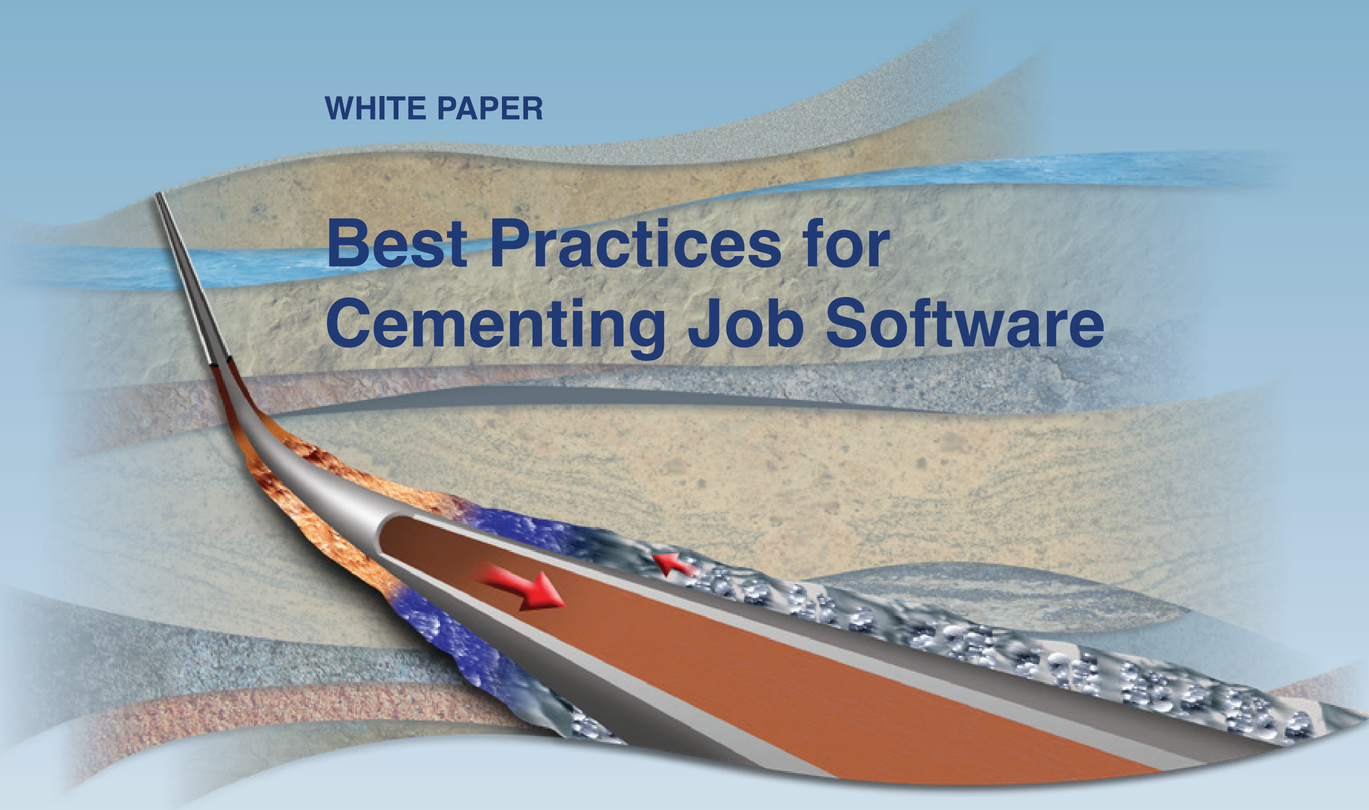
Pegasus Vertex, Inc.

Drilling Software | Sophisticated Yet Simple

WHITE PAPER

Best Practices for Cementing Job Software



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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 to the productive life of any well. Complete and durable zonal isolation is the foremost goal of a cement job.

Poor planning and operational execution can not only lead to cement failure but can 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 and excessive pump pressure, temperature prediction, etc.

These concerns can be best analyzed using computer models, which allow the engineers to see the efforts of different design parameters prior to the job. Potential problems can be identified and the cementing design can be tuned before the pump starts.

Pegasus Vertex, Inc. (PVI) has engaged in the research and development of well cementing operations for more than a decade. 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 potentially make or break the financial viability of a well or project, so it is vital to prevent mistakes and not let small problems become big ones. Making cementing decisions to correct potential problems is a complex process because many factors have to be considered. A cement job software becomes a powerful tool, because it can model the effects of various job design parameters before the job is actually performed. A good 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 the flow rate and the frictional pressure drop, based on fluid properties, mainly viscosity. There are 4 different rheology models, as illustrated in Figure 1.

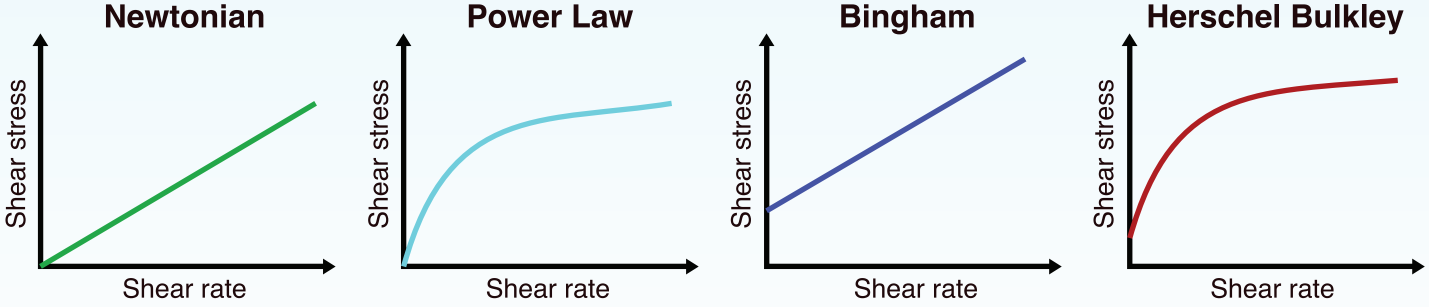

Figure 1: Rheology Models

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

- Evaluate the slurry's pumpability
- Determine the friction pressure when the slurry flows into the pipes and the annuli
- Calculate pump pressure requirement and ECD
- Predict U-tubing or "free-fall"
- Handle both forward and reverse circulation

The cement slurries are usually heavier than drilling fluid, chemical wash, or spacer. When the cement slurries are pumped into the casing, a hydrostatic pressure imbalance is created between the inside of the casing and the annulus. As a result, the cement slurries have a tendency to free-fall and draw a vacuum inside the upper portion of the casing.

Eventually, as heavy cement slurries enter the annulus and hydrostatic pressure equilibrium is regained, the outward flow falls 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 easily misinterpreted as partial or complete loss of circulation. When the casing is backfilled, the inward and outward flow will be equal. During this period, the well is on vacuum and the surface pressure indication is zero.

U-tubing must be considered to account for dynamic annular fluid velocities and pressures to the safe and successful execution of a cement job.

PVI recognizes the need for an advanced cementing model to handle the fluid dynamics during cement job. Figure 2 shows the simulated inward and outward flow rates with predicted pump pressure.

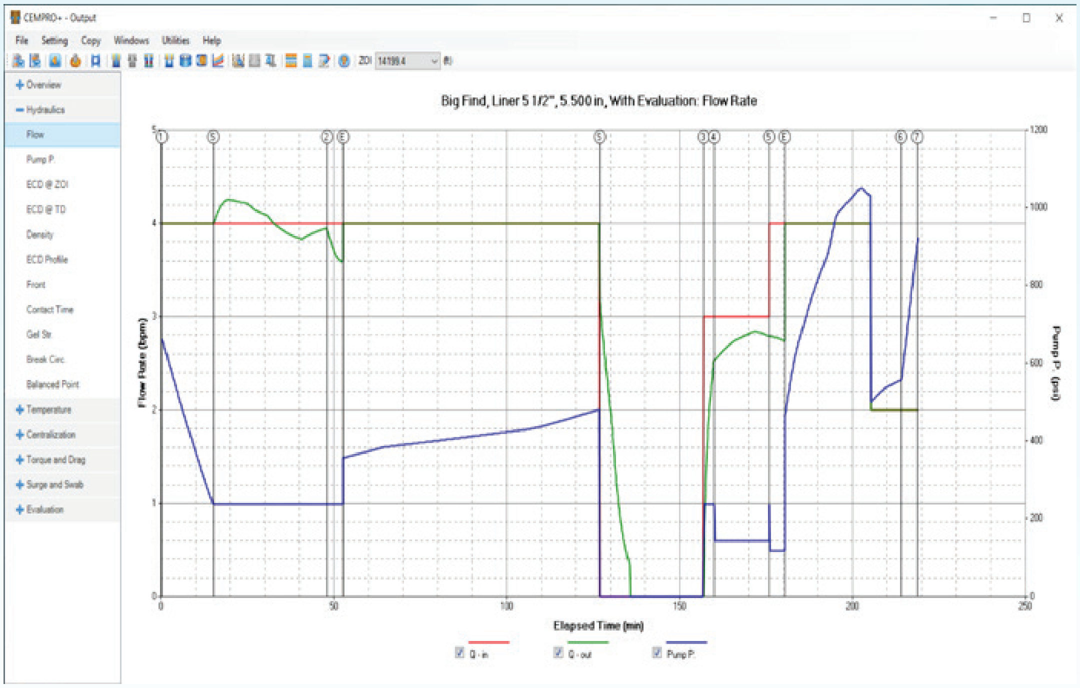

Figure 2: Flow Rates vs. Elapsed Time

2. Displacement efficiency

Poor mud removal is normally identified as the major source of communication problems. To improve the sealing property of the cement sheath, we will need to design our fluids and operation parameters to prevent mud channeling, especially in annulus.

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

PVI has gone beyond focusing solely on accurately predicting hydraulics and has scientifically investigated the 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 is the unwrapped view of the annulus showing the mixture of all the fluids, mud concentrations, velocities at the narrow and wide sides of the annulus, and overall displacement efficiency in pipe and in annulus.

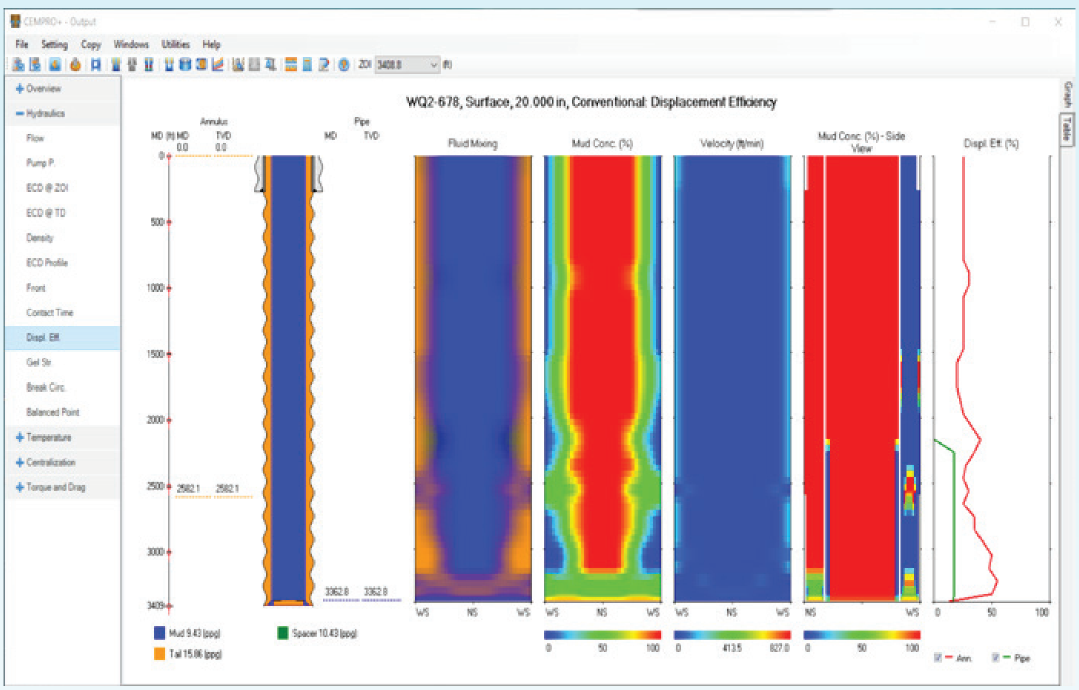

Figure 3: Simulated Mud Channel

3. Temperature prediction

As the search for petroleum resources goes more extreme in terms of depths, pressures, and temperatures (HTHP drilling), wellbore circulating temperature prediction becomes very crucial. For deep water wells, predicting the circulating temperature is further complicated by the presence of riser, choke/kill/boost lines. However, the temperature must be accurately predicted in order to properly design the fluid and eliminate excessive waiting on the cement.

For cementing operations, temperature prediction needs to address the transient heat transfer between wellbore and sea water/rock formation. Using the fully implicit finite difference method, the model treats the wellbore as a two-dimensional thermal model that accounts for the dynamic flow of mud with appropriate heat interchanged by convection and conduction.

The dynamic temperature profiles inside the casing, on pipe, in the annulus are calculated using an iterative method at each time step.

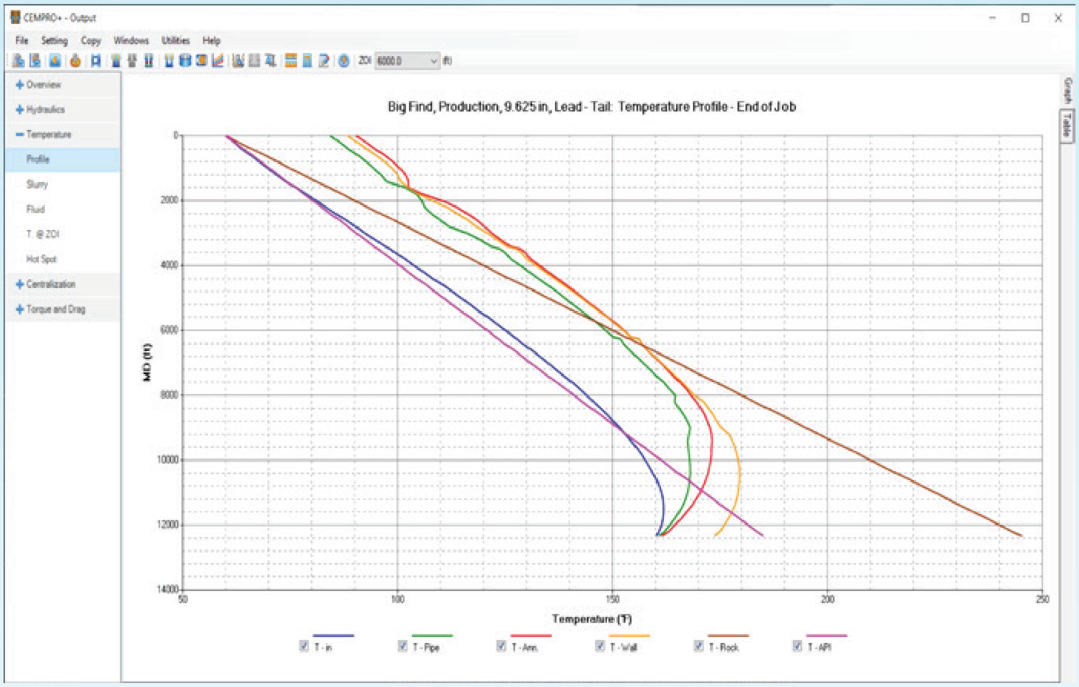

Figure 4: Temperature Profiles at the End of a Cement Job

4. HTHP consideration

The density of a fluid changes with temperature and pressure. Fluid viscosity tends to decrease (or alternatively, its fluidity tends to increase) as its temperature increases. For HTHP wells, handling of temperature and pressure dependent rheology and density becomes necessary. Users should be able to optionally choose to consider temperature and pressure effects on fluid density and rheological properties, as shown in Figure 5.

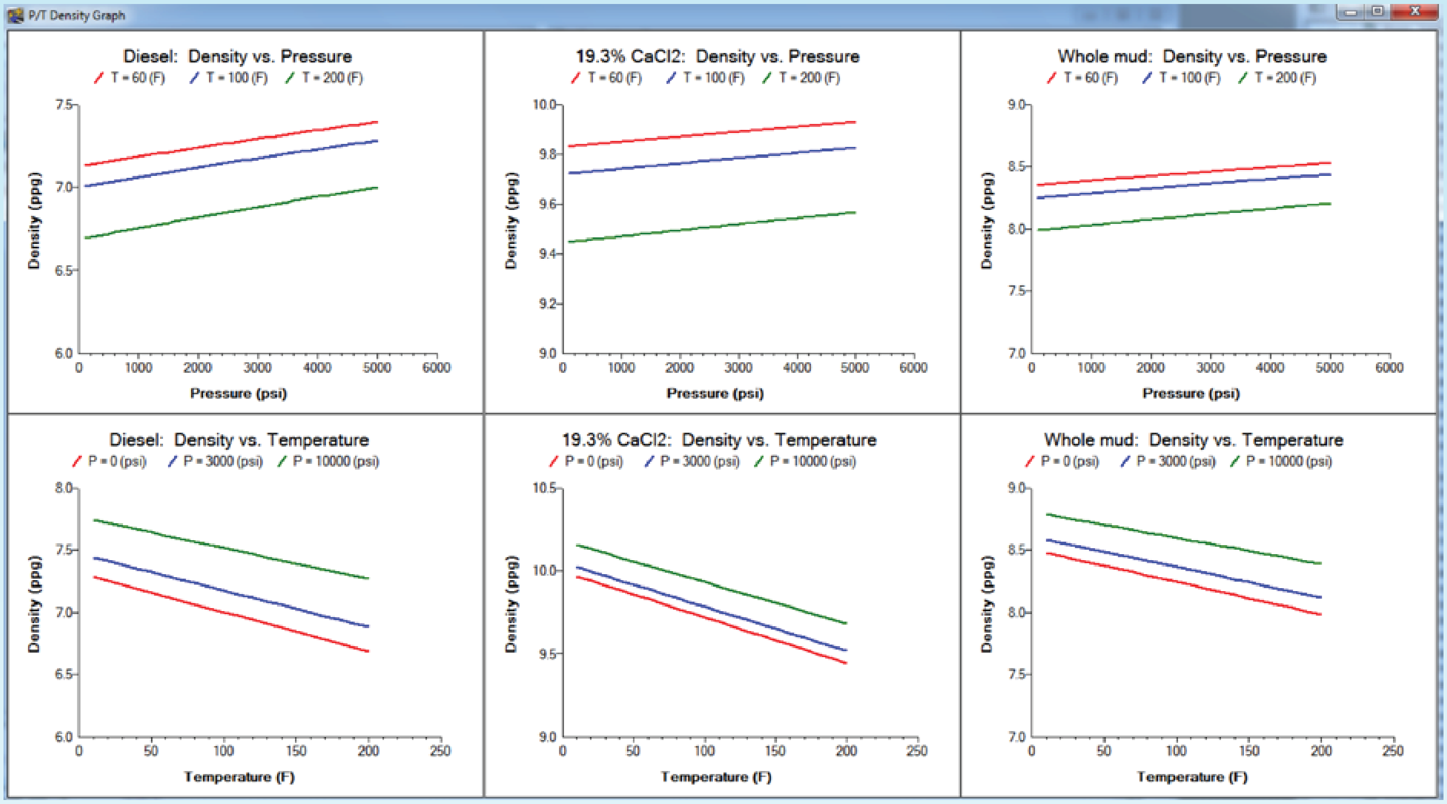

Figure 5: Density as Functions of Temperature and Pressure

5. Foamed cement

Foamed cement has long been regarded as an answer to the problem of effectively cementing lost circulation zones. While conventional cement jobs have been extensively modeled, designing a foamed cement job requires cumbersome calculations to take into account the influence of pressure and temperature on compressible fluid. To fully understand the hydraulic behavior of foamed slurry as functions of temperature and pressure at various times of circulations, a numerical simulator is required.

Foamed cementing techniques rely on the prediction of the density of foamed slurry based on the downhole pressures and temperatures. The slurry density at any point in the well will be determined by the pressure exerted on the slurry, the temperature at that point in the well, the volume of the base slurry, and the concentration of nitrogen.

Prior to the field execution of a foamed cement job, one can calculate the required nitrogen loading ratios using one of the 3 operation methods: constant nitrogen rate, constant density, or “hybrid” (a combination of both). The method of constant nitrogen rate calls for a nitrogen rate to be held constant throughout the job. Thus, slurry density will increase as depth increases. The technique of constant density requires increasing the nitrogen flow rate as the slurry is pumped into the well. This results in a slurry column with a uniform density from top to bottom.

The hybrid method combines the merits of both methods: use less stages of nitrogen ratios while maintaining reasonably homogeneous density and foam quality profiles. Figure 6 shows that the operation calls for 6 stages of nitrogen loading ratios.

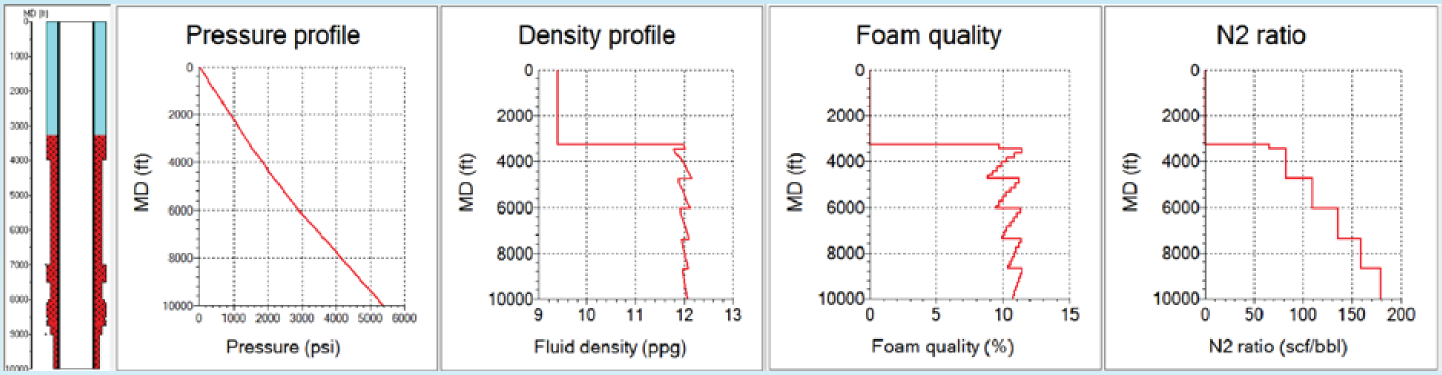

Figure 6: Foamed Cement - Hybrid Method

6. Hook load prediction

Hook load is the actual weight of a casing string measured at the surface, affected by buoyancy, friction and other factors in the wellbore. During a cement job, pumping cement and displacement fluid can lift the casing, because of the pressure imbalance and buoyancy. Figure 7 shows the variation of the hook load during a displacement. If the hook load becomes negative, that means the casing will be hydraulically pumped out of the well.

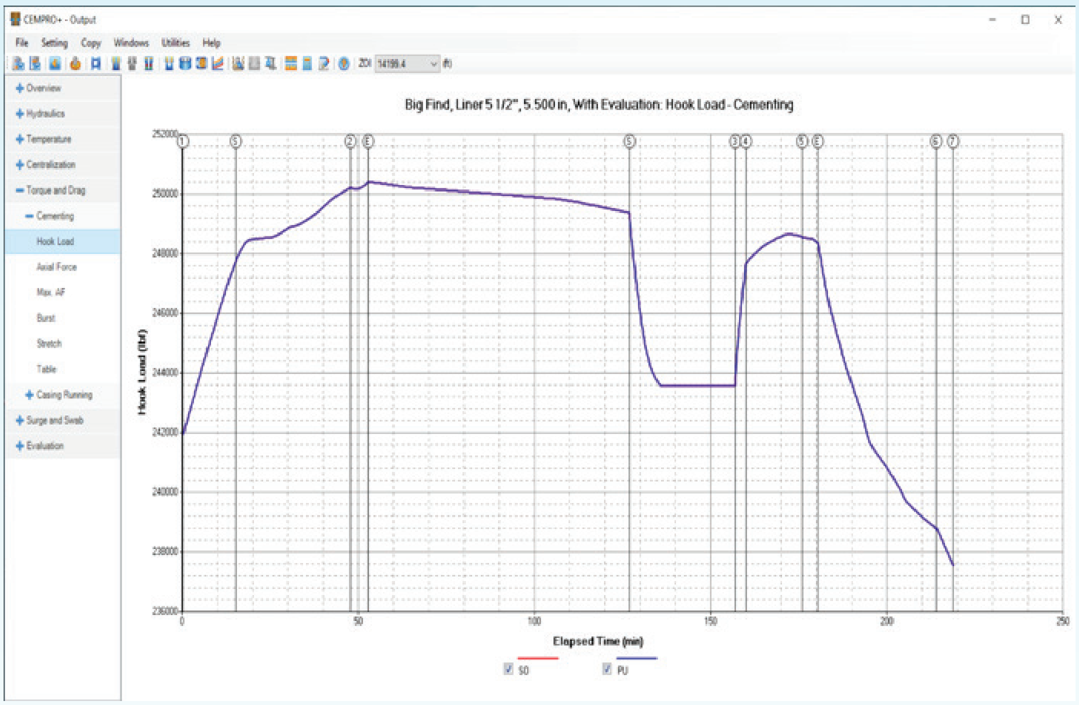

Figure 7: Hook Load during Fluid Displacement

7. Job evaluation

Ideally, users should be able to evaluate job results by comparing the pre-job simulation to simulation based on actual recorded data. This information can be extremely useful in planning future jobs and in trouble shooting. In CEMPRO+, actual job execution data can be imported to compare designs with actual results to verify the success of the operation. This permits adjustments to be made for improvement on subsequent jobs.

Figure 8: Job Evaluation

8. 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 the development teams.

To meet global demands, PVI has translated CEMPRO+ into Spanish, Russian, Portuguese and Chinese.

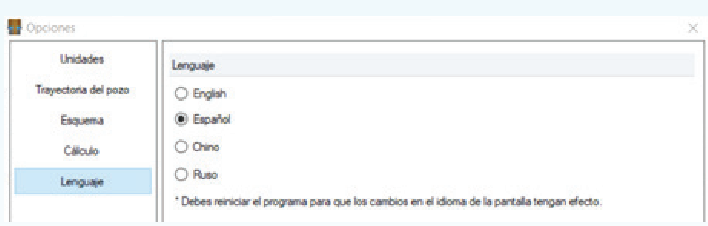

Figure 9: CEMPRO+ in Spanish

9. Usability

Usability reveals whether users feel comfortable with an application according to different parameters - the flow, navigation and layout, and speed and content, especially in comparison to prior or similar applications. Cement engineering software should also be tested 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 to the end users?

Designed by professional software architects and cement engineers, CEMPRO+ contains the best elements of advanced computing technology and practical cementing engineering. The following features of the program make the program user-friendly and let users see what is invisible to engineers.

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

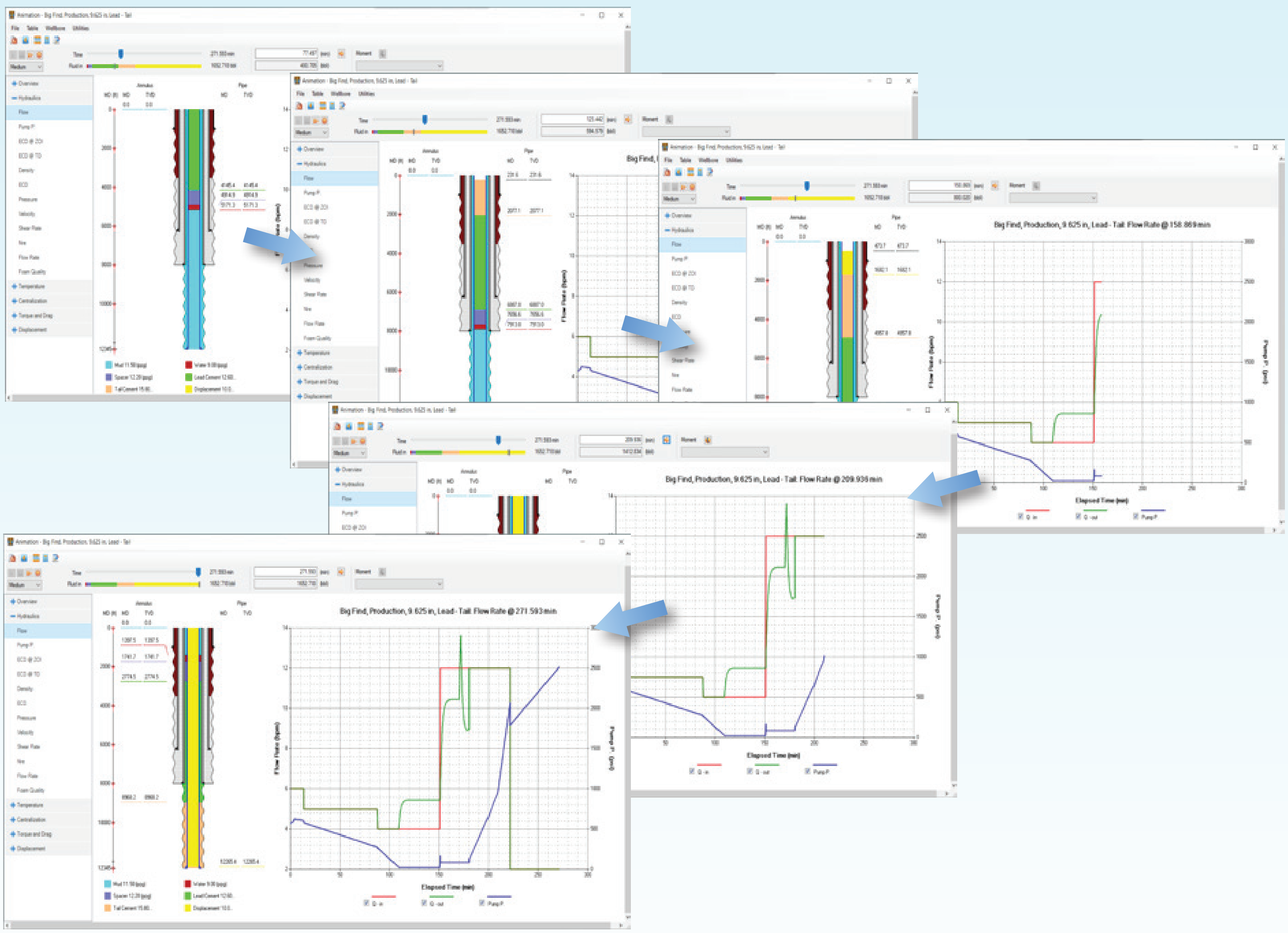

Figure 10: Animation in CEMPRO+

III. Benefits

A computer program like CEMPRO+ enables pumping companies and operators to provide the best in technical expertise at all levels. The benefits of using computer modeling are multifold, as shown below.

- Excellent planner – The software allows engineers to see big and complete pictures at the design stage. It reduces rig time by looking at the pump requirement for the particular wellbore configuration, slurry properties and operation parameters.
- Training – For entry level or advanced engineering skills training, companies can use CEMPRO+ to instruct individuals or cementing and pumping crews.
- Reduce risk – CEMPRO+ software allows you to see the effects of various cement job design parameters before the job is actually performed. That way, many potential problems can be identified before the pumping starts, and appropriate modifications can be made. Lost circulation, fluids migration, poor cement bond, or slurry contamination can be avoided or minimized.
- Safer operation – Having a standard software application provides consistency and confidence in results and helps reduce unnecessary errors which could jeopardize cementing operations. Software tools help foretell well behavior with enough notice to allow cementing teams to calmly make sound technical decisions that lead to a safer operation.

IV. Conclusion

Since its first release in 2002, CEMPRO+ has evolved into a comprehensive cementing job simulator, with features covering all the concerns mentioned above. It distills the essence of the best R&D on cementing operation over the past 40 years. CEMPRO+ offers the industry a better understanding of fluid displacement, helps our engineers make informed decisions regarding the placement and minimize risk throughout the well's life. It provides a platform for both service companies and operators to ensure a successful cementing job by putting all parties on the same page.

The successes of CEMPRO+ stem from the combination of PVI's technical strengths in engineering modeling and collaboration with industry leaders of cementing operation. Our goal is to work collaboratively with our customers to design and deliver the best sophisticated yet simple cement job software in the market.

For more information on CEMPRO+, please contact PVI at:

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