Ewbank and associates
GEO SYSTEMS PROFESSIONALS

Ewbank Geo Testing, LLC
Suite 401, 121 E. Broadway, Fairview, OK 73737 Phone (580) 227-2358 Facsimile (580) 227-3349 E-mail gewbank@geotctest.com **Pioneering In-situ Thermal Conductivity Testing since 1994** www.geotctest.com

5 February 2013

Applied Research Project, Hope Crossing, Oklahoma City, OK

Procedures of the OG+E Ground Source Applied Research Project

Planning for the project occurred with two meetings of all involved parties sponsored by OG+E.

Strategies were laid out for the objective of lowering the borehole resistance consisted of ground heat exchangers (GHEX) of two pass HDPE (high density polyethylene), four pass HDPE and PEX (cross linked high density polyethylene), HDPE concentric, Fiberglass concentric, and a highly condensed multi-pass horizontal. The primary objective was to determine if lowering the borehole resistance in the piping of the GHEX and the grouts would shorten the GHEX lengths to reduce the higher first cost of ground source geothermal systems.

All homes were to have a new and the same capacity HVAC units installed with the outside air closed. The structure loads were provided to OG+E by Guaranteed Watt Saver Systems Inc., 6444 Northwest Expressway, Suite 836A, Oklahoma City, OK 73132 (GWS) using ACCA Manual J.

Lithology, deep earth temperature, and designs for all GHEX design teams assumed a thermal conductivity of 1.6 Btu / (hr-ft-°F) and 63 °F for vertical and 0.6 BTU / (hr-ft-°F) for horizontal and were provided to participants by Ewbank as the expected general ground thermal properties at the sites. All participants used the loads and estimated ground properties to size the lengths of their ground heat exchangers. (Oklahoma State University, Division of Engineering Technology, 1988) (Oklahoma State University, Division of Engineering Technology, 1989) (Ewbank, 2008)

The research group consisted of both collaborators (C) and participants (P) and several held both roles.

Collaborators entity and contact person(s) were as follows: OG+E, Michael Anderson, Michael Ballard, Thomas Gibson; Ewbank Geo Testing, LLC, Garen Ewbank; Halliburton/Bariod IDP, Charles Landis, Gary Williams, and Lyndon Pense; Oak Ridge National Labs, Xiaobing Liu; Oklahoma State University, Rick Beier, Bill Holloway, Jim Bose; IGSHPA, Jim Bose; ClimateMaster, Dan Ellis, Shawn Hern; the Oklahoma Water Resources Board, Kent Wilkins. Collaborators were generally researchers.

Participants: Associated Environmental Services, Inc., Comfort Works, Inc., Geothex; The Charles Machine Works, Ditch Witch; Amasond; Geo-Enterprises, Inc.; Ewbank Geo Drilling; TEVA HyperLoop. Participants were generally manufacturers of ground heat exchangers and equipment; and interested parties.

The process chosen

Ten sites were selected by OG+E. Two of the ten were to remain air source heat pumps to be the basis of low first cost technology. OG+E contacted homeowners in Hope Crossing to find those agreeable to participating. OG+E then contracted with the homeowners. Written instructions and a contract with home owners included:

Offer from OG+E and written acceptance by home owner

Description the utility marking by Okie to all homeowners

Let homeowner know of initial damages and restoration processes

Review previous site plan

Designate new site plan with vault and valving

Confirm ingress and egress with owner

Locate new drill site(s) by staking

Locate existing supply and return lines

Examine access to HVAC unit and desuperheater

Locate power supply for internet access, mountings, placement and access to HVAC data logger

Locate water supply for drilling and grouting

Select GHEX to install

The installation date(s) was selected for each site and the homeowner informed of the time. The dates were in April and May of 2011 for the Hope Crossing locations. Coordination of specific site activities started with site utilities location services using CALL OKIE. Designating call in time, first operations timing and length of time of valid marking were given to participants. A pre-installation and safety meeting at each site by those specific to selected GHEX was conducted by OG+E. Participants were allowed to choose their own drilling contractor and method(s).

Field Coordination of Activities:

Cuttings and drill fluids haul off was done using a vacuum truck and place within in the addition at an undeveloped site.

Water at site for drilling, clean up and grout preparation was provided at the OG+E Wilshire facility.

Rig up activities were coordinated for the mobilization at each site by the installation crews.

Drill activities

Utility marking by OKIE

Review home owner knowledge of initial damages and restoration processes

Review previous site plan

Designate new site plan with vault

Confirm ingress and egress with owner

Locate new drill site at stake

Locate existing supply and return lines

Locate water supply for drilling and grouting (water was supplied by OG+E from the nearby Wilshire facility).

Borehole logging activities were contracted with Frontier Logging Corp., at 7221 NW 3rd, Oklahoma City, OK, 73127, through Mr. Francis Weeden. The logging occurred immediately after drilling with the borehole full of water and before GHEX installation. One logging session was to occur at each site on one borehole. The electric logs chosen were as follows:

Caliper, to measure the actual borehole diameter in inches with depth

Deviation, to measure and determine the location of the borehole with depth using magnetic declination

A suite logs of five (5) electric logs:

SP, Spontaneous Potential, measured in milli-volts

R, Resistance, measured in Ohms

Natural gamma, measured in gamma counts per second

16” (Short) and 64” (Long) normal resistance, measured in Ohms-meter

A legend of encountered formations was provided with each suite of logs by Frontier.

Installation of GHEX was done by each participant at their direction with assistance from collaborators.

Grouting of GHEX (Oklahoma State University, Division of Engineering Technology, 2000)

Mix water preparation, recommended a neutral ph.

Pumping the selected grouts using positive displacement pumps.

Grout borehole;

If grouting through drill pipe then upon reaching total depth pump the grout before tripping out the drill pipe and grout to surface then install GHEX

If grouting by tremie run with GHEX or after GHEX installed

Grout sample collection (see Ewbank procedure for ASTM-5334 (ASTM D 5334)) testing was done by Ewbank and Halliburton/Bariod IDP using the Ewbank test units.

If cementitious grouts by agreement of Bariod, Ewbank, and Beier using ASTM-5334, however no cementitious grouts were used.

Sample collection from the field was by both five gallon plastic containers and 2-3/4 quart plastic canisters from the mix tanks of the grout units. The shop built unit by Ewbank had a discharge valve in the piping to obtain a pumped sample.

Sample weights using mud scales which should match manufacturers information

Field thermal conductivity

Laboratory thermal conductivity

Grout testing results:

APPLIED RESEARCH PROJECT, HOPE CROSSING, OKLAHOMA CITY, OKLAHOMA						
	measured	**target**	**GROUT**		**type of**	
unit number	**grout κ**	**grout κ**	**MFGR**		**GHEX**	
1		1.0	BARIOD	PRE-MIXED 1.0 GOLD	2.5" HDPE CONCENTRIC	tbd
2					NONE	air source
3	2.69	1.6	BARIOD	PRE-MIXED 1.6 MAX	2.5" HDPE CONCENTRIC	
4	3.20	1.6	BARIOD	PRE-MIXED 1.6 MAX	2.5" HDPE CONCENTRIC	
5	0.83	1.0	BARIOD	PRE-MIXED 1.0 GOLD	3/4" 4 PASS PEX	
6	0.82	1.0	BARIOD	PRE-MIXED 1.0 GOLD	3/4" 4 PASS HDPE	
7	0.81	1.0	BARIOD	PRE-MIXED 1.0 GOLD	1" 2 PASS HDPE	
8			BARIOD		NONE	air source
9	0.83	1.2	BARIOD	PRE-MIXED 1.2 GOLD	2.5 " HDPE CONCENTRIC	
10	1.28	1.0			2-3/4" Ø, 3/4" 2 PASS HDPE	
11		1.6	RYGAN		3.5" FIBERGLASS CONCENTRIC	not measured
12	1.07	back fill			TRENCH BACKFILL FROM OVERBURDEN REMOVED	
					AT CONSTRUCTION SITE TO THE NORTH	
	* AVERAGED IF MULTIPLE BOREHOLES					
			HIGHEST	LOWEST		
			MEASURED	MEASURED		
			GROUT SAMPLE	GROUT SAMPLE		
		1.0	0.851	0.77		
		1.2	0.869	0.78		
		1.6	3.2	2.69		

Restoration of the site (partial) was typically simple leveling of the area and removing all drilling and grouting spoils.

Direct measurements of one borehole at each site consisted of determining the thermal conductivity, (κ), estimating the thermal diffusivity (α), and the deep earth temperature.

Rig up in situ unit for ASHRAE/IGSHPA testing

Conduct deep earth temperature test

Conduct up to a 48 hour heat of rejection test (with bottom hole sensor at selected sites). The power input chosen was to be approximately 20 Watts/foot of borehole. Similar heat fluxes and durations were chosen for the testing. Bottom of borehole temperature was used on concentric configurations to determine the heat loss of the center, or drop pipe, and then to aid in analysis of the borehole resistance. Reporting of the direct measurements the deep earth temperature, local earth thermal conductivity, borehole resistance was conducted using IGSHPA and ASHRAE standards and further using Ewbank and Beier additional testing procedures. The in situ reports are available in a separate section of the research information. NOTE: The average thermal conductivity increased with borehole depth which was expected. The deeper drilling formation was sandstone and the percentage of sandstone to total borehole increased with depth.

The boreholes were headered and supply and return lines ran to a ground vault. Isolation valves (HDPE) were installed. New heat pumps were installed and the systems connected only to the research heat exchangers and flushed and purged and 15% methanol by volume added to the circulation fluid as freeze protection.

The data acquisition systems from Oklahoma State University and IGSHPA were installed and connected to a wireless internet access. The data was recorded at one minute intervals only when the heat pumps were called to operate. The measured data consisted of:

Unit number

Date of record

Time of record

Entering water temperature °F

Leaving water temperature °F

Return air temperature °F

Relative Humidity

Flow rate in gallons per minute

Power consumed by the heat pump

Power consumed by the circulating pump

Power consumed by the desuperheater pump

(Numerous other data points were collected)

Data from each of the units was collected for **one and one-half years of operation**. The data was used by Oak Ridge National Laboratory for analysis of the operation of the units. All data is available from IGSHPA under the research tab at: (www.igshpa.okstate.edu). One issue for all parties reviewing the data sets should recognize the reported energy efficiency ratio (EER). A casual analysis of comparing the EER to the coefficient of performance (COP in the heating mode) would seem the units were better at heating then cooling. The contribution of the desuperheater in cooling model was not measured separately in our study and thus was not accounted for in the EER calculation. It was accounted for in the heating COP calculation though (because it is part of the heating output that is determined from the loop side heat transfer and the compressor power consumption). Should it be accounted for, the GSHP system EER could be about 10% higher according to the catalog data of the heat pump.

Domestic hot water was produced by all ground source units in both the heating and cooling modes.

Issues that Arose:

1) Grouting the boreholes turned out to be a difficult except for the small diameter boreholes at site ten using silica gravel. The grouting created a lot of materials on the surface at the sites. The grouting added considerable time, labor, and effort to the installation of the GHEX.

   First, for the concentric designs, the initial the plan was to drill a borehole large enough to insert a tremie pipe outside and alongside of the GHEX. The dimensions became large enough that the concentric participants became concerned that the increased annular area would increase the borehole resistance for their GHEX. One site (944) successfully used a collapsible lay flat vinyl tube as a grout tremie at the recommendation of Ewbank.

   Second, manufactured grouting units typically arrived with HDPE SDR-11 piping on a powered reel. SDR-11 has a working pressure rating of one hundred and sixty (160) psi, and a design pressure of two hundred and forty (240) psi at seventy-three (73.4) degrees Fahrenheit. ¾" and 1" SDR-11 piping was on the grouting units and required pressures higher than the tremie pipe rating to pump the sand enhanced grouts. Units with six hundred feet of piping on the reels arrived at the sites. The winding of the piping also increased the required pressure to pump the enhanced grouts.

   Third, only one grout unit (shop built) had a discharge valve in the pump to tremie plumbing to obtain a pumped sample. The manufactured units required the sample to be taken from the mixing tank; not from the pumped flow of the unit to the tremie. Operators could and occasionally would add water to the mix after grout samples were taken to insure the grout could be pumped.

   Fourth, measuring the mix water quality was not found to be a trade practice. Experienced grout crews were instructed in the preparation of the water to handle the calcium and pH before any mixing of grouting materials.

   > (**Definition:** pH is a measure of hydrogen ion concentration; a measure of the acidity or alkalinity of a solution. Aqueous solutions at 25°C with a pH less than seven are acidic, while those with a pH greater than seven are basic or alkaline. A pH level of is 7.0 at 25°C is defined as 'neutral' because the concentration of H_3O^+ equals the concentration of OH^- in pure water. Source About.com, Chemistry)

   A review of the grout testing results indicates some interesting information:

APPLIED RESEARCH PROJECT, HOPE CROSSING, OKLAHOMA CITY, OKLAHOMA						
	measured	**target**	**GROUT**		**type of**	
unit number	**grout κ**	**grout κ**	**MFGR**		**GHEX**	
1		1.0	BARIOD	PRE-MIXED 1.0 GOLD	2.5" HDPE CONCENTRIC	tbd
2					NONE	air source
3	2.69	1.6	BARIOD	PRE-MIXED 1.6 MAX	2.5" HDPE CONCENTRIC	
4	3.20	1.6	BARIOD	PRE-MIXED 1.6 MAX	2.5" HDPE CONCENTRIC	
5	0.83	1.0	BARIOD	PRE-MIXED 1.0 GOLD	3/4" 4 PASS PEX	
6	0.82	1.0	BARIOD	PRE-MIXED 1.0 GOLD	3/4" 4 PASS HDPE	
7	0.81	1.0	BARIOD	PRE-MIXED 1.0 GOLD	1" 2 PASS HDPE	
8			BARIOD		NONE	air source
9	0.83	1.2	BARIOD	PRE-MIXED 1.2 GOLD	2.5 " HDPE CONCENTRIC	
10	1.28	1.0			2-3/4" Ø, 3/4" 2 PASS HDPE	
11		1.6	RYGAN		3.5" FIBERGLASS CONCENTRIC	not measured
12	1.07	back fill			TRENCH BACKFILL FROM OVERBURDEN REMOVED	
					AT CONSTRUCTION SITE TO THE NORTH	
	* AVERAGED IF MULTIPLE BOREHOLES					
			HIGHEST	LOWEST		
			MEASURED	MEASURED		
			GROUT SAMPLE	GROUT SAMPLE		
		1.0	0.851	0.77		
		1.2	0.869	0.78		
		1.6	3.2	2.69		

The sand enhanced high solids grouts generally had lower than expected thermal conductivity values. Since the materials were pre-mixed and bagged then extra water had to be added which lowered the density. Observations in the field indicated the grout unit operators would increase the water content after the sample was taken to make the grouts pumpable through their SDR-11 piping.

The graphite enhanced grouts had higher than expected thermal conductivity values and were easily mixed and pumped.

2) Marking the GHEX and headers was originally to be with tracer wire. Wire end grounding had to be described and a ground rod used. Heavy clay was trenched for the supply and return header piping at the locations and as the clay dries it shrinks away from the ground wire end and becomes unusable. Later it was decided by the team to also include passive locator discs in the supply and return trench and at each borehole.

3) ACCA Manual J Designs

   Should ground source heat exchangers lengths be modified to extended or maximum and minimum outside air temperature bins? Modification can be easily done since residential loads are conductive loads and the heating and cooling loads trend lines may be extended to the desired outside air temperatures for a given location. The answer is yes; and the main reasons are to keep the GHEX fluid minimum and maximum temperatures within specific ranges to provide capacity and efficiency of the ground heat exchanger and then the HVAC units.

ACCA Manual J loads were obtained from GWS used 97 to 13 °F weather data. No fault is found with GWS since they used the prescribed industry methodology. Also, GWS used the methodology the ground source industry was teaching to obtain the facility loads. However, the weather data was insufficient since extended periods occurred during the first summer of higher temperatures (peak loads) and longer run times (durations or usage). **This is important to recognize, particularly, if the GHEX is to be a utility or third party owned asset available for a return based on investment.**

At these sites one could consider temperature ranges of 107 to 3 °F, or 112 to -2 °F, for facility conductive loads to design of the GHEX length.

The first summer of operation some of the GHEX temperatures rose to high causing poor performance of the HVAC systems and poor comfort levels for the homeowners. When this occurred the systems were valved back to the original loops and operated successfully. The cause was the peak and duration of cooling loads was greater than the design using ACCA Manual J thus increasing the GHEX loads and therefore the temperatures.

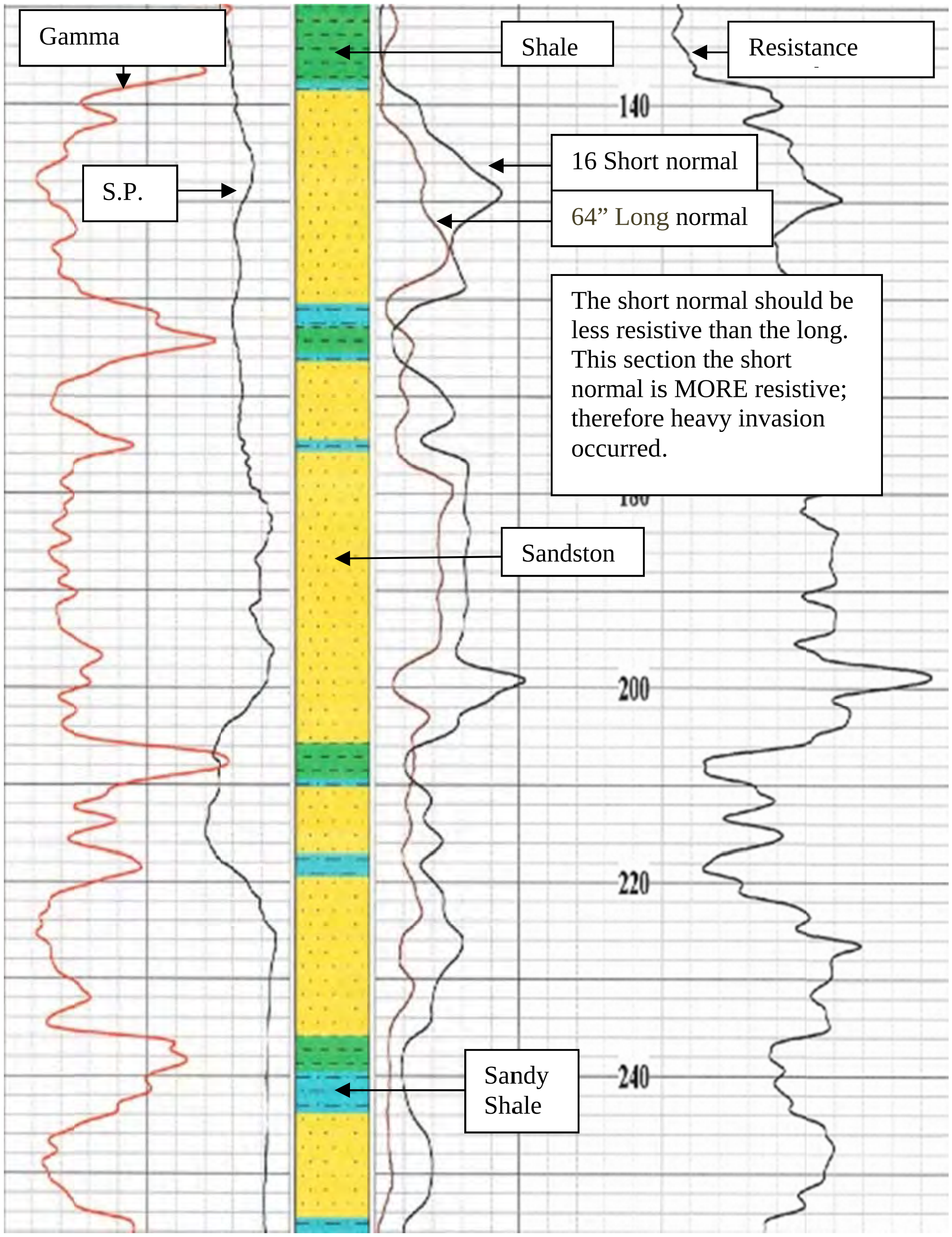
Best practices found

Recommendations to the Ground Source Industry

GHEX vertical configurations can lower borehole resistance by alternative piping methods and configurations.

One can use concentric or multiple pass GHEXs to lower piping resistance. Also, both increase the quantity of water in the GHEX compared to the flow rate through the GHEX. Laminar and turbulent flow should be studied to determine flow rates to maximize heat transfer and minimize frictional loss.

Lower borehole resistance can be obtained in formations with primary porosity and permeability by eliminating borehole invasion of clay cuttings in solution. Also, the weight of circulation fluids should be minimized by using a mud cleaning system in the circulation system. Air circulation systems also must be properly operated to minimize borehole invasion. Both increase the differential pressure in the borehole wall, thereby, filtering the clay from the solution/mud. The borehole invasion was clearly shown when the 16” short normal had a higher resistance then the 64" long normal. A five suite log is shown below to show the invasion.

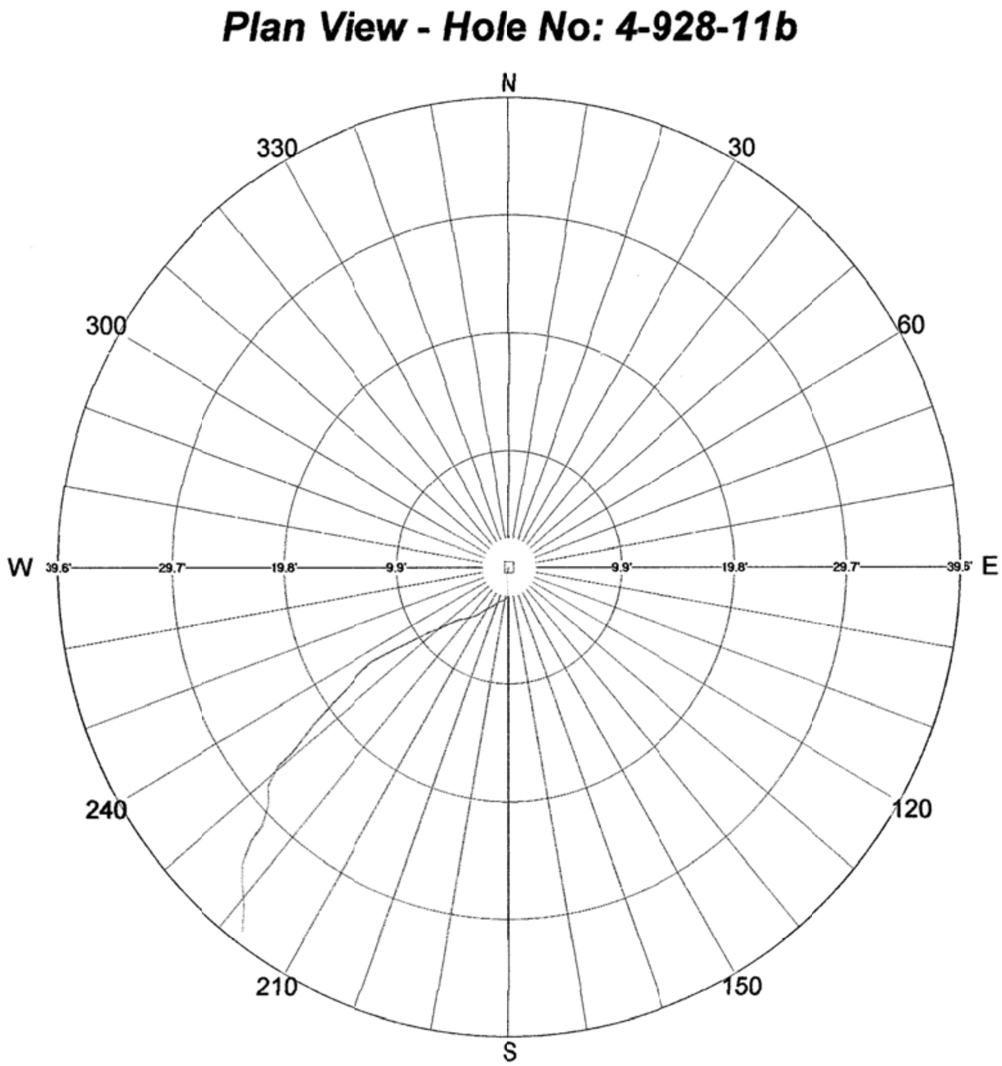


It was found that the development of wall cake is important to limit borehole invasion. The oil and gas industry has been doing this for years and the methods are fully developed. Actions to develop wall cake (requires creating enough gel strength for water loss control) are necessary to minimize the increased borehole resistance from invasion during drilling using either air or mud.

Competent rocks with low porosity and permeability are not subject to invasion. However, secondary and ternary porosity and permeability from fractures and rubilization are a concern if encountered.

Borehole deviation

Borehole deviation occurred on all boreholes measured. One deviated more than thirty-eight (38) feet during drilling of three hundred and twenty (320) feet in depth.



The GHEX placement in the grout/borehole was not determined. The thoughts of the drilling professionals were that the GHEXs are buoyant due to the grout having a higher density than the water filled GHEX. The tendency would be to force, or buoyantly float, the GHEX up and along the restraining borehole wall.

Grouting practices and measurements followed the Oklahoma Water Resources Board requirements which are the same as IGSHPA recommendations. Grouting followed IGSHPA's procedures with the exception of unit ten (10) which used silica gravel from the static water level and below then bentonite chips from the static water level to the surface.

When collecting the grout sample a discussion and decision should come from the ground source industry of:

Not sampling from the mixing tank (safely) but from the pump discharge to insure what is measured is what was pumped.

Sample valve ports in pressure lines of portable grout units

Hydration build and times are most likely that sodium bentonites require up to eight hours to fully build, graphite enhanced grout require three days, and cements twenty-eight days. Needle probe testing using the ASTM 5334 methods are not useful in the field as grouting is proceeding.

Information concerning the following should be made available to the industry:

Mixed versus actually pumped out the end of tremie

Tremie pipe pressure rating(s)

Tremie pipe sizing, diameter and lengths

Grout unit spool frictional loss of the spooled piping

Temperature effects on hydration and pumping of grouts

pH of mix water and calcium concentration

Grouting materials and methods included using silica sands to enhance the grout thermal conductivity of the bentonite grout can be greatly improved. However, little accurate training is given to field quantification of grout and enhancements. This can be easily changed simply by field measurements of the pumped grout to determine the density of the grout. The importance of knowing the density of the pumped grout is that the thermal conductivity of the silica sand enhanced grout is determined by the additional sand content or density of the grout mix.

Concentric GHEXs used both silica sand and graphite to enhance the thermal conductivity of the grout. Graphite was found to greatly increase the conductivity beyond the silica sand. The graphite mix pumped much easier due to the lower density and the friction reduction from the graphite. However, it was expensive and no indication that the higher conductivity improved the GHEX performance. Most likely (in the author's opinion), this is due to the high borehole invasion which occurred during drilling and not poor performance of the enhancing materials. The sand enhanced grouts tested trended to the low end of the measurement range of + or – 15% and some did not fall within the expected range. The 1.2 and 1.0 sand enhanced grouts tested up to 0.87 Btu /

(hr-ft-°F) indicating “watered down” grouts so the grouts could be pumped through the 160 psi rated SDR-11 piping.

The following is a recommendation of “Field Testing of Grout Samples Using the Ewbank Portable Grout Thermal Conductivity Unit as per the ASTM D-5334 Method and Mud Scales”:

Notes sheets should include the desired grout mix properties:

1) Bentonite solids content, by weight

2) Water content, by weight

3) Enhancement additives, by weight

4) Mix yield anticipated thermal conductivity

Obtaining a sample of the grout mix:

As the mixed batch of grout is pumped samples should be taken from the <u>discharge</u> line when approximately one half of the batch has been pumped away. The grouting unit must have a valve in the flow line to be opened for discharging the sample as it is pumped.

<u>No samples should be taken from the mixing tank, as this is dangerous; and the mix may be later altered by adding water after the sample is obtained to make the mix easier to pump down hole.</u>

Two (2) samples should be taken. One sample should be taken for weighting by using a set of mud scales and one sample taken for thermal conductivity testing in later in the laboratory and/or after hydration and build by the installer. The grout sample container should be greater than two (2) inches in diameter and eighth inches deep. A one gallon plastic paint container with a latching and sealing lid is recommended for most field samples. Usually a Lowe’s or Home Depot will have these containers in the paint section.

The samples taken for the mud scales should be weighted as per the instructions of the scale manufacturer to determine the sample density in pounds per gallon. Grout manufacturers recommend the addition of solids (or silica sands and graphites) to increase the thermal conductivity of the grouts. The weight in pounds per gallon should be noted on the container of the sample taken for the thermal conductivity testing by a third party.

Thanks,

Garen N. Ewbank, CEM, CGD, CRM, CEA, CBEP, CSDP for
Ewbank Geo Testing, L.L.C.