ULTRA-DEEP DRILLING COST REDUCTION; DESIGN AND FABRICATION OF AN ULTRA-DEEP DRILLING SIMULATOR (UDS)

FINAL REPORT

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Abstract

Ultra-deep drilling, below about 20,000 ft (6,096 m), is extremely expensive and limits the recovery of hydrocarbons at these depths. Unfortunately, rock breakage and cuttings removal under these conditions is not understood. To better understand and thus reduce cost at these conditions an ultra-deep single cutter drilling simulator (UDS) capable of drill cutter and mud tests to sustained pressure and temperature of 30,000 psi (207 MPa) and 482 ℉ (250 ℃), respectively, was designed and manufactured at TerraTek, a Schlumberger company, in cooperation with the Department of Energy's National Energy Technology Laboratory. UDS testing under ultra-deep drilling conditions offers an economical alternative to high day rates and can prove or disprove the viability of a particular drilling technique or fluid to provide opportunity for future domestic energy needs.

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References

1. *Drilling, Completion and Stimulation Program Announcement DE-PS26-05NT42395-0*, US Department of Energy, January 25, 2005
2. *RMP-NT42654: Research Management Plan for Ultra-deep Drilling Cost Reduction*, November 4, 2005
3. *A Review of Single Cutter Rock Excavation and Some Related Topics*, G. Cooper, November 30, 2005
4. *ASME Boiler and Pressure Vessel Code*
5. *Quality Assurance Test Plan for: The Ultra-Deep Simulator DCN-1003-0056-3-00-0*, L. Soccorsi

Acronyms/Abbreviations

CAD	Computer-Aided Design
COR	Contracting Officer's Representative
DOE	United States Department of Energy
GFI	Ground Fault Interrupter
HP	High Pressure
HT	High Temperature
NETL	National Energy Technology Laboratory
NPC	National Petroleum Council
UDS	Ultra-deep Drilling Simulator
XDL	Extreme Drilling Lab

1. Summary

An ultra-deep single cutter drilling simulator (UDS) was designed and manufactured by TerraTek for the National Energy Technology Lab (NETL) as part of its Extreme Drilling Lab (XDL) to better understand and reduce cost of drilling at ultra-deep conditions. The UDS provides a simulated drilling environment to study fundamental behavior and interactions among drilling fluids, bit cutters, and rock of wells beyond depths of 20,000 ft (6,096 m), and is therefore capable of drill cutter and mud tests to 30,000 psi (207 MPa) pressure and 482 °F (250 °C) temperature.

The main components of the UDS consist of tie rod/support column load frame, pressure vessel, hydraulic charge pump, hydraulic circulation pump, hydraulic load actuator, and hydraulic torque actuator (Figure 1).

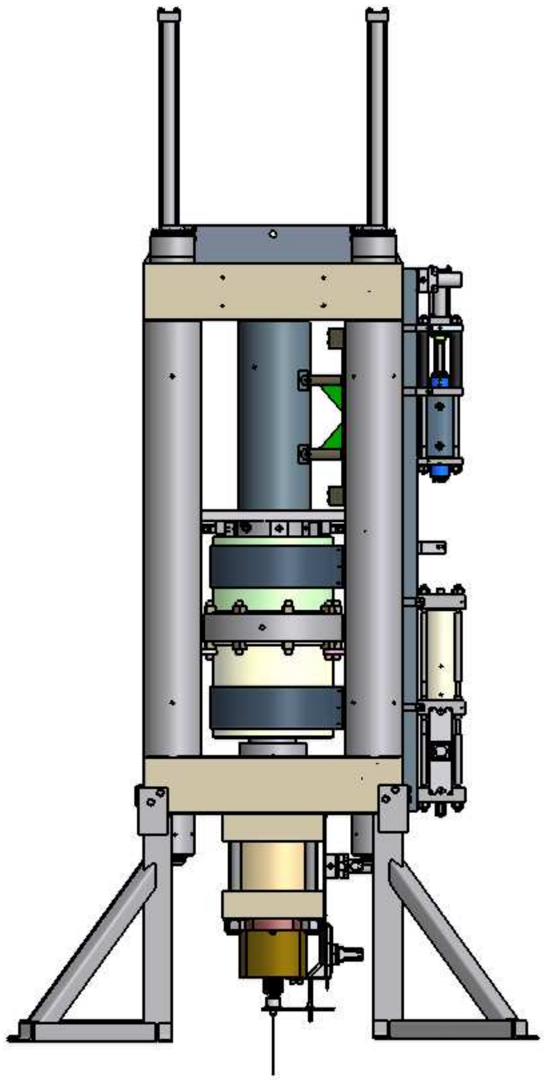

Figure 1 CAD model of UDS

2. Introduction

In 2003 the National Petroleum Council (NPC) stated that deep, tight, and unconventional resources are the leading frontiers for future gas reserve development in the United States. Deeper wells, deeper water, and non-conventional sources will be the areas of future domestic supply. In these conditions, however, the rock is typically hot, hard, abrasive, and highly pressured, making it so that over 50 percent of total well construction costs can be expended in drilling the last 10 percent of a deep well [Reference 1]. With these factors in mind, the NPC recommended that efforts be made to define key research and development priorities, and in response NETL sought out cost-shared applications for research and development efforts to enhance and sustain the domestic energy supply through the DOE's Deep Trek program (DE-PS26-05NT42395-1).

As part of the Deep Trek program, TerraTek was awarded funding for the program titled "Ultra-Deep Drilling Cost Reduction; Design and Fabrication of an Ultra-Deep Drilling Simulator (UDS)" (Project DE-FC26-05NT42654). The project objective is to design, construct, test, train DOE staff, deliver, and commission the UDS.

The Research Management Plan [Reference 2] organized the work of this project into nine tasks, divided into two phases. The resulting top-level work breakdown structure is as follows:

Phase I: UDS Design

- Task 1: Research Management Plan
- Task 2: Technology Status Assessment
- Task 3: Set-up of Industrial Guidance Board
- Task 4: Hazard Analysis Assessment
- Task 5: Develop Specifications and Designs for UDS
- Task 6: Additional Specifications

Phase II: UDS Construction and Shakedown

- Task 7: Construction of the UDS
- Task 8: Overall System Testing and Commissioning
- Task 9: Support to DOE NETL

3. Results Phase I

3.1 Task 1: Research Management Plan

The Research Management Plan was completed as a scheduled deliverable, which covered the project execution plan, including project staffing and management, technical objectives, work breakdown structure, budget, milestones, schedule, and deliverables.

3.2 Task 2: Technology Status Assessment

The Technology Status Assessment was sub-contracted out to Cooper Consulting to provide an independent assessment regarding current single-cutter technology [Reference 3]. In the analysis of single cutter and rock interactions it is noted that “it is worthwhile to emphasize the dangers of allowing too large a communication gap to develop between mathematical modelers and the experts in rock mechanics who have direct knowledge of how rocks behave in real life,” and “to make experiments designed to verify the assumptions and physical parameters being used in the advanced calculations of bit performance.” It is concluded that such developments would impact the industry by allowing oil companies and drilling contractors to achieve lower well construction costs, and would also allow for improved services by service companies.

3.3 Task 3: Set-up of Industrial Guidance Board

In January 2006 TerraTek held an Industrial Guidance Board to provide input on the industry’s needs and experience in the HP/HT drilling environment. The industry representatives responded positively and had many insightful suggestions for priorities on the overall system design (Figure 2).

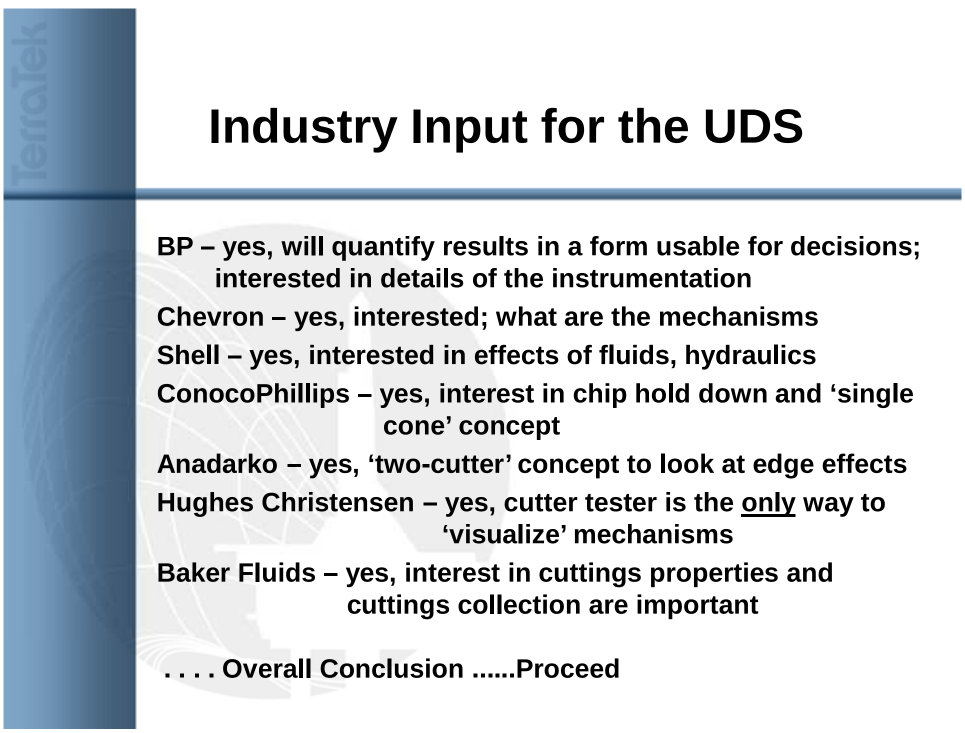

Figure 2 Industry Input for the UDS

3.4 Task 4: Hazard Analysis Assessment

The Hazard Analysis Assessment was held at DOE NETL in February 2006. The main points of concern were HP/HT fluid leaks, physical failures (i.e. pressure vessel), high temperature, electrical shorts, and loss of control. In dealing with these hazards it was concluded that the UDS would be operated remotely through computer feedback control, and behind sufficient guards and barriers. Additional safety systems are installed such as, clamp valves on all systems powered through hydraulics and GFI protection on the electrical heating system.

3.5 Task 5: Develop Specifications and Designs for UDS

A detailed and complete design package for the UDS was created based upon proposed and recommended specifications. The main design specifications for the UDS can be seen in Table 1.

Table 1 UDS Design Specifications

Physical	
Pressure, Max	30,000 psi
Temperature, Max	550 °F
Internal Bore	10 in
Sample Size, Max	8 in dia. X 6 in long
Mud Flow	5 gpm @ 200 psi ΔP
Dynamic Load (@ MAWP)	20,000 lbf
Displacement Rate	0.27 in/sec
Dynamic Torque	50,000 in-lbf
Rotation Angle	Continuous
Rotation Rate	60 rpm
Load Frame	4 column
Frame Capacity	3,000,000 lbf
Power	
Hydraulic Power Supply	20 kW
Heating Power	8 kW
Controls and Data Acquisition	
Data Acquisition	16 bit
Standard Data Channels	32
Standard Data Rate	1 samples/sec
High-speed Data Channels	8
High-speed Data Rate	10,000 samples/sec

Figure 3 shows the schematic for the HP mud system. To begin a test the system is first filled with the drilling mud to be tested by an air powered diaphragm pump (Mud Fill). Next, the system is brought up to high pressure through a hydraulic powered charge pump (Down Stream Pressure Control). During testing, the drilling mud is circulated by a hydraulic powered circulation pump (Mud Flow Pump). Loading and cutting of the sample is applied by hydraulic loading and torque actuators, respectively (Load and Torque).

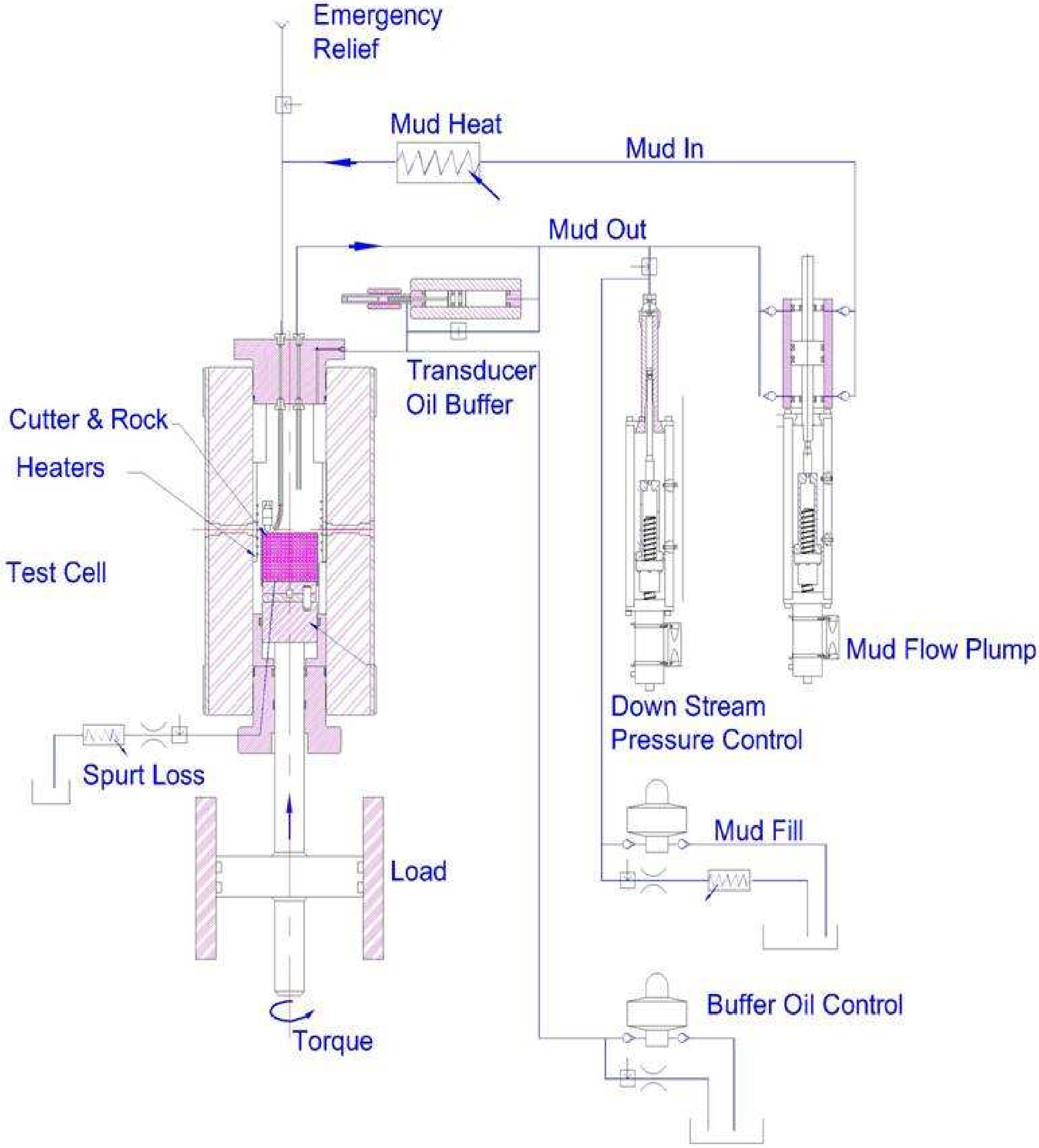

Figure 3 HP Mud Schematic

For the design of the main test vessel it was decided that a three piece assembly would be best to incorporate the x-ray viewing windows and would also allow for alternate test configurations for a more robust design (Figure 4). Design of the test vessel was specified using the ASME Boiler and Pressure Vessel Code Section VIII Division I [Reference 4]. A 630 type stainless steel, SA 564, was selected as the material for the vessel. The wall thickness was determined from equation 1, section UG 27 of the ASME Code, to be 7.5 in.

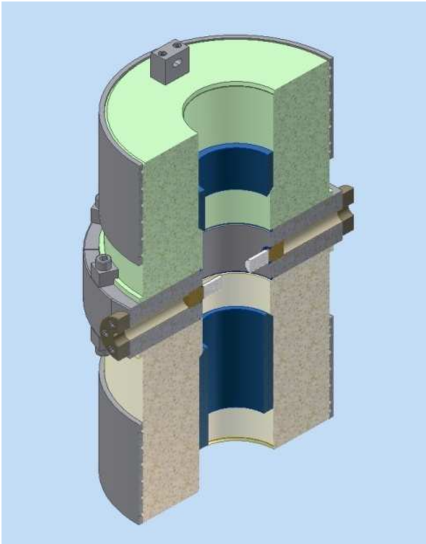

Figure 4 Section CAD Model of Test Vessel

The main test vessel is sealed using "plugs," parts that the HP seals are installed on and inserted into the test vessel (Figure 5). The lower plug has two HP seal stacks as it has to accommodate the load/torque shaft as well as the vessel sealing surfaces. The upper plug assembly contains one HP seal stack, heating elements, load cell, and attachment for the single-cutter.

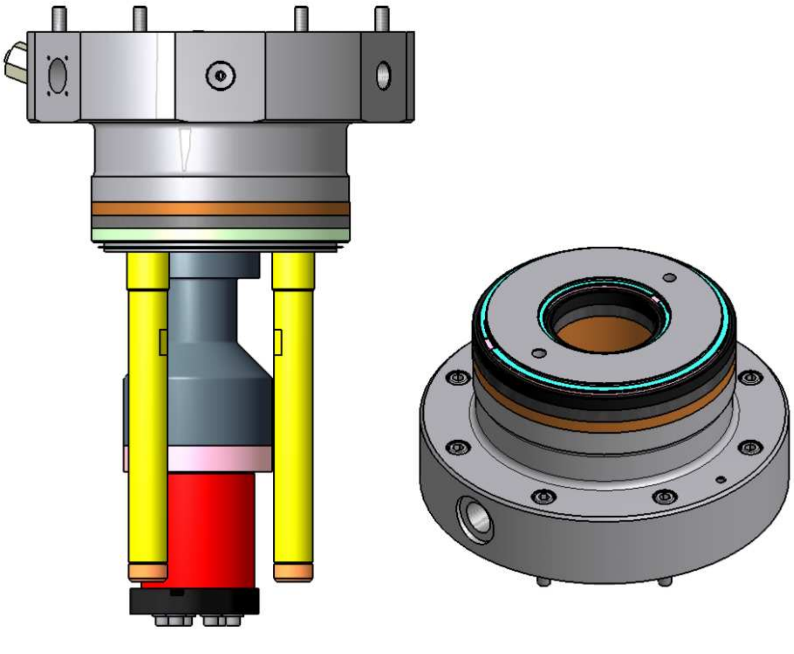

Figure 5 CAD Model of Upper Plug (left) and Lower Plug (right)

Under max pressure and load conditions the UDS generates over two million pounds of force. To be able to contain this force, and maintain a “stiff” system the load frame of the UDS is designed using a tie rod/support column design (Figure 6). Pre-load is applied through the use of Supernuts, which use a jack-bolt system to help reduce the required torque applied.

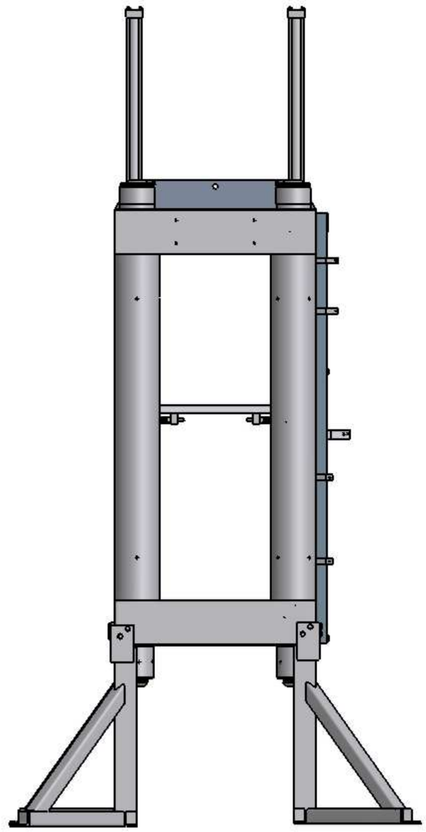

Figure 6 CAD Model of Load Frame

3.6 Task 6: Additional Specifications

Additional specifications for the UDS include but are not limited to viewing windows for the x-ray system, electronic computer feedback control, and ability to retrieve cuttings.

4. Results Phase II

4.1 Task 7: Construction of the UDS

Construction of the UDS began once all specifications and designs were approved by the DOE COR. Figure 7 shows initial construction of the load frame conducted at TerraTek. As construction continued, more components are added such as the three-piece main test vessel, the hydraulic powered mud charge pump, and the hydraulic powered circulation pump (Figure 8).

Figure 7 Picture Showing Construction of the UDS Load Frame

Figure 8 Picture Showing Construction of UDS (Main Test Vessel, Hydraulic Charge Pump, and Hydraulic Circulation Pump have been added)

4.2 Task 8: Overall System Testing and Commissioning

Upon completion of construction of the UDS, testing and system shakedown programs were started. The Quality Assurance Test Plan for: The Ultra Deep Simulator (UDS) (DCN-1003-0056-3-00-0) [Reference 5] was prepared by RDS-Parsons for on-site mechanical verification and hydrostatic testing. The QA criterion is based on the ASME B31.3 Code for Process Piping and the ASME Section VIII, Division I Boiler and Pressure Vessel Code with respect to testing, inspection, and acceptance; and Section II, Part D is utilized for material properties. For the hydraulic system made with ASTM A269 stainless steel tube (316L) and with a design pressure of 3,000 psi, a proof pressure of 4,603 psi is calculated from ASME B31.3 Code. For the main test vessel a proof pressure of 40,945 psi is calculated from the ASME Boiler and Pressure Vessel Code. During QA testing the proof pressure was held for ten minutes.

After preliminary testing and system shakedown programs were completed at TerraTek, the UDS was shipped and installed at the XDL in Morgantown West Virginia (Figure 9).

Figure 9 UDS Upon Installation at the XDL

4.3 Task 9: Support to DOE NETL

In further to support to DOE NETL on the UDS, TerraTek has helped to select a software contractor to improve upon the machine/controller interface in the control system.

5. Conclusion

With the unique ability to simulate drilling conditions in both the high pressure and high temperature realms, the UDS will provide important information on ways to improve efficiency of drilling in ultra-deep, extreme conditions. The improved efficiency will lead to cost reduction in this important area of future energy needs.