Drilling Under Extreme Conditions Complementary Program Project Abstracts

Task 1: Extreme Drilling Laboratory

The Ultra-Deep Single-Cutter Drilling Simulator (UDS) is to operate in Building 12 (B-12) at the NETL Morgantown site as part of its Extreme Drilling Lab (EDL). The UDS provides a simulated drilling environment found at the bottom of ultra-deep wells, having conditions of High-Pressure and High-Temperatures typically encountered in wells having depths beyond 20,000 feet.

The UDS consists of a pressure vessel, a charge pump, circulating pump, heat exchanger, x-ray source and detector.

Figure 1. Close-up of UDS pressure vessel

Figure 2. Reaction Column (solid aluminum) shown on hinges above UDS pressure vessel

Figure 3. UDS vessel lifted off of bottom plug (shaft not shown in plug).

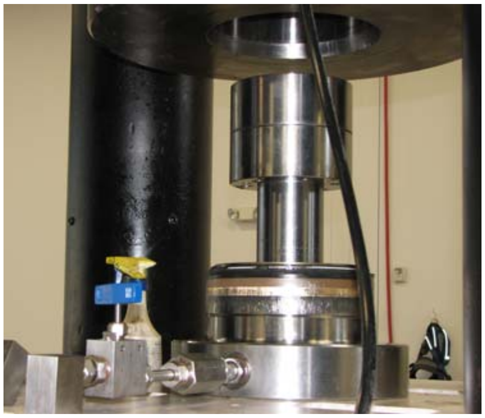

Figure 4. Close-up of bottom plug. Static seal shown on end of plug allows for UDS vessel to be lifted off of Load Frame quickly. A similar, Dynamic Seal exists on the inside annulus of this plug, to allow for shaft rotation and axial translation while maintaining fluid containment at maximum operating pressure. Rock sample would be secured to the top of the shaft shown here.

The test specimen is a rock core having maximum dimensions of 8” diameter x 12” long (cylinder shaped). This rock specimen will be attached to a sample holder on the bottom plug that is driven by hydraulic motor. This hydraulic system provides rotational motion in the x-y plane and linear displacement in the Z-direction. When the reaction column (Figure 2) is swung out of the way, the hydraulic system provides project personnel with the capability of lifting the pressure vessel off of the bottom plug very quickly. This is shown above in Figure 3 and Figure 4. The massive load frame, partially shown in Figure 2, is necessary to contain the thrust forces generated by the immense fluid pressure acting on the vessel ends.

The UDS machine will also have one or more “cutters” installed within the pressure vessel that contacts the rock specimen. The cutter is specified by the researcher in the test plan request, but will often be a 25 mm PDC (polycrystalline diamond cutter) disk, or a carbide roller cone, or a diamond-impregnated cutter. Whatever cutter is specified, it will be chemically inert in the UDS and will tend to have very high Hardness value.

The UDS machine will also be loaded with a liquid drilling fluid. This fluid will be prepared within the EDL by project personnel and will either be a water-base mud or an oil-base mud. The fluid will be compressed by the UDS to pressure up to 30,000 psi. Pressurizing to 30,000 psi from ambient pressure will likely cause non-negligible fluid compression in the liquid phase. Estimates project that the specific volume of the liquid will decrease by 7%. Since actual UDS volume is constant, more liquid must be injected by a positive displacement pump during the compression that initiates a UDS test. Since the approximate liquid capacity of the UDS is 5 gallons, a 7% addition translates to injecting approximately 0.3 gallons of new fluid to achieve maximum operating pressure. Suspending solid particles in the liquid, which is typical in drilling fluid preparation, will have the tendency to decrease the compressibility of the fluid. Also, UDS testing at pressures less than the maximum operating pressure will decrease the amount of injected fluid.

The UDS will have motion controlled exclusively by a hydraulic system. This hydraulic system is pressurized by an electric motor. The UDS is internally heated with electric heaters. The research program has charged this project to have capability to heat the drilling fluid at the center line of the pressure vessel to be 250 deg C (482 deg F). However, the pressure vessel was designed for a maximum operating temperature (i.e. temperature of the steel) of 550 deg F. The pressure vessel will not have external insulation, so it will have the tendency to operate near the mean temperature between the process temperature and the ambient air temperature. This is a very conservative situation and provides amble opportunity to push process fluid temperature higher without any additional engineering changes. The project does not wish to request authorization for operating temperature above 482 deg F at this time. The pressure vessel itself (not including the load frame) consists of 6,000 lbs. of stainless steel, which represents a huge thermal heat sink. It will take many hours to pre-heat the vessel to operating temperature.

An X-ray system will be used during UDS testing to visualize the pressure vessel internals. The source and detector will have lead shielding around them. The very thick ($t \approx 4$ inch) steel vessel provides inherent shielding against radiation scattering from the sample inside the vessel.

Task 2: Modeling HPHT Rock and Drill Cutter Behavior

Much of our nation’s future supplies of oil and natural gas for our energy needs are expected to come from deep formations in High Pressure and High Temperature (HPHT) environments. Optimizing the drilling performance in these HPHT operations is crucial to successful, economic mineral extraction, and is one of the major goals behind the Department of Energy's (DOE) "Deep Trek" program and the primary goal of the Ultra-Deep Drilling Simulator (UDS) laboratory currently being designed and constructed at DOENETL. To best leverage the valuable unique data from experiments in the UDS, this project is developing a three-dimensional FLAC model of a single cutter interacting with the rock formation. This cutter rock model will be augmented with an advanced, non-local failure mechanism, and then the model will be used to back analyze the experiments in the Ultra-Deep Drilling Simulator (UDS) in order to calibrate, validate, and optimize the simulated rock mechanics. The validated cutter-rock model, coupled with the UDS experiments, can then be used to analyze the influence of: temperature, pressure, formation, and mud properties, bit design and drilling parameters on the cutting process and ultimately optimize drilling Rate Of Penetration (ROP) in HPHT environments.

By performing validation studies of existing and new numerical models, numerical simulation techniques will be advanced to the stage of reliably predicting drilling mechanisms under extreme conditions such that commercial advanced drilling products can easily be developed in the private sector.

Task 3: Novel Drilling Fluids for HPHT Drilling Applications

Drilling fluids or drilling muds are relatively complex materials based on water or oil. The drilling fluids have many functions. They are used to cool the drill bit, lubricate the rotating drill pipe, remove drill cuttings etc. The ultimate goal of this research project is to create a magnetically/electronically controllable drilling fluid that could, for example, not only provide cooling of the drill bits but also simultaneously offer significant nanoparticle based lubrication and also offer an independent control of rheology. In so doing we have developed a highly interdisciplinary program with the goal of developing nanoparticle based drilling fluids that would be smart and multifunctional in that the fluid compositions will be designed such that their transport and rheological properties can be adjusted themselves according to operation conditions or using an external field.

The characterization of the laser-synthesized mixed-metal hydroxide (MMH) mud has been focused on and analyzed. It is based on mixed aluminum/magnesium hydroxide. When added to prehydrated clays (bentonite, laponiteRD..) the hydroxidex interact with the clay particles forming a strong complex that behaves like an elastic solid when at rest. Although MMH has great gel strength at rest, the structure is easily broken. So it can be transformed into a low viscosity fluid that does not induce significant friction losses during circulation and gives good hole cleaning at low pump rates.

Additional accomplishments also include work on laser synthesis of nanomaterials, on the viscosity of Fe_2O_3 – DW nanofluid and the theoretical study on the distribution of the velocity, pressure and drag forces in the flow field induced by the drilling oscillation motion.

Task 4: HPHT Materials Development and Performance

Objective is to identify potential performance gaps in currently available tubular materials in environments representative of ultra deep well drilling and sour environments.

Catastrophic materials failure is a concern associated with the high temperature, high pressure, sour environments encountered in deep well drilling applications. The pressures (> 25ksi), temperatures (> 450F) and corrosive (> 5 ppm H2S) environment including corrosive slurries can result in sulfide-stress-cracking (SSC), fatigue cracking, significant wear/ corrosive wear of a variety of tubulars. Consequently, alloys utilized in these applications must possess fatigue strength, corrosion and wear/ corrosive wear resistance, and maintain required metallurgical properties and microstructural stability during operation.

Initial research will focus on 1) sulfide stress cracking (sour gas), and 2) wear-corrosion of tubular materials. Alloys to be investigated include conventional high strength pipe steels (e.g., N-80 (standard), C-90, G-105, XD-105, etc), "advanced" commercial alloys (e.g., nickel base and titanium alloys), and experimental alloys (e.g., NETL-high interstitial strengthen steels (HISSs), C-22HS). Research will also be initiated to develop computational approaches to fatigue behavior in deep well drilling environments.

Results will provide insight into the metallurgical and microstructural features that influence materials performance in these extreme environments, identifying existing materials that can be used in these applications, and guiding the development of new, cost effective materials, such as low cost CRA and casing and tool joint friendly coatings.