Early Kick Detection and Optimization by Advanced Mud logging

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Abstract

Hydrocarbon influx from the formation into the wellbore possesses a serious threat to the safety of the well. So early kick detection is of great concern while drilling wells. The late kick detection will be hazardous and it can leads to uncontrolled blowout. This later increases the possibility of injury and potential loose of life and equipment. So various causes of kick and the importance of early kick detection are analyzed from advanced mud logging system. The real time data observation i.e. drilling, mud and gas data; log plots like d-exponent and pore pressure calculation. 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 8 years of experience in monitoring real time mud logging data while drilling and analyzing flow and kick reports.

Keywords: *Early kick detection***,** *Advanced Mud logging***,** *Near-balance detection, d-exponent, Pore pressure*

1. Introduction

Oil well drilling is an inherently a risk and uncertain process, which is associated with high impact and consequences upon occurrence of an accident. The consequences could be environmental damage, human loss, and monitory loss. Recent experience shows that kick poses the highest risk to the safety of the wellbore. Kicks that evolved into blowout stage cost billions of dollars, human lives and damage to the environment. For instance Macondo well incident that occurred in 2010 cost about $40 billion and 11 fatalities, Piper alpha in north sea that occurred in 1988 cost about $3.4 billion and 167 fatalities, and Petrobras 36, Brazil, that occurred in 2001 cost about $350 million and 11 fatalities (Tabibzadeh & Meshkati, 2014a). So it's better to incur cost to detect and control kicks rather than healing its consequences. A kick is an undesirable inflow of formation fluids into the wellbore.

Early Kick Detection System Using Numerical Models:

An early kick detection system using a Bayesian probabilistic model is proposed by Hargreaves et al. [1]. Similarly Kamyab et al. [2] proposed a dynamic neural network model that uses real time data analysis for early kick detection. The model uses real time analysis of mud logging data to detect the kick early. The dynamic wellbore model uses rig data such as pump rate and pipe rotation rate to predict the mudflow out and standpipe pressure. The predicted values are compared with the corresponding measured values from the wellbore. Kick is detected based on deviations between measured data and the model predicted values [3]

When kick occurs, the delay in the detection and controlling process may allow the formation fluids to flow uncontrollably leading to a blowout incident. The earlier the detection and control of a kick the better for well safety.

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. This will help to better understand what is

actually happening in the down-hole. Monitoring multiple kick indicators in the down-hole might improve the quality of interpretation and can significantly reduce the chances of false alarm.
The focus of this article is to:

- Develop a laboratory scale down-hole assembly of the drilling rig model and a kick injection setup.
- Investigate the relative pressure changes in the down-hole when influx occurs.
- Examine the relative changes in the drilling fluid density and conductivity when influx occurs.
- Evaluate the changes in the mass flow rate in the down-hole when influx occurs.
- Identify the parameters those are most sensitive to formation fluids.
- Develop a methodology to detect the kick without false alarms.

1.1 The Significance of Early Kick Detection

Early Kick Detection (EKD) is one of the most important focus areas for preventing Loss of Well Control (LWC) events throughout the world and elsewhere. The definition of Loss of Well Control as provided by the Bureau of Environmental Enforcement (BSEE) is:

- Uncontrolled flow of formation or other fluids. The flow may be to an exposed formation (an underground blowout) or at the surface (a surface blowout).
- Flow through a diverter.
- Uncontrolled flow resulting from a failure of surface equipment or procedures.

When kicks are accurately detected and recognized early they can be more readily managed and stress levels on equipment and personnel can be reduced, thereby lowering the risk of adverse consequences. Normal operations can resume safely and quickly. Two recent observations related to the importance of EKD are:

- An analysis of the Bureau of Safety and Environmental Enforcement's (BSEE's) incident database has shown that approximately 50% of drilling related LWC events could have been prevented or ameliorated with early kick detection.

To monitor the down-hole conditions, majority of the early kick detection systems focus on analyzing the returning drilling fluid at the surface. The possibility of blowout prevention could be high if the down-hole monitoring is done along with the surface monitoring. This is because, apart from delay, the exclusive surface monitoring has several limitations, including misrepresentation of the down-hole condition due to: mechanical problems, execution issues, wellbore breathing or ballooning, solubility of the gas in the oil based drilling fluid, and time required to manifest increase in mud tank volume at the surface, thus losing precious reaction time available to the personnel.

1.2 Limitations of Surface Monitoring for Early Kick Detection

Kick does not turn into blowout instantaneously. Most often, when influx occurs, it takes some time to evolve into a critical incident such as a blowout. Kick detection systems that exclusively rely on the surface measurements of the kick indicators might delay the kick detection process. The possibility of blowout prevention could be high if the down-hole monitoring is done along with the surface monitoring. This is because most often there is a time lag between kick initiation and the identification of any abnormality at the surface.

Apart from delay, the exclusive surface monitoring may become inadequate due to many reasons. For example, surface equipment failure, such as improper functioning of flow meters, may allow a kick to remain unidentified. The increase in mud tank volume at the surface also takes some time to manifest. Sometimes execution issues, such as an incorrect lining up of trip tanks, may give incorrect information regarding wellbore conditions in the down-hole. Mechanical problems, such as plugged pipelines and hydrate formation may also interrupt the kick monitoring at the surface. When formation fluid enters the wellbore and if the gas is soluble in the oil based drilling fluid then formation gas remains unnoticed until it breaks out of the drilling fluid. Since most often the separation of gas and drilling fluid occurs at low depths, the gas may reach above the Blow Out Preventer (BOP) before it is identified. Wellbore breathing or ballooning is sometimes confused with the kick. When wellbore is over-pressured (wellbore pressure is greater than the formation pressure), the formation may crack and the drilling fluid is lost in the formation cracks. When the pressure in the wellbore decreases, the lost drilling fluid in the formation cracks flows back into the wellbore. This phenomenon is called wellbore breathing or wellbore ballooning. If the focus is on monitoring kick indicators only at the surface, then this scenario sometimes can be confused with a kick.

1.3 Down-hole Monitoring for Early Kick Detection

Down-hole monitoring is specifically important when the influx occurs as a result of a lost circulation condition. When the down-hole pressure becomes lower than the formation pore pressure, the formation fluid may starts to enter the wellbore. When the lost volume of the drilling fluid is compensated by the formation fluid flowing into the wellbore, it becomes difficult to identify the kick based on flow rate or pit volume observations at the surface. Because, the increase in flow rate and pit volume at the surface is only noticed when the loss of drilling fluid is overcompensated by the inflow of formation fluid. However, a significant amount of fluid influx would have already entered the wellbore.

2. Result and discussion

2.1 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 parameters, mud parameters, gas parameters 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. 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 or Stand Pipe Pressure (SPP). 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.

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, and 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. 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 bearing zone. 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. 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. 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 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.

Some of the other primary quick kick indications observed by mud logging units are

- *Increase in Return Mud Temperature*
- *Increase in the Drag and Torque*

- *Rapid Increase in the Drilling Breaks*
- *Severe Lost Circulation*
- *Insufficient Drilling Fluid Level*
- *Increase in Mud Tank Volume*
- *Increase in Flow Rate*
- *Flowing Well*
- *Increase in Drill String Weight*
- *Changes in Pump Pressure*
- *Changes in Return Mud Properties*

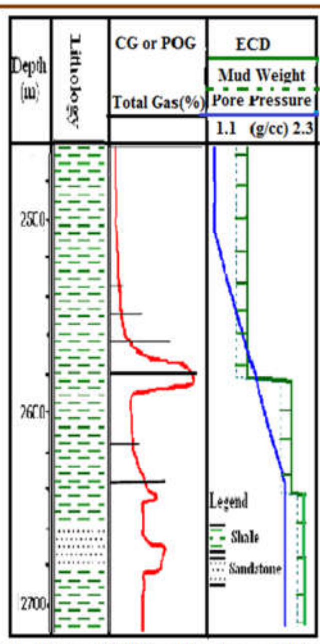

Fig.1 - Relation of CG, POG and TG to changes in differential pressure

Flow Chart 1 – Proposed advanced early kick detection method steps if a kick or a near-balance state is suspected.

2.2 Transition Zone

This is an argillaceous sequence of gradual pore pressure increase above a permeable high pressure formation. It is an important zone as par as drilling is concerned. Causes of Abnormal Pressure is due to rapid subsidence and sediment accumulation, thermal expansion, tectonic movement, reservoir altitude, clay digenesis, repress ring of shallow reservoirs. Signs of Abnormal pressure from mud logging are nnormalized drilling rate (Drilling models), change in rotary torque, change in drag, shale density, gas analysis, flow line temperature, size and shape of cuttings, open hole logs in Fig. 2.

Normalized Drilling Rate depends on Weight on bit, Rotary speed, Bit diameter, Bit type, Rock type, Mud properties, Differential pressure, Hydraulics.

2.3 "d" Exponent

Decrease in d-exponent Value: Generally, as drilling progresses, the d-exponent trends will increase, but a decrease in this trend may be an indication of abnormal high pore pressure zones in Fig.4. The d-exponent equation was developed to normalize the penetration rate. The d-exponent is calculated using the following equation

R/60N= (12W/10^6D) ^d
Log(R/60N) =d*log (12W/106D)
d= Log(R/60N)/ log (12W/10^6D)
Where (R=rop (ft/hr), N= rpm, W=wob (ib), D= bit diameter (in).)
Corrected "d" exponent
Dc = d*(n/mw)
Where (N= normal pp, Mw= mud weight)
Factors Affecting Dc are Bit wear, Lithologic change, Drastic changes in drilling parameters, Bit types.

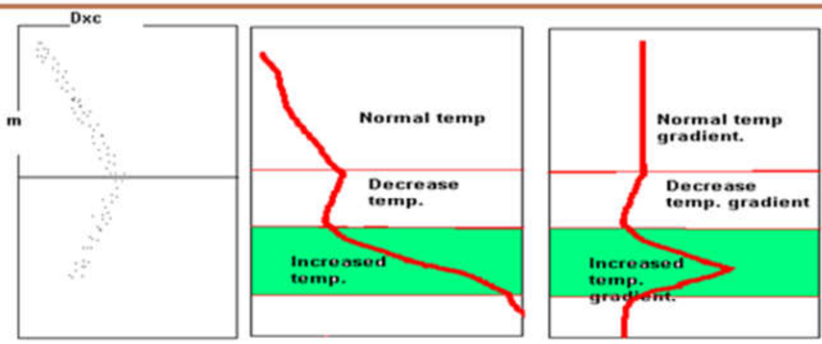

Fig.2 d-Exponent and temperature gradient

2.4 Size and shape of cuttings

A cutting drilled near balanced conditions will be larger and more angular in shape than one which is drilled under conditions of greater overbalance is collected by mud logging. Increase in cutting size and shape indicates underbalanced situations developed by abnormal high pore pressure zones can cause the formation to break. Since broken cuttings are not ruined by a drill bit they are more sharp and big in comparison to normal cutting size shown in fig. 3.


Fig.3 Size and shape of cutting near over balance condition

2.5 Pore Pressure Calculations

1. Depth of seal FP=Sf-[(Se-n)/(TVDe/TVDf)]

(Where FP= fm pressure, Sf= overburden at wanted depth, Se= overburden at depth of seal, N= normal pp, TVDe= depth of seal, TVDf= fm depth)

2. Eaton equation

FP=Sf-(Sf-n)*(DCo/DCn)^m

Where (FP= fm pressure, Sf= overburden at wanted depth, N= normal pp, DCo= observed dxc, DCn= normal dxc)

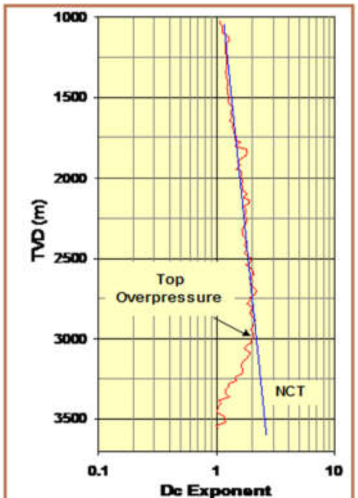

Fig.4 Predecting overpressure from d-Exponent

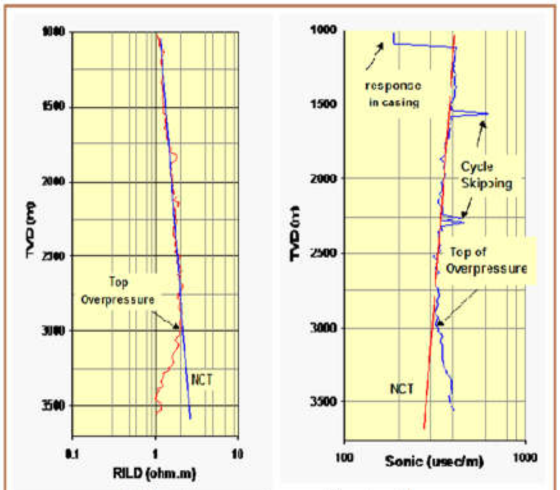

Fig.5 Top of overpressure from resestivity and sonic log

2.6 Shale density

With increased depth and greater compaction, shale density will show a normally increasing trend. An overpressure zone will be indicated by a decrease in shale density owing to decreased compaction and higher porosity i.e. a higher proportion of formation fluid in relation to rock matrix.

2.7 Shale factor

With normal diagenesis and cation exchange, clay minerals such as montmorillonite and smectite will transform to illite, thus a reduction in CEC (cation exchange capacity) will be seen with depth. An approximation to CEC is achieved by using Methylene Blue to determine the *shale factor*. As with the CEC, the shale factor will normally decrease with depth as the amount of illite increases. In an abnormally pressured zone, the increased temperature actual speeds up the process of cation exchange, therefore the shale factor would show a more rapid decrease.

Table 1 – 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

3. Conclusion

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.

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.

In order to safely control the inflow of formation fluids, the influx must be detected as early as possible. If the kick detection process is delayed, then formation fluids will continue to enter the wellbore. This will eventually accelerate into uncontrolled flow of formation fluids leading to a blowout scenario. So a proper closed observation is highly necessary while drilling, tripping in and tripping out operation in a wellbore. Using of trip tank also quietly monitored while tripping time. Most of the kick occurs only in tripping time. Swab/surge pressure monitoring while tripping should be observed. Measurement of hydrostatic pressure and effective mud weight in the down-hole should be maintained.

The following are some of the existing methods for early detection of a kick that are in practice in the industry. Most of the commercial early detection systems are automatic.

Some the examples are Microflux™ detection by Weatherford. Intelligent kick detection by MezurX. Kick Detection System Designed by @balance. Flag Fluid Loss and Gain Detection System – Schlumberger, X-OMEGA System.

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