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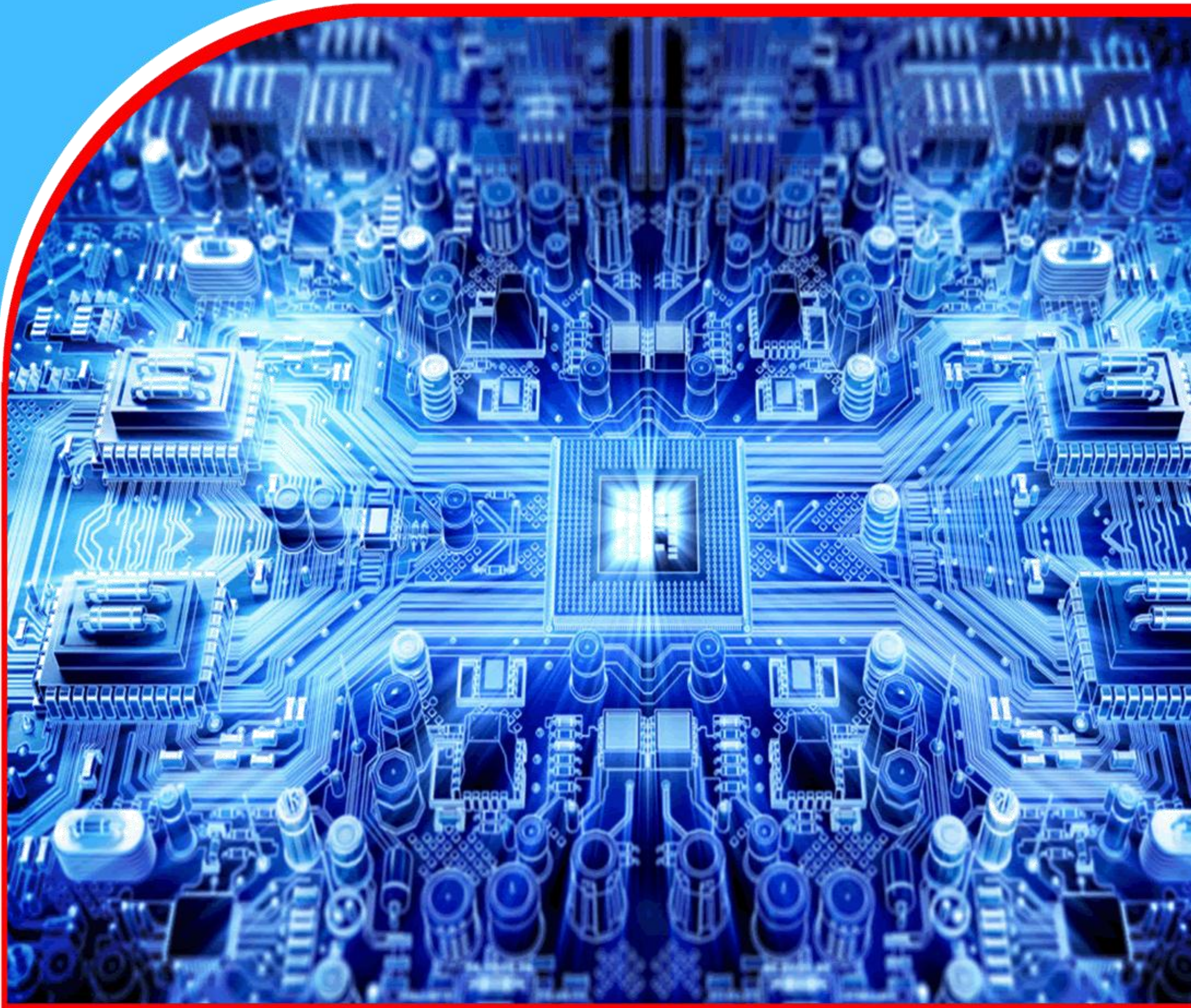

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Understanding the Well Control Procedures for optimizing the Well Control System during Drilling

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Abstract

Well control is an essential part of any drilling operation. Improper well control procedure may result in blowout, and blowouts must be controlled to ensure a smooth drilling operation. The majority of well control incidents occur as a result of a failure to understand the fundamental principles involved. As a result, proper training and understanding are required for a drilling engineer. Every company in the world provides drilling engineers with training and an overview of various well control operations. The goal of taking well control as an engineering project is to think about and visualize the significance of well control in any drilling job. The purpose of this paper was to understand of well control procedures as well as the selection of the most effective well control system. The concurrent technique should only be utilized in exceptional circumstances; in the majority of occasions, the driller method is employed. However, if a suitable casing shoe is available, Wait & Weight method should also be used.

Keywords: *Well control, oil & gas drilling, blowout preventer, artificial intelligence, lost circulation drilling engineering, kick identification*

1.0 INTRODUCTION

Maintaining control over the fluids that occur in the pore spaces of the formations being penetrated by the well is important during the bulk of operations related to drilling, completing, workover and ultimately abandoning a well. Extreme pressures and temperatures can be applied to these fluids in-situ, but these conditions are not necessary for the fluids to cause issues with well control (Khan et al., 2021). If these fluids are not kept under control, they may flow spontaneously and occasionally quickly into the wellbore (Mallah et al., 2021). The degree of pressure imbalance between the wellbore and the reservoir, along with the reservoir's permeability, influence the rate of flow. Such a flow's beginning phase is referred to as a kick. A blowout is the term used to describe when such a flow is uncontrolled and degrades uncontrollably (Salehian et al., 2022).

Blowouts can have a significant negative influence on the environment, which makes them extremely harmful to the operator (Liu et al., 2021). The early phases of a blowout can also be extremely dangerous for workers and seriously harm nearby equipment. Costs associated with control and recovery might range from $10 to $100 million (Muneer et al., 2021). The blowout, however, can also seriously harm the producing reservoir by depleting it and forming preferred water and gas flow routes. Additionally, it may have a secondary effect on the above formation, which could become contaminated or under abnormal pressure. Long after the surface environmental impact has been mitigated, these factors continue to have an impact on operations (Alpak, 2022).

Therefore, it is essential that well engineering staff members understand how to manage this risk through prevention using primary control approaches, control, and recovery - if an underbalanced scenario does develop, how to regulate it and regain primary control (Anfinsen et al., 2021). Secondary control measures are the actions taken to recover control over the primary well. These seek to recover control while having the fewest negative effects on the well's short- and long-term integrity and productivity. And more stringent tertiary well control techniques may be used if these primary and secondary measures are unsuccessful (Ruzhnikov & Yurtaev, 2021).

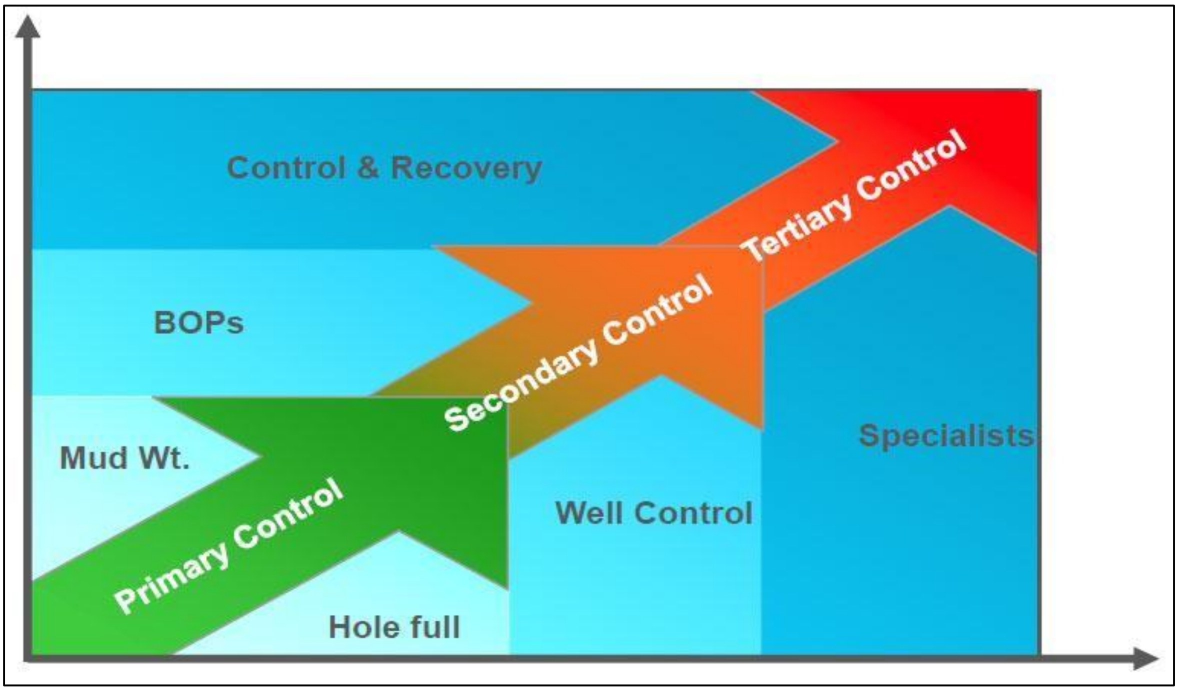


Figure 1: Well control principles (B. Atchison, 2022)

An understanding of various well control activities has been acquired during this investigation. The Driller Method, Wait & Weight Method, Concurrent Method, and Volumetric Method are some of the well control systems that are investigated for this purpose in order to choose the best and most effective well control system.

2.0 DRILLER'S METHOD

After the initial kick response and the formation flow are stopped, a kick must be circulated out of the well to allow ordinary operations to resume (Ashena et al., 2021). To prevent more kicks, the kick must be cycled to the surface while the wellbore pressure is kept constant. The best way to circulate an influx out of the wellbore is frequently highly contested by well control professional (Aarushi & Krishnakanth, 2021). One of the earliest techniques for circulating well kick is the driller's method. It is the simplest approach. A popular kick circulation technique is called the Driller's Method. It practically requires no computations, which makes it useful for use during traditional drilling. In this technique, the elimination of kick requires two circulations (B. W. Atchison & Wuest, 2021). During first circulation, kick is removed from the wellbore using the mud that is already there. Calculations are made, kill sheets are finished, and the mud is weighted up to the necessary kill weight during the first circulation. The original mud is replaced with kill mud in the second loop, and the drilling procedure is continued (. et al., 2021). By keeping the bottomhole pressure constant or, preferable, just above the formation pressure, which is adjusted dependent on the pump pressure, Diller method circulates the kick. To do this, the choke opening is modified (B. W. Atchison, 2021).

2.1 Mud Circulation

The Driller's Method requires two circulations,

2.1.1 First Circulation

The influx is removed during the initial circulation together with the initial mud weight. Recirculation drill pipe pressure is kept constant throughout the first circulation to maintain consistent BHP (Pump the kick out of the well, using existing mud weight).

2.1.2 Second Circulation

The well is put out of service by circulating a heavier mud (kill mud) in a second cycle if the first mud weight is insufficient to balance the formation pressure (Pump the kill mud into the well).

2.2 Steps for Driller's Method

When a kick is detected, calculate the shut-in drill pipe pressure constant (SIDPP) and the shut-in casing pressure constant (SIDCP) (SICP). It is important that. If you are unsure at any point during the procedure, shut down the well, read and record the shut-in drill pipe pressure and shut-in casing pressure, and proceed accordingly. Surface pressures are known to fluctuate slightly due to temperature, gas migration, or gauge issues. The second statement is especially important to remember. When in doubt, close the well! The dominant impulse appears to be to continue circulating regardless of the consequences.

Set the pump rate. Because the mud is not weighted for the first circulation, the pump rate is not limited by the rig's weighting material mixing capacity. However, other factors such as increased SIDPP, the need for choke adjustment, and surface gas handling equipment limit the maximum pump rate. Furthermore, if the choke begins to block off, pressure surges will be less at lower circulating rates (Li et al., 2021).

Bringing the pump to speed without allowing an additional influx or fracturing the casing shoe has proven to be one of the most difficult aspects of any kill procedure. Attempts to achieve a precise kill rate exacerbate the problem. There's nothing magical about the kill rate used to distribute a kick (Abdali et al., 2021). Surface facilities were insufficient in the early days of pressure control to bring an influx to the surface at a high pump speed. As a result, one-half normal speed became the arbitrarily chosen rate for circulating the influx to the surface (Brohi et al., 2021). However, if only one rate is acceptable, such as one-half speed, problems can arise when the pump speed is slightly less or slightly greater than the precise one-half speed. The potential issue stems from the fact that the circulating pressure at rates other than the kill rate is unknown (Cusworth et al., 2021).

Examine ICP (Initial Circulating Pressure), the pressure usually needed on the drill pipe for something like the circulation of the well first time.

$$ICP = P_{SCR} + SIDPP$$

Where,

Initial Circulation Pressure = ICP

Slow Circulation Rate Pressure = P_{SCR}

Shut-in Drill Pipe Pressure = SIDPP

Open the choke about a quarter, start the pump, and stop the circulation. Adjust the choke opening until the choke pressure equals the pressure in the closed-in annulus plus the overbalance margin. Throughout the first circulation, record the choke pressures (Thorogood et al., 2022).

Driller increases pump rate to Kill Rate. The choke operator should keep the casing pressure at or near the shut-in casing pressure (SICP) reading. This step should take no more than 5 minutes (Ahmed & Memon, 2018). One of the most difficult problems in any well control procedure is getting the pump up to speed. Experience has shown that keeping the casing pressure constant at the shut-in casing pressure while bringing the pump up to speed is the most practical approach. Over the five minutes required to bring the pump up to speed, the initial gas expansion is negligible. It is not necessary for the initial volume rate of flow to be exact. Any rate within 10% of the kill rate is acceptable.

This procedure will determine the appropriate drill pipe pressure to use to displace the kick (Francis & Ogbeide, 2021). In practice, the rate can be lowered or raised at any time during the displacement procedure. Simply read and record the circulating casing pressure and keep it constant while adjusting the pumping rate and establishing a new drill pipe pressure (Nedwed & Mitchell, 2021). Because the expansion near the surface is quite rapid, changing the rate should take no more than one to two minutes (Muneer et al., 2021).

Once the pump has reached a satisfactory Kill Rate, the Choke operator should shift his focus to maintaining the initial circulating pressure (ICP) reading on the drill pipe pressure gauge (Muhammad et al., 2022). Displace the influx while maintaining the measured drill pipe pressure constant. ICP should be maintained at a constant throughout the first circulation by adjusting the choke until all of the kick fluid has been circulated out of the well. During the first circulation, the pump rate is held constant to Kill Rate. Record the casing pressure after the influx has been displaced and compare it to the original shut-in drill pipe pressure (SIDPP) recorded in Step 2. It should be noted that if the influx has been completely displaced, the casing pressure should equal the original shut-in drill pipe pressure (SIDPP) (Mallah et al., 2021).

Consider the U-Tube Model in Sketch 1 and compare it to the U-Tube Model in Sketch 2. If the influx has been properly and completely displaced, the conditions in Sketch 1's annulus side are identical to the conditions in Sketch 2's drill pipe side. If the frictional pressure losses in the annulus are negligible, the conditions in Sketch 1's annulus side will be similar to those in Sketch 2. As a result, once the influx has been removed, the circulating annulus pressure should equal the initial shut-in drill pipe pressure (Chagas et al., 2021).

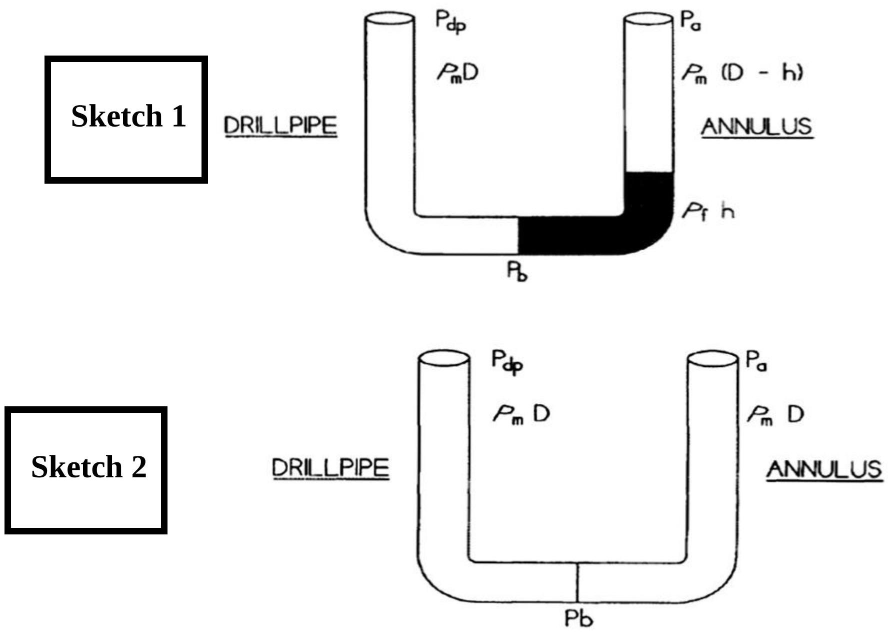


Figure 2: U-Tube Model (Wen et al., 2021)

If the casing pressure is equal to the original shut-in drill pipe pressure recorded in Step 2, close the well by maintaining a constant casing pressure while slowing the pumps. If the casing pressure exceeds the original shut-in drill pipe pressure, continue circulating for an additional circulation while maintaining the drill pipe pressure constant, and then shut in the well while maintaining the casing pressure constant while slowing the pumps (Nissanka & Yapa, 2016). If the shut-in casing pressure exceeds the shut-in drill pipe pressure, repeat Steps 2.2.3–2.2.8. 2.2.10 If the kick is no longer in the hole, close the well and begin preparing the kill mud. This is usually assumed prior to the start of the second circulation (Graham et al., 2022).

$$Kill\ Mud\ Weight = Orignal\ Mud\ Weight + \left(\frac{SIDPP}{TVD * 0.052}\right)$$

Prepare Kill Mud for the Second Circulation. Increase the density of the mud in the suction pit to the density determined in step 10. Calculate the number of strokes to the bit by dividing the drill string capacity in barrels by the pump capacity in barrels per stroke.

$$Pump\ Strokes = \frac{Volume}{Pump\ Displacement}$$

$$Time = \frac{Pump\ Strokes}{Slow\ Pump\ Rate}$$

$$Volume\ (Annulus) = Length * Capacity\ Factor\ (Casing, Open\ hole)$$

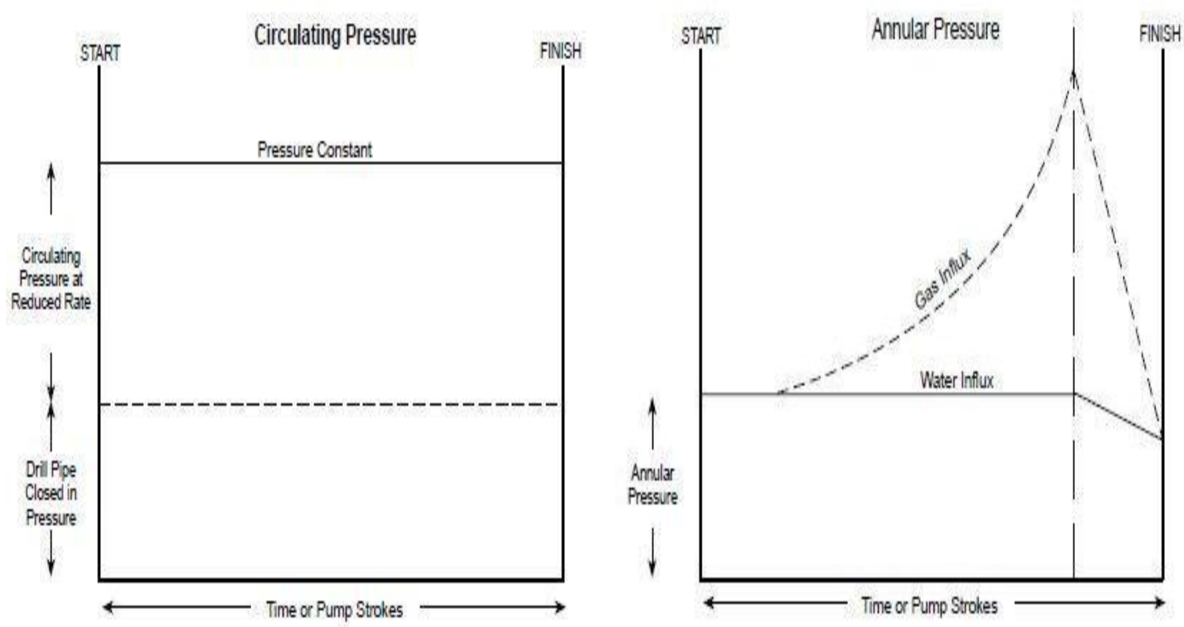
$$Volume\ (Pipe) = Length * Capacity\ Factor\ (DP, HWDP, DC)$$

Half-open the choke, start the pump, and stop circulation. Set the pump to Kill Rate. As the driller raises the pump, the choke operator should keep the casing pressure at or near the shut-in casing pressure (SICP) reading. Read and record the drill pipe pressure after pumping the number of strokes required for the kill mud to reach the bit. When the Drill Pipe is filled with mud, two options are used to maintain constant BHP.

Casing pressure is maintained constant while pumping kill mud from the surface to the bit, and drill pipe pressure is maintained constant until kill mud is observed returning to the surface. Alternatively, during the second circulation, a drill pipe pressure schedule can be calculated and followed while pumping kill mud from the surface to the bit, and drill pipe pressure is then maintained constant. Typically, a graph is drawn from ICP to FCP to examine how the drill pipe pressure drops as Kill Mud moves down to the bit without moving the choke. Kill Mud moves down the pipe toward bit as it is added. When it reaches the bit (bottom), the drill pipe pressure is just enough to circulate the Kill Mud around the well (Eren, 2018). As the kill mud begins to flow down the drill pipe, the drill pipe pressure drops below the initial circulating pressure, eventually reaching the final circulating pressure when the kill mud reaches the bit. Following that, the drill pipe pressure is maintained at the final circulating pressure by gradually opening the choke as the kill mud moves up the annulus. This FCP value is equal to SCR pressure and increases slightly when Kill Mud is added (Chen et al., 2018).

$$FCP = P_{scr} + \frac{Kill\ Mud\ Weight}{Orignal\ Mud\ Weight}$$

When Kill Mud reaches the surface via the bit, stop pumping, close the well, and confirm that it is dead. Close the well by maintaining constant casing pressure while slowing the pumps. The shut-in drill pipe pressure and the shut-in casing pressure should be read and recorded. Both pressures must be zero. Check for flow by opening the well. Repeat the procedure if the well is flowing. If no flow is observed, increase the mud weight to include the desired trip margin and circulate the system until the desired mud weight is reached throughout.



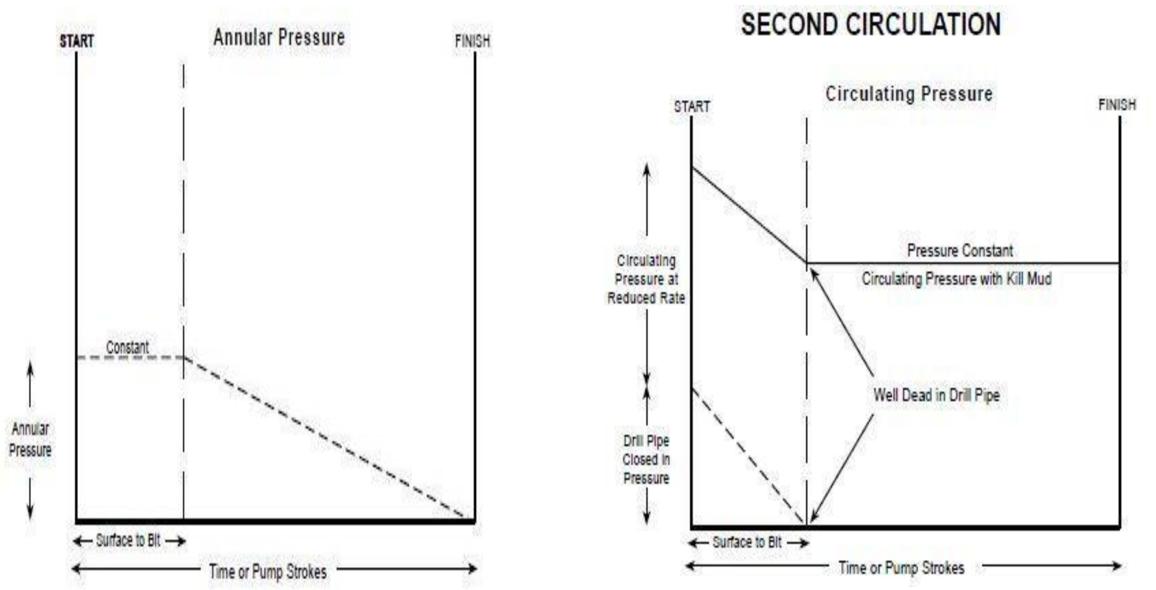


Figure 3: First and Second Circulations Plot (Vajargah et al., 2014)

3.0 WAIT & WEIGHT METHOD OR BALANCED METHOD

The Wait & Weight method, also known as the one circulation method, entails circulating the kick fluid out while the original mud is displaced concurrently with the kill mud. It is also known as the 'Engineer's Method.' It does, in theory, kill the well in a single circulation. The well is closed while the mud is weighted to the required kill weight, calculations are performed, and kill sheets are prepared.

3.1 Steps for Wait & Weight Method

The well is sealed and the necessary data is recorded.

Make Kill Mud and determine the Initial Circulating Pressure.

$$ICP = P_{SCR} + SIDPP$$

$$Kill\ Mud\ Weight = Orignal\ Mud\ Weight + \frac{SIDPP}{TVD * 0.0522}$$

The choke is opened, and the pump is started to interrupt circulation. Bring the pump to Kill Rate, and the choke operator keeps the casing pressure at or near the SICP while the drill is pumping up. Choke operator should maintain the ICP on drill pipe pressure gauge after the pump is at Kill Rate, and as Kill Mud proceeds down the drill pipe, drill pipe pressure is allowed to drop from ICP to FCP by choke adjustment. The choke is cracked open and start pump to break circulation.

$$FCP = \frac{Kill\ Mud\ Weight}{Orignal\ Mud\ Weight} * SCP$$

Adjust the choke to keep this pressure for the duration of the operation. As kill mud enters the annulus, the SICP decreases, increasing the overall hydrostatic pressure in the annulus. SICP and pit volume will increase as the influx reaches the surface. When the kill mud reaches the surface via the bit, stop pumping and close the well. If some SICP value is still recorded, continue to circulate mud until all remaining influx is removed from the well.

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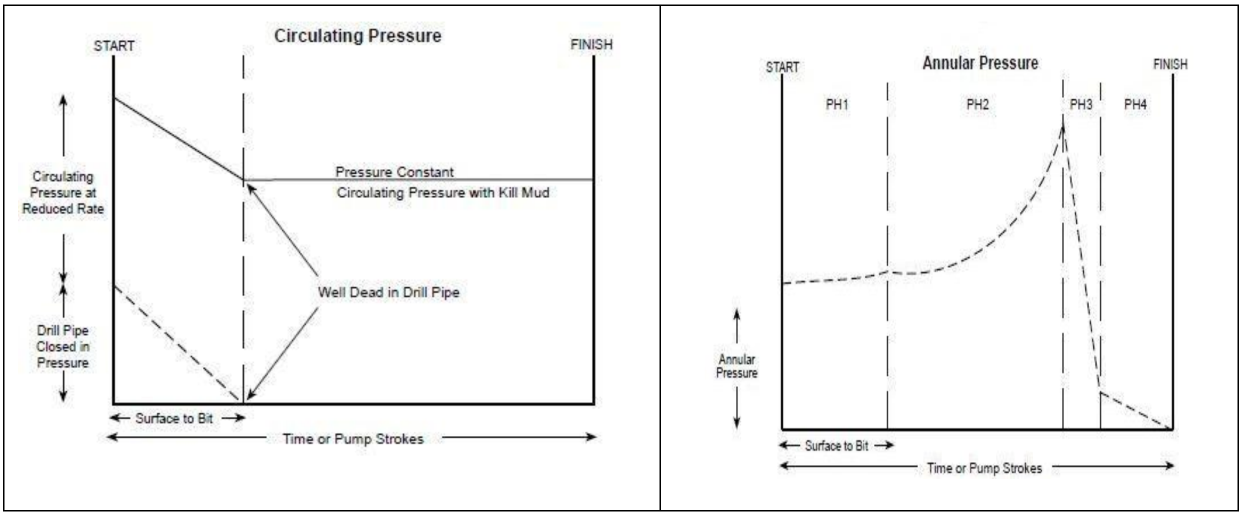

Figure 4: Wait & Weight Method Plot (Jahanpeyma & Jamshidi, 2018)

4.0 VOLUMETRIC METHOD

The volumetric control method is not a kill method; rather, it controls bottom hole pressure until provisions can be made to circulate or bullhead kill mud into the well. Volumetric control allows for controlled expansion of the gas bubble as it migrates up the hole (Sule et al., 2019). Gas bubbles are allowed to expand by bleeding off mud at the surface while maintaining constant casing pressure. Only when the mud is being bled off is the casing pressure held constant; otherwise, it is allowed to rise naturally. Each barrel of mud bled off at the surface alters the wellbore environment in four ways (B. W. Atchison & Sarpangal, 2022).

- The gas bubble to expand by one barrel
- The hydrostatic pressure of the mud in the annulus to decrease
- The bottom hole pressure to decrease
- The surface casing pressure to stay the same

4.1 Steps for Volumetric Control

Volumetric control is achieved through a series of steps that cause the bottom hole pressure to rise and fall sequentially. We allow the gas bubble to rise, causing the bottom hole pressure to rise. The bottom hole pressure decreases as we bleed mud from the annulus. Then we let the gas bubble rise, followed by mud bleeds, and so on. Bottom hole pressure is thus kept within a range that is both high enough to prevent another influx and low enough to prevent an underground blowout (Van Noort et al., 2022).

4.1.1 Calculations

Before a volumetric control procedure can be executed, three calculations must be completed. The Safety Factor, Increase in pressure and increase in Mud level

4.1.1.1 Safety Factor

The safety factor is an increase in bottom hole pressure caused by natural gas migration up the annulus. Allowing the gas bubble to rise in the annulus causes the bottom hole pressure to rise. It is critical that we allow the bottom hole pressure to rise above the formation pressure so that we do not become unbalanced when we bleed mud from the annulus in later steps. In most cases, an appropriate value for the safety factor is in the 200 psi range. It may take several hours for the gas bubble to rise sufficiently to increase the casing pressure, depending on the depth, angle, and fluid in the well. Depending on how close the shoe is to exceeding its fracture pressure under initial shut-in conditions, a safety factor less than 200 psi may be recommended. Any increase in bottom hole pressure will result in an increase in shoe pressure as well. If the shoe is nearing its fracture pressure, the safety factor must be reduced accordingly (Nasir & Durlofsky, 2022). If you calculate that a 200-psi safety factor will break down the shoe, a 100-psi safety factor would be more appropriate.

4.1.1.2 Pressure Increment

The pressure increment is the decrease in hydrostatic pressure that occurs each time we bleed a given volume of mud from the annulus (Echeverría Ciaurri et al., 2021). The Drilling Foreman should choose a pressure increment those results in a decrease in hydrostatic pressure equal to one-third of the initial safety factor value (rounded to the nearest 10 psi). For example, if a 150-psi safety factor was chosen, the pressure increase should result in a 50-psi decrease in hydrostatic pressure (i.e., one-third of 150 psi).

PI = SF / 3

Where,

Pressure Increment = PI

Safety Factor = SF

4.1.1.3 Mud Increment

The mud increment is the volume of mud that must be bled from the annulus to reduce the annular hydrostatic pressure by the amount determined above. The mud increment can be calculated using the right-hand equation. It is critical to have some way of measuring the small volumes of mud that are bled off from the annulus.

$$Mud\ Increment = \frac{PI * ACF}{MW * 0.007}$$

PI = Pressure Increment (psi)

ACF = Annulus Capacity Factor (bbl/ft)

MW = Mud Weight (pcf)

4.1.2 Allow Casing Pressure to Increase Establish Safety Factor

After the calculations are completed, the next step in Volumetric Control is to wait for the gas bubble to migrate up the hole and cause an increase in the shut-in casing pressure. (In reality, this would happen while you were doing your calculations.) Allow the gas bubble to rise until the casing pressure rises by an amount equal to the safety factor. Because no mud has been bled from the annulus, the hydrostatic. While the Gas Bubble Moves

$$Bottom\ Hole\ Pressure\ (goes\ up)$$
$$= Hydrostatic\ Pressure\ (stays\ same) + Surface\ Pressure\ (Goes\ Up)$$

The bottom hole pressure has increased by the safety factor at this point, and the well should be safely overbalanced.

4.1.3 Hold Casing Pressure Constant by Bleeding Off the Mud Increment

The first mud increment can be bled from the well after the safety factor overbalance is applied. The way the mud is bled off the annulus is critical; it must be bled in such a way that the casing pressure remains constant throughout the bleeding. This is done to ensure that the bottom hole pressure is reduced solely by a loss in mud hydrostatic pressure and not by a loss in surface pressure as well (Feo et al., 2020). During the bleeding process, the pressure increment reduces the hydrostatic pressure while holding the surface pressure constant, so the pressure increment also reduces the bottom hole pressure. While the Annulus is Bleeding Mud

$$Bottom\ Hole\ Pressure\ (goes\ down)$$
$$= Hydrostatic\ Pressure\ (goes\ down) + Surface\ Pressure\ (stay\ same)$$

When we bleed mud out of the annulus, the gas bubble expands to fill the space left by the mud. According to Boyle's Law, the pressure in the gas bubble decreases as it expands.

4.1.4 Wait for Casing Pressure to Rise as the Gas Bubble Migrates

Each mud bleed from the annulus reduces the bottom hole pressure by the pressure increment. This reduces the overbalance of our safety factor. We simply wait for the gas bubble to migrate up the annulus to restore the full value of overbalance to the well. As the gas bubble migrates, both the surface and bottom hole pressures rise, just as they did when the safety factor was applied. We wait for the gas bubble to rise until the surface casing pressure rises by the same amount as the pressure increase. We have also increased bottom hole pressure by the amount of the pressure increase, and the well is now fully overbalanced (Raza et al., 2019).

4.1.5 Hold Casing Pressure Constant by Bleeding Mud from the Annulus

We can safely bleed another mud increment from the annulus once we have our full overbalance back on the well. This step, like the first, is completed while maintaining constant casing pressure. Because a similar amount of mud hydrostatic pressure has been bled from the well, the bottom hole pressure is reduced by the amount of the pressure increment. As a result, the gas bubble has expanded by the volume of the mud increment.

4.1.6 Wait for Casing Pressure to Increase as the Gas Bubble Migrates

After the bleed, we wait for the gas bubble to migrate as the well is shut down. The bottom hole pressure will return to its fully overbalanced state (Elgibaly, 2019). We can tell when this has happened because the casing pressure has increased by the amount of the pressure increase.

4.1.7 Alternate Holding Casing Pressure Constant and Letting It Rise

The rest of the volumetric control procedure is simply a series of bleeding and migrating, bleeding and migrating, bleeding and migrating, until the gas has finally migrated to the surface. When we bleed, we lower the bottom hole pressure; when we migrate, we raise the bottom hole pressure. We allow the gas bubble to expand during each bleed step, lowering the pressure inside the bubble. The gas has expanded by the time it reaches the surface.

4.1.8 Lubricate Mud into the Well

After the gas has reached the surface, the casing pressure should stop increasing. The well is stable at this point, but before proceeding with further well work, you should bleed the gas from the well and replace it with mud. This step entails bleeding gas from the well in order to reduce casing pressure by a predetermined amount. The well should then be pumped with a measured volume of mud to increase the hydrostatic pressure in the annulus by the amount of surface pressure lost when the gas was first bled off. These steps should be repeated until gas cannot be bled from the well any longer.

5.0 CONCURRENT METHOD

This method is the most complicated and unpredictable of the three. Its main advantage is that it combines the driller's and engineer's methods, allowing the kill operation to begin immediately upon receipt of the shut-in pressures. Rather than waiting until all of the surface mud has been weighted, pumping begins at the kill rate right away, and the mud is pumped down as the density increases. The rate at which the mud density is increased is determined by the mixing facilities available and the crew's capability. The main drawback of this method is that the drill pipe can be filled with muds of varying densities, making calculation of the bottom hole hydrostatic pressure (and drill pipe pressure) difficult.

This can be a very efficient method of killing a kick if there is proper monitoring, communication, and understanding of the procedure. Figure shows the variations in drill pipe pressure with kill mud volume brought on by the mud's various densities. The shut-in process is the same as what was previously described. The pumps are steadily triggered until the starting circulating pressure is obtained at the chosen kill rate after all kick data has been recorded. In order to warn the choke operator as the mud density changes in the suction pit, the mud should be weighted up as quickly as feasible. When the new density is pumped, the choke is adjusted to suit the new drill pipe circumstances, and the total number of pump strokes is monitored on the drill pipe pressure chart. With this technique, circulation starts right away and the mud progressively becomes heavier as circulation continues. This will go on until the well is dead and the last amount of kill mud necessary has reached the surface.

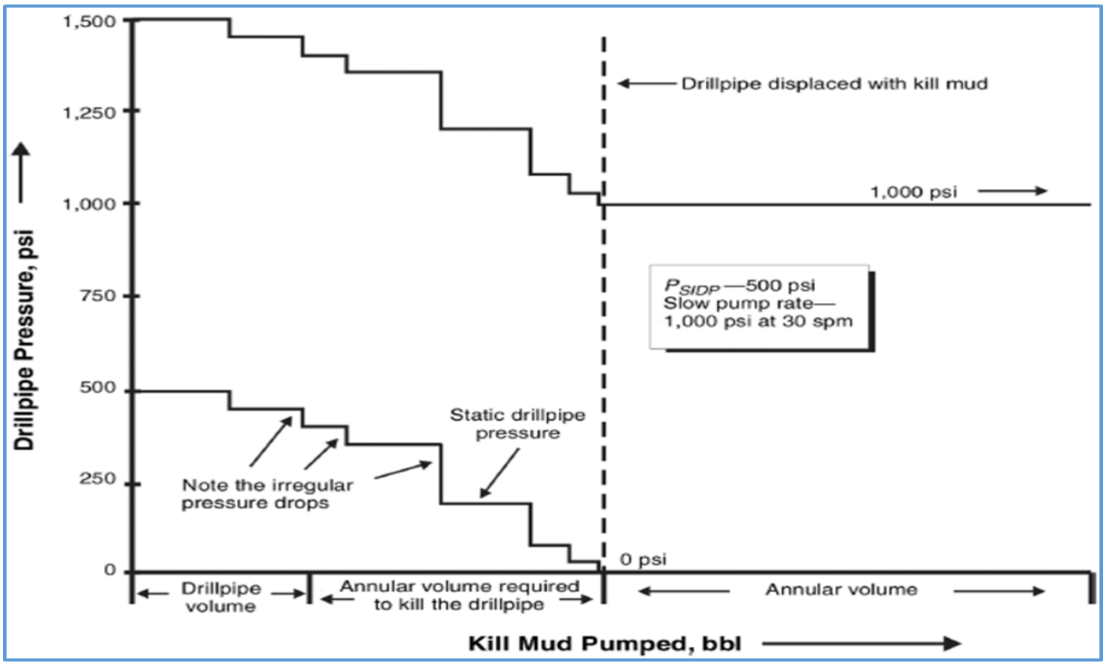

Figure 5: Concurrent Method Plot (Jahanpeyma & Jamshidi, 2018)

5.1 Procedure

- Calculate the ICP, kill mud weight, and FCP with the well shut down.
- Determine the pressure reduction required in terms of incremental mud weight until the final kill mud is circulated rather than stroke increments from surface to bit. Over several circulations, the mud weight will be increased while the drill pipe pressure will be reduced.

- Adjust the choke to bring the pump up to a slow circulation rate while ensuring the drill pipe pressure is equal to the ICP.
- As the mud density increases, the drill pipe pressure is reduced through the choke in accordance with the step down chart.
- Drill pipe pressure decreases with each incremental increase in mud weight. The drill pipe pressure should be at the FCP when the final kill mud is at the bit.

6.0 CHOOSING THE BEST METHOD

The time required to execute the kill procedure, the surface pressures from the kick, the complexity relative to the ease of implementation, and the downhole stresses applied to the formation during the kick killing process are all factors to consider when determining the best well control method for most situations. Before deciding on a procedure, all points must be considered.

7.0 CONCLUSION AND RECOMMENDATIONS

The following list summarizes the industry's general opinion on these methods.

- In most cases, the Driller (one circulation) method should be used.
- If a good casing shoe is available and there will be a delay in weighting up the system, the Wait & Weight (two circulation) method should be used.
- The Concurrent method should be used only in exceptional circumstances, such as a severe (1.5 lbm/gal or greater) kick with a large influx and the possibility of developing lost circulation.

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