Challenges Associated with Drilling Hydrostatic/Subhydrostatic Reservoir: Fluid Engineering Aspect*

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Search and Discovery Article #40744 (2011)
Posted May 31, 2011

*Adapted from extended abstract presented at GEO-India, Greater Noida, New Delhi, India, January 12-14, 2011.

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Abstract

Large sections of lithological sequences covering sand, clay, shale and coal are required to be drilled to reach the pay sand for assessment of reservoir as anticipated by G&G. At present, there is always a emphasis on drilling large interval of shale and pay sand alternations with lowest possible fluid weight in developed fields. This may be due to reservoir depletion and for enhancement of productivity. In a case of Southern field of ONGC, desired fluid weight is hydrostatic + 5% for drilling shale/ sand alternations. Whether it is feasible with this weight or not forms the basis of the present study. Fluid weight performs two functions. On one hand, it controls the influx of fluid (oil or gas) by controlling pore pressure and on the other hand, it also controls the effective stress of the formation matrix and preventing it from collapsing due to overburden. Thus minimum fluid weight required should be in excess of pore pressure and collapse pressure requirement. In an effort to maximize productivity by maintaining fluid weight as per the reservoir pore pressure may result in destabilization of overlying/ associated shale, which may need higher fluid weight. Study on shale cutting samples of the area showed it to be moderately dispersive in nature and can be easily controlled chemically by using KCl or Amine or Cationics-O. Inhibition achieved through said additives definitely push the fluid weight to lower bound side of fluid weight window but care has to be taken that in no case it bypass collapse pressure requirement. Only satisfying pore pressure requirement is erroneous. Practically it has been observed in the area that fluid weight around 1.10-1.16 SG had to be maintained for successfully drilling the well, which per se also meets the requirement of collapse pressure. The study has come out with following conclusions: Pore pressure and Collapse pressure may be considered for selecting lower bound fluid weight and must be displayed in Geotechnical order of the well. It is not feasible to drill large interval of shale/sand with low fluid weight. Additional casing may be lowered up to the top of reservoir sand and then reservoir may be drilled with desired fluid weight using lightweight filler in fluid. Geomechanics study of the

area will be extremely useful for plotting „Fluid weight window for Lower bound fluid weight and Upper bound fluid weight. KCl, Amine, or Cationics-O based fluid system may be used for stabilizing shale.

Introduction

Production over the years has diminished reservoir pressure to near hydrostatic to sub-hydrostatic. Pressure depletion in shales (above pay sands or associated with pay sands) is not the usual occurrence as nothing is being produced from shale. In the past, pay zones were having pressures more than hydrostatic, hence unknowingly; shales were stabilized with higher mud weight with least effect on productivity of oil well. In near hydrostatic/ sub hydrostatic scenario, it is becoming more or less a requirement to stabilize shale with low mud weight to cause minimum damage to reservoir.

A case in point is the requirement for formulation of mud system to drill large sections of shale and reservoir alternations without isolation by casing in Southern field of ONGC. The required mud weight suggested by asset is ~1.05 in order to minimize pay zone damage.

Mitigation of shale problems has led to development of high performance water base fluids based on rock- fluid interaction principles. Different high performance water-based mud systems used in ONGC viz KCl-PHPA, KCl-PHPA-Polyol has resulted into stabilizing of shales with reduced mud weight. However now emphasis is on to reduce mud weight further to meet the current requirement. This calls for understanding applicability of "mud weight window", criteria for selection of ‘mud weight’ and effect of depletion on reservoir rock and its adjacent formation.

Mud Weight Selection

Selection of mud weight for pressure control requires knowledge of:

- Pore Pressure Gradient
- Collapse gradient
- Fracture gradient

These gradients can be determined from nearby wells or measured while drilling. Pore pressure and collapse gradient define the lower limit of mud weight while Fracture gradient define the upper limit of mud weight. Mud weight should be kept as low as is safe, to reduce cost.

Pore Pressure Gradient: It is the density of pore fluid per foot of depth and is expressed as equivalent mud weight, ppg or psi/ ft. It is determined from density logs, or from VSP data. Mud weight is increased to confine pore pressure and therefore kick and subsequent blow out.

Mud weight > Pore pressure gradient = Controlled
Mud weight < Pore pressure gradient = Kick is taken

Collapse Gradient: It is the collapse resistance of the borehole per foot of depth and is expressed as equivalent mud weight, ppg or psi/ ft.

Mud weight > Collapse gradient = Borehole wall supported
Mud weight < Collapse gradient = Borehole wall collapses

Borehole instability can lead to:

- Borehole collapse
- Trapped tools
- Most logging operations affected
- Reduce casing support
- Blocked offholes

Fracture Gradient: It is the fracture resistance of the borehole per foot of depth. It is determined by performing a leak off test on the borehole. Mud is slowly pumped into the open borehole and measuring the pressure increase. When the increase becomes non-linear, the borehole has started to fail. This indicates fracture pressure at that point. Fracture gradient is expressed in equivalent mud weight, ppg or psi/ ft.

Mud weight < Fracture gradient = Safe borehole
Mud weight > Fracture gradient = Fractured borehole

Fractured boreholes can lead to:

- Underground blowout
- Lost circulation

Collapse and Fracture gradients depend on formation rock properties, in-situ stresses, pore pressure and well bore trajectory.

Mud Weight Window

The boundary between Collapse pressure/ Pore pressure and Fracture pressure is called the mud weight window. It should be in excess of former and lesser than the latter. There are several approaches for optimizing mud weight while drilling. One approach that attempts to optimize mud weight such that hoop stress is zero, is the median line principle proposed by Aadnoy. This principle suggests that mud weight should be half way between the pore pressure and the fracture gradient to bring the hoop stress to zero. There may be a temptation to keep mud weight as low as possible in order to maximize penetration rate. Unfortunately this often leads to hole enlargement and lost time due to tight hole problems. The median line approach sacrifices penetration rate early on in the well but makes for it by minimizing hole problems. Even with an approach like the median line principle, the mud weight can only be optimized for the hole at one depth. An optimum mud weight for the hole at one depth will be too high for the well at shallower depth and too low for deeper depth. This means optimum mud weight window for a small section of the open hole can be had. The best course of action is to optimize the mud weight at the drilling depth and raise mud weight as required, but never reduce it.

Depleted Reservoir Effects

Depletion of a zone has two major effects: the horizontal stresses drops causing the effective stresses to rise. This results in:

- Drop in pore pressure in the depleted zone
- Increase in confining stress i.e. stronger rock
- The reservoir shrinks because of drop in pore pressure
- Increase in horizontal stresses above and below the zone
- Effects on vertical stress are negligible
- Pore pressure can be expected to be low
- In some cases the reservoir enters a condition of shear failure (or collapse)
- There may also be issues of casing shear
- Free gas development in the reservoir

Consequences:

- Slower drilling because rock is tougher
- Lost circulation and Blow out risks go up substantially
- More casing strings and LCM squeezes
- Most serious in HTHP wells, multiple zones

Depleted reservoirs exhibit lower pore pressure and horizontal stress magnitudes than the overlying shaly formation. Drilling through depleted reservoirs can cause lost circulation and drilling induced well bore instability. Though the overburden stress is expected to increase with depth, both horizontal stresses are significantly smaller in depleted sand than the overburden shale. However, both the horizontal stress magnitudes increase again in the shale below the depleted sand or in shale/ sand alternations i.e. in multiple zones. Such rapid variations in horizontal stress magnitudes cause large fluctuations in safe mud weight window.

Discussion

The maintenance of wellbore stability is one of the most critical considerations in any drilling operation. An unstable wellbore will reduce drilling performance resulting in drilling and tripping difficulties and in the worst case could result in the loss of the hole through borehole collapse. Wellbore instability can occur as a result of chemical effects, mechanical effects, or a combination of both.

Chemical effects are related to electrochemical interactions between mud and formation being drilled. The problems may result due to inappropriate mud type being used or inadequate inhibition being given to mud system.

Mechanical effects, in simple terms, are usually related to inadequate mud weight (too high or too low) and inappropriate drilling practices (rate of penetration, vibration effects, torque and drag, poor practices, and frequency of trips).

Chemical Effects; Mud Design Perspective

Based on CST and dispersibility studies, the following fluids were found to be best suitable for providing optimal inhibition and mitigating shale problems in respect of 'Chemical effect perspective' for the shales of the area:

- 6 cp. PBS + 5% KCl + 0.2 % XCP + 0.4% PHPA + 0.6% PAC (L) + 0.4 % PAC ® + 2% SA + 2% Polyol
- 6 cp. PBS + 2% Amine + 0.2 % XCP + 0.4% PHPA + 0.6% PAC (L) + 0.4 % PAC ® + 2% SA + 2% Polyol
- 10 cp. PBS + 1% CATIONICS-O+ 2% PGS + 2% SA

Mechanical Effects; Mud Weight Perspective

The objective of the present study is to formulate a very low weight (close to hydrostatic ~1.05) drilling fluid system for drilling large sections of shale and reservoir sand alternations. As per GTO, expected formation pressure is hydrostatic + 5% in the interval 1,150-1,800 m. This interval covers the shale and reservoir sands. Mud weight corresponding to this interval as per GTO is 1.10-1.22, which is on higher side vis-à-vis expected formation pressure. Why is it so? As pointed out earlier, Mud weight selection is based on following:

- Pore pressure

- Collapse pressure
- Fracture pressure

Pore pressure data are given in the GTO (expected formation pressure) and Fracture pressure data is obtained through LOT. Collapse pressure data is not provided in the GTO. Pore pressure is due to fluid in the pore and Collapse pressure is due to solids in shale matrix. Generally, sediment at a depth has to support the weight of the sediments above it. The total stress (S) imposed by the overburden (solids+water) is given by the equation:

$$S = \rho b \times Z$$

Where ρb is the bulk density of sediments and Z is the depth. Mud weight should be maintained in excess of Pore pressure/ Collapse pressure and less than fracture pressure. However, once sediment has been compacted sufficiently and establishes grain-to-grain contact, the overburden load is carried independently by the solid matrix and fluid in the pores separately, so that:

$$S = \sigma + Pf$$

Where σ is effective stress (or intergranular stress or matrix stress) and Pf is pore pressure. Deformation and strength of a rock is dependent on the effective stress and is independent of pore pressure. Collapse of the rock is related to effective stress. If mud weight is not maintained above the effective stress, the rock will fail under compression due to overburden at that depth. Therefore, mud weight has to play two roles: a) to control pore pressure to prevent fluid influx as well as b) to control effective stress to prevent rock failure. Hence as per given GTO, mud weight of 1.05 is sufficient to control pore pressure but may fail to check the effective stress. So keeping a mud weight in the range 1.10-1.22 is completely justified in terms of controlling pore pressure as well as effective stress. Incorporation of collapse pressure data in GTO would have solved the issue once for all.

Shale and Sand Alternations

There will be changes in stresses in shale sand alternations. It would be different for shale falling adjacent to sands. As has been pointed earlier, depleted reservoirs exhibit lower pore pressure and horizontal stress magnitudes than does the overlying shaly formation. Drilling through depleted reservoirs can cause lost circulation and drilling induced well bore instability. Though the overburden stress is expected to increase with depth, both horizontal stresses are significantly smaller in depleted sand than the overburden shale. However, both the horizontal stress magnitudes increase again in the shale below the depleted sand or in shale/ sand alternations i.e. in multiple zones. Such rapid variations in horizontal stress magnitudes cause large fluctuations in safe mud weight window. In near hydrostatic/ sub hydrostatic scenario impact of collapse pressure becomes all the more important. In an effort to minimize pay zone damage, the decrease in mud weight may bypass collapse pressure requirement of adjacent formation. As a result, the borehole will fail under compression.

The designed mud systems will definitely push mud weight requirement to lower bound side of mud weight window, but care is to be taken that it may not ignore collapse pressure requirement. Determination of collapse pressure is done through geomechanics studies or through logs. In the absence of collapse pressure data, a practical way in field is to see the incidence of caving when the low mud weight is used. If it occurs then gradual increase in mud weight is made until the caving is stopped.

Review of Casing Policy

In such scenario, drilling long interval of shale and sand alternations without any isolation casing is not possible, for which review of casing policy is required. Higher mud weight to control shale may damage underneath near hydrostatic/sub-hydrostatic reservoir. Using mud weight required for drilling reservoir may destabilize the shale. Therefore, additional casing is required to be lowered up to the top of reservoir and then reservoir may be drilled with desired mud weight.

Conclusions

Following mud systems may be used to mitigate hydrational stress:

- 6 cp. PBS + 5% KCl + 0.2 % XCP + 0.4% PHPA + 0.6% PAC (L) + 0.4 % PAC ® + 2% SA + 2% Polyol
- 6 cp. PBS + 2% Amine + 0.2 % XCP + 0.4% PHPA + 0.6% PAC (L) + 0.4 % PAC ® + 2% SA + 2% Polyol
- 10 cp. PBS + 1% CATIONICS-O+ 2% PGS + 2% SA

Additionally,

- It is not feasible to drill with low mud weight until collapse pressure/pore pressures are known.
- Collapse pressure along with pore pressure may be considered for selecting lower bound mud weight and must be displayed in GTO.

- Additional casing may be lowered up to the top of reservoir and then reservoir may be drilled with desired mud weight.
- Geomechanics study of the area will be extremely useful for deciding „Mud weight window for delineation of Lower bound mud weight and Upper bound mud weight.
- Efficient solid control equipment may be used.

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