Review Article

Early detection enhancement of the kick and near-balance drilling using mud logging warning sign

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ABSTRACT

Early kick detection is of great concern while drilling wells. The late kick detection can lead to uncontrolled blowout which increases the possibility of injury and potential loss of life and equipment. Causes of kick and the importance of early kick detection are introduced. Kick detection from mud logging real time data and kick detection in the offshore Nile Delta are discussed. Limitation of the conventional well control procedure in low permeable formation is introduced. A comparison between gas parameters warning sign and drilling parameters warning sign was carried out. A new advanced early kick detection method is proposed based on more than 10 years of experience in monitoring real time mud logging data while drilling and analyzing flow and kick reports. The proposed advanced early kick detection method uses additional accurate flow check using trip tank and recommends adding two additional accurate pressure sensors while shut-in well. The proposed method has a great advantage using gas parameters which can detect near-balance state before kick occur. The advanced kick detection method does not require any rig equipment modification nor interfere with any drilling operation. Case studies in the offshore Nile Delta wells illustrate the limitation of the conventional well control procedure and the advantage of the proposed method.

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Offshore Nile Delta
Pore pressure
Connection gas

1. Introduction

The kick prevention and early kick prediction is of great concern in the petroleum industry. The late kick detection can increase the amount of formation fluids that enters the well borehole, which increases the kick pressure and makes it hard controlling the kick. It leads to uncontrolled blowout, lose circulation, waste time and losing the hole section. Consequently it costs the oil industry billions of dollars a year, as well as the more serious consequences of injury and potential loss of life.

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The use of mud logging gas anomalies was recommended as an overpressure indicator and as a warning of impending blowouts [1]. Similarly [2], proposed mud gas anomalies as an aid in controlling drilling fluids hydrostatic head–pore pressure relationships. Nowadays there are a lot of complicated services for early kick detection, but mud logging service is still the first choice for early kick detection because it is simple, cheap, requires low technological maintenance and does not interfere with any drilling operation.

The objective is to focus on real time mud logging warning signs not only when kick starts with small intensity specially in low permeable zone (e.g. shale) using drilling parameters but also before kick occurs when pore pressure increased gradually close to hydrostatic pressure (near-balance state) using gas parameters warning sign like increase in background gas (BG), appearance of connection gas (CG) and pump off gas (POG). Finally recommendations for early kick detection while drilling will be achieved. The mud logging terms used in this study are listed in Table 1.

2. Causes of kick

A kick is defined as an unintentional influx of formation fluids into a borehole. It occurs because the pressure exerted by the drilling fluid column is not great enough to overcome the pressure exerted by the fluids in the formation drilled.

As described by Nas [3] there are three conditions required for a kick to occur in the open hole and these are:

1. The exposed formation pore pressure must be greater than the drilling fluids pressure in the open hole.
2. The formation must have sufficient permeability to allow flow into the open hole.
3. The pore fluids must have sufficient low viscosity so that it can flow.

Therefore, this explains why some intervals of low permeable zone (mainly shale) in the Nile Delta were drilled underbalanced without hole problems till drilling a permeable zone which allow kick flow.

3. The importance of early kick detection

The time from start of formation fluids influx to the detection of a kick is of great importance. If the kick is detected early, the amount of low density fluids that enters the borehole can be reduced and thereby the maximum pressure that occurs at a given location in the well can be reduced. Therefore, evaluating the existing kick detection parameters is important. Where late kick detection increases the influx amount, which decreases the hydrostatic pressure, then additional influx of formation fluids increases the possibility of flammable and toxic gas to come out, as well as the more serious consequences of injury and potential lose of life and equipment. According to gas expansion [4] and gas solubility in mud [5], the late gas influx detection can lead to rapidly expansion near surface. For example one cubic meter gas influx at depth 4000 m if ignored may become 50 cubic meter or more at depth 500 m by which time the gas bubble is rapidly expanding. So any small warning sign for kick indication from mud logging real time data must be taken into consideration.

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Table 1 - The mud logging terms used in this work.

| Terms                        | Symbols | Definitions                                                                 |
|------------------------------|---------|----------------------------------------------------------------------------|
| Background Gas               | BG      | The gas enters the drilling mud as the formation is drilled by the bit and usually maintains a steady but low level. |
| Blowout preventer            | BOP     | A large valve at the top of the well that may be closed if the drilling crew losses control of formation fluids. |
| Connection Gas               | CG      | The gas released from the formation to the bore hole while pump off at pipe |
| Differential pressure        | __      | The difference between the hydrostatic pressure and the formation pore pressure in the well |
| Equivalent Circulating Density | ECD    | The combination of the hydrostatic pressure of the mud in a static condition, plus the fractional forces caused by mud moving up the annulus. |
| Hydrostatic pressure         | __      | The pressure exerted by an overlying static column of mud fluid corresponding to its density and vertical height |
| Measurements while drilling  | MWD     | Tools uses for measuring the physical properties of the well while drilling |
| Near-balance                 | __      | The state when formation pore pressure increase close to hydrostatic pressure and hydrostatic pressure still higher |
| Pump off Gas                 | POG     | The same like connection gas but occurs when pump off without pipe connection |
| Rate of penetration          | ROP     | The speed at which the drill bit can break the rock and thus deepen the wellbore |
| Shut-in casing pressure      | SICP    | The surface pressure exerted at the top of the annulus when the BOP is closed, this pressure represent the difference between the formation pressure and the hydrostatic pressure in the annulus when kick occurs |
| Shut-in drill pipe pressure  | SIDP    | The surface pressure exerted at the top of the drill pipe when the BOP is closed, this pressure represent the difference between the formation pressure and the hydrostatic pressure in the drill pipe when kick occurs |
| Total Gas                    | TG      | The measurement of the total combustible hydrocarbon gasses which are present in the mud out flow |
| Trip Tank                    | __      | A low-volume, calibrated tank that can be isolated from the remainder of the surface drilling fluid system and used to keep track of fluid volumes while tripping |
4. Limitations of the early kick detection in the offshore Nile Delta

4.1. Limitations of the estimated pore pressure while drilling

There are various methods used for pore pressure estimation while drilling. Traditional methods (D exponent and sigma log) have limitations in the Nile Delta and elsewhere, because they use indirect pressure indications from drilling data and not measure formation properties directly \([6]\). Nowadays the most advanced method used for pore pressure prediction in the offshore Nile Delta is measurement while drilling (MWD) resistivity data which depend on the petrophysical properties of the rock with accuracies in pore pressure estimation between ±0.2 and ±0.5 ppg (±0.024 to ±0.06 g/cc) \([7]\). While drilling, the offset distance between resistivity sensor and the hole bottom is from 13 m to 14 m that resulted in delay of pore pressure prediction and early kick detection. For early kick detection while drilling, we can not only depend on MWD resistivity data due to the error range in pore pressure estimated. Moreover, the offset distance from the hole bottom. Accordingly, any warning sign from mud logging real time data should be taken in consideration to safe the well from kick.

4.2. Limitations of the conventional well control procedure

If the kick is suspected, the conventional well control procedure is as follow:

1. Pick up off bottom, space out and shut off the pump.
2. Check for flow by visual watching the well level.
3. If flow is observed, shut-in the well and record the shut-in drill pipe pressure (SIDP) and shut-in casing pressure (SICP).
4. Prepare to handle the kick.

In a low permeable zone (e.g. shale), kick often starts with small volume and intensity increases with time and with continue drilling, therefore, the conventional well control procedure may fail to detect kick early in low permeable zone due to two reasons: 1. small flow at the kick starts, and 2. low shut-in pressure at the kick starts. Small flow at the kick starts does not allow the inaccurate visual flow check by “eye” to detect this flow. In addition, the drilling crew may ignore this small flow and consider it as due to U-tube effect. The U-tube effect occurs when the mud in the drill pipe flows into the annular until the pressures equalizes between the annular and the drill pipe \([8]\). To overcome this problem see recommendation number 3 of flow check using trip tank. Low shut-in pressure at the kick starts due to low formation permeability and low differential pressure between pore pressure and hydrostatic pressure. The pressure sensors which measure the SIDP and SICP were designed to measure high pressure values. They measure pump pressure while drilling and chock pressure while schedule test. They had a measuring range from 0 to 10,000 psi and from 0 to 15,000 psi, respectively. This wide measuring range with accuracy error (±100 psi) does not allow measuring small kick pressure while shut-in well. To overcome this problem see recommendation numbers 1 and 2 of pressure sensor with high accuracy.

5. Kick detection from mud logging real time data

Mud logging is a continuous real time well site information services record and analysis of the drilling parameter, mud parameter and cuttings, plots of such data often include a sample log (mud log). Besides formation and reservoir evaluation, mud logging focuses on improving safety during drilling \([9]\).

The flow in and flow out of the well is in a steady state condition in normal circulation. What goes in must come out. A kick break this balance and return flow from the well will increase if a kick is taken. Following this flow increase in surface volumes as formation fluids is added to the circulation process.

Monitoring of mud logging real time data provide at least seven parameters for kick detection. These are increase in pit gain, flow out, rate of penetration (ROP), total gas (TG), pump off gas (POG), connection gas (CG) and drop in pump pressure. None of these requires sophisticated downhole electronics or advanced signal processing. Excellent discussions and detailed reviews of kick detection from mud logging data are available in the literature (e.g. References \([5–12]\)).

The mud logging real time data can be divided into instantaneous parameters (drilling parameters) and lagged parameters. Drilling parameters are ROP, pit gain, pump pressure, flow out. Whereas, the lagged parameters comprise gas parameters delayed by the lag time. The lag time is defined as a definite time interval that is always required for pumping the drilled formation cutting from the hole bottom to the surface. The lag time depends on the volume of drilling fluid in the annular and the flow rate of the drilling fluid. The faster the drilling fluid is pumped into the borehole, the quicker it returns to the surface \([11]\).

Most impermeable shale will contain some gas, while abnormally pressured shale often contain large quantities of gas, an increase in the background gas over time can indicate an increase in pore pressure or penetration of a hydrocarbon-boring zone \([13,14]\). But unexplained increases in background gas are always a cause for concern. The amount of gas is directly proportional to the pressure difference between the shale pressure and the equivalent mud pressure \([15]\).

The presence of connection gas (CG) or pump off gas (POG) is used to indicate near-balance or underbalanced drilling, where the formation pressure is near or greater than the equivalent density of the static mud column. The drop in pressure from a dynamic circulating mud density to that of a static mud density (pumps off) may allow gas to seep in to the mud from the formation producing an increase in gas at the point of seepage.

Correlation of the frequency and level of POG and CG with respect to the mud weight can give an accurate indication of differential pressure \([4]\). In Fig. 1, the ECD decreases to the static mud density while pump off, when the pore pressure increases near to static mud pressure, connection gas and pump off gas appear as sharp peaks of produced gas, the connection gas and pump off gas increase as the pressure differential...
decreases. When the pore pressure finally exceeds the ECD, background gas readings also rapidly increase as an underbalanced condition exists. On the other hand when drilling a hydrocarbon bearing zone the total gas readings increase without pore pressure increase.

6. Kick detection in the offshore Nile Delta

In deltaic deposition like offshore Nile Delta, lithology is characterized primarily by shale, sandstone with siltstone and limestone streaks. Shale acts as a source of overpressure and also as a seal rock. Due to low permeability of shale, pore pressure may increase gradually with depth until it reach underbalanced drilling without strong significant kick sign till drilling a permeable zone, which allows a big amount of formation fluids entering the open hole increasing the kick volume and increasing the kick intensity. This delay in kick detection makes the kick controlling harder and may lead to uncontrolled incidents.

6.1. Offshore Nile Delta case studies

A lot of kicks in low permeable zone start with the same scenario like case #1: suspect a kick from small warning sign. When the drilling crew stop drilling and apply 1st visual flow check by eye, “well static” or “slightly flow,” close the well and record pressure no pressure recorded, then back to normal operation (drilling). After drilling a few meters more, stronger warning sign for a kick appear, stop drilling and make another flow check, “Well flowing.” This delay in kick detection may lead to uncontrolled kicks and potentially blowouts. The following case studies will discuss the warning sign from mud logging real time data and operation reports for enhancing early kick detection with two mud log examples.

6.1.1. Case#1

The case study in the offshore western Nile Delta while drilling “8 1/2 x 9 7/8” section with advanced technique using bicenter bit. The mud weight was 1.83 g/cc. At 4352 m suspect a kick from mud logging real time warning sign (increase in ROP, flow out, pit gain and BG also presence of CG and POG). The decision was taken to follow conventional well control procedure, stop drilling and made a visual flow check by eye “well static,” then back to normal drilling until 4379 m is reached with increasing of warning sign from mud logging real time data. The second flow check showed “well flowing”, the well killed by increasing the mud weight from 1.83 g/cc to 1.87 g/cc. While killing the well resulted to losses, more than 170 hours were recorded as lost time dealing with kick and cure losses.

6.1.1.1. Comparison between (1st kick detection) at 4352 m and (2nd kick detection) at 4379 m.

1st kick detection: while drilling at 4352 m observed increase in flow out, 6 bbl pit gain and ROP increased gradually from 4 m/h to 8 m/h at 4348 m and 4351 m, respectively. The total gas increased from 0.7% to 4.75% at 4348 m and 4351 m, respectively. Moreover, the POG and CG increased with depth as shown in Table 2 and Fig. 2. The decision was taken to apply visual flow check, well static then close the well and record pressure, the SIDP and SICP read zero, the wrong decision was taken to continue drilling.

2nd kick detection: at 4379 m, continued pit gain and POG and CG increased with depth until reach 5.2% and 9.46%, respectively (Table 2 and Fig. 2). The operator stopped drilling (made visual flow check by eye, had slightly flow and made another flow check using trip tank observed increasing in trip tank, then close the well and recorded pressure, the SIDP was 320 psi and SICP was 51 psi. The SIDP is higher than SICP that is illogical; this small reading of the SICP compared to SIDP gave indication that the SICP reading was not accurate.

The mud logging real time data gave excellent indicators for early kick detection both drilling parameters and gas parameters. The drilling parameters showed increase in ROP and pit gain and the gas parameters showed increase in background gas with many connection gas and pump off gas increased with depth from 2.89% at 4320 m to the maximum connection gas of 9.46% at 4368 m. On the other hand, the conventional well control procedure (flow check by eye and the recorded pres-

![Table 2](image)

| Type of Gas     | Total Gas (%) | Depth Interval (m) |
|----------------|---------------|--------------------|
| Pump Off Gas   | 2.89          | 4320               |
| Pump Off Gas   | 3.27          | 4330               |
| Connection Gas | 2.76          | 4336               |
| Pump Off Gas   | 4.75          | 4352               |
| Pump Off Gas   | 5.2           | 4366               |
| Connection Gas | 9.46          | 4367               |
sure while shut-in the well) failed to confirm the kick early. Moreover the MWD resistivity data delayed in pore pressure prediction until resume drilling, because the offset distance from resistivity tool to hole bottom was 13 m. The estimated pore pressure from resistivity data showed trend increase from 1.76 g/cc at 4320 m to 1.81 g/cc at 4349 m, the maximum pore pressure estimated from resistivity did not exceed 1.81 g/cc, which did not assist in kick detection. In addition, the MWD resistivity data absence from 4371 m to the end of this hole at 4384 m (offset distance 13 m) was shown in Fig. 2.

6.1.1.2. Comparison between first warning sign from gas parameters and drilling parameters. The first warning sign from gas parameters appears as POG at 4320 m which gives the first sign of reaching near-balance state before kick occurred. The POG and the CG were recorded while pump off at the static mud density of 1.83 g/cc. On the other hand, the first warning sign from drilling parameters appears (pit gain and increase in flow out) at 4351 m; the delay in drilling parameters warning sign was because the drilling parameters give warning sign when underbalanced drilling occurs. In addition the drilling parameters were recorded while pump on with ECD 1.88 g/cc. The difference between static mud density and ECD (0.05 g/cc) prevents the underbalanced condition while pump on and make delay in early kick detection. The time required to drill from first gas parameters appearing at 4320 m to first drilling parameters appearing at 4351 m was 4 hours, and the lag time was 1 hour. Therefore, the first gas parameters warning sign was recorded at surface 3 hours before the appearance of the first drilling parameters warning sign. This means that when

Fig. 2 – The composite mud log and the estimated pore pressure while drilling, case #1 showing the CG and POG started appearing at 4320 m and increased with depth until the kick detected at 4379 m, on the other hand, the last estimated pore pressure at 4371 m was due to MWD offset distance.
pore pressure increases gradually with depth and if the ROP reaching underbalanced is not high, CG and POG give warning sign of near-balance state before kick occurs.

6.1.2. Case#2
In the second case study, which is a well in the same area while drilling 20″ section, the mud weight was 1.14 g/cc. The mud logging real time data showed that ROP increased from 10 m/hr to 15 m/hr at 1578 m and 1580 m, respectively. Moreover at 1583 m flow out increased and pump pressure dropped by 150 psi. The operator stopped drilling, made visual flow check slightly flow, then made additional flow check using trip tank gain 2.5 bbl, after that close the well and record SIDP = 0 psi and SICP = 20 psi (this small flow and pressure expected due to low formation permeability and low accuracy in the pressure sensors). The right decision was taken to weight up mud from 1.15 to 1.2 g/cc according to the mud logging real time data warning sign (increase in ROP, flow out and drop in pump pressure) with the aid of positive flow check using trip tank. Also the underbalanced state was confirmed after the lag time (1 hours) by an increase in background gas from 1% at 1570 m to 1.4% at 1583 m and by MWD resistivity data after continue drilling by 14 m (resistivity offset distance from hole bottom 14 m) by a rapid build up in estimated pore pressure from 1.07 g/cc at 1570 m to be 1.16 g/cc at 1580 m as shown in Fig. 3a.

No problems were encountered while drilling this hole section due to early kick detection from mud logging real time data with no extra costs and no time wasted dealing with kick.

At 2223 m, connection gas appears giving excellent warning sign to detect near-balance state when pore pressure increased close to the hydrostatic pressure. The decision was taken to increase mud weight from 1.2 g/cc to 1.22 g/cc and the near balance state was confirmed after continue drilling 14 m by MWD data by increase in estimated pore pressure from 1.16 g/cc to 1.19 g/cc at 2221 m while the mud weight was 1.2 g/cc. The increase in total gas at 2235 m was due to penetration permeable zone (sandstone) as shown in Fig. 3b.

6.2. Kick detection parameters comparison
Pore pressure increases gradually with depth until reaching near-balance state; the POG and CG will appear giving warning

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**Fig. 3** - The composite mud log and the estimated pore pressure while drilling, case #2. (a) At depth 1580 m ROP increased to 15 m/h, whereas BG increased to 1.4% at 1583 m giving indication of underbalanced drilling. The underbalanced drilling was confirmed by increasing in estimated pore pressure at 1580 m after continued drilling (MWD offset distance 14 m). (b) At depth 2220 m the ROP increased to 18 m/h, while the CG appear at 2223 m giving indication of near-balance drilling which confirmed by increasing in estimated pore pressure after continued drilling.
sign recorded on surface after the lag time. On the other hand the drilling parameters will not give the warning sign unless kick start except the ROP parameter may increase, but we cannot depend on ROP increase only to detect near-balance because ROP was affected by change in drilling parameters, bit condition, bit hydraulic and lithology change. In the case of abrupt pore pressure increase exceeding the ECD (underbalance) the drilling parameters will give the first kick warning sign which will be confirmed from gas parameters after the lag time. On the contrary the pore pressure estimation while drilling using MWD logging was always delayed by the offset distance from MWD logging sensor to the hole bottom. Needed data processing and complicated calculations were shown in Table 3.

7. Proposed method and recommendations for early kick detection

7.1. Proposed advanced early kick detection method

In a low permeable formation the conventional well control procedure shows delay in kick detection, as previously discussed, in Case #1 while drilling (first visual flow check showed well static). On the other hand, the mud logging data gave many warning signs (increase in flow out ROP, pit gain, and BG also presence of CG and POG). A new advanced early kick detection method has been proposed based on more than 10 years of experience in drilling exploratory wells. The proposed method has many advantages more than the conventional well control procedure. The proposed method not only can detect small kick early but also can detect near-balance state before kick occur. For example when kick is suspected the proposed method recommends to make additional accurate flow check through trip tank which can be recorded through mud logging real time chart, giving accurate volume returned per minute. For recording accurate SIDP and SICP, the proposed method recommends adding two additional pressure sensors with high accuracy for measuring low pressure values ranged from 0 to 2000 psi. Moreover, it is recommended in the case of negative flow check, not to resume drilling, circulate bottom’s up to check if there is a presence of CG and POG or increase in BG at the bottom which help to detect near-balance state before reaching underbalanced state as shown in Table 4 and Flow Chart 1.

7.2. Recommendations for advanced early kick detection

1. Add two high accuracy pressure sensors ranging from 0 to 2000 psi to measure the SIDP and SICP in the case of zero or small pressure reading.
2. Test the traditional wide range pressure sensors and also the additional accurate pressure sensors with small pressure values 100, 300 and 500 psi before drilling a new section to check accuracy.
3. In the case of static visual flow check make another flow check using trip tank for two reasons: A) flow check using trip tank is more accurate than visual flow check especially in small kick. B) flow check using trip tank can be seen from mud logging real time chart which shows how many barrel increase every minute.
4. In the case of slight flow, do not ignore that flow or consider it as an effect of U-tube, do the safe action, close the well and record pressure, if no pressure, do not continue drilling, apply another SIDP and SICP measurements using the additional pressure sensors as shown in Flow Chart 1.
5. The drilling operator and the higher decision maker when kick suspected should take in consideration the error range in the SIDP and SICP pressure reading, visual flow check and pore pressure predicted method used.
6. While drilling high-temperature high-pressure well make at least one dummy connection while drilling every stand to check the hole condition, presence of POG and CG in the

### Table 3 – Kick detection parameters comparison between drilling parameters, gas parameters and MWD logging tools.

| Kick Detection parameters | bottom Recording time | Near-balance state (before kick occur) | Underbalanced state (after kick occur) |
|---------------------------|-----------------------|----------------------------------------|----------------------------------------|
| Drilling parameters (ROP, pit gain, pump pressure, flow out) | Instantaneous | All drilling parameters Cannot detect near-balance state except ROP can detect near-balance using increase in BG and presence of CG and POG | Instantaneous detection |
| Gas Parameters (BG, CG, POG) | Delayed by Lag time | Detection delayed by lag time |
| MWD Logging tools (Resistivity, Sonic) | Delayed by offset distance from the MWD tool to the hole bottom then need data processing and complicated calculations |

### Table 4 – Comparison between proposed advanced kick detection method and conventional well control procedure.

| Kick detection procedures comparison | Conventional well control procedure | New advanced early kick detection method |
|--------------------------------------|------------------------------------|----------------------------------------|
| Flow check                            | Use visual flow check               | Use additional accurate flow check using trip tank |
| Pressure measure                      | Use wide range pressure sensor with low accuracy for measuring low pressure values | Use two additional pressure sensors with high accuracy for measuring low pressure values |
| Near-balance detection                | Not able to detect near-balance     | Can detect near-balance by circulate bottom’s up to check if there is a presence of CG and POG or increase in BG at the bottom |
8. Conclusions

Monitoring of mud logging real time data provides at least seven parameters for kick detection. The mud gas anomalies give indication that aids in controlling drilling mud hydrostatic head–pore pressure relationships. In the offshore Nile Delta, shale acts as a source of overpressure and also as a seal rock. Due to low permeability of shale, pore pressure may gradually increase with depth until reach underbalanced drilling without strong significant kick sign which lead to many failures to detect kick early using conventional well control procedure. The proposed advanced early kick detection method when the kick suspected uses additional accurate flow check utilizing trip tank. Moreover in the case of zero or small pressure reading while shut-in well the proposed method recommends open the pre-added two additional high accuracy pressure sensors for measuring low pressure values. The proposed method has a great advantage: not only can it detect small kick early but it can also detect near-balance drilling before kick occur by circulating bottom’s up to check the presence of CG and POG or increase in BG at hole bottom. The studied cases show that small kick and the near-balance drilling can be early detected using the proposed advanced early kick detection method.

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