

SPECIFICATION OF WATER WELLS

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ABSTRACT

The water well or wells serving a Ground-Water Heat Pump (GWHP) system are as pivotal part of the mechanical design as the boiler and cooling tower would be in a water loop system. As such they should warrant the same degree of attention with respect to specification as the more conventional components would receive. Unfortunately, this is rarely the case and the HVAC design engineers lack of familiarity with the topic is sometimes at fault. This paper is intended to identify the key sections of water well specifications and briefly discuss their contents.

INTRODUCTION

Design and construction of water wells is a topic unfamiliar to many, if not most mechanical engineers. As a result, the task is often poorly handled or worse, ignored. This rarely results in a well completed in the best interests of the owner. Although the HVAC engineer may not always be directly responsible for the design of the well, it's specification or construction management, it is, in the context of a ground-source heat pump system, a critical part of the mechanical design. Consequently, it is in the interest of the HVAC design engineer to become familiar with the terminology of water wells and the key specification issues relating to their construction. The goal of this paper is not to provide suggested specification text but to briefly discuss the key sections found in a well specification document and comment on the contents of each.

WATER WELL TYPES

The design of a water well and the preparation of the construction documents related to it is a function of several issues including the purpose (domestic, municipal, irrigation, injection, etc.), capacity (low <10 gpm [0.6 L/s], medium 10 - 100 gpm [0.6 - 6.0 L/s], high >100 gpm [>6.0 L/s]), geology penetrated (consolidated, unconsolidated, combination) and construction method (mud rotary, air rotary, reverse circulation, cable tool) (NWWA, 1975). Since this paper is limited to wells serving commercial GWHP systems (normally medium to high capacity, rotary constructed), the primary influence on design and specification is the nature of the geology penetrated in the process of construction.

Although, there are an infinite number of well construction designs for a substantial part of the country, the alternatives can be reduced to some variation on one of the two basic designs as shown in Figures 1 and 2. Special modifications to these basic designs can be made to accommodate conditions such as artesian aquifers, injection rather than production, corrosive water etc. The simplest well is one completed in rock formations in which the water is produced from fractures in the rock. In these wells, sometimes called open-hole completions due to the nature of

the geology, no casing or screen is necessary to stabilize and filter the aquifer materials adjacent to the well bore. Casing is normally placed in the upper portion of the well for a short distance to accommodate the installation of a surface seal.

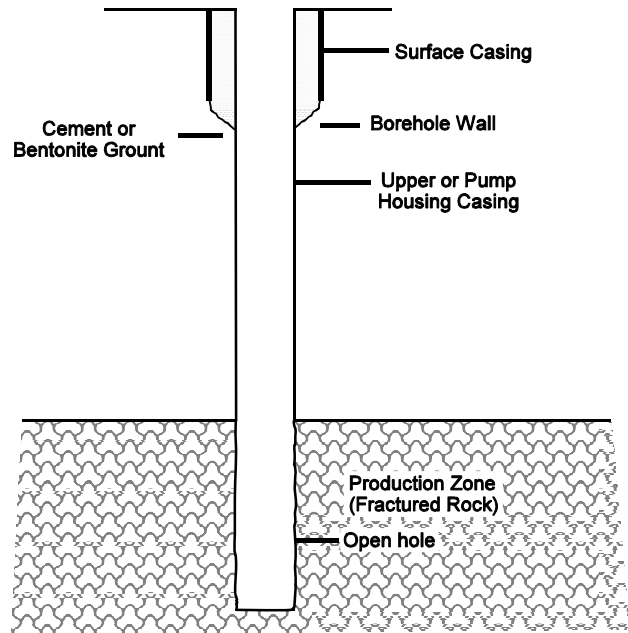


Figure 1. Open-hole well completion.

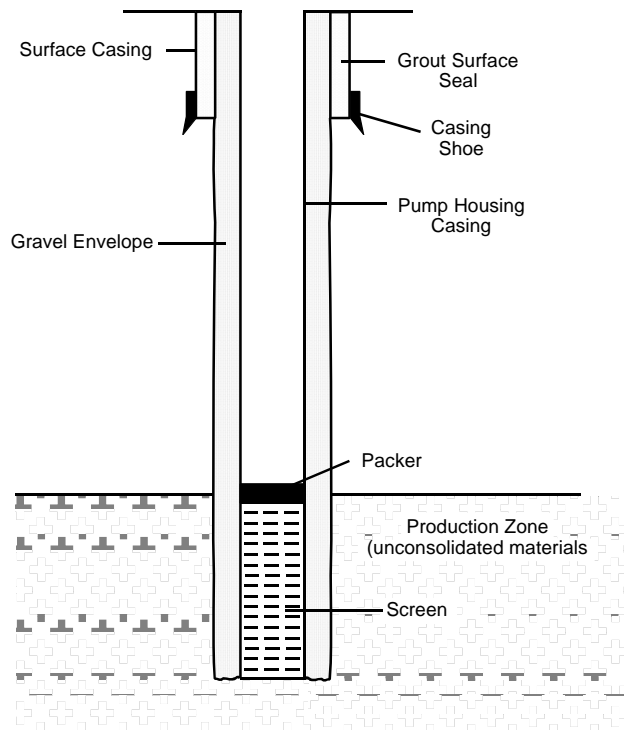


Figure 2. Gravel envelope well.

The second type of well, completed in unconsolidated materials (sand, gravel, clay, soil and mixtures thereof) is more complex. In these applications the well is completely lined with casing, screen and sometimes an artificial filter or “gravel pack.” In unconsolidated settings, the variation in the size of the aquifer materials results in the need to adequately filter the water entering the well to control the content of sand in the water produced. In some cases, a screen alone, attached to the bottom of the casing, will provide the necessary filtering of the water. In other cases, the screen must be accompanied by an artificial filter or gravel pack located between the screen and the borehole wall. This gravel is sometimes only a formation stabilizer of relatively uncomplicated description. For other situations, a more carefully specified filter gravel must be used. The need for accurate description of these components and their installation results in a more voluminous specification document for these wells compared to an open-hole well.

WATER WELL TERMINOLOGY

Prior to discussing the details of individual well specifications sections, it is useful to review a few of the key terms relating to water wells and their operation. Figure 3 includes many of these terms. In any well, under non-pumping conditions, the level at which the water resides in the well is known as the static water level. When the pump is started, the water level will drop to a new level known as the pumping level and this level is a function of the pumping rate. The difference between the static water level and the pumping level is referred to as the drawdown. Dividing the pumping rate by the drawdown yields a value known as the specific capacity with units of gpm/ft (lps/m). This value provides a rough indication of the aquifer/well capacity to produce water. The drawdown is the manifestation, at the well, of the “cone of depression” which forms around the well in response to pumping.

The lower portion of the well in the production zone may be completed with only a borehole (in rock formations), a screen or with a screen and artificial filter (gravel pack) depending on the nature of the aquifer materials. Casing is placed in the well to support the borehole and prevent collapse, to accommodate the installation of a pump, or to facilitate the placement of a seal. The diameter of the innermost well casing (known as the pump housing casing) is primarily a function of the size pump to be installed. Submersible pumps, the type most often used in GWHP systems due to their operation at 3600 rpm, often require one size smaller casing than line shaft driven pumps which normally operate at 1800 rpm or less. Other well casing is sometimes installed in the upper portion of the well to accommodate the installation of the surface seal. The surface seal, often a cement grout, prevents surface water from draining down between the casing and borehole into the subsurface.

WELL SPECIFICATION ISSUES

There are several areas which should be addressed in the course of preparing a specification for a water well and

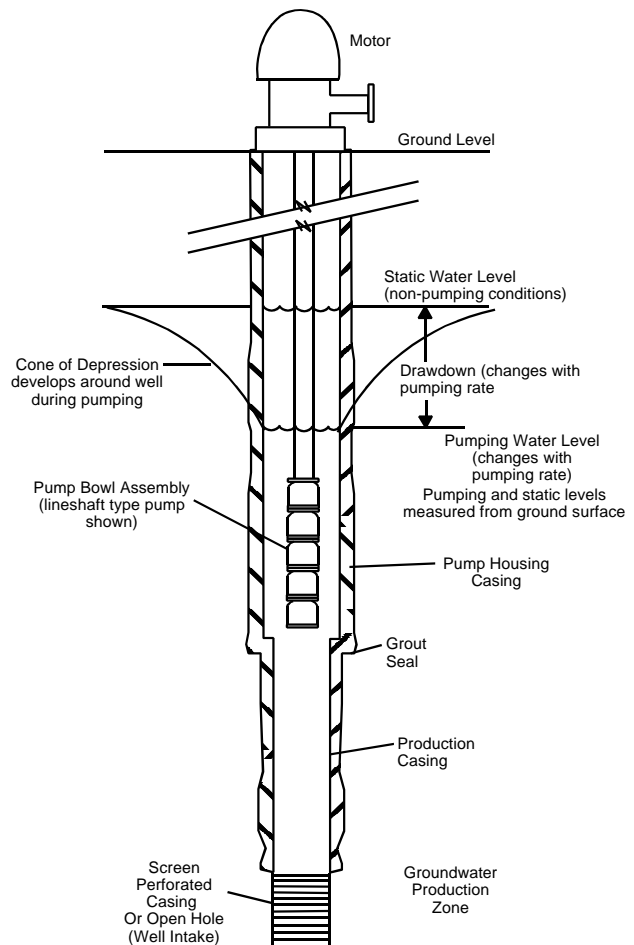


Figure 3. Water well terminology.

Table 1 presents the most important of these. Some issues relate only to certain types of wells or conditions, but this table is a useful checklist for the specification process. There are two approaches to the design and specification of a water well. If there are other wells nearby producing from the same formation and of approximately the same yield, the design of a new well can be based upon the existing wells. This is an acceptable practice assuming the existing wells operate without problems. In other cases, the well design is determined to a large extent by the geology and aquifers it penetrates. A preliminary design can be developed, but it may be necessary to modify this in the course of construction.

Table 1. Key Water Well Specification Sections (gravel pack well)

| | | |
|--------------------|---------------------|---------------|
| Scope of Work | Logs/Records | Flow testing |
| Non-Technical | Plumbness/Alignment | Sterilization |
| Well Issues | | |
| Equipment | Casing | Abandonment |
| Requirements | | |
| Drilling Fluid | Screen | |
| Drilling Program | Gravel | |
| Formation Sampling | Development | |

For a well completed in a consolidated formation (rock), the sections on screen, gravel and sometimes development can be eliminated.

SCOPE OF WORK

This is the section in which a general description of the work is provided. The scope at a minimum, includes the type of drilling rig to be used, approximate depth and number of wells along with the expected yield for production wells. When available, the scope may also provide additional detail on the general construction of the well in terms of casing size, depth, screen type diameter, location and development method. If a performance guarantee with respect to yield, or specific capacity is required, this is also included in the scope section (Roscoe Moss, 1985).

NON-TECHNICAL WELL ISSUES

Non-technical well issues (a phrase used in this paper and not in the specification document) include items not directly related to the technical details of construction. Contractor qualifications, site description, noise control, archeological discovery and facilities provided by owner are normally covered as individual sections, but are grouped together here for simplicity.

The contractor qualifications paragraph normally includes a minimum experience requirement (number of wells similar to the current project, and years in business) and a licensing requirement. Details for a list of reference projects may also be spelled out. The site description is especially important, particularly if potential drillers are from outside the area. A physical description of the site is provided along with background on the geology/hydrogeology. If available, well completion reports from nearby wells are a key part of this information. Noise is normally addressed through the specification of acceptable operating hours for drilling operations. Facilities provided by the owner is one of the few specification issues actually requested by contractors—particularly in the case of site access and water availability. Sufficient water supply for the drilling operation is a critical issue.

EQUIPMENT REQUIREMENTS

In this section, either a specification is made with respect to the drilling rig capabilities required and/or a form is provided on which the contractor must submit a description the equipment to be used in the construction of the well. In cases of shallow wells, such issues as mast, hook and draw-works load limits are not often approached even for small rigs. As a result, it is possible to omit this section in some small projects.

DRILLING FLUID

This is a section that relates primarily to conventional (direct) rotary drilling operations. In this section, an acceptable value (or range of values) for key drilling fluid (sometimes called “mud”) parameters is provided. The drilling fluid or mud is circulated down the rotating drill pipe, out the bit and back up the annular space between the borehole

wall and the drill pipe. It serves to lubricate and cool the bit, carry away the cuttings and form a “cake” stabilizing the borehole walls. Included are such characteristics as weight (11 lbs/gal maximum), marsh funnel viscosity (32-38 seconds maximum), 30-minute water loss (15 cc maximum), filter cake formation (2/32" [1.6 mm] maximum) and sand content (2% maximum). It should be understood that fluid parameters are regularly adjusted in the course of drilling to accommodate situations encountered in the construction process. In some fluid specifications, reference is made to a requirement for a drilling mud engineer’s involvement in the project. On small projects, these services are usually available to the drilling contractor from the mud vendor and the specification of a mud engineer’s availability to the contractor rather than his on site presence is appropriate.

DRILLING PROGRAM SUBMITTAL

This section provides the requirements for submission, by the contractor, of a schedule of tasks to be completed in the process of completing the well. Included are personnel, schedule of tasks (drilling, casing, screen gravel installation, development), and details of the drilling fluid make-up (additives) (Roscoe Moss Company, 1985)

FORMATION SAMPLING

Formation sampling, described in this section is a pivotal part of the well drilling process. It is the samples from the production zone of the well from which decisions are made as to the screen slot size and gravel pack gradation necessary for completion. In rotary drilled wells, if a pilot bore is used, the samples are taken as the pilot hole progresses. If the approximate depth of the producing zone is known, it is normal practice to specify a regular interval over which samples will be taken, the handling, appropriate containers and labeling of the samples along with the individual (or organization) to whom they should be delivered. Sieve analysis of these samples provides the data upon which screen slot size and gravel pack size distribution are based. This consists of passing the samples through a set of progressively finer sieves or screens to determine the size distribution of the sampled material.

LOGS/RECORDS

Depending on the depth, drilling method and purpose for the well, a variety of logs and reports may be specified in this section. For wells of the type used for GSHP systems, it is normally sufficient to specify that the driller report on the depth and physical description of strata penetrated, depth of water producing intervals, and associated static water levels and penetration rates accomplished. If well completion reports are required by regulatory agencies, copies should be provided to the owner/engineer as well. Reporting requirements for flow testing, development and plumbness/alignment are covered in those respective sections.

PLUMBNESS/ALIGNMENT

Plumbness (deviation from the vertical) and alignment (“straightness”) of the well are issues of importance

with respect to the installation of a pump in the well. In particular, lineshaft type pumps are much more sensitive to the alignment issue than are submersible pumps. With a rotating shaft extending from the surface to the pump (sometimes hundreds of feet down in the well), wells in which lineshaft pumps are to be installed must be held to tighter tolerances than submersible installations. Two approaches can be taken to this specification. For small projects using a submersible pump, the required test often involves a 40 ft (12 m) section of pipe ½"(12 mm) smaller in diameter than the inside of the casing, which must be capable of passing freely through to the bottom of the pump housing casing. For larger wells or those using lineshaft pumps, a more sophisticated test involving a device for measuring deviation of the bore is necessary.

CASING

Casing is a term that refers to tubular material extending from the surface to some depth in the well. It is installed to accommodate the sealing of the well, to stabilize the walls of the borehole or to allow the installation of screen or liner (tubular products not extending to the surface). In shallow wells of the type serving GWHP systems, at least two types of casing are often found. Surface casing is installed a short distance (to the first impermeable strata or minimum of 18 ft [6 m] by many codes) from the surface to a depth sufficient to allow the installation of the surface seal (usually cement grout) between the surface casing and the wellbore. The surface casing also helps to support near surface unconsolidated materials during the drilling operation. Sometimes, this surface casing is removed as the grout is placed.

The second casing type is the pump housing casing which as the name implies is the casing in which the pump is installed. This casing is installed inside the surface casing, from the surface to the top of the screen in gravel pack wells or to the top of the producing interval in shallow open hole wells. If used, the screen would be attached to the bottom of the pump housing casing.

In the casing portion of the specification, information is provided on the size, wall thickness, material, and installation method of the casing along with the location (depth), in some cases. Surface casing is normally at least two inches larger than the pump housing casing in order to accommodate the placement of the grout to an adequate thickness. Diameter of the pump housing casing is a function of the pump to be placed in the well. Generally, it is desirable to have a pump housing casing of two nominal sizes larger than the pump to be installed. Pump bowl (impeller housing) diameter is related to pump type and flow rate. Submersible pumps, which typically operate at 3600 rpm, produce more flow per unit diameter than lineshaft pumps which operate at 1800 rpm or less. In most commercial applications, a minimum of 6"(150 mm) casing would be used with 8" (200 mm) for flows >100 gpm (6 L/s) and 10"(250 mm) for flows >300 gpm (18 L/s)(Kavanaugh and Rafferty, 1997). Casing wall thickness is normally specified in this section. Wall thickness requirements vary with drilling method, depth,

diameter and seal placement. In general for sizes up to 14" (350 mm) and depths to 600 ft (180 m), 0.250"(6 mm) wall thickness is acceptable (AWWA, 1997). Most wells serving commercial applications use carbon steel well casing. Plastic materials can be used in very shallow applications permit. Detailed specifications are available on the placement of the casing; however, drilling method (rig type) largely determines the techniques used and in many cases, this issue simply adds needless detail to the well specification.

SCREEN

The screen plays a critical role in the performance of the well since it provides the filtering of the water entering the well. In this section, the type of screen, aperture size, diameter, length, entrance velocity, and material of the screen is described along with the installation method. The determination of aperture (slot) size is made based on the results of a sieve analysis of the drill cutting samples from the production interval of the well. On occasion, when sufficient information is available, the screen can be specified based on the performance of existing wells in the same aquifer. For this to be an effective strategy, detailed knowledge of the geology must be available. In applications where no gravel pack will be used, the screen slot size is specified as that which will retain 30 to 50% of the aquifer materials depending on the corrosiveness of the water and the uniformity coefficient of the aquifer materials. In applications where a gravel pack will be used, the slot size is selected for retainage of 70 to 100% of the gravel pack materials (AWWA, 1997). All slot size selections are based on the aquifer materials sieve analysis distribution curve. The specification can allow the contractor to have a lab do the analysis with the results delivered to the owner/engineer for approval or the samples can be delivered directly to the owner/engineer for analysis.

There are several types of screens available and two of the most common are wire wound and louvered. Wire wound screens (continuous slot) provide a higher degree of open area, through which the water can pass (a critical issue in fine sand aquifers), are generally more expensive than other types and in larger diameters are lower in collapse strength. Louvered screens are generally less expensive, have higher collapse strength, lower open area and provide for more effective development using swabbing. Entrance velocity specification influences the type of screen. In many references (some written by a major manufacturer of wire wound screen), an entrance velocity limit of 0.1 ft/sec (0.03 m/s) is cited. This low velocity tends to require the use of screens with high open area ratios (wire wound). Other research suggests that entrance velocities of as much as an order of magnitude greater than this do not significantly reduce well performance in many applications. Wire wound screens are normally constructed of 304 stainless steel to reduce corrosion problems. Louvered screens can be of carbon steel in many applications due to their higher strength.

Placement of the screen, like the placement of the casing is best left to the contractor; since, it is determined to a large extent by drilling method.

GRAVEL

Gravel is sometimes placed outside the screen to support the aquifer materials (called formation stabilizer) or to increase near bore permeability and to assist in filtering aquifer materials (called artificial filter). Regardless of function, the common term for the practice is gravel pack. The importance of the selection of the size distribution of the gravel material is much greater when it is intended to serve as an artificial filter. Issues to be addressed are size, gradation (uniformity coefficient), geology, thickness and placement.

As in the case of the screen slot size selection, the determination of the gravel pack parameters is based on the cuttings sieve analysis results. One common criteria for the gravel pack specifies that it have a 70% retained grain size of 4 to 6 times the 70% grain size of the cuttings sample and a uniformity coefficient (40% size divided by 90% size) of not greater than 2.5 (NWWA, 1975). Gravel material should be clean and well rounded with a maximum of 10% flat surfaces and should be a minimum of 95% siliceous in content (to avoid dissolution in low pH water).

The thickness of the gravel pack should be between 3 and 8" (75 and 200 mm) thickness. Placement of the gravel is generally accomplished by either pouring from the surface (in shallow wells) or by placement through a tremie (in wells of greater than 1000 ft depth [300 m])(Roscoe Moss Company, 1985). In most shallow wells of the type serving GWHP systems, the pack material will be poured from the surface. This is done while circulating drilling fluid down the drill pipe and up the annular space (between the casing and the bore wall). A key part of the specification is the requirement to maintain drill fluid density below a specific density limit (9.1 lb/gal). The fluid tends to pick up drilling mud from the walls of the borehole as the gravel is placed. The viscosity limit requires this material to be continuously removed during the process. The gravel placement should be completed in one continuous operation.

DEVELOPMENT

The process of development is one in which the fines in the aquifer material or gravel pack and any remaining drilling fluids in the near bore area are removed by a variety of methods. The development process is divided into two phases--initial development using the drilling rig and final development by pumping after the rig has been removed. To some extent, the type of development is influenced by the geology and well type. Specifications describe the type of development, when it should be terminated and most importantly in the final development, what the acceptable sand production for the well is.

In gravel pack wells, preliminary development is often by the so called "flushing" method using a tool known as a "double swab" which can be accomplished with the rotary rig. A more effective method known as line swabbing requires the use of a cable tool rig. Both of these methods are best applied with louver type screens. Jetting is a development technique often used most effectively with wire wound screens and it involves directing high velocity water jets at the

screen/gravel pack. Air lift pumping and sand pumping (used in naturally developed wells) are other methods of development.

Preliminary development is carried on until all of the fines and sediment have been removed from the gravel pack and the pack ceases to settle. Final development is carried on until the specified sand content of the production water is reached. This limit is typically expressed as a sand content in ppm after some period of pumping. Water samples for chemical analysis can be taken toward the end of the preliminary development or during final development pumping.

WATER SAMPLES

Water samples for the purpose of analysis for system design (corrosion and scaling) should be taken during the development pumping. The specification describes the size of the sample and the type of container in which it will be stored (normally a container supplied by the lab doing the analysis) and when the sample should be taken (after 1 hr of pump operation). Finally, the chemical constituents to be tested for are listed. All major anions and cations along with alkalinity, total hardness, carbon dioxide, hydrogen sulphide and oxygen should be included.

FLOW TESTING

Flow testing of the well provides important data for the design of the heat pump system, since the groundwater flow rate chosen is based on pumping power (flow and drawdown).

There are several types of flow tests which can be done on a production well. In many cases, a step drawdown test is done for wells serving GWHP systems. In this test, the well is pumped at three rates until water level has stabilized. The specification describes the flow rates, instrumentation (for water level and flow data), frequency of readings, length of test and facilities for disposal of the water. This so-called single well test provides information primarily on the well itself (yield, drawdown, and specific capacity). A more sophisticated test in which nearby wells are monitored, provides information on the aquifer. These tests are rarely done for GWHP systems.

Generally, the flows chosen approximate 1/3, 2/3 and full design flow anticipated for the system served. Starting with the lowest flow the pump is operated at constant rate until the water level in the well has stabilized at which time the flow is increased to the next rate. Water level is typically measured with an electric continuity device on the end of a calibrated spool of wire. Flow is measured with an orifice plate discharging to atmosphere and pressure across the plate monitored with a manometer. Flow tests are often sub-contracted to a well pump contracting firm.

Some jurisdictions require that any well penetrating a potential drinking water aquifer be sterilized. The paragraph relating to sterilization describes methods, chemical concentration and length of the sterilization procedure which normally consists of chlorine treatment.

ABANDONMENT

In the event that the well is unsuccessful and cannot be used for the intended purpose, it must be abandoned according to the requirements of the regulatory agency responsible for water wells. Most states have very specific regulations covering abandonment which typically require filling the well with an impermeable material--often cement grout. It is not necessary to cover these procedures in detail. Referencing the appropriate state administrative rule will suffice.

INJECTION WELL ISSUES

Injection wells, used for disposal of the water after passing through the heat pump system, differ from production wells in several ways. Two of the more important are screen design and seal placement. Most references recommend a water velocity through the screen of one half that used in the production well. It appears that this guideline is primarily related to the allowance for plugging of the injection screen with particulate carried into the well with the water. From this comes the widely held perception that the injection well should be a larger diameter than the production well. This is not the case. The reduced screen velocity can be achieved by screening more of the aquifer since production wells in water table aquifers normally screen only the lower 1/2 to 1/3 of the aquifer. Beyond this, the need for the additional screen area assumes the presence of particulate in the injected fluid. If the production well is sand-free or if a surface strainer is used to minimize sand, the additional screen may not be necessary.

Sealing of an injection well should be done in much the same way as a production well penetrating an artesian aquifer. The reason for this is that in the course of the operation of the well, the pressure exerted on it is greater than the natural pressure of the aquifer it penetrates. As a result, there is a tendency for water to migrate up around the casing toward the surface. If the well is exposed to a positive pressure at the ground surface, the potential exists for water to leak out around the casing at the surface. To prevent this, injection wells should be sealed from just above the injection zone, continuously to the surface with a minimum 2" (50 mm) annular (between the casing and the wellbore wall) cement seal.

The injection stream should be introduced into the well using an injection tube terminating below the water surface. This prevents the injected water from cascading down from the well head and generating air bubbles in the process. Bubbles driven out into the aquifer can act as an obstruction to water flow in much the same fashion as particulate matter.

SPECIFICATION TEXT

The goal of this paper has been to identify the key sections necessary in the specification document for a water well and to comment on the general contents. Actual guide specification text has been published by many others (Roscoe Moss Company, 1985; AWWA, 1997; EPA, 1975, Montana Water Well Drillers Assoc, 1970). In many cases, these references are published in the form of guidelines for the specification of water wells in which explanatory paragraphs are included ahead of actual specification sections. Editing is normally required to use these sources in construction documents.

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