A Dry Injection System for the Emplacement of Filter Packs and Annular Seals in Ground Water Monitoring Wells

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Abstract

The reliability of filter pack and annular seal emplacements, and the degree of integrity of installed seals, are two of the most important factors to be considered when both installing and later utilizing ground water monitoring wells.

Numerous, and often costly, problems of using existing methods of installing filter packs and annular seals during the construction of ground water monitoring wells have led to the development of a technique of installing these monitoring well components using a dry injection system.

The dry injection system has been used to construct monitoring wells in extremely complex overburden in bedrock environments with a variety of drilling techniques. The system has shown that a high degree of reliability in the. construction of monitoring wells and greater confidence in obtaining representative ground water samples can be achieved over existing methods of filter pack and annular seal emplacement. The system has also been more cost effective than existing methods, especially for deep boreholes and multilevel monitoring system installations.

Introduction

The reliability of filter pack and annular seal emplacements, and the degree of integrity of installed seals, are two of the most important factors to be con-sidered when installing and later utilizing ground water monitoring wells. Errors made in the emplacement of filter packs and annular seals in monitoring wells can lead to costly redrilling and reinstallation of wells. In addition, poorly installed monitoring wells, which are mistakenly considered to be reliable, may give rise to detection of anomalous chemical results or failure to detect legitimate contaminants. Reliability of installa-tion, seal integrity, and ability to obtain representative ground water samples are not only important in detect-ing ground water quality problems, but may also form the basis of litigation arguments that may follow.

A number of methods for installing filter packs and annular seals have been described or reviewed (Kurt and Johnson 1982, Fetzer 1982, Barcelona et al. 1985, Barcelona and Helfrich 1986, Gibb 1987, Calhoun 1988, Hackett 1988, Aller et al. 1989, and Nielsen 1991). Present methods (e.g., pouring and tremie piping) are fraught with problems such as bridging, jetting of seal materials into filter packs, long material fall times in borehole water columns, and cross contamination. The reliability of many types of installations in which these methods are used, and thus the ability to obtain representative chemical and hydrological data, are therefore dubious under even the best of conditions.

The Geological Survey of Canada Filter Pack and Annular Seal Injection System (Canadian and U.S.A. patents pending; marketed, under license, by Solinst

Canada Ltd.), which uses air or inert gas as the carrier, was developed to overcome the problems with the methods mentioned previously and defray the costs inherent in such methods, especially with regard to standby times on drilling rigs and hourly rates for installers.

Description of Instrumentation

Schematic and photo views of the injector system are shown in [Figures 1]and 2. Numbers in brackets in the following discussion refer to components of Figure 1 (injector system). The two models shown in [Figure 2] differ only in their tank capacities, the smaller model being used mainly for shallow single monitoring well installations in small-diameter boreholes. The instrumentation consists essentially of a pressure tank (6) capable of handling up to 15 liters (large model) of various types of material for injection and an injection nozzle assembly (11), which can be opened or closed on a convex injector base (5). Other features include:

a. A special grit-proof entry valve assembly (8) for con-tinuous loading of injection material when the injec-tion nozzle is closed on the convex injector base (5).

b. A calibrated fine-adjustment cam lever (10) for accurate movement of the injection nozzle off the injector base.

c. Injection side ports (12) on the injector nozzle (II) to ensure fast, uniform injection of material.

d. A pressure gauge (15) to show air or inert gas pres-sure in the tank relative to tine pressure. The gauge is also used to indicate when the tank has been emptied of injection material and if the injection line has become clogged.

e. A valve (14) for relieving tank pressure when the injection nozzle is closed, thus allowing injection material to enter the tank through the material entry valve (8), while air flow is maintained down the injec-tion tubing.

f. A level indicator (16) for measuring the amount of material injected or remaining in the tank after the specified level of screen packing or annular seal has been reached in the borehole.

g. A pulley system (19) for handling a depth rod and cable assembly.

h. A depth rod/cable assembly (not shown) for continu-ous measurement of filter pack and annular seal levels during injection. This assembly is comprised of a 36-inch long, 1/2-inch diameter, lead-filled stain-less steel tube, coned at both ends, with a 3/8-inch Kevlar strain member attached to one end.

i. Various drill casing and rod adapters (1) to fit under the injector support stand (3).

Construction materials are stainless steel (tank body, injection nozzle/shaft assembly, depth level, and valves) and aluminum (injector cap and base, support stand, drill casing or rod adapter, and pulley assembly). Pres-sure ratings for the large and small models are 500 and *350* psi, respectively, with a 3:1 safety ratio. This would allow injection of material into standing water columns of approximately 1000 and 750 feet, respectively, assum-ing a minimum of 50 psi overpressure for operation.

System Operation

After installation of a monitoring well in an open borehole, through drill rods or hollow-stem augers, or inside casing which is to be later withdrawn, the depth of the borehole is verified using the depth rod indicator described in (h) above. The location of filter packs and annular seals to be installed, and the approximate amounts of material needed to complete them, are entered on an installation log.

An injection tubing line with an attached stainless steel leader pipe is introduced down the borehole to a level just above the first zone to be packed and sealed. The diameter of the injection tubing will depend on the annular space between the monitoring well and bore-hole or casing wall. Generally, 3/8-inch or 'A-inch poly-propylene or nylon tubing is used. Both ends of the leader pipe are coned and the inner diameter of the pipe is equal to or greater than the inner diameter of the injection tubing. The

preceding method is also used to replace a clogged or damaged line, or to change to a different diameter of injection tubing. In many cases the injection tubing can be temporarily attached (for later detachment) to the monitoring well as it is being installed (see Figure 3, Example C).

Depending on the drilling method being used, drill rods, augers, or casing are withdrawn from the borehole so that the bit face is just above the first injection level. The drill rods, augers, or casing can be broken at any desired level above the drill platform, generally 0 to 10 feet. This step is eliminated for an open borehole situation.

The injector system is mounted on the drill rods or a tripod, and the injection tubing is attached to the bottom outlet using a swage/ferrule fitting. The injector unit is hooked up to a pressurized source of air or inert gas having an in-line water trap and pressure gauge.

The air injection nozzle (11) is closed down on the convex injector base (5) using the calibrated fine-adjustment cam lever (10) and air or inert gas is allowed to flow into the injection tubing by opening the air shut-off valve (13). This permits purging of water from the injection tubing prior to injection. The amount of air pressure used will depend on the length of the tubing (friction loss) and the standing water level in the bore-hole; a pressure of 50 to 70 psi greater than the pressure required to overcome water head and friction loss is necessary to maintain efficient flow of material down the injection tubing.

While air is still running through the injection tubing, a required amount of filter pack or annular seal material is poured into the tank through the continuous loading valve (8). If bentonite is to be used, it is advisable to run a small amount of sand (1 liter) down the injection tube first in order to aid drying of the inside of the injection tube.

The amount of material injected for each filter or seal unit will depend on the volume of the borehole (minus the volume of the well casing), the desired thick-ness of the filter pack or annular seal, and certain drilling conditions such as washouts when using rotary or reverse-circulation drilling methods. A depth rod indi-cator (not shown in Figure 2) is used continuously over the pulley system (19) at the base of the injector to monitor the level of injected material down the bore-hole. A minimum of 1 foot should be kept between the end of the injection tubing and the final level of each

filter or annular seal unit being emplaced. Adjustments must be made for the swelling of bentonite mixtures.

After a filter pack and/or annular seal interval (e.g., first monitoring well interval) has been completed by injection, the air jet nozzle (11) is closed down on the convex injector base (5), the air valve (13) is shut off, and the pressure release valve (14) is opened to release air pressure from the injector body (6). The injection tubing is then removed from the base of the injector unit and pulled up until the down-hole end of the tubing is above the next injection level. The extra tubing at the surface is cut and the surface end of the tubing remaining downhole is reattached to the outlet of the injector. When casing, augers, or drill rods are being continuously pulled while emplacing filter packs and annular seals, the injector unit must be removed from the top of the rods, augers, or casing. The injection tubing is then pulled up to the next injection level and the extra tubing at surface is cut, sealed with tape or a stainless steel plug, and fastened to the monitoring well installation inside the casing/rods. The desired length of casing, augers, or rods is then extracted from the borehole and the procedures mentioned previously are repeated until the installation is completed.

Applications

The injector system can be used on most types of drilling rigs where installation of monitoring wells is required during or after the extraction of drill rods or casing. Examples of its use with three typical

drilling systems are given in Figures 3 and [Figure 4.]

The reverse-circulation method shown in Figure 3 (Example A) involves the deconing of a tricone drilling bit using a special high-intensity shaped explosive with subsequent introduction of a single monitoring well unit and attached injection tubing down the center of the rods (a detailed description of this method is in prepara-tion). The injector is then mounted directly onto the drill rods, and packs and seals are emplaced as the rods are withdrawn in 10-foot lengths. This method is effec-tive in unconsolidated glacial overburden characterized by thick horizons of thixotropic clays and saturated sands or sandy tills.

With hollow-stem augering (Figure 3, Example B), monitoring well units and attached injection tubing can be installed in the hollow stem and pack/seal injection performed during withdrawal of the augers. Alterna-tively, the monitoring well system, filter packs, and annular seals can be emplaced after the augers have been removed, provided borehole integrity can be main-tained.

The injector system performs well with many types of casing advance/withdrawal methods of installing monitoring wells (Figure 3, Example C), and multilevel monitoring systems on which the annular space is small and the geometry of the monitoring well of a multilevel system is such that bridging of pack or seal materials would be highly probable when using other methods.

Table 1

Injection Rate (litres/min) for Varios Types of Filter Pack and Seal Materials

Injection was done at the bottom of a 100-foot water column, with a 50psi overpressure.

Material	3/8-inch Tubing	1/2-inch Tubing
Ottawa silica sand (<2mm)	1.5	5.5
Granular bentonite (<2mm)	2.0	5.0
Powdered bentonite (<75 micron)	1.0	4.0
Granular PTFE (1mm)	1.5	3.5

If borehole integrity can be maintained, the injector system can be mounted on a suitable tripod over the open borehole after installation of the monitoring system.

Any type of granular or powdered material, such as silica sand, bentonite (granular or powdered), sand/bentonite mixtures, and granular plastics with densities greater than ground water (fresh or saline), can be used for injection provided they have a maximum grain size of no greater than one-quarter the inner diameter of the injection tubing used. Examples of injection rates for various materials are given in Table 1. Injection rates increase with increasing diameter of the injection tubing. Generally, granular material can be injected faster than powdered materials, but the rates for powdered benton-ite are still quite high.

Because of its high-density, granular PTFE, as a filter pack, can be injected at very high rates. Granular plastics may be used in situations where silica sand and other similar filter pack materials may seriously compromise monitoring objectives for inorganic compounds (e.g., chemical attenuation or dissolution of filter pack mate-rials under severe Eli/pH conditions).

Although all materials can be easily injected into a dry borehole, seal materials are best emplaced into a water column to allow for maximum setting of the seal. For relatively dry boreholes, clean water can be

introduced into the borehole during injection of the seal material. If this is not feasible or presents a risk of contamination, then reasonably coarse (0.5 to 3.0 mm) granular sealing compound should be used for injection. When injected into a water-bearing borehole, dry ben-tonite expands quickly (within one to two hours; see Figure 5). Injected material generally drops to settling velocity within 6 inches of the end of the injection tubing; jetting of one material into another has not been observed, provided the end of the injection tubing is kept a minimum of 1 foot above the final level of the sand pack/seal column.

The injector system is particularly suited to bore-holes that telescope in diameter with depth such as a large-diameter borehole in overburden and a smaller diameter continuation into bedrock. A small-diameter injection tubing can be used in the bedrock portion and a new, larger diameter tubing introduced down the bore. hole to complete the overburden section.

Many monitoring wells consist of 2-inch nominal diameter well casings installed in 3- or 4-inch diameter boreholes, leaving only a one-half or 1-inch annular space into which to place sand packs and seals. The ability to use small-diameter injection tubing (down to 3/8-inch) with the present injection method allows place-ment of filter pack and seal materials to be carried out with a high degree of reliability.

The injector system has been used under a wide variety of climatic conditions from -30 C in winter to hot, humid summer conditions. The only precautionary measure that needs to be taken is that bentonite and other similar sealing materials be kept very dry to prevent clogging of the injector orifice. If the orifice does become clogged it can be cleaned easily using a small-diameter test tube brush. Clogging of the injection tubing may occur if moist bentonite is used in the pres-sure tank, a high-quality water trap is not installed in the air pressure line, or adjustments are not made for the swelling effects of dry bentonite in a water-saturated hole and the end of the injection tubing becomes imbedded in the top of the seal. If the injection tubing becomes clogged, a new injection line can be installed easily (see section on system operation). During periods of rain, a rainproof cover over the drill hole is necessary during injection. The injector system can be disassembled easily for cleaning and any necessary repairs.

Advantages over Other Methods

The injector system has many advantages over exist-ing methods of emplacing filter packs and annular seals in ground water monitoring installations. These may be summarized as follows:

a. The delivery of dry sealants, such as granular ben-tonite or sand/bentonite mixtures, allows for maximum expansion and sealing qualities. This is especially important where ground water chemistry may seriously affect the swelling and sealing efficiency of seal materials, many of which are delivered in slurry form with greatly reduced swellirig capabilities.

b. Emplacement of filter pack and seal materials by injection eliminates the problems of bridging so com-mon with boreholes having a small annulus and bore-holes in which multilevel monitoring systems have been installed (see Hackett 1988).

c. Fall times of sand pack and granular sealing com-pounds in a deep borehole with a static water level near ground surface can be considerable during monitoring well installation, particularly if large quantities of mate-rial must be used. The injector system delivers these materials to the site of deposition at a much faster rate.

d. Injection of sand packs overcomes the problem of segregation of falling screen packing material in the water column, especially when using graded filter packs (see Hackett 1988).

e. For multilevel ground water monitoring installa-tions in a single drill hole, the dropping of sealing mate-rials down the water column of the borehole may result in contamination of the upper sampling levels. Using the injection method, most of the water just above the end of the injection tubing is lifted out of the borehole and only the level immediately above a sand pack receives sealing material. After injection, the water col-umn is replenished to static water level either naturally or by addition of clean water. Further filter pack and annular seal zones can then be emplaced.

f. in some cases, a fine silica flour should be placed between sand packs and annular seals (Ramsay et al. 1982). For installations in fine-grained tills and sands, the filter pack should be silt-sized (<200 microns) and a fine-meshed screen (<0.O5mm) should be used (Paul et al. 1988). The injection system can easily alleviate the costly problem of extremely long fall times for this type of material in the water column of the borehole, as well as the problems of bridging when using such fine-grained material.

g. Three of the main problems of using a tremie pipe for emplacement of annular seals are easily over-come by the dry injection system, namely (1) use in temperatures below 0 C, as is the case for three- to six-month working periods in much of the northern hemi-sphere; (2) jetting of seal materials into filter packs due to the high pressures required for delivery; and (3) loss of full expansion and sealing qualities of sealing and grout compounds due to high fluid-to-solid ratios needed to facilitate pumping.

h. The ability to inject various types of sealing and filter pack mixtures directly to a desired location in a monitoring well greatly increases the reliability of the installation and thus the confidence that collected ground water samples will represent monitoring objec-tives.

Discussion

The injection system described has seen wide use on a number of Geological Survey of Canada ground water projects. The system has aided in the installation of single hole, multilevel monitoring systems (up to six sampling piezometers) in complex glacial overburden exceeding 150 feet in depth and in overburden/bedrock up to 400 feet deep. The pressure rating of this system. with a 3:1 safety ratio, allows it to be used to depths of 750 to 1000 feet depending on hydrological conditions.

The development of this system is the direct Outcome of repeated and costly failures with existing "conven-tional" methods of installing filter packs and annular seals, especially when using "casing advance/with-drawal" and "through drill rod" methods of monitoring well installation.

The injection system is not a panacea for all ground water monitoring applications; it will not be useful in situations where sand blows or borehole caving occurs (except in portions above the affected zones). Nor will it have maximum efficiency when inappropriate drilling methods are used for given ground water conditions. It has been found, however, to be superior to present methods used for installing filter packs and annular seals.

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