GeoEnergy – a national shallow geothermal research project

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Keywords: Shallow geothermal energy, borehole heat exchangers, Ground source heat pumps, thermal conductivity, borehole database.

ABSTRACT

Shallow geothermal energy is a renewable energy source, where the low enthalpy heat in the shallow subsurface can be exploited using borehole heat exchangers in a combination with heat pumps. Despite the energy saving and CO_2 emission reduction potential of the technology, the utilisation of shallow geothermal energy in Denmark is relatively limited compared to e.g. Sweden and Germany. Today, the total number of ground source heat pumps in Denmark is around 27,000, currently increasing by 5,000 per year. By far, most of the existing installations are horizontal closed loop systems, while four to five hundred are borehole heat exchangers, and only some tens are groundwater based open loop systems. However, during the last couple of years the number of borehole heat exchangers has increased significantly, and in 2011 and 2012 more than a hundred new borehole heat exchangers were installed each year.

In contrast to our neighbouring countries, the main part of Denmark is situated in a sedimentary basin dominated by soft sediments and variable depth to the water table. Only few investigations of the thermal properties of Danish sediments have been carried out, but preliminary results indicate that the energy extraction may be up to 40% lower for unfavourable geological scenarios compared to more favourable geological conditions, and better knowledge and local experience are needed. The 3-year project “GeoEnergy” aims at paving the way for a wider use of borehole heat exchangers by acquiring and disseminating know-how and developing tools and best practice for the design and installation of systems under typical Danish conditions.

The main activities of the project are:

- Collection and analysis of existing information and experience, as well as identification of key parameters for planning, design and installation of heat pump systems based on borehole heat exchangers.
- A comprehensive mapping and measuring programme for surface temperatures, temperature gradients and thermal properties of different soil types and materials.
- Optimization of system design with respect to environment and economy based on experience from existing installations and a new test site. The analysis includes drilling work and completion of boreholes, system control and automation, calculation of energy balance, energy storage (heating and cooling) and modelling of heat and fluid flow.
- Development of a publically accessible web-based GIS application using and presenting relevant data from existing databases together with results of the measuring and mapping programme as a tool for system design.
- Dissemination activities including training and education, workshops and seminars, technical guidelines and recommendations for the legal framework.

1. INTRODUCTION

It is the objective of the Danish government that by 2035 the electricity and heat supply in Denmark will be based on renewable energy sources and that the use of coal and mineral oil will be phased out by 2030. In order to achieve a cost-effective conversion of the heat supply, a number of research and development projects have been initiated.

In this context shallow geothermal energy has the potential to contribute to the conversion towards a more sustainable heat supply. Despite a large potential, the application of shallow geothermal energy in Denmark is relatively limited compared to e.g. Sweden or Germany, (Mahler et al. 2013). To investigate and promote the use of shallow geothermal energy, a three year research project (GeoEnergy) supported by the Danish Energy Agency has been initiated. The aim is to provide knowledge and a set of tools that can be used for planning and designing minor and major heat pump systems based on closed loop boreholes. Furthermore, the project will contribute to developing a best practice for such installations in order to protect both the environment and the consumers / plant owners. The focus is on both the heating and the cooling of buildings and on energy storage.

The project addresses a number of different topics related to ground source heating and cooling such as the importance of geological variations, drilling and grouting in soft sediments, mapping shallow geothermal gradients in Denmark, modelling of heat and groundwater flow as well as groundwater protection and other environmental considerations.

2. SHALLOW GEOTHERMAL ENERGY IN A DANISH CONTEXT

Today the total number of ground source heat pumps in Denmark is around 27,000, currently increasing by 5,000 per year. By far, most of the existing installations are horizontal closed loop systems while four to five hundred are borehole heat exchangers and only a few tens are groundwater based open loop systems. However, during the last couple of years the number of borehole heat exchangers has increased significantly, and in 2011 and 2012 more than a hundred new borehole heat exchangers were constructed each year.

In contrast to our neighbouring countries, the main part of Denmark is situated in a sedimentary basin dominated by soft sediments and variable depth to the water table.

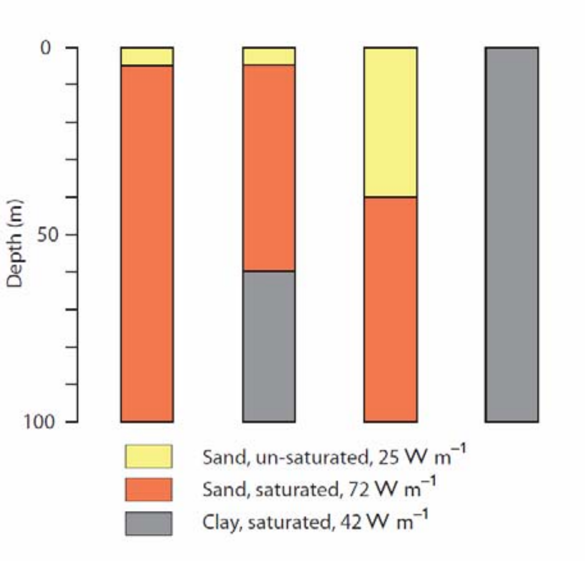

Figure 1: Four simple geological successions with average, specific heat-extraction rates from table 1 VDI (2001). The possible energy extraction has been calculated to 12.537; 10.373; 9.576 and 7.560 kWh respectively (left to right), based on 1800 hours of production per year.

In order to roughly estimate the possible effect of the geological variations expected in Denmark, the energy extraction for a 100 m closed loop borehole was initially calculated in four simple geological successions, figure 1 (Vangkilde-Pedersen et al. 2011). The estimates were based on specific energy extraction rates from VDI (2001), assuming standard design and operating conditions and 1800 hours of production per year. These preliminary results indicate that the energy extraction may be up to 40% lower for the most unfavourable of the geological scenarios compared to the most favourable.

In order to evaluate the possible energy extraction from a specific new site and estimate the required depth and number of boreholes, information about the geology and hydrogeology is crucial.

2.1 Shallow geology

The greater part of Denmark is underlain by a sedimentary basin dominated by shallow marine to deep marine, clastic and biogenic sediments (figure 2A), overlain by Pleistocene deposits. In some areas the Pleistocene cover is thin and limestone or Tertiary sand, silt and mud are found close to the surface.

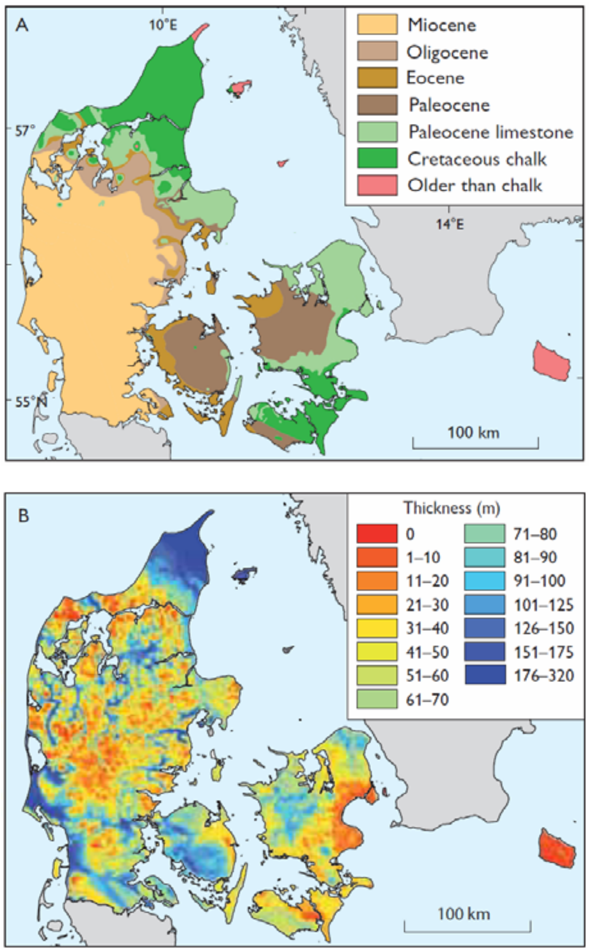

Figure 2: Maps showing the pre-Pleistocene geology (A) and the thickness of Pleistocene sediments (B) in Denmark.

Thick successions of Pleistocene sediments are common in the northern and south-western part of the country (figure 2B).

Thick successions of Pleistocene deposits are also found in buried valleys (Jørgensen & Sandersen 2006). The geological variation within the Pleistocene sediments is high, and regional scale geological models are not sufficiently detailed to estimate the possible energy extraction from a vertical system. Therefore local information from boreholes and geophysical data are necessary to map the Pleistocene strata and the elevation of the water table at a new site.

2.2 Thermal properties of shallow sediments

Only few investigations of thermal properties of Danish sediments have been carried out (e.g. Balling et al. 1981) and thermal conductivity values for different rock and sediment types published by e.g. Banks (2008) and VDI (2010) show large variations for sediments relevant in a Danish geological context, see Vangkilde-Pedersen et al. (2011) for details. Therefore a program to investigate the thermal properties of common shallow sediments has been initiated. The work focuses on determining the water saturated thermal conductivity of prevalent sediment types. The range of the thermal conductivity within common sediment types is determined from measurement on a large number of samples from different localities. The preliminary results suggest that it is possible to recognise a number of lithological groups with similar thermal properties.

The measurements will be made accessible from a public database and will serve as input for numerical modelling of relevant scenarios with different geology and operating conditions. The final results will serve as a guideline for Danish planners and administrators of shallow geothermal installations.

2.3 Databases and utilisation of exiting geological data

Since 1926 the geological Survey of Denmark and Greenland (GEUS) pursuant to the Danish water supply act have been collecting borehole data including information on location, construction, geology, water table and groundwater chemistry, etc. (Hansen and Pjeturson, 2011). Data is stored in the national borehole database (Jupiter) from where it is made freely available on the internet. The database holds more than 270,000 boreholes, corresponding to around 6 boreholes per km². This provides planners, drillers and administrators with a unique possibility to evaluate local geological conditions at a given site.

In order to compile the data that is most relevant when planning borehole heat exchangers, a new web based planning tool is being designed. This application focuses on the data that are particularly relevant, such as depth to water table and lithology. From a GIS showing catchment and water protection areas as well as existing boreholes you can specify a project area interactively. Within this area, a compilation is made of the thermo related geological variations that can be expected.

Furthermore, GEUS hosts a database for shallow geophysical data (GERDA) which contains densely measured data acquired during the national hydrogeological mapping over the past decade (Møller et al. 2009a,b). In addition to measured data, inverted model results are stored in the database. This enables the generation of various maps and detailed 3D geological models providing a unique possibility for detailed modelling of heat flow and groundwater flow around borehole heat exchange installations. The GERDA database also contains temperature logs from wire-line logging acquired from a large number of existing boreholes. These logs are evaluated during the GeoEnergy project, and logs that are believed to show undisturbed temperature conditions are selected and, together with new temperature logs, included in an assessment of the variability of shallow geothermal gradients in Denmark.

2.4 Modelling of near-surface heat flow

Various model systems are available for calculating the efficiency of vertical systems in terms of energy extraction, ranging from simple and easy-to-use models to complex numerical models. The easy-to-use models consider the long term aspects assuming homogeneous and constant subsurface thermal properties, whereas the complex models also take into account the effect of alternating system operation, heterogeneity in thermal properties as well as groundwater flow.

In addition to heterogeneity in geology and thermal properties, the efficiency of vertical systems is highly affected by possible groundwater flow. To evaluate the importance of the hydrogeological heterogeneity observed in Denmark, modelling will be carried out based on a complex numerical model that allows the inclusion of subsurface heterogeneity as well as groundwater flow. The aim of the modelling is to identify the aspects that must be considered in the design phase of closed loop systems, and to estimate the maximum energy that can be extracted under different hydrogeological conditions typical in Denmark.

2.5 Administration and groundwater protection

In Denmark, all drinking water resources come from groundwater aquifers. Therefore, the mapping and protection of catchment areas etc. have a high priority, (Thomsen et al. 2004).

Protection of the environment and groundwater is therefore of paramount importance in shallow geothermal projects. Borehole heat exchangers are regulated pursuant to the Danish environmental protection act and permissions are issued by the Municipalities, that must include groundwater interests in their considerations. The main issues are leakage of water with antifreeze, cross-connecting different aquifers, seepage of surface water along the borehole wall, drilling into artesian aquifers and unwanted thermal effects on the aquifers.

In the legislation, safety distances to other ground source heat exchangers and to extraction wells for drinking water are specified. The legislation also specifies which antifreeze agents can be used in the ground loop – only non-toxic and easily biodegradable fluids are allowed. Furthermore, the regulation provides the municipalities with a possibility to increase the required safety distance to water wells and to stipulate special conditions in the permit regarding e.g. the construction of the installation, in order to protect a water catchment area against contamination.

Often the administrators do not have a hydro-geological background, and the administration of permits often appears to vary from one municipality to another. Some municipalities reject applications for borehole heat exchangers if there is uncertainty regarding a possible content of anti-corrosives in the brine. Others are generally very reluctant to issue permits for borehole heat exchangers because of general considerations regarding the groundwater protection and drinking water quality.

In order to overcome this administrative heterogeneity, it is the aim of GeoEnergy to prepare guidelines and recommendations for typical hydrogeological situations as well as regard the use of different brines. These recommendations will be based on numeric modelling of heat and groundwater flow under typical hydrogeological conditions and on an evaluation of the toxicity of carrier fluids and additives in commercial brines.

2.6 Dissemination

An important objective of the project is to disseminate knowledge of the possibilities, focus points and limits of establishing borehole exchange heaters under Danish conditions. So far, courses and presentations have been given to geologists, drillers, students and administrators. The presentations and training materials have primarily been produced within the project and are available on the project website www.GeoEnergi.org. But also more general materials from the GeoTrainet organisation have been applied.

3. CONCLUSIONS

Shallow geothermal energy is a renewable energy source exploiting the low enthalpy heat in the shallow subsurface in combination with heat pump technology. The use of shallow geothermal energy in Denmark is limited but increasing. The 3-year project GeoEnergy aims at paving the way for a wider use of borehole heat exchangers by acquiring and disseminating know-how and developing tools and best practice for the design and installation of systems.

Preliminary estimates indicate that there may be a difference of up to 40% in the energy extraction between sites with a favourable and unfavourable geology. Within the framework of the GeoEnergy project, investigations of the thermal properties of Danish sediments as well as mapping of geothermal gradients are in progress. The measurements will be made accessible from a public database and will serve as input for numerical modelling of relevant scenarios with different geology and operating conditions.

Optimization of drilling and system design with respect to environment and economy under Danish geological conditions is also being investigated. The analyses will include calculation of energy balance, energy storage (heating and cooling) and modelling of heat and fluid flow.

Based on the achieved results, it is the aim of the project to prepare tools, guidelines and recommendations for typical hydrogeological situations as well as regard the use of different brines. These tools and recommendations are aimed at planners, drillers and administrators working with borehole heat exchangers.

Results from the project are available on www.GeoEnergi.org.

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Acknowledgements

The EUDP programme of the Danish Energy Agency is thanked for financial support for the GeoEnergy project.