TECHNICALNOTE

Grouting and the environment

by Michael Arstall

Grout in one form or other is widely used for repairing and sealing but specifications are frequently vague, to say the least. Many so-called "grout jobs" form ineffective seals which could have serious environmental and financial implications for owners, specifiers and contractors.

The reason is partly historical because in the past, most grouting was used in mines to stabilise workings or to repair leaks in formations and structures, ie hard rock grouting for which a cement based slurry was an obvious choice.

However, more and more projects involve drilling holes in soft rock, for a wide range of applications from geothermal, installing piezometers, electrical earthing, water wells and so on. These frequently pierce several geological strata, which in nature are isolated from each other.

The problem is that engineers often have little or no idea of the potential impact of making different strata contiguous, and there is growing concern that many of the grouts currently used may be ineffective in terms of their sealing abilities. In some cases they may even present a real threat to the environment.

A far greater understanding is needed of not only what is trying to be achieved with the grout, but also how these actions can upset the sometimes delicate balance of nature.

The challenge

The number of holes drilled each year is increasing dramatically and with it, almost geometrically, the risk of serious contamination, especially where holes cut across different geological strata or where the ground is relatively uncompacted and subject to deformation, channelling and movement.

Even in the case of fully lined holes (as with most oil wells) there is the issue of communication between different geological strata at shallow depths because an uncompacted formation can channel easily around the outside of the casing if exposed to liquid or gas pressure from a deeper level.

Some major risks are:

- Migration of subsurface fluids to ground level – be they liquid or gas.

- Contamination of subsurface aquifers from the surface.
- Contamination of subsurface aquifers by contaminated fluids from other levels.
- Damage to subsurface objects or pipes and cables in grouted conduits.
- Water or gas ingress into tunnels owing to poor grouting or ground movement.

Natural solutions

Happily, nature has given a good steer on how best to achieve these joint objectives. It has shown how effective a seal can be, by forming oil and gas reservoirs and underground aquifers, not to mention preventing highly radioactive deposits from contaminating the ground above.

What is pertinent is that 99% of all these naturally occurring seals are sedimentary in origin and clay based, starting life as soft flexible argillaceous layers that have compacted over time. They consist of natural clays or mudstone which may have become shale with heat and pressure but all have retained their ability to move and deform, thus maintaining the integrity of the seal.

By contrast, hard formations like sandstone or limestone do not deform and tend to fracture under stress in the same way that concrete will split and shatter when overstressed. For the same reason pure cement is not a good basis for a sealing grout in soft ground.

Grout selection criteria

The objective in any grouting project is to select the best technical solution. The criteria are:

1 It should match the strength of the surrounding ground, and in weakly compacted recent formations that can vary from less than 1MPa* to 15MPa which is much lower than the 35MPa of many strongly cementitious grouts. (*ASTM fracture strength).

2 It should have a permeability less than 6.9x10-8m/s.

3 For geothermal work, it should match the conductivity of the formation, typically 1.7-2.4W/m^{oc}.

4 It must prevent migration of water or gas from one formation to another and prevent ingress of contaminants, be it from the surface or from subsurface formations, into areas that may cause future problems.

5 It must stabilise the hole and retain its sealing properties over time, allowing ground movement, settling and change in moisture levels and the removal and replacement and/or repair of any embedded pipes, tools and cables etc.

Planning and design

All these demands can be met by a range of grouts that start with 100% pure clay at one end and progress through a combination of clay, aggregates or cement up to 100% cement at the other, using delivery methods from powder, through granules, pellets and briquettes.

However, most holes are drilled in sedimentary deposits and any one hole may encounter harder, compacted older rocks that have been exposed by geological movement and erosion and softer, more recent deposits that are uncompacted and which can be very variable in composition.

Grout should be considered then as more than a solid plug or a glue, it is more like a flexible caulk. A detailed grout programme design may even include several different grouts in the same hole, which must take account of all the following:

- The reason for grouting the hole, annulus or conduit in the first place, eg support, sealing, containment, protection, strengthening, improving conductivity between objects and land etc.
- The ground conditions, determined from geological data for that area and previous experience, if any, of work already that has been carried out. This will give a guide to the strength of grout needed.
- The presence of any running water courses as well as any surface gas deposits or zones already contaminated in the formations to be penetrated and the depth of the local water table. This will determine speed of set required and resistance to scouring.
- Potential risks to the environment.
- Whether, once in place, there is risk of ground movement, expansion or contraction of any objects contained within the grout. This will determine the degree of flexibility needed.
- Whether any object encased in the grout ever needs to be removed or repaired.
- Longevity required for grouted hole, tunnel or conduit.
- The diameter, depth and number of holes, as the solution must be financially viable.
- Access to site.
- Equipment available for mixing and placing grout.

Conclusions

Pumped grout

For most soft ground applications where sealing is the main priority, a high solids clay powder or high density clay blend with barite or sand is recommended.

For harder ground applications, or where strength is more of an issue, a clay/cement powder blend will work well, with additions of sand if thermal conductivity or strength is to be maximised. It is worth noting, however, that sand mixes can be very hard on pumps and equipment.

Poured grout

For soft formations, where sealing is the main issue, the choice is between clay granules and clay pellets, with the latter preferred where sealing must be done below the water table.

Where higher density grouts are required in a dry hole and good mixing/blending equipment is available, then clay granules and sand and clay powder and sand are options.

For applications needing a stronger plug that is easy to place then, clay/cement briquettes can be considered.

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Michael Arstall has worked in the field of bentonite and its applications for over 30 years, in the oil industry providing a well site geological logging service and later maintaining the drilling fluid used to clean and stabilise the hole.
He provides commercial and technical expertise to a wide variety of UK and overseas companies, and is currently helping Kentish Minerals of Westerham in Kent on new product development for its bentonite and grouting business.

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GROUT SELECTION TABLE

Product	Pros	Cons
Sand	Cheap Can be poured Dense so good thermal conductivity	Highly porous Will flow and leave voids Extremely damaging to pumps Will not form a seal on its own
Cement	Strong Quite dense Good seal for hard substrates Easily pumped Relatively cheap Set time can be varied Very good resistance to erosion	Will not take up any land movement Will not maintain seal/contact around pipes that expand and contract Fluids can channel around it Relatively poor thermal conductivity ~ 0.74W/m^{oc} A large amount of heat is produced as it sets which may damage embedded tools or pipes Too hard for most surface soils Cannot remove any embedded tools or pipes
CE bentonite powder	Easily pumped Forms good seal if stays wet Relatively cheap Will accommodate any expansion or contraction of land and stay in close contact with any tools or pipes Good stabilisation of weak friable formations such as uncemented sand layers Good thixotropic properties Any tools or pipes can be removed and replaced if required	Low solids, typically <10% with max SG around 1.05 Can be difficult to mix and pump at higher solids levels as swells rapidly Can dry out and lose seal completely Low strength Poor thermal conductivity <.6W/m^{oc} Can be degraded by strongly valent cations such as Ca & Mg, and Cl from salt water Low resistance to erosion and channelling + longevity suspect
High Solids Clay powder	Easy to mix to high solids content Can be pumped easily SGs up to 1.2 possible with solids content over 30% Better thermal conductivity than CE bentonite Much more resistant to drying out compared to CE bentonite Forms an excellent seal Will deform plastically to allow for expansion and contraction of land and stay in close contact with embedded objects such as geothermal pipes Very low fluid loss to formation, with excellent hole stabilising properties Good thixotropic properties to support embedded tools pipes or cables Relatively unaffected by Ca & Mg Cations or Cl from seawater Will not seep away into fissures Any tools or pipes can be removed and replaced if required	Density still fairly low Low strength Thermal conductivity still only around 0.74W/m^{oc}
Clay granules	Cheap Can be poured Swells to form an excellent seal when wet Solids content over 60% is possible SGs up to 1.5 can be achieved Good thermal conductivity ~ 1.47W/m^{oc} Will not dry out easily Will deform and maintain seal as land moves Will deform plastically to allow for expansion and contraction of embedded objects such as geothermal pipes Good resistance to chemical attack Will not channel easily Any tools or pipes can be withdrawn later if required	Cannot be pumped Needs to be wetted to form a good seal Risk of bridging if poured too rapidly in small holes Variable size particles give different rates of fall through water and can bridge in narrow holes Can be variable in quality Relatively low strength
Clay pellets	Clean and easy to handle Easy to pour down narrow holes Very consistent quality ie swell and size Less chance of bridging Swells to form an excellent seal when wet SGs up to 1.5 can be achieved with solids content over 55% Can be placed below water table Will not dry out easily Good thermal conductivity ~ 1.42W/m^{oc} Will deform and maintain seal as land moves Will deform plastically to allow for expansion and contraction of embedded objects Good resistance to chemical attack Will not channel easily Any tools or pipes can be withdrawn later if required	More expensive than cement or granules Cannot be pumped Need to be wetted to form a good seal or poured through water Relatively low strength

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Product	Pros	Cons
Clay – cement briquettes	Clean and easy to handle Easy to pour down vertical holes No mixing apparatus needed on site Fairly fast breakdown to form dense solid plug that will set hard over the course of a few days Plug not so hard as pure cement or cement + aggregate Strength of plug can be adjusted within limits SGs up to 1.5 can be achieved with solids content over 55% Can be placed below water table Reasonable thermal conductivity ~ 0.75W/m^{oc} Good resistance to erosion Shelf life of up to six months	More expensive than cement or granules Cannot be pumped Will not deform once set Will not maintain seal/contact around pipes that expand and contract Fluids can channel around it once set
Clay + sand blends using clay powder or granules	Can be blended on site Powder blends can be pumped – see 'Cons' re abrasivity Clay granule + sand blends may be poured allowing for risk of separating SGs up to 1.8 possible with solids content up to 68% using powder Very good thermal conductivity up to 2.42W/m^{oc} possible Cheaper material cost than using barite additive Very resistant to drying out due to high solids content Will deform plastically to allow for expansion and contraction of land and stay in close contact with embedded objects such as geothermal pipes Any tools or pipes can be removed and replaced if required	Good blending equipment is needed if seal is to be consistent throughout the plug If poured care must be taken to avoid segregation and cannot be poured into holes containing water Relatively low strength Sand makes blend highly abrasive and pump wear can be very high Density lower than using barite additive More complex to use than simple clay powder especially at high solids content
High density clay powder blends with barite	Easy to mix Can be pumped easily Low abrasion barite additive reduces pump wear SGs up to 2.0 possible with solids content up to 65% Good thermal conductivity > 1.5 and possible >2.4W/m^{oc} as density is higher than sand, but precise figures need to be confirmed Very resistant to drying out due to high solids content Forms a very good seal Will deform plastically to allow for expansion and contraction of land and stay in close contact with embedded objects such as geothermal pipes or electric cables Very low fluid loss to formation, with excellent hole stabilising properties Good thixotropic properties to support embedded tools pipes or cables Relatively unaffected by Ca & Mg Cations or Cl from seawater Will not seep away into fissures Any tools or pipes can be removed and replaced if required	Relatively low strength More expensive than simple clay powder only mix
Clay + cement powder blends	Can be pumped easily SGs up to 1.8 possible with solids content up to 65% Reasonable thermal conductivity ~ 0.75 -1.2W/m^{oc} Can select strength required by varying cement/water/clay ratio Can vary setting time Very resistant to drying out due to high solids content Forms a very good initial seal Degree of plastic deformation will depend on strength which depends on cement/water/bentonite ratio Good support of embedded objects Relatively unaffected by Ca & Mg Cations or Cl from seawater Will not seep away into fissures Good resistance to erosion	Higher strength mixes will not maintain seal/contact around pipes that expand and contract Care needs to be taken in the formulation and mixing of blends Degree of flexibility a direct trade off with strength A large amount of heat is produced as it sets which may damage embedded tools or pipes Difficult to remove any embedded tool or pipes
Cement + sand or aggregate	Very strong Cheap Good seal for hard substrates Can be pumped or poured Set time can be varied Very good resistance to erosion	Will not take up any land movement or expansion and contraction of ground Will not maintain seal/contact around pipes that expand and contract Fluids can channel around it Too hard for most surface soils A large amount of heat is produced as it sets which may damage embedded tools or pipes Cannot remove any embedded tool or pipes Damaging to pumps