July HDD Netherlands:Feb 24 thru 26.qxd 6/19/2007 8:59 AM Page 36

project recap/

Excellent Design

HDD well drilled for potable water supply is the right choice at Netherlands site.

By Dr. Harrie Timmer and Bas Pittens

The water supply company Oasen[1] in Gouda, Netherlands, and its partners designed a well drilled with the horizontal directional drilling (HDD) technique. Specific attention was given to the drilling fluid, and problems with well clogging and bacterial growth were overcome. Cost comparison and other considerations have led to the conclusion that HDD is the preferred solution for the renovation of the Zwijndrecht wellfield in the Netherlands.

The theoretical benefits of horizontal wells are well known.[2,3] Horizontal wells may be placed in thin aquifer zones that would require many vertical wells to achieve the same water output. Screen lengths are possible up to 1600 feet. Fewer wellheads mean lower costs of pumps, piping, process control, etc. Fewer wellheads and housings on the surface also mean less concern about vandalism or even terrorist activities. Another advantage is the stable quality of water as regards the purification processes of a drinking water company when it is extracted from one horizontal layer.

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Horizontal wells are not a new idea. In fact, the first written records refer to the use of horizontal ground water wells (qanats) in the central plateau of Iran more than 2000 years ago. Since the late 1980s, HDD wells have been successfully used for drilling wells. Most of these wells have been installed for ground water and soil remediation.[4] However, most cases have had limited capacities of less than 10 m^3/h (less than 45 gpm).

The few horizontal wells for high-capacity water supply purposes that exist in the Netherlands are radial collector wells, a system by which horizontal filter screens are installed radially in a central caisson from which the water is pumped. These systems are relatively expensive and mostly installed due to specific local problems with environmental agencies or the water quality. Only five of approximately 250 Dutch drinking water wellfields contain a radial collector well.

The technique of horizontal directional drilling, which has become a proven technique during the last 20 years for various purposes, was never seriously considered for potable water wells in the Netherlands. One reason is that water supply companies tend to rule out risks and therefore new techniques, but the most prominent problems were technical:

1. The use of large amounts of bentonite as a drilling fluid
2. The impossibility to apply a gravel pack around the filter screen during construction.

These problems are also recognized in the United States.[5] The problem with bentonite is its notorious capacity to obstruct ground water flow and the fact that it is very hard to remove during the development of the well after drilling. Dutch research on well clogging revealed that even small amounts of bentonite will reduce the lifetime and capacity of the well significantly.[6,7]

The problem with the gravel pack was more psychological. The use of a gravel pack around PVC or steel filter screens has been the Dutch standard for more than 50 years and was never discussed.

recap/ continues on page 38

recap/ from page 36

New Insights

Insights have changed since the year 2000. Tests on two Dutch wellfields in 2001 proved that a continuous slot rod-based Johnson screen with a naturally developed gravel pack could be used for water wells without extra sand production, even in the Dutch situation where the aquifer is quite homogeneous (low Uc values of about 2.5 down to 1.5) and where the material consists of Pleistocene fluvial sand and gravel deposits (median grain size: 350 micrometers, 0.0138 inch).

With this knowledge, two projects were initiated using the HDD technique for larger capacities. One project is in Krefeld, Germany, with two HDD wells with a screen length of 558 feet and a capacity of 300 m^3/h (1320 gpm) for potable water purposes. The wells were realized using the HDD technique in a gravel-sized material aquifer, using bentonite as a drilling fluid.[8] The crew discovered that the removal of the drilling fluid during development was indeed a problem which could be overcome using special development techniques and equipment such as a special high-pressure water jet, Jetmaster®.[9]

The other project was in Houten, Netherlands, which was intended for aquifer thermal energy storage in Pleistocene fluvial sands. The first well was made with an alternative drilling fluid, which ended in the collapse of the well. However, two HDD wells that were drilled afterward using bentonite were successful after months of costly efforts to remove the bentonite.[10]

Added to the information of the geotechnical research institute GeoDelft[11] that alternative degradable drilling fluids are available with the required strength as equivalent to that of bentonite for HDD drilling, these insights have solved Oasen's jigsaw puzzle of techniques and experiences and have led to the conclusion that an HDD well has become a serious option for well design.

This conclusion was discovered and tested at the renovation of the Zwijndrecht wellfield. At this location, 14 shallow wells with a capacity of 25 m^3/h (110 gpm) each and a filter screen at 15 to 20 meters (50 to 65 feet) below surface level needed to be replaced. An additional problem was that the wells were located in a park with public access, whereas Oasen intended to optimize security by diminishing the amount of wells in the public area. Based on a back-of-the-envelope way of comparing the cost of different water production systems, Oasen decided to start a "research, design, and construct" project for the development of a horizontal well at Zwijndrecht in 2005.

Project Approach

An HDD well cannot be picked off a shelf. A large amount of practical and technical details have to be tested and invented. Therefore, Oasen formed a joint venture with selected partners. These were the consultancy firm IF Technology[12] for its well construction knowledge and experiences in the Houten project, the contractor Visser & Smit Hanab[13] for its experience with HDD pipelines and innovative strength, and the research institute GeoDelft for its knowledge of drilling fluids.

Research Approach and Results

Research and design were carried out during an intensive six-month cooperation, starting with an informative trip and discussion with the German colleagues of the Krefeld Water Works.[14] The research topics were focused on the drilling fluid and the removal of this fluid after drilling. The questions that were investigated referred to alternatives for bentonite and to the effects of such alternative biodegradable fluids on the microbiological growth afterward. The research process scaled up from literature research to laboratory research and field tests. The resulting solution and design were discussed with the Krefeld engineers.

Laboratory Research

GeoDelft took some continuous soil samples from the entire aquifer depth. Sieve analyses were conducted on these samples. Then the aquifer material was mixed with a selection of five possible drilling fluids in various concentrations, with bentonite being used as a reference.

The necessary geotechnical parameters were obtained from these mixtures, such as compactness, viscosity, and yield point. For each possible drilling fluid, the optimum geotechnical concentration for HDD was determined.

These optimum mixtures were tested on potential bacterial growth in the laboratory of Kiwa Water Research in Nieuwegein, Netherlands.[15]

From the geotechnical tests, it could be concluded that only bentonite and xanthan (XCD) were suitable as drilling fluids for a successful HDD well in the selected aquifer. Only these fluids (in combination with the natural drilled soil) had the necessary thixotropic properties. These fluids exhibit a stable form at rest, but become fluid when agitated. This means that cuttings of the drilling process do not settle during rest periods of the drilling process and

recap/ continues on page 40

Table 1
Results of Laboratory Research on Bacterial Growth Caused by Drilling Fluids

Drilling fluid	Incubation conditions	Potential for bacterial growth (ng ATP/mL drilling fluid)	Time up to maximum ATP concentration (days)
Xanthan	H_2O_2	45*	26
Potato derivate	H_2O_2	22,400	26
Guar gum	H_2O_2	66*	26
CMC	H_2O_2	55	12
Bentonite	H_2O_2	22	26
Xanthan	anaerobic	1500	6
Potato derivate	anaerobic	7900	5
Guar gum	anaerobic	3300	2
CMC	anaerobic	42	4
Bentonite	anaerobic	9	15
blank 1	—	0	15

CMC=carboxyl methyl cellulose
ATP=adenosine triphosphate
*After 26 days the test ended, but the maximum ATP concentration had not been reached yet. Probably, the potential for bacterial growth is higher than the potential for bacterial growth without hydrogen peroxide, but bacterial growth started later as it was inhibited by the hydrogen peroxide.

recap/ *from page 38*

will be removed or flushed after the drilling has been restarted.

The results of the tests on bacterial growth are given in Table 1. Tests were conducted on the selected optimum mixtures with and without hydrogen peroxide (H_2O_2). Hydrogen peroxide was added based on the idea that removal of a biodegradable drilling fluid such as CMC or xanthan would be accelerated by dosing hydrogen peroxide during the development of the well.

From the bacteriological tests it could be concluded that bacterial growth of xanthan was not negligible and could therefore result in bacteriological problems in the drinking water facility. However, bacterial growth on xanthan was seriously slowed by the presence of hydrogen peroxide. Because of the lack of an alternative, it was decided to conduct field tests with xanthan in which extra attention should be given to the attenuation and flushing of the xanthan as quickly as possible after drilling.

Field Tests

To verify the laboratory results on a field scale, a protocol was developed for drilling and developing a horizontal well. This protocol was tested on a vertically drilled well (reverse circulation rotary drilling technique). This well was equally designed, dimensioned, and drilled as foreseen for the horizontal well. This includes:

- Similar aquifer properties
- A 10-inch stainless steel Johnson filter without gravel pack
- An equally dimensioned discharge of the well
- A similar drilling fluid and development method (Table 2).

The most important goal of the field test was to test the protocols and examine the behavior of the well during development as regards well yield, sand production, and bacterial growth.

The development procedure of the test well consisted of:

1. A physical step using high-velocity jetting and pumping
2. A chemical/physical step introducing hydrogen peroxide
3. Hydro-jetting and pumping
4. Pumping at maximum capacity.

Table 2
Design Characteristics of the Vertical Test Well and the Proposed Horizontal Well

Specification		Test well	Horizontal well
Diameter of borehole	mm (inch)	300 (11.8)	300 (11.8)
Diameter of well screen	mm (inch)	250–270 (9.8–10.6)	250–270 (9.8–10.6)
Length of well screen	m (ft)	10 (33)	150 (492)
Depth of filter	m (ft) below surface	14–24 (46–79)	16–18 (52–59)
Well screen		Stainless steel continuous slot, rod-based Johnson filter	Stainless steel continuous slot, rod-based Johnson filter
Slot size	mm (inch)	0.3 (0.012)	0.3 (0.012)
Surface area of well screen	m^2 (ft^2)	9.4 (99)	141 (1520)
Pumping yield during development	m^3/h (gpm)	20 (88)	300 (1320)
Proposed production yield	m^3/h (gpm)	20 (88): maximum 10 (44): average	300 (1320): maximum 150 (660): average
Apparent velocity on borehole wall	m/h (ft/h)	2.12 (7.2): maximum 1.06 (3.48): average	1.06 (3.48): average

From the field tests it was concluded:

- With the proposed combination of filter material, drilling fluid, and development method, it is possible to drill, install, and develop a well that is free of sand, silt, and drilling fluid (Figures 1 and 2).
- Bacterial growth can be minimized within four weeks (Figure 3).

From the field test, Oasen concluded that a horizontal well is technically possible for the specific location.

Cost Comparison and Conclusion

A detailed cost comparison revealed that a horizontal well for the specific location would be equally as expensive as the renovation of 14 vertical wells. This comparison included the unforeseen extra costs needed for an expensive renovation of the existing power supply when using the horizontal wells with high-capacity submersible well pumps. When designed "from scratch" and not puzzled into the existing drinking water field situation, the horizontal well would be less expensive by about 10% to 20%.

As a result of the benefits on purification and policy, the research project team concluded that an HDD well was the best solution. Oasen plans to employ the described technique to renovate its Zwijndrecht wellfield in the near future. *WWJ*

Footnotes

[1]http://www.oasen.nl/ (accessed January 10, 2007).

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