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Groundwater for Heating and Cooling in Melhus and Elverum in Norway – Highlights from the ORMEL-Project with Focus on Infiltration Wells

Randi Kalskin Ramstad, Sondre Gjengedal, Bjørn Syvert Frengstad, Bernt Olav Hilmo, Mari Helen Riise and Henrik Holmberg

S.P. Andersens veg 15A, 7431 Trondheim

Randi.Kalskin.Ramstad@ntnu.no

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ABSTRACT

The main objective in the research project called *Optimal Utilization of Groundwater for Heating and Cooling in Melhus and Elverum* (2015-2018) in Norway has been to provide a sufficient and sustainable base of knowledge for optimized utilization and management of the aquifer in the two town centers. Many open system GWHP in the center of Melhus have challenges with clogging of the injection wells due to iron and manganese precipitations, and/or filling of the wells with particles of sand and silt pumped with groundwater. Precipitation of iron and manganese reduce the capacity of wells and affects pumps, pipes and heat exchangers. The infiltration capacity is gradually reduced by the filling of the well screen part of the infiltration well. Therefore, the screened groundwater wells in sand and gravel aquifers, and especially the infiltration wells have gained special attention in this article. Re-infiltration of heat exchanged groundwater to the aquifer seems to be more challenging than pumping groundwater from a production well. Another important point is that the experience with the use of screened infiltration wells at least in Norway, is scarce and almost limited to the open ground source heat pump installations where the first ones were established around 20 years ago. Before the ORMEL-projects including the sequel ORMEL2, there has been little systematic studies on the use of groundwater for energy purposes in Norway.

The experience from rehabilitation of an infiltration well in an open system GWHP installation at Melhus, namely Lena Terrace, has been used to illustrate the complexity of the problem to be addressed and the need for a systematic approach with the topic. Here a mix of both precipitation of iron oxides and sedimentations seems to occur. Theoretically and in general, we cannot exclude the possibility that some pumping wells also continuously produces suspended solids with the groundwater. The best rehabilitation results of the infiltration well at Lena Terrace seems to be the steaming and the sectional mammoth pumping. Rehabilitation of drinking water wells also often obtain good results with this method. However, the method is not widely used maybe due to limited availability by the industry and knowledge. Compared to production wells, the need of rehabilitation of infiltration wells seems to be more present with respect to both sediments and precipitation of e.g. iron and manganese oxides. Therefore, it is time to develop the steaming and mammoth pumping procedure further so that this well cleaning method is easily available, effective and can be used on a regular basis and before the infiltration rate in the infiltration well is critically low. Two more important issues are also addressed in the Lena Terrace case, namely the usefulness of the video inspection and the need for good surveillance of the operation of the open system GWHP. Video inspections document, and give a cost effective well condition analysis, and should be used before and after well rehabilitations in addition to hydraulic tests. The need of a central control and monitoring system is essential. With the new central control system available at Lena Terrace this winter, the last rehabilitation in July 2019 was initiated with basis in the monitoring of the water level in the infiltration well and done as a preventive measure before the situation got critical.

This broad perspective and approach concerning the use of groundwater to energy purposes should continue taking into account the ongoing plans for establishing a large-scale system in Melhus. This involves further work with design, to understand precipitation mechanisms and conditions, to achieve effective operating strategies with routinely and cost-effective maintenance and targeted well rehabilitation procedures.

1. INTRODUCTION

The main objective in ORMEL has been to provide a professional and sustainable basis for an optimal use and management of the groundwater resources in the town centers of Melhus and Elverum in Norway. The groundwater resources consist of sand and gravel aquifers. A comprehensive program of investigations has been performed within the project (2015-2018), e.g. drilling of investigations- and production wells, well testing, well rehabilitation and modelling. Previously, mapping of the groundwater resources has been lacking, and different levels of experience and competence by the use of groundwater to energy purposes has been limiting factors for the use of this renewable energy source.

The aquifer in Melhus is large and should be utilized on a commercial and large scale. The potential for heat extraction from the groundwater in the center of Melhus is estimated to be in the range from 5-10 MW and 15-30 GWh/year depending on how the systems are operated (Ramstad et al. 2018). The potential for cooling is in the same order of magnitude or more. These numbers are larger than the demand for heating and cooling in the center of Melhus. There are also areas in Elverum where large quantities of groundwater can be used locally. ORMEL2 (2018-2021) is a sequel to ORMEL focusing on iron and manganese issues in groundwater, and a hydrogeological design and operational basis for a large scale utilization of the groundwater resource for energy purposes in the center of Melhus.

The use of groundwater for energy purposes

The use of groundwater for energy purposes has a relatively short history in Norway. The ATES system at Oslo airport Gardermoen build in 1998 is among the first systems in Norway (Eggen and Vangsnes 2005), together with the first in Melhus in

1999 (Riise 2015). Traditionally, groundwater in sand and gravel aquifers in Norway has been used for drinking water purposes. When starting to utilize groundwater for energy purposes, the heating industry was introduced for hydrogeology. Unfortunately, the hydrogeological knowledge and experience already gained by the drinking water industry regarding groundwater wells in sand and gravel aquifers, has to a little extent been taken advantage of by the heating industry. Thus, some mistakes experienced and overcome within the drinking water industry, have therefore been redone within the heating industry when starting using groundwater for energy purposes. The ORMEL-project has contributed to bridge this gap in every level of the value chain so that there is enough system knowledge to design, operate and maintain profitable open system ground source heat pump systems (GWHP) in a systematic way. The complexity of these kind of systems requires multidisciplinary skills spanning from knowledge on extraction of groundwater from sand and gravel deposits, heat pump technology, automation/monitoring and operation and maintenance. Extensive cooperation between the disciplines and a sufficient level of system knowledge are necessary to ensure the integrity of the system as a whole.

Figure 1 shows the principles for the use of groundwater for heating purposes. In heating mode the groundwater is pumped from a production well. The energy is extracted by lowering the temperature of the groundwater in a separate heat exchanger prior to the heat pump. Finally, the groundwater is re-infiltrated into the aquifer by an infiltration well. Both the production and infiltration well are typically made by continuous and slotted (con-slot) screens as seen to the left in Figure 2. In cooling mode, e.g. the system can be switched.

An important difference between the use of groundwater for drinking and energy purposes, is the need for an infiltration well for re-infiltration of heat exchanged groundwater to the aquifer. Due to the re-infiltration there is no net extraction of groundwater from the aquifer, only a net extraction of energy either by lowering or elevating the temperature of the re-infiltrated groundwater. Except for a few drinking water plants with artificial infiltration of water in vertical groundwater wells, the experience with infiltration wells in Norway is limited.

Many open system GWHP in the center of Melhus have challenges with clogging of the injection wells due to iron and manganese precipitations, and/or filling of the wells with particles of sand and silt pumped with groundwater. Precipitation of iron and manganese reduce the well capacity and the life-time of pumps, pipes and heat exchangers. The infiltration capacity is gradually reduced by the filling of well screen part of the infiltration well. The solution to many of these problems are better maintenance and system design ensuring simple and routinely maintenance. This paper presents the highlights from the ORMEL-project with special focus on rehabilitation of infiltration wells with reduced infiltration capacity due to sedimentation and precipitated iron oxides, illustrated by an example from one of the plants in Melhus called Lena Terrace. These results have a wide application and transfer value within hydrogeology and screened water wells.

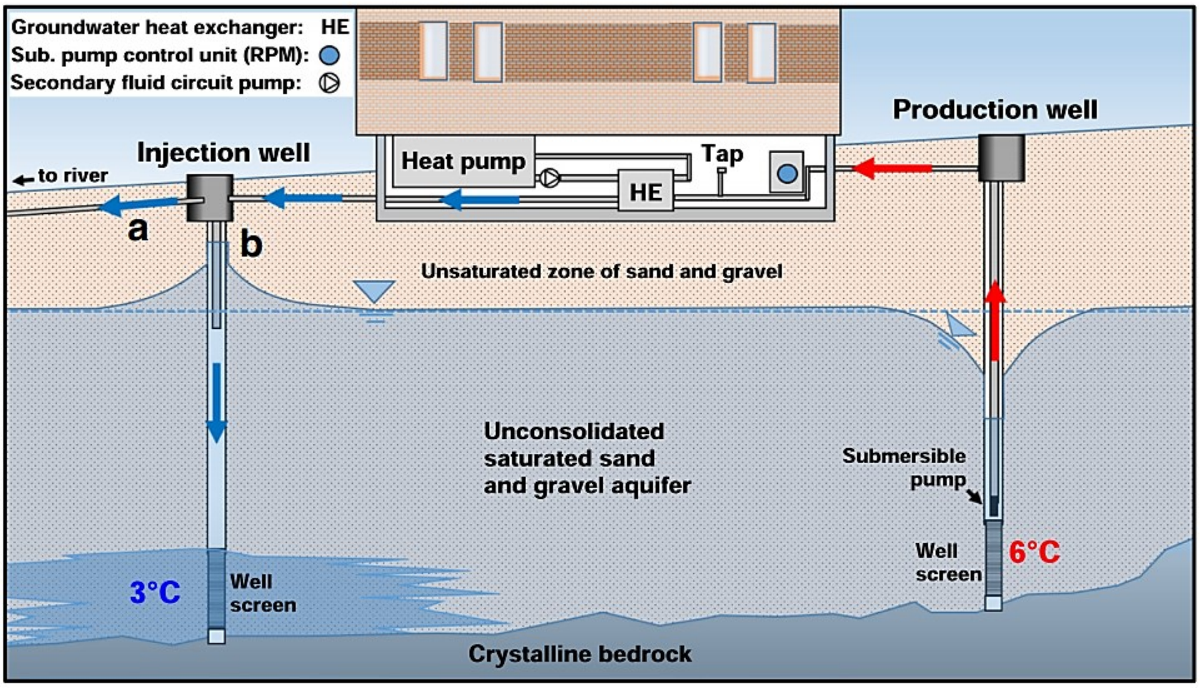

Figure 1: Principle drawing of the use of groundwater for heating purposes. Groundwater is pumped from a production well, the groundwater is heat exchanged in a separate heat exchanger prior to the heat pump. Groundwater with a few degrees lower temperature is re-infiltrated into the aquifer by an infiltration well (Gjengedal et al., 2019). Both the production and infiltration well are typically made by continuous and slotted (con-slot) screens as seen to the left in Figure 2.

A typical groundwater well in Norway

A typical groundwater well in Norway consists of con-slot well screens in a sand and/or gravel aquifer of glacial or fluvial origin. Figure 2 shows a con-slot well screen seen from the outside. A natural filter of coarser sand and gravel near the screen is made by washing out the finer particles which can be seen further out in the formation. Washing of the well screen after installation is an important step in establishing the groundwater well. The procedure consists of pulses with pumping air into the formation after the installation of the well screen. The groundwater is pushed back in the formation and when the air pressure releases, the hydraulic pressure creates a flow back which can be seen as a "blow out" of water from the well (to the right in Figure 2). Many repetitions and sectionalized washing ensure a well-functioning natural filter with high permeability around the well screen as seen in the left picture.

Commonly a groundwater well is between 10 and 40 meters deep and produces10-30 liters/second, but sometimes more. The groundwater has a stable temperature all year around. In the most northern and in mountain areas of Norway, the groundwater temperature can be too cold to utilize for heating purposes. The content of iron and manganese solved as ions in the groundwater can sometimes be challenging with respect to precipitation of oxides.

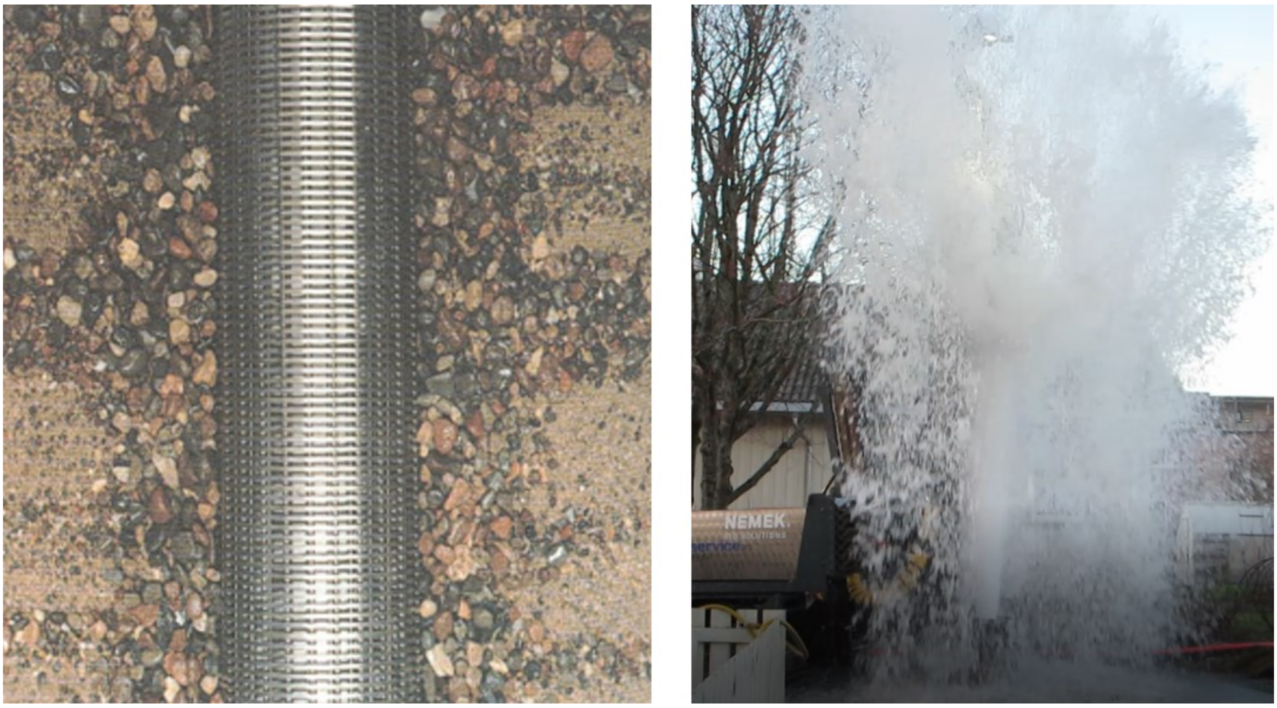

Figure 2: The left picture (from Driscoll) shows a con-slot well screen seen from the outside. A natural filter of coarser sand and gravel near the screen is made by washing (picture at the right) out the finer particles which can be seen further out in the formation. Washing of the well screen after installation can be seen of the picture to the right. Pulses of pumping air into the formation after the installation of the well screen, creates a "blow out" of water from the well. Many repetitions and sectionalized washing, ensures a well-functioning natural filter with high permeability around the well screen as seen in the picture to the left.

2. METHODOLOGY

The methodology is divided into two parts. First the sedimentation potential of suspended solids in infiltration wells is estimated, and secondly, the method for rehabilitation the infiltration well at open system GWHP plant at Lena Terrace in Melhus is described.

The main objective of the calculation of the sedimentation potential is to highlight how small concentration of suspended solids that is needed to fill up the screened part of an infiltration well with a normal diameter and a given time. Some general assumptions are the basis for the calculations, e.g. the amount of suspended solid in the groundwater is set to 0.1 mg/liter. The groundwater containing this amount of suspended solids is produced by the production well, pumped through the heat exchanger and deposited within the well, or in the well formation outside the well screen. In this study and for simplicity, all the suspended particles are assumed to be deposited in the bottom of the infiltration well. The density of the suspended solid is assumed to be 1800 kg/m^3, which is an average of the rock density (2600 kg/m^3) and water (1000 kg/m^3).

The GWHP plant at Lena Terrace was first established in 2003 and rebuilt due to several technical problems both with the groundwater system and the heat pump in 2015. Before the rebuilding, the infiltration well was used as the production well. The well screen has a diameter of 161 mm, is 10-meter-long and placed 23.5-33.5 meters below the wellhead. The specific pumping capacity of the infiltration well before the plant was put into operation in the fall of 2015 was 12 liters/second per meter cone of depression. A normal pumping rate of the plant is 16-17 liters/second supplying a heat pump of 340 kW. The infiltration capacity was too low both in February and October 2018, and a rehabilitation method by suction, jet flushing and pumping was attempted. In February the infiltration well was flowing over the wellhead with a pumping rate around 10 liters/second, and approximately 0.6 meters of the bottom of the well was filled with sediments. Several steps with jet flushing, video inspection, pumping and infiltration tests were performed. In October 2018, the groundwater level was critically high with reduced pumping rate, and suction and jet flushing were repeated in order to get the infiltration capacity high enough to secure the operation of the plant during the following heating season.

A new rehabilitation was necessary summer 2019, but now a steaming and washing method with mammoth pumping was used. The steaming means that the infiltration well is continuously filled with boiling water 12-16 hours prior to the start of the mammoth pumping. The well screen washing / mammoth pumping was done in sections of 0.5 meter which ensures a thorough and systematic cleaning of the well screen. The rubber packers sealing the section are adjusted to the well diameter. The air supply between the packers are done by an air hose around 3 meters above the section. The function of the mammoth pumping is quite similar to the washing procedure which is carried out immediately after the screen installation to obtain a natural formation filter (Figure 2).

The different rehabilitation methods used in the infiltration well at Lena Terrace will be compared with respect to removal of sediments and improvement of hydraulic properties. The different stages of well rehabilitation are documented by video filming of the well.

3. RESULTS

Sediment production, rehabilitation of the infiltration well and documentation

Assuming a very modest content of suspended solids of 0.1 mg/liter in the groundwater, the left diagram in Figure 3 shows the pumping rate versus the amount of suspended solids in the groundwater produced per day. With a constant pumping rate of 15 liters/second the amount of suspended solids following the groundwater is about 130 grams per day. These numbers correspond to a sedimentation height in the infiltration well of 1.5 meter per year if the diameter of the well is 161 mm (the right diagram in Figure 3).

Figure 4 (left picture) shows a section of the well screen before rehabilitation in February 2018 when the water was flowing over. Pictures from the video inspection of the well screen after jet flushing can be seen in the middle and to the right. The two pictures are within 10 centimeters, and large parts of the screen is still clogged with precipitated iron oxides (picture in the middle) as prior to the jet flushing (left picture), while the natural filter of sand and gravel can be seen in some parts (right picture). Some areas where the formation behind the well screen is tight and cemented were also observed. After jet flushing and simultaneously pumping, the specific capacity of the well was 7 liter/second per meter cone of depression of the groundwater.

The infiltration well at Lena Terrace has a total depth of 36.5 meter below the wellhead. In the cleaning performed in February 2018, the sediment column within the well increased from 0.6 to around 1 meter of the 3 meter long catcher pipe in the bottom of the infiltration well due to the remains from the high pressure jet flushing. Only minor sediments was removed in the cleaning in October 2018, and the infiltration well was filled with sediments up to around 32 meters below the wellhead (Figure 5 to the left– the camera stopped at 31.92 meters as the deepest) after the rehabilitation, i.e. a total of 4.5 meters with sediments. This includes 3 meters in the catcher pipe below the well screen and 1.5 meters into the well screen. This also means, that the sediment filling in the infiltration well increased by 3.5 meters in a period of approximately eight months, from February to October 2018. After the rehabilitation in July 2019 with steaming and mammoth pumping in sections of 0.5 meters, the sediments were completely removed from the infiltration well (Figure 5 and the pictures to the right). The color of the muddy water and the content of mud from the mammoth pumping varied between the sections, but was mainly brown and reddish (the pictures to the left in Figure 6). Some of the removed sediments from the well can be seen in the picture to the right of Figure 6.

Figure 7 shows the groundwater part of the monitoring display for the open system GWHP at Lena Terrace around one month before (left) and 3 weeks after (right) the rehabilitation of the infiltration well (“returbrønn), respectively. The water level in the infiltration well is only 3 meter below the wellhead with a pumping rate of 9.9 liter/second before rehabilitation, and is 17.8 m meter below the wellhead with a slightly higher pumping rate of 11.6 liter/second after the rehabilitation. The groundwater level in the infiltration well is approximately 14.5 meter lower than prior to the rehabilitation, taken into account a dry period with little precipitation. The monitoring display was established during winter 2019 and is still under development and testing.

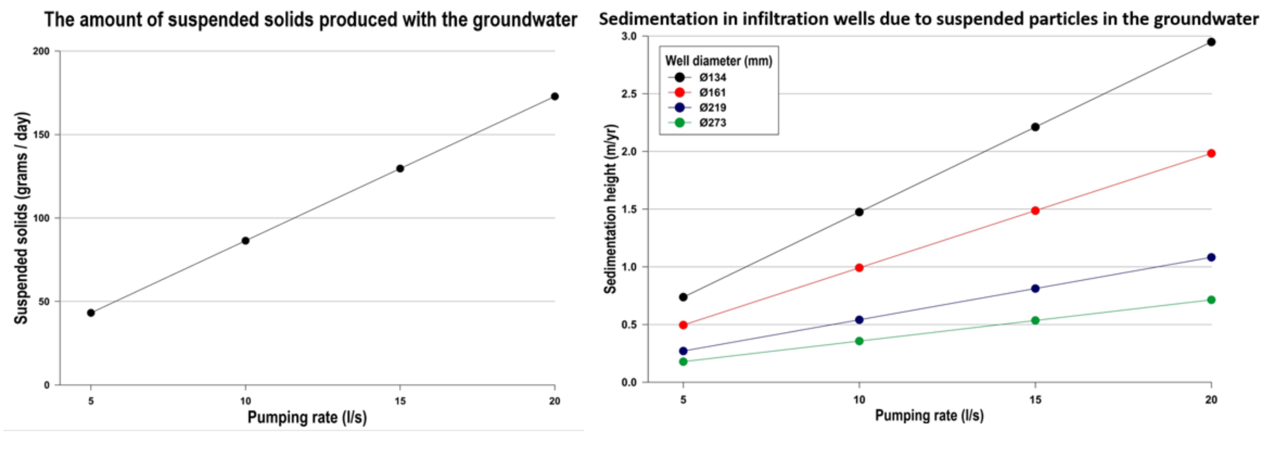

Figure 3: Pumping rate versus the amount of suspended solids and the sedimentation height in an infiltration well with different diameter can be seen on the diagram at the left and right, respectively.

Figure 4: Picture at left: The well screen is tight before rehabilitation in February 2018 when the water was flowing over. The blurry picture is caused by a thin film on the camera lens. Picture in the middle and at the right: Video inspection of the well screen after jet flushing with mixed results. The pictures are within 10 centimeters, and large parts of the screen is still clogged with precipitated iron oxides (middle), while the natural filter of sand and gravel can be seen in some parts (right picture)

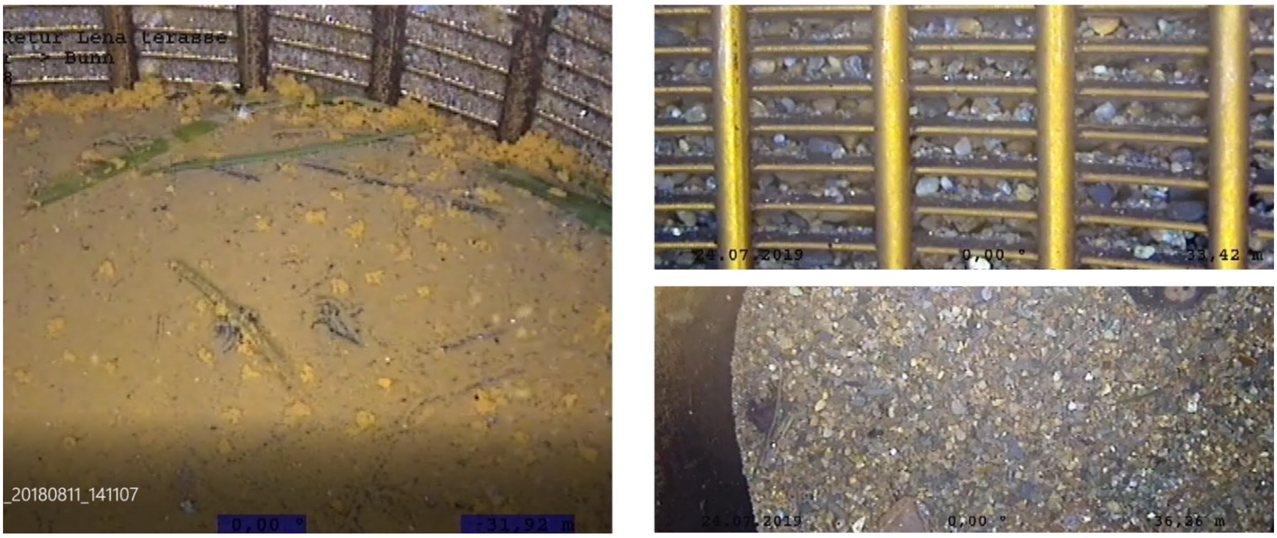

Figure 5: The left picture from the video inspection shows the infiltration well after the rehabilitation in October 2018 when sediments still fills up parts of the well screen (up to approximately 32 meters below the wellhead). The pictures at the right shows the infiltration well after rehabilitation in July 2019. The well is cleaned all the way, including 3 meters below the well screen. The upper picture is from the bottom of the well screen which was filled with sediments prior to the rehabilitation (left picture). The sand grains can clearly be seen behind the slots. The lower picture shows the sediments in the bottom of the well at around 36.5 meter below the wellhead.

Figure 6: The pictures at the left shows the mammoth pumping in the upper and lower screen section, respectively. The upper picture is muddy water cleaning the aquifer formation outside the screen (inside the formation), while the lower picture shows very muddy water from removing the sediments in the lower part of the well. The picture to the right shows some of the removed material from the well. Note the reddish color.

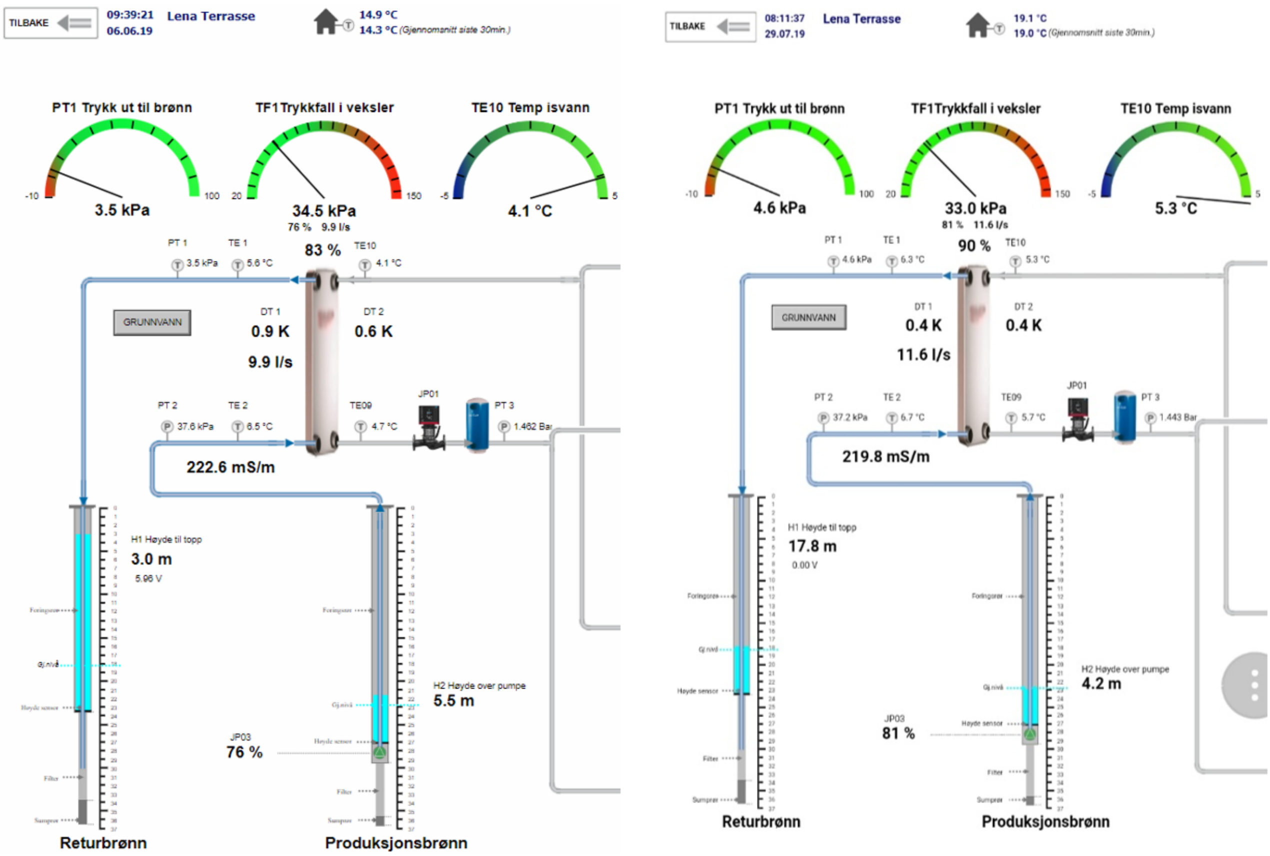

Figure 7: The groundwater part of the monitoring display for the open system GSHP at Lena Terrace around one month before and 3 weeks after the rehabilitation of the infiltration well ("returbrønn), respectively can be seen to the left and right. The water level in the infiltration well is only 3 meter below the wellhead with a pumping rate of 9.9 liter/second before rehabilitation, and is 17.8 m meter below the wellhead with a slightly higher pumping rate of 11.6 liter/second after the rehabilitation.

4. CONCLUSION AND DISCUSSION

The research project ORMEL (2015-2018) and the sequel ORMEL2 focus on the use of groundwater for energy purposes. The screened groundwater wells in sand and gravel aquifers, and especially the infiltration well has gained special attention in this article. Returning heat exchanged groundwater to the aquifer by means of an infiltration well seems to be more challenging than extracting groundwater from a production well. Another important point is that the experience with the use of screened infiltration wells at least in Norway is scarce and nearly limited to the open system GWHP installations. Before the ORMEL-projects, there has been little systematic studies on the use of groundwater for energy purposes in Norway. The key is to include the entire value chain in the research and to imply the new knowledge at the operating level in the business.

The experience from rehabilitation of an infiltration well in an open system GWHP installation at Melhus, namely Lena Terrace, has been used to illustrate the complexity of the problem and the need for a systematic approach to the topic. Here both precipitation of iron oxides and sedimentations seem to occur. The cause of the problem is not yet fully understood as well as the best rehabilitation practice for the each, and a mix of the phenomena. A calculation of the sedimentation potential where the groundwater contains a modest concentration of suspended solids was included to show that we cannot exclude the possibility that some production wells of groundwater also continuously produces suspended solids with the groundwater. For instance, a content of suspended solids of 0.1 mg/l and a continuous pumping of 15 liters/second will cause a filling of 1.5 meter per year in a 161 mm diameter infiltration well.

The sedimentation production at Lena Terrace cannot be fully explained by now, but the sedimentation filling the first 2.5 years of operation was approximately 0.6 meter, while the filling during the 8 months period from February to October 2018 was around 3.5 meters. A possible explanation of the considerable filling of sediments in that short period of time, is that the remaining residuals from the rehabilitation in February 2018 (jet flushing and simultaneously pumping) settled when the pumping was finished. The filling of 0.6 meters the first 2.5 years corresponds to only 0.016 mg/l of suspended solids with the groundwater.

The best rehabilitation results of the infiltration well at Lena Terrace seems to be the steaming and the sectional mammoth pumping. Rehabilitation of drinking water wells also often obtain good results with this method. However, the method is not widely used and offered by the industry. Compared to production wells, the need of rehabilitation of infiltration wells seems to be more present with respect to both sediments and precipitation of e.g. iron and manganese oxides (Gjengedal et al. 2019). Therefore, it is time to develop the steaming and mammoth pumping procedure further so that this well cleaning method is easily available, effective and can be used on a regular basis and before the infiltration rate in the infiltration well is critically low. In addition to the trial and error approach with jet flushing, pumping and suction, as well as the steaming / mammoth pumping, the Lena Terrace example illustrates two more important issues, namely the usefulness of the video inspection and the need for good surveillance of the operation of the open system GWHP. Video inspections document, and gives a cost effective well condition analysis, and should be used before and after well rehabilitations in addition to hydraulic tests (Gjengedal et al., 2018). The need of a central control and monitoring system is essential (Gjengedal et al. 2019). As shown for Lena Terrace which got their central control system this winter, the last rehabilitation was performed with basis of the monitoring of the water level in the infiltration well and could then be done in advance and before the situation was critical. The central control also shows the results of the rehabilitation instantly and for long periods by saving all the monitored data for eventually deeper analysis.

This broad perspective and approach concerning the use of groundwater to energy purposes should continue taking into account the ongoing plans for establishing a large-scale system in Melhus. This involves further work with design, to understand precipitation mechanisms and conditions, to achieve effective operating strategies with routinely and cost effective maintenance and targeted well rehabilitation procedures.

5. ACKNOWLEDGEMENTS

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