Technology Assessment for

Fundamental Research on Percussion Drilling: Improved Rock Mechanics Analysis, Advanced Simulation Technology, and Full-Scale Laboratory Investigations

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Technology Assessment Overview

1. Introduction: History of Technology

In 1859 at Titusville, Pennsylvania, Colonel F. L. Drake completed the first oil well using a cable tool percussion-type machine. One of the earliest reports of percussion drilling technique occurred in 1949 (Harpst and Davis, 1949). Since then different terms have been used, such as downhole hammer, percussion hammer, Down-The-Hole hammer, percussive drill, percussive-rotary drill, etc.

Major development and research in percussion drilling have been reported between 1950s and 1960s (Wanamaker, 1951; Faihust and Lacabanne, 1956; Topanelian, 1958; Fish, 1961; Simon, 1964; Hartman, 1966; McGregor, 1967). Significant gains in understanding the percussive mechanism have been achieved in lab. Some single-well applications have been reported in the oilfield for the purpose of demonstrating the effectiveness of percussion drilling (Smith and Kopczynksi, 1961; Bates, 1964).

Mainly because of frequent mechanical failures, poor understanding and therefore control of drilling operations, and economic uncertainties, wide application of hammer drilling technology in the oilfield was not reported until 1980s. In 1987, Pratt reported that air hammers were tested on 27 wells in the Waterton, Jumping Pound, and Clearwater areas of Alberta, and in the Flathead valley of British Columbia. Average time to total depth for recent air/mud drilled wells at Jumping Pound has been 80 days (best 66 days), compared to the record mud drilled well which took 103 days. Whiteley and England (1986) also showed that field applications of air hammer drilling in the Arkoma basin, which has significantly improved air drilling operations including a large increase in ROP, improved hole geometry, reduced drillstring stresses, and a substantial reduction in cost per foot.

Since 1990s, oil and gas wells have been drilled deeper and deeper, and consequently the rocks become harder and harder. A hydraulic hammer or water hammer has been developed to accommodate these new challenges and efficient mechanical designs have been achieved (Kong et al, 1996; Giles et al, 2001; Tibbitts et al, 2002). These designs, however, are still in pre-field stage.

2. Pros and Cons of Percussion Drilling

It has been widely recognized that percussion drilling (even without rotary) results in a faster penetration speed than conventional means such as rotary or diamond drilling, especially in some hard formations such as siliceous granite, sandstone, limestone, dolomite, etc (Whiteley and England, 1986; Pratt, 1987). With the same rotation and WOB the percussive-rotary method is 7.3 times faster than the conventional rotary method in a medium-hard granite, while at the best operational conditions for both methods, percussive-rotary has a 2.3 times advantage in ROP over the rotary (Melamed, et al., 2000).

In additional to a faster ROP, some other benefits are also documented in the literature, such as lower WOB, less contact time with rock that leads to a less abrasion of the bit and therefore a longer bit life, less hole deviation and easier control of a deviation problem for straight hole drilling, and larger cuttings are generated which gives a better representation for geological study. The impact of the hammer may also provide a steady seismic signal at the hole bottom to estimate porosity, elastic moduli of the rock, and synthetic seismograms (Minear et al., 1996); the hammer may be used as a steerable drilling device that provides down-hole rotation (Bui 1995); and, impact energy may be exploited for Down-hole electricity generation, down-hole high-pressure jet intensification, etc.

Because of these attractions, it has been predicted that "…The combination of rotary and percussion-type drilling could make a frontal attack into the drilling technology and open a new era of drilling." (Samuel, 1996)

On the other hand, inclusive overall results, poor understanding of drilling fundamentals, and economic uncertainties greatly jeopardize the acceptance of percussion drilling technology by operators. As a consequence of this lack of confidence, no evidence on the performance of percussion drilling in either directional wells, horizontal wells, slim hole drilling, or coiled tubing drilling has been reported. The best ROP with acceptable economics lies more in the basis of field experience rather than a convincing theory.

There is a serious lack of fundamental research, which is essential for operational control. Many unclear but critical issues are yet to be solved. The most important and difficult one would be to convincingly describing failure mechanisms for the rock defragmentation during percussion drilling, based on a reliable simulation tool that can be developed to predict when, where, and how much rock will fail before the hammer hits the rock so that the values for hammer type, number of blows, energy per blow, etc. can be optimized for field operations. This may also help to explain the poor performance of this technology in shale and other soft rocks, and provide suggestions.

3. **Discussion: Development Strategies**

The objective of this project is to significantly advance the fundamental understandings of the physical mechanisms involved in combined percussion and rotary drilling, and thereby facilitate more efficient and lower cost drilling and exploration of hard-rock reservoirs. The project has been divided into three major components: rock mechanics modeling to answer when, where and how rock fails under percussive loading pattern, cuttings transport modeling to describe how much and how fast the failed rock can be carried out of the annulus by mud circulation, and full-scale lab testing to verify the developed models (see Fig.1).

A comprehensive review of percussion drilling technology has been carried out to evaluate its current status such as development that has been achieved and challenges that industry faces. This review covered a wide range of work from penetration with vibration in mining, boring, tunneling, cutting, excavating, and defragmenting applications to theoretical modeling efforts on rock failure, rock damage and cuttings transport. As a summary of the review, a conceptual physical model with prototypes for

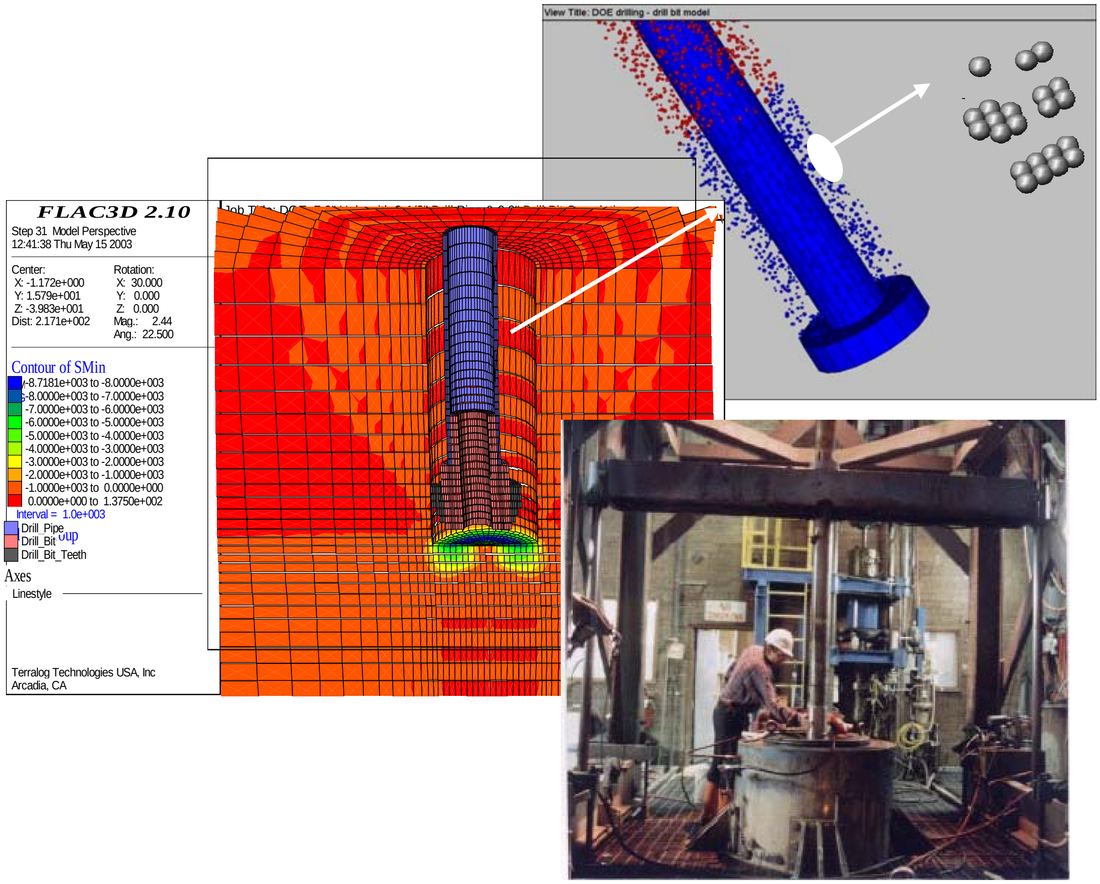

Fig. 1. Three project components: rock mechanics modeling (middle left), cuttings transport modeling (up right), and full-scale lab test (down right)

rock, bit, and debris flow has been developed. This model has served as the basis for our modeling efforts.

Three main processes involved in percussion drilling have been summarized, such as drillbit penetration with compression, rotation and percussion, rock response with stress propagation, damage, and failure, and debris transportation inside the annulus after disintegration from the rock. Three failure mechanisms have been proposed to account for rock damage and failure during bit-rock interactions, including rock crushing by compressive bit load, rock fracturing by both shearing and tensile forces, and rock fatigue by repetive compression-tension type of loading. These mechanisms and processes are modeled as follows.

- With aid of a finite-difference based numerical code (FLAC3D), a 1D dynamic wellbore model with stress wave input and dynamic features such as quiet boundary, free field boundary, local and Reyleigh damping mechanisms, etc., has been developed. A Mohr-Coulomb material model with strain-softening characteristics has been introduced. Three rock failure criteria have been developed to determine when, where, and how the rock fails in the post-yield state during percussive drilling. Rock fatigue due to cyclic loading is simulated through the application of plastic post-peak softening. Simulation results indicate that the stress distribution, failure pattern, and penetration speed (ROP) vary significantly with boundary conditions and rock damping features. Important mechanisms for rock failure during percussion drilling may each play dominant roles in different stages of the hammer-rock impact cycle.

- Based on a set of constitutive models that describe cuttings transport as a Newtonian/non-Newtonian laminar/turbulent flow, numerical modeling efforts have been carried out at particle scale in great detail with a numerical particle flowing code (PFC3D). Factors that affect the efficiency of particle transportation, such as density, viscosity, velocity, drilling equip geometry, etc, have been analyzed. The results have been visualized into various movies.
- After these models are developed, a set of full-scale laboratory tests will be carried out. The purpose of these tests is to verify the physics and mechanisms described in the theoretical models. Data from the tests will be used to validate the simulation tool.

A 3D rock model is constructed to simulate a true wellbore situation. Factors affecting rate of penetration (ROP) such as weight on bit (WOB), uniaxial compressive strength (UCS), rotation per minute, (RPM), etc, are to be analyzed to optimize drilling design. For cuttings transport, further modeling effort is needed to investigate non-Newtonian flow and turbulent. Coupling between rock mechanics modeling and cuttings transport modeling is needed in the end.

4. **Conclusion: Future**

These accomplishments capture fundamental physics of rock mechanics and cuttings transport during percussive drilling of hard-rock reservoirs. The to-be-verified analytical and numerical models can predict when, where, and how much rock fails when it is under percussive loading conditions, and describe detailed physics in cuttings transport. Development of such models sets up a platform for new simulation tools to describe and predict bit advancement based on solid physics and sound theoretical ground.

Deliverables include a series of quarterly reports and a final report that detail the research efforts in both rock mechanics modeling and cutting transport modeling, and a set of analytical and numerical models that are developed and verified to account for various rock and cutting physics. At the end of this research, a reliable simulation tool will be available for the petroleum industry to design and optimize percussion drilling technology.

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