

# High-Fidelity Training Simulators Enhance Drilling and Drilling Fluid Skills and Competencies

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## Abstract

Real-time, interactive drilling-related simulators have been developed to achieve step improvements in the training of drilling personnel, drilling fluid specialists, and university students with a broad range of experience. The “human-in-the-loop” simulators consider complex interactions among key parameters during a range of basic operations while drilling, tripping pipe, running casing, and mud engineering. The intent is to replicate the continuing success of interactive well-control simulators used throughout the industry.

The new simulators are based on a high-fidelity software engine used in the field for real-time equivalent circulating density (ECD) management and optimization. Hardware requirements for all except the mud-engineering simulator are minimal. These include a standard-issue computer with dual screens (to display results and 3D visualization of the wellbore) and a gamepad or joystick (to manipulate engineering inputs and navigate visualizations). The mud-engineering version links the software simulation to a small pit of drilling fluid that has to be engineered by a team of students during a multi-hour long exercise.

Pertinent details on the development, operation, and benefits of the simulators are provided in this paper. Opportunities for enhancements and additional scenarios also are included.

## Introduction

Human-in-the-loop (HITL) simulators provide unique opportunities to repeatedly immerse students into real-world, complex events without endangerment to people or equipment. They permit individuals and/or teams to interact with realistic models and respond almost as if in actual scenarios. Flight, space, marine, driving, and video action-game HITL simulators are among the best known, although such systems have great application in the drilling industry.

When O'Brien and Goins<sup>[1]</sup> introduced in 1960 the technology for proper mitigation and control of threatened blowouts, they stated that, “Blowouts prevention is not a matter of the number of valves in the preventer system, their arrangement, or the ability of people to operate them...Blowout prevention is a frame of mind existing throughout the drilling crew and supervisory staff.”

The drilling industry responded and soon thereafter introduced the first analog<sup>[2]</sup> and digital<sup>[3]</sup> HITL well-control simulators. The transportable and portable simulators, respectively, provided a giant step-improvement in training protocol that remains the industry standard. This concept is virtually unchanged despite huge advancements in the computer and electronics technology incorporated into today's systems that range from realistic rig-floor to readily accessible mobile versions. However, opportunities exist in other disciplines to reap the training benefits hands-on simulators can provide.

In a recent article on critical issues in drilling and completions,<sup>[4]</sup> a clear point was made about how the industry needs a competent, well-trained and credentialed workforce. The article also offered that team-based training is as important as individual training.

This paper presents newly developed high-fidelity training simulators (HFTS) for other drilling applications. Designed with the goal of reprising the extraordinary success achieved in well control and achieving new levels of training, they target basic operations including drilling, tripping pipe, and running casing. Their purpose is to achieve step improvements in the training of drilling personnel, drilling fluid specialists, and university students.

Additionally, an integrated, self-contained mud-engineering simulator (MES) version adds wellsite realism by injecting real-world drilling fluid into the system. The MES is designed to enhance mud-school training curricula at basic and experienced levels in a drilling fluids laboratory environment. A team must continually test and physically treat the drilling fluid to optimize density and rheology, check for contaminants, and respond to drilling issues such as lost circulation in a realistic environment. This promotes total immersion for testing multiple levels of technical, cognitive, and relationship skills among the team.

The purpose of this paper is to discuss the development, technology, and operation of the HFTS and MES systems as well as the benefits they provide for training and testing wellsite and staff personnel. Also included is a discussion of training optimized protocols based on results from extensive training sessions involving interactive HITL well-control simulators.

## General Descriptions

Basic simulator equipment requirements include a Windows standard-issue laptop or desktop and a gamepad or joystick for manipulating drilling parameters and navigating the simulated view of the downhole wellbore. Keyboard control can substitute if a gamepad is not available. The software engine is based on a real-time application used for hydraulics simulation and visualization on critical wells. A second computer display is required for the optional visualization application.

Fig. 1 shows a student using a joystick to control an HFTS during a typical training session. The left screen depicts the navigable 3D view of the simulated downhole environment. The right screen displays an engineering and graphics screen driven by the real-time engineering software.



Fig. 1 – High-Fidelity Training Simulator (HFTS).

Fig. 2 illustrates a gamepad with different zones highlighted for drilling, mud-property, and navigation controls. In this context, a student serves as driller, drilling foreman, drilling engineer, and mud engineer. The right mini joystick controls weight on bit (WOB) and pipe rotary speed (RPM). The left axis controls pump speed (Flow). For a tripping or casing-running exercise, the left joystick horizontal axis controls the drawworks (Pipe) to lift and lower the pipe. The same joystick is reassigned to control the back-pressure choke (Ck) for a managed-pressure drilling training exercise. Pressing the left or right joystick loops through a “time factor” that can be used to shorten exercise time.

The D-pad on the left permits full navigation around the wellbore image – down/up the well, and left/right rotation. Navigation (action) buttons allow inside/outside view toggle (I/O), zoom normal (Zn), zoom in (Z+) and zoom out (Z-).

Fig. 3 is a close-up view of the MES, neatly packaged in a laboratory cart, with the visualization screen shown at the top and the engineering display shown underneath. Different than the HFTS, the MES incorporates a small pit of drilling fluid and necessary electro-mechanical components required to add mud-engineering training capabilities.

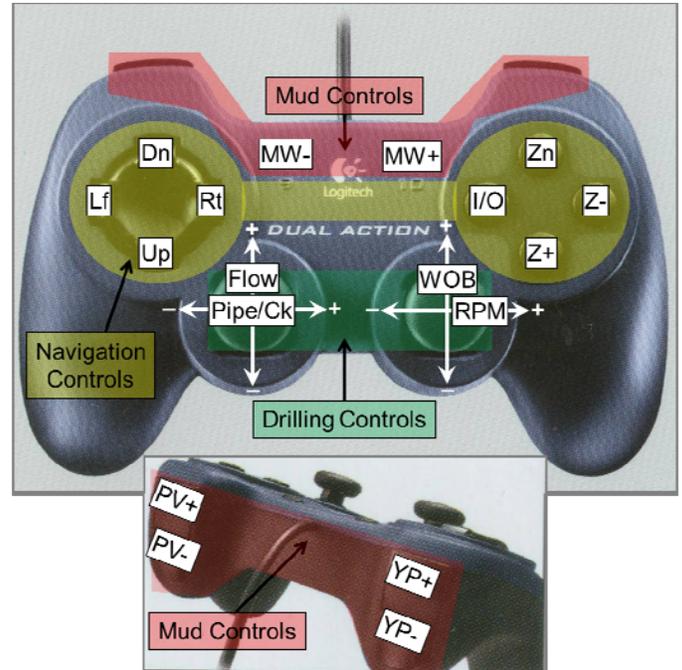


Fig. 2 – Gamepad controls for drilling, mud properties, and navigation.



Fig. 3 – Mud Engineering Simulator (MES).

Fig. 4 is of a team of students using the MES in a laboratory setting. Multiple MES units could conceivably be run simultaneously in the same facility to handle a larger training or competency class.



Fig. 4 – Mud-Engineering Simulator in mud-school training session.

### Software Applications

The main software engine is an enhanced version of a robust, high-fidelity application used for real-time hydraulics monitoring and management on critical wells.<sup>[5]</sup> The 3D visualization software is a separate program that runs concurrently and uses video-game technology to render results from the main simulation software in real time.<sup>[6]</sup> The visualization also can be run in real time in the field.

### Simulation Software

The engineering simulation is full-featured with regard to hydraulics-related modeling which considers the effects of temperature and pressure on drilling fluid density and rheological properties. The system has a history of accurate real-time prediction of equivalent static density (ESD), equivalent circulating density (ECD), and equivalent dynamic density (EDD) while tripping pipe and running casing. Quality estimates of surge pressures have been particularly valuable when running casing in deepwater situations. With no pressure-while-drilling tool installed, the software has successfully helped guide drillers in the field through narrow operating windows created by ultra-low fracture gradients, tight annular clearances, and cold, dense drilling fluid.

A continual stream of transient drilling parameter data is required for the field version, along with periodic manual entries for data not measured by surface sensors. In the HFTS, these data are provided directly by the student through adjustments on the gamepad, shown in Fig. 2. For the MES, drilling fluid density and rheological properties are not student inputs. Instead, the values are automatically measured and supplied to the simulation program. These, however, are not shared with the students, who instead must rely on their own physical measurements using conventional field equipment.

Modifications were necessary to adapt the existing engineering software to operate in a simulation environment.

In addition, multiple engineering models were added to simulate real-world responses that otherwise would be readily available in the field. Among them was a suitable penetration-rate model that considers the drilling parameters incorporated into the simulators.<sup>[7]</sup> Another was a statistical approach, based on an existing model<sup>[8]</sup> and internally developed models to estimate rheological properties from simple, inexpensive measurements provided for the MES. Models for bit dysfunction have not yet been included. However, they would not contribute at this time to the specific objectives of the simulators.

Fig. 5 is a screenshot of a sample engineering display. Notable components are a well schematic and lithology column on the left side, a graphic on the far right illustrating the current position of the blocks or elevators, a series of dual-channel, time-based strip charts, a set of color-coded downhole profile displays, and five meter displays for key drilling parameters. Formatting on this display is flexible and can be modified to provide profile charts and to best reflect the intent of a given simulation exercise.

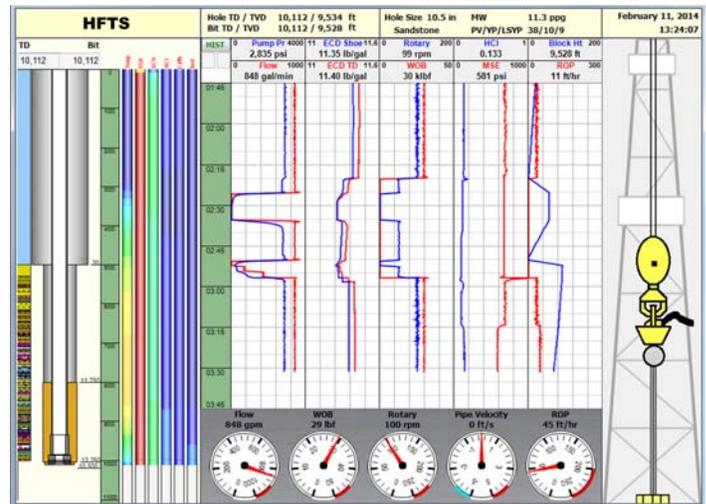


Fig. 5 – Screenshot of a HFTS engineering display.

### Visualization Software

This application permits interactive 3D visualization of the inside of the wellbore. The simulated downhole environment can be critically examined by navigating the well from surface to total depth using the navigation controls identified in Fig. 2.

Although the visualization feature is optional, it provides a unique opportunity to closely view internal and side projections of well tortuosity, cuttings beds, drillstring components and positioning (including eccentricity), annular velocity profiles, formation characteristics, downhole parameter profiles (temperature, ESDs, etc.), and downhole tools, among others. Students also can view the impact of changes they have made to improve drilling performance, or to correct existing or expected wellbore problems.

The graphics engine uses high-quality 3D perspective rendering and 3D game programming techniques commonly

used today. Depth-based engineering data, generated using a finite-difference scheme, are extracted directly from the main simulation program as downhole profiles, and converted into graphic images for display.

Fig. 6 is a screenshot of a sample visualization screen illustrating a side view of the wellbore (with cuttings bed) near well total depth. The inside view of the wellbore can be seen on the right side. The rainbow-colored cylinder in the center of the picture is the velocity profile. Also shown near the center is the heads-up display (H.U.D.) that can be used to pinpoint key data at any depth in the well.



Fig. 6 – Screenshot of 3D visualization display.

### Mud-Engineering Simulator Design

The hybrid MES shares computer and software elements with the HFTS, but adds real-world drilling fluid and appropriate electro-mechanical components to create a novel mud-school training and competency simulator for mud engineers, operators, university students, and staff personnel. Its purpose is to yield step improvements in mud-engineering

skills and competencies in a team environment.

The MES (shown previously in Fig. 3) is packaged in a standard laboratory cart (26-in. wide by 45-in. long by 33-in. high), requiring only external electrical power. However, access is required to a laboratory bench stocked with API equipment to run chemical tests and measure mud weight, funnel viscosity, rheological properties, and other physical properties.

Fig. 7 is a schematic drawing of the MES. Two 6-gal containers are used for the drilling fluid and waste pits. A third container houses an automated density and rheology system based on a Marsh funnel and laboratory balance. A 10,000-rpm dispersator ensures high shear levels for proper mixing of the mud and additives, and four peristaltic pumps are available to transfer mud under computer and manual control. The scale underneath the mud pit is used to help determine the mud volume in the pit.

Some processes run autonomously in the background, while others are manually controlled by the participants. The simulation software uses input values from these processes to conduct and display real-time predictions of downhole conditions. Controls are provided for drilling parameters (pump speed, weight on bit, rotary speed, trip rate, and brake), mud mixing, mud transfer, and alarms. Most of these controls can be transferred to a gamepad (Fig. 2) or a joystick to reduce costs and manufacturing complexity.

The following special features add to the realism in the MES during an exercise:

- Chemical and/or drilling solids contaminants can be incorporated into the active mud system under program control and/or at the discretion of the instructor.
- For a lost-circulation event, mud is automatically

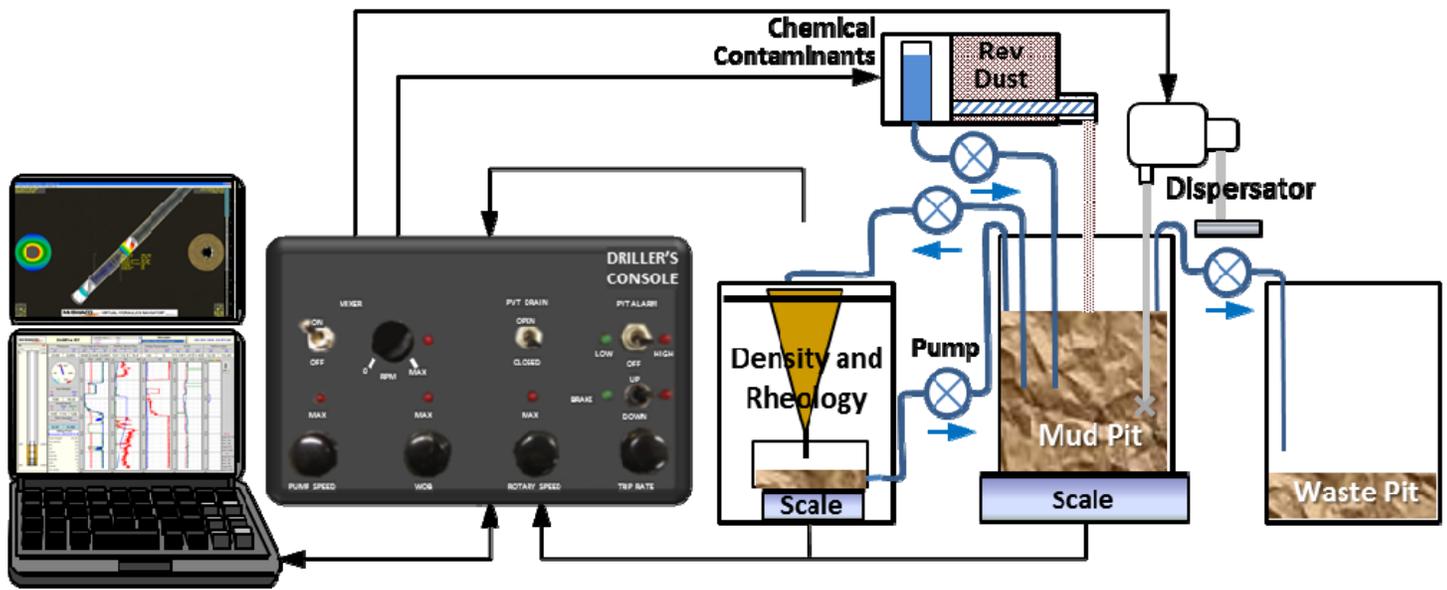


Fig. 7 – A schematic drawing of the MES.

transferred out of the main mud pit and into the waste pit at a rate commensurate with the severity of the event.

- Mud can be transferred to the waste pit during a weight-up sequence if necessary.
- Drilling rig sounds are played to create communication difficulties, psychological pressure, distractions, and enhance the realism of the experience.

### **Training and Competency Protocols**

The training and competency protocols for the HFTS and MES are fundamentally similar, but vary considerably due to the primary intent of the exercises and different equipment involved. The HFTS is primarily a single-student activity, while the MES targets group dynamics in addition to technical issues. Moreover, the MES involves a multi-hour session requiring considerable planning, set-up, and clean-up in a facility with mud-testing capabilities.

Simulations should look and feel as “real” as possible to students. Multiple scenario files can be tailored for specific training applications depending on the experience levels of the participants. As a necessity, these have to be fully tested and validated beforehand to achieve the desired objective.

The most important consideration is to maintain focus on the intent of a particular exercise, without being overshadowed by the perception that simulations need to be highly “accurate”. The fact that high-fidelity simulation software is used for these simulators in training and competency settings is based as much on availability as design.

However, the HFTS in particular also can be used on pending or ongoing wells to help prepare the drilling team sort out expected and unexpected issues. In these cases, simulation accuracy is critical.

In both simulator versions, sufficient time must be allowed to achieve familiarity with the equipment, especially the gamepad controls and the MES auxiliary equipment. In addition, taking responsibility for simultaneous control of key drilling parameters during an HFTS exercise can be daunting to individuals who may specialize and focus primarily on a given discipline. Then again, this provides opportunity to fully appreciate the interaction among all the parameters.

### **HFTS**

The general test protocol for the HFTS involves a series of scenarios designed to progressively increase student familiarity with simulator operation and controls depending on experience and expertise. For example, one of the starting levels disables all input controls except for wellbore navigation, allowing the student to oversee, but not interfere with the operation. If the student is a mud engineer, the system can then be set up so that mud properties are variable. This can be followed by a hole-cleaning exercise where flow rate also is variable.

Eventually, participants are able to control all options. At this point they can experience the interactions among drilling

and drilling fluid parameters to target desired topics within boundaries dictated by well conditions.

Strip-chart printouts allow review of different exercise and opportunity to discuss with the instructor if conducted in a training setting. Of course, the HFTS lends itself to independent practice and use as desired.

It is worthwhile to target a special concern during a given simulation even if the software behaves exactly the same regardless of the simulation intent. This is best done by refining the data file and letting the participant know the primary objective. Individual drilling examples include hole cleaning, ECD management, drilling efficiency, managed-pressure drilling, etc. Tripping pipe and running casing are others. In more advanced situations, the simple goal would be to properly handle all concerns to drill an interval, trip pipe or run casing efficiently without undue problems.

Over time, the HFTS will continue to be tweaked based on learnings with well-control simulators. For instance, early digital simulators were designed for the sake of realism to process lost-circulation-related mud volume changes if excessive back pressure was imposed while circulating out a kick. This only served to confuse and divert from the primary message. Software was subsequently changed so that the simulation stopped at this point, preserving all settings and pressure readings and allowing discussion with the instructor before proceeding.

A special opportunity exists with using the HFTS on ongoing wells. For example, the data file can be defined to match current well conditions just before making a critical trip out of the hole, allowing well engineers to use the simulator to evaluate issues and plan a strategy that ultimately makes the actual trip as efficient and safe as possible.

### **MES**

The MES training and competency protocol defines a multi-hour simulation exercise involving a team of 6-8 participants. Together, they control key drilling parameters; however, they also must mix, analyze, pilot test, and treat a water-based drilling fluid as if on a real well. This requires access to mud testing equipment and some facilities found in all mud laboratories.

Exercises are team efforts where ultimate success depends on how well teams organize, plan, interact, measure and interpret data, and respond to changing well conditions. Prior to starting an exercise, teams are given time to prepare, determine responsibilities, and develop contingencies based on a detailed well plan. The participants also use this time to become familiar with the equipment and process, and to mix the initial mud system.

The team must determine the most appropriate balance among drilling and mud parameters to maximize drilling performance without exceeding the boundaries defined by well conditions. Footage drilled during a given time frame is a very good metric, maximized by optimizing operations and minimizing lost-time incidents. The cost to build and maintain the mud system during the exercise also is important and is used as a performance indicator.

The MES is an excellent training and competency evaluation addition to basic industry mud schools and university classes. The environment, complete with loud rig sounds, is such that the participants feel much of the same time constraints, pressures, and communication difficulties similar to those encountered in the field during challenging situations.

In another setting, group dynamics can be maximized if individuals are selected from different industry sectors (operators, drilling contractors, suppliers, etc.) and/or with varied experience and expertise levels. A 6-person team, for example, could function as company man, driller, procurer, roustabout, and mud physical and chemical properties testers. At least one experienced mud engineer is preferred to run chemical tests and monitor others on measuring mud weight and rheology.

Inappropriate actions and responses can result in significant penalties, including lost circulation which automatically transfers mud from the active system into the waste pit and requires the team to react under time constraints similar to those encountered in the field. Additional realism is provided by low-gravity solids (Rev Dust) added proportionately during drilling phases (Fig. 7).

Chemical contaminants incorporated at random or on demand when entering certain rock formations require the participants to determine the type of contaminant and treat the drilling fluid appropriately in a timely manner. The simulation will continue regardless of whether the treatment was correct or not. The instructor also can use a remotely connected tablet or smart phone to create special problems at will, usually at the most inappropriate time.

For practical reasons, well design and mud type do not vary much. This is not an issue since the MES was developed for training and competency, not to expose the participants to specific well types and conditions.

### Future Plans

Clearly, there are opportunities to enrich the software. Highest priority should go to those that enhance the training experience rather than those that increase the fidelity at the expense of imparting the right messages to the participants.

Future plans also include wider distribution of the HFTS and MES units currently being introduced in various internal training and competency programs. This could spread to different industry segments and universities. While the HFTS installation is minimal, MES distribution is more complex, but with options. One is to partner with a few universities, perhaps encouraging them to design and build their own hardware that is compatible with the simulation software.

### Conclusions

1. High-fidelity, HITL drilling simulators can achieve step improvements in the training and competency evaluation of drilling personnel, mud engineers, and university students with a broad range of experience.

2. Targeted drilling simulators can achieve the acceptance, success, and cost-efficiency of other simulators, including those available for flight, space, marine, driving, and video action games.
3. Control over most key drilling parameters in a simulator setting can provide knowledge and appreciation for their complex interactions.
4. 3D visualization can give simulator participants insight into the downhole environment that significantly enhances the training experience.
5. A hybrid HITL simulation exercise involving physical drilling fluids can immerse participants of varied backgrounds into an environment with similar time constraints, pressures, and communication difficulties similar to those encountered in the field during challenging situations.
6. Certain hybrid drilling simulators are well adapted to team efforts where ultimate success depends on how well these teams organize, plan, interact, measure and interpret data, and respond to changing well conditions.
7. Simulation exercises conducted for multi-disciplinary teams in field-like settings can promote increases in technical, cognitive, and relationship skills.

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### Nomenclature

<i>Ck</i>	= Choke
<i>ECD</i>	= Equivalent Circulating Density
<i>EDD</i>	= Equivalent Dynamic Density
<i>ESD</i>	= Equivalent Static Density
<i>Flow</i>	= Flow Rate
<i>HFTS</i>	= High-Fidelity Training Simulator
<i>HITL</i>	= Human in the Loop
<i>H.U.D.</i>	= Heads Up Display
<i>I/O</i>	= Toggle Inside/Outside view
<i>MES</i>	= Mud-Engineering Simulator
<i>MW</i>	= Mud Weight
<i>PV</i>	= Plastic Viscosity
<i>RPM</i>	= Pipe rotary speed
<i>WOB</i>	= Weight on Bit
<i>YP</i>	= Yield Point
<i>Z-</i>	= Navigation Zoom out
<i>Z+</i>	= Navigation Zoom in
<i>Zn</i>	= Navigation Zoom normal

## References

1. O'Brien, T.B. and Goins, W.C., Jr. "The Mechanics of Blowouts and How to Control Them." *API Drilling and Production Practice*, 1960.
2. Letbetter, S.C. "Kick Detection and Well Control Training." SPE 5353, SPE California Regional Meeting, Ventura, California, 2-4 April 1975.
3. Zamora, M. and Gau, G. "Computerized Simulator Aids Well-Control Training." *Oil and Gas Journal* (19 August 1974) 61 and "Simulator for an Oil Well Circulating System." U.S. Patent 3,971,926, 27 July 1976.
4. Hsieh, L. "Critical Issues in Drilling and Completions." *Drilling Contractor*, Jan/Feb 2014, pp. 18-86.
5. Zamora, M. *et al.* "Major Advancements in True Real-Time Hydraulics." SPE 62960, 2000 SPE Annual Technical Conference, Dallas, 1-4 Oct.
6. Zamora, M. and Simpkins, D. "Development and Application of a 3D-Wellbore Visualization System for Hydraulics Analyses." SPE/IADC 92338, 2005 SPE/IADC Drilling Conference, Amsterdam, 23-25 Feb., and "Three-Dimensional Wellbore Visualization System for Drilling and Completion Data." U.S. Patent 7,603,264 B2, 13 Oct. 2009.
7. Detournay, E., Richard, T., and Shepherd, M. "Drilling Response of Drag Bits: Theory and Experiment." *International Journal of Rock Mechanics and Mining Sciences*, v.45 (2008) 1347-1360.
8. Balhoff, M.T. *et al.* "Rheological and Yield Stress Measurements of Non-Newtonian Fluids using a Marsh Funnel." *Journal of Petroleum Science and Engineering* v.77 (2011) 393-402.