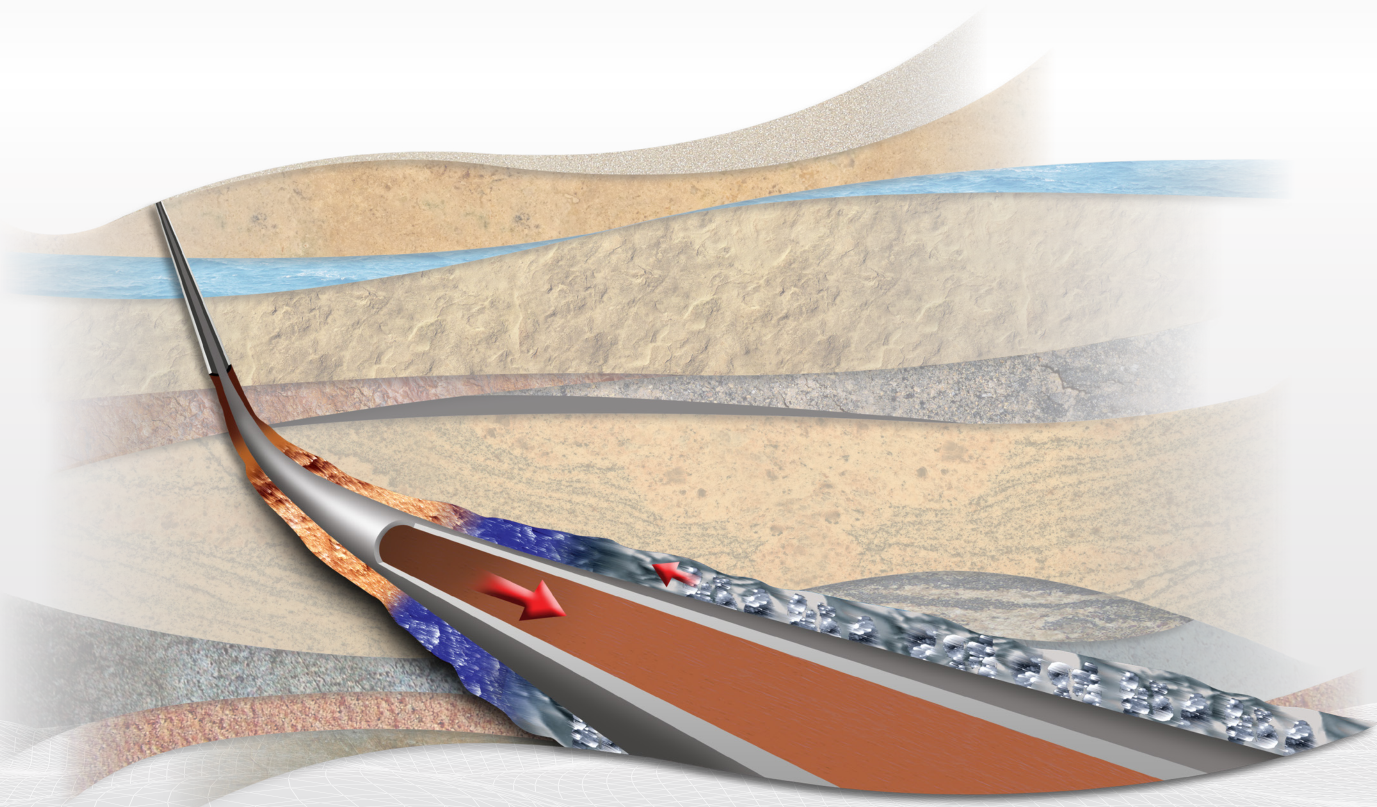
WHITE PAPER

Better Cement Jobs, Fewer Surprises:

A Lifecyle Approach to Cementing Design and Evaluation



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I. Introduction

Cementing is the process of displacing drilling fluids with cement slurry. A successful cement job is one of the most important factors in the productive life of any well. Complete and durable zonal isolation is the primary goal of a cementing operation.

Poor planning and operational execution can not only lead to cement failure but can also result in the loss of hydrocarbon recovery from the wellbore. Some of the challenges that oil and service companies face today include U-tubing, high ECD, loss of circulation, excessive pump pressure, and temperature prediction, among others.

These concerns are best analyzed using computer models, which allow engineers to evaluate the effects of different design parameters prior to the job. Potential problems can be identified, and the cementing design can be optimized before pumping begins.

Pegasus Vertex (PVI), now part of LINQX, brings more than a decade of research and development in well cementing operations. This white paper provides guidelines and a list of considerations for using computer models to perform pre-job design and post-job analysis of cementing operations.

II. Modeling

The success or failure of a cementing operation can significantly impact the financial viability of a well or project. Therefore, it is essential to prevent mistakes and ensure that small problems do not become larger issues. Making cementing decisions to correct potential problems is a complex process, as many factors must be considered.

Cementing software becomes a powerful tool because it can model the effects of various job design parameters before the job is actually performed. A robust simulator should cover the following aspects.

1. Hydraulics Modeling

Rheology is the study of the deformation and flow of fluids. Hydraulics attempts to determine the relationships between flow rate and frictional pressure drop based on fluid properties, primarily viscosity. There are four different rheology models, as illustrated in Figure 1.

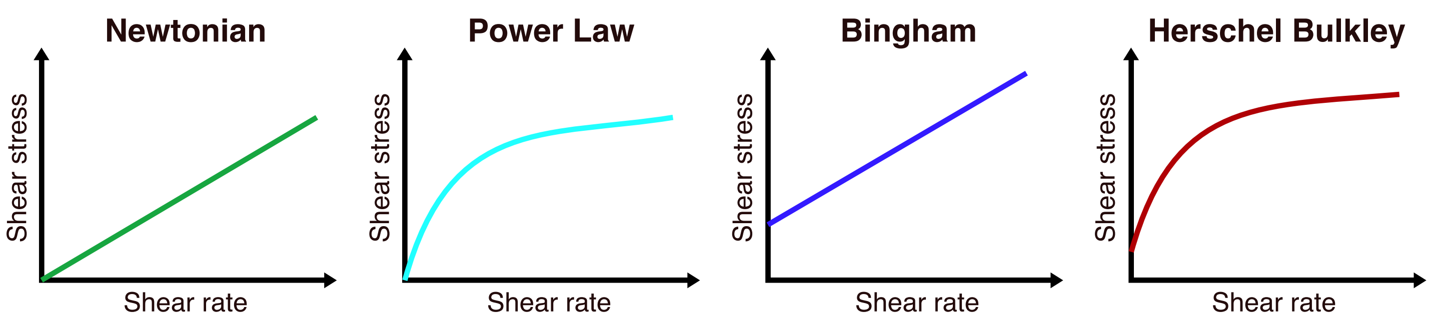

Figure 1: Rheology Models

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To properly design, execute, and evaluate a primary cement job, one must first understand the rheological properties of cement slurries and accomplish the following tasks:

- Evaluate the slurry's pump ability.
- Determine the frictional pressure when the slurry flows through pipes and annuli.
- Calculate pump pressure requirements and ECD.
- Predict U-tubing or "free-fall."
- Handle both forward and reverse circulation.

Cement slurries are usually heavier than drilling fluid, chemical wash, or spacer. When cement slurry is pumped into the casing, a hydrostatic pressure imbalance is created between the inside of the casing and the annulus. As a result, the cement slurry may tend to free-fall, creating a vacuum in the upper portion of the casing.

Eventually, as the heavier cement slurry enters the annulus and hydrostatic equilibrium is re-established, the outward flow drops below the inward flow and the casing gradually refills (backfilling stage). At some point, the outward flow may reach zero, and the fluid column in the annulus may become stationary. Such events are often misinterpreted as partial or complete losses of circulation. When the casing is backfilled, the inward and outward flows become equal. During this period, the well is under vacuum, and the surface pressure indication is zero.

U-tubing must be considered to account for dynamic annular fluid velocities and pressures for the safe and successful execution of a cement job. An advanced cementing model is required to capture fluid dynamics during cement operations. Figure 2 shows the simulated inward and outward flow rates along with predicted pump pressure.

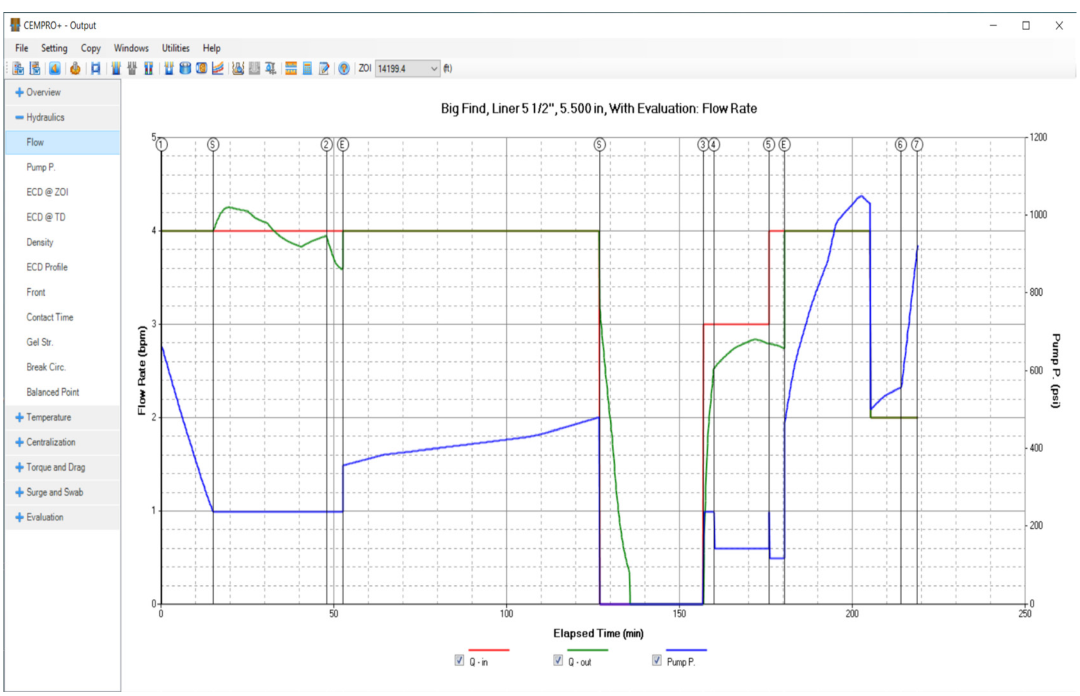

Figure 2: Flow Rates vs. Elapsed Time

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2. Displacement Efficiency

Poor mud removal is typically identified as the primary source of zonal isolation problems. To improve the sealing integrity of the cement sheath, fluid properties and operational parameters must be designed to prevent mud channeling, especially in the annulus.

The common parameter used to define the completeness of fluid displacement is displacement efficiency, which represents the fraction of the annular volume occupied by the displacing fluid.

Advanced modeling has expanded beyond focusing solely on accurate hydraulics prediction and has systematically studied displacement efficiency over pumping time. The CEMPRO© model uses a finite volume method to solve the equations of momentum, continuity, and concentration transport.

Figure 3 shows the unwrapped view of the annulus and pipe, illustrating the mixture of fluids, mud concentration, and velocities at the narrow and wide sides of the annulus, as well as overall displacement efficiency in both the pipe and annulus.

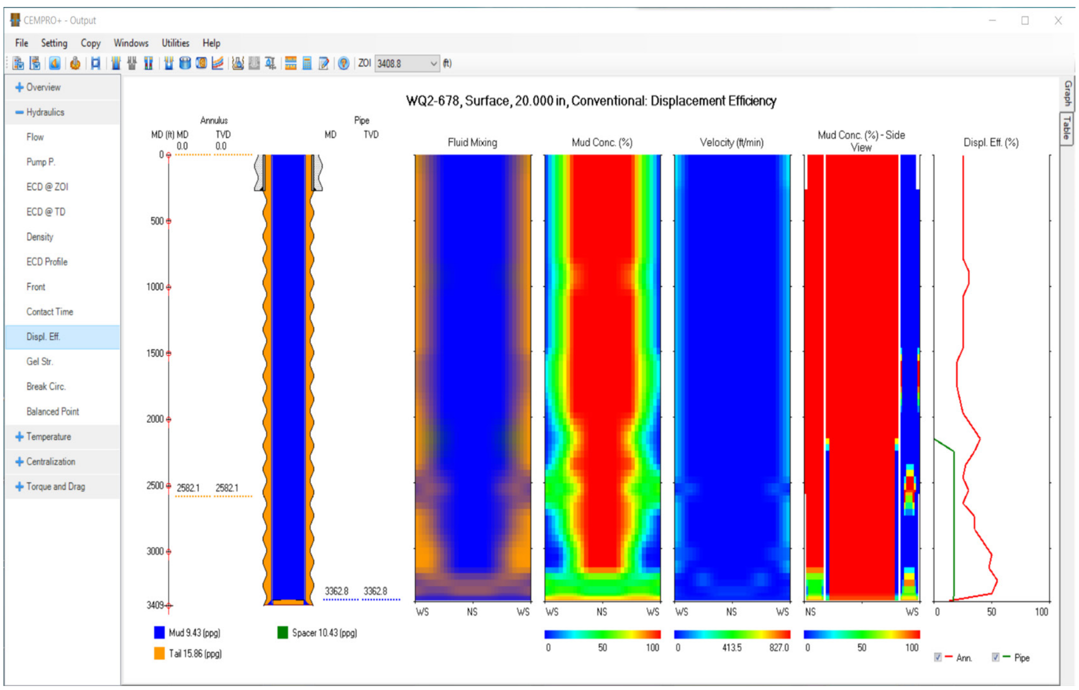

Figure 3: Simulated Mud Channel

3. Temperature Prediction

As the search for petroleum resources moves into more extreme environments in terms of depth, pressure, and temperature (HPHT drilling), accurate wellbore circulating temperature prediction becomes increasingly critical. For deepwater wells, temperature prediction is further complicated by the presence of risers, choke/kill/boost lines. However, temperature must be accurately predicted in order to properly design fluids and avoid excessive waiting on cement.

For cementing operations, temperature prediction must account for transient heat transfer between the wellbore and seawater or surrounding rock formations. Using a fully implicit finite difference method, the model treats the wellbore as a two-dimensional thermal system that accounts for dynamic fluid flow, with heat exchange governed by both convection and conduction.

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Dynamic temperature profiles inside the casing, tubing, and annulus are calculated using an iterative method at each time step.

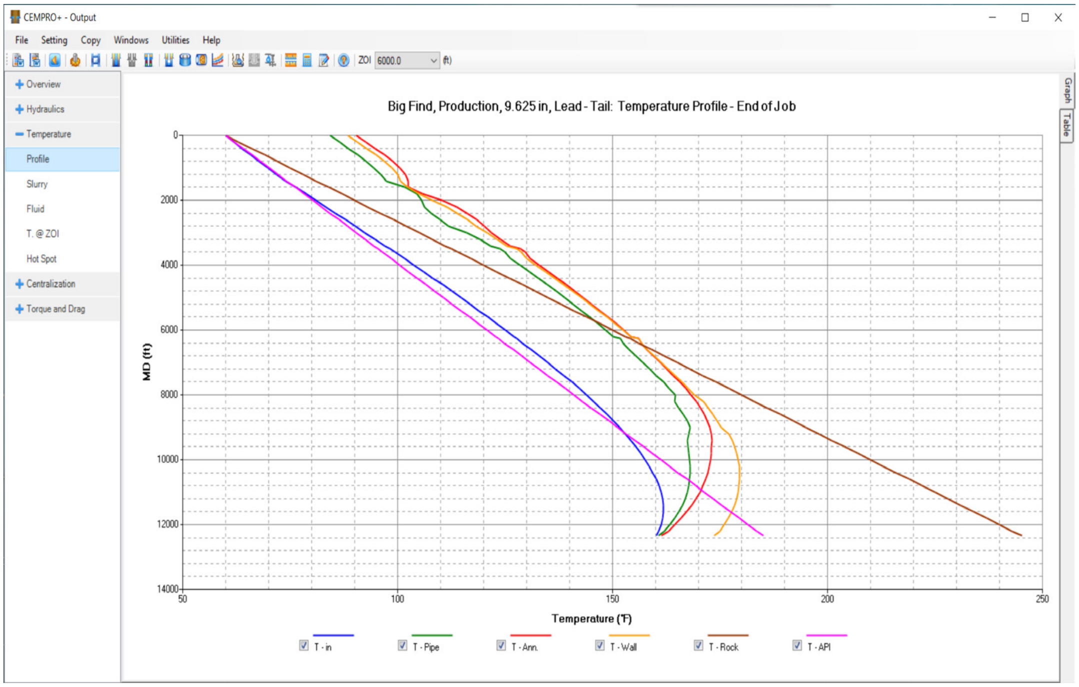

Figure 4: Temperature Profiles at the End of a Cement Job

4. HTHP Consideration

The density of a fluid changes with both temperature and pressure. Fluid viscosity typically decreases (or, alternatively, fluidity increases) as temperature rises. For HTHP wells, accounting for temperature- and pressure-dependent rheology and density becomes necessary.

Users should have the option to consider temperature and pressure effects on fluid density and rheological properties, as shown in Figure 5.

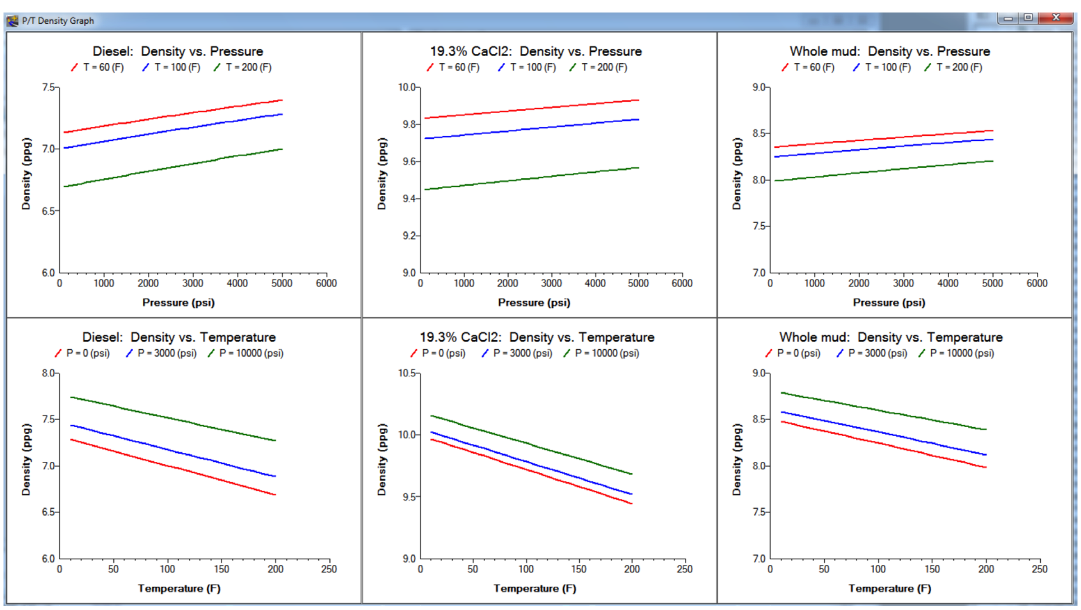

Figure 5: Density as Functions of Temperature and Pressure

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5. Foamed Cement

Foamed cement has long been regarded as an effective solution for cementing lost circulation zones. While conventional cement jobs have been extensively modeled, designing a foamed cement job requires more complex calculations to account for the effects of pressure and temperature on a compressible fluid. To fully understand the hydraulic behavior of foamed slurry as a function of temperature and pressure over time during circulation, a numerical simulator is required.

Foamed cementing techniques rely on predicting slurry density based on downhole pressure and temperature conditions. The slurry density at any point in the well is determined by the pressure exerted on the slurry, the temperature at that location, the volume of the base slurry, and the nitrogen concentration.

Prior to field execution of a foamed cement job, the required nitrogen loading ratios can be calculated using one of three operational methods: constant nitrogen rate, constant density, or hybrid (a combination of both). The constant nitrogen rate method maintains a fixed nitrogen injection rate throughout the job; as a result, slurry density increases with depth. The constant density method requires increasing the nitrogen flow rate as the slurry is pumped into the well, resulting in a slurry column with uniform density from top to bottom.

The hybrid method combines the advantages of both approaches by reducing the number of nitrogen stages while maintaining reasonably uniform density and foam quality profiles. Figure 6 shows an example in which the operation uses six stages of nitrogen loading ratios.

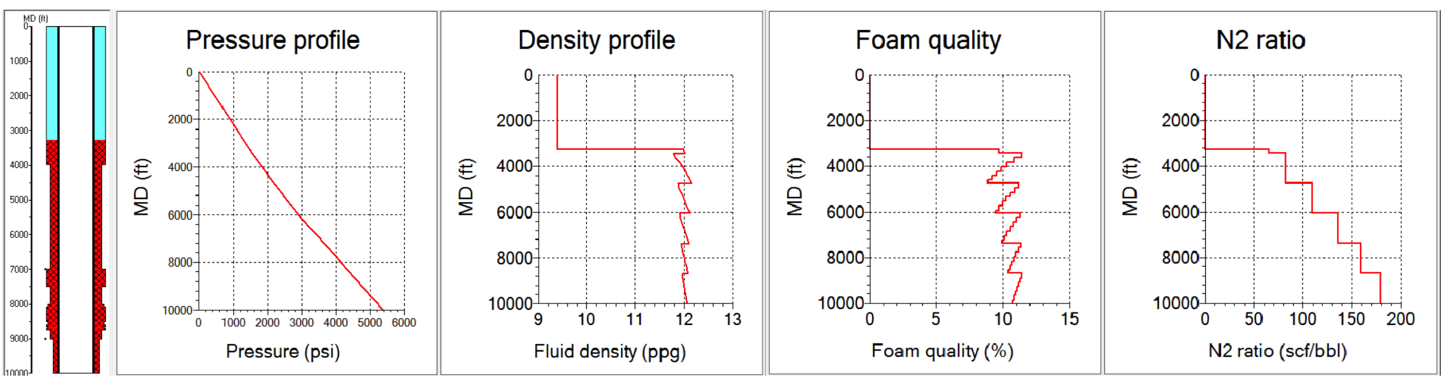

Figure 6: Foamed Cement — Hybrid Method

6. Hook Load Prediction

Hook load is the actual weight of a casing string measured at the surface, affected by buoyancy, friction, and other forces within the wellbore. During a cement job, pumping cement and displacement fluid can temporarily lift the casing due to pressure imbalance and buoyancy effects.

Figure 7 shows the variation of hook load during displacement. If the hook load becomes negative, it indicates that the casing may be hydraulically lifted or “pumped out” of the well.

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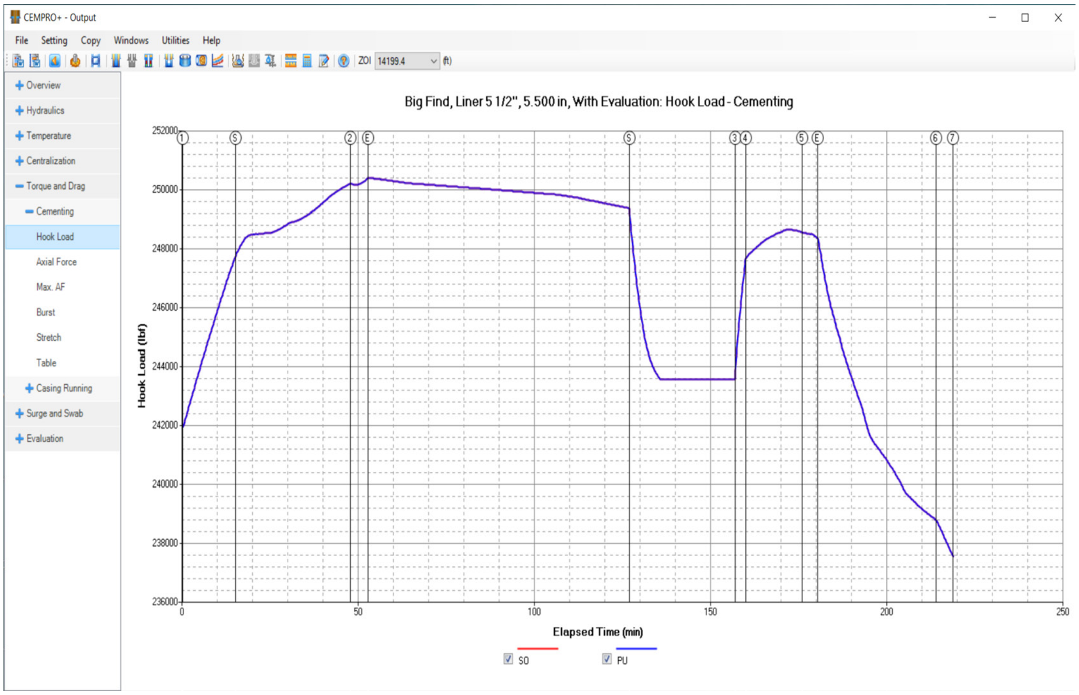

Figure 7: Hook Load during Fluid Displacement

7. Job Evaluation

Ideally, users should be able to evaluate job performance by comparing pre-job simulations with simulations based on actual recorded data. This comparison is extremely valuable for planning future jobs and troubleshooting operational issues. In CEMPRO©, actual job execution data can be imported to compare design predictions with real job results, enabling verification of operational success. This process allows engineers to refine parameters and improve performance in subsequent jobs.

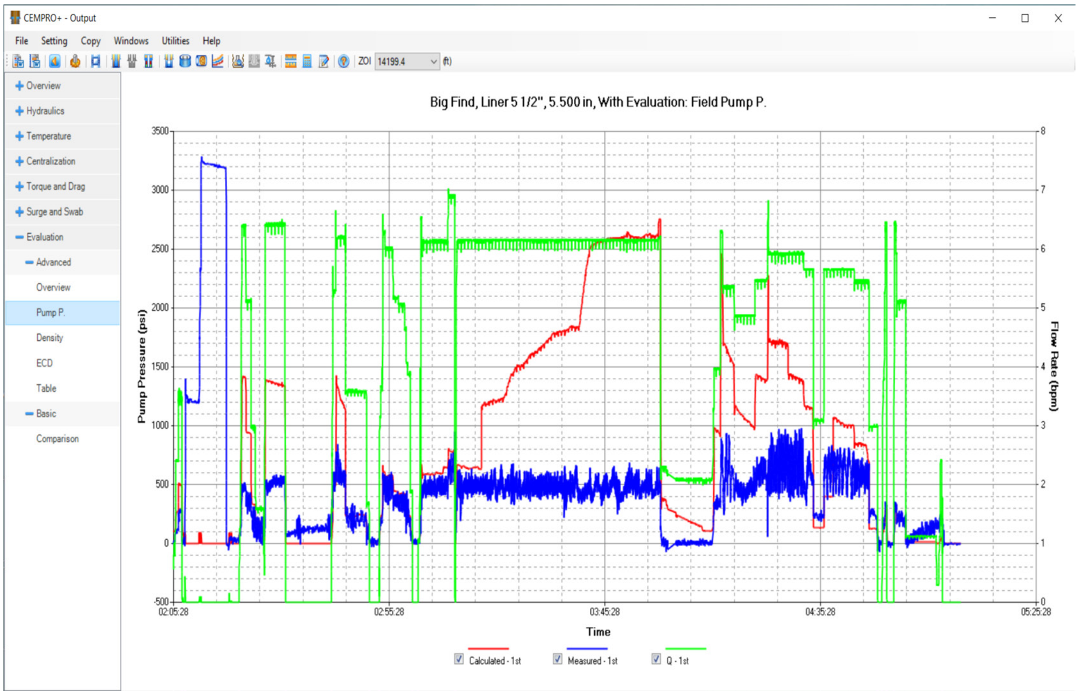

Figure 8: Job Evaluation

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8. Case Comparison and Sensitivity Analysis

CEMPRO© includes integrated Case Comparison and Sensitivity Analysis capabilities that allow engineers to evaluate multiple cementing design scenarios and understand the impact of key parameters within a unified workflow.

Users can compare hydraulics, ECD, displacement efficiency, and pressure responses across alternative cases to quickly identify optimal designs and operational margins. Sensitivity analysis automates parametric studies by varying selected inputs—such as slurry density, pump rate, or rheology—over defined ranges to quantify design robustness and risk exposure.

Supported by CEMPRO's multi-threaded computation engine, these tools significantly reduce evaluation time for multi-scenario studies while improving confidence in cementing design optimization and pre-job decision-making.

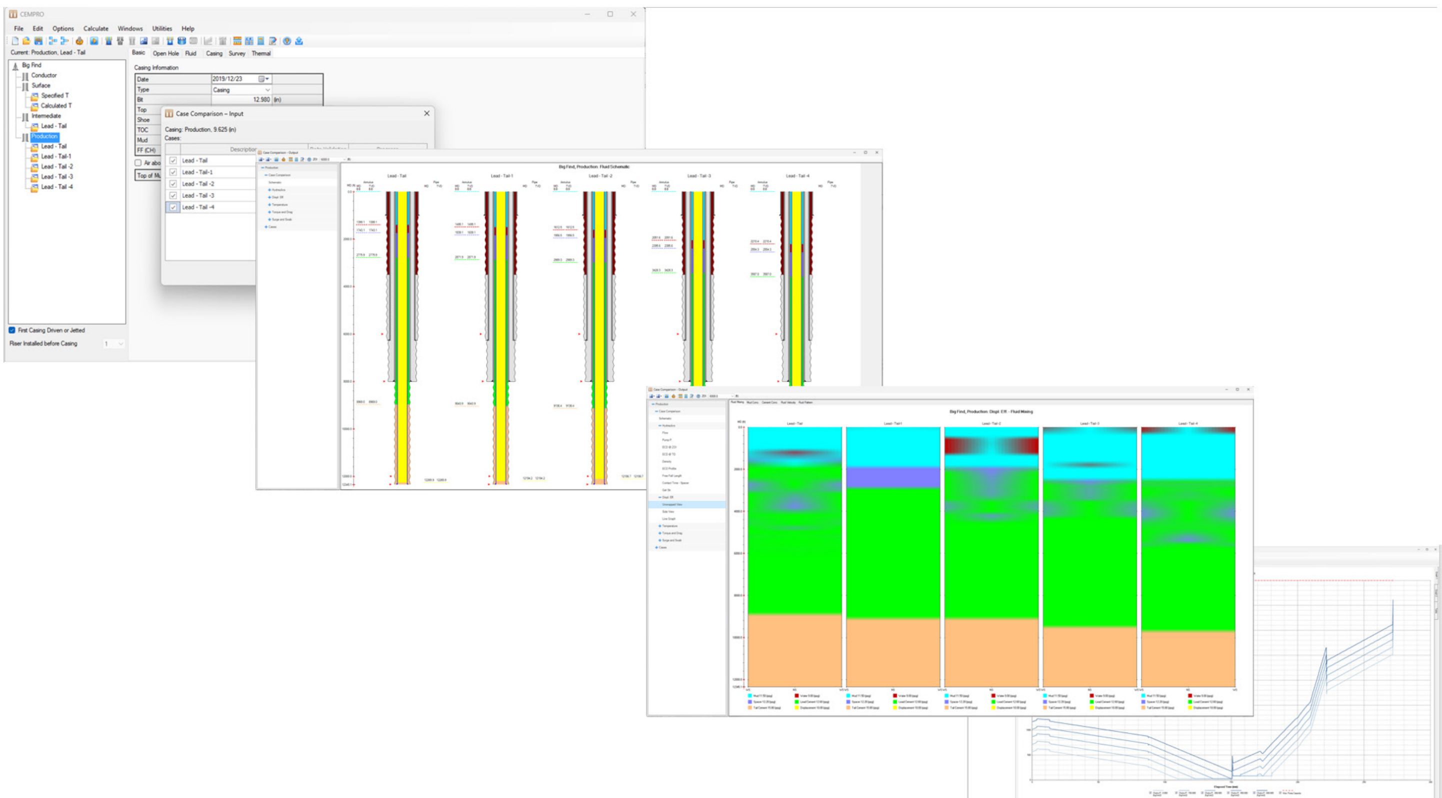

Figure 9: Case Comparison and Sensitivity Analysis

9. Localization

Software localization is the process of adapting a software product to the linguistic, cultural, and technical requirements of different countries. This process is labor-intensive and often requires a significant amount of time from development teams. To meet global demands, LINQX has translated CEMPRO© into Spanish, Portuguese, and Chinese.

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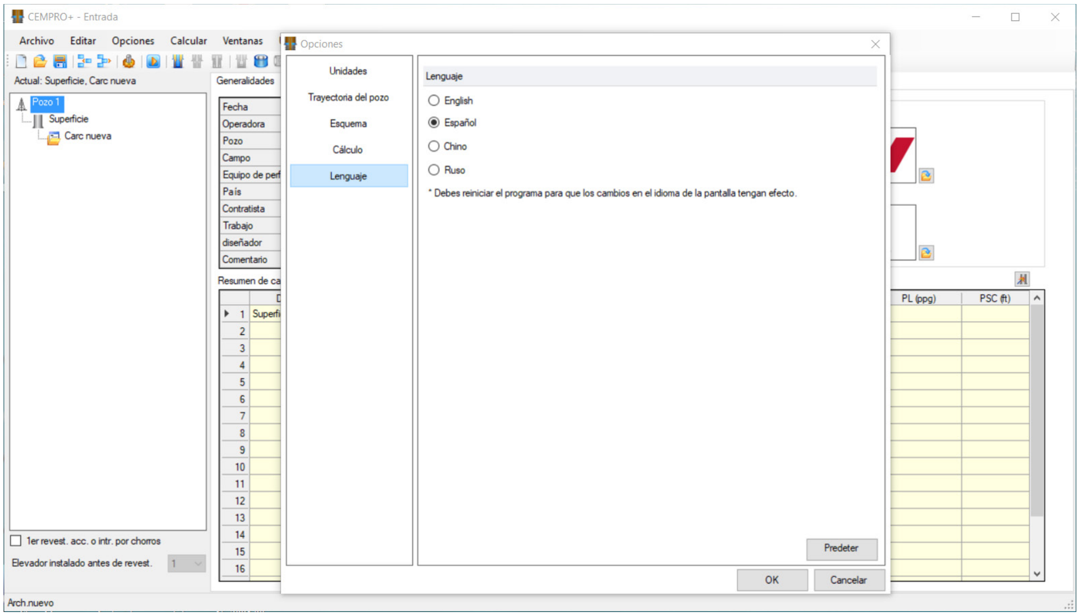

Figure 10: CEMPRO in Spanish

10. Usability

Usability reflects whether users feel comfortable with an application based on various factors, including workflow, navigation, layout, speed, and content—especially in comparison to prior or similar applications. Cement engineering software should also be evaluated with the following questions in mind:

- How easy is it to use the software?
- How easy is it to learn the software?
- How convenient is the software for end users?

Designed by professional software architects and cementing engineers, CEMPRO© combines advanced computing technology with practical cementing engineering expertise. The following features make the program user-friendly and allow users to visualize what is otherwise invisible to engineers:

- Survey data import from Excel spreadsheets, text, or PDF files
- 3D well path visualization
- Displacement animation

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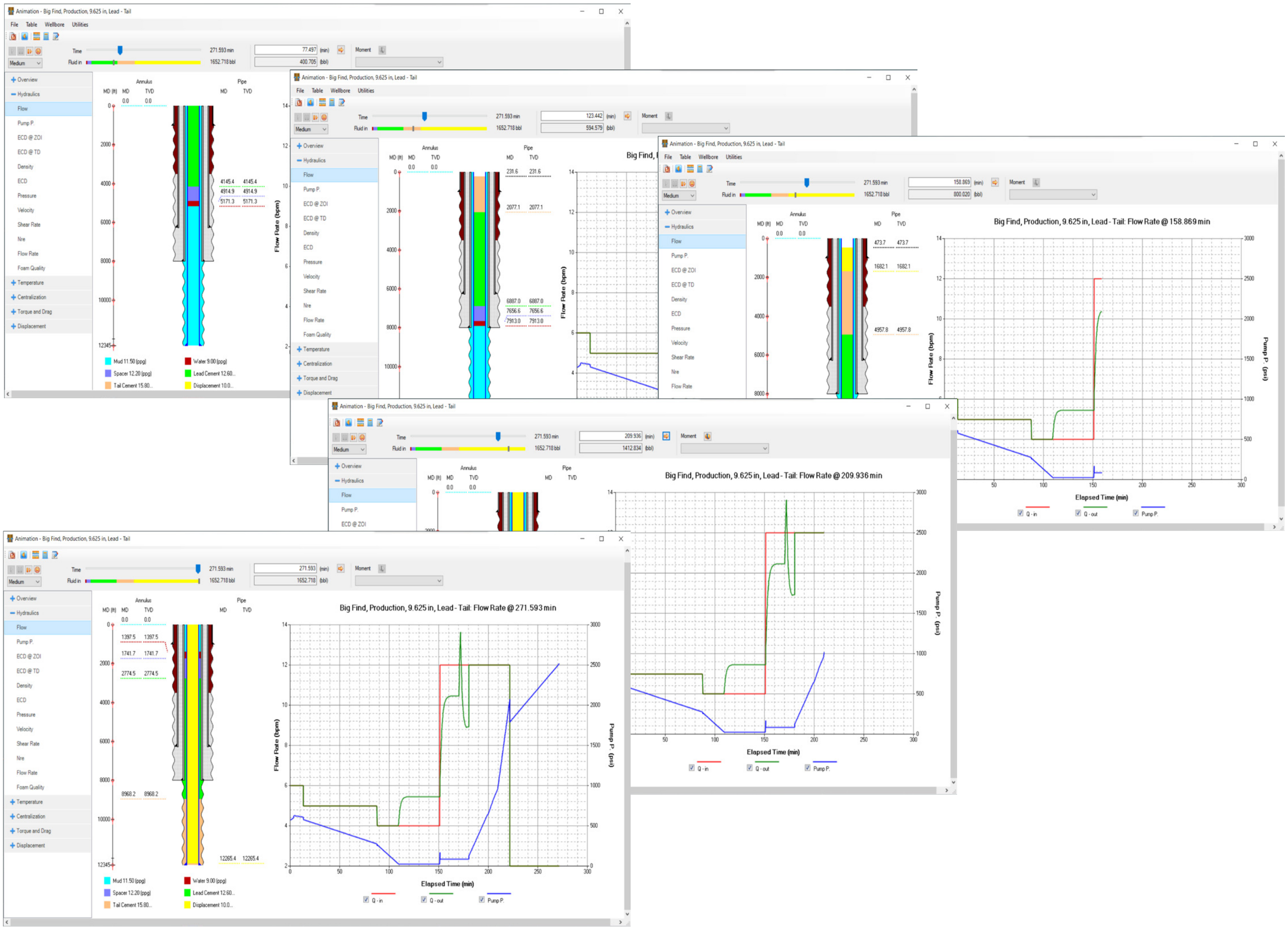

Figure 11: Animation in CEMPRO

III. Benefits

A computer program like CEMPRO© enables pumping companies and operators to deliver the highest level of technical expertise at all stages of a cementing operation. The benefits of using computer modeling are multifold, as shown below.

Excellent planner – The software allows engineers to view a complete and comprehensive picture at the design stage. It reduces rig time by evaluating pump requirements based on wellbore configuration, slurry properties, and operational parameters.

Comprehensive design optimization – Engineers can evaluate multiple cementing scenarios using integrated Case Comparison and Sensitivity Analysis tools to rapidly identify optimal designs and operational margins.

Accelerated engineering workflow – Multi-threaded computation enables simultaneous multi-case evaluation, significantly reducing turnaround time for design studies and what-if analyses.

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Training – For both entry-level and advanced engineering training, companies can use CEMPRO© to instruct individuals and cementing and pumping crews.

Risk reduction – CEMPRO© allows users to evaluate the effects of various cement job design parameters before execution. This enables identification of potential problems before pumping begins, allowing appropriate design modifications. Issues such as lost circulation, fluid migration, poor cement bond, and slurry contamination can be avoided or minimized.

Safer operations – A standardized software application provides consistency and confidence in results while reducing unnecessary errors that could jeopardize cementing operations. Modeling tools help predict well behavior with sufficient lead time, enabling cementing teams to make sound technical decisions that lead to safer operations.

IV. Conclusion

Since its first release in 2002, CEMPRO© has evolved into a comprehensive cementing job simulator, addressing all the challenges described above. It distills decades of research and development in cementing operations, incorporating the essence of more than 40 years of industry knowledge. CEMPRO© provides a deeper understanding of fluid displacement, supports informed engineering decisions in cement placement, and helps minimize risk throughout the well's lifecycle. It also provides a platform for both service companies and operators to align on cementing strategy and ensure successful job execution.

The success of CEMPRO© stems from the combination of LINQX's technical strengths in engineering modeling and collaboration with industry leaders in cementing operations. The goal is to work closely with customers to design and deliver the most advanced yet intuitive cementing software in the market.

Book a Demo—Experience Smarter Cementing Design

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Schedule Demo

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