DESIGN OF AN ULTRA-SPEED LAB-SCALE DRILLING RIG FOR SIMULATION OF HIGH SPEED DRILLING OPERATIONS IN HARD ROCKS

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ABSTRACT

Drilling is a common process in mining and petroleum engineering applications which have different objectives. For example, drilling deep boreholes in tight gas formations and gas shales is becoming more popular in the oil and gas industry. By contrast, drilling deep small sized holes for mineral exploration in hard rocks is performed to obtain samples for grade analysis purposes. In both applications optimising the drilling process includes using the most effective operating parameters such as rotation speed and weight-on-bit in order to maximise the rate of penetration. Obtaining the optimum drilling parameters requires sensitivity analysis over a range of data, which would be costly and time consuming during real field operations. Therefore, conducting several experimental simulations in the lab would be very beneficial before field operations begin.

A drilling rig was designed and developed to simulate various drilling scenarios. The rig works in conjunction with an existing true triaxial stress cell (TTSC) which is in use for different petroleum related applications. The rig allows drilling into a cubic rock sample of up to 300 mm size. Three independent stresses can be applied to the sample to simulate real in-situ field stress conditions while the sample may be saturated with fluid. A significant feature of the rig is its ultra-high speed rotation which can rotate up to 8000 rpm: this is to simulate hard rock drilling for mineral exploration applications where large weight-on-bit could damage the bit cutters. With the proposed design, a drilling fluid of any type can be circulated in the simulated borehole similar to the real situation, to study its effect on drilling performance. The TTSC drilling lid is equipped with torque and drag measurement systems which are two important drilling parameters to be recorded during drilling operation.

It is believed that this new drilling rig will open opportunities for performing major new applied research in the area of more efficient drilling in both oil and gas bearing formations and mineral exploration applications.

KEYWORDS

Drilling rig, High speed, Mineral exploration, Oil and gas, WOB, torque, RPM, ROP, stress, TTSC

INTRODUCTION

Exploration for hydrocarbons and unconventional resources such as gas shales at deep and ultra-deep levels (i.e. greater than 4km) requires technologies suitable for drilling deep wells in a cost effective manner. Similarly, in the mining industry, extraction of deep minerals (i.e. greater than 3km) is being targeted because near surface resources are diminishing. The rate of penetration (ROP) has been considered the key parameter to determine the efficiency of drilling deep wells. Larger ROPs would result in a well to be completed earlier; hence the rig daily costs and other associated expenses would be reduced significantly. The ROP is a function of many other parameters including the weight on bit (WOB), rotation speed (RPM), the type of drilling fluids used and formation properties. While several theoretical and empirical models have been developed to determine the optimum values for these parameters, the complexity of the problem especially when moving to a new well, has made these models approximate only. Performing physical simulations in the lab to reproduce specific field conditions as close as possible to reality is a useful approach which will provide a good understanding of how different parameters may interact during drilling operations.

Investigation of technical challenges associated with drilling deep wells in the lab has been the topic of research in the past. The results of studies carried out by Lyons et al., (2007) indicated that the costs of drilling increases significantly as depth increases and drilling the last 10% section of deep wells are more costly than any shallower intervals. This is partly due to the fact that the ROP reduces exponentially as borehole pressure increases at greater depths.

One of the large scale lab testing experiments which was performed to simulate deep well drilling conditions belong to the efforts of Terra Tek (Black and Judzis, 2006). In their study, the effects were studied of different bits including 6 inch impregnated, 4-blade and 7-blade PDC and roller cone bits and the drilling fluids used during drilling operations on ROP. Figure 1 shows a large drilled sample lifted out of a pressure vessel and also the bits used in this study. The borehole pressure during the test was as high as 10,000 psi and the results indicated how adding the weight to the drilling fluid can significantly reduce the ROP. Also, it was observed that using different bits with various geometries, the ROP will be different.

Figure 1 – View of drilled sample lifted out of a pressure vessel (left) and the bits used for drilling (Black & Judzis, 2006).

With the objective to increase the ROP in deep (15000 ft) to ultra-deep (25,000 ft) oil and gas wells, the US Department of Energy (DOE) developed an ultra-deep single cutter research drilling simulator (UDS). Cost reduction was the incentive for that project. During the operation the rotating rock sample was cut using a stationary cutter whose geometry, orientation and radial placement was flexible. The position of the fluid injection nozzle with respect to the rock sample could be changed and the experiments could be done with different flow rates and jet velocity. The angular speed of the rock core can be controlled up to 60 RPM, which is equivalent to a linear displacement rate of 6.8 m/s. The test facility was basically under ambient conditions; however, limited ability of controlling pore pressure to simulate the spurt loss was added to the system. Applying X-ray observation techniques, it would be possible to physically observe the solid-phase strain and flow of rock over extremely small time increments (Lyons et al., 2007). Figure 2 shows a computer-generated version of the UDS proposed in that work.

Figure 2 – A view of computer-generated rendering of the UDS ((Lyons et al., 2007).

The DOE, in a more recent study, used a new drilling rig for simulation of deep drilling. The rock sample had a dimension of 3×5×1.5 in. The rotation speed of the bit was 10,000 RPM, which produced an equivalent torque of 45 ft.lbf. At reduced speed of 4500 RPM the equivalent torque would increase up to 350 ft.lbf. The drilling fluid could be circulated to transfer the cuttings which were collected into the drilling tank. The experiment was conducted at atmospheric conditions which were not representative of downhole drilling. Figure 3 (left) shows the components of the system with Figure 3(b) being a view of a sample in place. Figure 4 shows a full view of this drilling rig (DOE, 2010).

Figure 3 – Components of the drilling rig used by the DOE for deep drilling (left) and a view of sample ready for drilling (DOE, 2010).

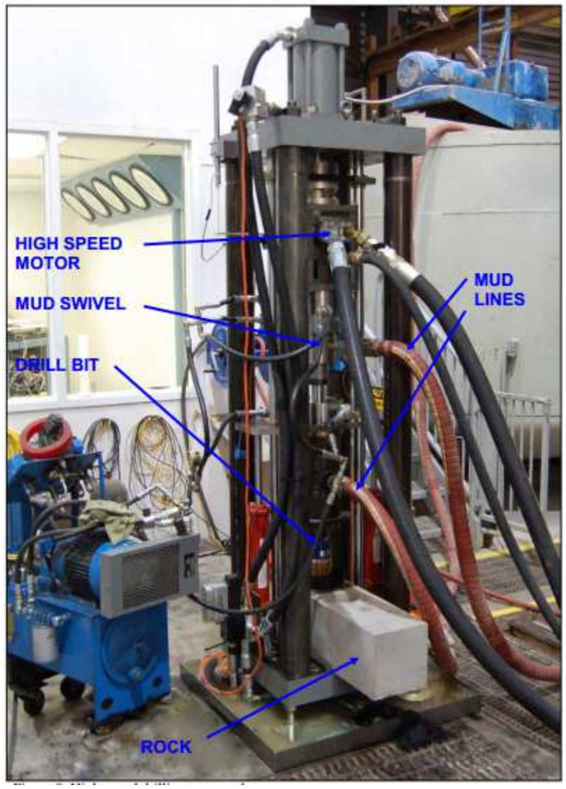

Figure 4 – A view of the drilling rig used by the DOE for deep drilling simulations in the lab (DOE, 2010)

While several other lab scale drilling facilities have been developed and proposed for simulation of deep drilling, it can be seen that most of them were operational under atmospheric conditions. In addition, in the majority of cases the drilling speed was not that high (i.e. over 5000 RPM) to simulate high speed drilling which represents the hard rock drilling scenario.

In this paper, a new rock drilling laboratory, which has been recently designed and developed, is introduced. The drilling lid consists of a high speed rotary drilling system which allows drilling into a cube of rock while the drilling fluid is circulated and drilling parameters are measured. The set-up is placed on top of an existing stress cell in which the rock sample can be subjected to three independent stresses and pore pressure. This unique laboratory allows investigation of the effect of different parameters on ROP including the in-situ stresses and allows different rock morphology and (faulted) geometry to be drilled.

NEW DESIGNED ROCK DRILLING LABORATORY

Figure 5 shows a view of an existing true triaxial stress cell, TTSC (Rasouli & Evans, 2010) which was used as a base for setting-up the new drilling machine. Using the TTSC as is seen in Figure 5 it is possible to apply three independent stress, two horizontal and one vertical through the top lid, on a rock sample as big as 300 mm. The innovation of the new design was to modify the top lid of the TTSC to allow drilling into any rock specimen as schematically illustrated in Figure 6. As is seen from this figure the idea is to drill through a rock sample, either dry or saturated, with any size up to 300 mm cubed which is subjected to three independent stresses. The drilling mud should be circulated during drilling operations and for hard rock drilling the set-up should allow very high speed drilling, in the order of 10,000 RPM.

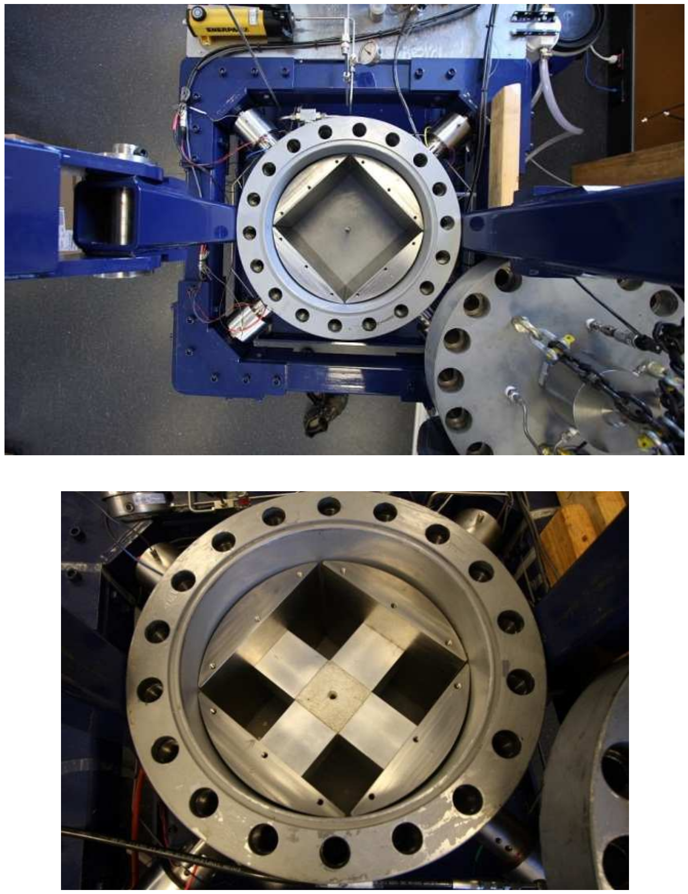

Figure 5 – A view of the true triaxial stress cell (TTSC) developed at Curtin Petroleum Engineering (top) and a view of a 100mm sample placed in the cell with a hole drilled at its centre (Rasouli & Evans, 2010)

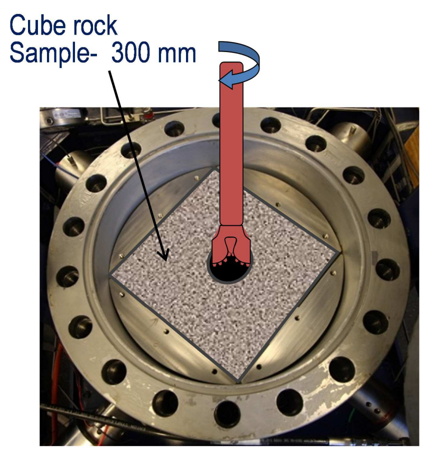

Figure 6 – Schematic of drilling through a cubic rock sample subjected to three independent stresses

With the above concept in mind the top lid of the TTSC was modified to be a drilling lid. Figure 7 shows the components of the new set-up. The main shaft passes through the top hydraulic ram and can handle bit sizes ranging from 1–2 inches. The lid is sealed using a set of extremely heavy-duty rotary seals that allow application of pore pressures up to 3,000 psi during the operation. The sealing system also enables circulation of drilling fluid at pressures up to 3,000 psi by adjusting a special wide-opening back pressure valve. Employing a 7.5 KW 3-phase electric motor which is equipped with a Variable Frequency Drive (VFD) along with a system of pulleys and belts, different rotational speeds can be achieved ranging from 10–8000 RPM. The Weight on Bit (WOB) is applied by a hydraulic cylinder located at the very top end of the main shaft: this can exert axial loads up to 3,000 lbf. The resulting torque on bit is measured using a torque and rotary speed sensor which is fitted in the main shaft. The maximum torque that the main shaft can tolerate is 120 N-m. A thrust bearing is fitted between the rotating shaft and the hydraulic cylinder to separate the rotating part from the static part.

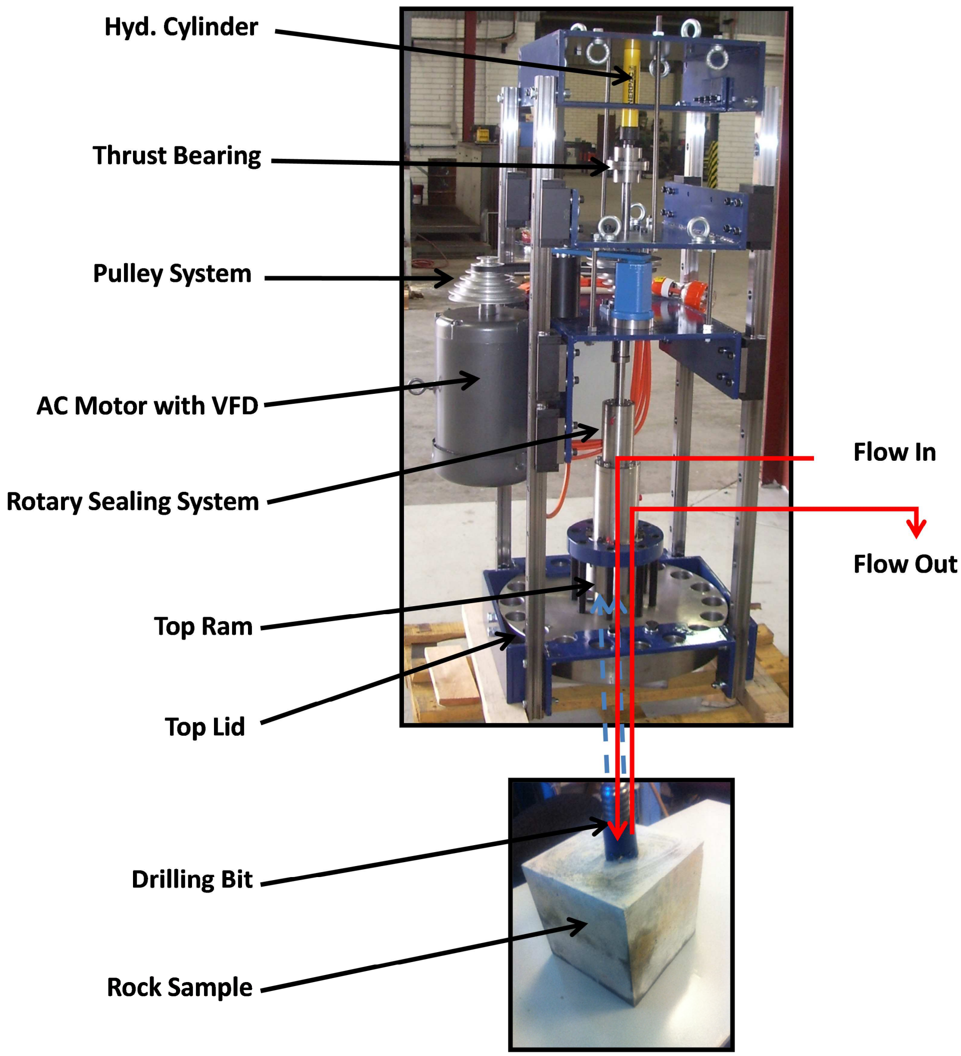

Figure 7 – The new lid designed for drilling simulations in the lab

Different types of drilling scenarios can be simulated using this innovative drilling lid. The drilling can be done by applying constant pressure on the top hydraulic cylinder and monitoring the resulting load on the shaft to represent a constant WOB. The depth of drill is measured using linear variable differential transformer (LVDT) sensors that can precisely detect the movement of the main shaft relative to the rock sample. The data acquisition system can be used to monitor the rate of drilling and by changing hydraulic pressure in the top cylinder; the rate of penetration can be kept constant. Under-balanced drilling can also be simulated by saturating the rock sample and applying pore pressure but keeping the circulation pressure lower than the pore pressure. When drilling a hard rock sample, impregnated diamond bits can be used at higher speeds (faster than 1,200 RPM) to enhance drilling performance. The high speed rotation of the shaft allows simulating ultra-high speed drilling for drilling hard rocks in mineral exploration.

CONCLUSIONS

In this paper a newly designed drilling rig was introduced for simulations of deep drilling conditions. The set-up is a lid which is used in conjunction with an existing stress cell and can be used to drill a cubic rock specimen up to 300mm. The system allows drilling at ultra-high speed of up to 8000RPM, which is useful to simulate drilling hard rocks in mineral exploration applications. The drilling mud can be circulated during operation and all the data can be monitored. Application of pore pressure and real field stresses are unique elements of this design.

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REFERENCES

Black, A. and Judzis, A. (2006). *Optimization of Deep Drilling Performance – Development and Benchmark Testing of Advanced Diamond Product Drill Bits & HP/HT Fluids to Significantly Improve Rates of Penetration*. Topical Report, U.S. Department of Energy, http://www.osti.gov/bridge/index.jsp.

Lyons, K. D., Honeygan, S., and Mroz, T. (2007). *NETL extreme drilling laboratory studies high pressure high temperature drilling phenomena*. U.S. Department of Energy, National Energy Technology Laboratory.

Rasouli, V., & Evans, J. B. (2010). *A True Triaxial Stress Cell (TTSC) to simulate deep downhole drilling conditions*. APPEA journal 50, p.p. 61-70.

United States Department of Energy National Energy Technology Laboratory (DOE), (2010). *Smaller Footprint Drilling System for Deep and Hard Rock Environments; Feasibility of Ultra-High-Speed Diamond Drilling*.