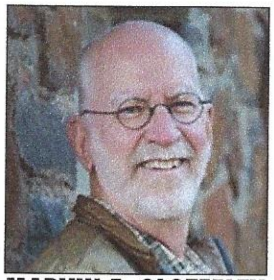

CEMENT OR BENTONITE ANNULAR WELL SEALS

Which to choose?

MARVIN F. GLOTFELTY, RG

I receive inquiries periodically from drillers, regulators, hydrologists, or other folks around the country asking whether a cement or bentonite annular seal is preferable. As with almost all other issues we face in the water well industry, the answer is "It depends."

A couple of years ago, I wrote a The Art of Water Wells column, "Effective Cement Annular Seal Installation," in the February 2022 issue of *Water Well Journal* (*waterwelljournal.com/effective-cement-annular-seal-installation*) on effective annular seal installation, but that column focused only on installation techniques for cement seals. This column will address the broader topic of selecting the right annular seal material for specific water well situations and considerations.

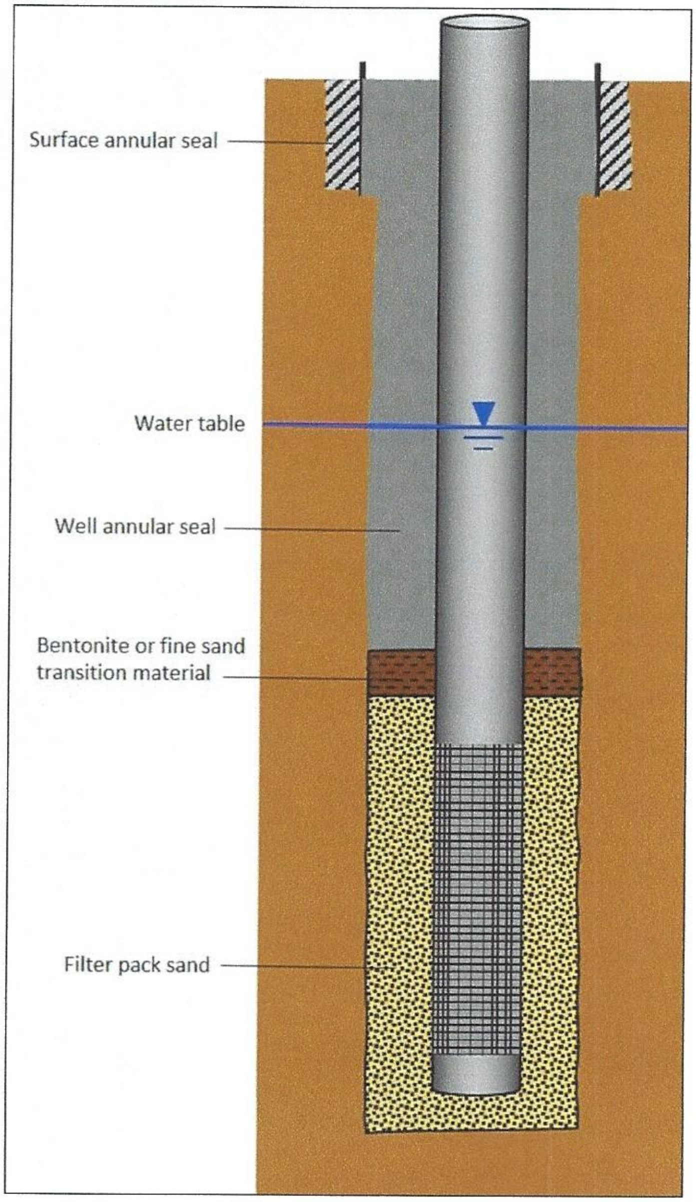

Figure 1. Well annular seal barrier to cross-contamination.

The Most Important Seal

Most states require a cement annular seal in the upper 20 feet to 100 feet of water wells to provide an annular seal outside the surface casing. Although the surface seal is important, the well seal (Figure 1) is actually even more important than the surface annular seal since it will provide the barrier to potential cross-contamination of poor-quality water between the upper aquifer and the area around the well screen.

The well annular seal is typically composed of cement or bentonite clay, and both these materials have advantages and disadvantages depending on the site-specific conditions of the well.

The surface annular seal of a water well is installed to meet regulatory requirements, provide wellhead protection, and to stabilize the work area around the drilling rig during well construction. The rationale for the design and installation of the well annular seal is more focused on functionality of the well rather than on land surface conditions or regulatory issues.

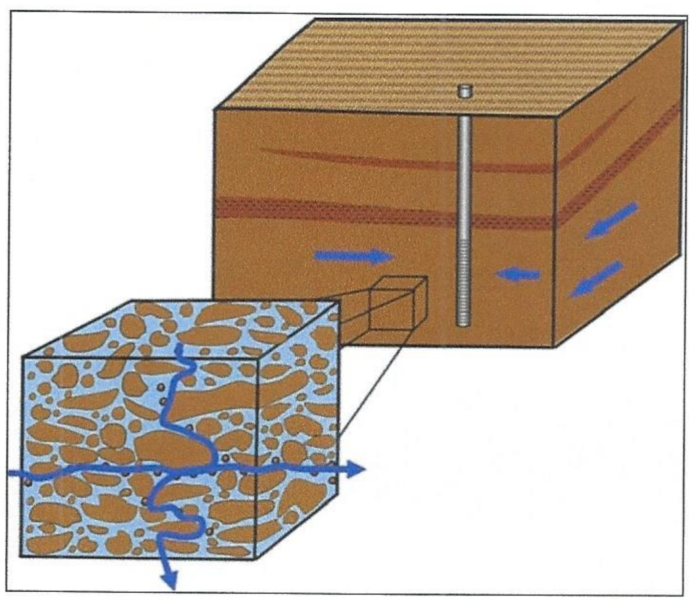

Figure 2. Alluvial aquifer horizontal water flow.

Table 1. ASTM Standards for Common Cements Used in Water Wells

	ASTM Standard		Equivalent API Class
	Ordinary Portland Cement	Portland-Limestone Cement	
General purpose cement	C150, Type I	C595, Type IL	A
Moderate sulfate resistance	C150, Type II	C595, Type IL(MS)	B
High early strength, and shorter curing time	C150, Type III	C595, Type IL(MH)	C
Low heat of hydration*	C150, Type IV	C595, Type IL(LH)	
High sulfate resistance	C150, Type V	C595, Type IL(HS)	

*ASTM Type IV or IL(LH) cement has a long curing time, so it is not commonly used in water wells.

As shown in Figure 2, alluvial aquifers will have preferential groundwater flow in the horizontal direction parallel to geologic bedding planes rather than vertically across those stratigraphic boundaries. This is the hydrologic effect of formation stratigraphy.

Within each individual bedding layer, the sediment is typically composed of elongate-shaped grains that also cause groundwater to follow preferential flow paths in a horizontal direction. This is the hydrologic effect of anisotropy. The effects of stratigraphy and anisotropy are shown by the blue arrows in Figure 2.

The influence of stratigraphy and anisotropy can cause aquifers to develop slightly different water table pressure heads at different depths of a well, which may result in a vertical hydraulic gradient (Figure 3). Although the natural geologic formation will inherently have characteristics of stratigraphy and anisotropy, the well annulus does not have these characteristics, so water movement through the annulus will not be impeded from migrating vertically as would be the case in the adjacent formation.

In cases where a vertical hydraulic gradient is present, the well annulus must be sealed off to prevent the well from becoming a pathway for the flow of water (potentially poor-quality water) from one depth interval to another.

Comingling of waters from different depths of an aquifer is almost always problematic. If the source area of groundwater inflow is of poor quality, cross-contamination will result. Even if the source area of groundwater inflow is of good quality, variabilities in the water chemistry and biological attributes will cause the mixing of the two waters to exacerbate scale formation or casing corrosion.

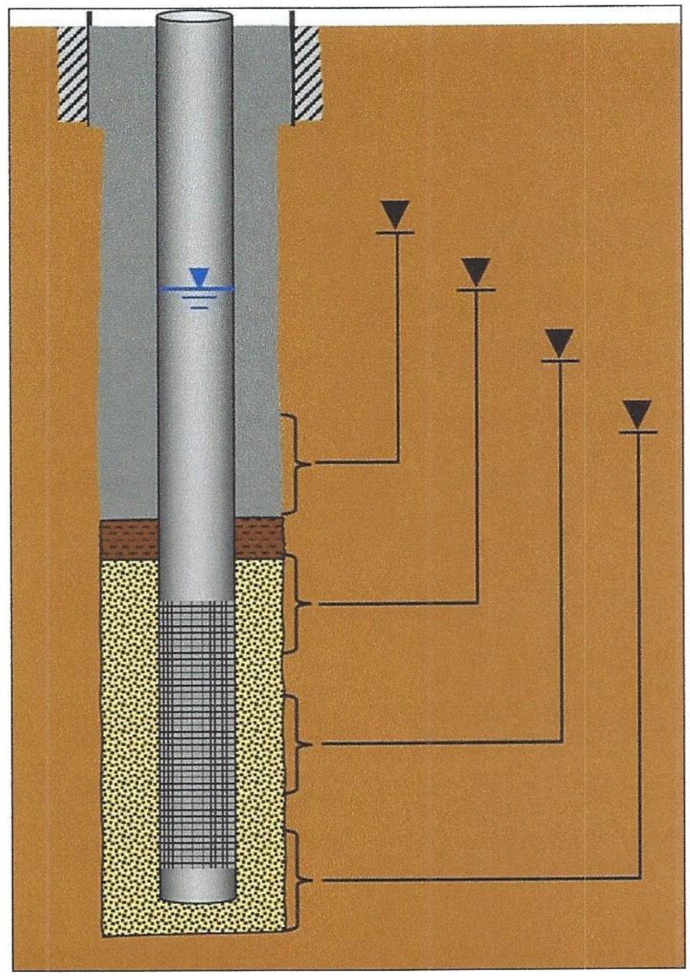

Figure 3. Vertical hydraulic gradient water flow.

Cement Seals: Standards and Additives

A variety of cement types have been designated by the American Society for Testing and Materials (ASTM) that are available to the groundwater industry. Ordinary Portland Cement has been used for many years, but the manufacturing of cement involves operation of high temperature kilns, which emit greenhouse gases. Since cement is the world's leading construction material, it represents a major source of greenhouse gas emissions and accounts for about 8% of all such releases (according to MIT researchers).

To address this, Portland-Limestone Cement has become common, which contains 5% to 15% of ground and uncalcined (unfired) limestone that is blended with the other cement ingredients. The resultant Portland-Limestone Cement reportedly provides similar performance as traditional Portland Cement but with a carbon footprint up to 10% lower. The ASTM Standards for common types of cement, along with some of their equivalent American Petroleum Institute (API) Classifications, are presented in Table 1.

Cement slurries generally contain 5.2 to 6 gallons of water per 94-pound sack of Portland Cement or Portland-Limestone Cement. This mix is variable depending on the specific well design, but it generally accommodates the desired cement properties, while providing a pumpable cement slurry that can be efficiently installed to seal the well annulus.

There are several cement additives that can be used to adjust

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various properties of the cement slurry, including:

- **Bentonite** added as an extender to increase cement slurry volume
- **Pozzolan (fly ash)** added to increase strength and chemical resistance of the cement
- **Sand** added as an extender to increase the slurry volume and reduce cost
- **Accelerator ($CaCl_2$)** added to reduce the cement curing time
- **Retardants** added to increase the cement curing time
- **Dispersants** sometimes added as a friction retarder to make the cement more pumpable
- **Fluid loss agents** added in some cases to reduce the bleed water volume as the cement cures
- **Lost circulation materials** sometimes added when the cement slurry will be in contact with very porous formations.

Bentonite Seals: Certifications and Material Options

Bentonite annular seals, as with other construction materials for water wells, should have National Sanitation Foundation and American National Standards Institute (NSF/ANSI 61) Certification.

Various sources report that bentonite will swell 8 to 15 times its dry volume when hydrated. Bentonite's swelling and sealing properties along with its inert chemistry make it a good option for use as an annular seal in water wells. However, bentonite is sometimes considered difficult to install since it can sometimes swell prematurely and clog tremie pipes or bridge within the annulus above the desired seal depth.

Three common types of bentonite annular seals used in water wells are high-solids bentonite grout slurry, bentonite chips, and bentonite pellets (which are also called bentonite tablets and can be either coated or uncoated).

High-solids bentonite grout is a slurry mixture of powdered bentonite and water that generally contains about 20% solids by weight. Since high-solids grout contains 20% solids, it is also 80% water. This means the bentonite grout slurry can be readily pumped into place, but if the high-solids grout is not kept hydrated, the slurry volume will be greatly reduced, and the sealing characteristics will be compromised.

Bentonite chips are quarried granules of naturally occurring bentonite that do not contain additives. Bentonite chips are commonly provided in ¼- to ⅜-inch or ½- to ¾-inch granule sizes. This bentonite seal material (at least in my area) is probably the most used for water well seals, although installation of the chips to significant depths can sometimes be challenging.

Bentonite pellets (tablets) are a good alternative to bentonite chips in some cases. Bentonite pellets are made with high-quality bentonite that is first field dried, and then further kiln dried and compressed into pellets of uniform shape and size, typically ranging from ¼-inches to ½-inches. Since the pellets are rounder and denser than bentonite chips, they tend to be easier to install through a tremie pipe.

However, pellets are generally more expensive than chips. Due to their higher-quality bentonite composition and their compressed nature, bentonite pellets reportedly have greater swelling capabilities and faster swelling rates than bentonite chips. The rapid swelling rate of pellets can be advantageous if speedy sealing of the annulus is desired, but that fast swelling rate also makes the pellets susceptible to bridging or clogging problems during their installation.

Bentonite pellets are available with a biodegradable nonstick coating that provides a time-released extension of the swelling time. The coating allows the pellets to be installed with less susceptibility for sticking, but a recent study by the Society of American Military Engineers found concentrations of PFAS in the coated bentonite pellets that were tested.

PFAS is a group of synthetic compounds that may cause detrimental health effects, so several PFAS compounds were recently assigned a maximum contaminant level (MCL) by the U.S. Environmental Protection Agency. Therefore, great care should be taken to assure that coated bentonite pellets used in any water well do not contain any PFAS.

Lessons Learned from the Nebraska Grout Task Force Research

Operated by NGWA, the Groundwater Foundation's 2011 McEllhiney Lecture was presented by Tom Christopherson on the Nebraska Grout Study, which involved testing wells that had been constructed with a clear plastic PVC casing so that the actual effects of various annular seal materials could be observed and evaluated. This study provided a good comparison of cement grout, high-solids bentonite slurry, and bentonite chips. Some of the primary conclusions of the Nebraska Grout Study were:

- High-solids bentonite grout appeared stable below the water table, but would not rehydrate if it dried up, so the material was found to be ineffective for the vadose zone.
- Bentonite chips perform well and will rehydrate if dewatered, but they were considered time-consuming to install.
- Cement grout seals provide structural stability, but are prone to cracking or forming a micro-annulus from cement shrinkage.

The Nebraska Grout Study generally determined that the subsurface condition we imagined existing in the annulus of a well was incorrect. Several examples of voids in annular seals were recognized, either due to material deficiencies (e.g., poor seal against the well casing, cracks in cement seals, etc.) or due to installation problems (e.g., void areas within annular seals).

Poor annular seals that result from ineffective installation techniques is an avoidable issue within our control. In cases where a high-solids bentonite grout is appropriate, the bentonite slurry can be pumped into place via a tremie pipe. For bentonite chips or pellets, the installation can be challenging, but many drillers have developed methods to achieve that installation by either pumping the dry bentonite in place through a tremie pipe or with an added stream of polymer solution to reduce the bentonite's hydration time.

Again, installation of cement seals was discussed in my February 2022 *WWJ* column (*waterwelljournal.com/effective-cement-annular-seal-installation*).

Having effective annular seals that are located where needed is a critical element of proper water well design. There is no single annular seal material or installation technique that is best for every well, but it is important to select and install annular seals in such a manner as to address the site-specific conditions and functionality of the individual water well being installed. WWJ

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