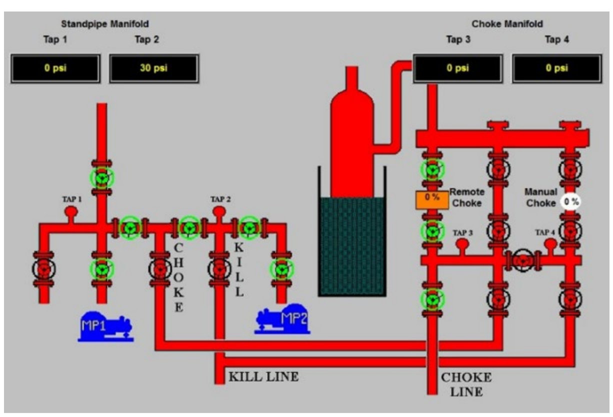


Fig. 3. Choke and standpipe line-up for normal circulation method [17].

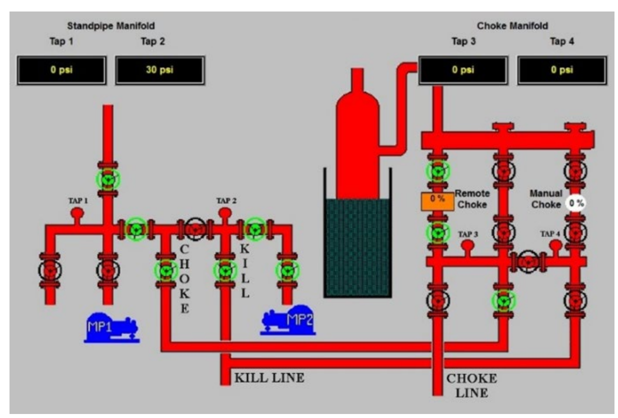


Fig. 4. Choke and standpipe line-up for reverse circulation method [17].

3.2.2. Reverse circulation killing methods

In reverse circulation killing methods, as illustrated in Fig. 4, the lineup of the standpipe manifold should be adjusted. The standpipe should be connected to the choke manifold. Since the return comes from the standpipe, all valves that connect the standpipe with the pumps should be closed.

To implement this method, it is necessary to connect the pumps to the kill line located below the ram BOP. All valves in this path should be opened to allow for the proper flow of fluids. It is crucial to note that only one pump can be operated in this configuration, as turning on the other pump can lead to its burnout or an increase in the pressure in the annulus, depending on the position of the valve connected to the discharge of the pump.

3.3. The line-up of the choke manifold

3.3.1. Normal circulation killing methods

During normal killing methods, the influx is circulated out of the well through the annulus. As a result, all valves connecting the choke line with the choke manifold should be opened, as illustrated in Fig. 3.

3.3.2. Reverse circulation killing methods

In Reverse Circulation Killing Methods, the choke manifold should be lined up as illustrated in Fig. 4. The valve in the choke line should be closed since the pump is connected to the annulus. As the return comes from the standpipe, all valves that connect the standpipe with the choke should be opened.

3.4. Blowout preventer (BOP)

3.4.1.Normal circulation killing methods

The ram BOP should be closed when the well takes in an influx. The HCR should be opened to read the pressure in the annulus, as illustrated in Fig. 5. None of the line-ups of the standpipe manifold, choke manifold, or BOP should be altered when starting the killing operation.

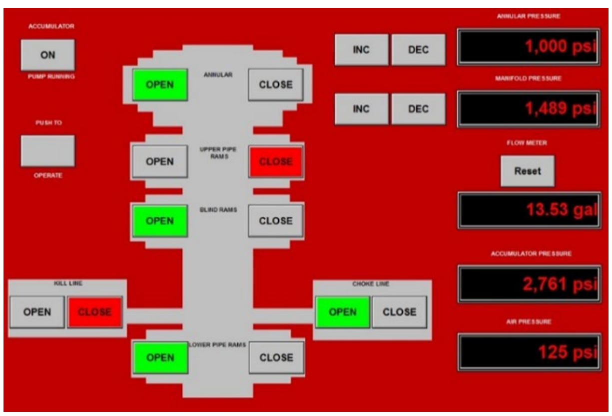


Fig. 5. BOP Line-up for normal circulation method [17].

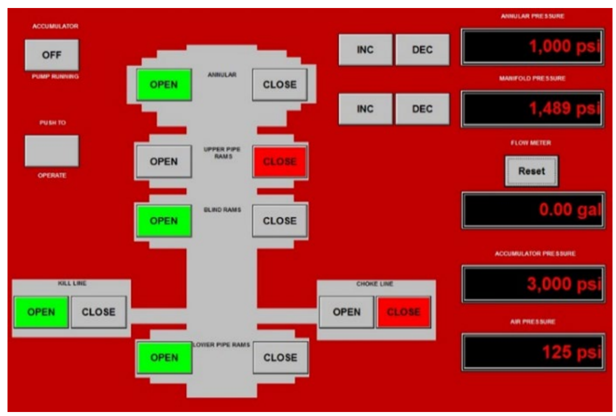


Fig. 6. BOP Line-up for reverse circulation method [17].

3.4.2. Reverse circulation killing methods

Regarding the line-up of the BOP, as shown in Fig. 6, the ram BOP should remain closed to contain surface pressure to balance bottomhole pressure. As the fluid is pumped through the annulus, the kill line should be opened. The HCR should be closed since the return comes from the standpipe. The focus of this study is on the Driller's Method, including both normal and reverse circulation techniques.

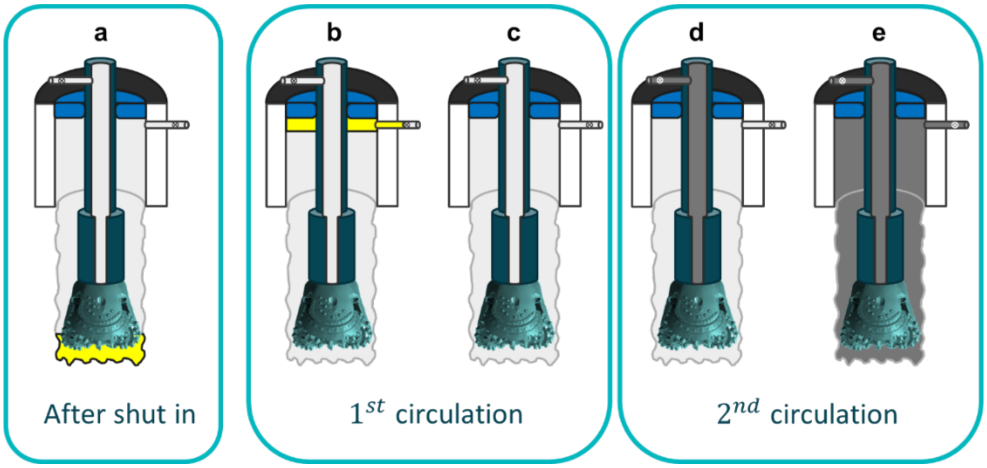
3.5. Stages of each method

3.5.1. Driller's method

This procedure can be divided into four stages as illustrated in Fig. 7.

3.5.2. Reverse Driller's method

The procedure can be divided into five stages as illustrated in Fig. 8.



a. After shutting in

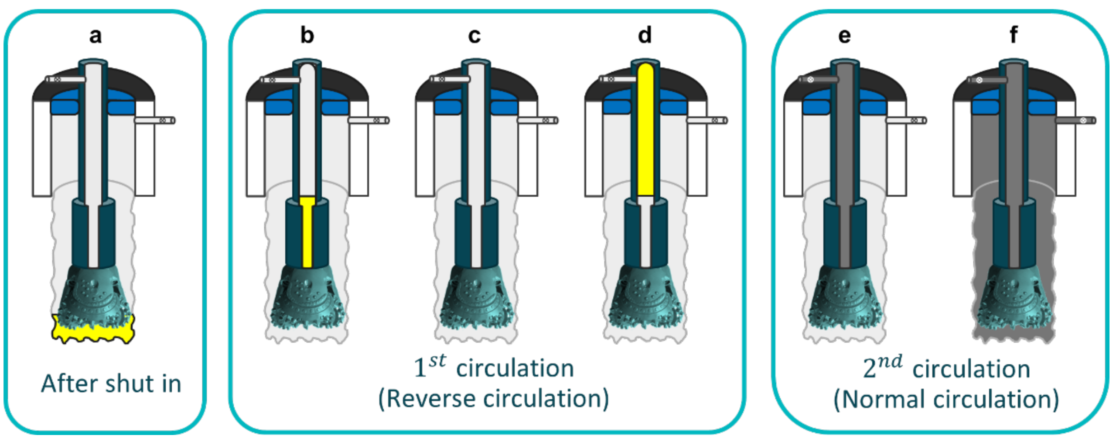
b. Stage I: Circulating the influx to surface.

c. Stage III: Fill drillstring with heavy mud.

d Stage II: Discharging influx.

e Stage IV: Fill annulus with heavy mud.

Fig. 7. Procedure of Driller's method.



a. After shutting in

b. Stage I: Circulating the influx into the drillstring.

c. Stage II: Circulating the influx to surface.

d. Stage III: Circulating the influx out of the well.

e. Stage IV: Circulating kill mud from surface to the bit.

f. Stage V: Circulating kill mud from the bit to surface.

Fig. 8. Procedure of Reverse Driller's method.

4. Results and discussion

4.1. Pump pressure

4.1.1. Driller's method

During the first circulation, the influx is circulated up through the annulus. In both Phase 1 and Phase 2, the original mud is pumped through the drillstring. Therefore, the pump pressure should be kept constant at the initial circulating pressure (ICP) as depicted in Fig. 9.

During the second circulation, the drillstring is displaced by the heavy weight kill mud in Phase 3. So, the pump pressure will decrease in steps till reaching the final circulating pressure

(FCP) at the end of that phase. Finally, pump pressure will remain constant at FCP as the drillstring is full of kill mud.

4.1.2.Reverse Driller's method

The pump pressure equals the initial SICP plus approximately 100 psi during Phase 1 as illustrated in Fig. 10. At the end of that phase, the value of overbalance equals the difference between the initial SICP and the initial SIDPP. The surface casing pressure should be decreased by this value to reduce the high overbalance. During 2 and 3, the surface pressure exerted on the casing remains constant because the annulus is full of original mud. In Phase 4, the surface pressure starts to decrease as a result of displacing the annulus with kill mud. Finally, it remains constant again during Phase 5 as the annulus is full of kill mud.

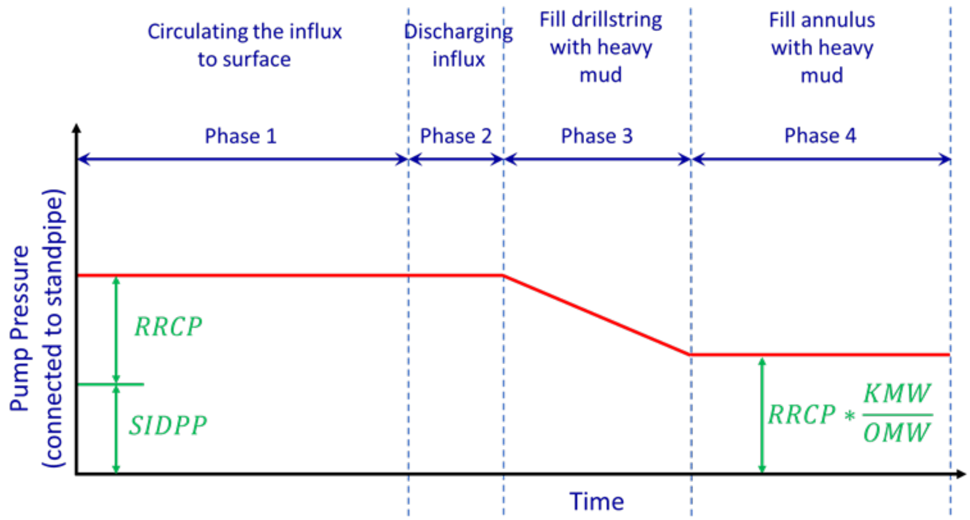


Fig. 9. Pump pressure versus time (for the Driller's method).

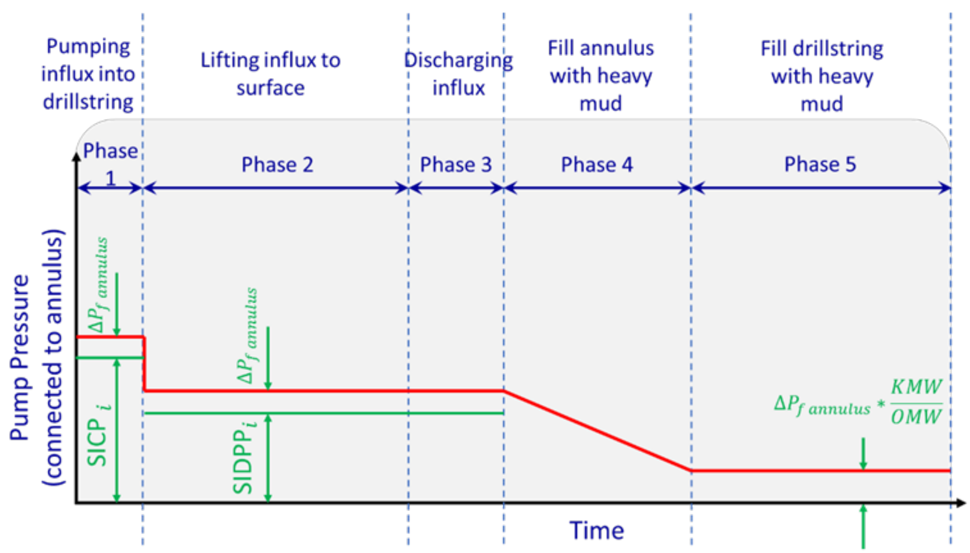


Fig. 9. Pump pressure versus time (for the Reverse Driller's method).

4.2. Choke pressure

4.2.1. Driller's method

During the first circulation, the influx is circulated up through the annulus. In Phase 1 to maintain a constant bottomhole pressure, the pressure of the influx should be decreased. If the influx is gas, its volume will increase as a result of pressure decrease. This will lead to a reduction in the hydrostatic head in the annulus. Therefore, the choke pressure will increase gradually, as illustrated in Fig. 11. In Phase 2, the influx is displaced out of the well through the annulus. As a result, the choke pressure will decrease until reaching the initial Shut in Drillpipe Pressure (SIDPP).

During the second circulation, the kill mud is pumped through the drillstring. In Phase 3 the annulus is full of the original mud, so the choke pressure will remain constant. On the other hand, in Phase 4, the kill mud displaces the annulus. As a result, the choke pressure will decrease until reaching zero at the end of this stage.

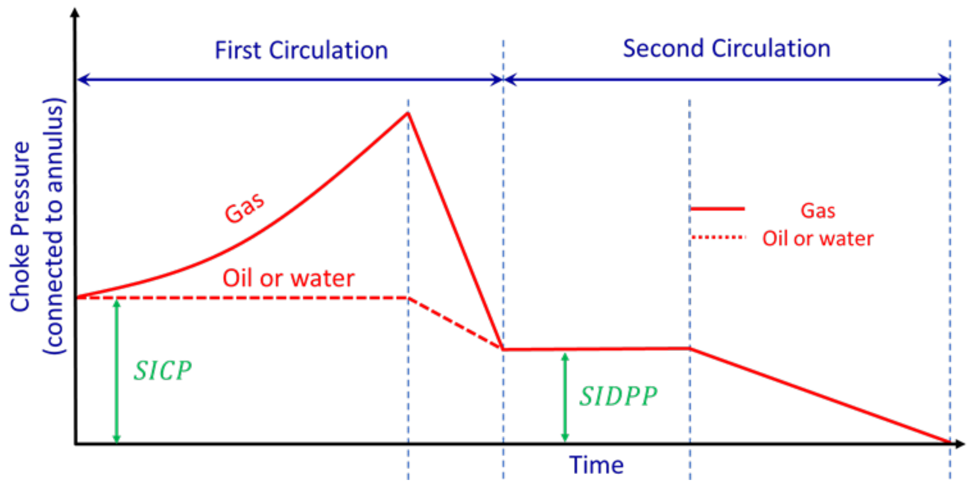


Fig. 10. Choke pressure versus time (for the Driller's method).

4.2.2. Reverse Driller's method

On the other hand, the influx is circulated in the drillstring and up through it to the surface. During the first circulation, the choke pressure will increase rapidly as the influx is circulated into the drillstring. As the drillstring capacity is much smaller than the annulus capacity, the height of influx in the drillstring is much larger than in the annulus. As a result, at the end of Phase 1, the choke pressure exceeds the value of initial SICP by a large value. Then, this pressure is reduced by the difference between the initial SICP and the initial SIDPP to reduce the overbalance, as shown in Fig. 12. During Phase 2, the choke pressure is increased gradually as the influx is circulated to surface. In phase 3, the influx is circulated out of the well through the drillstring. Therefore, the choke pressure will decrease dramatically.

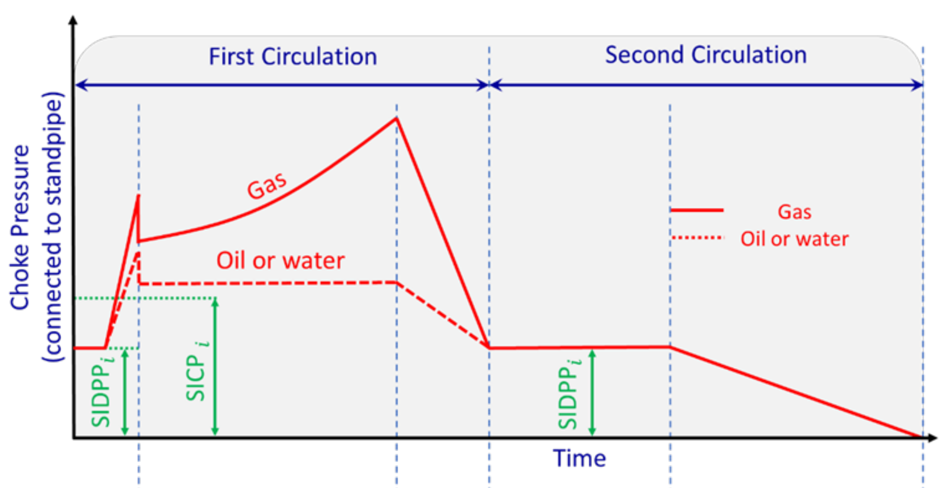


Fig. 11. Choke pressure versus time (for the Reverse Driller's method).

During the second circulation, it remains constant as the drillstring is full of the original mud in Phase 4. Finally in Phase 5, it diminishes to zero as the drillstring is displaced by kill mud.

4.3. Casing pressure

By combining Fig. 10 and Fig. 11, the result is Fig. 13. As shown in Fig. 13, the surface casing pressure for the normal Driller's method is higher than that of the Reverse Driller's method. As a result, the annulus is subjected to lower pressures when killing with the Reverse Driller's method. As shown in Fig. 13, the time required to kill the well by the Reverse Driller's method is lower than that of the Driller's method. The difference between t_2 and t_1 is calculated by:

$$t_2 - t_1 = \frac{Annulus\ volume\ (bbl) - Drillstring\ volume\ (bbl)}{Pump\ output\ \left(\frac{bbl}{min}\right)} \qquad (11)$$

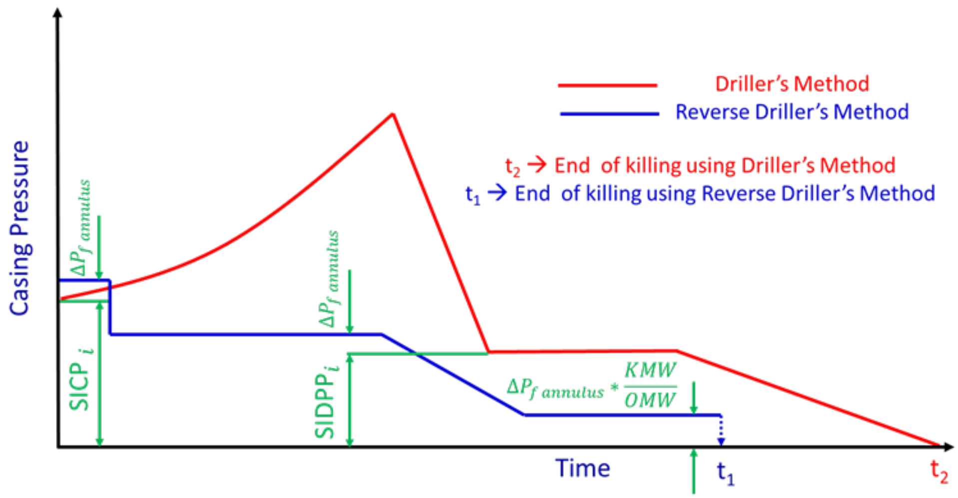


Fig. 12. Casing pressure for Driller's method and Reverse Driller's method.

4.4. Drillpipe pressure

By combining Fig. 9 and Fig. 12, the result is Fig. 14. As shown in Fig. 14, the surface drillpipe pressure for the normal Driller's Method is lower than that of the Reverse Driller's Method. As a result, the drillstring is subjected to higher pressures when killing with the Reverse Driller's Method. The worst case in the Reverse Driller's Method is the drilling hose failure as it is the weakest part in the system.

Fig. 13. Drillpipe Pressure for Driller's method and Reverse Driller's method.

4.5. Casing shoe pressure

4.5.1. Driller's method

During Phase 1, casing shoe pressure will increase as the influx is circulated up the annulus from the bottom till reaching the shoe. Then, the shoe pressure will decrease as the influx is circulated from the shoe to the surface, as illustrated in Fig. 15. During Phase 2, the hydrostatic head above the shoe increases. On the other hand, the choke pressure decreases by the same value. As a result, the shoe pressure will remain constant. During Phase 3, both the hydrostatic head above the shoe and the choke pressure remain constant. Therefore, the shoe pressure will remain constant. Finally, the shoe pressure will decrease as the kill mud is pumped up through the annulus.

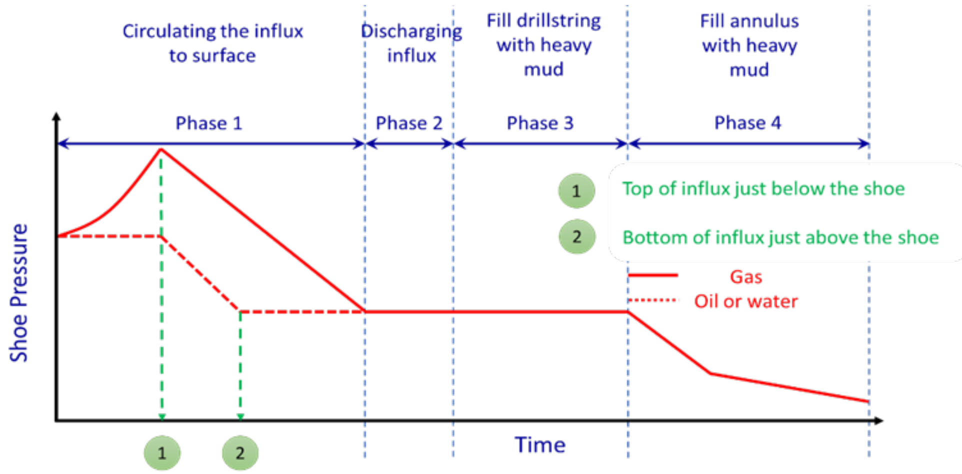


Fig. 14. Shoe pressure versus time (for the Driller's method).

4.5.2.Reverse Driller's method

The maximum shoe pressure occurs after shutting the well in and the pressure stabilizes during the static state. During the dynamic state, this value increased by a small value (i.e., approximately 100 psi). At the end of Phase 1, the value of casing shoe pressure decreases by the difference between the initial SICP and the initial SIDPP. During Phases 2 and 3, it remains constant as the annulus is full of original mud. During the second circulation, as the kill mud is pumped, shoe pressure starts to decrease in Phase 4. Finally, it remains constant again during Phase 5 as the annulus is full of the kill mud, as depicted in Fig. 16.

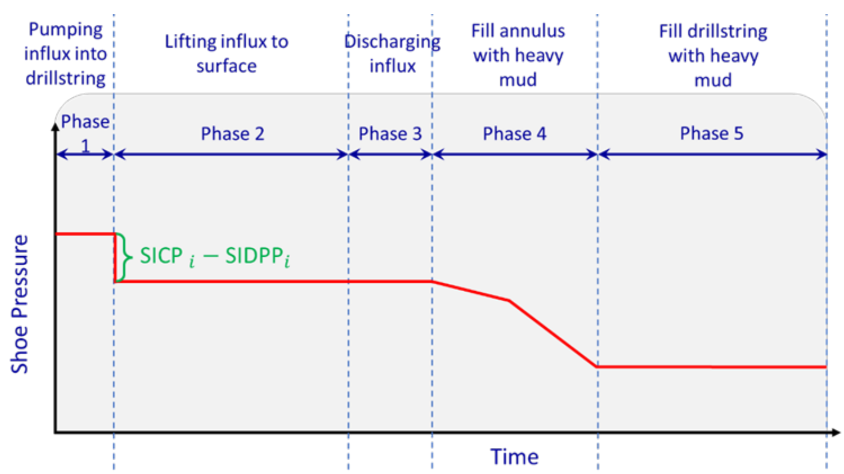


Fig. 15. Shoe pressure versus time (for the Reverse Driller's method)

4.6. Pit gain

4.6.1. Driller's method

During Phase 1, the pit gain increases dramatically as the influx is circulated up of the annulus because the influx height increases with time. During Phase 2, the pit gain decreases rapidly till reaching zero as the influx is circulated out of the well through the annulus. Finally, it remains constant again during Phases 3 and 4 of the second circulation as shown in Fig. 17.

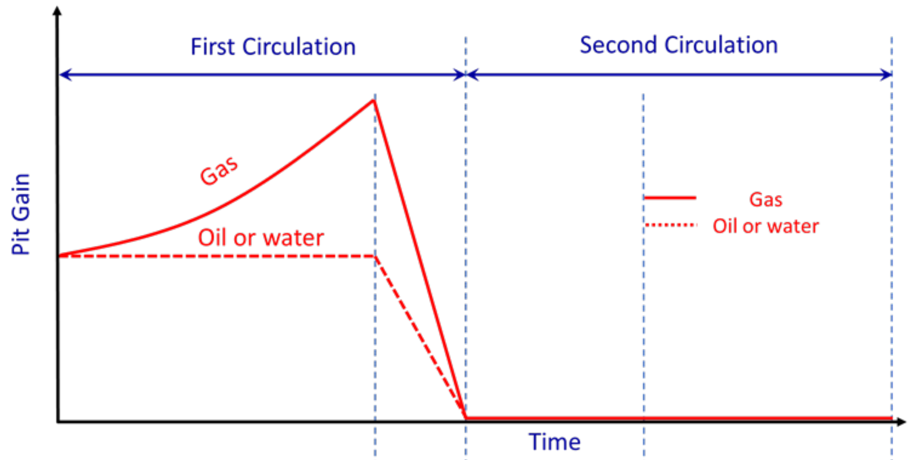


Fig. 16. Pit gain versus time (for the Driller's method).

4.6.2.Reverse Driller's method

Pit gain decreases as the influx enters the drillstring in Phase 1, because of the large increase in drillstring pressure. At the end of Phase 1, the pit gain increases slightly due to the decrease in the overbalance. During Phase 2, the pit gain increases dramatically. During Phase 3, the pit gain decreases rapidly till reaching zero as the influx is circulated out of the well through the drillstring. Finally, it remains constant again during Phases 4 and 5 of the second circulation, as depicted in Fig. 18.

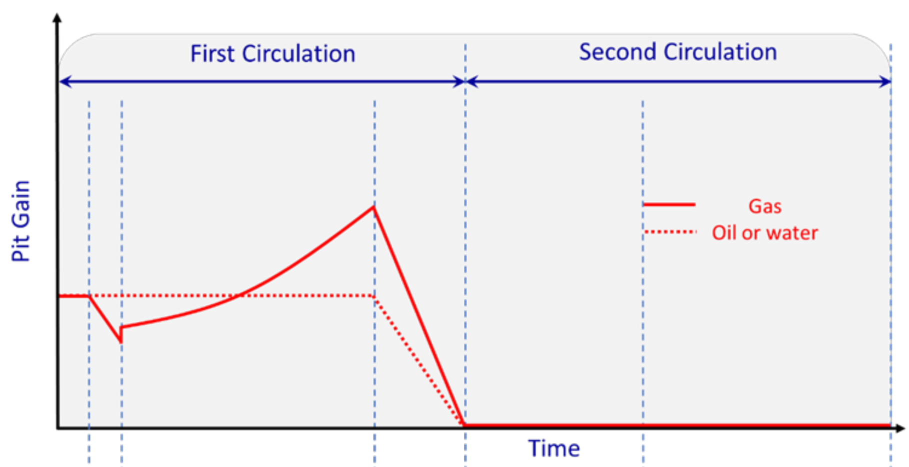


Fig. 17. Pit gain versus time (for the Reverse Driller's method).

4.7. Action Plan

4.7.1.Driller's method

1. When detecting a kick, shut the well in and record pit gain.
2. Record SICP and SIDPP after stabilization.
3. Do kill sheet calculations.

4. Keep choke pressure constant while bringing pump to the kill rate in steps (i.e., 5 SPM in each step).
5. Keep pump pressure constant at the Initial Circulating Pressure (ICP), Equation (6) till the end of the first circulation. $Pump\ Pressure = ICP = SIDPP + RRCP$
6. Start pumping the kill mud with keeping the choke pressure constant till the kill mud reaches the bit.

$$Choke\ Pressure = SIDPP \tag{12}$$

7. Continue pumping the kill mud up the surface and keep the pump pressure constant at the Final Circulating Pressure (FCP), Equation (7). $Pump\ Pressure = FCP = RRCP * \frac{KMW}{OMW}$
8. At the end of the kill and shutting in the well, both SICP and SIDPP should be the same and equal to zero.

4.7.2. Reverse Driller's Method

1. When detecting a kick, shut the well in and record pit gain.
2. Record SICP and SIDPP after stabilization.
3. Do kill sheet calculations.
4. Line up the standpipe manifold, choke manifold and BOP to fit the reverse circulation.
5. Pump original mud and bring the pump to the kill rate in steps (i.e., 5 SPM in each step) keeping the pump pressure constant at the Initial Circulating Pressure (ICP) by adjusting the choke, Equation (8). $Pump\ Pressure = ICP = SICP_i + 100$
6. Keep this pump pressure constant till all the influx enters the drillstring.
7. Reduce the pump pressure to Median Circulating Pressure (MCP) to reduce the overbalance by adjusting the choke, Equation (9). $Pump\ Pressure = MCP = SIDPP_i + 100$
8. Keep this pump pressure constant till all the influx is circulated out of the well.
9. Pump kill mud through the annulus and keep the choke pressure constant till the kill mud reach the bit.

$$Choke\ Pressure = SIDPP_i \tag{13}$$

10. Continue pumping the kill mud to surface and keep the pump pressure constant, Equation (10). $Pump\ Pressure = FCP = 100 * \frac{KMW}{OMW}$
11. At the end of the kill and shutting in the well, both SICP and SIDPP should be the same and equal to zero.

5. Conclusions

This study is concerned with the worst-case condition of any influx. This worst case represents that the influx is gas. In addition is assumes that this gas influx is circulated as a single phase. The major objective of this study is to develop the theory, procedure, and additional equipment needed to carry out a reverse circulation method to prove its applicability.

Pressure increase due to gas expansion has no effect on the annulus side in the Reverse Driller's method. The annulus is subjected to lower pressures when killing with the Reverse Driller's method. The surface drillpipe pressure for the normal Driller's Method is lower than that of the Reverse Driller's method. The worst case in the Reverse Driller's method is the drilling hose failure as it is the weakest part in the system. The Reverse Driller's method Loses more time when changing the standpipe manifold, choke manifold and BOP configuration. On the other hand, the Reverse Driller's method requires less time to kill the well than the normal Driller's method. The highest shoe pressure in the Reverse Driller's method is after pressure stabilization after shutting the well in. On the other hand, the shoe pressure increases during circulation in the Driller's method, reaching its maximum value when the influx is just below the shoe. The Reverse Driller's method gives the lowest pit gain due higher surface pressures. The Reverse Driller's method requires few calculations such as the normal Driller's method, so it is easy to be learned by the drilling crew. The driller or the supervisor has the freedom to kill the well normally or reversely.

Nomenclature

BOP	*Blowout preventer*
HCR	*Hydraulic choke valve*
P	*Pressure*
P_h	*Hydrostatic pressure*
P_f	*Formation pressure*
OMW	*Original mud weight*
KMW	*Kill mud weight*
TVD	*True vertical depth*
RRCP	*Reduced rate circulating pressure*
ICP	*Initial circulating pressure*
MCP	*Median circulating pressure*
FCP	*Final circulating pressure*
SICP	*Shut-in Casing Pressure*
SIDPP	*Shut-in Drillpipe Pressure*
$SICP_i$	*Initial Shut-in Casing Pressure*
$SIDPP_i$	*Initial Shut-in Drillpipe Pressure*
t_1	*End of killing using Driller's Method*
t_2	*End of killing using Reverse Driller's Method*

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