Closed Loop Ground Heat Exchangers & Aquifer Protection

Our industry is often asked to explain how a vertically drilled ground heat exchanger, or ground loop, can safely be installed through an aquifer without compromising the quality of the resource. To answer this, it is necessary to understand the purpose of a ground loop, how it is installed, advantages of such systems, and the requirements to assure both competent energy transfer and protection of both unconfined and confined aquifer assets. For the latter, energy transfer and aquifer protection, the installation requirements are mutually dependent on each other.

The grouting process and related facts are summarized as follows:

1. Borehole is drilled to the intended depth.
2. The ground loop u-bend circuit is loaded into the borehole immediately, followed by the tremie line (grout injection hose or pipe) to the bottom of the borehole.
3. Bentonite grout is pressure injected into the borehole from bottom to surface to fill all voids and completely seal the borehole from any kind of external water migration.
4. The grout is mined mostly from mines in Wyoming where the bentonite clay is exceptionally pure, requiring minimal processing to enhance sealing and swell properties.
5. Bentonite based grouts are preferred as they are natural; the grout also swells or contracts with the borehole as subsurface conditions change to eliminate the chance of voids.
6. Purpose milled bentonite grouts expand by 20X or more from their dry condition volume with water. It is blended with water and mixed as a slurry just prior to pumping.
7. To pump grouts into boreholes, the contractor often adds an agent to delay grout expansion to aid in pumping and maximize grout density during installation.

See Figures 1. and 2. for a visual description of the grouting process, and accompanying photos of loop installation and grouting, Photos 1. through 6.

Purpose

A closed loop ground heat exchanger (GHX) is a part of a mechanical heating and cooling system that is often described as a geothermal, geoexchange or ground source heat pump (GSHP) system. Although the term geothermal is often used, in this case it is not to be confused with an active temperature gradient application, as used for direct heating and electric power generation. Geoexchange mechanical equipment can function on supply water temperatures below 30°F and up to 110°F+ and do not require high thermal gradient conditions. Therefore, these systems can be installed in nearly any climate or geologic condition.

The objective of a closed loop ground heat exchanger (GHX) is to be able to provide an acceptable supply water temperature range that ground source heat pump HVAC/Radiant mechanical equipment can function with at any time of the year. The design of such systems requires 1) the cooling and heating requirements of the application expressed in units of energy such as Btuh, 2) the type of heat pumps used and their performance capabilities, and 3) the capacity of the earth at the specific location to gather and reject energy (heat), involving the thermal conductivity and temperature of the host geology.

Advantages

Economics – The annual operating cost of these systems can be up to half or less of other mechanical systems. For example, one sub-metered residential installation south of Parlin in the Gunnison Basin operates at under $250/year for a radiant floor system in a 3,500 ft² home[1] *without* auxiliary assist from any other heat source.

As the GHX replaces typical furnaces, boilers, outside condensers, the maintenance and long-term replacement cost of these more traditional items are eliminated. The GHX has no moving parts or mechanical connections in the earth, and the high-density polyethylene (HDPE) pipe used in the construction of these systems is purpose milled for the industry with an industry standard 50 year warranty.

Environmental – GSHP systems use a fraction of energy typically used for space conditioning. Even considering the point source of electrical generation, these systems reflect the least amount of greenhouse gas emissions generated, and are typically necessary to achieve true Net Zero [2] status for any residential or construction applications, far more favorably then compared to conventional air source heat pumps, conventional air conditioning, fossil fuel fired furnaces and boilers.

For the installation, there is no combustion associated with GSHP equipment. Therefore, there is no generation of carbon monoxide or need for exhaust venting with these systems.

Regulatory Oversight, Protection of Aquifer Resources

In the state of Colorado, **all** closed loop GHX installations are regulated by the Division of Water Resources (DWR), also known as the Office of the State Engineer [3]. Regulations are described in the DWR document '*Rules and Regulations for Permitting The Development And The Appropriation Of Geothermal Resources Through The Use Of Wells, document #2 CCR 402-10*'. This document is available online at *https://dwr.colorado.gov/services/well-permitting* under Well Permitting & Regulations.

Vertical closed loop boreholes are termed a non-consumptive well by DWR and are differentiated from high temperature geothermal wells as a 'Geoexchange System':

4.2.14 " Geoexchange System " means a heat pump or heat exchange system having a

[1] Wally Cox home, customer letter
[2] https://www.usgbc.org/resources/pathway-net-zero
[3] https://dwr.colorado.gov/about-us

horizontal or vertical closed-loop portion consisting of pipe buried in trenches, boreholes, or wells (ground-source), or submerged in a body of water (water-source), in which a heat exchange medium (fluid or vapor) is circulated and fully contained within the pipe or tubing. The purpose of the closed loop is to provide for the transfer of heat between the circulating fluid or vapor and the ground or water.

For vertical closed boreholes used to service GSHP installations, DWR defines these installations as follows:

4.2.28.3 " Type A-CLV Well " means loop fields in a vertical closed-loop geoexchange system that consists of pipe or tubing installed in drilled boreholes or wells.

It is important to note that while DWR uses the term 'well' for a closed loop vertical borehole, a Type A-CLV Well is not completed as a water well. There is no casing, downhole screens, submersible pumps or any other mechanical devices or infrastructure installed.

Once the borehole is drilled it is sealed from bottom to top using an impermeable grout. Other than the grout, a plastic pipe assembly, referred to as a u-bend, is installed just prior to sealing. This is the 'closed loop' portion and heart of the system that is used to both scavenge and reject low grade energy to allow the heat pump mechanical system to function. The plastic pipe used is purpose milled high-density polyethylene (HDPE), similar to that used in natural gas pipelines, potable and water lines, etc.

Grouting is required to assure thermal transfer in the host geology, and to protect any aquifers penetrated:

4.2.16 " Grout " means any material approved by these Rules that is used to form a permanent impermeable seal in the annulus between the ***closed loop*** *or casing and the borehole wall, between two strings of casing, or that is used in plugging, boreholes, loops or wells.*

Emphasis in bold is added to the above with regards to a Type A-CLV Well, typical of that to be used for the Gunnison Library, and as existing for the Gunnison County's court house, family services center, waste water treatment administration office, and pending retrofit of the Gunnison airport.

The type of grout used to seal a Type A-CLV Wells is prescribed by the following from DWR:

8.3.2 Grout materials approved by the State Engineer include the following:
a. neat cement;
b. cement-bentonite mixtures;
c. cement–fly ash mixtures;
d. high solids bentonite (at least thirty (30) percent solids by weight); and,
e. thermally enhanced grouts (cement-sand or bentonite-sand).

Major Geothermal Major Heating
6285 West 48th Avenue, Wheat Ridge, Colorado 80033 – 303 / 424-1622 voice, 303 / 423-6795 fax
Toll free - 800 / 707-9479 www.gomajornow.com

8.3.2.1 All grout materials shall be mixed by the method and in the proportions specified by the manufacturer. Excess water shall not be used in the preparation of grout materials. The type and amount (by weight) of each constituent used in the grout mixture shall be reported on a form prescribed by the State Engineer.

For the systems previously mentioned for Gunnison county or municipal projects, thermally enhanced (TE) grouts are specified (above, **bold** emphasis). TE grouts accelerate energy transfer between the HDPE pipe and host geology, increasing performance of the GSHP system. It should be noted that when the current Rules were drafted by DWR, this was prior to industry improvements for TE grout compositions that now utilize natural graphite blends with the bentonite instead of silica sand. This is recognized and allowed by DWR.

Type A-CLV Wells adjacent to Water Wells

Should a closed loop Type A-CLV Well be in the vicinity of a water well, the DWR requires a setback of 100'. This is outlined in the current regulations as follows:

6.4.2 No geothermal well shall be located closer than one hundred (100) feet to the nearest source or potential source of contamination unless a variance has been obtained from the State Engineer. For purposes of this Rule, the appropriation and reinjection of a geothermal fluid into the same reservoir shall not be considered as a source of contamination.

This rule is intended primarily for high temperature extraction and reinjection wells, not for non-consumptive closed loop ground heat exchanger boreholes (Type A-CLV Well). The intent is made clear from the above where '*…the appropriation and reinjection of a geothermal fluid into the same reservoir shall not be considered as a source of contamination*'.

When a vertical loop borehole is within the setback distance described by the regulations the licensed installer can ask for a variance (Rule 14 of the regulations). Where a Type A-CLV borehole does fall within the 100-foot setback rule, I know of no reasonable variance request that has not been granted by DWR.

Antifreeze

For some closed loop systems, a nominal amount of antifreeze is necessary to protect the mechanical components should the GHX fluid approach freezing temperatures. Typically, 15% to 20% by volume is more then sufficient for freeze protection when using food grade propylene glycol (PG) for closed loop GHX installations. Excessive amounts of any type of antifreeze can inhibit heat transfer so when it is necessary, the least amount possible is specified.

PG is used in everything from ice cream to tooth paste to other food products; in cosmetics; as a deicing agent for aircraft - where it is typically allowed to drain into the ground or sewer systems; as an additive to pharmaceutical products; and other uses where its properties are desirable yet the intended use requires a non-toxic impact.

PG is a type of glucose (sugar) and is biodegradable; it breaks down quickly if spilled, typically within a few days to a week depending on conditions.[4] As the amount used in a closed loop GHX is minimal, degradation is even faster if exposed.

Colorado DWR also recognizes PG as an acceptable antifreeze used in Type A-CLV closed loop ground heat exchangers:

8.3.3 Only a non-toxic fluid shall be used in a Type A-CLH or Type A-CLV well. Fluids approved by the State Engineer are:

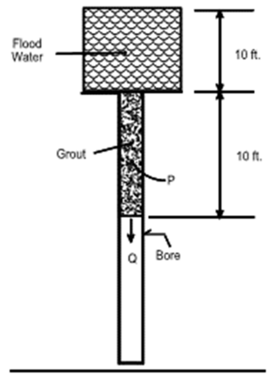
d. food grade propylene glycol

Sealing Performance of Bentonite Grout

To emphasize the sealing capability of bentonite grouts, consider the following excerpt:

> GSHP Bore Hole Water Migration[5]
>
> An ideal GSHP bore grout would protect groundwater, promote heat transfer, be easy to install, and have a reasonable cost. Conventional grouts that are used to seal the annular region around U-tubes may protect groundwater at the expense of effective heat transfer. This imbalance could result in a less efficient system that would reduce the environmental benefits associated with high efficiency (reduced power plant emissions and greenhouse gases).
>
> The potential of contamination from surface water pollutants can be demonstrated by calculation of the flow through a 6 inch grouted bore (only the top 10 ft. grouted) when a loopfield is flooded with 10 feet of water, a fairly extreme assumption.
>
> Flow = Permeability × Bore Area × Water height ÷ Thickness
>
> Permeability = 1.97×10^{-7} ft/min (1×10^{-7} cm/s)
> Bore Area = $\pi/4\ (6''/12)^2 = 0.196\ ft^2$
> Flow = 1.97×10^{-7} ft/min × $0.196\ ft^2$ × 10 ft. ÷ 10 ft.
>
> Flow = $0.0000000386\ ft^3/min$ = 0.000000289 gpm
> -or- **3,460,000 Bores Required to Flow 1 GPM**

[4] Agency for Toxic Substances & Disease Registry (https://www.atsdr.cdc.gov)
[5] Outside the Loop Newsletter, Volume 1, Number 4, Fall 1998, Dr. Steve Kavanaugh



Surface Water Flow in Grouted Bore

Note: Dr. Kavanaugh is the co-author of the ASHRAE[6] manual titled 'Geothermal Heating and Cooling, Design of Ground Source Heat Pump Systems (Commercial and Institutional Buildings). This manual is the industry 'bible' for the design of non-residential GSHP systems.

City of Gunnison – Land Development Code

The city of Gunnison recognizes the use of geothermal GSHP systems as a valid renewable energy technology as referenced in their Land Development Code manual:

Page 3-29:

C. Renewable Energy Systems

1. Characteristics. Renewable Energy Systems include photovoltaic arrays (solar electric panels) small wind energy conversion systems, ***and geothermal heating and cooling systems****.* (emphasis added)

Page 3-33:

11. Geothermal Heating and Cooling Systems. Geothermal heating and cooling systems are systems that use buried pipes to exchange heat with the ground, cooling buildings in the summer and warming them in the winter. Closed loop systems (horizontal loop systems and vertical loop systems) are permitted, provided that the loops are contained entirely within the lot and are setback five feet from property lines.

[6] American Society of Heating, Refrigerating and Air-Conditioning Engineers

Professional Organizations

The National Ground Water Association (NGWA) has been instrumental in establishing minimum safe grouting standards for vertical closed loop ground heat exchangers. Continual adjustment of standards has kept pace with higher performance grouts, with input from the International Ground Source Heat Pump Association (IGSHPA) and ASHRAE. DWR does in fact reference IGSHPA's standards for loop installations:

8.3.1 The circulating pipes installed below ground level shall consist of high density polyethylene (HDPE) pipe meeting the standards specified in Section 1 of the International Ground Source Heat Pump Association, Oklahoma State University, publication "Closed-Loop/Geothermal Heat Pump Systems: Design and Installation Standards 2000"….

Example Installations - Colorado

The following is a brief list of commercial, institutional, military, municipal and other GSHP systems using vertical closed loop ground heat exchangers. Residential installations can be found in almost any part of the state including the Gunnison area. Literally thousands of feet of closed loop vertical borehole heat exchangers exist in Colorado with no adverse environmental impact.

Facility	Location	# of Bores x Depth
Adams Co. Fire Dept. Administration	Commerce City	14 x 500'
Battalion Readiness Center	Ft. Carson	32 x 500'
B-909	Buckley AFB	64 x 500'
Courthouse	Gunnison	40 x 300'
Custer K-12	Westcliffe	60 x 500'
Echelon Above Brigade Operations Facility	Ft. Carson	24 x 400'
Family Services	Gunnison	16 x 350'
Holy Cross Lutheran Church	Wheat Ridge	28 x 400'
Josephine Commons Low Income Complex	Lafayette	50 x 400'
IKEA (under building footprint)	Centennial	130 x 500'
Kirkland Museum	Denver	21 x 475'
Large Vehicle Inspection	USAFA	8 x 250'
Middle School	Ft. Lupton	96 x 500'
Mill Building (under building footprint)	Aspen	24 x 350'
Mitchel Hall	USAFA	32 x 500'
Morgridge Foundation	Denver	8 x 500'
Moby Arena	CSU Fort Collins	342 x 550'
Rio Blanco Court House & Justice Center	Meeker	32 x 500'
Southeast Elementary	Loveland	72 x 500'
Wastewater Plant Admin. Office	Gunnison	5 x 300'

Note: Major Geothermal has designed vertical closed loop ground heat exchangers for over 19,000,000 ft^2 of conditioned space for commercial scope projects since 2001, with the majority of our work in Colorado. This excludes residential installations.

History

GSHP technology has existed since the 1950's and is in use globally, not just in the United States. There are millions of feet of vertical closed loop ground heat exchanger not just in the US but world-wide. If there were a problem with closed loop boreholes contaminating aquifers it would be known by now.

"FYI" Links

Grouting of Boreholes for GSHP Systems: https://www.youtube.com/watch?v=lkisI-Q5Z4Q

Geoexchange fundamentals, installation, FAQs, etc: https://www.geothermalforall.com/

Geothermal - Energy We Can All Agree On: https://www.youtube.com/watch?v=RB93YCOqoTA

Out of the Box - Utilities Geoexchange Project[7]: https://www.youtube.com/watch?v=Al5uZbcMEIE

The last link noted above, Out of the Box - Utilities Geoexchange Project, is a good overview of how a GSHP system works with a GHX. Instead of a vertical closed loop, this project utilizes a closed loop surface water heat exchanger (SWHX) situated in a large pond.

* * * * *

Terry Proffer, CGD, Geothermal Manager

Geologist
ASHRAE, IGSHPA, NGWA
IGSHPA Accredited Installer #12131-994
IGSHPA/NATE Certified Installation Instructor #T1063-496
AEE Certified GeoExchange Designer #16
IGSHPA CGD Instructor
Colorado Division of Water Resources Closed Loop Certification #GT-13
ClimateMaster Certified Installation Instructor

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[7] Produced by the City of Fort Collins.

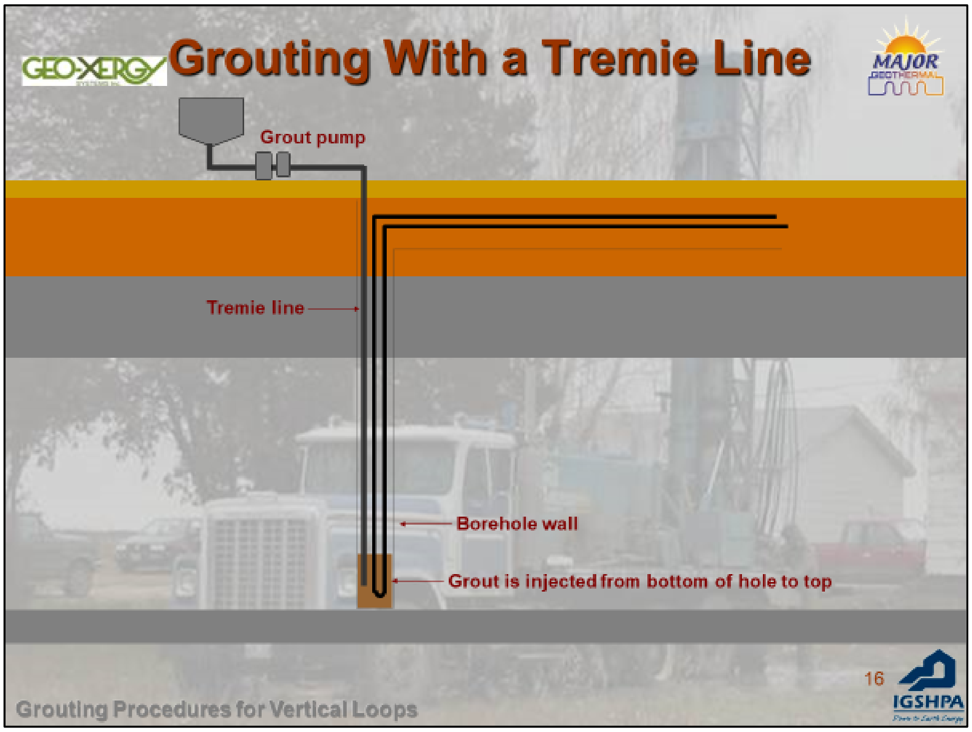

Figure 1. Grouting commences from bottom of borehole.

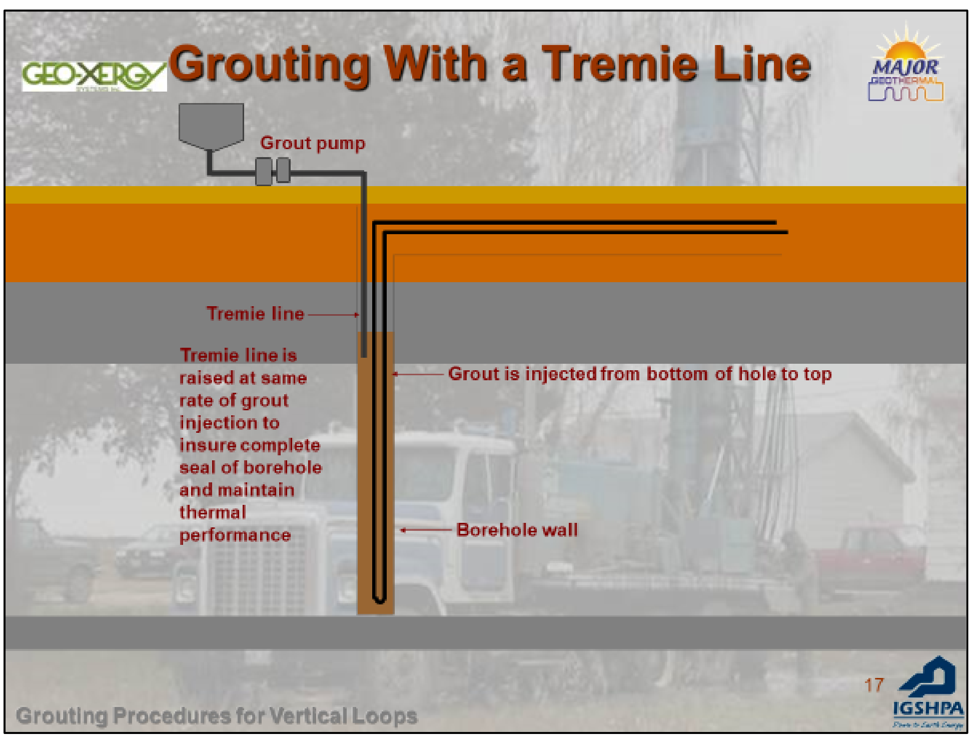

Figure 2. As grout level rises the tremie grout injection line is raised.

Photo 1. Loading HDPE ground loop in borehole. Custer County School, Westcliffe, CO.

Photo 2. Loading HDPE ground loop in borehole. Custer County School, Westcliffe, CO.

Photo 3. Typical grout pump with tremie line, mixing tank side. CSU Moby, Ft. Collins, CO.

Photo 4. Typical grout pump with tremie line, pump side. CSU Moby, Ft. Collins, CO.

Photo 5. Tremie line from pump feeding into borehole. Am. Indian Hall, MSU, Bozeman, MT.

Photo 6. Tremie line feeding into borehole. Am. Indian Hall, MSU, Bozeman, MT