HPHT operations pose escalating challenges for operators, suppliers

Expandables, MWD/LWD tools, completion systems offer potential solutions

By Sheila Popov, contributing editor

A Weatherford technician calibrates a high-pressure sensor on its LWD system, which is rated to an operating pressure of 30,000 psi.

TO DEVELOP AND produce hydrocarbons from increasingly higher pressure and higher temperature reservoirs, the oil and gas industry needs new drilling, evaluation, completion and production equipment designed to withstand these harsher environments. Operators and service providers alike face these challenges and must collectively take the lead in the research and development of new high-pressure, high-temperature (HPHT) technology to develop and produce deepwater and deep gas discoveries. Three oil majors have identified key challenges in HPHT development and production, and several oilfield service providers have offered insights regarding current or planned technologies to meet these challenges now and in the future.

OPERATORS FACE HPHT CHALLENGES

The key to successful HPHT development and production will be expanding the operating envelopes of essential components in operations across the board, including safety critical components such as BOPs and SCSSVs, according to **BP**'s head of drilling and completions for the Eastern Hemisphere. Operating envelopes of key components in the drilling process, such as directional drilling and LWD/MWD capabilities, need to be expanded, he said. Likewise, completion techniques and equipment such as perforating, expandables, fluids and sand control methods must be broadened to ensure reliability and productivity. He added that the reliability and standardization of key subsea production components, including wellheads, trees, manifolds and HIPPS, must be ensured for HPHT environments.

The escalating needs of HPHT have created gaps in equipment specifications, according to **Steve Cassidy**, the focus area manager of well systems for **Chevron Energy Technology Company**. High pressures increase size and weight requirements for BOPs and wellheads, Mr Cassidy said, and high temperatures generate problems for circuit boards and downhole electronics and the elastomers in completion equipment. If ultra-deep depths and/or corrosive environments are factored in, alternatives to regular steel-based tubular products also will be needed, he said.

"This equipment is currently not available in the sizes needed to be economic," said **Earl Shanks**, a HPHT consultant. "Neither can the equipment be made available with simple extrapolations or scaling of current equipment. Closing these HPHT technology gaps poses great challenges to the industry in the design, manufacture and testing/qualification of a whole new generation of equipment."

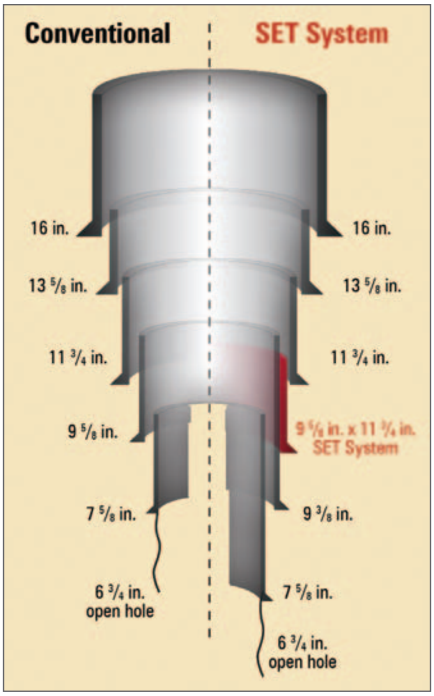
For drilling, **Chevron** said, kick detection and wellbore stability are key HPHT operational challenges. **Shell E&P** agreed that wellbore stability is one of the main technical drilling challenges on the development side of its business on mature HPHT fields, according to a Shell advisor drilling engineer. Drilling into deep, frontier HPHT environments often requires passing through depleted shallow zones. Well control and wellbore stability must be maintained while preserving wellbore diameter upon reaching deep target horizons and their reserves.

Shell has been successful drilling through deep, depleted HPHT zones with tight pore pressure fracture gradient margins using a combination of casing and liner drilling with managed pressure drilling techniques, its advisor drilling engineer said. Applications of these technologies in mature HPHT fields onshore South Texas have been successful, he said, and Shell plans to use lessons learned to expand applications globally — initially in the Gulf of Mexico and worldwide over the long term.

EXTREME-HPHT WELL

Shell's recently drilled Prospect Joseph, Well HI-10, High Island, Gulf of Mexico, is an example of an extreme-HPHT well. Although its shelf location meant a shallow water depth, Joseph was a deep HPHT gas well drilled to 25,552-ft TD, deeper than the initially planned 24,000-ft. The well was successfully drilled and evaluated, despite its more than 450ºF bottomhole temperature at TD and bottomhole pressure of about 25,000 psi.

Initially, though, extensive risk management was required because of issues associated with weak zones, the potential for hydrogen sulfide and borehole instability problems, the latter due to salts and faults. Shell also had to identify, plan and manage potential well control challenges with proper contin-



By utilizing expandable technology, operators have been able to not only maintain hole size but also explore virgin formation below the originally targeted total depth.

gencies. Drill string vibrations was also a concern that materialized, so Shell had to minimize BHA damage, tool failure and poor hole conditions.

Another risk management issue was the lack of deep offset information; the last 10,000-ft TVD had never been penetrated before in the area. As such, the well design needed to be flexible. The narrow margin anticipated between pore and fracture pressures also required a flexible well design. The well, therefore, was designed with contingency in mind, leaving open the possibility of the need for two extra casing strings.

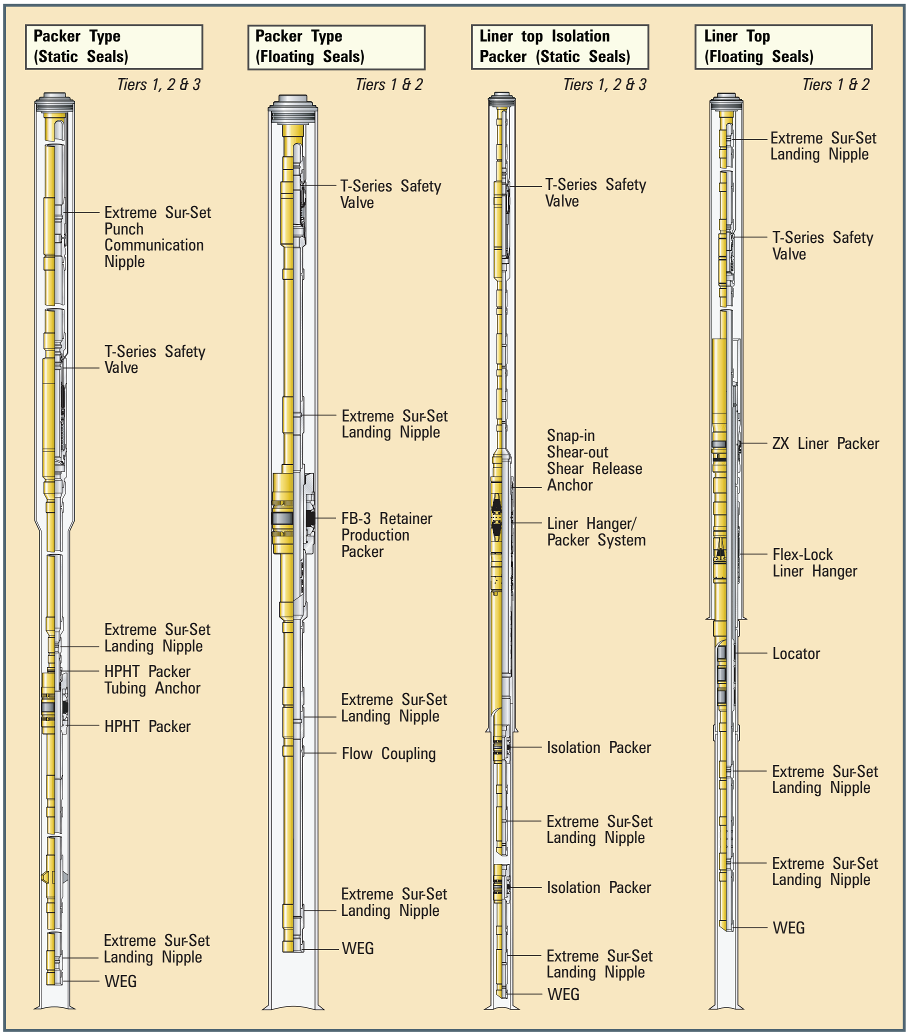
In the end, the well design was flexible enough to handle a pore-fracture pressure window that was narrower than predicted. This made reliable MWD data acquisition crucial in managing equivalent circulating density (ECD). Precise MWD data and computer modeling of hydraulic pressures enabled ECD to be managed to 0.01 ppg within the very small margin — despite the high circulating bottomhole temperatures. In addition to taking ECD management to a new level, the circulating mud temperature was managed to mitigate its effects on ECD and the MWD tools in the hot borehole. Clearly, the management of both ECD and mud temperature were major factors in the success of this deep HPHT well.

Another technical drilling challenge Shell has been encountering when drilling its deeper wells has been preserving wellbore sizes large enough to accommodate the planned evaluation and completion, according to the Shell advisor drilling engineer. The company has used expandable tubular technology to drill its deep HPHT plays. Either conventional or mono-diameter expandable technology will continue to be important to ensuring that sufficient borehole diameter is maintained, he said. The BP drilling and completions specialist also recognized the need to broaden the use tubular expandables in challenging HPHT operations.

EXPANDABLE TUBULARS

As discussed, one important issue about drilling wells through depleted or otherwise troubled (unstable, over- or underpressured) zones into deeper HPHT environments has been managing the narrow margin between fracture pressure and abnormal or depleted pore pressure while maintaining wellbore stability. Traditional efforts to sustain well control include setting numerous, increasingly smaller-diameter casing strings. These telescoping strings create a tapering effect that continually reduce the wellbore inside diameter (ID) and thus the conduit needed for optimized flow potential and maximized return on investment. Setting a casing string prevents induced fractures and underground flows from mud weights that are either too heavy or not heavy enough. However, the conventional method of setting casing and drilling ahead using modified weight muds and thus reducing hole sizes is being used less frequently, as operators are increasingly opting to apply new technology alternatives for their deeper and more challenging wells.

One of the most promising new alternatives is expandable tubular technology, which has served as an enabler to maintain the overall wellbore ID while drilling toward deep HPHT targets across trouble zones to TD. **Enventure Global Technology**'s Solid Expandable Tubular (SET) technology involves the controlled expansion of solid tubulars in situ, or downhole. As of June 2007, over 100 operators in more than 20 countries have used SET technology in more than 700 open- and cased-hole applications. Including expandable tubulars into the original well plan has, for some wells, decreased overall costs by almost 30%, according to Enventure.



Shown are examples of Baker Oil Tools cased-hole completion systems for Tiers I, II and III HPHT wells, or wells classified as HPHT, extreme HPHT and ultra HPHT.

"We are seeing a significant shift in how operators are using expandable tubular technology," said **Mark Holland**, Enventure global business development manager. "In its infancy, operators used the technology on a contingency basis when faced with unplanned downhole challenges. But now it is being planned into wells as the primary casing string to ensure hole size, especially in more challenging deep wells."

SET technology was used in the Joseph well to isolate a serious pressure regression interval, enabling the well to be evaluated (MWD/PWD/LWD) to 21,000 ft and the well to reach TD at 25,552 ft, both deeper than initially planned. The more than 2,000-ft long 9 5/8 in.-by-11 3/4 in. open hole expandable liner was run from 17,079 ft to 19,131 ft TVD below the 11 3/4-in. casing whose shoe was set at 17,397 ft. At the expandable shoe, the bottomhole static temperature of 371ºF was the second-highest temperature recorded, but when combined with the 17,410-psi bottomhole pressure, made the combination the highest ever achieved for a successful expandable tubular implementation. However, the individual temperature and pressure records now stand at ~400ºF and 23,000 psi, while the deepest expandable run currently remains at 28,750 ft. The use of SET technology helped achieve evaluation objectives and reach the targeted depth, while maintaining an acceptable borehole size.

MWD/LWD SYSTEM

Most LWD systems were originally designed about 20 years ago when drilling conditions were more benign and less aggressive than today. As such, the systems that were designed then were intended to accommodate the drilling conditions typical at the time. Operators have subsequently drilled deeper wells and ventured into greater water depths, with deep wells approaching almost 35,000 ft and offshore operations taking place in ultra-deepwater exceeding 6,000-ft depths. Trends related to drilling in ultra-deepwater have placed greater demands on LWD systems, including higher rig rates, flow rates and bottomhole pressures. Higher rig rates emphasize the demand for increased LWD system reliability. Operators need higher flow-rate LWD capabilities to accommodate deepwater hole cleaning and wellbore stability. As well depths get increasingly deeper, hydrostatic pressures get increasingly higher at TD. Deep-well drilling also has put added demands on LWD requirements, particularly by exposing them to higher bottomhole temperatures. Such hostile conditions are pushing conventional LWD systems beyond their original design limits.

A new MWD/LWD system has been developed, which was designed specifically with the objective of providing enhanced tool reliability and increased data accuracy in harsher environments and deeper operations. An MWD/LWD system has to be inherently by design more reliable to operate in deep-well, ultra-deepwater, HPHT environments. As such, it underwent extreme environmental testing runs, including combinations of thermal cycling, vibration, flow-loop and pressure trials. A design goal also was to achieve higher LWD triple-combo data accuracy at faster logging speeds. To accomplish this, the design specification was selected at a 400-ft/hr logging speed — currently the fastest LWD rates in the industry. Another objective was to design a tool that could handle both higher flow rates and concentrations of lost circulation material. Smaller electronics permitted larger-diameter bore sizes, which, coupled with higher-strength materials, enabled higher flow rate capabilities for all hole sizes. Along with enhanced erosion resistance, increased material strength also helped the tool withstand greater concentrations of lost circulation materials.

"This MWD/LWD system was designed specifically with the objective of providing enhanced tool reliability and increased data accuracy in harsher environments and deeper operations, with reliability being as the paramount benchmark," said **Paul Radzinski**, the strategic business manager for **Weatherford**'s formation evaluation group. "The resulting HEL system is rated to a 30,000 psi and 356ºF (180ºC) operating pressure and temperature."

Another result of the company's R&D was the PrecisionLWD system, which is

Component	Drivers	Design Issues	Regulatory Issues
Packer Systems	■ Rig cost/time (one trip and interventionless completion technologies) ■ Reduce casing stresses caused by packer slips and element	■ Metallurgy selection (downhole environmental conditions are key) ■ Sealing technologies (static and dynamic) ■ Packer to tubing interfaces ■ Combined loading and pressure differential ■ Interventionless packer setting devices	■ ISO/API Qualifications
Surface-Controlled Subsurface Safety Valves	■ Reliable well control ■ OD/ID ■ Cable bypass for downhole pressure gauges	■ Seal technology ■ Metallurgy selection (downhole environmental conditions are key) ■ Closure mechanism design ■ Combined loading and pressure differential ■ Control line and fluids ■ Rod piston design	■ API Qualifications/ Test Pressure issues
Flow Control Systems	■ Reliable well control ■ Select packer setting device ■ Monobore vs. step down nipple completions	■ Seal technology ■ Metallurgy ■ Pressure differential	■ ISO/API Qualifications

Baker Oil Tools summarizes the drivers, technical challenges and regulatory issues related to specific completion equipment components for extreme- and ultra-HPHT wells.

rated to an operating temperature and pressure of 329°F (165°C) and 30,000 psi. Combining the two systems forms an MWD/LWD system that measures wellbore position and formation properties, providing triple-combo gamma ray, resistivity and neutron/density porosity data. Both MWD and LWD systems incorporate electromagnetic (EM) data transmission with standard positive-pulse transmission, within the same set of tools, which enables data to be transmitted independent of rig activities and mud properties. Thus, data can be obtained at times when traditional signal transmission may be prohibited, including while tripping, in HP and HT settings, and during underbalanced and managed pressure drilling operations. EM transmission is particularly applicable in wells using unconventional drilling fluids like foam, mist, air or aerated mud.

On the Joseph well, the MWD/PWD/LWD run was successful, enabling logs to be obtained over the entire interval at a maximum circulating bottomhole temperature of 370ºF and bottomhole pressures exceeding 25,000 psi. Moreover, the combined tool ran to a 21,000-ft TVD, much deeper than deemed possible pre-spud. The successful LWD run enabled the primary and secondary well objectives to be evaluated successfully. Obtaining the MWD data at the high circulating bottomhole temperatures was critical in managing ECD to 0.01 ppg with a small margin. While the temperature appears to be an industry record, the combined MWD/LWD has been deployed and obtained logs successfully at pressures exceeding 30,000 psi.

COMPLETION SYSTEMS

The criteria for designating fields as HPHT have been changing over the years. In the past, it was fields with greater than 10,000-psi pressures and higher than 300ºF temperatures. Over the last 20 years, the HPHT designation tended to be at pressures and temperatures of 15,000 psi and 350ºF, an environment where technical operational challenges have mostly been met. Other terms are being used more recently to designate new HPHT thresholds for fields considered and assessed for development. These new thresholds have been called extreme- and ultra-HPHT fields, defined as having pressures of 20,000 psi and 30,000 psi and temperatures of 400°F and 500 °F.

Extreme-HPHT wells are currently being drilled in the GOM region, on the shelf and in deepwater. Many of them have TVDs deeper than 30,000 ft, exhibiting reservoir pressures and temperatures that approach 20,000 psi and 400ºF. Moreover, some deep gas reservoirs, also on the GOM shelf as well as in North American land locations, have pressures and/or temperatures upwards of 30,000 psi and 500ºF, propelling them into the ultra-HPHT designation. Although some technology gaps remain in the extreme-HPHT category, the most substantial gaps between available and needed technologies exist in the ultra-HPHT designation.

There are two main drivers in the development of extreme-HPHT cased-hole completion equipment: increased gas prices and the exploitation of hydrocarbons in deeper formations. **Baker Oil Tools** is developing completion systems for extreme- and ultra-HPHT environments. The drivers, technical challenges and regulatory issues associated with specific completion equipment components for extreme- and ultra-HPHT wells are shown in Table 1.

"Meeting HPHT requirements will require closing the technology gaps in three main areas, namely metallurgy, testing facilities, and seals and polymers," said **Bernardo Maldonado**, product line strategy manager for Baker Oil Tools.

The company's metal-to-metal sealing technology — a novel type of high-expansion seal — holds promise in changing the way downhole equipment provides pressure integrity in HPHT environments. The technology uses expanding metal to form a high-integrity seal that may be unachievable with conventional elastomeric seals, according to the company.

Baker Oil Tools is currently building its Center for Technology Innovation in Houston, Texas. The facility will be used to develop and test completion equipment, seal and polymer technologies, and to continue to conduct R&D in the areas of new metallurgies and materials, to meet the requirements for extreme- and ultra-HPHT environments.

UPDATE ON STANDARDS

To meet the HPHT challenges and needs for equipment reliability and standardization, an API Task Group of the Executive Committee on Standardization has been working to develop a Recommended Practice (RP) for equipment with pressure rating greater than 15,000 psi. The effort, now in draft form, is on the 5th revision. Its scope includes surface and subsea equipment. Equipment service conditions include drilling, completion, production, production testing, intervention and workover.

"Up to now, oilfield equipment has been designed and manufactured with pressure ratings greater than 15,000 psi," Mr Shanks said. "However, the equipment expected to meet near-future demands will have significantly larger bore sizes, so it was reasonable to concentrate on likely potential failure methods for this future equipment."

Enventure personnel conduct final inspections of the expandable casing at the rig site to ensure the liner's performance downhole. Expandable liners can be applied to both onshore and offshore wells using standard casing running equipment.

Equipment having working pressures of 20,000 psi and higher will require thick walls. Thus, the likely failure mode will be from fast fracture, resulting from a crack propagating to a critical crack size less than the thickness of the wall. Such fast fractures result in the vessel failing catastrophically. The appearance is similar to a brittle fracture, except the material of the component may be quite ductile.

The draft RP to date has addressed the design verification. It references the ASME Boiler & Pressure Vessel Code for Alternative Rules for Construction of High Pressure Vessels, ASME Section VIII Division 3 (Div3) because it is essentially valid for the design verification of pressure vessels for all — thin or thick — wall thicknesses. Moreover, the code requires a fatigue analysis that addresses full life cycle analysis of the component.

During the second half of 2006, the API RP 6HP Committee formed a Materials Work Group and charged it with writing the material testing protocols needed to give the material properties required for the analysis methodology. The ASME Div 3 code requires a fatigue analysis to simulate full life-cycle service conditions of equipment.

"An understanding of material properties not presently used universally in the oil and gas industry is needed, especially relating to large, thick wall forgings," Mr Shanks said. "Material properties used in the analysis need to be determined for the temperature and surrounding environment to which the equipment will be exposed while in service."

This requires testing materials for various temperatures and fluids or gas that may exist inside and outside the equipment. In addition to the material properties normally used in stress analysis, the crack growth rates, da/dN, and fracture toughness, K1C, values need to be determined for the fracture mechanics method used to determine fatigue life.

The API RP 6HP Committee is developing an example project to illustrate the methodology on applying the Div 3 code, developing the material testing protocols and obtaining the material properties for the analysis. It plans to complete a technical report to demonstrate the use of the RP.

THE OUTLOOK

Chevron believes the HPHT (15,000 psi and 350 °F) issues of 20 years ago have largely been overcome, Mr Cassidy said. While new ultra-HPHT challenges have emerged, with temperature and pressure environments up by one-third from old parameters, he said, his company acknowledges that equipment shortfalls may be exacerbated by a lack of market volume. There may not be enough operations in the ultra-HPHT arena to warrant large-dollar investments from the service sector, Mr Cassidy said.

Still, new equipment is needed for all phases of development and production designed to withstand higher pressures and temperatures. Reliability will be key, the BP drilling and completions specialist said, to future successes in HPHT developments, whether during the process of a well's construction or its subsequent operations, as these HPHT wells are too costly to tolerate substandard performance or limited life. Developing the necessary personnel skills is also important, he said, in supporting the critical nature of the high-cost, high-risk projects required to develop ultra-HPHT fields, both on- and offshore.

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