Differentially Stuck Pipe

Pipe sticking poses a significant global challenge in drilling operations. It stands as the most prominent cause of non-productive time (NPT), contributing substantially to increased well costs (Yarim et al., 2008; Reid et al., 2000; Pal et al., 2000). In severe cases, it can even necessitate abandoning the ongoing wellbore and opting for a sidetrack. Estimated that stuck pipe incidents can account for approximately 25% of the total budget in deep oil and gas wells. In certain regions, the expenses incurred due to differentially stuck pipe events alone can escalate to as much as 40% of the overall well cost (Reid et al., 2000). In 1991 research found that BP had spent more than $30 million every year for stuck pipe issues. Between 1985 and 1988, an average of $170,000 was spent per well because of stuck pipe. Lastly, in a technical paper titled "Evaluation of Differential Pressure Sticking and Stuck Pipe in Oil and Gas Drilling Technology and Its Production Operations", which was written by Shell Nigeria, the economic losses for only 2 wells that got differentially stuck was approximately US$ 50 million.

Stuck Pipe is the largest source of NPT in drilling worldwide

In the drilling industry, the term "stuck pipe" is commonly used to refer to the issue at hand. It is important to note that "stuck pipe" encompasses various elements such as drill pipe, drill collars, drill bits, stabilizers, reamers, casings, tubing, and other tools or equipment that can become lodged during drilling operations. Once a pipe is stuck, it loses its ability to be raised, lowered, or rotated. The presence of a stuck pipe leads to increased drilling costs due to operational downtime. In severe cases, if the stuck pipe cannot be released economically, it may result in the complete abandonment of the drilling operation at a particular site.

There are many causes of stuck pipe. The industry categorizes the causes as either **differential** or **mechanical sticking**.

These two sticking mechanisms are normally caused by different conditions and need to be treated separately. It is therefore important to identify why the pipe is stuck. The causes of mechanical pipe sticking are inadequate removal of drilled cuttings from the annulus; borehole instabilities, such as hole caving, sloughing, or collapse; plastic shale or salt sections squeezing (creeping); and key seating.

Generally, if the hole can be circulated but the pipe cannot be rotated it is differentially stuck.

<u>Differential Sticking</u>

Differential sticking occurs during most drilling operations. The hydrostatic pressure exerted by the drilling mud column is greater than the formation fluid pressure. In permeable formations, the mud filtrate flows from the borehole into the rock pores and builds up a filter cake. A pressure differential exists across the filter cake which is equal to the difference between the pressure of the mud column and the pressure of the formation.

When a pipe is positioned centrally within the borehole, the hydrostatic pressure, generated by the mud overbalance, exerts equal force in all directions around the pipe. However, if the pipe comes into contact with the filter cake, the mud overbalance starts exerting pressure to push the pipe further into the filter cake. This results in an increased contact area between the pipe and the filter cake.

Although filtrate continues to be expelled and squeezed from the filter cake between the pipe and the formation, causing the cake to shrink, it allows the pipe to penetrate deeper into the filter cake, thereby further expanding the contact area. This phenomenon is amplified in directional wells. If the pressure difference is significant enough and acts over a sufficiently large area, the pipe may become stuck. Differential sticking commonly occurs when the pipe remains motionless for a certain period, such as during pipe connections or surveying activities.

The force required to pull differentially stuck pipe free depends on many factors including:

1. The difference in the pressure between the borehole and the formation. Any overbalance adds to side forces which may exist due to the deviation of the hole.
2. The surface area of the pipe embedded in the wall cake. The thicker the cake or the larger the pipe diameter, the greater this area generally is.
3. The bond developed between the pipe and the wall cake is a very significant factor, being directly proportional to the sticking force. This can include frictional, cohesive and adhesive forces. It generally tends to increase with time, making it harder to pull the pipe free.

This is critical; over time the length of stuck pipe is likely to increase, especially in deviated wells as the solids settle creating a thicker filtercake. A common refrain is that if you do not have a chemical solution on board and haven't used it within 24 hours, the odds of freeing the pipe are less than 10%.

Differential sticking may be distinguished from other forms of sticking, such as mechanical sticking. Mud circulation is not interrupted as there is no obstruction in the borehole to stop the flow, as would be the case for pipe stuck due to hole bridging or caving. It is not possible to move or rotate the pipe in any direction.

In the event of pipe sticking, drillers typically attempt to liberate it through mechanical means, such as employing pulling, jarring, or reversing the direction of pipe movement if it was mobile just before sticking. However, these methods often prove unsuccessful in releasing the stuck pipe. It is important to note that there is a constraint on the amount of force that can be applied, as excessive force could potentially cause the pipe to fracture and exacerbate the situation.

If the pipe remains stuck, it is the practice to apply a pipe release agent (PRA), commonly called a "spotting fluid". These spotting fluids are chemically active mixtures, which may be oil or water based, which are placed over the stuck region in an attempt to free the pipe, if mechanically working the pipe fails to release the pipe. These spotting fluids are believed to act by attacking the mud filter cake. They are positioned in the borehole by pumping the spotting fluid down the hole to the stuck region in the form of a slug, also known as a pill. The pill generally contains sufficient material to cover the stuck zone and extend slightly beyond the area of the stuck zone. 50% excess is typically recommended and even from some sources, 100% excess. Pills frequently are left to soak the cake until the pipe is free or attempts to free the pipe are abandoned.

In a WBM, the PRA frequently consists of what may be called a mini-OBM, i.e., containing a concentration of oil-wetting agents to oil wet the solids in the filtercake thereby causing them to shrink, dehydrate, and increase lubricity. If stuck with an SBM/OBM, options have been limited to base oil pills and density reduction to reduce the hydrostatic or surfactant pills (sometimes with an acid added to dissolve any $CaCO_3$ in the filtercake) to try and disperse the filtercake. Both are weak responses. **HDC Mk II™ was developed in the UK over 4 years with the help of both Amerada Hess and BP as a PRA for use in OBM/SBM's.** It works in WBM too.

Differentially pressured stuck pipe normally occurs:

1. When the pipe is slow moving or stationary.
2. When there is contact between the pipe and the wellbore.
3. When an overbalance is present.
4. Across a permeable formation.
5. In a thick filtercake.
6. Poor hole cleaning and excessive rates of ROP can result in an increase in annular mud weight and produce excessive overbalance.
7. Excessive fluid loss and ineffective hydraulics

Indications on the rigsite:

1. Overpulls on connections or after surveys
2. No string movement
3. Full circulation
4. Subsurface losses
5. High overbalance
6. A permeable formation is exposed in the open hole

Differential pipe sticking can be prevented by following some precautions:

1. Apply the minimum possible safe overbalance while drilling.
2. Controlling the HTHP fluid loss and consequently reducing the filter cake.
3. Minimize the drilled solids percentage in the mud system.
4. Drill with a low friction coefficient mud system (The friction coefficient can vary from 0.04 for oil-based drilling fluids to 0.35 for water-based muds)
5. Reduce the time the string is static for example when repairing or making a connection.

Freeing Differentially Stuck Pipe

When differentially stuck pipe cannot be worked or pulled free within the safe allowable tension limits, there are two techniques that are commonly used to free differentially stuck pipe.

Reduction of Differential Pressure/U-Tubing
Spotting **HDC Mk II™**

Initial guidelines to free the stuck drill string caused by differential sticking.

1. Apply maximum flow rate as much as you can. This will clear the annuli of any solids loading.
2. Apply maximum torque in the drillstring and work down torque to stuck depth. Torque in the string will improve chance of free the pipe.
3. Slack off weight of string to maximum sit-down weight.

4. Jar down with maximum trip load. Torque may be applied with jarring down with caution. The chance of freeing the pipe by jarring down is more than jarring up. Be patient when a hydraulic jar trips because it may take around 5 minutes each cycle.

<u>The secondary actions to free the pipe are:</u>

1. Reduce hydrostatic pressure by pumping low weight mud or base oil pill (if using a SBM/OBM). You must ensure that overall hydrostatic pressure is still able to control reservoir fluid to accidentally come into the wellbore.
2. Continue jarring down with maximum trip load and apply torque into drill string.

<u>The following conditions will have an effect on the success of freeing differentially stuck pipe:</u>

Hole Angle: Low angle holes had the best success rates for freeing stuck pipe
Hole Size: Success rate for freeing stuck pipe was slightly higher for larger than smaller holes.
Mud Weight: The chance of freeing stuck pipe is higher in wells requiring lower mud weights.
Spotting Time: The quicker the spot is applied, the higher the chance of success.
Open Hole: Open hole length does not consistently affect the success rate for freeing stuck pipe.

Reduction of Differential Pressure

The reduction of differential pressure by mud weight reduction or U-Tubing techniques has been used to free differentially stuck pipe. It can, however, cause further problems and all factors should be considered before using these techniques. Reducing hydrostatic pressure can cause certain formations, usually shale, to become unstable. Often this leads to packing off and further stuck pipe problems. Reduction of hydrostatic pressure can lead to well control problems. For these reasons many operators will use spotting fluids as their first option to free stuck pipe.

Spotting Fluids

When differential sticking occurs, **HDC Mk II™** can be used to free the pipe. Options should have been discussed before drilling commenced.

Note: *It is critical to have the fluid readily available on the rig and apply it within six hours of the stuck pipe occurrence.*

Displacement procedure in Synthetic-based muds

Many pipe free pills are ineffective because they fail to contact the filter cake in which the pipe is stuck, due to the gelled mud in the narrow annulus. Thus the pipe free pill takes the easier route, up the wide annulus.

To increase the chances of placing the pipe free pill in the correct zone, the following procedures should be adopted:

- A turbulent flow or, as thin a spacer as possible, should be pumped ahead of the pipe free pill. In this instance, if base oil will not adversely affect the hydrostatic head, it should be used after prior agreement with the Operator Representative.

- As large a spacer as possible should be pumped and displaced at the maximum possible rate, with due consideration being given to the hydrostatic head.

- Thinners can be used in the spacer, but only at levels which will not cause problems if incorporated into the active mud system. This should help to remove gelled mud from the narrow side of the annulus.

- Increasing the density of the pipe free pill above that of the circulating mud weight will also act to drive out the gelled mud. The present recommendations are to increase the weight to 0.02 - 0.04 sg above circulating mud weight.

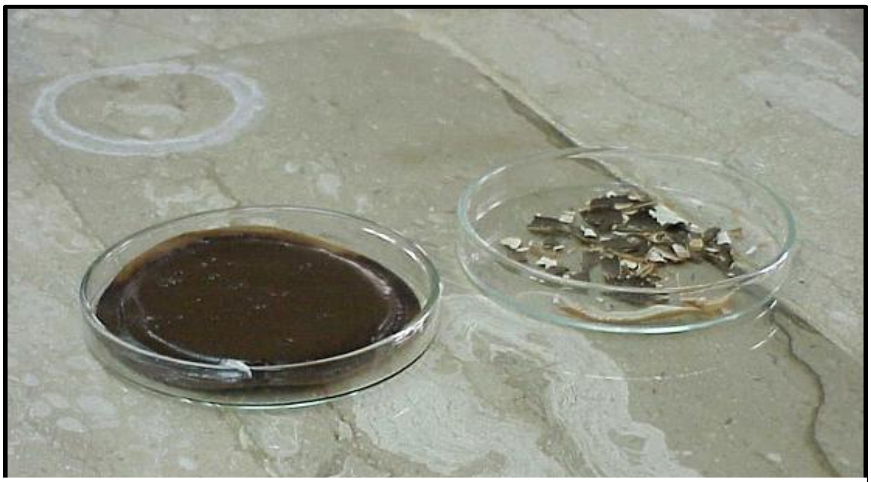
- The pipe free pill should be displaced to the stuck zone at the maximum possible rate.

- In general, the practice of retaining a portion of the pipe-free pill inside the drill pipe and slowly displacing to the annulus during the soak period is ineffective. The slow pump rate used for the practice will result in this fluid going up the wide annulus. It is better to displace the entire pill at the maximum rate to the stuck zone. However, the volume of pill pumped should make allowances for contamination by the spacer ahead of the pill. Volumes should be sufficient to cover the stuck zone plus a further 50%.

- There is very little benefit in pumping further pills as there will always be the problem of removing gelled pipe-free agent from the stuck zone. It is better to allow the first pill to soak (while working the pipe) for as long as possible. However, if packing off is a possible problem, it may help to leave some of the pill in the string, and then pump it away slowly to maintain a low circulation rate.

Facts and guidelines when using HDC Mk II™:

1. The density of **HDC Mk II™** is 1.31 SG (10.9 ppg).
2. It is used neat.
3. As **HDC Mk II™** chelates with calcium, a small spacer must be placed before and after, consisting of base oil or any brine NOT containing calcium (CaCl2, CaBr2, etc.) such as KCL, NaCl, etc. 3-5 bbls will suffice, before and after.
4. Or if a weighted pill is required for balance to avoid U-tubing, weighted SBM/OBM can be used, but the spacer is still required.
5. The **HDC Mk II™** will dissolve the filtercake within 1-2 hours depending upon the temperature, the higher, the faster.
6. The temperature limit is above 260°C (500°F).
7. Assuming the BHA is stuck and near the bit, leave some excess in the drillpipe/BHA so that after 2 hours if necessary 3-5 bbls of excess **HDC Mk II™** can be pumped into the annulus. And repeat if necessary until there is no more in the drillpipe.



Result with OBM cake : Before and after HDC Mk II treatment for 6 hrs @ 90 ^oC resulted in **95% dissolution.**

<u>What to do after the string becomes free?</u>

Drilling Fluid Impact

HDC Mk II™ can be incorporated into the drilling fluid without loss of density or substantial quality loss. It emulsifies quite easily when strung out through the system, and exhibits no risk to human health or marine life. It is, or has been, "E" rated or Gold Banded in the UK CEFAS system, the highest environmental rating allowing for unlimited dumping offshore (although all operators are zero discharge). Fluid loss control and electrical stability will have to be restored at the interface of the pill volumes where synthetic or oil-based fluids are used, as with the case of any water intrusion into an OBM system.

In water-based muds, the pH of the spotting fluid would have the biggest impact, but this is easily treated using citric acid or allowed to deplete back to system pH as it blends in the drilling fluid. Fluid loss and viscosity will have to be remedially treated to restore over all properties, with the weight however, unaffected.

If used as directed, the **HDC Mk II™** formulations will in effect, become spent during the spotting period, and have no effect outside the critical zone.

Note: In seawater-based fluids, the solubilised barium in the fluid will revert to barium sulphate due to the sulphate ions present in seawater.

1. Circulate at maximum allowable flow rate. Flow rate must be more than cuttings slip velocity in order to transport cuttings effectively.
2. Reciprocate and work pipe while cleaning the hole. Ensure that you can work pipe with full stand or joint while circulating.

Any balanced pill considerations must be determined based on the existing mud weight at the time the pipe became stuck.

With that in mind, the next few pages explain U-tubing and balanced plugs.

Understand U-Tube Concept and Importance of U-Tube

By DrillingFormulas.Com

We use the behavior of one of the fluid columns to describe the behavior regarding what is happening in the side of the fluid column, i.e., if two fluid columns are connected at bottom. Basically, this situation is simply described in the oilfield as a “U Tube”.

In the oilfield, especially in drilling, a “U Tube” can be considered as a string of pipe (drill pipe and tubing) in a wellbore where fluids are able to pass inside a string of pipe (drill pipe and tubing) and the annulus (area between wellbore and string of pipe). Figure 1 below demonstrates the “U Tube” concept.

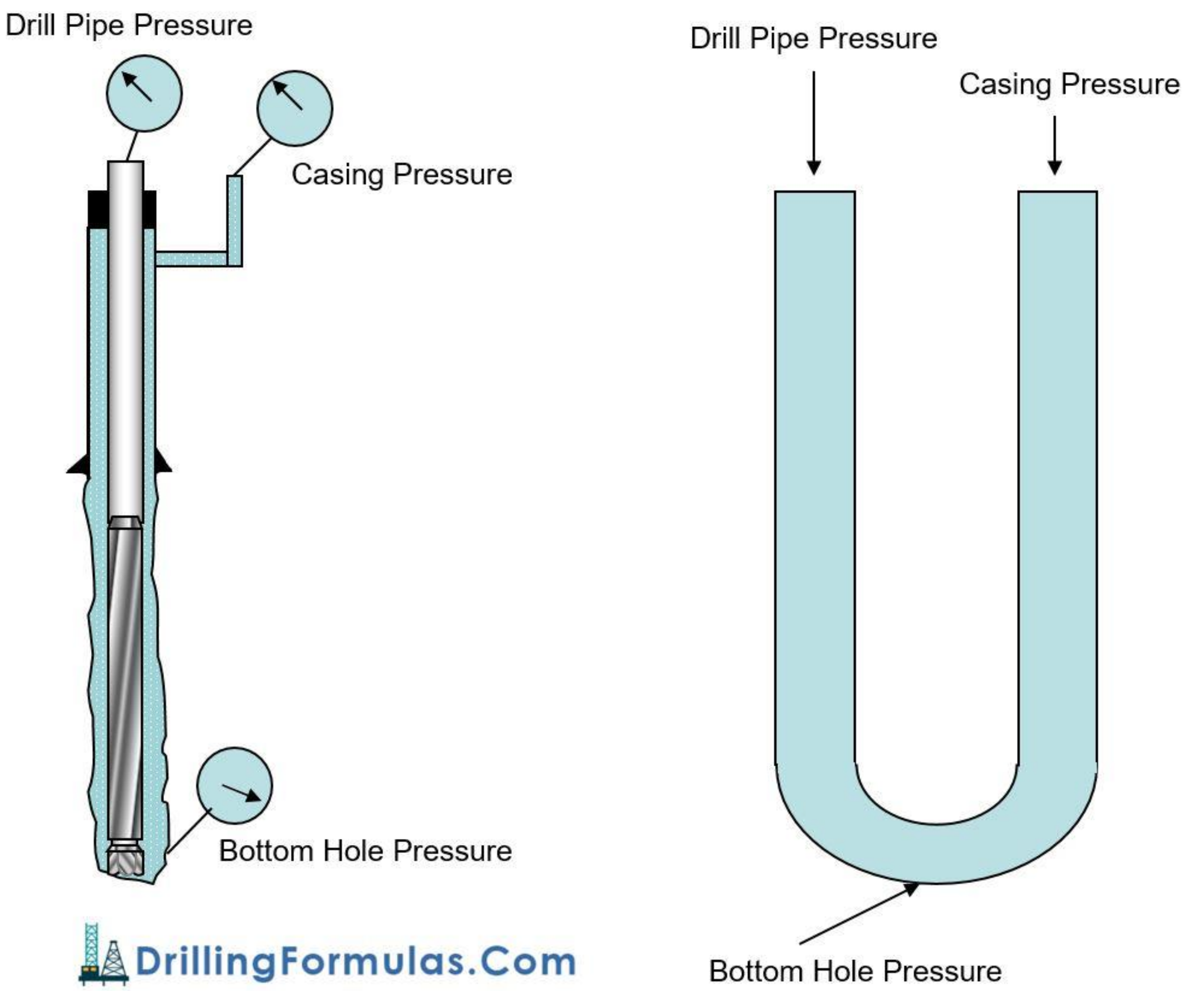


Figure 1 – U-Tube Diagram Represents Both Sides of Fluid Columns

A horizontal tube connects the right-hand side of the U-Tube and fluid levels in both columns should equalize when a fluid with a consistent density is used. The hydrostatic pressure should be equal at the bottom of both columns. The pressure found at the base of both columns is considered ‘bottomhole pressure’. To replicate the opening through the nozzles in the bit, the opening at the base exists. The fluids are balanced.

The mathematical relationship for this is shown below;

BHP = HP + SP

Where;

BHP = bottomhole pressure

HP = hydrostatic pressure

SP = surface pressure

With the U-tube concept applied, both sides of the fluid columns can be described with the equation below;

BHP = SIDPP + HP string = SICP + HP annulus

Where;

BHP = bottomhole pressure

SIDPP = shut in drillpipe pressure

HP string = hydrostatic pressure in drill string

SICP = shut in casing pressure

HP annulus = hydrostatic pressure in annulus

When the fluid density in both columns is equal, U-Tubes can be relatively simple. Surface pressures on the drillpipe and casing side will be the same when the drillpipe and casing are full of the same fluid density. However, U-Tubes become more difficult when fluids with varying densities are found in the columns. Despite the same BHP, both HP and SP will differ.

With hydrostatic and surface pressure equal in both columns, U-Tubes aren't too interesting because both columns are filled with fluids of the same density. For example, when the annulus and drillpipe contain the same weight drilling mud while a bit is run to the hole's bottom. The hydrostatic pressure is equal at both the casing and drillpipe side, fluid levels are static at the top, and the surface pressure on the drillpipe and casing sides are zero.

On the other hand, when columns are occupied by fluids of different densities, there's likely to be a difference in both surface pressure and hydrostatic pressure in both columns (drillstring and casing side). For example, this is commonly seen in a kick with the bit on bottom as you can see from the

Figure 2 diagram. As the formation pressure increases above the hydrostatic pressure (generated by mud in the well), it kicks. The well will stop flowing if it's shut-in; a surface pressure on the drillpipe gauge is then a reflection of the pressure underbalance. As opposed to the drilling mud in the annulus, the fluid now contains a lighter weight formation fluid and this leads to a reduction in total hydrostatic pressure (within the annulus). The shut-in casing pressure increases above shut-in drillpipe pressure to compensate to the underbalanced in the annulus side compared to the drillpipe side.

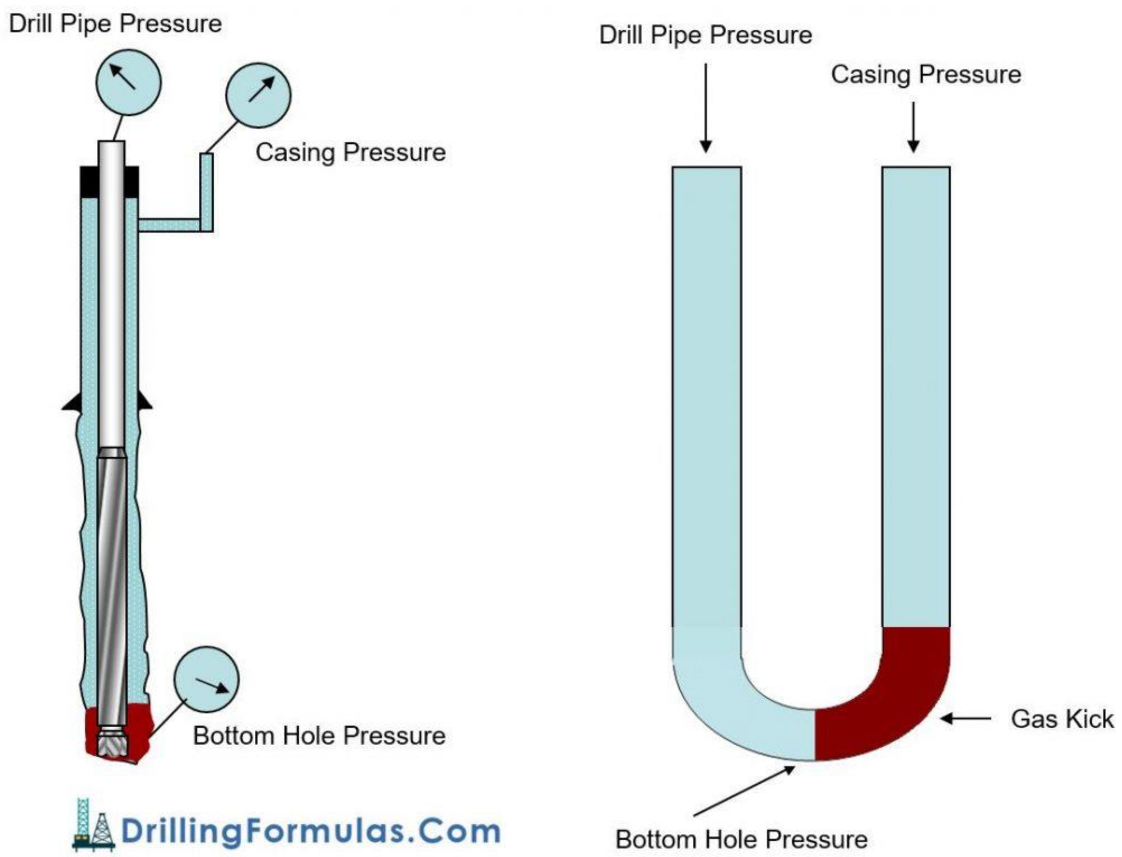


Figure 2 – U-Tube Diagram Represents Both Sides of Fluid Columns with Gas Kick

Why is U-Tube very important?

It is very vital to keep a basic concept of U-Tube in mind.

If there are two different fluids between inside of the string and the annulus, fluids always flow from a higher pressure area to a lower pressure. If the system is NOT closed, the lighter fluid will flow out and it will be stopped when the system pressure is stabilized (see the Figure 3 below).

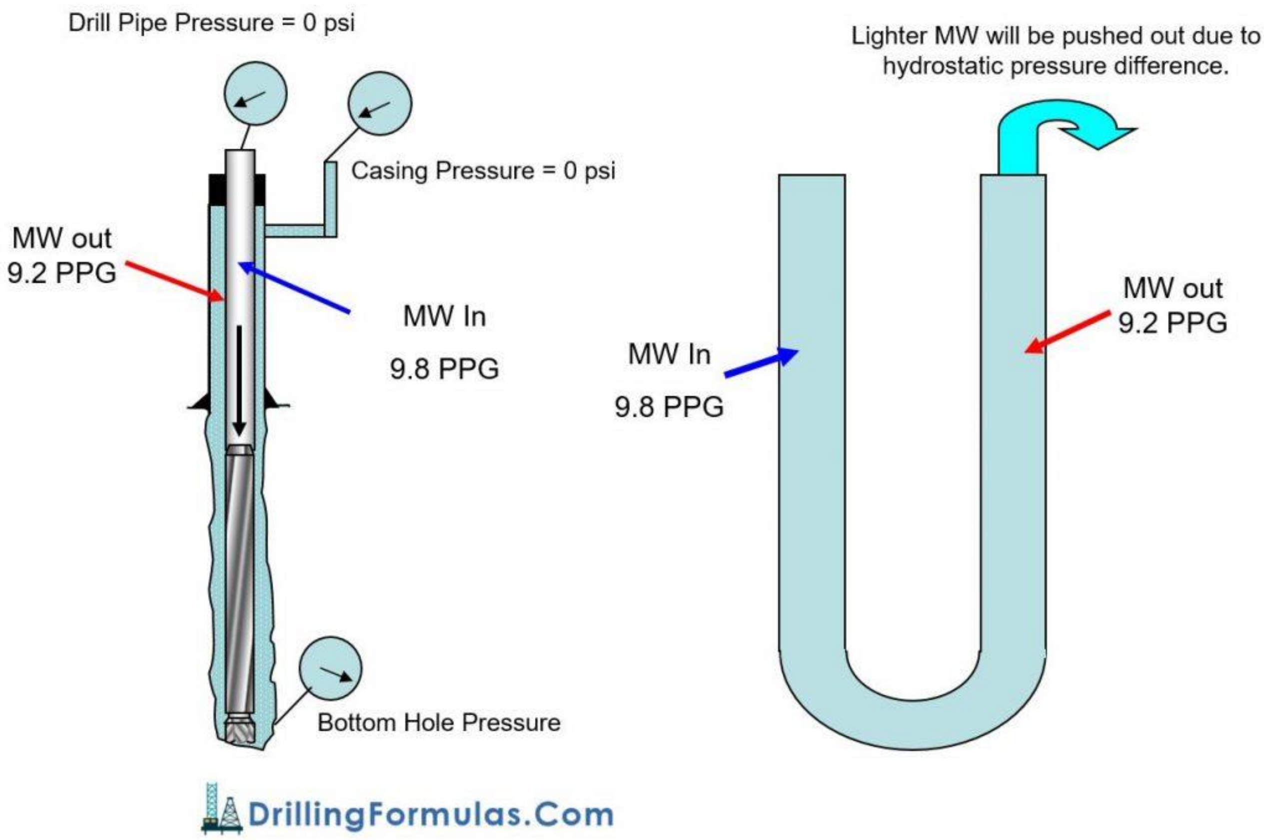


Figure 3 – U-Tube Diagram Represents Both Sides of Fluid Columns Without a Closed System

If the system is closed, for example with the well shut in, pressure must be the same at the bottom point where both sides of the U-tube are connected . Therefore, the drill pipe pressure and casing pressure (annulus pressure) respond based on the fluid in each side and the formation pressure at bottom hole (see the Figure 4).

Figure 4 demonstrates difference in hydrostatic pressure between the drill pipe and the casing when the mud weight 9.8 ppg is pumped to the bit and the well is shut in. The calculation is shown below.

BHP = SIDPP + HP string = SICP + HP annulus

BHP = 0 + (0.052 × 10,000 × 9.8) = 5,096 psi

5,096 psi = SICP + (0.052 × 10,000 × 9.2)

5,096 psi = SICP + 4,784 psi

SICP = 312 psi

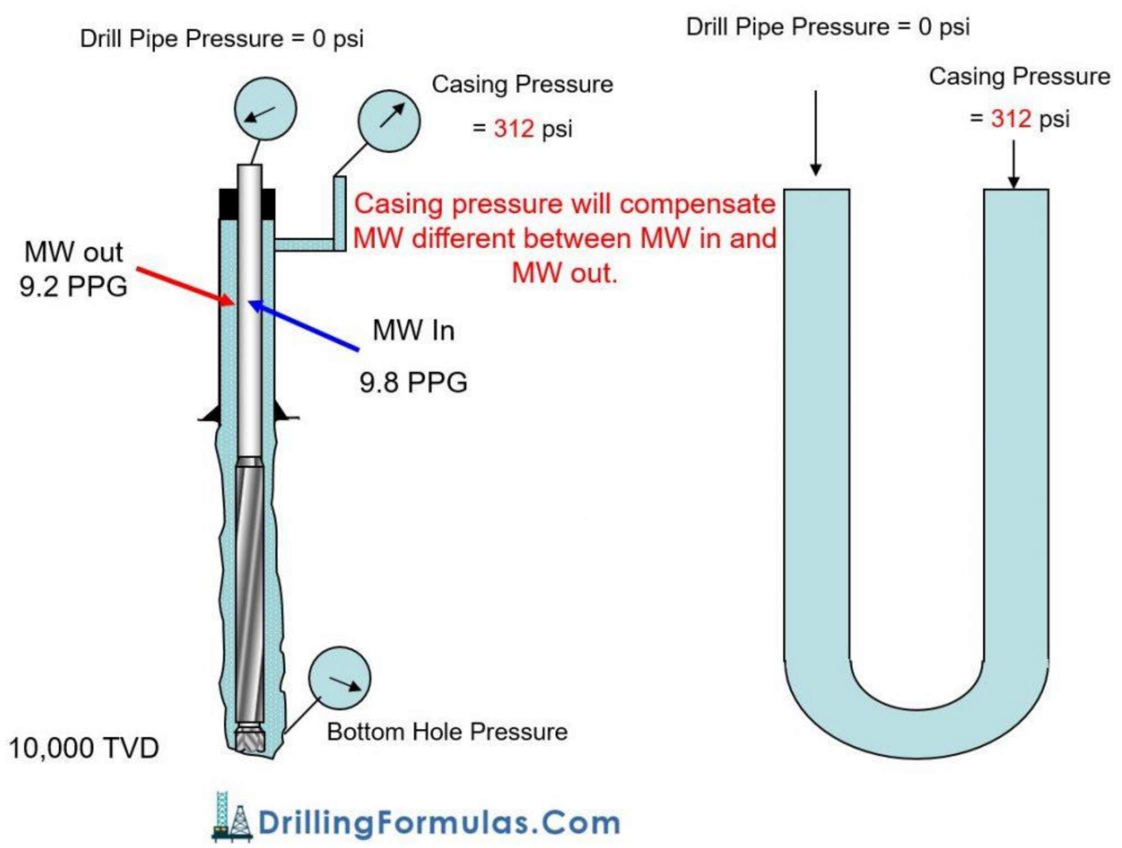


Figure 4 – U-Tube Diagram Represents Both Sides of Fluid Columns With a Closed System

The U-Tube concept can be widely applied in many drilling and workover applications such as well control, cementing, hole monitoring, pulling out of hole, pumping slugs, etc.

Example:

The mud weight inside the drill pipe is 9.8 ppg all the way to the bit and the mud weight in the annulus is 9.2 ppg all the way to surface. The depth is 10,000' MD/8500' TVD. The well is shut in and the drill pipe pressure is equal to 0 psi. Determine the casing pressure.

According to the U-tube concept, both sides (casing and drill pipe) have the same bottom hole pressure so we can write the equation to describe the U-tube concept as shown below;

SP (casing) + HP (casing) = BHP = SP (drill pipe) + HP (drill pipe)

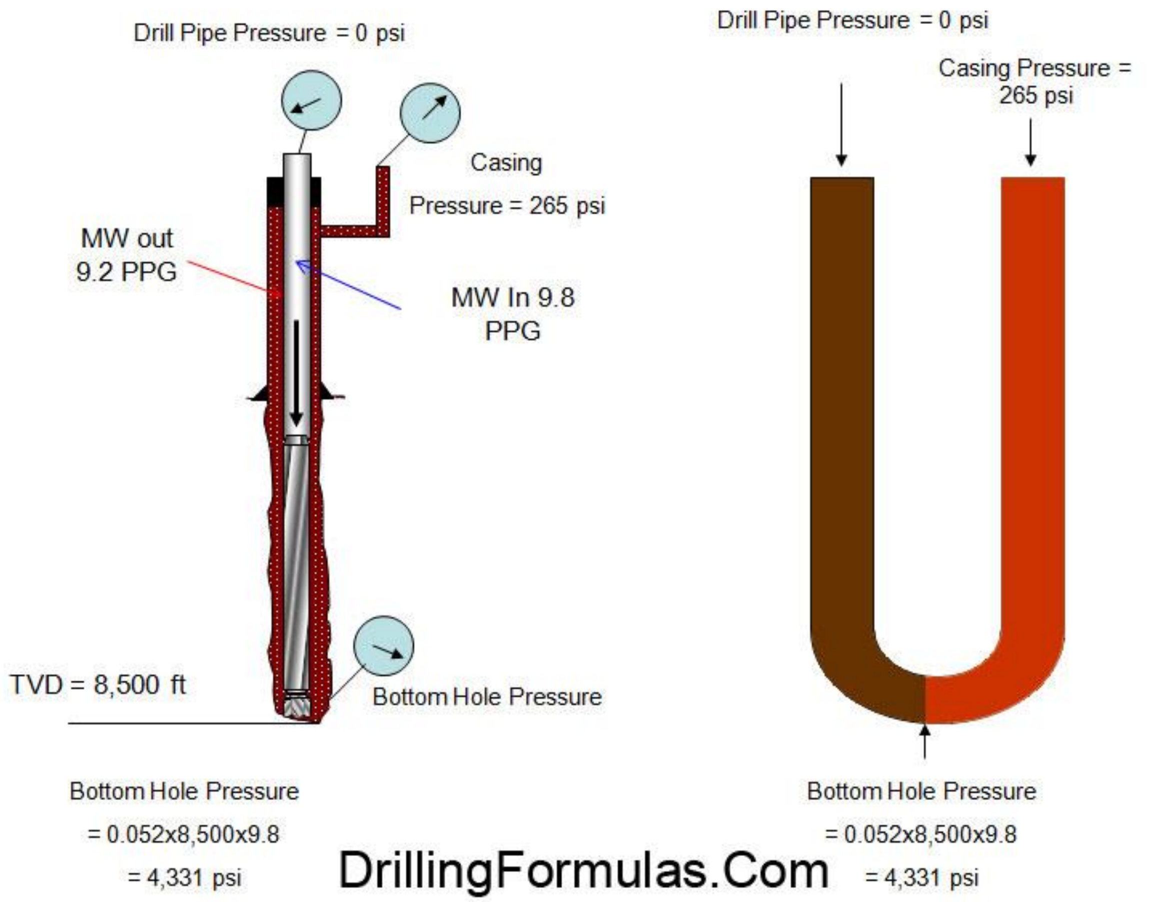
At drill pipe side: BHP = 0 psi (Drill pipe Pressure) + 0.052×9.8×8,500 (**Hydrostatic Pressure** at drill pipe side) = 4,331 psi

At casing side: BHP = 4,331 psi = (Casing Pressure) + 0.052×9.2×8,500 (**Hydrostatic Pressure** at casing)

With this relationship (**SP (casing) + HP (casing) = BHP = SP (drill pipe) + HP (drill pipe)), we** can solve casing pressure.

4331 = Casing Pressure + 4066

Casing Pressure = 4331 – 4066 = 265 psi



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