A Collective cum Effective Use of Drilling Events in Evaluating Bottomhole Overbalance

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Keywords

Real-time monitoring, Connection gas, Total gas, Pore pressure, Mud weight modeling, Kick prevention.

Summary

Understanding the downhole pressure differential ('or' overbalance) established due to difference between drilling fluid pressure and prevailing formation pressure, enables safe and efficient drilling operations. Simply put, bottomhole pressure exerted by mud column is mud pressure gradient times the vertical hole depth, and factors such as cuttings load, friction and annular velocity can be considered for more accurate estimates under two scenarios – during static condition, equivalent static density (ESD), and during dynamic conditions, equivalent circulating density (ECD). Pore pressure is predicted during drilling using logging-while-drilling (LWD) data, drilling parameters, and events analysis. In this manuscript we showcase using an integrated illustration of drilling events and critical parameters on a single plot – "Drilling Event Chart" for proactive prevention of kick/well-flow instances.

Magnitude and trend of gas peaks ('or' events – connection/pumps-off/background gas) are important drilling indicators that can act as precursor to an influx or kick event. Drilling fluid type plays an important role along with knowledge of the solubility extent of gas in synthetic-oil-based-mud (SOBM) under high pressure, especially to understand that the magnitude of the gas levels can get subdued in SOBM. Factors such as lithology and rock permeability influence the magnitude of gas peaks as well hence, monitoring and honoring the trend of gas peaks is rather vital than considering only an isolated gas peak magnitude. Some other indicators namely – a sudden drop in rate of penetration (ROP), cavings rate/volume, drop in ECD, drop in standpipe pressure, and pit-volume increase can also indicate a decrease in the bottomhole overbalance.

Being able to interpret all these parameters and trends at once has proven useful especially in absence of LWD data. This tool, the drilling event chart, entails information such as mud weight, ESD, ECD, gas peaks or events, other abnormal drilling events (such as cavings, high torque, etc.), and pumps-off time. A qualitative pore-pressure profile can be established based on normalized gas events profile i.e., connection/pumps-off gas events normalized over pumps-off time. Interpretations based on the observed variation in drilling events under the prevailing mud-weight/ESD/ECD profiles have been useful in decluttering the cause of these events.

The use of this tool for early kick detection has been successful in various basins around the globe. Although the relationship of the drilling events with the bottomhole overbalance is known, their combined usage in this type of single tool provides a quick and novel approach to better understand the cause of these events and accurately evaluate the overbalance in the borehole for safe and efficient drilling.

Introduction

Early prediction of overpressure zones has always been challenging. Failure to predict events might lead to kicks and blowouts, which has health, safety and the environment (HSE) and non-productive time (NPT) implications. To avoid these, multiple parameters are monitored in real time for safe completion with minimum NPT. This paper discusses a novel tool called the "drilling event chart" and its role in early detection of an overpressure zone.

The drilling event chart integrates inputs from drilling and the mud-logging unit (MLU). It mainly consists of plotting background gas (BG), peak above BG at pumps-off or connection time, normalized pumps-off/connection gas, mud weight (MW), equivalent-static density (ESD), equivalent-circulating density (ECD), and fracture gradient. Visualizing these parameters on a single chart has proven useful, especially in absence of logging while

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drilling (LWD) data for cost-constrained drilling campaigns. Various components of the chart include:

Total Gas (TG): TG value is a critical measurement recorded by MLU and has multiple applications, namely: detection of hydrocarbon-bearing zones and can also act as a qualitative indicator of the difference between MW and pore pressure (PP) in shales.
Gas released from drill cuttings, measured by the sensors of the MLU unit, can have multiple sources:

- the pore space of hydrocarbon-bearing zones or;
- it may be gas adsorbed on the rock surface that is released when rock is crushed/sheared.

Background Gas (BG): BG is the trend of TG identified based on the TG measured. Background level is also dependent on the type of mud system being used. In the same formation with similar drilling parameters, its magnitude may vary from water-based-mud to oil-based-mud systems.

Connection Gas (CG) and Pumps-Off Gas (POG): Connection gas (CG) and pumps-off gas (POG) are readily explained, and yet can be difficult to interpret. The mud pumps are stopped at the time of connection, thereby reducing the effective downhole mud pressure and letting extra gas enter the hole. Similarly, any swabbing due to movements of drill-string during connection may cause influx of gas.
CG is defined as TG value observed above BG level during connection. On a TG curve, CG will look like a small peak/spike over a short period - connection time. It needs to be ensured that it is not linked with change in lithology or a drilling break.
Similarly, POG is defined as the magnitude of TG above a normal BG level when pumps are off.

Peak Above BG (ABG): The peak above BG is the difference between the magnitude of TG and BG at the depth under investigation.

Normalization of the Gas Events: CG/POG values are normalized to subdue the effect of varying pump-off time to better understand formation behaviour. Simplistically normalization is, as per Eq. 1:

$$\text{Normalized Gas Peaks} = \left(\frac{\text{Peak ABG}}{\text{Pumps off time (hrs)}}\right)$$

Any deviations from the BG trend are likely to be a direct indicator of variations in porosity-permeability of the formations 'or' changes in drilling conditions; any of which merits a detailed further investigation. A drift or gradual shift in BG trend toward higher end may indicate a slow gas influx into mud column.
One of the early stage key indicators of any influx/well-flow activity, the gas counts, can get subdued in oil-based drilling fluid (OBDF). OBDF systems tend to produce comparatively lower background gas (BG) values compared to water-base drilling fluid (WBDF) systems. Hence, for OBDFs to be used for drilling, understanding the influx/kick/natural gas and OBDF interaction is extremely essential for planning and safe execution of drilling operations.
The gas loading capability of OBDFs by far exceeds that of WBDFs. And as the potential natural gas loading is more pronounced at higher pressures, special care needs to be taken while handling OBDFs. Especially, while considering the ability of early detection of gas influx into the drilling fluid (Linga et. al., 2016). Plot between gas solubility for drilling fluid with refined, "normal", mineral base oil vs. pressure and between gas solubility for refined, "normal", OBDF vs. pressure, at various temperature levels (Linga el. al., 2016), shows the variation in gas solubility at higher pressures (Fig.1).

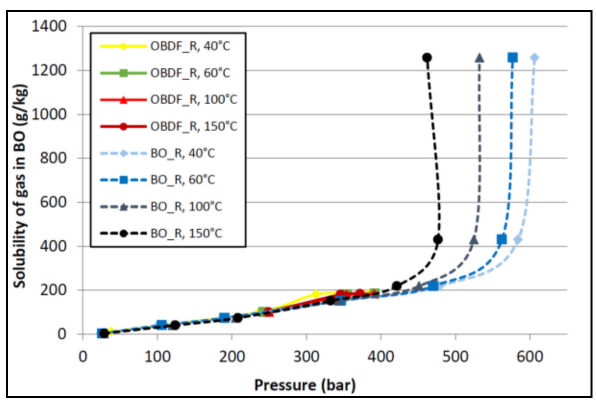

Fig. 1—Gas solubility characteristics for the refined "normal" mineral base oil (BO) and the corresponding drilling fluid. Data recalculated from Torsvik et al. (2016) in (Linga et al. 2016).

Drilling Event Scenarios and Interpretation

Evaluation of connection or pumps-off gas events while approaching an expected pressure ramp is of prime importance for deciding on casing shoe depth.

It has been observed in many overpressured Tertiary sediments globally that shales above a pressurized sand show not only intermittent gas events but can also show a continuous trend. A relationship between the trend of BG, CG and POG events with respect to the MW can be established by analysing the bottom hole overbalance and formation behaviour. **Fig. 2(a)** illustrates a scenario in which, without any variation in static drilling MW, the BG and CG events show increasing trend. The red curve, normalized gas peaks, also shows increasing trend. This a strong indication of reducing bottom hole overbalance due to increasing overpressure and proximity to the pressure ramp zone. This situation strictly demands increase of MW to maintain the overbalance, as shown in **Fig. 2(b)**. However, this may not hold true in the case of variation in formation lithology. The concept of increasing gas events trend as an indicator of reducing overbalance holds good only in case of overpressured mud-rock zones, whereas gas events from permeable lithologies coinciding with any pipe connection/pumps-off activity cause uncertainty.

Although the increasing trend of the gas events indicates decreasing overbalance, its use as a quantitative calibration for PP is highly uncertain. **Fig. 3(a)** shows a case when MW was increased following increasing gas events trend. All drilling parameters being unchanged, after the MW increase, the gas events have subsided. Confirming that the increase in the gas events trend was due to increasing overpressure. MW (or specifically, ESD), after the increase that subdued the gas events, can be considered as a proxy for the formation pressure.

Influence of lithological variation can introduce complexities in the evaluation of the gas events trend and establishing a relation with the pressure profile. A sample case is illustrated in **Fig. 3(b)**. Presence of lithologies such as coal, fractured volcanic rocks, or limestone streaks within a thick shale can cause sharp gas peaks during pumps-off or connection. BG value may also show a high. This combined effect of elevated BG levels along with consistent occurrence of CG or POG events may be mistaken for reducing bottomhole overbalance. In these cases, even with increasing MW, gas events may not get subdued.

In overpressured zones, underestimation of overbalance reduction leads to conservative MW increments in response to increased gas events trend, which may not be enough to subdue the gas levels in the borehole resulting in continuous increasing gas events trend even after increased MW. This indicates further increment in MW may be required.

Understanding the interplay among swab pressure (swab) and mud hydrostatic both in dynamic (ECD) and static (ESD) conditions can help establish a qualitative estimate of the PP. Various scenarios of swab, ECD and ESD interplay are explained along with corresponding TG readings to understand the bottom-hole overbalance qualitatively, (**Fig. 4**), (Alberty et al., 2013).

For instance, a stable TG reading both during the drilling process and pumps-off time would mean PP is likely to be lower than swab as well as ESD and ECD, indicating a scenario in which PP < swab < ESD < ECD, (**Fig. 4a**).

In case of stable TG trend during drilling but a TG spike during pumps-off time, a qualitative estimation of PP value would require further investigation. This can be done by comparing the previously observed TG value with the TG value observed during current and upcoming pumps-off time event. If TG values are comparable during two or more consecutive pumps-off events, then the rise in TG values is likely due to PP being higher than the swab value but lower than the ESD and ECD, resulting in scenario b, i.e., swab < PP < ESD < ECD (**Fig. 4b**).

In scenario c, like scenario b, a stable TG reading is expected during drilling, but a spike in TG value is observed during pumps-off time. The difference between two scenarios arises from the fact that values of multiple consequent TG spikes remain comparable in scenario b, whereas the values of TG spikes will increase at every incremental pumps-off event in scenario c. Resulting interpretation would be swab < ESD < PP < ECD (**Fig. 4c**).

Of all the scenarios discussed, scenario d presents the case in which it is easiest to interpret PP qualitatively. If the TG shows an increasing trend during the drilling process and an even higher TG value is observed during pumps-off time, then the system is highly likely to be underbalanced. In this scenario, PP value should be higher than the other three parameters. The order of these parameters would be swab < ESD < ECD < PP (**Fig. 4d**).

Some cases, specifically those in which massive overpressured shale zones that do not have any - interbedded permeable zones, may exhibit a continuous gas events trend. The computed normalized gas peak curve may qualitatively

represent the PP profile. In absence of quantitative real-time PP model, this normalized gas curve can form a basis to decide on changes in MW (**Fig. 5**).
If incremented MW results in reduced gas event levels, then last gas peak can be taken as a substitute for PP calibration. Usually, in these cases, there would be another cycle of increasing gas events trend and subsequent increment in MW would reduce gas levels again providing another proxy point for PP calibration. Connecting these points, with already increasing normalized gas curve can provide a qualitative PP profile.

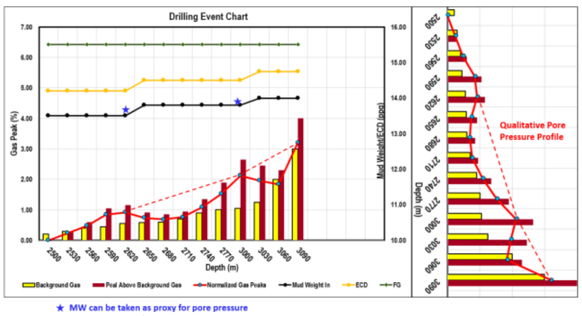

Fig. 5—Use of normalized gas peak curve in deciphering a qualitative PP profile.

The event chart can also be helpful in deciphering a wellbore breathing (or ballooning) effect. Ballooning occurs when formations take in drilling fluid when pumps are on and throws it back under static conditions. During pumps on, if the ECD reaches the formation fracture gradient opening microfractures, mud will be lost. Under static conditions, the ESD (<ECD) may cause the microfractures to close and return the mud back into the hole. Along with mud, the formation will also release some gas. The magnitude of gas may vary based on pumps-off duration, the extent of micro fracturing, and the volume of mud lost/returned. On the event chart, during ballooning, gas levels increase with an increase in MW and/or ECD, and gas levels subside on reduction in MW and/or ECD (**Fig. 6**).
Detection of water/oil kick is difficult as TG might not give any indication. In such case, a difference of temperature of MW-In and MW-Out, change in mud salinity and viscosity can be helpful. Dealing with water or oil influx is much easier because the water and oil do not expand like gas. Differentiation of well flow events into water or oil can be done using the mud sample properties, such as viscosity, salinity, and oil-water ratio.

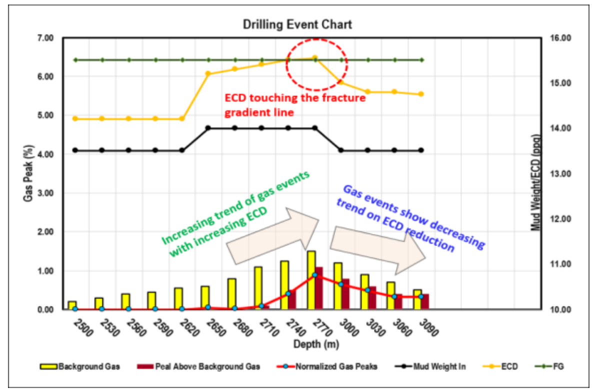

Fig. 6—Deciphering ballooning situation from the event chart.

Other Indicators for Early Detection of Kick

Increase in ROP: Usually a sudden increase in rate of penetration (ROP) (also called a drill-break) is usually the earliest indication of a kick. However, it must be checked against the lithology.

Increase in Pit Volume: Pit volume is another key indicator of well influx. Before concluding the cause is influx, it must be checked that observed changes are not due to any surface-controlled operations.

Drop in SPP and ECD: Drop in SPP and ECD is another crucial kick indicator. During well flow instance, low density fluid invading into wellbore dilutes the mud column.

Cavings: Occurs when the effective downhole MW is lower than the formation pressure. Usually in the impermeable formations like shales, this condition will result in cavings splintery in nature.

Increase in Torque and Drag: Torque and drag alone are difficult to interpret for a well flow event. These parameters are influenced by other factors and should be used in combination.

Displaying Kick Indicators: On Gas versus Depth plots, other anomalous drilling indicators such as cavings, increase in torque, etc., can be plotted as isolated events. An integrated plot (**Fig. 7**) presents an accurate picture of overbalance and helps pragmatic decision making.

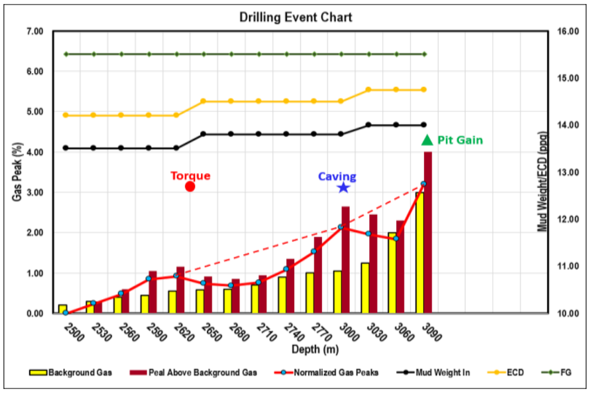

Fig. 7—Plotting of occurrence of abnormal drilling indicators other than gas events to complement a robust understanding of the bottom hole overbalance.

Conclusions

Variation of TG can be used as an effective tool to characterize shale PP during underbalanced or near-balanced PP-MW scenario. This paper has discussed different practical cases for which a drilling event chart can be used for prevention of a kick by proper and pragmatic MW management. Key parameters and their influence are summarized in **Table 1.**

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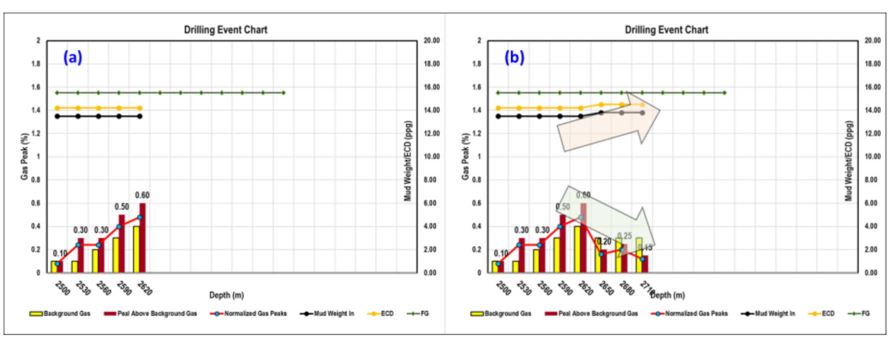

Fig. 2(a)—Increase in CG magnitude at constant MW suggests decrease in overbalance; **(b)**—Increase in CG magnitude at constant MW suggests decrease in overbalance. Increase in MW is required to maintain the overbalance.

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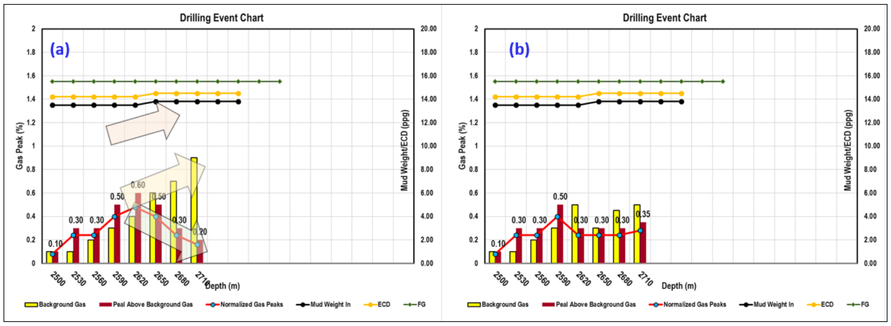

Fig. 3(a)—BG increases and CG decreases with increase in MW; **(b)**—BG and CG peaks remain constant with increase in MW. This is probably an effect of change in lithology.

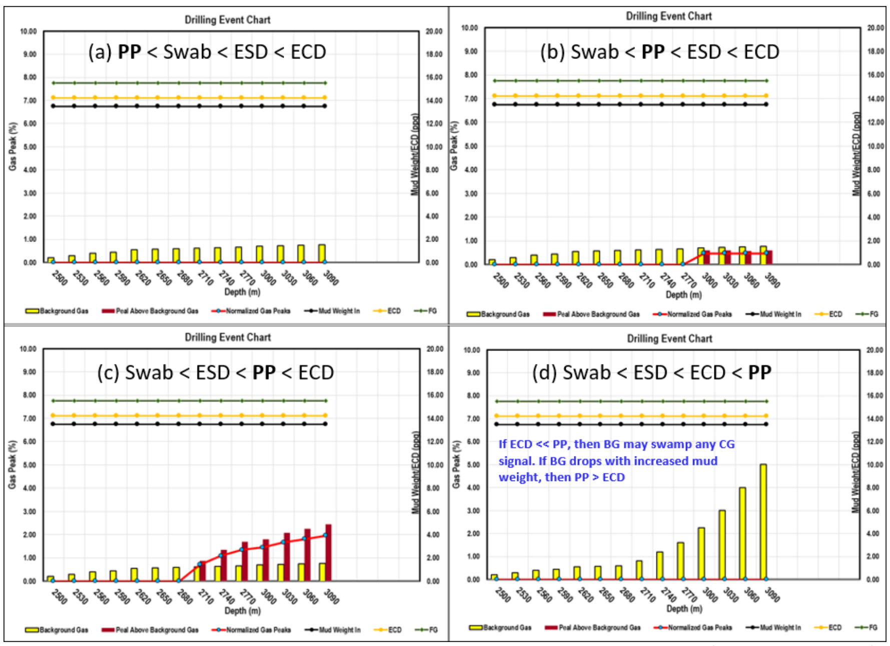

Fig. 4—Understanding the interplay between PP, swab pressure, ESD, and ECD based on occurrence of gas events (modified from Bratton et al., 2013).

S.No	Parameters	Pattern	Interpretation	Risk	Remark
1.	CG/POG	CG/POG/BG	Underbalance or Close to Balance	High	Monitor cuttings regularly. Check for any coal or highly fractured gaseous formation
2.	ROP	ROP jump in Shales	Underbalance or Close to Balance	High	Monitor cuttings (Splintery type)
3.	Pit Levels	Increase	Underbalance or Close to Balance	High	Check surface operators and analysis mud samples from bottom
4.	Cavings	Splintery	Underbalance or Close to Balance	High	Monitor cuttings with mud weight increase
5.	Cavings	Angular	Close to Balance	Med	Monitor cuttings with mud weight increase
6.	Standpipe Pressure (SPP)	Drop in SPP	Underbalance or Close to Balance	Med	Check for any changes in flow rates and mud weight
7.	ECD	Drop in ECD	Underbalance or Close to Balance	Med	Check for any changes in flow rates and mud weight
8.	Torque and Drag	Increase		Low	Check Borehole condition/cuttings shape/bit drillability
9.	Mud Properties-Viscosity and Salinity	Increase	Case of water or oil kick	High	Used for differentiating between water or oil kick

Table 1—Summary of different drilling indicators for early kick detection and understanding (adapted from Bahuguna et al., 2011).