Dual Gradient Drilling in Energy Efficient and Safe Manner

A. Kartik, Abhay Sharma, and Arti Jain

***Abstract*—At present the deep sea drilling utilizes conventional drilling fluids and enormous number of casings which significantly affects the fluid density. The well productivity is directly affected by the inculcation/leakage of mud in low producing zones. The cost of deep sea water exploration rapidly increases and at the same time imposes technical boundaries on the depths of the well that can be reached thereby affecting the productivity. Dual Gradient Drilling (DGD) is the establishment of multiple pressure gradients within the selected sections of the annulus for managing the annular pressure profile. DGD is a particular type of managed pressure drilling. In this paper we discuss the process of DGD in detail using energy efficient methods and the various advantages which this technology has to offer keeping in mind the health, safety and environment. In a nutshell DGD is an area which implemented properly using appropriate methods can help in reaping maximum benefits of Off-Shore Drilling.**

***Index Terms*—Bottom hole pressure, managed pressure drilling, variable frequency drives, water effluent treatment.**

I. Introduction

Drilling of hydrocarbons to satisfy the ever-growing needs of the world in deep oceans is a challenging task. Deep water exploration and production sector is necessary if the ever increasing needs for hydrocarbons of the world are to be satisfied. In order for this sector to evolve, research and development of new technologies has become a necessity. Among the various technologies "Dual Gradient- Drilling" or "Deep-Sea Drilling" is the most eye catching one at present in the world.

In this method the mud returns to one or more than one pipe(s) according to the needs, separate from the drill pipes instead of returning through the conventional, large diameter, drilling risers. Oil and Gas industry has heavily relied only on single gradient drilling to drill the deepest of the deepest. In this technology of drilling, the problem is the control of bottom hole pressure by the mud column which extends from the rig to the bottom of the wellbore. This problem makes it difficult to reach the total depth of the formation because of narrow margin between the pore pressure and the fracture pressure. The comparison between the conventional and dual gradient drilling is depicted in Fig. 1.This problem is the prime reason which has led to invention of deep sea water drilling technology (DSD) or dual gradient drilling technology (DGD). [1]

One of the big advantages of this technique is the easy discovery of oil and gas pools at greater depths by an engineer than conventional method. This is also known as riser less drilling. In this new technology a heavy density fluid runs from the bottom hole to the mudline and a low density fluid of around 8.6 ppg from the mudline to the rig floor, which helps in the maintenance of bottom hole pressure according to the requirements. This technology also helps in the elimination of the impact of water depth on the well design [2].

Some background preparations must be done before the commencement of the dual gradient drilling process. Two circulation systems must be installed, one for mud control and the other for the control of sea water. The sheer weight of the mud pump must be considered in addition to the presence of subsea rotating diverter. This diverter provides the required mechanical interface between the mud in the wellbore and seawater in the riser, also helping in preventing the gas from entering the riser [3].

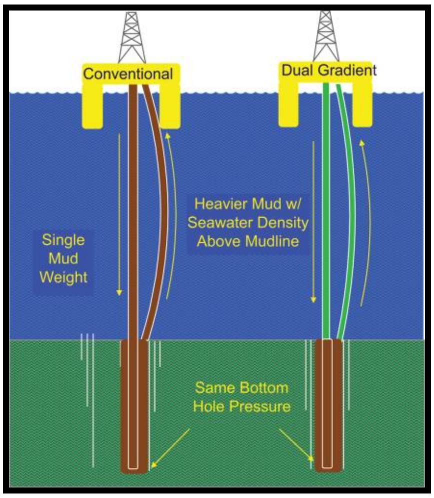

Fig. 1. The comparison between the rig structures of conventional drilling and dual gradient drilling depicting the different density fluids from the bottom hole to the rig floor [4].

II. Need for DGD/Issue to Be Rectified / Problem

Dual Gradient Drilling is required in water depths greater than 5000 feet. The formations of reduced fracture gradient below the mudline due to reduced weight or gradient which in itself is a consequence of water above the mudline as seen from the drill ship at sea level makes dual gradient drilling a necessity. [5] This concept helps in reducing the total number of equipments required for operations and the intervention risks on the sea floor. To avoid hitting the legendary wall in deep waters and ultra-deep water drilling dual gradient drilling is only feasible pathway for the oil and gas industry. In conventional deep water drilling, the depth of water

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increases the complications in the well design which leads to the use of numerous casing strings. This leads to very close tolerance levels in the working environment and there may be significant stresses on long riser strings due to vibration in deep water levels. But dual gradient drilling allows us to overcome this problem as the well design is not affected by the depth of water. [6] Unwanted hydrostatic pressure is exerted on the well bore due to the filling of marine riser with weighted drilling fluid. This enormously impacts casing design and creates a host of down-hole technical issues which sometime become uncontrollable. In dual gradient drilling the riser is entirely filled with sea water which exerts less pressure and the drilling fluid is confined to the well bore. Therefore, the thin drilling window which exists due to the narrow margin between pore pressure and fracture pressure becomes appreciably wider and safer to drill. In a nutshell, the conventional fluids and casing programs result in numerous fluid density variations to navigate pore-pressure and fracture gradient window and multiple casing strings which result in the restriction of well depth achievable in the required hole size. The differences in the internal pressure of the mudline are depicted in Fig. 2.

The following are some of the unfulfilled wishes of the drilling managers and well designers:

- To overcome the narrow pressure fracture gradient (PPFG) margin.
- Drill deep and large holes than which are drilled at present with fewer casing strings.
- The management and control of the down hole pressure on the fly while drilling through shale, sand, rubber, salt and tar.
- To maximize the well productivity by controlling and managing the kicks and losses in the same open hole section.
- Maximization of well productivity using efficient ways of pore-pressure prediction.

III. Process

A specific type of managed pressure drilling is the dual gradient drilling. In this technology, the well bore is drilled with two different annulus fluid gradients in place. The efficiency of the entire process depends on the operating environment. To maintain optimum operating conditions a low density fluid is injected through a parasite casing string in a land well or through the marine riser when operating at subsea levels, or by actively pumping fluid returns from the sea floor through the lines external to a sea water filled riser. In each and every scenario the aim is to allow the adjustment of the bottom hole pressure to a pre-determined range without changing the base weight of the drilling mud. [8] This technology enables total well depth in the appropriate hole size in deep sea and deep well drilling.

Two types of dual gradient drilling are pump based drilling and dilution based drilling. In pump based drilling the entire system is dependent on subsea pumps. This system is designed so that it provides continuous loop circulating system for pumping the mud down the drill string and up the annulus to the well head, where the wellbore pressure at the seafloor is fundamentally the hydrostatic pressure of the sea water column above it. The main advantage of this type is absence of riser margin.

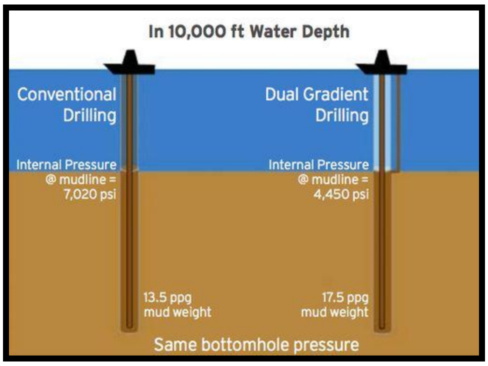

Fig. 2. Difference in internal pressure of the mud line [7].

In dilution based method of dual gradient drilling two fuel gradients are employed in the well bore. The down-hole mud weight determines the riser mud weight. Solids dilution, gas dilution etc. are the various types of dilution methods. The dilution to be used is dependent upon the type of hydrocarbon faced, the depth of the target and other chemical properties issue. Fig. 3 depicts dual gradient pressure profile. The location of the most critical and complicated components on the drilling rig is the main advantage of dilution based dual gradient drilling, this makes repair and maintenance works easier, more efficient and less costly [2]-[9].

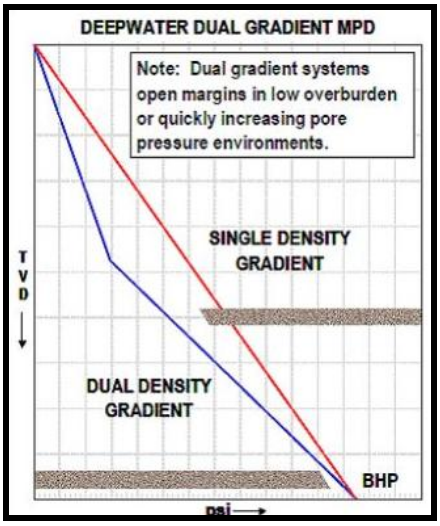

Fig. 3. Use of single density fluid for well bore causes the wellbore pressure to exceed the formation pressure and results in lost circulation. A lighter fluid in upper portion of the well bore and heavier fluid in the lower portion of the wellbore enables the pressure to stay constant in the pressure window between the pore pressure and fracture pressure in dual gradient drilling [10].

IV. Requirements of Dual Gradient Drilling

The equipments required for dual gradient drilling are as follows:

- Subsea Rotating diverter
- Mud Lift Pump
- Drill String Valve
- Marine Riser
- Mud Return Line
- Dual Trip Tanks
- Mani folding

A. Subsea Rotating Diverter (SRD)

This device is utilized for the following purposes:

- It separates the mud in the well bore from the seawater or seawater density fluid in the drilling riser using a mechanical barrier.
- The SRD operates with minimum differential pressure across it, but is used for maintaining pressure from either below or above to its working pressure of about 1000 psi.
- It diverts the mud in annulus through a solid processing unit.
- The SRD ensures that the size of all the debris and cuttings are minimum so that they do not block the mud lift pump and the return lines [2].

B. Mud-Lift Pump

This pump is installed on the riser above the blowout preventer. The drilling fluid enters this pump after passing through the SRD. Mud-lift pump is the most important part of the system. It performs the following operations:

- Mud-Lift pump channelizes the fluids up separate 6-inch ID return lines which is attached to the riser exterior, much like the choke and kill line.
- The Six diaphragm chambers of the mud-lift pump are activated by the sea water which is pumped into these using rig surface mud pumps enabling continuous pumping of mud.
- The six chambers can be operated together or can be operated in groups according to the needs or during emergency situation. This provides redundancy to maintain continuous operations.
- This pump is the used to feed the return lines also resulting in the dual density mud system [2].

C. Drill String Valve (DSV)

During the dual gradient drilling an undesirable condition of ‘u-tubing’ occurs when the mud pumps are stopped. These pumps deliver drilling mud into the drill string and also extract the return mud from the well bore and riser. Even after the mud pump is switched off the fluid continues to flow inside the drill string until the inside pressure of the drill string is balanced with the outside pressure creating the ‘u-tubing’ problem. This problem becomes severe in situations where a heavier density fluid precedes a lighter density fluid in the drill string. In this situation the heavier density fluid due to its own weight causes continuous flow in the drill string even after the powering down of the mud pumps. This ‘u-tubing’ issue creates undesirable well kicks and damages the drilling system. Therefore, to overcome the problem drill string valve is used. The drill string valve is a pressure balance drill pipe float with a huge spring that is run at or near the bit. In a nutshell the drill string valve performs the following functions:

- DSV controls the imbalance created due to the shutdown of the mud pumps.
- This prevents the occurrence of ‘u-tubing’ of fluid flow in the drill strings during the process.
- Provides more certainty in kick determination.
- Very helpful in flow rate management and well control pressure reading. [11]

D. Marine Riser

During the dual gradient drilling process the marine riser consists of sea water only. The mud lift pump is sea-water powered therefore; modifications in the riser are a must. The modifications in the marine risers have resulted in the attachment of two external lines to the existing structure. One line allows the passage of sea water power fluid to the mud-lift pump and the other line allows the return of drilling fluid from the sea floor to the rig surface. Boost line is absent from this. The sea water power line and mud return line are of six inches each [4]:

E. Mud Return Line

The mud return line is a part of the seafloor mud suction system. This system is required for returning the drilling mud back to the drill rig for re-circulation and conditioning. This return line works in coordination with the sea floor mud pump and it extends from the sea floor equipment back to the drill rig. The mud return line is positioned down to the sea floor and secured properly as the pipe exits the rig’s moon pool. In shallow depths of water this line is very flexible with a large diameter hose. But in deep water depths the mud line is made like strong steel pipe. The mud return line is one of the pillars of dual gradient drilling. Fig. 4 depicts the need of only few casing strings in dual gradient drilling and also achieving greater bottom-hole completion. [6], [12]

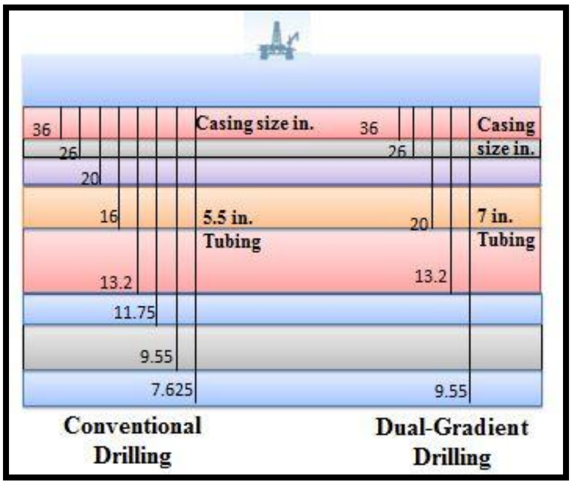

Fig. 4. Advantage of Dual Gradient Drilling[6].

F. Dual Trip Tanks and Manifold

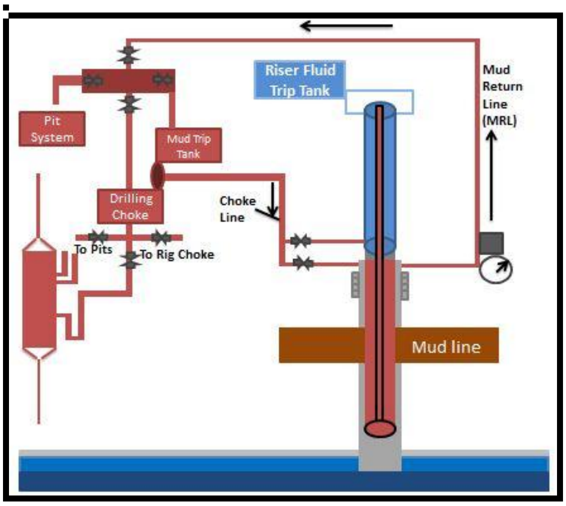

Fig. 5. Depiction of various manifolds used in the dual gradient drilling process [13].

In dual gradient drilling dual trip tanks are used. One is used for the riser fluid. While the other one is used for the mud in the hole below it. Both the tanks are circulating trip tanks. The manifold provides the required path for diversion of mud to the pits, rig choke and the drilling choke. The tripping and displacement manifold allows the management of fluids in the choke and kill line and also in the riser; which have been appropriately depicted in Fig. 5 [13].

V. Advantages and Limitations

The benefits and advantages of dual gradient drilling are as follows:

- This technology provides an opportunity to adjust equivalent mud-weight or the effective bottom-hole pressure by 0.5ppg or more without having to incur any flat time to perform a mud-density change.
- The management of the components of the hydrostatic head imparted on the well-bore by the mud and cuttings contained in the marine riser become more manageable.
- Dual-gradient deep water drilling moves the rig closer to the mud-line while viewed from the hydraulic effect perspective.
- This technique can be applied hand-in-hand with other managed pressure drilling (MPD) techniques. Pressurized mud-cap drilling and constant bottom hole pressure are the variants of the MPD in which dual-gradient drilling can be applied.
- This drilling is cost effective for operators and helps in the control of trouble zones through proper mud properties.

The issues which are limiting the growth and implementation of dual gradient drilling are as follows:

- Enormous gas expansion occurs during the flow of gas from shallow to deep waters.
- Deeper water depths utilize large amounts of gas for effective operations thereby increasing the running costs.
- The control of hydrostatic pressure for the given riser margin becomes difficult.

VI. Control of Energy Consumption/ Energy Efficient Practices

Lots of energy is used in dual gradient drilling process in various forms right from electrical energy for pumps, motors, cooling purposes for cabin work and water which is also a source of energy as a drilling fluid.

The pumping motors require lot of electrical current for the drilling purpose. The motors employed for pumping purposes can work up to a maximum permissible limit only. This limitation is decided by the locked rotor current of the pump motor. The locked rotor-current is four to seven times of the value of rated current. The value of locked current should be limited in order to protect various other equipments involved in the drilling process against power surges in connection with the power load. This limiting value of the locked rotor current will help in the protection of piping structures against excessive pressure surges [14]. Direct-on-line starter, star-delta starter, auto-transformer starter, resistor and soft starter and frequency converters can be used for limiting the locked rotor current. Of all these starters, frequency converters are the perfect device to control the performance of the pumps by adjusting the working speed of motor. This starter is ideal for reducing the locked rotor current and pressure surges on the drilling pipes.

The setting of the pump plays a major role in the drilling process. The depth at which the pump is installed beneath the ground is known as pump setting. One of the critical conditions to be taken care of is dynamic level of the working fluid; it must never fall below the inlet of the pump, if it does then there are chances of formation of cavity. This risk of cavity can be decreased by the use of submersible pumps [15]. This pump is a centrifugal pump attached to the electric motor and operates when submerged in water. This sealed electric motor spins a series of impellers. These pumps are highly efficient than the normal pumps, with high working capacity, require minimum maintenance and are economical for deep wells.

In some scenarios water hammering creates vacuum resulting in the penetration of air in the suction piping and pressurized piping. Variable frequency drives or soft starters can be used to prevent such critical situations. The installation of variable frequency drive offers following advantages:

- Decreases motor starting current and required kVA
- Provides high power factor which in turn decreases the reactive power in the circuit operations thereby reducing heat losses and unnecessary usage of energy
- It helps in energy savings and can be installed easily as per our requirements [16]

There are situations when the motors consume too much of electricity (kilowatt hours) than required of every m3 of fluid pumped out, thereby increasing the running costs and the overall economics of the process. This situation arises due to the requirement of very high starting frequencies for carrying out the operations. This situation can be rectified by installing variable frequency drives or by the decreasing the pump capacity.

Since, this drilling process is a continuous one and the equipments keep working non-stop, the operating temperatures of the motor increases over the time and the working performance of the pumps fall. This occurs due to various types of deposits on the surface of the motors and in the hydraulic parts of the pump. The solution to this problem lies in the continuous and proper maintenance of the pumps and motors. The piping should be cleaned properly at regular intervals and well filters should be used. The installation of the cooling sleeve on the motor also helps in such a scenario.

Air emissions from drilling operations are also an area of concern. The major sources of emission from drilling operations are as follows:

- Emissions from well testing and well clean up.
- Emissions from combustion processes occurring in the power generating equipments on the rig.
- Fugitive emissions from the process equipments.
- Emissions due to venting of storage vessels, drilling of fluids, bulk material transfer and other treatment facilities.

Emissions from power generating equipments on the rig are calculated, based on the diesel fuel consumption during the drilling operation. Flow rate of hydrocarbon production and its duration give the estimation of emissions from well testing. The most important and significant air emission which is of highest concern is from the combustion of diesel fuel for power generation, well testing and transportation. Diesel engines used for power generation are the major source of emissions from drilling operations. For reducing these operational emissions, improvement of the diesel engine efficiency is a must. One of the methods to make diesel engine more energy efficient and environmental friendly is by adapting the diesel injection technology. This technology decreases energy consumption and nitrogen dioxide emissions without affecting engine response or the output power deliverable. Centrifuge solids control equipment can also be installed for the removal of unwanted solids from recirculating mud stream [17].

VII. Safety Measures to Be Taken During Dual Gradient Drilling

Dual gradient drilling process offers various advantages over conventional drilling as explained earlier in this paper but appropriate safety measures must be taken to extract the maximum output from the DGD process without any mishap. The safety measures to be taken under various emergency situations are as follows:

1) Blow out Preventers (BOPs) are the devices used to control the release of oil in the situation of loss of well control. Extreme emergency situations may result in loss of power and communication between the surface equipments and blow out preventers resulting in a crisis. To avoid such a crisis detailed equipment certification should be done considering all the parts of the blow out preventers and specific care should be taken of the BOP stack design and its compatibility with the rig equipment without compromising any services. BOPs must have at least two sets of blind shear rams to prevent any kind of system failure if the drill tool is kept across one set of rams during an emergency [18].
2) During drilling operations the well creates a channel for the subsurface formations to potentially flow without any control to the surface. This is a concern in aspect of safety point of view. Appropriate methods like proper casing design; installation of mechanical plugs and securing the casing is a must for well control to avoid any kind of emergency.
3) The major pollutants which cause harm to the marine life and are very hazardous are the suspended solids, biodegradable organics, heavy metals and dissolved inorganic solids. To minimize the effects of these pollutants effluent water treatment is the best way forward which can be accomplished by the use of API separator, Tilted Plate separator, Flocculator, Clarifier and Trickling Filters. [19]
4) The health and safety of the working personnel is an area of major concern. The wind speed is nearly hundred knots in the working conditions so appropriate measures of safety is a must. Therefore for the safety of working personnel, proper offshore living areas should be established with minimum required basic amenities and proper health meals. [20]
5) Since the entire setup is in the water for its entire operations, corrosion is a major concern as it affects the marine life and the structure's stability is a concern after few years of operation. Carbon dioxide when introduced in the well-bore with the drilling fluid results in the formation of carbonic acid corroding the steel and dissolved salts present in the drilling fluids increase the rate of corrosion due to increased conductivity. High corrosion also results in the failure of drill string due to dissolved gases, acids and dissolved salts in the well-bore. Caliper log n should always be used to detect the corrosion of the casing. Stub liners should be used instead of full- string of casing for providing the necessary extra protection from corrosion. The pH of the mud can be kept high by adding caustic soda NaOH thereby preventing corrosion [21], [22].

VIII. Conclusion

Dual gradient drilling provides one of the most efficient and unique methods to carry out drilling in deep waters in the oil and gas industry. This method helps in combating the narrow drilling window between the pore pressure and fracture gradient. The advantages which DGD provides if implemented in an energy efficient and safe manner will help to carry out drilling in those wells which till date have been termed as un-drillable wells. This technology also helps in the minimum use of casings which otherwise are required in large numbers in deep depths of waters with low formation strengths and high pore pressures. More Indian oil companies need to identify the benefits of dual gradient drilling and use the technique for combating the oil crisis which we face today. Further research is suggested in combating the U-Tube effect more efficiently, measures to control the enormous gas expansion during its movement from the shallow waters to deep waters and methods for efficient separation of subsea cuttings.

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