One-Part CP Grouts for Ground Source Heat Loops

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Presentation Overview

- Introductions
- Purpose of grout
- Review of grouting materials
- New generation CP Grouts
- Potential misconceptions re CP Grouts
- Testing and results
- Q&A
Purpose of Grouting Geothermal Bore Holes

- Protect groundwater by filling annular spaces boreholes.
- Creation of low permeability, low shrinkage seals to prevent entry of surface run-off water into borehole, and downhole cross-contamination of aquifers.
- Efficient heat exchange in GHXs
Review of Traditional Grouting Materials

Bentonite (sodium montmorillonite)

Bentonite & sand

Neat cement (Portland cement & water)
Bentonite Grout

- High, rapid swell with water. Long history of use as a sealing material.
- Limited working time, especially at higher air & mix water temperatures.
- Mix water pH must stay within a limited range or the addition of soda ash is required.
- Degradation in gel structure and seal effectiveness on exposure to saline groundwater.
- Desiccation, shrinkage and cracking occurs in dry formations, compromising seal & reducing system efficiency.
- Low thermal conductivity (~0.4) when used neat.
Bentonite Grout

Typical drying shrinkage cracking.
Bentonite & Sand Grout

Specification grade sand required to increase TC of bentonite grout.

- Multiple mix materials measured by hand often cause inconsistent batching.
- Stiffened slurry & short working time (<30 min.) increase difficulty of pumping & placement.
- Addition of non-swelling sand results in a severe drop in slurry volume.
- Sand increases permeability. Some states do not allow use of grout above 5:1 sand:bentonite.
- Sand does NOT mitigate desiccation shrinkage or saline attack.
Bentonite & Sand Grouts

Drying shrinkage / cracking of 5:1 sand-bentonite grout. Note annular void space created at exterior surface (well wall).
Neat Cement Grouts

- Long history of use in the construction industry.
- Easily pumped.
- Limited pot life.
- High heat of hydration can warp plastic lines.
- Shrinkage / cracking upon curing.
- Chemical and physical degradation on exposure to saline water.
Neat Cement Grouts

ATTACK BY SALINE GROUNDWATER

- Portland cement hydration:
  
  \[
  C_3S/C_2S + nH_2O \rightarrow C-S-H + Ca(OH)_2
  \]
  
  \[
  C_3A + CaSO_4 + nH_2O + OH^- \rightarrow AFt \text{ (sulfoaluminate)}
  \]

- Attack by saline groundwater:
  
  \[
  C-S-H + SO_4^{2-} / Cl^- \rightarrow CaSO_4 + CaCl_2 + Si(OH)_n
  \]
  
  \[
  Ca(OH)_2 + SO_4^{2-} \rightarrow CaSO_4 + OH^- + nH_2O
  \]

- Expansion with loss of integrity and strength
- Results in increased permeability and loss of seal
Neat Cement Grouts

Degradation of structural Portland cement concrete exposed to saline environment for approximately 6 months.
New Generation
CP Grouts
Cementitious-Pozzolanic Grout
New Generation CP Grouts

GA-Xtra™

- One-bag mix for consistent batching.
- High TC; 1.0 BTU/hr-ft²-0F without any additives.
- Very low water demand, wide range of mix water pH acceptable.
- Easy handling, extended working time, excellent pumping consistency facilitate proper placement.
- Negligible shrinkage & low heat of hydration.
- High exposure resistance to saline waters, e.g. in the coastal plain and connate water in shale formations.
- NSF Certified.
New Generation CP Grouts

Features of GA-Xtra™ Grout:

- Thermal conductivity, $k$ (ASTM D5334): 1.0 BTU/hr-ft$^2$-°F
- Compressive strength (ASTM C109): 200-300 psi
- Permeability, 28d (ASTM D2434): $< 9 \times 10^{-11}$ cm/sec
- Drying shrinkage, 28d (ASTM C596): $< 0.15\%$ (no cracking)
- EPA SW-846, Method 1311, TCLP: Non-hazardous
- NSF/ANSI 60 Certification: Yes

Stable to a wide range of groundwater pH and salinity conditions
New Generation CP Grouts

SALINE RESISTANCE

GA-Xtra™ grout after 180 days exposure to saline groundwater (chloride and sulfate) simulating coastal plain. Excellent stability, retention of integrity and low permeability.

VERY LOW SHRINKAGE

GA-Xtra™ grout after 360 days in simulated GHX loop. Excellent retention of contact with loop and pipe.
Potential Misconceptions Concerning CP Grout
1. Cement grout shrinks & cracks; seal fails and voids form?
   - GA-Xtra CP grout has negligible shrinkage (<0.15%)

2. Heat of hydration causes HDPE plastic loop pipes to deform & collapse?
   - GA-Xtra CP grout has a very low heat of hydration.

3. High compressive strength makes cured cement grout difficult to remove from top of borehole to connect horizontal lines; damage to HDPE piping occurs?
   - GA-Xtra CP grout has a compressive strength of only 200-250psi (concrete: 3,000psi) and can be broken apart easily with hand tools. CP grout has an extended cure time (28 days), so there is plenty of time to clean upper ends of loop before full cure.
4. High thermal expansion coefficient of HDPE causes hard grout to fracture when HDPE expands (seal failure) and voids to form when HDPE contracts away from hard grout (impedes efficient heat transfer)?

- GA-Xtra CP grout’s low compressive strength makes it very compliant; it can give as pipe expands, and will “close in” over time. It is simply not hard enough to shatter; if micro-fracturing should occur, the pozzolanic chemistry continues the hydration reaction, resulting in autogenous healing.

- Recent testing demonstrates that cured GA-Xtra grout maintains excellent impermeability under repeated heating and cooling cycles. The BNL study of 1999 on Mix 111 supports the science of cement-based grouts.
5. CP grouts are new & untested, possibly unreliable?

- GA-Xtra CP grout has been in use since 2007. It is safe, effective, and reliable when mixed according to manufacturer’s directions. Plus the manufacturer’s directions are much simpler than the directions for competing products.

6. Specialty grouts are cost-prohibitive?

- GA-Xtra CP grout costs $8/50lb bag and yields 6.4 gallons of slurry (about $1.25/gal).
GA-Xtra Grout:
Thermal Expansion Testing
Experimental Set Up

Simulated thermal loop:
- Casing 6” (ID) x 84” (L)
- HDPE loop 1”
- Reservoir 16” (L)
- Temps: max 100°F; min 34°F
- Min cycle duration 10 hours at T
- 5 cycles
HDPE pipe installed at ambient temperature midway between operating temperature extremes (34°-100°F). Therefore, both expansion and contraction occur relative to installation state. HDPE pipe is constrained laterally by grout.

Lateral expansion/contraction (±0.002”) is minimal and is absorbed by the compliant grout.
Differential Temperatures: Lateral Effects

Thermal Expansion Coefficients:
HDPE = 67x10^-6 in/in°F
Grout = 16x10^-6 in/in°F

1" Dia. HDPE Pipe

6" Dia., fixed by Constraint of Rock

Lateral Expansion = 0.002"
Lateral Shrinkage = 0.002"

Initial Condition at Installation - 70°F

Heating Condition – HDPE Pipe at 100°F

Cooling Condition – HDPE Pipe at 36°F

1.00201" Dia.

0.9977" Dia.
Differential Temperatures: Longitudinal Effects

- Calculated potential longitudinal expansion/contraction = ±4” over 400 ft in temp range 34°-100°F.
- However, HDPE pipes are not perfectly centered in borehole.
- Friction between HDPE pipes and grout does not allow expansion/contraction to propagate along length of pipe. Forces are readily absorbed by the compliant plastic.
- High density bentonite-sand grout will also constrain the HDPE pipes in the same way.
Findings

- No observed cracking of the grout matrix or creation of annular gap during thermal cycling. Thermal transfer efficiency retained and not degraded.
- Cured GA-Xtra grout maintains excellent impermeability under repeated heating and cooling cycles.
- Translates into effective seal against surface water contamination and cross-aquifer migration.
CP Grout in Action
Projects

Antietam Academy, Hagerstown, MD

Well field
Projects

FEMA National Fire Academy  Emmitsburg, MD  200 Boreholes
Projects

Private Residence
Gregor Well Drilling
Long Island, NY
Closing Remarks

- CP grouts are effective in high performance geothermal systems. NSF certified.
- Ideally suited for use coastal regions where bentonite and neat cement grouts have instability problems.
- Very low shrinkage in dry conditions provides excellent long-term sealing properties.
- Simplicity of use promotes quality control and reliability on the job site.
- CP Grouts are cost competitive with 2-part grouts that require more labor.
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