UNDERBALANCED DRILLING OVERVIEW

"Underbalanced drilling operations reduce the hydrostatic pressure of the drilling fluid column so that the pressure in the wellbore is less than the formation pressure".

Introduction

Conventional drilling practice calls for maintaining the hydrostatic pressure of the drilling fluid between the formation's pore pressure and its fracture pressure. The drilling fluid is continuously circulated within the wellbore to control the formation fluids and transport cuttings to the surface. It also works as a stabilizing agent within the wellbore, and lubricates and cools the drill bit. The fluid is either a water-based or oil-based liquid that varies from 7.8 to 19 pounds per gallon, and contains a variety of solid and liquid products to impart density, fluid loss characteristics and rheological properties.

The conventional practice described above has long been recognized as the safest method for drilling a well. It does, however, have drawbacks. Since the drilling fluid pressure is higher than the natural formation pressure, fluid invasion frequently occurs, causing permeability damage to the formation. This damage is mainly caused by washout or physical blockage by the intrusion of fluids and/or solids into the formation structure.

**Underbalanced drilling (UBD)** is defined as the practice of drilling a well with the wellbore fluid gradient less than the natural formation gradient. It differs from conventional drilling in that the bottomhole circulating pressure is lower than the formation pressure, thereby permitting the well to flow while drilling proceeds.

![Figure 1](image)
Besides minimizing lost circulation and increasing the penetration rate, this technique has a widely recognized benefit of minimizing the damage caused by invasion of drilling fluid into the formation. In many UBD applications, additional benefits are seen due to reduction in drilling time, increased bit life, and early detection and dynamic testing of productive intervals while drilling. It is critical to keep the well underbalanced at all times, if formation damage is to be minimized.

Underbalanced drilling technology is a valuable method for minimizing formation invasion related problems. Because the majority of hydrocarbons today are found in existing fields with depleting pressures, or in complex and low quality reservoirs, the economical use of UBD becomes more and more popular.

Most of the underbalanced drilling applications today are conducted through the use of coiled tubing systems. Forty percent of all the onshore wells drilled in the year 2000 were conducted through underbalanced conditions. Joint industry projects currently underway off the coast of Brazil will likely change the conventional drilling practices in offshore applications.

"Underbalanced drilling technology can save the industry millions of dollars by increasing the amount of recoverable oil within a shorter time frame".

History of Underbalanced Drilling

The concept of drilling with low pressure circulating fluid was first patented in the United States in 1866. Early applications used compressed air to drill the hole. As the technology evolved over the years, gas internal systems with stable foams and aerated fluids were introduced for specific drilling conditions.

the technique called flow drilling was first developed in South Texas, and became very popular worldwide with early successful applications in Southern Canada, Australia and China. It was primarily used for re-development of fields where depleted pressure was an important concern.

During the 1990’s, underbalanced drilling was successfully applied in onshore and offshore drilling operations throughout Europe.

Early techniques developed by Angel (1957) and, Moore and Cole (1965) tried to predict the volume of air or gas required to adequately clean the air-drilled hole. There were also several attempts published in the literature to develop a systematic design procedure for estimating wellbore hydraulics in underbalanced drilling applications.
Currently, underbalanced drilling is the most exciting development in the area of drilling engineering.

Together with horizontal and multi-lateral drilling techniques, it holds tremendous value for drilling more cost-effective wells.

**UNDERBALANCED DRILLING TECHNIQUES**

Underbalanced drilling techniques are classified according to density of the fluids used in the process. Typical fluid densities range from near 0 to 7 pounds per gallon.

In fresh-water applications, the density of the circulating fluid can be reduced by nitrogen gas injection. This reduced density helps to achieve a bottom hole circulating pressure that is less than that of the formation pressure.

Even conventional liquids can provide underbalanced conditions with proper density control of the drilling fluid. On the other hand, it is also possible for a low-density fluid to cause overbalance due to the frictional pressure drop.

Underbalanced drilling has proved to be an economical method for drilling in depleted/low pressure reservoirs. Since it is possible to record production during drilling, operators can easily and accurately identify inflow mechanisms and pay intervals, and cease drilling operation as soon as the target zones are identified.

One method of controlling the bottomhole pressure (BHP) is to use a choke at the surface. BHP is controlled by opening or closing the choke to lower or raise the standpipe pressure. Since the speed of a pressure wave through a static fluid column is equal to the speed of sound in the same medium, a lag time is experienced until the choking action at the surfaces reaches bottomhole. Estimating the lag time in a single-phase system is relatively easy, whereas the same calculation in multi-phase systems can be quite complicated.

Instead of using a choke, the BHP can also be controlled by adjusting the Equivalent Circulating Density (ECD). This technique essentially creates an increasing fluid density gradient between the surface and the bottomhole. If the casing is set at a shallower depth, ECD is preferred over choke pressure control. Since ECD is a function of flow, underbalanced conditions should be preserved by controlling the hydrostatic head when flow stops during connections.

The greater the flow resistance, the higher ECD will be. On the other hand, it can also create an opposing condition when pipe is pulled out of the hole, causing a swabbing effect.
Underbalanced Drilling Fluids

There are three primary types of fluids used in underbalanced drilling operations:

- Gaseous (Compressible)
- Two-phase
- Liquid (Incompressible)

The fluid type is dictated by the boundary conditions of the drilling system. Typically, the boundary conditions are defined by bottomhole flowing pressure, formation fracture pressure, borehole collapse pressure and formation pore pressure. The density range of various drilling fluids is summarized in the following diagram.

Two different measures are used to define the type of fluid system:

- Ratio, the gas-to-liquid volume at standard conditions.
- Quality, the ratio of gas volume to liquid volume at hole conditions.
Gas-to-liquid ratios of various drilling fluid systems are shown in the following figure.

![Diagram showing gas-to-liquid ratios](image)

**Figure 3**

**Gaseous Drilling Fluids**

The oldest and most basic technique is dry air drilling, which involves pumping air down the drill string and up through the annulus. A rotating wellhead between the blowout preventer and rotary table is used to divert the returns. The cuttings are sent away from the rig via a discharge pipe, and a water spray is used to kill dust at the outlet. A flame is used to burn any returning hydrocarbons.

Nitrogen is another common drilling fluid. Other inert gases are too expensive to be used in this process. A typical method to generate N₂ is to use membrane type filters that extract the N₂ from the air stream before it is pumped into the wellbore.

Natural gas is also a drilling fluid option, since it is easily available from pipelines. It can directly be used without the help of compressors. More information on nitrogen and natural gas drilling is provided under the "Underbalanced Drilling Methods" subtopic.

Circulating pressure and hole cleanup are dependent on each other. More cuttings in the wellbore
cause higher downhole pressures. Angel’s method provides some guidelines regarding air flow rates required for hole cleaning. His charts are still widely used. According to these charts, 3000 ft/min is the minimum velocity for effective cutting transport.

Two-Phase Drilling Fluids

Two-phase drilling fluids, or lightened drilling fluids, consist of either foam-type fluids or aerated drilling mud. Liquids are mixed with gas to achieve a required circulating fluid density. The equation of state method is used to predict fluid properties at downhole conditions.

A pump is used to inject liquid into a gas stream before it enters the well. The small liquid droplets affect the behavior of the circulating gas. If more liquids (2.5% -25%) are introduced, then a foam phase is generated in which the liquid forms a continuous structure, entrapping the gas bubbles inside.

Once the liquid volume exceeds 25%, we no longer have a foam structure. This next level comprises aerated drilling muds (fresh water, brine, diesel or crude oil). Parasite strings are typically used to introduce gas into the circulating liquid stream. A parasite string is an external flow path (possibly coiled tubing), which is run and cemented outside of the casing.

Since gas and liquid compressibility values differ significantly from each other as pressure and temperature changes, the liquid fraction changes as well. Frictional pressure drops are controlled mainly by the flow regime, flow rate, fluid properties and flow geometry. Therefore, phase behavior is a very important component in underbalanced drilling models. Many investigators, including a special institute at the University of Tulsa, have extensively analyzed two-phase flow patterns and regimes. Some of the most common two-phase flow regimes are:

- Bubble flow
- Annular dispersed flow
- Stratified or laminar flow
- Plug or churn flow
- Slug flow

Liquid Drilling Fluids

Since formation pressure is usually larger than the hydrostatic pressure of fresh water or saline water, conventional drilling fluids might also provide underbalanced conditions. Even if the drilling fluid density exceeds the formation pore gradient, fluid loss into a formation can cause reduced
pressure regions within the wellbore, thus allowing formation fluids to flow in.

**BENEFITS AND LIMITATIONS OF UNDERBALANCED DRILLING**

**Advantages**

Underbalanced drilling offers a number of important benefits:

- Maintaining wellbore pressure below the reservoir pressure allows reservoir fluids to enter the wellbore, thus avoiding formation damage. Since significant formation damage is avoided, the stimulation requirements during well completion are also reduced, leading to considerable savings.
- During underbalanced drilling there is no physical mechanism to force drilling fluid into the formation drilled. Therefore, lost circulation is kept to a minimum when fractured or high permeability zones are encountered.
- Drilling underbalanced can help in detecting potential hydrocarbon zones, even identifying zones that would have been bypassed with conventional drilling methods.
- Due to the decreased pressure at the bit head, UBD operations demonstrate superior penetration rates compared to conventional drilling techniques. Along with reduced drilling times, an increase in bit life is typically reported.
- Since there is no filter cake around the wellbore wall, the chances of differential sticking are also reduced.
- Since conventional drilling fluids are not used in underbalanced drilling applications, there is no need to worry about disposing potentially hazardous drilling mud.

A combination of all these factors can significantly improve the economics of drilling a well. UBD is often preferred if it reduces formation damage and hole problems, and reduces the cost of stimulation in fractured or moderate/high permeability formations. Moreover, with good mud logging and drilling records, UBD can provide valuable Formation Evaluation data.

**Disadvantages**

Underbalanced drilling also has disadvantages that can prove detrimental to the outcome of the drilling process:

- There is a higher risk of blowout, fire or explosion.
Underbalanced drilling is still an expensive technology. Depending on the drilling fluid used, the cost can be significant, particularly for extended reach horizontal wells.

- It is not always possible to maintain a continuously underbalanced condition. Since there is not a filter cake around the wellbore, any instantaneous pulse of overbalance might cause severe damage to the unprotected formation.
- UBD has its own unique damage mechanisms, such as surface damage of the formation due to the lack of heat conduction capacity of underbalanced drilling fluids.
- It is more complicated to model and predict the behavior of compressible drilling fluids.

**Hole Cleaning Considerations**

Decreased bottom hole pressure typically causes higher penetration rates. However, higher penetration rates can increase the circulating bottom hole pressure and bring the well back to overbalanced conditions. Moreover, due to the annular fluid segregation, there is an increased risk that the wellbore will pack-off, resulting in stuck pipe. In this situation, gas tends to rise while the liquid settles to the bottom of the hole. This is a major cause of increased bottom hole pressures because of the increased fluid density at the sand face.

Large cutting volumes generated by high penetration rates are also difficult to remove. Therefore, penetration rates should be carefully adjusted to ensure sufficient hole cleaning and slug removal.

Inadequate liquid flow rates can cause sticky-hole conditions that result in differential sticking. A decrease in ROP would therefore be needed for the cuttings to be transferred to the surface. A viscosified aqueous phase is an important factor in achieving better ROP.

When drilling with foam and mist, hole cleaning efficiency reaches a limit after a certain level of underbalance, and the drilling rate starts to decrease as illustrated in the following figure.
In this situation, an increase in fluid rate is needed to increase the cleaning action and allow a higher rate of penetration.

**Limiting Technical Factors**

Major technical factors that restrict the application of underbalanced drilling techniques are listed as follows:

- Reduced wellbore pressure gradients can cause hole stability problems
- Formation of mud rings can block air flow, leading to downhole fires
- Water causes cuttings to accumulate, possibly causing the drill string to stick. If aerated mud is used rather than air, differential underbalance can be reduced.
- HC’s and air often mix to achieve a flammable range. With a small spark, which can be generated by the contact between the drill string and hard minerals, the risk of fire increases.
- Stable foam condition is not easy to achieve.

Depending on the drilling site location, logistical and economical constraints can be substantial. Similarly, the need for specialized drilling equipment can also render underbalanced operations uneconomical.
“Even though the cost of drilling underbalanced could be more expensive than conventional overbalanced drilling, due to the increased ROP and reduced formation damage, it often turns out to be the more cost-effective drilling technique.”