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Indications of the Relationship between Fluid Invasion, Sand Content and Thermal Conductivity in Enhanced Geothermal Grouts

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OG & E Geothermal Heat Pump Project: Objectives & Scope

- Evaluate Advances in Borehole heat exchanger designs
  - Newly installed heat exchangers will be evaluated relative to existing single U-tube heat exchangers
  - Thermally enhanced grouts
  - Borehole depth of 400 ft per home
  - Coupled to a 2-ton heat pump unit (ClimateMaster Tranquility 27® Model 038, Part Load) in each home

- Evaluate State-of-the-Art Drilling and Grouting methods
  - Commercially available grouts established in the market place
  - Pre-qualified for the study
  - Two-step thermally enhanced grouts vs one-bag grouts

- Installation of new ground heat exchangers and related instrumentation occurred in April and May 2011

Field Support and Grout Evaluation

- Two enhanced grouts based on thermal conductivity (BTU/hr/ft/F)
  - BAROTHERM GOLD 1.0
  - BAROTHERM MAX 1.6
- Project Design and Field Support
  - Six holes drilled & grouted for comparison
    - Field samples of grout thermal conductivity
    - Relative invasion (caliper log)
    - Mixed grout quartz sand content
- Other factors recorded for evaluation of system performance (discussed elsewhere by other contributors)
  - Hole diameter
  - Loop type
  - Tremie line diameter
  - Borehole resistance

Grout Thermal Specifications

- Two grouts selected
- High Thermal Conductivity
  - 1.6 BTU/hr/ft/F
  - Graphite thermal conductivity enhancement
- Standard Thermal Conductivity
  - 1.0 BTU/hr/ft/F
  - Quartz sand thermal conductivity enhancement

Important Aspects of Thermal Conductivity in the Industry

- Critical specification for most work
- Several ASTM tests for conductivity measurement
- Needle probe adopted by the industry: ASTM D 5334-08
- Responsibility falls to suppliers/distributors
  - Rare budget for testing after initial qualification
- General lack of consensus of field QA/QC

Needle Probe Method

- ASTM D 5334-08
  - "Determination of Thermal Conductivity of Soil and Soft Rock by Thermal Needle Probe"
  - IGSPHA adopted method (Standard 2B.1.2.1)
- Infinite line heat source
- Calculated from power, temperature, time and distance (6-in. probe)
- Limitations
  - Manual data interpretation; user-dependent variability
  - **Published sensitivity by ASTM is +/- 15%**

Custom needle probe apparatus
ASTM D 5334-08

- Relatively simple modular system
- Consists of probe detector
- Power supply
- Lap top computer & software

Factors Impacting ASTM D 5334-08 Data in the Geothermal Market

- Conductivity is always a specification for a job
- The range of “error” is not understood
  - For example, a 0.90 BTU/hr/ft/F is statistically the same as a 1.0 BTU/hr/ft/F result
- Small deviations from a prescribed blend of sand, clay, and water lead to potentially big problems with qualifying a grout
- Small deficiencies in quartz content lead to problems in grout qualification

Thermal Conductivity of the Components

Material	Thermal Conductivity (Btu/hr ft °F)
Water	0.33*
Bentonite	0.38-0.43
Sand	1.16 – 2.31*

*http://www.engineeringtoolbox.com/thermal-conductivity-d_429.html; Sand numbers are for sand saturated with water

Why is the Silica Content Important?

- Silica content (quartz sand) <u>IS</u> the ingredient that "enhances" the thermal conductivity of these grout types
- Anything that decreases its required content in these grouts reduces the conductivity
- Silica in the form of the mineral quartz (quartz sand)
- Sand for two step grouts should have a silica (quartz) content of ≥99%
- Contaminants impact mixing, pumpability, equipment wear, and conductivity measurements
- Water (moisture) can become a contaminant
  - too much water absorbed by the bentonite and the thermal conductivity decreases

The Optimum Sand

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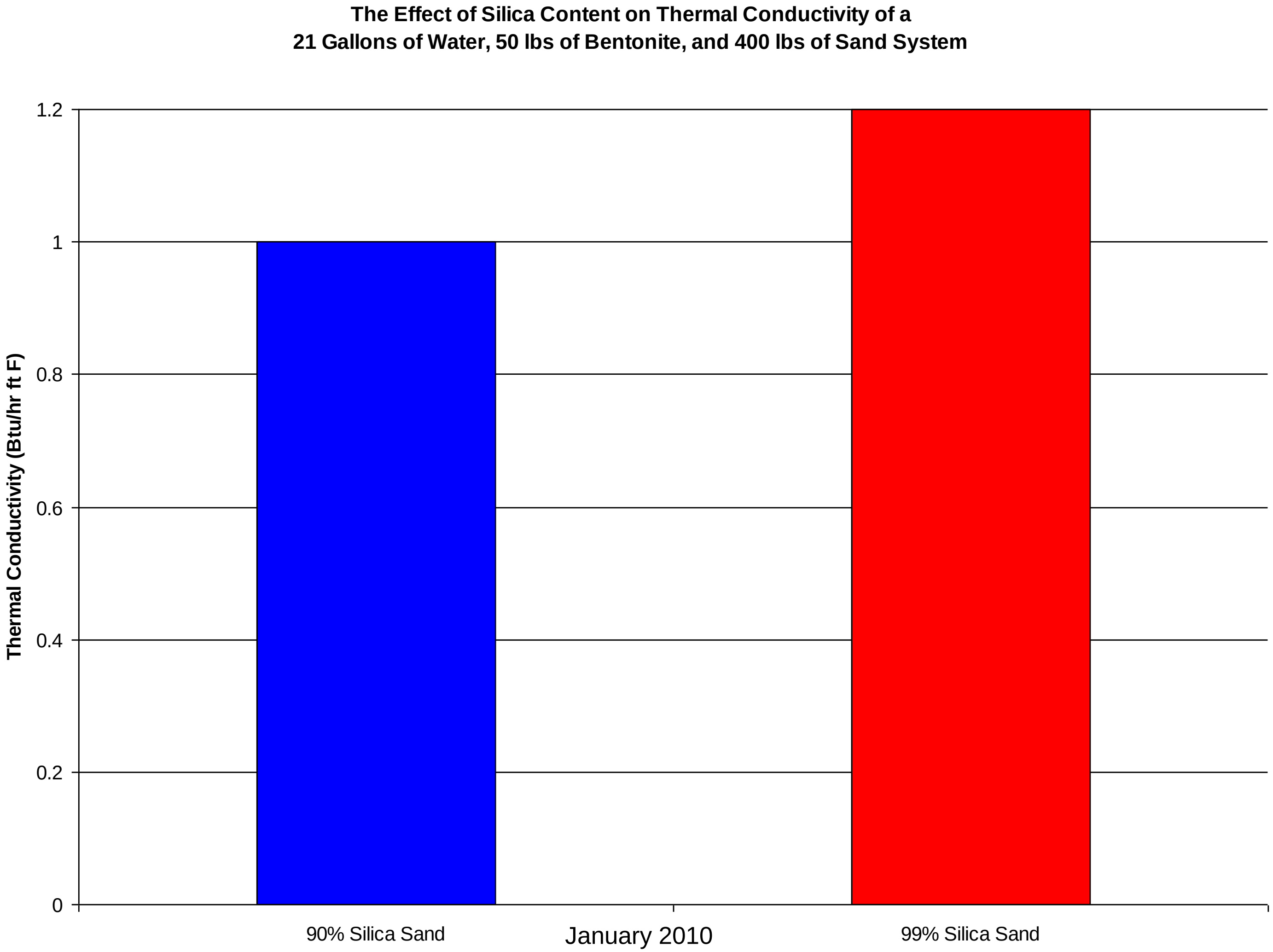
Sand with Issues

The Effect of Low Silica Content



Common Examples of Sand Contamination

- Clays in the sand – increased viscosity leads to difficulty in mixing & pumping
- Organic matter – thins the gel strengths and impairs the grout set
- Calcite – impacts make-up water chemistry
- Feldspars – lowers the thermal conductivity
- Unknown extraneous material –What exactly is the thermal conductivity of a frog?

** these components even at relatively low levels have the tendency to lower the thermal conductivity and impact the pumpability of the grout

Caliper Log Evaluation

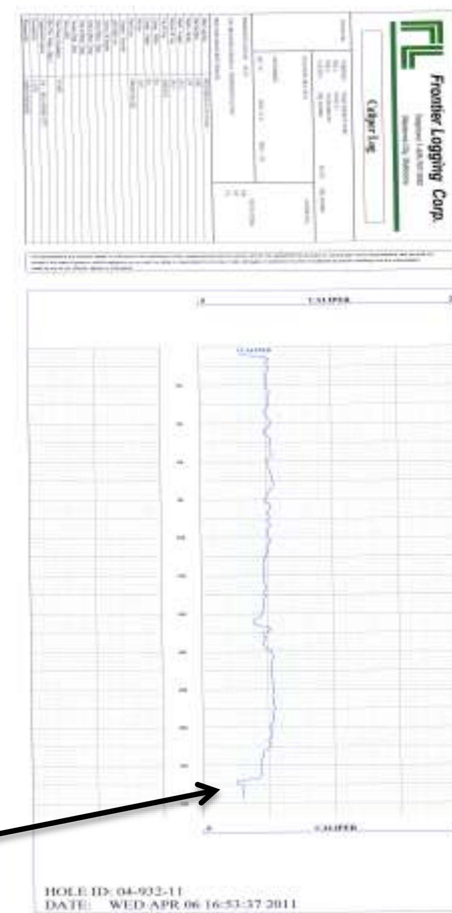
(data courtesy of Ewbanks & Associates)

Full Borehole caliper logging

Six holes completed

Excursions from center mark loss
due to fluid invasion

Fluid invasion classified on a relative basis
1 = highest amount of invasion
6 = lowest amount of invasion



Zone with fluid invasion

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Siliciclastic Stratigraphy of the Study Area

Sequence of interbedded iron-bearing sandstones and relatively thin clays and shales

Iron-bearing sandstone

Iron-bearing friable clay

Sand Content of Field Mixed Grouts

Sample	Container	Sand Content (%)	Grout
TC73	Bucket	na	Barotherm Max
TC74	Bucket	na	Barotherm Max
TC75	Bucket	na	Barotherm Max
TC76	Bucket	50.45	Barotherm Gold 1.0
TC77	Bucket	54.95	Barotherm Gold 1.0
TC78	Bucket	51.39	Barotherm Gold 1.0
TC86	Bucket	50.92	Barotherm Gold 1.0
TC87	Bucket	49.57	Barotherm Gold 1.0
TC100	Standard	51.50	Barotherm Gold 1.0
TC101	Standard	-	Cuttings
TC102	Standard	-	Cuttings

Bucket Size	**H=12" D=9"**

Comparison of Fluid Invasion, Thermal Conductivity and Sand Content

83rd St -	932	928	813	833	925	944
Relative Invasion**	1	6	2	4	5	3
Thermal Cond. (field sample) (BTU ft hr F)	2.78	0.81	0.85	2.90*	0.92	0.90
Sand Content (wt%)	n.a.	50.5	49.6	n.a.	55.0	51.4

* Average of duplicate set
** Relative Invasion: 1 highest, 6 lowest

925 83rd St: lowest invasion, best sand content, closest conductivity agreement to qualified grout

Indications From the Work

- Many factors control the performance of enhanced grouts
  - Stratigraphy/local geology
  - Mixing precision of grouts and water
  - Pumping and delivery equipment
  - Complex problems requiring more field work to refine the protocol
- Certainly sand content and fluid invasion are important
  - Proper drilling fluid design and use is required
- Sound science requires standardized procedures
  - Recognize thermal conductivity test is sensitive among even the best of labs
  - Recognize that the industry will require specified equipment too
  - Recognize that the costs of a successful geothermal hole is not the same as a water well

Questions

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Suspension Issues?

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