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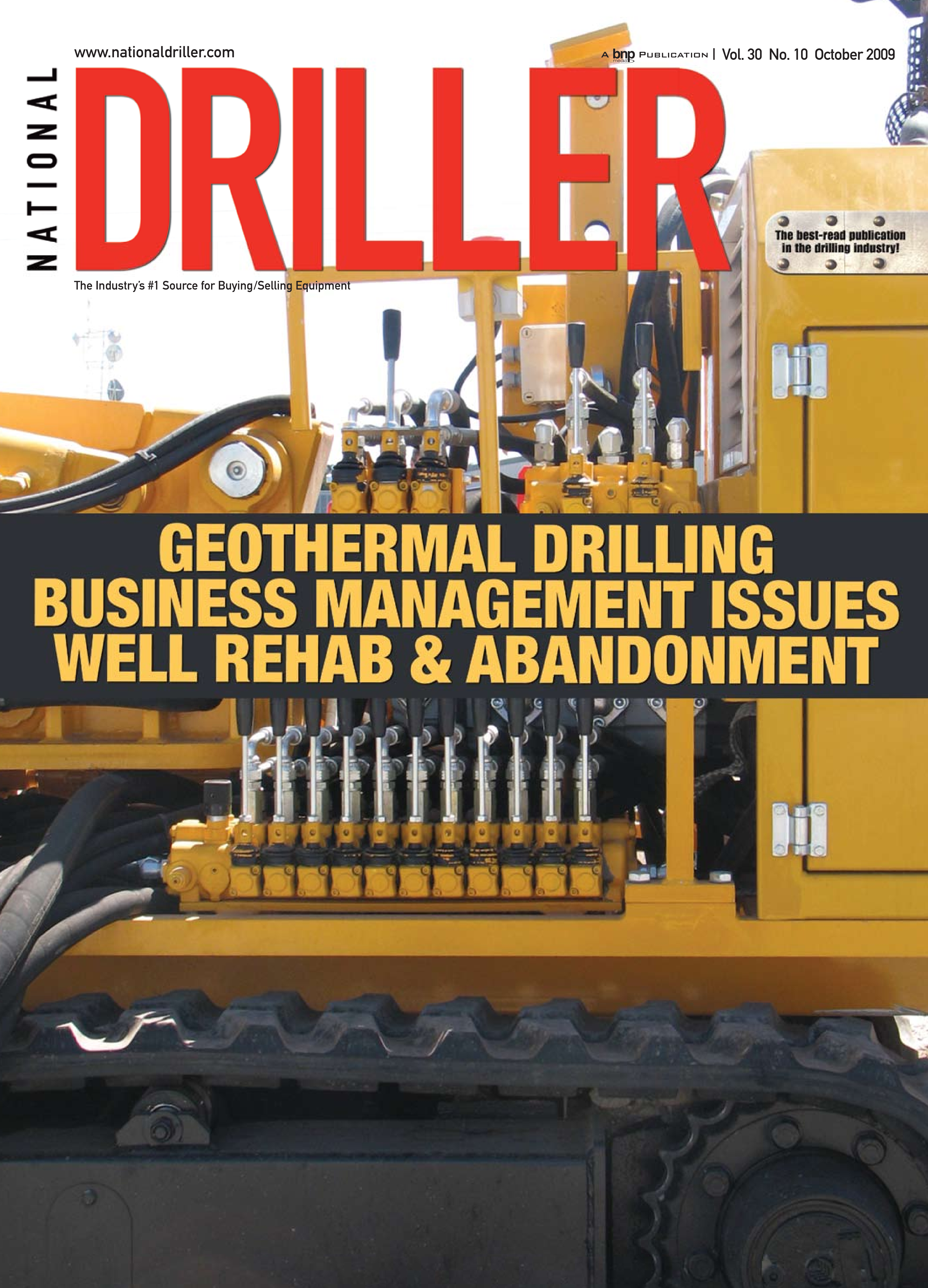


## GEOTHERMAL DRILLING
## BUSINESS MANAGEMENT ISSUES
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# An Overview of Geothermal Grouts

by Ryan Collins and Toby McClain

The geothermal heat loop industry has seen tremendous growth over the last decade. With that growth, there have been significant advances in geothermal grout technology. For the contractor and system designer, it is important to know as much as possible about each grout type to ensure not only selection of the proper material, but proper mixing and placement, too. Many types of materials can be used to grout a geothermal heat loop. To determine the optimum grout for a given project, the system designer must consider the following factors:

- Formation properties (thermal conductivity, permeability and diffusivity).
- Static ground water level.
- Ground water chemistry (potential effects of the chemistry on the grout).
- Vadose zone impact.

After determining this information, the correct grout can be selected that will meet the technical specifications of the project, provide efficient heat transfer for the loop system, and protect the quality of the ground water. It is important to remember that grouts and, by extension, the heat loop system itself, can only perform their intended functions when a proper hole has been drilled. Drilling success involves developing a plan before starting the project, effective fluid design and management, proper drilling practices, and proper grouting techniques.

The four most common grout types are bentonite, bentonite/sand mixtures, cement-based materials, and graphite-based materials (See Table 1 at right).

## Pure Bentonite

Bentonite is a naturally occurring clay mineral that has been used for many years as a grout in the water well industry. It is available in many forms (chip, pellet, coarse granules, fine granules or powder), and it can be poured or pumped, depending on the form required.

Bentonite offers a flexible seal with low permeability (less than 1.0*10-7 cm/s) and no heat of hydration. Although it has a low thermal conductivity (0.37-0.43 Btu/hr*ft*°F; 0.64-0.74 W/m*K), it can provide an effective seal for heat loop installations in formations that have similar or lower thermal conductivity. However, if the subsurface water has a total hardness of greater than 500 ppm and/or chloride concentration greater than 1,500 ppm, bentonite may not be the best choice because hardness and chlorides impair the swelling ability of the clay. It is this swelling ability that provides the low permeability, so in these subsurface conditions, cement or modified cement could be the better option.

## Bentonite/Sand Mixtures

Bentonite/sand mixtures are the most widely utilized for grouting geothermal heat loops because they provide a low permeability seal with higher thermal conductivities (0.52-1.20 Btu/hr*ft*°F) than pure bentonite. The mixtures are pumped into place, and they can contain up to 400 pounds of sand (in 50-lb. increments) for every 50 pounds of bentonite. Mixtures with the largest amounts of sand have the greatest thermal conductivity. These materials require specific pumping and mixing equipment, and as always, the manufacturer's recommendations should be followed. In addition, each component of the mixture (bentonite, sand and water) must pass certain specific technical criteria if the grout is to be acceptable.

One of the problems identified with use of two-step grouts is the issue of sand settling. It is important to obtain a uniform grout with a consistent thermal conductivity across the entire grout column, so the suspension properties of the bentonite must be optimized for two-step grouts. It is crucial that the bentonite uniformly suspends all of the sand that has been added to the mixture to ensure proper heat transfer from the loop to the formation. Considering that 50 pounds of bentonite could be required to suspend up to 400 pounds of sand, this property is especially important. The bentonite also must provide low hydraulic conductivity in order to ensure the protection of ground water. Even though the well is not producing drinking water, the loop could be drilled through freshwater aquifers, so it is important to protect this vital resource.

In addition, several technical specifications must be met for the sand component. The sand used should be 50/70 mesh, with greater than 99 percent silica content. Sand with a lower silica content is likely to have different (and non-uniform) thermal conductivity, possibly resulting in inconsistent thermal conductivity across the grout column. Coarser sand often causes suspension problems (see Figure 1 on next page) and impacts the thermal conductivity of the mixture. The result of this segregated grout column is zones of high and unacceptably low amounts of sand, and by extension, variable thermal conductivity within the column. In addition, heat transmission through the grout column depends on the amount of contact between the sand grains, and coarse sands have less grain-to-grain contact. This can be visualized by imagining the amount of contact between multiple basketballs in a container vs. the amount of contact between multiple golf balls in that same container.

**Thermal Transmission Grouts and Backfills**

| Thermal Conductivity Range (Btu/hr ft °F) | CLASS |
|---|---|
| 0.37 - 0.43 | Bentonite Grouts (One Step) |
| 0.52 – 1.20 | Thermo-Enhanced Bentonite Grouts (Two Steps) |
| 0.80 – 1.40 | Cement-Aggregate Grouts (Formulated Cement) |
| 1.20 – 1.60+ | High TC Graphite Based Grouts (One Step) |

Table 1. General classification of thermal transmission grouts and backfills.

If the sand is too fine, it could cause the following problems:

- It will cost more.
- It will increase grout viscosity. This is because there is a greater amount of sand particles for a given weight. With a greater number of particles, there also is a greater interaction between the particles, and that contact impedes the flow of the liquid phase (water) through the grout.

The amount of water in the mixture is critical; any excess water can lead to suspension problems and reduced thermal conductivity. To eliminate this problem, the manufacturer's recommended concentrations should be strictly followed.

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(Grouts - Continued)

## Cement-based Materials

Cement-based materials are useful in environments that have high hardness and chloride content because cement is not impaired like bentonite by these chemistries. They offer a rigid, low-permeability seal that has compressive strength (measured in pounds per square inch), while bentonite has shear strength (measured in lbs. per 100 sq. ft.). The low thermal conductivity (0.46-0.52 Btu/hr*ft*°F; 0.80-0.90 W/m*K) of neat cement means that, as with bentonite, cement must be amended if a grout of higher thermal conductivity is required. Also, the thermal conductivity of neat cement can vary based on the manufacturer, density of the cement slurry, and curing temperature. There are two properties of neat cement that can make it problematic for use in heat loops – heat of hydration and lack of filtration control.

Heat of hydration is the heat that is generated when the cement reacts with water. This heat can cause a micro annulus to form in the grout, due to thermal expansion and then contraction of the loop material. Micro annulus formation is especially common when larger diameters of cement are needed due to washouts and erosion caused by poor drilling practices. Formation of a micro annulus often is detrimental to heat flow because air within the micro annulus has a very low thermal conductivity (0.014-0.015 Btu/hr*ft*°F; 0.024-0.026 W/m*K).

Lack of filtration control means that, in porous formations, the water phase of the cement flows into the formation and away from the grout column. If this occurs, it is necessary to return to the borehole to top off the column. In addition, cement requires a specific amount of water for proper curing reactions, so a change in the water present will impair the final set, hydraulic bonding (contact between the loop and cement and/or the cement and the formation), and the chemical resistance of the cement. It is important to remember that chemical resistance could be the very reason that cement was selected over bentonite in the first place. Neat cement can completely dewater in a porous formation with 100 pounds per square inch of pressure (124 feet of a cement column mixed at 94 pounds per 5.2 gallons of water) in less than 1 minute.

For these reasons, cement used in grouts should be modified. The components commonly used to modify cement can include any number of the following ingredients:

- Various sizes of sand and/or other thermal conductivity enhancers.
- Friction reducers.
- Filtration control polymers.
- Retarders to aid in filtration control and pumpability.

The most common modification is one to increase the thermal conductivity (up to 0.80-1.40 Btu/hr*ft*°F or 1.73-2.42 W/m*K can be achieved), and this is readily done without sacrificing compressive strength. Additional modifications then can address the filtration control problem, heat of hydration, and aid in the pumping of the material. All modifications are made to address the specific needs of each job, and provide the best solution.

Figure 1. Suspension problems with coarse sand.

## Graphite-based Materials

Graphite has emerged as an additive for enhanced thermal conductivity applications because it can produce grouts with high thermal conductivity (in excess of 1.60 Btu/hr*ft*°F; 2.77 W/m*K). Graphite-based materials can be the easiest of all the grout types mentioned here to pump. Graphite-based grouts also can be one-sack solutions, so they do not require the addition of multiple constituents on site. However, they have lower yields than a typical bentonite/sand grout, and there is extra cost for the ease of pumping and convenience of the one sack system. As with all materials, the use of graphitic materials must be based on the technical needs of the project.

## Conclusion

There are many products that can be used to grout geothermal heat loops, and the material should be selected based on the technical requirements of the project, geologic conditions, and ground water chemistry. There is no one-size-fits-all solution, so it is important to determine the best solution for each specific situation. The grout selected can only be effective if it can effectively be placed in a hole that has been properly drilled, so it is important to remember that proper fluid design and maintenance, good drilling practices, and good grouting techniques are required to ensure the selected material provides a low permeability seal and transmission of the heat from the loop to the formation.

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