Overview of Well Cement Behavior and Gas Migration During Early Hydration

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Conducted prior research on SGS

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Modeling and optimization in cement & concrete materials; Model development

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Molecular Modeling of subsurface phenomenon

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**Modeling/Simulation**

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Task 2: Well Cement Behavior and Gas Migration During Early Hydration

**PROBLEM**

- Gas migration in wellbore cement after placement can lead to loss of well control and/or blow outs.
- Static Gel Strength (SGS) is current standard testing method for cement.
  - **Overestimated – costs money.**
  - **Underestimated – safety and environmental issues possible.**
- Previous research: NETL and U. of Pittsburgh → Limitations of SGS

**BENEFIT**

- Improved methods for predicting and preventing gas migration in cement.
- Current technology on market will have comparable measurements.
- Revised American Petroleum Institute recommended practices.
- Lower costs for cementing and improve efficiency in completing wells.

**APPROACH**

- Align existing technology on the market that is used daily for all wells.
- Experiments in CT scanner and with wellbore simulation chamber under realistic onshore wellbore conditions to verify model and revise industry practices.
- Simulate cement interaction with formation gas to establish gas migration potential.

Will the Cement prevent fluid migration?

Cement: Barrier between the well casing and the formation.

Highest priority task within American Petroleum Institute

SGS: Once placed, how long till cement gels and has strength?
Barriers to Increasing Recovery

How far will the needle move?

• **Barrier to increasing recovery** → Gas migration in cement and uncertainty with standard measurements.

• **Project is addressing** → Improving accuracy and precision of industry’s method to prevent gas migration.

• **Extent the needle has been moved**

Confidence in SGS Measurement (estimate):

**API Task Group:**

• Gas migration in cement is a known issue - around 60 years.

• SGS has been used for over 40 years to address issue of gas migration.

• 5 years of cement testing data.
A. Tests in machine(s) at NETL with known materials.
B. Tests with materials with known properties to verify machine correlation.
C. The SGS properties of cement will be determined with correlated machines.
D. Tests with cement at participating laboratories will be completed.
E. Testing will be completed to determine parameters influencing the cement SGS.
Gas Migration in Wellbore Cement and Cement Static Gel Strength

Cement SGS:

Cheung and Beirute, 1985
Static Gel Strength Measurements

Basic Design – Vane Method

Number of blades (cylinder):

Non-solid blades – different geometries:

Relationship between torque and yield stress:

\[ T_m = K \tau_y \]

\[ K_{cylinder} = \left(\frac{\pi D^3}{2}\right)\left(\frac{H}{D} + \frac{1}{3}\right) \]

Static Gel Strength Measurements

Testing of Materials with a Yield Stress and Constant SGS

- Vanzan/Xanthan Gum
- Aloe Vera Gel
- Laponite RD and RDS

Example: Laponite

Laponite RD + Laponite RDS + DI Water

Detailed mixing instructions to reduce variables
Rheological Behavior of Non-Newtonian Fluids

Shear Thinning (Pseudoplastic)
- Ketchup
- Viscosity decreases with increasing shear rate

Shear Thickening (Dilatant)
- Cornstarch and water mixture
- Viscosity increases with increasing shear rate

Thixotropic
- Yogurt
- Viscosity decreases with stress over time

Rheopectic
- Printer ink
- Viscosity increases with stress over time


\[ \eta = \frac{\tau}{\dot{\gamma}} = K\dot{\gamma}^{n-1} \]
Rheology of cement slurry:

- Viscosity depends on the shear rate, particle concentration, ...
- Cement has a yield stress
- Cement shows thixotropic behavior

In house NETL constitutive model for cement slurry

Total stress: \( T = T_v + T_y \)

Viscous stress:
\[
T_v = -pI + \mu_0 \left( 1 - \frac{\phi}{\phi_m} \right)^{-\beta} \left( 1 + \lambda^m \right) \left[ 1 + \alpha_2 A_1 \right]^m A_1 + \alpha_1 A_2 + \alpha_2 A_1^2
\]

Yield stress:
\[
T_y = \left[ m_1 \phi^2 \left( \frac{\phi - \phi_{perc}}{\phi_m - \phi} \right) \right] \left( -175 w/c + 137 \right) \left[ A_1 \right]^{1/2} + K \left[ \Pi A_1 \right]^{n-1/2} A_1
\]
for \( \Pi A_1^{1/2} > \dot{\gamma}_c \)

\( \Pi \) and \( A_1 \) are parameters related to the thixotropic behavior of the cement slurry.

NETL Cement Slurry Model

Steady Flow of a Cement Slurry

MODEL DESIGN

- Constitutive cement model – cement flow at onshore wellbore conditions
- Cement slurry modeled as non-Newtonian fluid
- Viscosity depends on the shear rate and particle concentration
- Study the impact of parameters on behavior of cement slurry

OUTCOMES

- Parametric study results indicate that the following significantly affect the velocity and particle distribution:
  - Angle of inclination $\theta$
  - Maximum packing fraction of cement particles
  - Pressure and gravity terms

Schematic diagram of cement slurry flow in an inclined channel

Simulations & Experiments

**Simulations**

- 6 cm
- V = 0.01 (m/s)
- V = 0.2 (m/s)
- V = 1 (m/s)

**Experiments**

- 1 m
- Air inlet: 5 mm

**Example:**
- 3D Pipe
  - Air injection into Cement Slurry

**Liquid Properties**

- Viscosity: 1 kg/ms
- Density: 998 kg/m³
- Surface Tension: 0.07 N/m

**Example:**
- 2D Channel Flow
  - Air in Water

Mofakham, A., Ahmadi, G., Tao, C., Massoudi, M., Rosenbaum, E., Kutchko, B., Computational Modeling of Oil Well Cementing and Gas Migration Process, Proceeding of the ASME 2020 Fluids Engineering Division Summer Meeting, FEDSM2020, July 12-16
Multiphase Cement Slurry Flow

Simulation of Cement Slurry Placement

Gas Injection Into Cement in Annulus

SIMULATION DETAILS

- Applied ANSYS-Fluent volume of fluid (VOF) method for multiphase flow
- Simulated initial tests and geometries with Newtonian fluid
- Implemented NETL cement slurry model into ANSYS-Fluent with use of “user-defined functions”

Two-phase flow of 3D cylindrical geometry
API TASK GROUP COLLABORATION

- NETL has NDAs with the 5 manufacturers of SGS machines.
- NETL is participating in co-op testing with the API Task Group.
- NETL has access to the data collected as part of this unprecedented collaboration.

EXPERIMENTAL WORK

- Extensively studied the machine designs.
- Provided a path forward to align industry testing and machines – API approved.
- Conducted testing to confirm calculations.
- Compared two separate machines and many paddles.

CEMENT SLURRY MODEL

- Studied the impact of parameters on behavior of cement slurry.
- Incorporating our models into computational fluid dynamics packages.

PRODUCTS

- Solution to API/industry priority.
- Improved technology currently on the market.
- Provided guidance on calibration process.
- Multiple presentations on the modeling results.
- Presentations at all API Conferences.
- Paper summarizing the modeling results to date; another one in draft.
- Report summarizing the study of the SGS device measurements.
- Analysis of API Co-op testing data.
- Report summarizing the influence of paddle design.
- Extensive review paper of cement slurry models.

TAKE AWAY

- Industry standard measurements can provide accurate and precise SGS information.

Technology Transfer

PAPERS AND TECHNICAL REPORTS:


PRESENTATIONS AND CONFERENCES:

• Numerical analysis for flow of a cement slurry, Presented at Mid-Atlantic Numerical Analysis Day, November 9, 2018, Temple University, Philadelphia, PA.

ADDITIONAL INFORMATION: