Kicks

A kick is a well control problem in which the pressure found within the drilled rock is higher than the mud hydrostatic pressure acting on the borehole or rock face. When this occurs, the greater formation pressure has a tendency to force formation fluids into the wellbore. This forced fluid flow is called a kick. If the flow is successfully controlled, the kick is considered to have been killed. An uncontrolled kick that increases in severity may result in what is known as a "blowout."

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Factors affecting kick severity

Several factors affect the severity of a kick. One factor, for example, is the "permeability" of rock, which is its ability to allow fluid to move through the rock. Another factor affecting kick severity is "porosity." Porosity measures the amount of space in the rock containing fluids. A rock with high permeability and high porosity has greater potential for a severe kick than a rock with low permeability and low porosity. For example, sandstone is considered to have greater kick potential than shale, because sandstone has greater permeability and greater porosity than shale.

Yet another factor affecting kick severity is the "pressure differential" involved. Pressure differential is the difference between the formation fluid pressure and the mud hydrostatic pressure. If the formation pressure is much greater than the hydrostatic pressure, a large negative differential pressure exists. If this negative differential pressure is coupled with high permeability and high porosity, a severe kick may occur.

Kick labels

A kick can be labeled in several ways, including one that depends on the type of formation fluid that entered the borehole. Known kick fluids include:

- Gas
- Oil
- Salt water
- Magnesium chloride water
- Hydrogen sulfide (sour) gas
- Carbon dioxide

If gas enters the borehole, the kick is called a "gas kick." Furthermore, if a volume of 20 bbl (3.2 m^3) of gas entered the borehole, the kick could be termed a 20-bbl (3.2-m^3) gas kick.

Another way of labeling kicks is by identifying the required mud weight increase necessary to control the well and kill a potential blowout. For example, if a kick required a 0.7-lbm/gal (84-kg/m^3) mud weight increase to control the well, the kick could be termed a 0.7-lbm/gal (84-kg/m^3) kick. It is interesting to note that an average kick requires approximately 0.5 lbm/gal (60 kg/m^3), or less, mud weight increase.

Causes of kicks

Kicks occur as a result of formation pressure being greater than mud hydrostatic pressure, which causes fluids to flow from the formation into the wellbore. In almost all drilling operations, the operator attempts to maintain a hydrostatic pressure greater than formation pressure and, thus, prevent kicks; however, on occasion the formation will exceed the mud pressure and a kick will occur. Reasons for this imbalance explain the key causes of kicks:

- Insufficient mud weight.
- Improper hole fill-up during trips.
- Swabbing.
- Cut mud.
- Lost circulation.

Insufficient mud weight

Insufficient mud weight is the predominant cause of kicks. A permeable zone is drilled while using a mud weight that exerts less pressure than the formation pressure within the zone. Because the formation pressure exceeds the wellbore pressure, fluids begin to flow from the formation into the wellbore and the kick occurs.

These abnormal formation pressures are often associated with causes for kicks. Abnormal formation pressures are greater pressures than in normal conditions. In well control situations, formation pressures greater than normal are the biggest concern. Because a normal formation pressure is equal to a full column of native water, abnormally pressured formations exert more pressure than a full water column. If abnormally pressured formations are encountered while drilling with mud weights insufficient to control the zone, a potential kick situation has developed. Whether or not the kick occurs depends on the permeability and porosity of the rock. A number of abnormal pressure indicators can be used to estimate formation pressures so that kicks caused by insufficient mud weight are prevented (some are listed in **Table 1**).

TABLE 4.1—ABNORMAL PRESSURE INDICATORS	
Qualitative Methods	Quantitative Methods
Lithology	Shale density
Offset well-log analysis	*d* exponent
Temperature anomaly	Normalized penetration rate
Gas counting	Other drilling equations
Mud or cuttings resistivity	
Cutting character	
Hole condition	

Table 1- Abnormal Pressure Indicators

An obvious solution to kicks caused by insufficient mud weights seems to be drilling with high mud weights; however, this is not always a viable solution. First, high mud weights may exceed the fracture mud weight of the formation and induce lost circulation. Second, mud weights in excess of the formation pressure may significantly reduce the penetration rates. Also, pipe sticking becomes a serious consideration when excessive mud weights are used. The best solution is to maintain a mud weight slightly greater than formation pressure until the mud weight begins to approach the fracture mud weight and, thus, requires an additional string of casing.

Improper hole fill-up during trips

Improperly filling up of the hole during trips is another prominent cause of kicks. As the drillpipe is pulled out of the hole, the mud level falls because the pipe steel no longer displaces the mud. As the overall mud level decreases, the hole must be periodically filled up with mud to avoid reducing the hydrostatic pressure and, thereby, allowing a kick to occur.

Several methods can be used to fill up the hole, but each must be able to accurately measure the amount of mud required. It is not acceptable—under any condition—to allow a centrifugal pump to continuously fill up the hole from the suction pit because accurate mud-volume measurement with this sort of pump is impossible. The two acceptable methods most commonly used to maintain hole fill-up are the trip-tank method and the pump-stroke measurements method.

The trip-tank method has a calibration device that monitors the volume of mud entering the hole. The tank can be placed above the preventer to allow gravity to force mud into the annulus, or a centrifugal pump may pump mud into the annulus with the overflow returning to the trip tank. The advantages of the trip-tank method include that the hole remains full at all times, and an accurate measurement of the mud entering the hole is possible.

The other method of keeping a full hole—the pump-stroke measurement method—is to periodically fill up the hole with a positive-displacement pump. A flowline device can be installed with the positive-displacement pump to measure the pump strokes required to fill the hole. This device will automatically shut off the pump when the hole is full.

Swabbing

Pulling the drillstring from the borehole creates swab pressures. Swab pressures are negative, and reduce the effective hydrostatic pressure throughout the hole and below the bit. If this pressure reduction lowers the effective hydrostatic pressure below the formation pressure, a potential kick has developed. Variables controlling swab pressures are:

- Pipe pulling speed

- Mud properties
- Hole configuration
- The effect of “balled” equipment

Some swab pressures can be seen in **Table 2**.

TABLE 4.2—SWAB PRESSURES (psig) FOR A 14.0-ppg MUD, 4 1/2-in. PIPE WITH VARIOUS HOLE SIZES AND SEVERAL PULLING SPEEDS

	Pulling Speeds (sec/stand)					
Hole Size (in.)	15	22	30	45	68	75
8 1/2	267	167	124	98	84	75
6 1/2	589	344	256	192	159	140
5 3/4	921	524	294	289	231	200

Table 2- Swab Pressures (psig) for a 14-ppg mud 4½ -in. Pipe With Various Hole Sizes and Several Pulling Speeds

Cut mud

Gas-contaminated mud will occasionally cause a kick, although this is rare. The mud density reduction is usually caused by fluids from the core volume being cut and released into the mud system. As the gas is circulated to the surface, it expands and may reduce the overall hydrostatic pressure sufficient enough to allow a kick to occur.

Although the mud weight is cut severely at the surface, the hydrostatic pressure is not reduced significantly because most gas expansion occurs near the surface and not at the hole bottom.

Lost circulation

Occasionally, kicks are caused by lost circulation. A decreased hydrostatic pressure occurs from a shorter mud column. When a kick occurs from lost circulation, the problem may become severe. A large volume of kick fluid may enter the hole before the rising mud level is observed at the surface. It is recommended that the hole be filled with some type of fluid to monitor fluid levels if lost circulation occurs.

Warning signs of kicks

Warning signs and possible kick indicators can be observed at the surface. Each crew member has the responsibility to recognize and interpret these signs and take proper action. All signs do not positively identify a kick; some merely warn of potential kick situations. Key warning signs to watch for include the following:

- Flow rate increase
- Pit volume increase
- Flowing well with pumps off
- Pump pressure decrease and pump stroke increase
- Improper hole fill-up on trips
- String weight change
- Drilling break
- Cut mud weight

Each is identified below as a primary or secondary warning sign, relative to its importance in kick detection.

Flow rate increase (primary indicator)

An increase in flow rate leaving the well, while pumping at a constant rate, is a primary kick indicator. The increased flow rate is interpreted as the formation aiding the rig pumps by moving fluid up the annulus and forcing formation fluids into the wellbore.

Pit volume increase (primary indicator)

If the pit volume is not changed as a result of surface-controlled actions, an increase indicates a kick is occurring. Fluids entering the wellbore displace an equal volume of mud at the flowline, resulting in pit gain.

Flowing well with pumps off (primary indicator)

When the rig pumps are not moving the mud, a continued flow from the well indicates a kick is in progress. An exception is when the mud in the drillpipe is considerably heavier than in the annulus, such as in the case of a slug.

Pump pressure decrease and pump stroke increase (secondary indicator)

A pump pressure change may indicate a kick. Initial fluid entry into the borehole may cause the mud to flocculate and temporarily increase the pump pressure. As the flow continues, the low-density influx will displace heavier drilling fluids, and the pump pressure may begin to decrease. As the fluid in the annulus becomes less dense, the mud in the drillpipe tends to fall and pump speed may increase.

Other drilling problems may also exhibit these signs. A hole in the pipe, called a "washout," will cause pump pressure to decrease. A twist-off of the drillstring will give the same signs. It is proper procedure, however, to check for a kick if these signs are observed.

Improper hole fill-up on trips (primary indicator)

When the drillstring is pulled out of the hole, the mud level should decrease by a volume equivalent to the removed steel. If the hole does not require the calculated volume of mud to bring the mud level back to the surface, it is assumed a kick fluid has entered the hole and partially filled the displacement volume of the drillstring. Even though gas or salt water may have entered the hole, the well may not flow until enough fluid has entered to reduce the hydrostatic pressure below the formation pressure.

String weight change (secondary indicator)

Drilling fluid provides a buoyant effect to the drillstring and reduces the actual pipe weight supported by the derrick. Heavier muds have a greater buoyant force than less dense muds. When a kick occurs, and low-density formation fluids begin to enter the borehole, the buoyant force of the mud system is reduced, and the string weight observed at the surface begins to increase.

Drilling break (secondary indicator)

An abrupt increase in bit-penetration rate, called a "drilling break," is a warning sign of a potential kick. A gradual increase in penetration rate is an abnormal pressure indicator, and should not be misconstrued as an abrupt rate increase.

When the rate suddenly increases, it is assumed that the rock type has changed. It is also assumed that the new rock type has the potential to kick (as in the case of a sand), whereas the previously drilled rock did not have this potential (as in the case of shale). Although a drilling break may have been observed, it is not certain that a kick will occur, only that a new formation has been drilled that may have kick potential.

It is recommended when a drilling break is recorded that the driller should drill 3 to 5 ft (1 to 1.5 m) into the sand and then stop to check for flowing formation fluids. Flow checks are not always performed in tophole drilling or when drilling through a series of stringers in which repetitive breaks are encountered. Unfortunately, many kicks and blowouts have occurred because of this lack of flow checking.

Cut mud weight (secondary indicator)

Reduced mud weight observed at the flow line has occasionally caused a kick to occur. Some causes for reduced mud weight are:

- Core volume cutting
- Connection air
- Aerated mud circulated from the pits and down the drillpipe

Fortunately, the lower mud weights from the cuttings effect are found near the surface (generally because of gas expansion), and do not appreciably reduce mud density throughout the hole. **Table 3** shows that gas cutting has a very small effect on bottomhole hydrostatic pressure.

TABLE 4.3—EFFECT OF GAS-CUT MUD ON THE BOTTOMHOLE HYDROSTATIC PRESSURE

	Pressure reduction (psi)		
Depth (ft)	10 lbm/gal cut to 5 lbm/gal	18 lbm/gal cut to 16.2 lbm/gal	18.0 lbm/gal cut to 9 lbm/gal
1,000	51	31	60
5,000	72	41	82
10,000	86	48	95
20,000	97	51	106

Table 3- Effect of Gas-Cut Mud On The Bottomhole Hydrostatic Pressure

An important point to remember about gas cutting is that, if the well did not kick within the time required to drill the gas zone and circulate the gas to the surface, only a small possibility exists that it will kick. Generally, gas cutting indicates that a formation has been drilled that contains gas. It does not mean that the mud weight must be increased.

Kick detection and monitoring with MWD tools

During circulation and drilling operations, measurement while drilling (MWD) systems monitor:

- Mud properties
- Formation parameters
- Drillstring parameters

The system is widely used for drilling, but it also has applications for well control, including the following:

- Drilling-efficiency data, such as downhole weight on bit and torque, can be used to differentiate between rate of penetration changes caused by drag and those caused by formation strength. Monitoring bottomhole pressure, temperature, and flow with the MWD tool is not only useful for early kick detection, but can also be valuable during a well-control kill operation. Formation evaluation capabilities, such as gamma ray and resistivity measurements, can be used to detect influxes into the wellbore, identify rock lithology, and predict pore pressure trends.

- The MWD tool enables monitoring of the acoustic properties of the annulus for early gas-influx detection. Pressure pulses generated by the MWD pulser are recorded and compared at the standpipe and the top of the annulus. Full-scale testing has shown that the presence of free gas in the annulus is detected by amplitude attenuation and phase delay between the two signals. For water-based mud systems, this technique has demonstrated the capacity to consistently detect gas influxes within minutes before significant expansion occurs. Further development is currently under way to improve the system's capability to detect gas influxes in oil-based mud.
- Some MWD tools feature kick detection through ultrasonic sensors. In these systems, an ultrasonic transducer emits a signal that is reflected off the formation and back to the sensor. Small quantities of free gas significantly alter the acoustic impedance of the mud. Automatic monitoring of these signals permits detection of gas in the annulus. It should be noted that these devices only detect the presence of gas at or below the MWD tool.

The MWD tool offers kick-detection benefits, if the response time is less than the time it takes to observe the surface indicators. The tool can provide early detection of kicks and potential influxes, as well as monitor the kick-killing process. Tool response time is a function of the complexity of the MWD tool and the mode of operation. The sequence of data transmission determines the update times of each type of measurement. Many MWD tools allow for reprogramming of the update sequence while the tool is in the hole. This feature can enable the operator to increase the update frequency of critical information to meet the expected needs of the section being drilled. If the tool response time is longer than required for surface indicators to be observed, the MWD only serves as a confirmation source.

Kick identification

When a kick occurs, note the type of influx (gas, oil, or salt water) entering the wellbore. Remember that well-control procedures developed here are designed to kill all types of kicks safely. The formula required to make this kick influx calculation is as follows:

$p_{kr} = p_{\Sigma} - p_{sidp}$,....................(1)

where g_i = influx gradient, psi/ft; g_{mdp} = mud gradient in drillpipe, psi/ft; and h_i = influx height, ft. The influx gradient can be evaluated using the guidelines in **Table 1**.

TABLE 4.9—INFLUX GRADIENT EVALUATION GUIDELINES

Gradient (psi/ft)	Influx Type
0.05–0.2	Gas
0.2–0.4	Probable combination of gas, oil, and/or salt water
0.4–0.5	Probable oil or salt water

Table 1- Influx Gradient Evaluation Guidelines

Although p_{sidp} and p_{sic} can be determined accurately for **Eq. 1**, it is difficult to determine the influx height. This requires knowledge of the pit gain and the exact hole size. Example 1, described later, illustrates Eq. 1.

Kill-weight mud calculation

It is necessary to calculate the mud weight needed to balance bottomhole formation pressure. “Kill-weight mud” is the amount of mud necessary to exactly balance formation pressure. It will be later shown that it is safer to use the exact required mud weight without variation

Because the drillpipe pressure has been defined as a bottomhole pressure gauge, the p_{sidp} can be used to calculate the mud weight necessary to kill the well. The kill mud formula follows:

$$\rho_{kw} = 19.23 p_{sidp} / D_{tv} + \rho_o, \text{ ....(2)}$$

where ρ_{kw} = kill-mud weight, lbm/gal 19.23 = conversion constant D_{tv} = true vertical-bit depth, ft ρ_o = original mud weight, lbm/gal.

Because the casing pressure does not appear in **Eq. 2**, a high casing pressure does not necessarily indicate a high kill-weight mud. The same is true for pit gain because it does not appear in Eq. 2. Example 1 uses the kill-weight mud formula.

Example 1

What will the kill-weight mud density be for the kick data given below?

D_{tv} = 11,550 ft

ρ_o = 12.1 lbm/gal

p_{sidp} = 240 psi

p_{sic} = 1,790 psi

Pit gain = 85 bbl

Solution.

$\rho_{kw} = p_{sidp} \times 19.23 / D_{tv} + \rho_o$ = 240 psi × 19.23/11,550 ft + 12.1 lbm/gal = 0.4 lbm/gal + 12.1 lbm/gal = 12.5 lbm/gal

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Nomenclature

D_{tv} = true vertical depth, bit depth, ft

g_i = influx gradient, psi/ft

g_{mdp} = mud gradient in drillpipe, psi/ft

h_i = influx height, ft

ρ_{kw} = kill mud weight, lbm/gal

ρ_o = original mud weight, lbm/gal

p_{sic} = shut-in casing pressure, psi

p_{sidp} = shut-in drillpipe pressure, psi

Noteworthy papers in OnePetro

Nas, S. 2011. Kick Detection and Well Control in a Closed Wellbore. IADC/SPE Managed Pressure Drilling and Underbalanced Operations Conference and Exhibition, 5–6 April 2011, Denver, Colorado, USA. SPE-143099-MS. http://dx.doi.org/143099-MS (http://dx.doi.org/143099-MS)

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Hornung, M.R. 1990. Kick Prevention, Detection, and Control: Planning and Training Guidelines for Drilling Deep High-Pressure Gas Wells. SPE/IADC Drilling Conference, 27 February-2 March 1990, Houston, Texas. SPE-19990-MS. http://dx.doi.org/10.2118/19990-MS (http://dx.doi.org/10.2118/19990-MS)

External links

See also

Well control

Variables affecting kill procedures

Production logs to assess gas kick

PEH:Well_Control:_Procedures_and_Principles

Category

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