Deepwater Reverse-Circulation Primary Cementing

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Crystal Wreden
CSI Technologies

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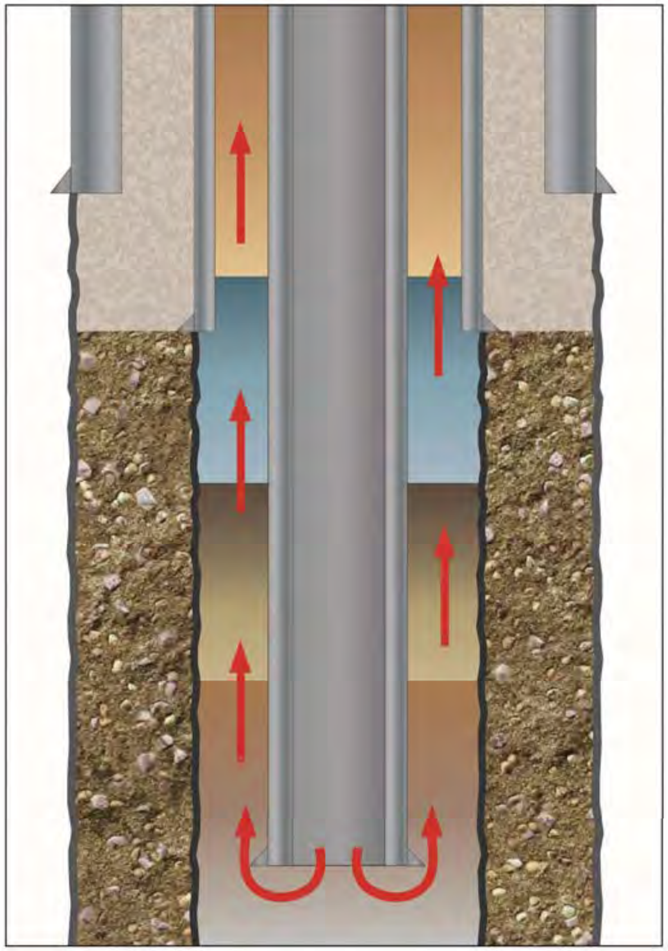
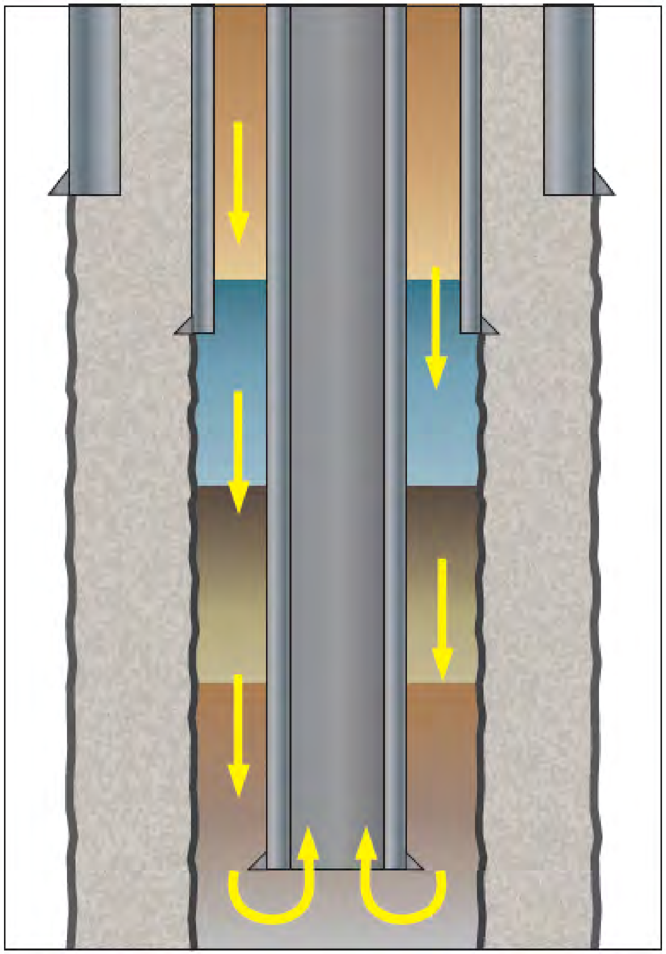
Presentation Outline

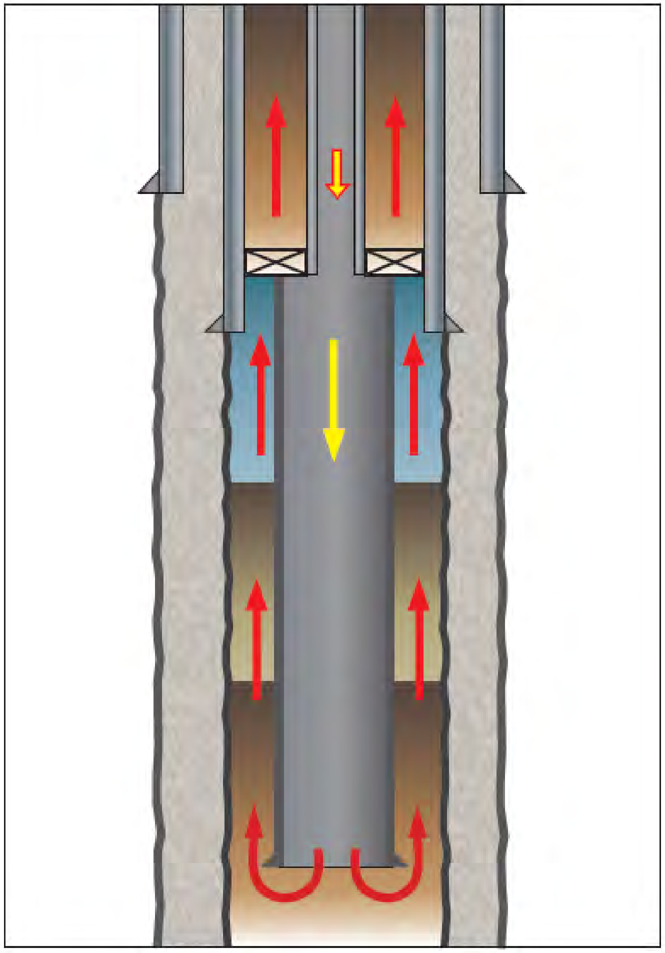
- Reverse-Circulation Background
- RPSEA Project Introduction
- Deepwater RCPC Development Challenges
- Identified Technology Development Areas
- Path forward for Deepwater RCPC

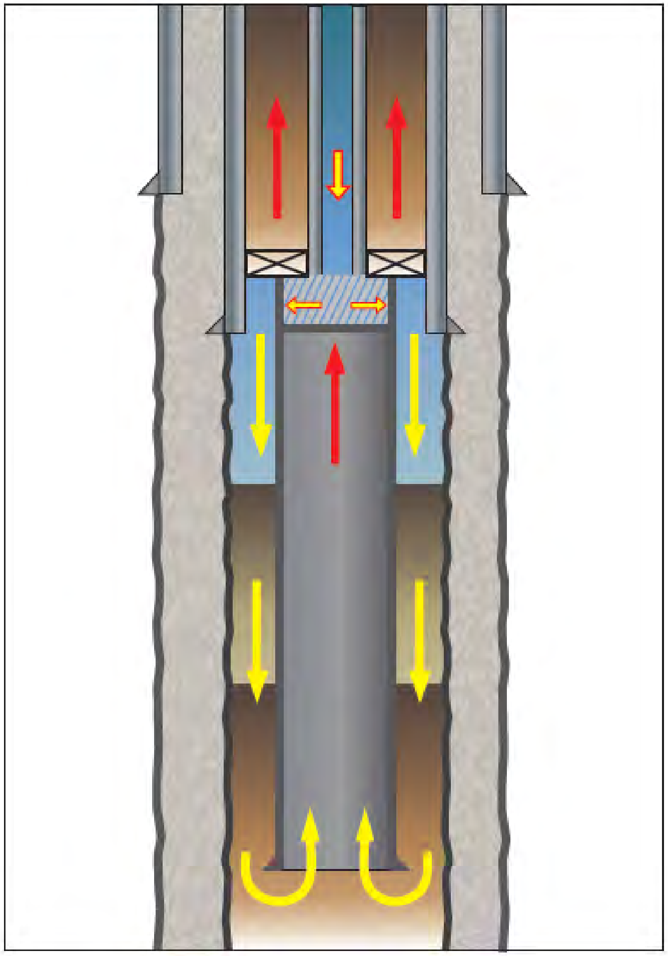
Reverse-Circulation Primary Cementing (RCPC)



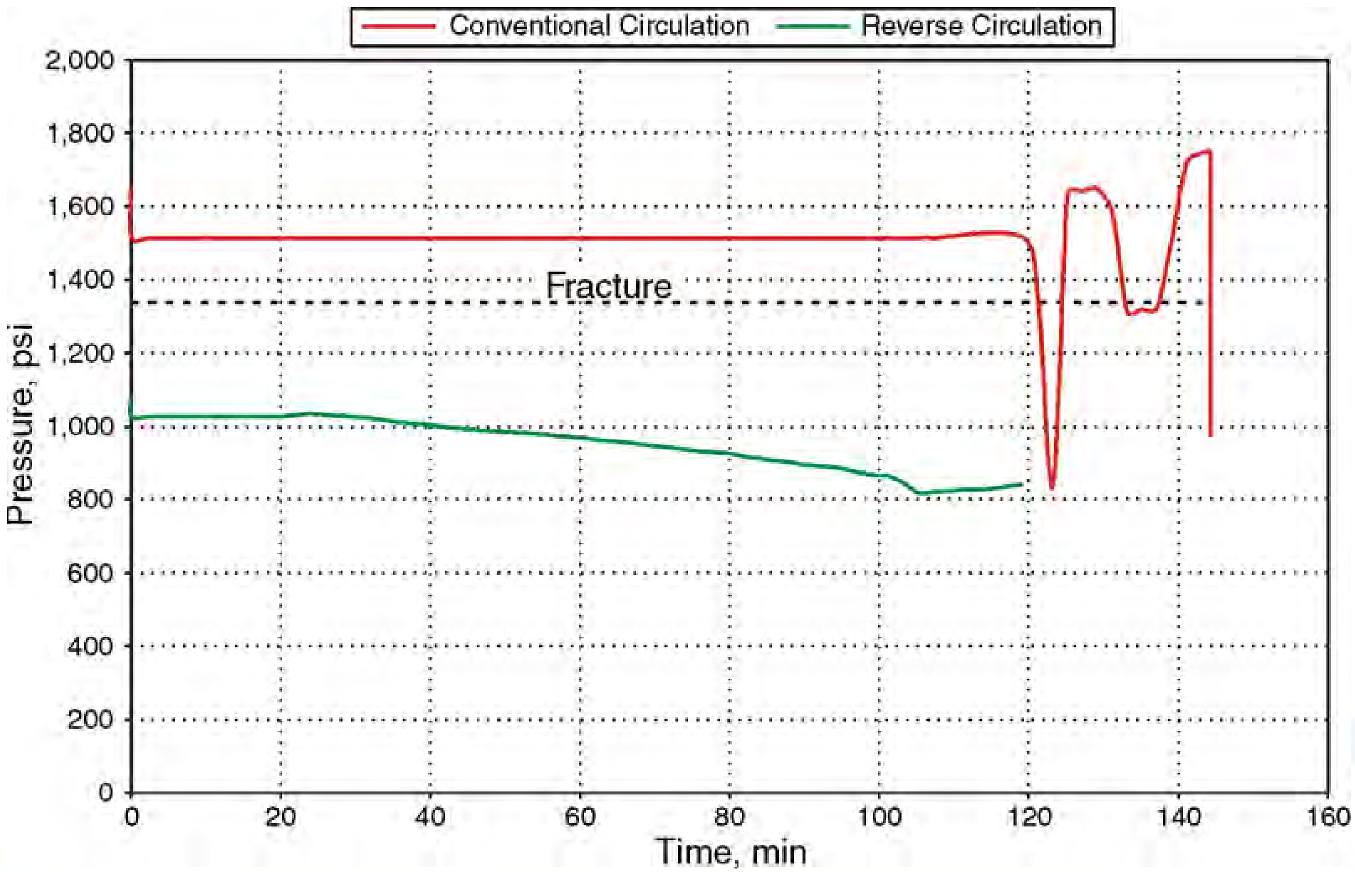


Deepwater RCPC Application





Reverse-Circulation – Literature Review Example



Mariott et al. 2007, Paper OTC 18839
Reverse-Circulation Cementing To Seal a Tight Liner Lap

RCPC Potential Benefits to Deepwater

- Reduces risk of lost circulation
  - Lower equivalent circulating density (ECD)
  - Lower friction pressures
- Safety
  - Preventing lost circulation improves bonding & zonal isolation
  - Reduces placement time
  - Lower wellhead pressure during placement
- Minimizes environmental impact
  - Can reduce amount of retarding additive needed in slurry
  - Reduces amount of excess pumped
  - TOC can be increased

RPSEA Deepwater RCPC Project Objectives

- Provide step-by-step development path for deepwater RCPC

- Phase I Objectives:
  - Assess viability of performing RCPC on deepwater wells
  - Determine required technology to apply RCPC to deepwater

- Phase II Objectives:
  - Present development strategy for required technologies
  - Develop operational procedures to perform deepwater RCPC
    - Including contingencies

- "Prototype Tested" Technology Readiness Level

RCPC Technology Development Challenges

- Mechanical Placement Controls
  - Evaluation of mechanical flow requirements and components
  - Identification of development areas

- Analysis and investigation includes:
  - Fluid diverters
  - Mechanical fluid separation
  - Seal assemblies
  - Crossover design
  - Float equipment

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Identified Technology Development Areas

Mechanical Placement Controls

- Compatibility with current tools and systems
- Development of a switchable crossover – 3 positions
- Float equipment needs to be decided upon on a case by case basis

- Initial Design Requirements for Mechanical Placement of Cement in a reverse cementing application are detailed in the following slides

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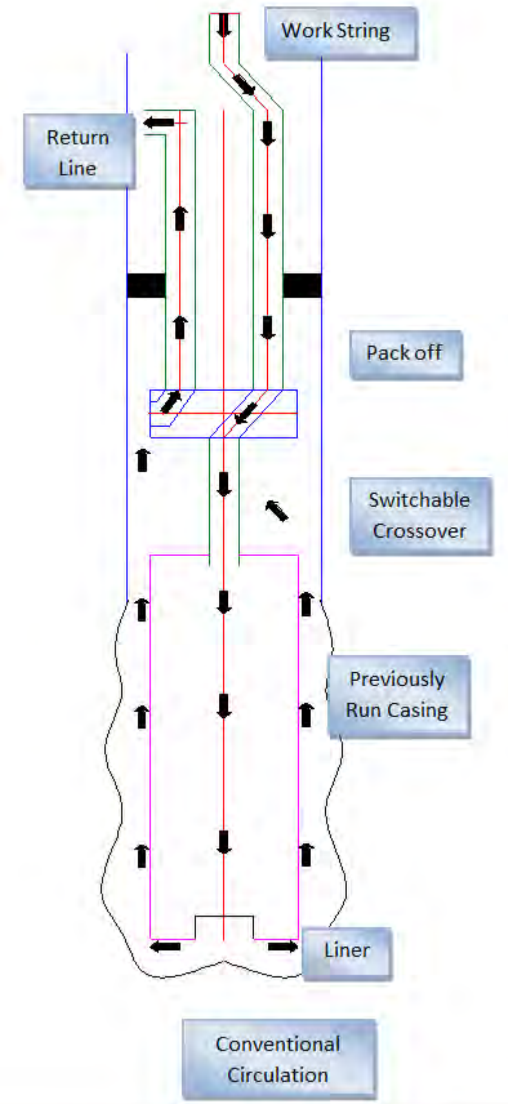
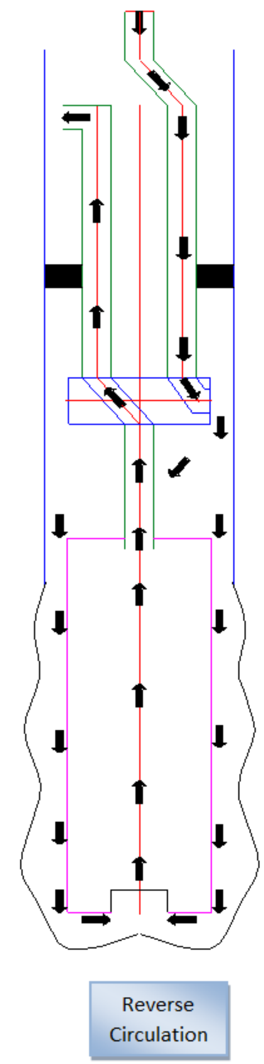
Deepwater RCPC Mechanical Placement Control

- Reverse cementing system must work with casing run on a work string
  - Liners
  - Long strings hung off on previously run casing hangers
  - Tie back strings, etc.
- The system, as a minimum, should allow circulation in the primary direction
  - Circulation down the work string, through the ID of the casing, and up the annular area between the casing and open hole/previously run casing ID while going in the hole with the casing.



Deepwater RCPC Mechanical Placement Control

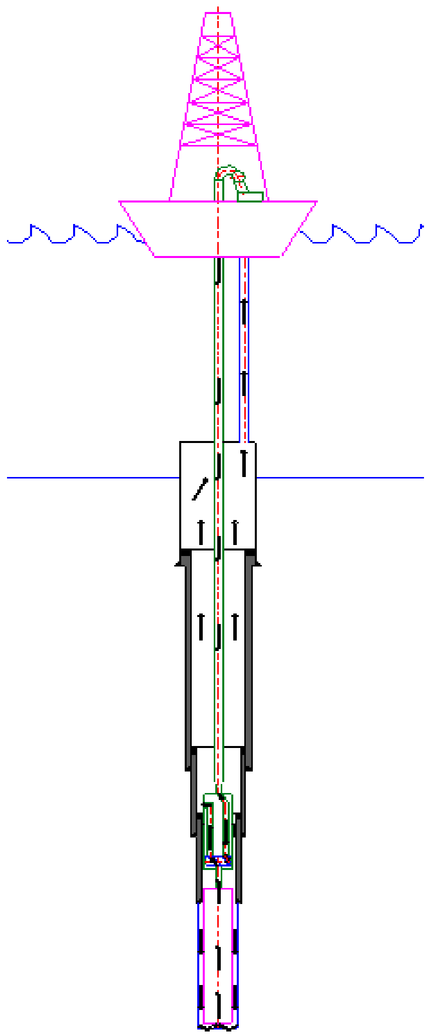
- The system, as a minimum, should be able to switch from circulation in the conventional direction to the reverse direction.
  - All flow down the work string should be directed to the casing annulus at the top of the casing
  - Returns are taken from the casing ID then diverted to the annular area between the previously run casing ID and the work sting OD
  - A pack-off between the work sting OD and previously run casing ID is needed to keep the two flow streams separated.



- For liners in particular, the reverse cementing system should be able to switch back to the conventional circulation position
  - Preferable on demand, after the cement has been placed.
  - This allows the setting of liner hangers in the conventional manner.

Deepwater RCPC Mechanical Placement Control

- Additional considerations:
  - Ability to ream into the open hole using the reverse cementing mode – the pack-off needs to work while rotating the work string and moving the casing down
  - Ability to switch the crossover tool from conventional flow direction, to reverse cementing direction, back to conventional flow direction on demand, preferably without using balls, darts, or mechanical pipe manipulation
  - Ability to separate fluids using viscous plugs instead of balls and/or darts



RCPC Technology Development Challenges

- Numerical Modeling and Simulations
  - Development of simulations and numerical models
  - Modeling parameters determined using Phase I results
- Analysis includes:
  - Review of available modeling software and simulators
  - Finite Element Modeling
  - Temperature Simulations
  - Job Placement Simulations

Identified Technology Development Areas

Modeling and Simulations:

- Standard commercially available software packages are unable to model complex flow path
- A *COMSOL Multiphysics*® finite-element software package has been developed.
  - General purpose FEM software with heat transfer and fluid flow modules, as well as the ability to solve custom equations.

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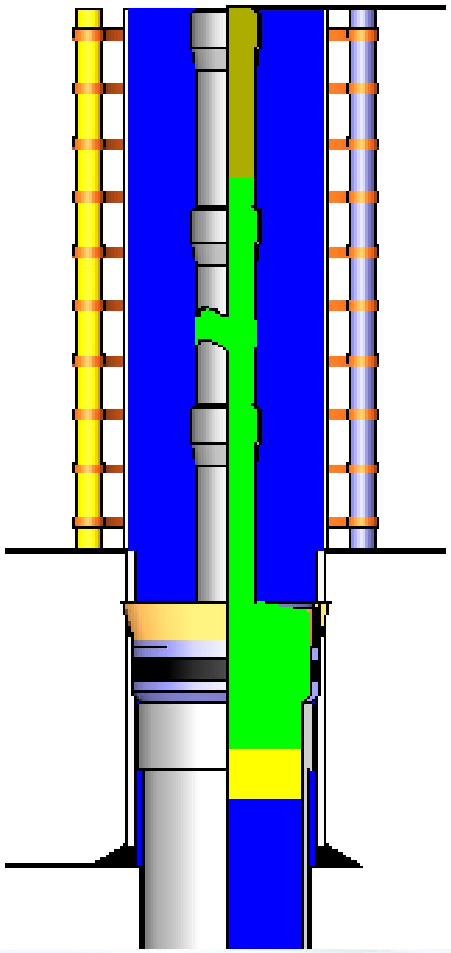
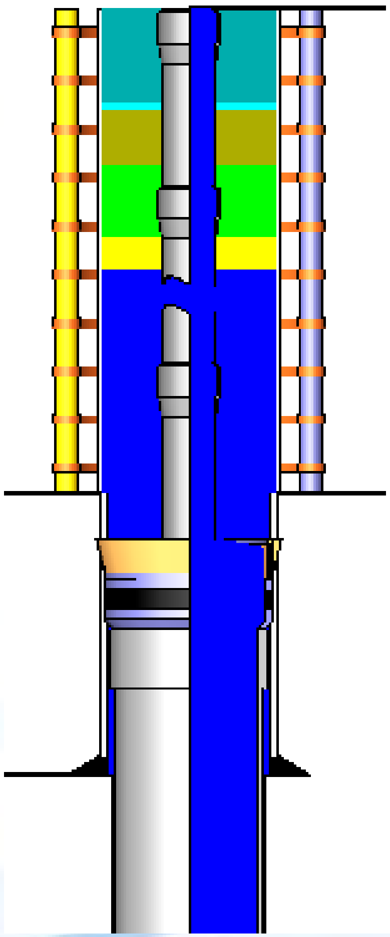
Modeling and Simulations – Commercial Limitation



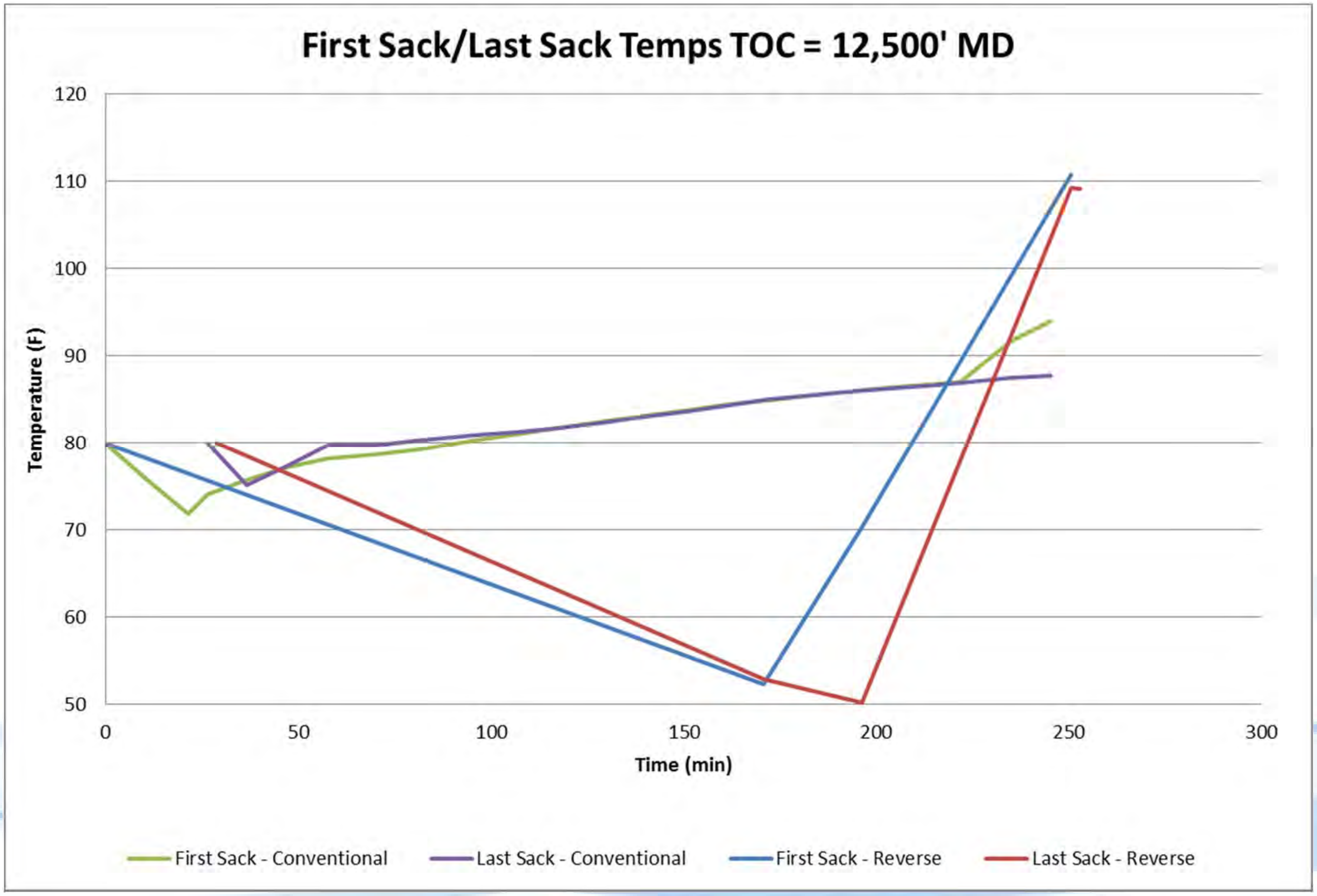
Conventional



Reverse

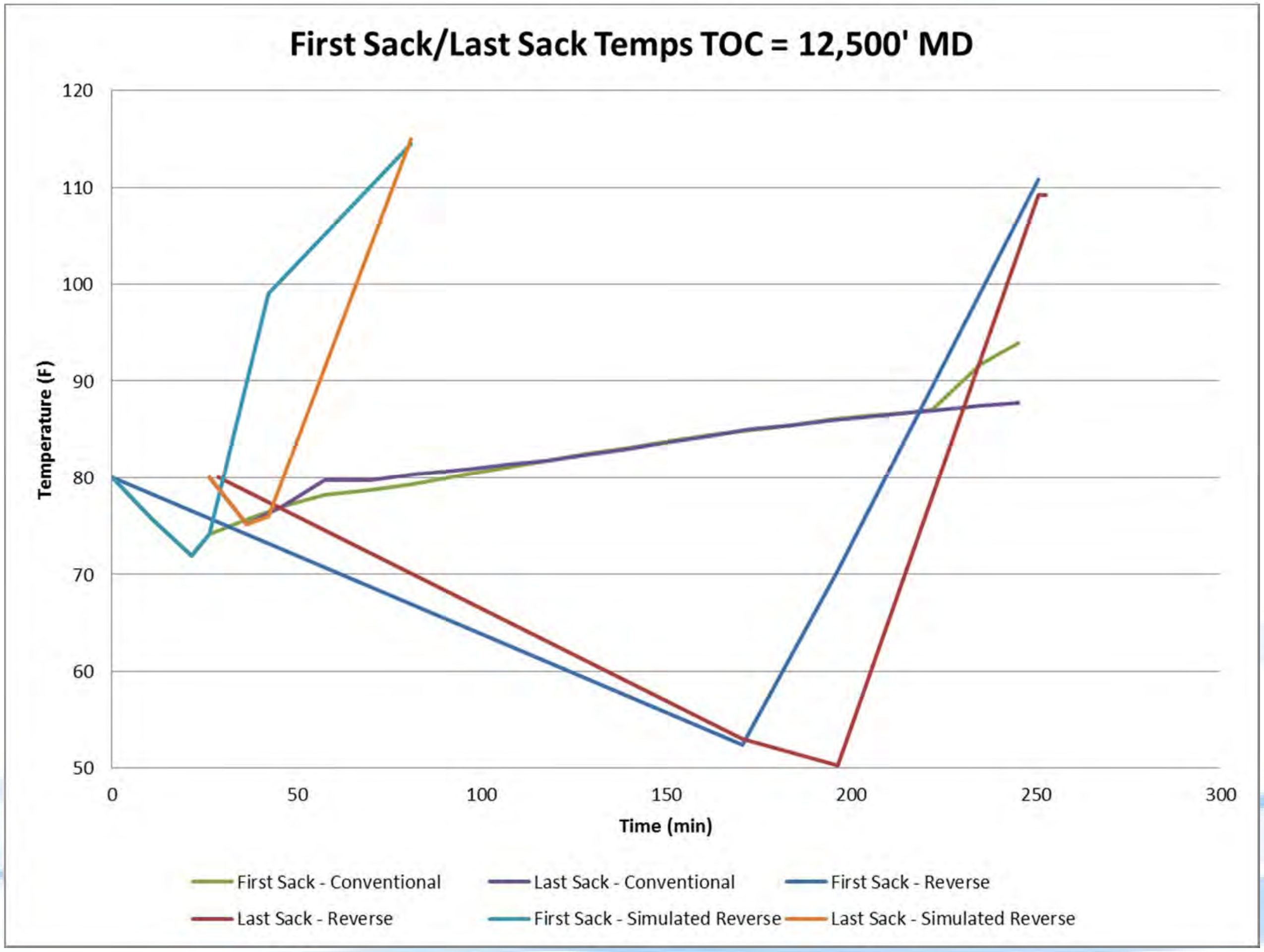
Modeling and Simulations – Commercial Limitation

Temperature Simulations with Commercially Available Software



Modeling and Simulations – Commercial Workaround

- Workarounds in conventional simulation software



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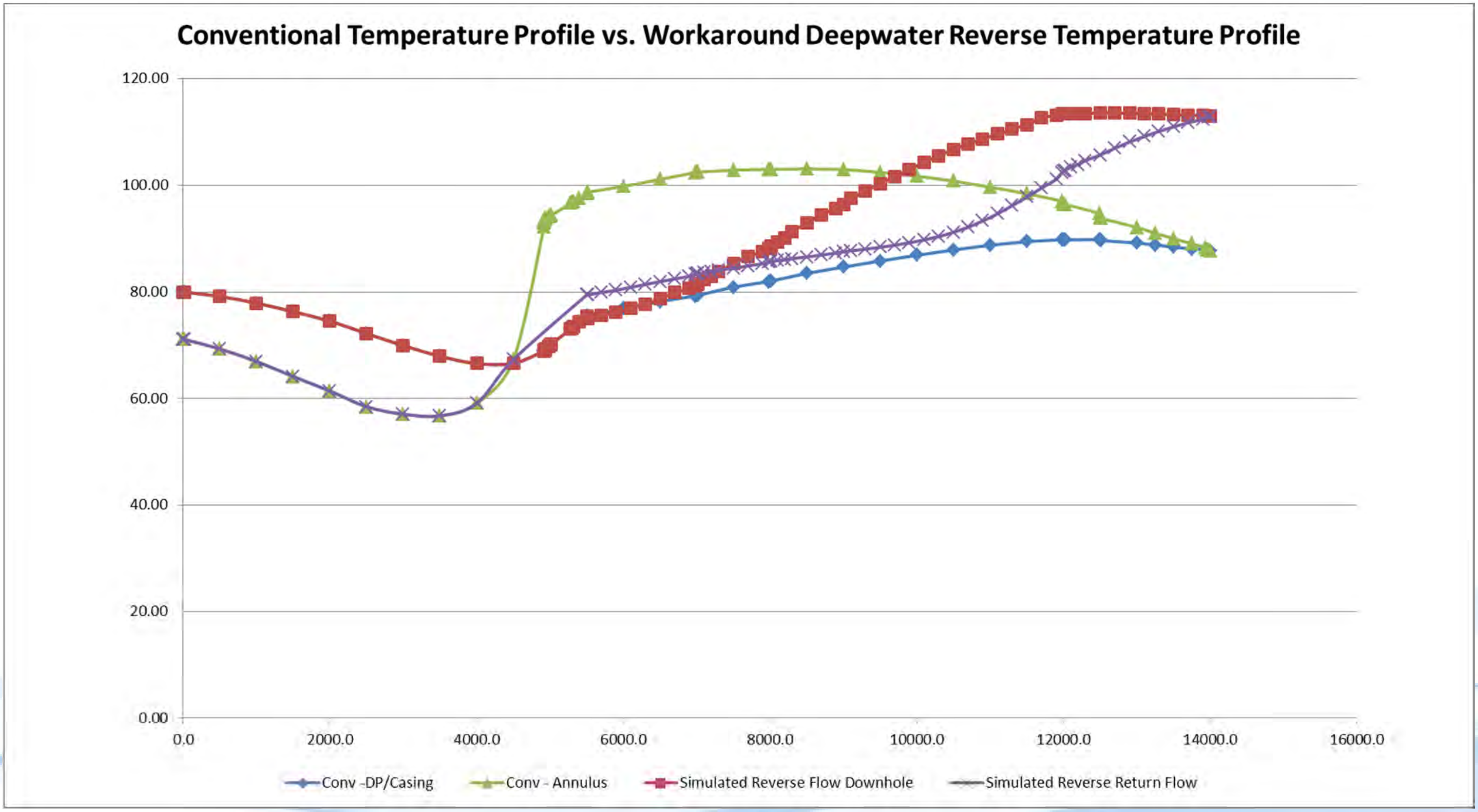
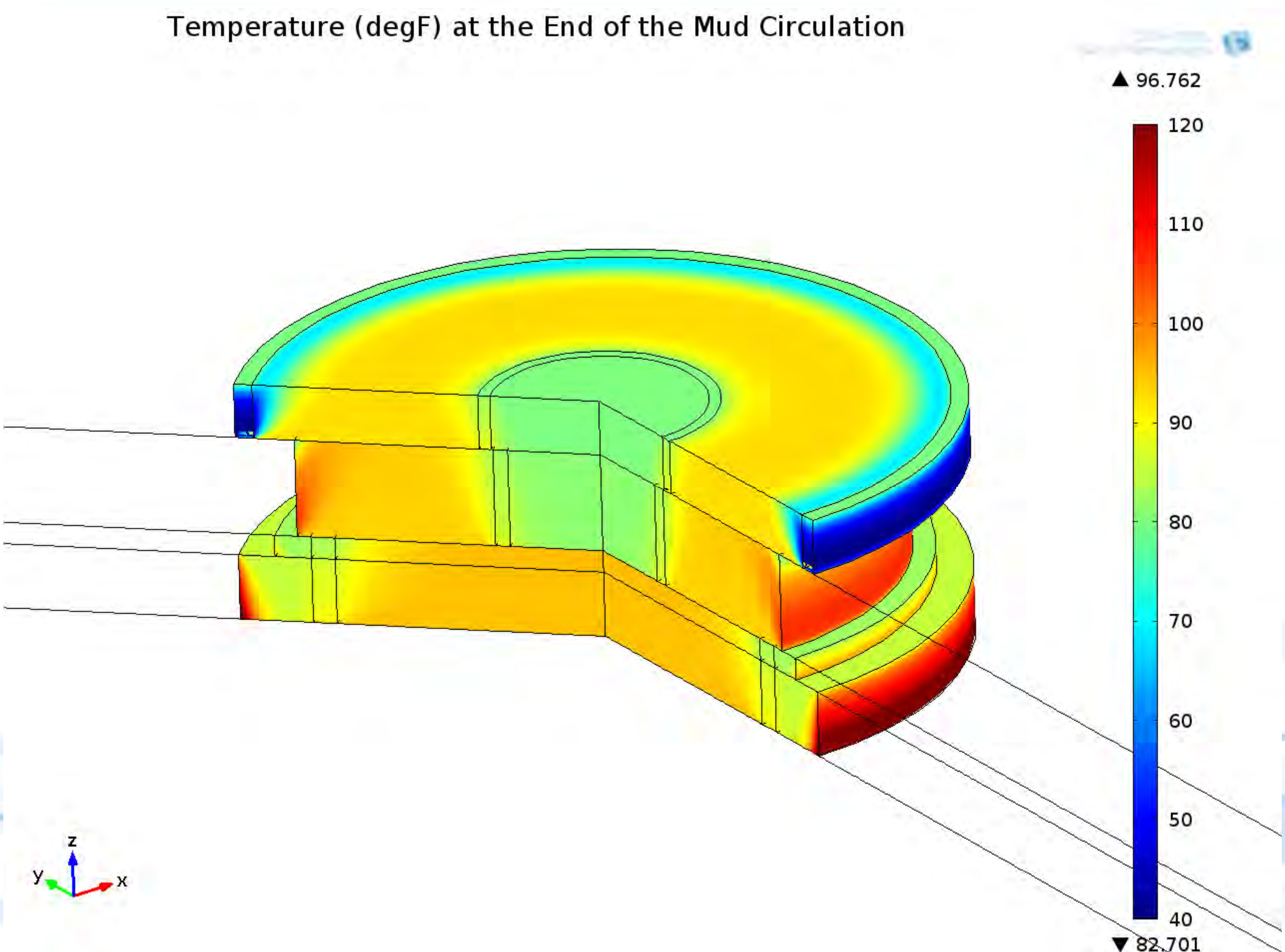
Modeling and Simulations – Commercial Workaround



Modeling Goals – COMSOL

- Develop model to predict desired quantities:
  - Temperatures
  - ECDs/Pressures
- Once the full-size simulations are complete, comparisons with commercial software simulation results are needed to evaluate the applicability of the commercially-available software to deepwater RCPC operations
- Apply model to conventional flow and validate with *Wellcat*® simulation
- Apply validated model to reverse flow

Well Temperature - COMSOL



RCPC Technology Development Challenges

- Cementing Materials Considerations
  - Laboratory simulations on cement performance under deepwater RCPC conditions

- Laboratory analysis includes:
  - Effects of fluid intermixing
  - Spacer design and mud removal
  - Additive sensitivity
  - Compressive strength development

Identified Technology Development Areas

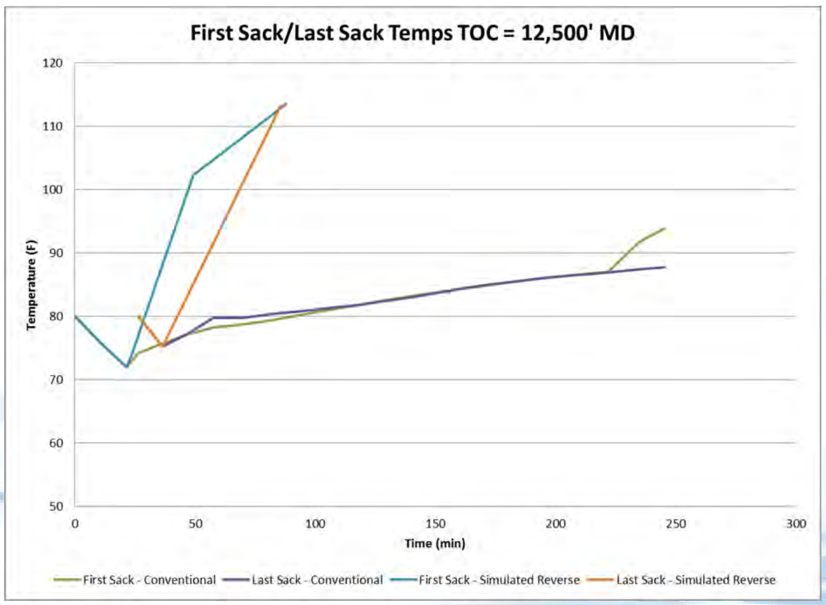
Cementing Materials

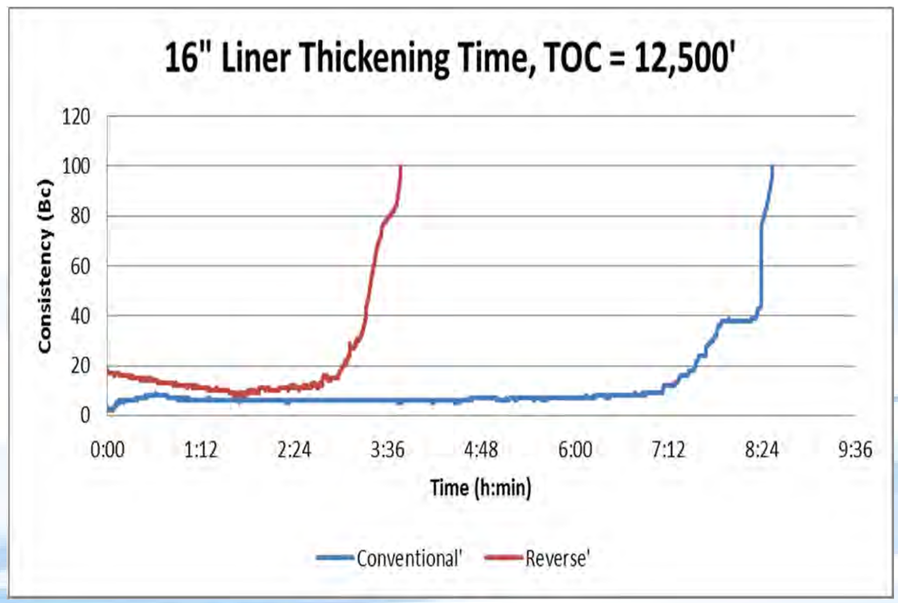
- Fluid intermixing is dependent on fluid rheology, fluid density, well geometry and flow rates. These properties affect the design of both slurries and spacers. In Phase I, rheological and density hierarchy effects were investigated.

- Further investigation is needed on the effects of well geometry, eccentricity and deviation, as well as the quantification of these effects in order to provide best practices for RCPC fluid design.

Cementing Materials

- Cement slurry design modifications due to temperatures variations during placement affecting:
  - Wait-on-Cement (WOC) time
  - Thickening time





RCPC Technology Development Challenges

- Operational Performance
  - Identify and address expected issues with RCPC placement on a deepwater rig

- Anticipated considerations include:
  - Redirecting flow between conventional and reverse
  - Effect on rig-up
  - Monitoring of return flow volumes
  - Installation of specialized equipment
  - Impact on rig logistics
  - Safety and training

Identified Technology Development Areas

Operational Considerations

- Many operational considerations are expected to remain the same as with a conventional deepwater primary cementing. However, there are many anticipated additional considerations introduced by RCPC.
- Considerations that need further study include hole cleaning, circulation direction, mixing rates, measurement of displacement volumes and measurement of downhole and return flow rates.
- Additional considerations specifically for deviated wells need to be investigated

Path Forward

- Continue development of the Finite Element Modeling performed in Phase I
  - ECD, friction pressure, deviated wells
- Compare the developed *COMSOL Multiphysics®* model with results from commercially available simulators
- Key mechanical components identified in Phase I will be analyzed under real-well conditions
  - Switchable crossover
  - Crossover design for liner hangers
  - Float equipment

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Path Forward

- Identify RCPC slurry design considerations compared to conventional deepwater designs
- Prepare a high-level conceptual operation plan to successfully perform a deepwater RCPC job
- Develop a conceptual high-level contingency plan for all major contingency situations in a potential deepwater RCPC application
- Develop a conceptual report which identifies major equipment, software, placement design and techniques in detail

Contacts

PI: Jeff Watters
CSI Technologies
jwatters@csi-tech.net
281-784-7990

RPSEA PM: Don Richardson
drichardson@rpsea.org
281-313-9555

Presenter: Crystal Wreden
CSI Technologies
cwreden@csi-tech.net
281-784-7990

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