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Exploring Underbalanced Drilling: A Comprehensive Review

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ABSTRACT:
Underbalanced Drilling (UBD) is an advanced drilling technique employed in oil and gas industry to improve well productivity and reduce formation damage. In conventional drilling, overbalance conditions are maintained in order to prevent the influx of formation fluids. In contrast, UBD involves maintaining a hydrostatic pressure lower than the formation pressure during drilling operations. UBD offers several advantages, such as increasing drilling rates, reducing formation damage, improving wellbore stability. By preventing the flow of drilling fluids in to the formation, UBD reduces the risk of formation plugging and improves the recovery of hydrocarbons. This technique is particularly beneficial for depleted reservoirs or formations prone to lost circulation problems. Despite its advantages, proper planning and execution are essential for UBD to manage the associated risks, such as wellbore stability challenges and the potential for unexpected influx of formation fluids. UBD involves the use of specialized equipment such as BOPs, RCDs to manage the hydrostatic pressure of well and control the influx of formation fluids. In conclusion, a comprehensive understanding of UBD is essential for maximizing hydrocarbon recovery alongside a commitment to operational safety and environmental sustainability in the dynamic landscape of the oil and gas industries.

Keywords: Underbalanced drilling, Formation Fluids, Hydrocarbons, BOP, RCD.

INTRODUCTION:

In the ever- evolving landscape of global energy demands, the exploration and extraction of petroleum and natural gas play a crucial role in sustaining industrial progress and meeting the increasing demands of a growing population. Oil and gas drilling is a crucial process of the petroleum industry which involves extracting hydrocarbons typically oil and gas from beneath the earth's surface. This process serves as a gateway to access the vast deposits of hydrocarbons beneath the earth's surface. The earliest records dates back to the 19th century, where the first modern oil well was drilled in Pennsylvania, United States by Edwin Drake. The discovery of vast petroleum reserves in regions like Texas and California led to the expansion of the oil and gas industry. The 20th century witnessed more advancements in drilling operations with the introduction of rotary drilling, directional drilling, automated drilling and many more. Since then, the implementation of advanced drilling techniques such as rotary drilling and the utilization of offshore drilling rigs have undoubtedly resulted in significant improvements in the efficiency of oil extraction. Various modern techniques like Underbalanced Drilling, Managed Pressure Drilling has also enabled the extraction of hydrocarbons from depleted reservoirs that are challenging to drill conventionally. The oil industry has experienced a significant transformation as a result of the advancement of various drilling

methods, leading to a rise in the production of hydrocarbons, a crucial requirement to meet the increasing global energy needs.

This paper aims to provide a concise review of the key aspects of Underbalanced Drilling (UBD), including its benefits, challenges as well as the execution of UBD in India.

UNDERBALANCED DRILLING:

Underbalanced Drilling (UBD) is an advanced drilling technique employed in oil and gas industry to improve well productivity and reduce formation damage. Conventional drilling involves the use of drilling fluids with density greater than that of formation fluid, creating a hydrostatic pressure which prevents influx of formation fluid and wellbore instability. However, the conventional drilling techniques comes with some inherent limitations such as formation damage, lost circulation and reduced drilling rates. To encounter these problems, underbalanced drilling was introduced which mainly aims at maintaining a hydrostatic pressure lower than the formation pressure. This technique not only reduces formation damage but also promotes faster drilling rates and improved well productivity. Borehole problems such as pipe sticking and lost circulation can be significantly reduced by transitioning to underbalanced drilling.

Drilling in matured reservoirs which are characterized by declining hydrocarbon production rates, is challenging due to their high cost. Surrounding formations typically exhibit high pore pressure, requiring the use of high density drilling fluids to maintain a balance. However, the use of highly dense fluids can lead to problems like formation damage and lost circulation. Underbalanced drilling emerges as the solution to these problems where the density of drilling fluid is precisely calibrated to counterbalance the lowest pore pressure in the reservoir, thus mitigating the problems associated with excessively dense fluids. The density of drilling fluids employed in underbalanced drilling ranges from 0 PPG TO 7 PPG.

Underbalanced drilling requires the use of specialized equipment to manage the hydrostatic pressure of the well and to control the influx of formation fluids. Proper risk management and utilizing sophisticated well control systems are essential for ensuring the safety of operations during underbalanced drilling. Nowadays, underbalanced drilling is gaining widespread acceptance at a rapid rate due to its capability to reduce invasive formation damage and drilling problems associated with many horizontal wells in challenging reservoir conditions.

INDICATIONS OF A GOOD CANDIDATE FOR UNDERBALANCED DRILLING:

- Underbalanced drilling is more effective for depleted and consolidated formations.
- Naturally fractured formations which are susceptible to problems such as differential sticking and high lost circulation are regarded as viable options for the practice of underbalanced drilling.
- Highly permeable formations with reduced pore pressure are considered as good candidates for underbalanced drilling.
- Underbalanced drilling is considered a healthy option for formations with low to moderate permeability.
- Underbalanced drilling is often considered a desirable choice for formations which exhibits low rate of penetration in overbalanced drilling.
- Formations with rock fluid sensitivities are considered as good option for underbalanced drilling.

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UNDERBALANCED DRILLING FLUID SYSTEM:

Various low-density drilling fluid techniques have been formulated to maintain the well in an underbalanced state, whose classifications are listed below:

a) **Air/Gas Drilling:** The use of air or gas as a circulation medium commenced in the early 1950s.It mainly involves utilizing compressed air as drilling fluid. The density of compressed air or gas ranges from 0.01–0.1 pounds per gallon (PPG). Air drilling is limited to only dry formations.

b) **Mist/Unstable foam Drilling:** Compressed air or gas along with an incompressible fluid (oil, water) is injected into the formation. The introduction of liquid into the gas stream leads to the formation of a mist or an unstable foam, thus establishing an unstable foam drilling method. It is widely used for formations such as CBM.

c) **Stable Foam Drilling:** The introduction of foam drilling fluids to underbalanced drilling dates back to the 1970s to encounter the problems of lost circulation. Foam drilling involves the addition of gas into a liquid phase to create a stable foam. This stable foam has a low density and possess very high carrying capacity. It is mainly suitable for formations with low to moderate permeability.

d) **Aerated Drilling:** Aerated drilling fluid involves injecting compressed air into a viscosified fluid or mud to create an aerated mixture. The main objective of aeration is to lower the density of the fluid column within the formation and minimize the risk of lost circulation, while also maintaining the properties of the drilling fluid.

Table 1. Properties of drilling fluids (Al-Darweesh, 2022)

Type of Fluid	Density (PPG)	Gas ratio	Annular Velocity (ft./min)
Air/gas	0.01-0.1	>99%	3000
Mist	0.1-0.3	96-99%	3000
Foam	0.3-7	55-99%	100-300
Aerated Fluids	4-7	<55%	1000-1600

SURFACE EQUIPMENTS FOR UNDERBALANCED DRILLING:

a. **Rotating Control Device (RCD):** An RCD is a specialized equipment installed at top of the annular BOP that contracts and seals the drill string for the purpose of preventing the influx of formation fluids into the wellbore and maintaining unbalanced conditions.

b. **Blowout Preventers (BOP):** These are the high-pressure valves which seals off the top of the well. BOPs are used to prevent the uncontrolled flow of formation fluids into the wellbore.

c. **Choke Manifold:** The choke manifold is a critical component in underbalanced drilling used for controlling the flow of drilling fluids and maintaining the desired pressure at wellbore. It typically consists of a set of high-pressure valves and chokes that regulates the fluid flow.

d. **Four- Phase Separation System:** In underbalanced drilling, a four-phase separation system is used to separate and manage the different fluid phases (oil, gas, water and solids) encountered during the operation.

ADVANTAGES OF UNDERBALANCED DRILLING:

The various advantages of underbalanced drilling are mentioned below:

a) **Reduction in Formation Damage:** During overbalanced drilling operations, the increased hydrostatic pressure leads to the invasion of drilling fluids into the formation, forming a skin around the wellbore. This skin hinders the flow of formation fluids into the wellbore, thereby reducing the production rate and increasing fluid loss. This effects are more pronounced in fractured formations where drilling fluids penetrates deep into the formation, making recovery of hydrocarbons more challenging. Since hydrostatic pressure is kept lower than the formation pressure in underbalanced drilling, there are no chances of drilling fluid invasion into the formation which can cause formation damage.

b) **Improved penetration rates:** In underbalanced drilling, hydrostatic pressure is kept lower than the formation pressure due to which rate of penetration (ROP) increases. This can lead to an increase in drilling efficiency, potentially saving both cost and time.

c) **Eliminates Differential Pipe Sticking:** The differential pipe sticking problems are very uncommon in underbalanced drilling operation. Differential pipe sticking mainly occurs when there is a huge pressure difference between the hydrostatic pressure and formation pressure which leads to the formation of thick mud cakes in the borehole. However in underbalanced drilling, the hydrostatic pressure is less than the formation pressure so no mud cake builds up. Thus, the conditions for differential sticking are reduced.

d) **Prevents Lost Circulation:** Lost circulation is the uncontrolled flow of drilling fluids into the formation, especially observed in fractured or high permeable formations during overbalanced drilling operations. However this problem can be encountered by employing the underbalanced drilling techniques. In this case, the formation pressure is kept high enough to prevent drilling fluid to flow into the formation, ultimately reducing the chances of lost circulation.

e) **Increasing Recovery Efficiency:** The invasion of drilling fluid into the formation is very common in overbalanced drilling which can decrease the formation permeability and also alter the viscosity of formation fluids. Employing underbalanced drilling hinders the occurrence of this alteration in properties, thereby maximizing the hydrocarbon recovery.

f) **Improved reservoir Characterization:** Underbalanced drilling allows for better reservoir evaluation by minimizing the invasion of drilling fluids into the formation as the hydrostatic pressure is maintained less than the formation pressure. This can result in more accurate measurements of formation properties like porosity and permeability.

g) **Extended Well Life:** Underbalanced drilling has the potential to extend the well's productive life by minimizing formation damage and maintaining the permeability of the formation.

LIMITATIONS OF UNDERBALANCED DRILLING:

Despite its advantages, underbalanced drilling also comes with its own set of challenges which are mentioned below:

a) **Well Control Challenges:** Underbalanced drilling involves maintaining a lower hydrostatic pressure than the formation pressure which increases the risks of kicks and blowouts if not properly maintained. Rigorous well control procedures and equipment are required to mitigate these challenges.

b) **Invasion of Formation Fluids:** The low pressure in the wellbore in the case of underbalanced drilling causes the invasion of formation fluids into the wellbore. This may not be desirable in some drilling scenarios and hence proper measures must be taken to handle such problems.

c) **Wellbore Instability:** Lower hydrostatic pressure in the wellbore can lead to its instability. This may lead to wellbore collapse and caving of wellbore walls, thus giving rise to problems like stuck pipe and lost circulations.
d) **Cost Factor:** Implementing underbalanced drilling is very costly as it involves the use of specialized equipment, increased safety measures and additional monitoring to manage the risk associated with this technique.
e) **Limitability:** Underbalanced drilling is only limited to low permeable formations. Highly permeable formations with high pore pressure are not suitable for underbalanced drilling because the fluid production rates will be high that leads to extra handling and control equipment.

A STUDY ON THE EXECUTION OF UNDERBALANCED DRILLING IN INDIA:

The first execution of underbalanced drilling in India took place at Bombay High in 2016 which was carried out by ONGC. The main objectives of this project was:

- Zero damage to formation and thereby enhancing oil production from the wells.
- Reduction of NPT due to mud losses.
- Reservoir assessment while drilling.
- Improved well placement in the reservoir through real-time analysis.

Project execution: The drilling for three wells of HK up to the target point was completed by March 17, 2016. The assembly of the underbalanced drilling equipment rig commenced 11 days prior to the rig's involvement in the preparation of the wells for underbalanced drilling.

Underbalanced drilling started on April 6, 2016 in the first well HK#2H. Drilling was initiated by injecting nitrogen in a concentric annulus of 9⅝-in. x 7-in. tieback casing with an under balance of 100 psi while pumping base oil as drilling fluid.

Based on the knowledge and experience gained from the first well, equipment rig-up on the second well, HK#9H, was completed in 5.5 days. The well started producing crude while drilling a 6-in. drain hole in under balanced condition.

The well was flowing at an average rate of 1683 b/d during the test. Drilling operations were then ceased, followed by the real-time analysis of the reservoir fluid and LWD logs.

Highlights:

- Real time monitoring of reservoir behaviour while placing the well improved decision making.
- Well HK#9H produced well fluid while drilling a 6-in. drain hole.
- A complete package of RSS-LWD was run in UBD conditions.
- Lower completion ERD packer set in under balance condition.
- During drilling with UBD technology about 4,699 bbl. of crude was exported to the platform.
- UBD specific wellhead assembly was designed in consultation with M/s BHEL.

CONCLUSION:

Underbalanced drilling emerges as a promising solution to overcome the limitations associated with overbalanced drilling techniques, especially in depleted formations which are experiencing declining production rates. The implementation of underbalanced drilling spans a wide range of reservoir classifications, ranging from conventional oil and gas reservoirs to unconventional resources like shale

formations, thereby exhibiting its adaptability and flexibility within the oil and gas industry. The implementation of underbalanced drilling has seen a remarkable success in terms of well productivity, minimizing formation damage, increasing reservoir efficiency etc. However, underbalanced drilling comes with its own set of challenges such as well control problems, safety issues, need for specialized equipment, high cost factors etc.

But with the continuous advancement of technology, the industry's ability to overcome these challenges and optimize underbalanced drilling techniques is likely to increase. Ongoing researches and studies are focussing on development of more effective well control methodologies, improving the reliability of the equipment and broadening of the utilization of underbalanced drilling to a wider array of geological formations. The unyielding pursuit of knowledge and progress in this particular domain is crucial for unlocking the potential of underbalanced drilling while promoting a responsible and sustainable extraction of hydrocarbons.

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