Development of an Improved Cement for Geothermal Wells

Project Officer: Eric K. Hass

Total Project Funding: $2,154,238

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Principal Investigator

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Track 2 HRC

High Temperature Tools, Drilling Systems

Relevance/Impact of Research

Project Objective

- Develop a novel, zeolite-containing lightweight, high temperature, high pressure geothermal cement, which will provide operators with an easy to use, flexible cementing system that saves time and simplifies logistics.

Impact of New Cement Development

- Eliminate the requirement to “sterilize” pumping equipment before use.
- Eliminate the need to foam the slurry to achieve lightweight qualities.
- Eliminate incompatibility issues in the selection of retarders and accelerators.
- Provide predictability and minimize the effect of down-hole temperature fluctuation.
- Facilitate the development of geothermal resources in remote locations.

Methodology

- Build on existing zeolite-containing cement technology for low temperature, weak formation applications.
- Systematic, scientific approach on trial cement blends to consider the variables of:
  - Zeolite type
  - Zeolite particle size
  - Zeolite percentage by weight of cement
  - Additives for thermal stability and resistance to carbonation
- Clear and concise performance characteristics provide a systematic method for initial screening, second stage development and ultimately for the final stage of cement development.
- Involvement of industry for guidance on actual cementing practices.
- Solicit industry expert peer review on research methods and results.
- A logical progression of scientific study results in five Tasks that lead to realistic project milestones and go / no-go decisions points.

Scientific/Technical Approach

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TASK 1 – RESEARCH

- Literature Search
- Geothermal Cementing Practices and Constraints
- Mechanisms of Geothermal Well Failure

TASK 2 – DESIGN

- Compile Research Findings
- Modification of Project Tasks 3 and 4

TASK 3 – DEVELOP

- Zeolite Sample Acquisition
- Zeolite Type Confirmation
- Zeolite Particle Size Preparation
- Initial Screening of Cement Formulations

TASK 4 – TEST

- Second Stage Cement Development
- Final Stage Cement Development

TASK 5 – DEMONSTRATE

- Laboratory Scale Demonstration
- Logistics and Ease of Use Field Demonstration – Chena Hot Springs Resort
- High Temperature EGS Well Demonstration – Ormat Technologies

Zeolites Used in Development

- Four different zeolites were evaluated.
  - Clinoptilolite (California)
  - Clinoptilolite (New Mexico)
  - Chabazite (Arizona)
  - Ferrierite (Nevada)
- One thousand pounds of each zeolite type was collected to ensure repeatability and sufficient volume for all Screening and Second Stage Cement Development.
- Each sample type was field crushed to a uniform minus US 8 Mesh product.

Zeolite Preparation

- Following XRD, XRF and SEM confirmation of zeolite type three hundred pound bulk samples were shipped to CCE Technologies for preparation.
- Micronized using Jet Mill Technology.
- Prepared sizes with 80% in range:
  - 5 micron
  - 10 micron
  - 44 micron

Developed Cement Performance Criteria

- Thermal stability with little strength retrogression to 300° C.
- Tensile strength to withstand temperature and pressure changes.
- Low-density, low-viscosity slurries with low equivalent circulating densities (ECD) without the need for air or nitrogen foaming.
- A single cement blend allowing density adjustments without adversely affecting slurry properties to eliminate the need for separate blends for lead and tail slurries.
- Resistance to carbonation.
- Accurate downhole densities throughout cement placement without significant changes in viscosity.
- Water absorption capacity without retaining free water.
- Good bonding to casing and formation.
- Adequate compressive strength.

Accomplishments, Results and Progress

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Original Planned Milestone/ Technical Accomplishment		Actual Milestone/Technical Accomplishment	Date Completed
Task 1	Research	Completed as planned	July 2011
Task 2	Design	Completed as planned	Sept. 2013
Task 3	Develop	Completed as planned	Oct.2012
Task 4	Test	Completed as planned	Sept. 2013
Task 5	Demonstrate	Low temp, ease of use completed	Jan. 2015

Variances

- Industry partner ThermaSource failed to participate as committed resulting in loss of cost share and lab testing equipment availability.
- Schedule slippage resulting from delays in the fabrication of Chandler Engineering specialized high pressure/high temperature cement testing equipment.
- Suitable high temperature demonstration well did not become available before the end of the Period of Performance.

Blended Zeolite-Containing High Temperature Cement

Mechanical and material properties at 300°F and 400°F.

Temp (°F)	Cure time (days)	Density (ppg)	Density (g/cm^3)	q_u (psi)	E (ksi)	ν	Tensile strength (psi)	Thermal conductivity (W/m°C)	Permeability (mD)
300	2	13.5	1.61	6484	1243	0.33-0.38	990	1.11	0.005
300	3	13.5	1.61	5533	1112	n/a	572	n/a	n/a
400	5	13.5	1.62	3205	1185	n/a	341	1.66	0.003

Blended High Temperature Zeolite-Containing Cement is lightweight with high compressive strength, good ductility and tensile strength with extremely low permeability. This dry blend was intended for use in an Ormat well.

Carbonation Resistance

Three week cure in brine/CO_2. Right sample is treated with phenolphthalein. No color change indicates pH < 10.

Permeability for Ferrierite and Clinoptilolite before and after brine/CO_2 exposure. Slurry Density - 13.5ppg

	Ferrierite			Clinoptilolite		
	Initial	1 week	3.5 week	Initial	1 week	3.5 week
Permeability (mD)	0.0031	0.010	0.012	0.003	0.012	0.010

How Do We Make This Commercial?

Problem - Micronizing zeolite for a dry blend is expensive.

Solution - Intergrinding Cement Clinker and Whole Rock Zeolite

Method

Hot cement clinker and “fist” sized zeolite are blended together in the final grinding mill at the cement plant in a predetermined ratio. Zeolite being softer than clinker preferentially grinds to a smaller particle size.

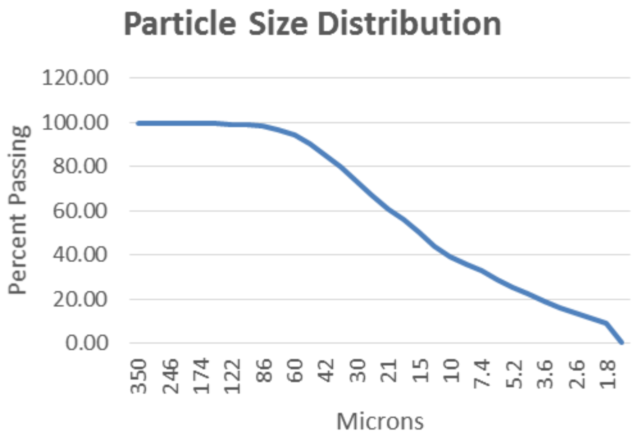
Benefits

- Economic gain of replacing a higher cost clinker with a lower cost zeolite.
- Lowering the resulting interground cement environmental cost associated with greenhouse gases during Portland manufacture.
- Increased physical properties of the zeolite intergrind being improved strength, lower permeability and resistance to carbonation.

Intergrind Number One Completed Lehigh Southwest Tehachapi Plant

1,000 Ton Production Run
60% Class G Clinker
40% Clinoptilolite Zeolite

Blaine = 7640 cm2/g



Interground Cement Properties

- Optimum density – 12.73 ppg
- Water requirement – 7.214 gal/sk
- Yield – 1.469 ft^3/sk
- Bulk density - 79.7 lb/sk

Interground Cement Performance

Thickening Time

40Bc	1:19	70Bc	2:05	100Bc	2:29

Rheology	300 rpm	200 rpm	100 rpm	6 rpm	3 rpm
125^{o}F	102	97.5	82.5	32.5	16.5

Compressive Strength

8 hours	11:31	12 hours	24 hours	48 hours
319 psi	500 psi	537 psi	1262 psi	1581 psi

Intergrind Number Two
Eagle Materials Nevada Cement Plant

Planned Full Scale Run
65% Type I/II Clinker
35% Ferrierite Zeolite

Summary Slide

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1. Successfully developed zeolite-containing lightweight, high temperature, high pressure well cement suitable for geothermal applications.

2. Identified and bench scale tested Intergrinding as an economical method for the production of zeolite-containing cement that…

   - Allows for density adjustments within a single blend without affecting slurry properties.
   - Eliminates the need for separate blends for lead and tail slurries.
   - Provides thermal stability with the addition of silica for little or no strength retrogression.
   - Provides resistance to carbonation to maintain compressive strength and low permeability.

3. Completed full scale cement plant production run of Interground Lightweight Variable Density Zeolite-Containing Cement as commercial proof of concept.