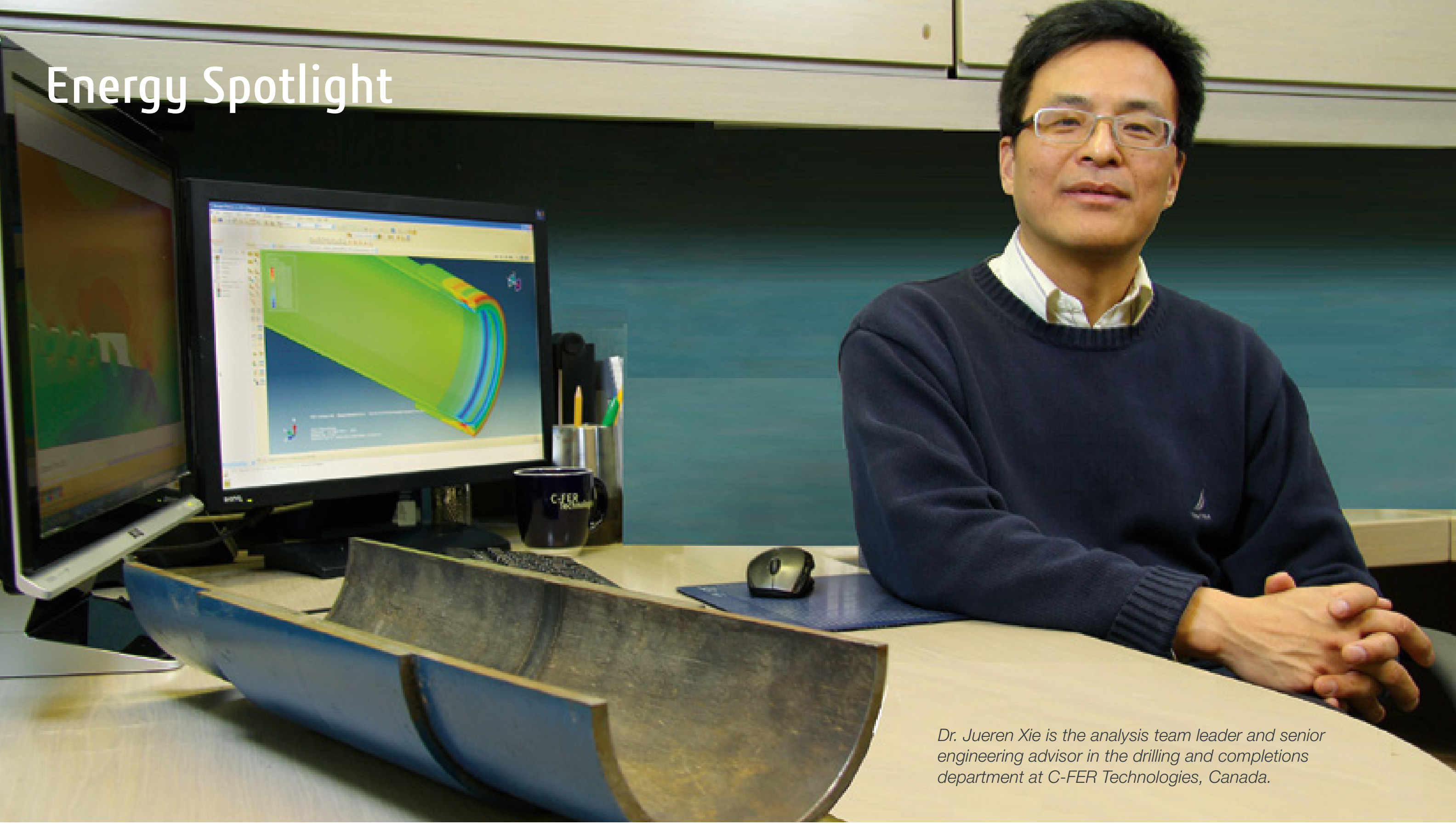


Dr. Jueren Xie is the analysis team leader and senior engineering advisor in the drilling and completions department at C-FER Technologies, Canada.

Simulating the Physical Challenges of "Unconventional Oil"

Abaqus accurately predicts realistic performance of well designs in challenging oilfield applications

These days, oil wells are deeper, well locations less accessible, and the oil heavier or otherwise more difficult to extract. All of this has led to the development and testing of a host of technologies needed to reach, and recover, what is now called "unconventional oil."

Many of these technologies have been explored and improved upon by C-FER Technologies Inc. (C-FER). Originally the Centre for Frontier Engineering Research, it was founded in the 1980s as an industry-directed engineering, testing, and applied research center to solve problems posed in constructing and maintaining offshore and Arctic structures in Canada. In the 1990s, C-FER formed a wholly owned subsidiary, C-FER Technologies Inc., to bring its advanced engineering and testing services to the marketplace on a competitive, commercial basis.

Computer-aided engineering is key to oil well performance analyses

Today C-FER's structural, mechanical, petroleum, and reliability engineers conduct applied research and development, perform full-scale testing, and provide engineering consulting for the upstream oil and gas, and pipeline transmission industries, as well as other industries. "We have a longstanding tradition of rigorous physical testing for products," says Dr. Jueren Xie, senior engineering advisor for C-FER, "but we have nearly as long a history with computer-aided engineering (CAE) tools."

From the beginning, finite element analysis (FEA) software has been an important tool at C-FER. In 1994, as the company's FEA services met with increasing demand, they adopted Abaqus FEA. Projects conducted by C-FER using the software include design of full-scale tests, failure investigation, and design optimization.

"Proving out technologies for unconventional oil wells with FEA has long been one of C-FER's most important tasks," says Xie. Unconventional oil and gas typically refers to resources such as oil sands, heavy oil, oil and tight gas shales, deep and deep-sea reservoirs, and Arctic reservoirs located below thick layers of permafrost. "These wells frequently involve ancillary extraction technologies that place considerable loads on the wellbore equipment," Xie notes.

For example, thermal well technologies, such as Cyclic Steam Stimulation (CSS), with peak temperatures higher than 330°C, and Steam Assisted Gravity Drainage (SAGD), with peak temperatures higher than 220°C, have been widely used to produce viscous heavy oil and bitumen. Many of these applications use large diameter wells with complex three-dimensional trajectories to reach the target reservoirs.

The high temperature and/or high pressure often cause significant formation loading from the interaction of the wellbore equipment with the surrounding formation. This can potentially induce large deformations and changes in material properties, causing well mechanical failures, such as buckling, shear, and collapse; casing connection failures from parting or fluid-leaking; cement functional failures (cracking and the formation of fluid flow paths); horizontal well failures due to structural damage; serviceability failures (wellbore access and sand control); and in rare instances, wellbore leakage and blowout events.

Since the traditional stress-based design criteria used for conventional wells no longer apply, C-FER developed a strain-based design concept for designing unconventional wells. Incorporating initial well-completion designs and operational and field conditions, C-FER evaluates projects using both full-scale physical tests and numerical simulations. "Because such physical testing is generally costly, especially for qualification testing under a wide range of load scenarios, it is more economical and efficient to evaluate early-stage designs with FEA," says Xie.

Two recent examples where C-FER has used FEA to optimize wellbore designs in unconventional applications include coupled thermal-mechanical analysis of wellbore production and optimization of casing and slotted liner designs. "Both of these applications involve highly nonlinear response of wellbore equipments to production loads," Xie notes, "and in both cases, Abaqus helped to determine the realistic load response and to evaluate whether or not the field equipment would perform properly for the life of the well."

Case 1: Coupled thermal-mechanical analysis of wellbore production

The coupled thermal-mechanical analysis demonstrated that at a typical heating rate of 0.6°C/min on casing internal surface (i.e. about six hours to reach a peak temperature of 220°C), the cement sheath over the entire well depth would experience significant cracking, potentially compromising the primary function of the cement sheath hydraulic (see Figure 1).

However, the analysis also showed that heating rates slower than 0.6°C/min appeared to mitigate this cracking potential because slower heating rates allow sufficient heat to be transmitted to the formation, so that both the outer surface of the cement and near wellbore formation expanded, resulting in more confinement to the wellbore. The coupled analysis showed that slow heating rates would lead to less potential damage to the cement.

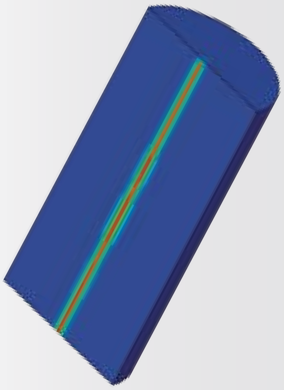


Figure 1. Simulation of a thermal well production showed significant temperature gradient from well center, suggesting high potential for cement cracking during heating (red for the high temperature, and blue for the ambient temperature).

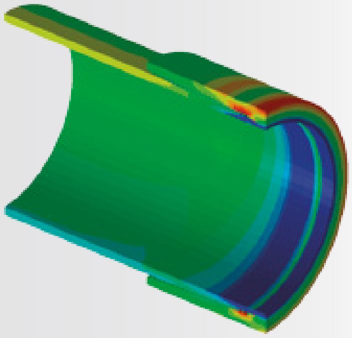
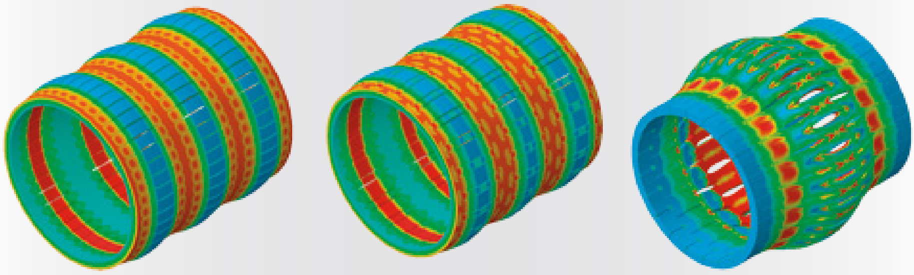


Figure 2. Simulation of a premium connection under curvature loading showed that the critical threads in the connection would experience alternating tensile (red) and compressive (blue) axial strain, causing potential connection fatigue failure under casing rotation loading.

Case 2: Optimization of casing and liner designs for thermal wells

Another area related to casing connections in thermal wells was the combined mechanical-thermal cycle fatigue life. Engineers created a 3D computer model for a "premium" casing connection design to analyze an initially axisymmetric structure subjected to the nonlinear, non-axisymmetric deformations associated with the bending rotation of the casing. The analysis results suggested that a 244 mm connection design could tolerate several hundred thermal cycles with the casing rotation (in a well with up to 12°/30 m curvature) and a somewhat larger number of thermal cycles without (see Figure 2).

With formation-induced cyclic shear loading, the analyses showed that the connection design could endure about one-fifth the number of thermal cycles with casing rotation and only about 8% more thermal shear cycles without. "The results clearly showed that cyclic formation shear loading was much more critical than thermal cycle loading," Xie points out.



Simulation of slotted liners revealed that the staggered (left) and gang (center) slot patterns had sufficient axial strain absorption capacities, while the overlapping (right) slot pattern had limited strain capacity by exhibiting "birdcaging" deformation mode, compromising the sand control functionality (red for high plastic strains).

For the examined scenario, the analyses also established that casing rotation had only a modest impact on fatigue life of the connection design. Giving support to the results, the predictions showed good agreement with physical test results published for connections of the same size and similar design.

Drilling down to FEA results

Advancements in the industry's understanding of design factors for unconventional oil wells is ongoing—for instance, a future study is anticipated wherein the potential synergy effects of plastic material deformation and corrosion mechanisms on the long-term integrity of casing connections will be explored—and Xie looks to continue to advance C-FER's research capabilities and expertise with FEA-based projects. "With the help of Abaqus, we've been able to gain a far greater understanding of complex nonlinear and multiphysics processes in these unconventional recovery applications," he says. "The software has helped us fine-tune existing designs and predict the behavior of new ones for clients, long before they begin to drill and operate the wells. Overall, FEA has played a key role in improving the safety of oil and gas extraction while also providing significant business benefits from reduced downtime and failures."

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