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Testing Grout Seals with an Ultrasonic Probe

by Tom Riewe

In a 1996 report, I described the problems we had found with the use of rotary drilling mud & cuttings slurry as a grout. I reported we planned to continue to study these problems, working with Professors Tuncer Edil and Craig Benson of the University of Wisconsin-Madison Department of Civil & Environmental Engineering. They had developed a down-the-hole ultrasonic probe to evaluate the integrity of grouts. (Photo 1)

Within the past couple years, their graduate students successfully used this probe to test the grout seals of water wells constructed with rotary mud-circulation methods. They first tried to use the probe in steel-cased wells. It did not work because the transducer signal was completely scattered by the rough inner surface of the steel casing and would not penetrate through it. They were able to test wells installed with 5-inch diameter thermoplastic (PVC) casing. PVC casing has a smooth inner surface, so the transducer can be firmly seated against it. The ultrasonic signal is not scattered and passes easily through the PVC casing wall.

They tested wells having both drilling mud & cuttings slurry annular space seals and high solids bentonite grouts. Test results support what we have long suspected, that there are serious shortcomings with the use of cuttings slurry as an annular space seal. The probe sensed significant voids in every cuttings slurry seal tested, including a well in which the slurry was tremie-pumped into the annular space surrounding the casing.

Sealing annular spaces with rotary drilling mud & cuttings slurry has been allowed for private, low-capacity wells in Wisconsin since the late 1950s. For years we have had serious concerns about the use of this material as a grout because we have seen many instances where the slurry settled to a significant depth in the annular space. The results of the recent ultrasonic probe tests offer compelling evidence that cuttings slurry does not provide an adequate grout; and that additional restrictions should be considered for the use of this material as a grout.

On the other hand, the test results have a positive side. In the majority of wells sealed with high solids bentonite grout, the probe did not detect significant voids. The University researchers tested eighteen wells sealed with this material. The grout adhered tightly to the casings and did not settle to a significant depth in the annular space of any of these wells. This indicates that when properly mixed and emplaced, high solids bentonite grouts can provide dense, low permeability seals; seals without the voids the probe detected in the cuttings slurry seals.

BACKGROUND

Pulse-echo technology can be used to evaluate grout seal integrity surrounding a PVC casing. A pulsing transducer, placed inside the casing, transmits an ultra-sonic energy signal through the casing and into the grout. A portion of the signal is reflected by the grout and returns to the transducer. A computer analyzes the returning signal. (Photo 2) The smaller the magnitude of the returning signal, the denser the grout. Each type of seal, or lack thereof, creates a specific, identifiable energy signature that can be interpreted by comparisons with the results from previous field calibration tests. By knowing what grout material was placed, one can infer that the higher the density of the grout, the more impermeable it is.

Early test results showed it was difficult for the probe to tell the difference between water and bentonite slurries. Field calibration tests on both materials yielded very similar energy signatures. This is because bentonite slurries have a very high moisture content causing the probe signal response to be similar to water. This is not a problem when trying to differentiate water from cement grout.

Other researchers have tried and failed to obtain a significantly different energy signature from water as compared to bentonite slurry. The University of Wisconsin researchers accomplished this by first laboratory testing several different sealing materials using transducers of various frequencies. After many trials, they found a relatively high frequency transducer that can induce a signal returning from water that is different from the signals returning from bentonite slurries. The probe can therefore distinguish between the two.

However, use of this high frequency transducer comes with a tradeoff. The higher the frequency of a transducer, the smaller the distance the signal will penetrate through the casing, the grout and the surrounding formation. The signal of the transducer used for these tests penetrates only about an inch beyond the casing. This is enough penetration, however, to evaluate annular space seals.

Testing a grout seal in this way is a tedious, time-consuming process. Due to time constraints in a typical test, the probe is only extended down along one side of the inside of the 5-inch diameter PVC casing. The seal is therefore not checked all the way around the circumference of the casing. In spite of this restriction, if voids exist in a grout seal, there is a good chance some of them will be found at one or more of the selected test points down the casing.

PROBLEMS WITH ROTARY-MUD WELL CONSTRUCTION METHODS

The original impetus for this study was based on our concerns about the adequacy of the annular space seals associated with the use of rotary, mud-circulation drilling methods. The wells tested with the ultrasonic probe were constructed using these methods. First the driller constructed an 8 3/4-inch diameter drillhole (borehole) to total depth while circulating bentonite drilling mud. Into the bottom of this mud-filled hole he inserted a string of 5-inch diameter PVC casing with a continuous-slot stainless steel screen permanently attached to the bottom of the casing. He developed the screen by jetting with water and air.

During the screen development process typically used with this construction method, some of the cuttings slurry often gets disrupted, removed out the top of the annulus, and replaced with water. (Figure 1) Once the screen is thoroughly developed, the driller refills the annulus with the cuttings slurry.

We questioned this sealing method because we were concerned with the adequacy of annular space seals when these development and refilling procedures were used. Also, while the hydrostatic head of the water in the hole will tend to hold it open, there is potential for differential collapse. This is especially a risk when air, along with the water, is aggressively injected during the screen development process.

Some drillers who used this development procedure were making up for the loss or settling of the cuttings slurry by simply shoveling additional slurry out of their mud tank back into the top of the annular space. We asked them to refrain from using this method to try to reseal the annulus. Shoveling drill cuttings slurry back into the top of the annulus and simply allowing it to settle by gravity can result in voids in the seal. Voids can subject the well and groundwater to risk from surface contamination. Interconnecting voids can allow contaminated surface or soil water to migrate down along the outside of the casing. Although most rotary-mud drilled wells using this development procedure produce safe water; any method that leaves voids in an annular space seal is a cause for concern.

We asked several drilling firms to experiment with alternate methods for the installation and development of the screen, and for resealing of the annulus. We wanted to come up with construction and development methods that would not degrade the annular space seal. If this was difficult to prevent, we wanted to find an effective way to reseal the annular space with an approved high solids bentonite grout.

These drilling firms worked closely and cooperatively with us to try to solve these problems. They modified their screen development processes to reduce the amount of water forced down the inside of the casing, and injected air in a less vigorous manner, at lower pressures, and for shorter periods of time. These changes reduced the risk of collapse of the drillhole above the screen. Any collapse of the hole would affect the adequacy of the annular space seal.

The problems discussed here regarding the loss of the cuttings slurry during development of the screen, regarding stabilization of the drillhole, settling of the cuttings slurry in the annular space, and the methods of resealing the annular space, are not unique to wells constructed with PVC casing. These same problems can occur with steel-cased wells because the methods of drillhole construction and screen development are often the similar.

SPECIFIC TESTS WITH PROBE

The ultrasonic probe is designed to check the adequacy of an annular space seal. To conduct the study, several wells to be tested were constructed, developed and grouted in a variety of ways. The grout seals were typically tested at 5-foot intervals, as deep as possible. However, in some of the latter tests, the grout seals were checked at one-foot intervals. These tests are difficult and tedious, so the entire length of the grout seal could often not be tested. A probe returning energy reading of well below 100 indicates a dense grout seal; one just above 100 indicates the presence of water outside the casing; a reading of 700 or more indicates an air-filled void. If evidence of a void was detected, several additional readings were taken, sometimes at 6-inch intervals. The following describes some of the tests and their results:

<u>Gravity-fed drilling mud & cutting slurry seals:</u>

The first set of wells tested with the probe had drilling mud & cuttings slurry as the annular space seal. Two of these wells had been resealed by the driller simply shoveling the cuttings slurry back into the top of the annulus. As seen in Figure 2, in the first well resealed in this way, the probe detected several voids in the seal within the gravel formation extending from the 4 to the 25-foot depth. These voids were above the static water level, at the 25-foot depth. The largest void was found at the 16-foot depth. This seal was tested to a depth of about 50 feet. The probe sensed no significant voids below the water table, indicating different conditions exist when the formation is saturated.

In the second well, similarly constructed and sealed, the water table was not encountered until the 85-foot depth. The formation in the upper 28 feet was primarily coarse gravel, with a sand layer below it, extending to a depth of 112 feet. Below the sand, a clay layer extended from the 112 to the 188-foot depth. A screen was placed in the sand and fine gravel aquifer from the 188 to 199-foot depth.

The seal in this well was tested to the 40-foot depth. As seen in Figure 3, a couple of significant voids were found in the first 10 feet. Another even larger void, extending for about 6 feet, was detected between the 23 and 29-foot depths. This latter void was in the interface zone between the upper coarse gravel layer and the sand layer below it.

The results of these initial tests indicate that voids in the seals tended to be larger and more likely to occur above the water table, and within coarser, more permeable formations. More importantly, the tests show that the gravity method of attempting to reseal the annular space did not provide an adequate seal. After considering these results, we instructed the drilling firms to stop using this gravity method and experiment with other methods that would more likely reseal the annulus without voids.

<u>Tremie-injected drilling mud & cuttings slurry seals</u>:

In the second set of tests, the wells were constructed in a similar manner, but were developed in a less aggressive manner, as described above. The annular spaces were also sealed with cuttings slurry, but were resealed using a pressure-injection method. After the driller finished developing the screen, he inserted a tremie pipe and pumped the cuttings slurry from his mud tank back into the annular space. This was done to try to eliminate the voids in the seal we suspected had been created when the driller simply shoveled the cuttings slurry back into the top of the annulus.

In the first well resealed in this manner, the driller inserted the tremie pipe to the 35-foot depth in the annulus. However, as seen on the graph in Figure 4, even when the driller used this pressure injection method to reseal the annulus, the probe detected one significant void. It extended from about the 6 to the 10-foot depth. This was within the native gravel formation encountered from the 7 to the 23-foot depth. The void was near the top of the annulus where it could have occurred simply due to settling of the seal. Further, it was in the depth zone where the excavation would be made for the installation of the pitless adapter. It did not present a major concern here because it could be easily refilled from the surface.

However, the probe also detected several small voids below the water table, which was encountered at the 17-foot depth. These voids were within the native clay and gravel layer extending from the 23 to the 42-foot depths. They appeared to be much smaller than the void up in the gravel formation, and may not pose a significant hazard to the well and the aquifer.

These test results demonstrate that the pressure-tremie method of injecting the cuttings slurry back into the upper portions of the annular space can provide a better seal than the seals applied by the gravity-feed method. However, even the use of this pressure procedure to re-inject the cutttings slurry did not go far enough to completely prevent the occurrence of voids.

<u>Tremie-injected high-solids bentonite grout seals:</u>

Following these less than perfect results, we asked the drilling firms to go one step further; to mix and pump a Wisconsin-approved high solids bentonite grout into the annulus to replace the cuttings slurry. We asked them to mix the bentonite grout according to the manufacturers specifications and to pump it through a tremie pipe inserted to the bottom of the annular space. In this way the cuttings slurry would be displaced up and out of the annular space by the grout. The drillers agreed and began grouting wells in this manner.

The first well tested with high solids bentonite grout penetrated formations consisting primarily of clay from the ground surface all the way down to the gravel aquifer found from the 94 to the 104-foot depth. There was, however, a thin layer of fine gravel from the 86 to the 88-foot depth. The water table was 21 feet below the ground surface.

This grout seal was tested to a depth of 85 feet. As seen on the graph in Figure 5, all probe readings were below 100, indicating a thorough dense seal throughout the depth of the annular space.

The second well tested with a bentonite grout seal penetrated a more permeable gravel formation from just below the ground surface to a depth of 50 feet. A clay layer was then encountered from 50 to 100 feet. There was fine gravel within the aquifer from 100 to 109 feet. The static water level was at the 35-foot depth. This grout seal was checked to a depth of about 90 feet. As seen in Figure 6, almost all the probe readings were low, indicating a good grout seal, although a small number of readings in the mid-depths were slightly above 100, where there may have been a minor void or gap in the grout. Several readings near the bottom were very low, below 50, indicating a very dense seal. These low readings were perhaps a result of both compaction of the grout with depth and an incomplete displacement of settled drill cuttings by the grout.

Using the probe, the researchers tested eighteen wells sealed with high solids bentonite grout. Geological formations adjacent to the annular space seals varied from clay to gravel. Most of the seals were in good condition, did not settle to significant depths, and contained no significant voids. Eleven of the eighteen seals had virtually no voids below the pitless adapter depth. In the other seven wells the probe occasionally encountered anomalies in the seals where the material appeared to be something other than high solids grout. However, none of these anomalies appear to be of sufficient size to compromise the hydraulic integrity of the seal. Thus, these results indicate that pressure-injected high solids bentonite grout can provide a good seal within native geological formations having both low and high permeability.

CONCLUSIONS

Wisconsin's Private Well Construction Code continues to allow the use of drilling mud & cuttings slurry as an annular space seal. The results of this study provide significant evidence that this material often does not provide an adequate annular space seal. A poor seal can occur even when the cuttings slurry has a weight of at least 11-pounds per gallon, as specified by Wisconsin's Code, and is tremie injected into the annular space.

It appears that serious consideration should be given to modifying Wisconsin's private well grouting requirements to further restrict the use of drilling mud & cuttings slurry as a grout. Within the past decade several states have banned the use of this material as a grout.

On the positive side, these test results offer field evidence that approved high solids bentonite grout, when properly mixed and emplaced, can do good job of sealing the annular space. All of the drilling firms that cooperated in this study have now switched to using this grout on a routine basis and are having good success with it. Some of these firms have either purchased new grouting machines or have made their own.

Although the tremie-injection grouting process adds an extra time-consuming step, and costs these drilling firms more to construct their wells, some are using the grouting step as a selling point with their customers. By showing their customers how the grout will provide a better seal for their wells, and thereby help protect their drinking water from contamination, the drillers are able to sell them on the grout. The drillers are then able to charge an extra fee for this added step and thereby maintain their profitability.

Other researchers have expressed concerns about the use of drilling mud & cuttings slurry as a grout. Last year, in an article published in the *National Drillers Buyers Guide*, Ray McLarty, a bentonite grout expert, expressed amazement that some state regulatory agencies continue to allow the use of cuttings slurry as a grout.

As Ray explained, a drilling mud slurry is a low-solids, high-viscosity fluid that is expressly designed for the process of drilling the hole and holding it open, but is not designed for use as a grout for permanently sealing the annular space.

A drilling mud & cuttings slurry usually consists of more than 90% water; water that can easily be lost to the surrounding formation, leaving behind the meager solids component of the slurry that will likely not provide an adequate seal. This is what makes a cuttings slurry such a poor choice as a grout material.

An adequate grout needs to have just the opposite characteristics. It must be a material with high-solids and low-viscosity that will provide a complete and impermeable seal when properly introduced into the annular space. Some of the newly developed high solids bentonite grouts have these characteristics. Not only do these grouts provide anywhere from 20-30% solids, but, just as importantly, the solids of this type of sodium bentonite readily absorb and hold water, and swell to form a low permeability seal that will not significantly settle in the annular space.

In some discussions with another researcher, Mike Madcharo of the Continental GeoScience Company of Omaha, Nebraska, we learned he has developed a similar sonic density logging tool. His tool uses a gamma ray source that emits an acoustic pulse. It can be centered within the casing, moved up and down, and be used to evaluate the density of annular space seals. He has successfully used this tool within steel cased wells to evaluate the annular space seal, and has not had problems with scattering of the energy signals. We plan to investigate this tool. If it looks like it can work here in Wisconsin, we may use it to also test the grout seals of steel-cased wells.

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