CI-01-3-3

Specification of Water Wells

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ABSTRACT

The water well, or wells serving a groundwater heat pump (GWHP) system, are as pivotal a 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

The 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, its specification, or construction management, they are, 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 are functions of several issues, including the purpose of the well (domestic, municipal, irrigation, injection, etc.), its capacity (low <10 gpm [0.6 lps]), medium 10 - 100 gpm [0.6 - 6.0 lps], high >100 gpm [>6.0 lps]), the geology penetration (consolidated, unconsolidated, combination), and the construction method (mud rotary, air rotary, reverse circulation, cable tool) (EPA 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 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, and corrosive water. 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," no casing or screen is necessary to stabilize and filter the aquifer materials adjacent to the well bore due to the nature of the geology. Casing is normally placed in the upper portion of the well for a short distance to accommodate the installation of a surface seal.

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

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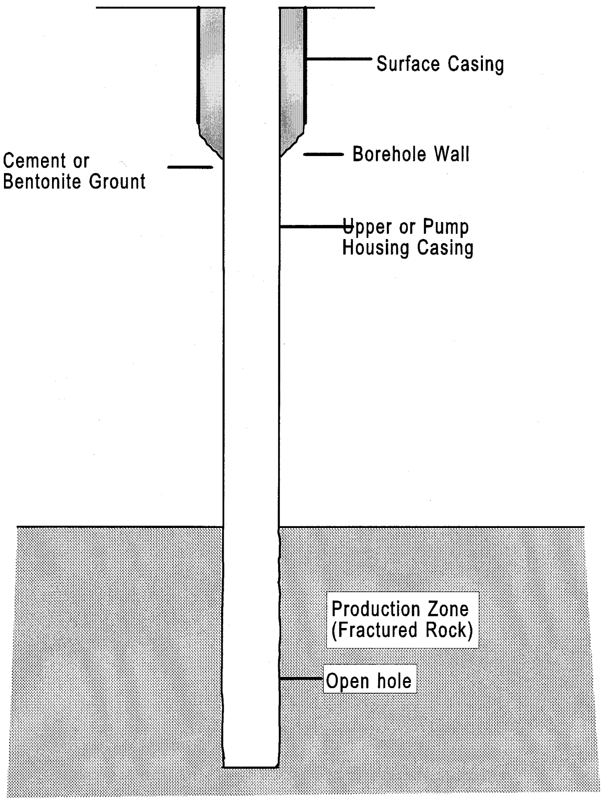

Figure 1 *Open hole well completion.*

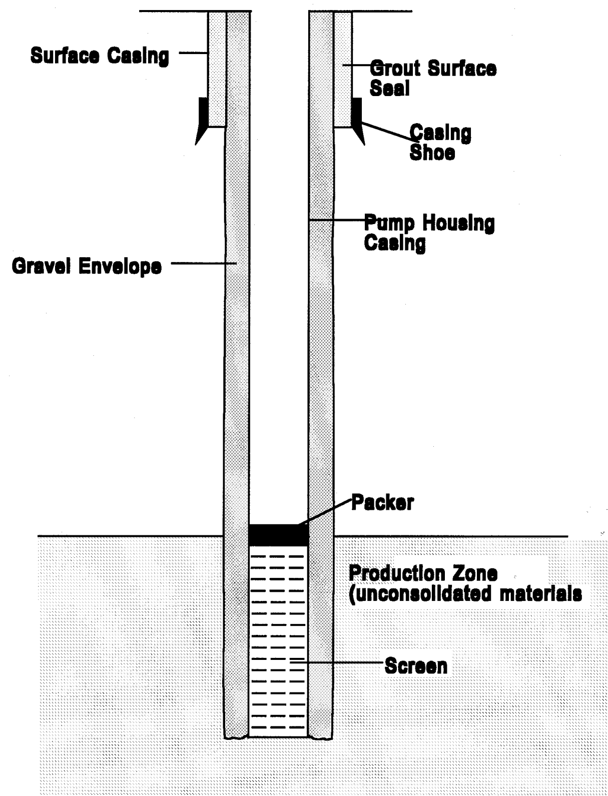

Figure 2 *Gravel envelope well.*

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 descriptions of these components and their installation results in a more voluminous specification document for these wells than for an open hole well.

WATER WELL TERMINOLOGY

Prior to discussing the details of individual well specification 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 nonpumping 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 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 a screen and an 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 of the pump to be installed. Submersible pumps, the type most often used in GWHP systems, often require one size smaller casing due to their operation at 3600 rpm 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 that should be addressed in the course of preparing a specification for a water well, and Table

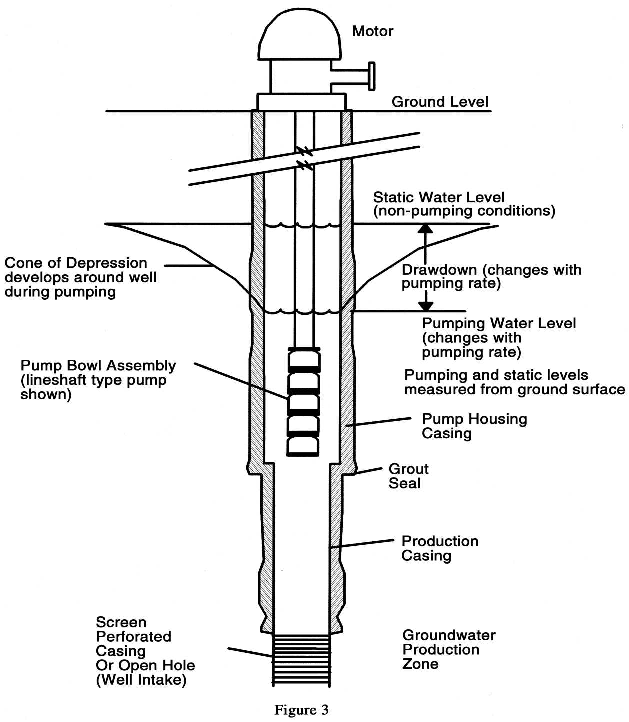

Figure 3 *Well water terminology.*

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 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.

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, number of wells, and 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 (RMC 1985).

TABLE 1
Key Water Well Specification Sections (Gravel Pack Well)

Scope of Work	Logs/Records	Flow testing
Nontechnical Well Issues	Plumbness/ alignment	Sterilization
Equipment requirements	Casing	Abandonment
Drilling fluid	Screen	
Drilling program	Gravel	
Formation sampling	Development	

Nontechnical Well Issues

Nontechnical 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 the owner are normally covered as individual sections but are grouped together here for simplicity.

The paragraph on contractor qualifications normally includes a minimum experience requirement (number of wells similar to the current project, 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. The facility 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, 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 of the equipment to be used in the construction of the well. In cases of shallow wells, such issues as mast, hook, and draw-work 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 lb/gal maximum), marsh funnel viscosity (32-38 seconds maximum), 30-minute water loss (15 cc maximum), filter cake formation (2/32 in. [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 makeup (additives) (RMC 1985).

Formation Sampling

Formation sampling is described as a pivotal part of the well drilling process in this section. Decisions are made, based on samples from the production zone of the well, as to the screen-slot size and gravel-pack gradation necessary for completion. If a pilot bore is used in rotary drilled wells, the samples are taken as the pilot hole progresses. If the approximate depth of the production 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 of 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 the depth and physical description of strata penetrated, the depth of water producing intervals, associated static water levels, and penetration rates accomplished on the driller report. 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 line-shaft 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, **2** in. (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 line shaft 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 well bore. 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, the size, wall thickness, material, and installation method of the casing are provided, along with the location (depth) in some cases. Surface casing is normally at least 2 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 paced 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 line shaft pumps, which operate at 1800 rpm or less. In most commercial applications, a minimum of 6 in. (150 mm) casing would be used with 8 in. (200 mm) for flows >100 gpm (6 lps) and 10 in. (250 mm) for flows > 300 gpm (18 lps) (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 in. (350 mm) and depths to 600 ft (180 m), a 250 in. (6 mm) wall thickness is acceptable (AWWA 1997). Most wells serving commercial applications use carbon steel well casing. Plastic materials can be used in a 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 are 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 retaining 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 with larger diameters are lower in collapse strength. Louvered screens are generally less expensive, have higher collapse strength and 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 criterion 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 (EPA 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 in. and 8 in. (75 mm 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 [300 m] depth) (RMC 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, the acceptable sand production for the well in the final development.

In gravel pack wells, preliminary development is often accomplished by the so-called "flushing" method, using a tool known as a "double swab" that 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, 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 hour of pump operation). Finally, the chemical constituents to be tested 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 that 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, 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 one-third, two-thirds, and full design flow anticipated for the system served. Starting with the lowest flow, the pump is operated at a 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 subcontracted 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 of 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 have 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 one-half to one-third 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 in. (50 mm) annular (between the casing and the well bore 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 a specification document for a water well and to comment on the general contents. Actual guide specification text has been published by many others (RMC 1985; AWWA 1997; EPA 1975; MWWDA 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.

REFERENCES

AWWA. 1997. *Standard for water wells*. Denver Colo.: American Water Works Association, A 100-97.

EPA. 1975. *Manual of water well construction practices*. Washington D.C.: U.S. Environmental Protection Agency, Water Supply Division, 570/9-75-001.

Kavanaugh, S., and K. Rafferty. 1997. *Ground-source heat pumps: Design of geothermal systems for commercial buildings*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

MWWDA (Montana Water Well Drillers Association). 1970. *Recommended standards for preparation of water well construction specifications*. Helena, Mont.: Montana Water Well Drillers Association.

RMC (Roscoe Moss Company). 1985. *The engineer's manual for water well design*. Los Angeles: Roscoe Moss Company.

DISCUSSION

Kirk Mescher, Principal, CM Engineering, Columbia, Mo.: What is the screen velocity recommendation for injection wells? What is the screen velocity recommendation for .05 f/sec or 1/2 value of a production well?

Kevin Rafferty: The rule of thumb for entrance velocity on injection wells is 0.05 ft/sec. This appears to be simply an arbitrary allowance for plugging in the injection well. In my view oversizing of the injection well screen (to achieve the reduced velocity) is not necessary if the injection stream is sand free and incrustation or other plugging mechanisims are not indicated.