Special design strategies vital as HPHT completions edge toward 500° F, 30,000 psi

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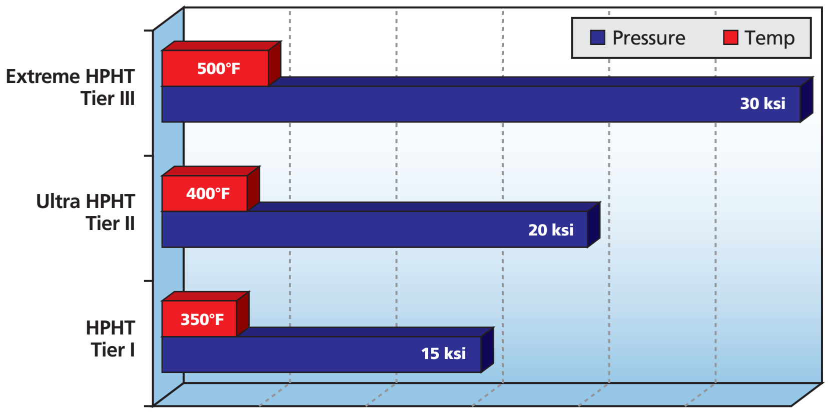
THE COMPLETION OF high-pressure/high-temperature (HPHT) wells involves high-risk and high-cost operations with exposure levels among the highest in the completion sector.

The task ahead is to teach the old dog some new tricks needed to complete super HPHT wells through new methods for product testing, development and manufacturing.

As a completion service company, **Baker Oil Tools** is working closely with operators to fill the technology gaps.

HPHT Regimes



HPHT operations are segmented into tiers that are defined by reservoir temperatures and pressures.

To help identify HPHT operating environments, safe operating envelopes and technology gaps, a new terminology is developing.

The terminology segments HPHT operations into three tiers. Tier I refers to wells with reservoir pressures up to 15,000 psi (1034 bar) and temperatures up to 350º F (177º C).

Most HPHT operations to date have taken place under Tier I conditions. Tier II are the "ultra" HPHT wells which are characterized by reservoir pressures of up to 20,000 psi (1379 bar) and/or temperatures of up to 400º F (204º C).

Many upcoming HPHT deepwater gas/oil wells, particularly in the Gulf of Mexico, fall into the Tier II category. The Tier III encompasses "extreme" HPHT wells, with reservoir pressures of up to 30,000 psi (2068 bar) and/or temperatures of up to 500º F (260º C).

Tier III is the HPHT segment with the most significant technology gaps. Several deep gas reservoirs on North American land and the Gulf of Mexico shelf fall into this category.

RISKS DICTATE APPROACH

The risks and demanding performance requirements for HPHT completions dictate special considerations and investments. Most completions are designed based on the casing and tubing program selected for the well. For most Tier II and Tier III HPHT completions, however, the completion design is identified first (such as the OD/IDs of the SCSSV), which will dictate casing and tubing design.

Other considerations include a strategy to address the potentially damaging effects of HPHT conditions on downhole components. High temperatures can cause:

- Significant pipe movement or high compressional loads at the packer, particularly when the high temperatures are combined with high operating pressures;
- Increased mechanical and fluid friction as well depth increases and/or deviates from vertical;
- Thermal cycling and resulting tubing stresses requiring careful consideration of the use of tubing to packer connections (floating seals vs. static or no seals at all);
- Shorter elastomer performance life and derated yield strength of metals used in packers and seals.

High pressure regimes require:

- Much thicker cross-sections in all tubulars and downhole equipment;
- High-yield-strength materials to handle excessive burst and collapse pressures;
- Corrosion-resistant alloys (CRAs) where needed to protect from wellbore fluids that can corrode high-yield steel.

CRITICAL SUCCESS FACTORS

To ensure that completion equipment will perform safely and productively in specific HPHT environments, it is important to:

- Accurately define a set of operational parameters and performance rating requirements for any new equipment;
- Set approved design specifications "in stone" as soon as possible;
- Ensure that engineering feasibility work is accurate so equipment can be delivered as designed;
- Ensure adequate testing facilities (there is a technical gap for Tier III HPHT equipment).

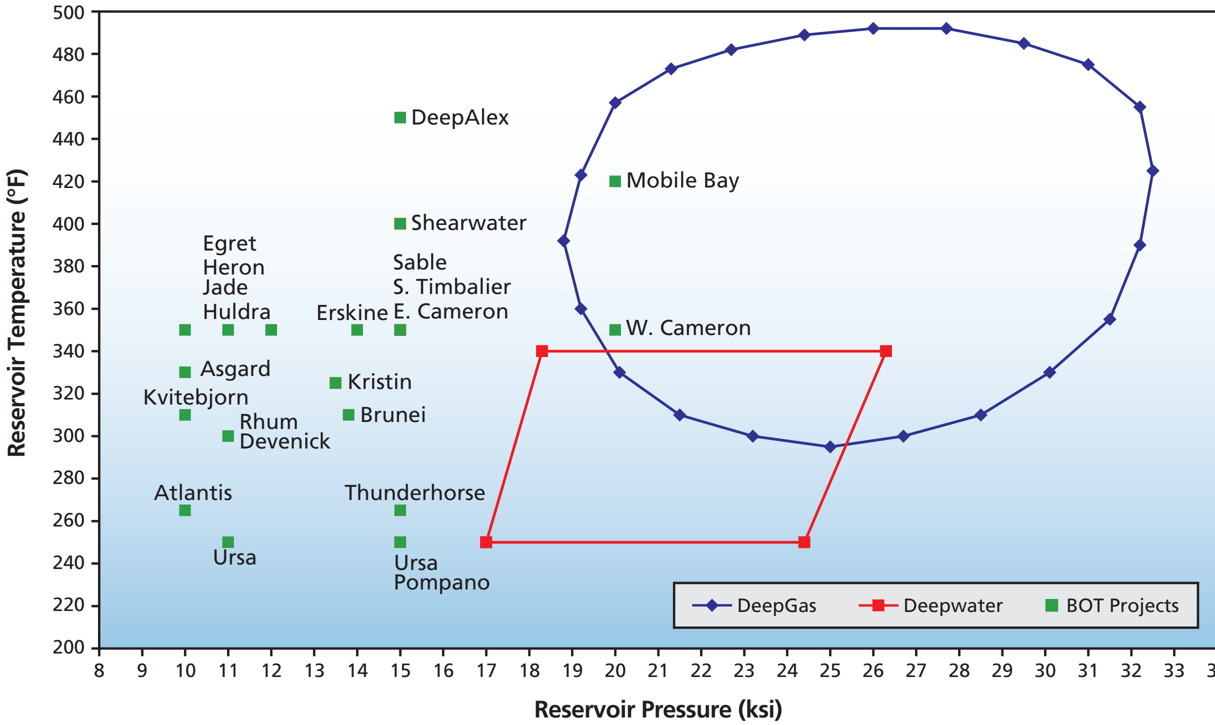
Completion engineering and well test design should begin during initial well planning. The overall completion philosophy will have significant impact on subsequent equipment selection.

Detailed contingency planning is crucial for situations that require lead times for alternate equipment or services.

PROJECT MANAGEMENT

No process has proven to be more critical to successful HPHT completions than Quality Assurance and Quality Control (QA/QC). Equally important, the success of the QA/QC process depends on exten-

Major HPHT BOT Projects & HPHT Potential Extreme/Ultra Reservoir Regimes



Most HPHT projects to date have been Tier I. Industry growth areas such as deepwater oil and gas and deepwater shelf gas, are in Tiers II and III.

sive operator involvement and clear, ongoing, accurate communication between the operator, completion provider and among project team members.

Both the operator and service provider must establish a project management structure that is customized to meet the specific product challenges.

Extensive operator involvement in equipment design and manufacture is not typical for standard wells, but it is crucial to successful HPHT completions.

Operator involvement in equipment design reviews ensures that the operational requirements are addressed before the design is released for prototype manufacture.

Similarly, the operator's participation in identifying safety-critical elements and components is vital to subsequent processes such as engineering, qualification testing, manufacturing, assembly, subassembly make-up, testing, and installation.

Safeguards and processes from earlier stages of the project are wasted if the HPHT equipment is not deployed flawlessly at the wellsite.

To assure that knowledge and information are transferred and the equipment is properly installed, the operator and completion company project management team members should continue their involvement through the drilling and completion phases.

Service center personnel and field service technicians should be members of the team that plans the completion procedure.

Detailed knowledge of how the equipment was designed, tested and assembled can prevent installation mishaps.

Some operators also conduct a complete run-through of the completion procedures with the entire team of service technicians.

CLOSING TECHNOLOGY GAPS

High gas prices and the search for hydro-

Tier II and Tier III HPHT Technical Challenges

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

carbons in deeper formations are key drivers of the development of Tier III HPHT cased hole completion systems (CHCS).

At the same time, these systems must satisfy the need for reduced risk, rig time and cost.

Meeting these needs depends on closing technology gaps in three key areas – testing facilities, seals and polymers, and metallurgy.

"Extreme" HPHT testing facilities must be designed for ultimate safety in testing equipment to severe combined loads and pressures to meet regulatory requirements.

Test facilities must include high-pressure consoles, torque machines, nitrogen booster pumps and tanks as well as sand flow loops.

Additionally, pumping large volumes of nitrogen at extremely high pressures presents health, safety and environmental (HSE) issues that must be addressed.

The industry must develop polymers and seals that can withstand these "extreme" HPHT well conditions up to 30,000 psi (2068 bar) and 500º F (260º C) while retaining mechanical properties, chemical performance and well fluid compatibility.

Baker Oil Tools Recent Experience

Project	Pressure (psi)	Temperature (F)	Tier Level
Atlantis	10,000	265	Tier I
Kvitebjorn	10,000	310	Tier I
Asgard	10,000	330	Tier I
Huldra	10,000	350	Tier I
Ursa 1	11,000	250	Tier I
Rhum/Devenick	11,000	300	Tier I
Jade	11,000	350	Tier I
Egret/Heron	12,000	350	Tier I
Sable Island	12,000	350	Tier I
Kristin	13,500	325	Tier I
Brunei	13,800	310	Tier I
Erskine	14,500	350	Tier I
Ursa 2	15,000	250	Tier I
Pompano	15,000	250	Tier I
Thunderhorse	15,000	265	Tier I
South Timbalier	15,000	350	Tier I
E. Cameron	15,000	350	Tier I
Shearwater	15,000	380	Tier II
DeepAlex	15,000	450	Tier III
Elgin/Franklin	16,000	400	Tier II
W. Cameron	20,000	350	Tier II
Mobile Bay	20,000	420	Tier III

Reliability prediction and HSE issues must be addressed. Extensive seal research must be conducted. In some cases, metal-to-metal seals may replace elastomers.

Metallurgy, first and foremost, must be available. Sourcing metals such as nickel alloys, Hastelloy (C-276) or possibly titanium, will be a challenge.

Well fluid compatibility (sour vs sweet service) is another key issue, as are temperature de-rating effects on minimum yield strength (MYS).

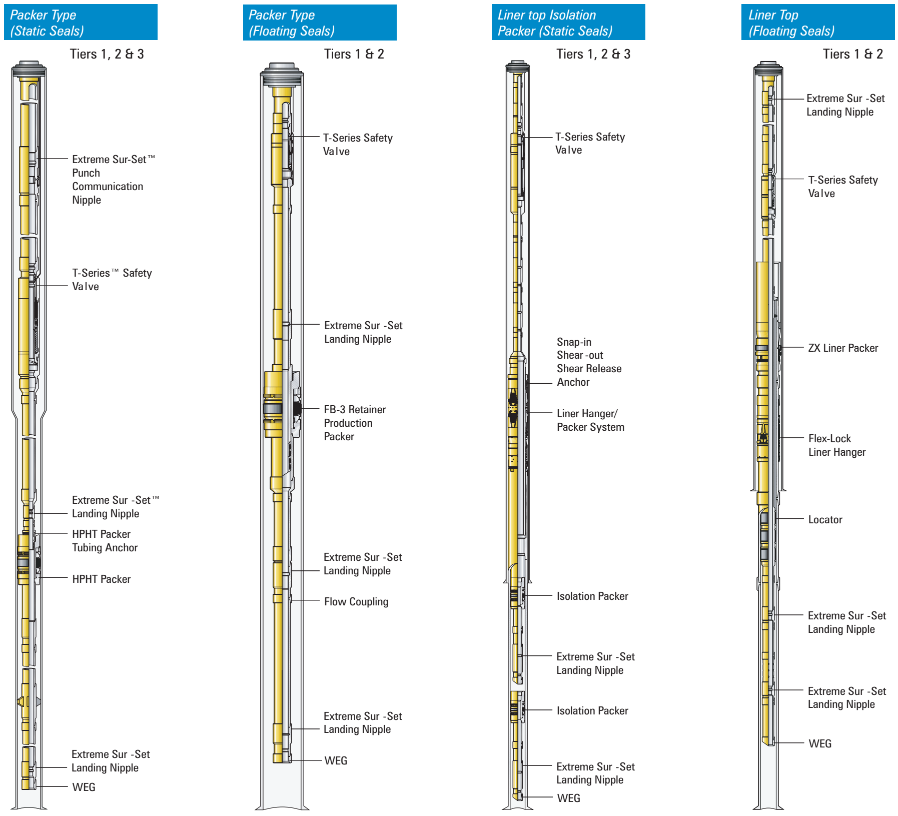
Careful planning must consider lead times and availability of these metallurgies in the overall procurement/manufacturing schedule of the equipment.

For example, materials needed to manufacture HPHT equipment with lead times of up to 3-4 months is not uncommon.

In addition, heat treated nickel alloys are not NACE-approved above 450º F (232º C), which may present regulatory challenges.

There is no question that the E&P industry is developing "new tricks" to deal with the exciting but challenging prospect of drilling "ultra" and "extreme" HPHT hydrocarbon reservoirs.

Those "new tricks" will help this "old



The above illustration shows samples of Baker Oil Tools' cased hole completion systems for Tier I, II and III HPHT wells.

dog" continue to meet the world's growing demand for energy for the foreseeable future.

HPHT QUALIFICATION, TESTING

A key factor in the success of HPHT projects is the physical qualification and testing of the proposed equipment.

Testing facilities such as the Baker Oil Tools' Navigation R&E Test Lab can recreate downhole HPHT environments with pressures to 30,000 psi and temperatures to 680º F. Each test cell has a video monitoring and data acquisition system.

The existing lab equipment is suitable for testing HPHT systems designed for Tier II conditions.

The industry will have to undertake significant investment in equipment and materials to generate the technologies and qualify the equipment for "extreme" Tier III conditions. ■

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