# Real-Time Determination of Pore and Fracture Pressure using Managed Pressure Drilling Technology

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## ABSTRACT

Well blow-outs, kicks, fluid influx and other sundry drilling problems have been known to be caused by abnormal pressures, especially overpressures. This can greatly increase drilling non-productive time and consequently raise the cost of oil and gas exploration and production activities. Overpressure is any pressure above the hydrostatic pressure. Accurate determination of pore and fracture pressure is critical to a successful drilling operation. Managed pressure drilling technology has been used successfully to determine the lower and upper pressure limits of lithologic successions. The lower and upper limits being pore pressure and fracture pressure respectively.

The rotating control device (RCD) which acts as a flow diverter, managed pressure drilling choke manifold, flow meter and ancillary sensors and pipework are the tools needed to achieve the objectives of determining the pore pressure and fracture pressure of the formation. Closing or opening of the chokes leads to an increase or decrease in the surface pressure. And the magnitude of the surface pressure together with the drilling fluid density determines the bottom hole pressure.

A dynamic pore pressure test (DPPT) is performed to measure the lower limit of the formation while dynamic formation integrity test is conducted to determine the upper limit or fracture pressure. The dynamic pore pressure test is done by reducing the surface pressure in stages of 50psi or 100psi until an influx is detected or to a predetermined pressure point. However, to conduct a dynamic formation integrity test, the surface pressure is increased in steps of 50psi or 100psi till drilling fluid losses into the well are noticed.

The ability to determine formation and fracture pressure as drilling activities are carried out is very important as this provides invaluable information as to whether the drilling operation can proceed safely or not. The managed pressure drilling option is faster and more reliable than other methods that rely on drilling or geophysical well data when real time pressure information is required.

**Keywords:** Pore Pressure, Fracture Pressure, Overpressure, Hydrostatic Pressure, Drilling fluid, Lithology.

## INTRODUCTION

Pressure studies are carried out at different stages of oil and gas exploration and production activities. Pre-drill analysis of pressures are carried out before wells are drilled; further pressure studies are conducted during drilling operations especially at exploration and appraisal well drilling stages. And after the well has been drilled, all available data and information are used to build or improve on existing pressure model. The models thus developed are used as basis for further drilling and production activities within the same or adjacent fields. They can also be used in comparative studies of different fields.

Formation pressure is the pressure exerted by the fluids contained within the pore spaces of the formation. Pore pressure can be normal, subnormal or abnormal depending on if it is hydrostatic, lower or higher than hydrostatic pressure respectively (Odofin, 2014, Ugwu, 2015, Asedegbega, *et al.,* 2017). Pore pressure can be estimated using various methods or measured directly by specialized tools during or after drilling operations.



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Formation pressure is the difference between the overburden and effective stress (equation 1)

$$Pp = S - \sigma \quad \text{equation 1}$$

Where:

$Pp$ = pore pressure

$S$ = overburden pressure

$\sigma$ = effective stress

Fracture pressure is the pressure required to cause mud invasion into the surrounding formation at a depth of interest or the pressure required to break the formation. At this pressure a fracture is propagated within adjacent sediments at a specific depth (Goodwyne, 2012, Odofin, 2014, Emudianughe and Ogagarue, 2018). Fluid losses and lost circulation may be the consequences if the fracture pressure is exceeded when drilling a well.

Overpressure because of under-compaction is usually attributed to an increase in formation porosities and can be easily detected (Tingay et al., 2009). Knowledge of the expected pore pressure and fracture gradients is the basis for the efficient drilling of wells, with correct mud densities, proper engineering of casing programs and completions (Alao et al., 2014).

Pore pressure in normally compacted sediments is entirely due to the density and height of the fluid column (Babu and Sircar, 2011). Porous rocks are subjected to both internal and external stress. The internal stress is due to formation pore pressure while external stress is due to the weight of overlying sediments referred to as the overburden (Biot, 1941). Pore pressure varies from hydrostatic to severe overpressure where formation pressure could be as high as 48% to 95% of the overburden pressure (Zhang, 2011).

Pore pressure prediction is not only important in deciding the mud weight, but also the number of casing strings and casing seat selection. This has huge impact in well integrity and economics (Babu and Sircar, 2011, Contreras et al., 2011).

Influx into the well bore can result when an abnormally pressured formation is drilled with a lower mud weight than what could have kept the formation fluid in check. A blowout can result if the rate of influx is higher than the rate of well shut in or the overpressure is greater than blow out preventer (BOP) equipment pressure rating. Formation pore pressure evaluation is an invaluable exploration tool as it is used in detecting the presence of hydrocarbon seals, mapping of hydrocarbon pathways, analyzing trap configuration and basin modelling (Nton and Ayeni, 2014).

With accurate pore pressure prediction, it is possible to build a model that will enhance safe exploration, drilling and production activities.

Formation pressure and fracture gradient estimates are critical in deep water exploration as the well costs are high and pore pressure related problems are difficult to handle due to narrow drilling margins (Goodwyne, 2012). Hottman and Johnson (1965) established the use of Shale properties for Formation pore pressure estimation, this was further developed by Eaton (1975).

Velocity analysis of both seismic and well log data have also been used for pressure studies in various oil and gas fields of the Niger Delta (Ugwu, 2015, Asedegbega, et al, 2017). Drilling and well log data as good as they are in predicting or estimating pressures are not as versatile as the managed pressure drilling option. The main advantage of the MPD technology is its ability to increase or decrease bottom hole pressure by manipulating surface back pressure as the drilling operation progresses. Increase in bottom hole pressure will keep influxes in check while decrease in bottom hole pressure will reduce or stop the rate of mud loss into the formation.

The International Association of Drilling Contractors (IADC) defined managed pressure drilling (MPD) as "an adaptive drilling process used to precisely control the annular pressure profile throughout the wellbore. The objectives are to ascertain the downhole pressure environment limits and to manage the annular hydraulic pressure profile accordingly" (Malloy, 2007).

In conventional drilling, the bottom hole pressure results from the hydrostatic pressure derived from the mud column and frictional pressure generated from mud circulation (equation 2). Circulation out of the well is open to the atmosphere.

$$P_{bh} = P_{hyd} + P_{af} \quad \text{equation 2}$$

Where;

$P_{bh}$ = Bottom Hole pressure

$P_{hyd}$ = Hydrostatic Pressure

$P_{af}$ = Frictional Pressure

However, in managed pressure drilling, the bottom hole pressure is a combination of hydrostatic pressure, frictional pressure and surface back pressure from the MPD manifold (equation 3). Circulation out of the well is contained within a close system that makes it possible to choke back on return flow from the well (Bhandari, 2013).

$$P_{bh} = P_{hyd} + P_{af} + P_{sbp} \quad \text{equation 3}$$

Where;

$P_{bh}$ = Bottom Hole pressure

$P_{hyd}$ = Hydrostatic Pressure

$P_{af}$ = Frictional Pressure

$P_{sbp}$ = Surface Back Pressure

## METHODOLOGY

There are various equipment and processes involved in managed pressure drilling, these include, the rotating control device (RCD), MPD Choke Manifold, Coriolis flowmeter, Pressure relief Valves (PRV), and the Control System.

### Rotating Control Device (RCD)

The rotating control device (Fig. 1) is what effectively creates the seal on the well annulus, such that it diverts the return flow away from the normal flowline creating a pressure tight barrier, forcing mud and drill cuttings into the MPD Choke manifold for monitoring and control (Boer, *et al,* 2014).

**Figure 1:** Weatherford Rotating Control Device and Bearing Assembly (Wilson, 2014).

### MPD Choke Manifold

The choke manifold (Fig. 2) consists of chokes and sets of valves to control the flow of mud and drill cuttings flowing back from the annulus of the well. The choke can be of different sizes ranging from 2 to 6 inches. The chokes open and close to regulate surface backpressure, essential to manage equivalent circulation density (ECD) and consequently, controlling the wellbore's pressure profile. There is usually more than one choke on the manifold, these can be used at the same time depending on the rate of flow in and out of the well. Sometimes when one choke is in use the other chokes are tagged as backup.


**Figure 2:** MPD Choke Manifold (Wilson, 2014).

### Coriolis Flowmeter

The Coriolis flowmeter (Fig. 3) measures the density, flow, and temperature of the material that passes through it (Cadd, *et al*, 2018). Coriolis flow meter eliminates the need to measure and correct for pressure, temperature, and density fluctuations to determine mass flow rate. The basic operation of Coriolis flow meter is based on the principles of motion mechanics (Emerson, 2022). As fluid moves through a vibrating tube it is forced to accelerate as it moves toward the point of peak-amplitude vibration. Conversely, decelerating fluid moves away from the point of peak amplitude as it exits the tube. The result is a twisting reaction of the flow tube during flowing conditions as it traverses each vibration cycle.


**Figure 3:** Coriolis Flow Meter.

### Control System

This acts as the brain of the MPD system, it receives information in the from of data form sensors that are installed at different locations within the MPD package. Using the received data after processing, the control unit sends signal to the choke to either open or close depending on initial setup. The chokes are calibrated from 0 to 100% open. At 0%, the choke is fully closed, while at 100%, the choke is fully opened. With the control system fully functional, operating the choke is entirely automatic and this ensures reliability and repeatability. Pressure set points can be entered directly into the human machine interface (HMI) which serves as both input and output for signals sent to and from the control unit.

## RESULTS AND DISCUSSIONS

### Case Study 1

Overpressure and high temperature made it impossible for Bowleven to drill any well to planned total depth (TD) for more than forty years in the Etinde field. It was also difficult to get accurate formation pressure due to tool failure because of high temperature. Pre-drill formation pressure and fracture pressure studies were used for drilling mud formulation. The result was kicks and mud losses into the formation in the form of well and life-threatening kick/loss cycles, and major variations in the pressure gradient at different depths. These always led to plugging and abandoning the well with attendant huge financial losses.

Managed Pressure Drilling (MPD) Technology was adopted in the same field in 2014 to drill the Isongo 1X well, and this led to successful drilling operation. MPD also enabled a better understanding of pressure regimes within the field due to the ability to successfully use choke manipulations to determine the lower and upper pressure limit of the formation (Santamaría, *et al*., 2016, Graham, *et al*., 2015).

In order to determine the actual fracture pressure of the well while drilling, confirm computed pre-drill pressure estimations and evaluate the optimal mud weight required for a successful operation, a dynamic leak off test (DLOT) was performed (Boer *et al*, 2014). To conduct DLOT, the surface back pressure (SBP) was increased in 50psi steps from line frictional pressure to a maximum of 600psi (Fig. 4) where drilling mud began to invade the formation, signifying formation fracture propagation due to high pressure. Having determined the maximum pressure limit of the formation, the surface back pressure was quickly relieved in order to avoid formation fracturing and damage which could lead to a well control situation.

The algorithm for pressure calculation in the control system is based on equation 4 below.

$$P = MW \times 0.052 \times TVD \qquad \text{equation 4}$$

Where;

P = Pressure

MW = Mud Density/ Weight

0.052 = Conversion factor

TVD = True Vertical Depth in feet

Equivalent mud weight can be calculated using equation 4 when other parameters are known. In this case, the TVD and pressure were 3310m and 600psi respectively. The equivalent mud weight therefore was,

$$MW = P/ (0.052 \times TVD) \qquad \text{equation 5}$$

$$MW = 600psi/ (0.052 \times 3310m \times 3.281)$$

$$MW = 1.06ppg$$

The original density of the mud in the well when the test was performed was 16.5ppg. Therefore, the upper pressure limit of the formation was,

$$EMW = 16.5ppg + 1.06ppg$$
$$= 17.56ppg$$

### Case Study 2

An Operator mobilized a drilling rig and other equipment and tools to a location within the Niger Delta to drill an exploration well. The plan was to take pressure points with Measurement While Drilling/ Logging While Drilling (MWD/LWD) tools as the 8 ½" section of the well was being drilled.

The tool however failed when it was activated to measure the pore pressure of the formation. After several attempts with much time wasted, it was decided to use the MPD system for pore pressure measurement.

A dynamic FIT was conducted to a maximum of 17.3ppg at 4004m TVD with 800psi surface back pressure (Fig. 5) and drilling mud density of 16.2ppg. The surface back pressure was bled off in gradual steps to line friction pressure of 40psi. The FIT gave an indication of the upper pressure limit of the formation.

The pore pressure test is conducted by decreasing the surface back pressure in 50psi steps from 800psi (fig. 6) until a change in the mud flow out signature is noticed, that is, flow out begins to deflect to the right of the mud flow into the well indicating a kick. Once kick is noticed the surface back pressure is quickly increased to control the influx and circulate out the kick. Change in mud flow out signature was seen at 1.96sg (16.3ppg) signifying that the formation pressure at that stratigraphic level is 16.3ppg. The mud density must be increased if the well will be statically overbalanced since the mud density at the time the DPPT was performed was 1.95sg (16.2ppg).

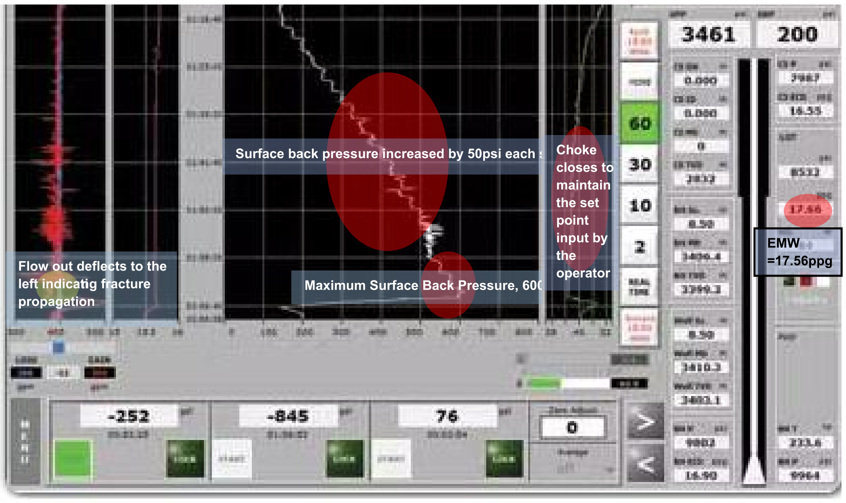


**Figure 4:** Surface Back Pressure increased in 50psi steps to a Maximum of 600psi to perform DLOT/ DFIT

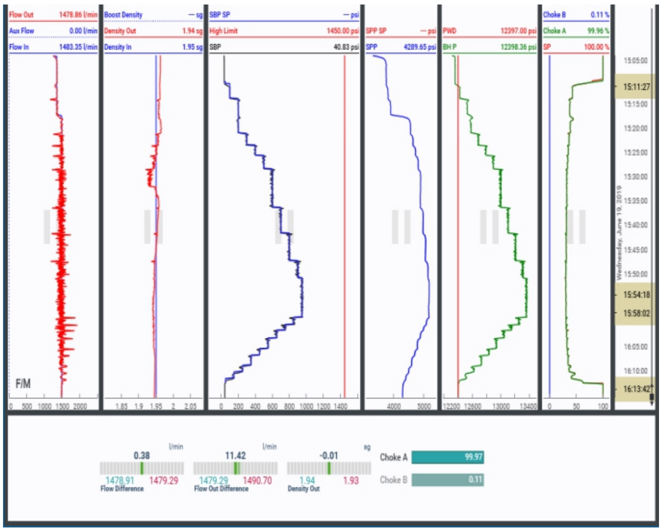

**Figure 5:** Surface Back Pressure increased in 50psi steps to a Maximum of 800psi to Perform DLOT/ DFIT and Pressure bled off to avoid loss of drilling fluid into the formation.

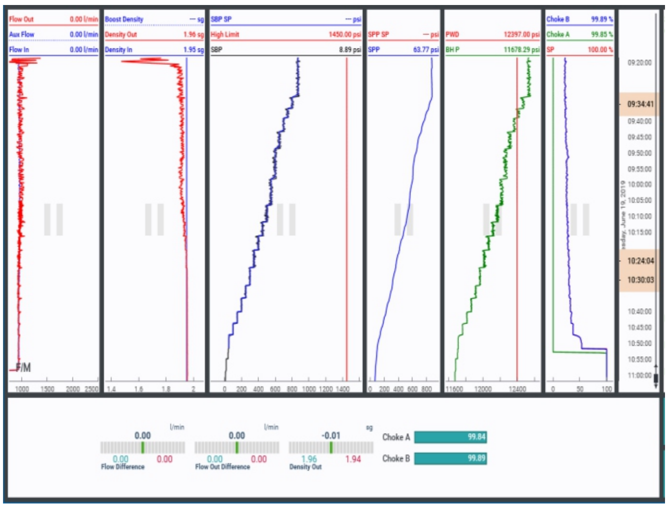

**Figure 6:** Surface Back Pressure decreased in 50psi steps to a Minimum of 50psi to Perform DPPT.

## CONCLUSION

Managed Pressure Drilling technology have been used successfully to determine the upper and lower pressure limits of the formation during drilling operations. This does not require pulling out of hole with the drill string as would be done for pressure measurement with wireline logging or stop drilling operation as needed in conventional FIT/ LOT. The operation is fast and timely and does not require additional equipment to be rigged up. It may be the only option available in wells where the drilling windows are narrow and high temperature/ high pressure (HP/HT) wells. Limitations caused by high formation temperatures in HP/HT wells make it impossible for pressure measurement tools to take accurate and reliable pressure measurements. Using MPD technology, therefore saves valuable resources in terms of time and money and makes it possible to determine formation pressure where it would have been impossible to do so.

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