

The Delft Aardwarmte Project (DAP): Providing Renewable Heat for the University Campus and a Research Base for the Geothermal Community

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Keywords: district heating, research well, well casing, well monitoring

ABSTRACT

The Technical University of Delft in the Netherlands are planning to produce significant amount of the heat required for the campus buildings from a resource recoverable from below their feet: A geothermal well doublet will be drilled on campus for heating a substantial part of our TU Delft buildings. The “Delft Aardwarmte Project” (DAP - Delft Geothermal Project) was initiated by students in 2007, which was a major step to increase public awareness of the potential of geothermal energy as a sustainable heating source in the Netherlands. The Dutch subsoil is well explored with (test) drillings for natural gas and oil, giving insight into the geothermal potential as well.

For the well doublet on campus, two possible drilling targets are considered, depending on funding and economic scenarios: In scenario I, the wells will reach a well-characterized sandstone reservoir, the Upper Cretaceous “Delft Sandstone”, at a depth of 2200 -2500m and will be operated by commercial partners. In scenario II, deeper reservoir rocks of the Lower Triassic at approx. 4000m depth are the target. To reach this depth, research funding for a national research infrastructure is required. If the deeper target is productive enough, the option of co-generating electricity and heat will be investigated.

In both scenarios, the wells will serve as infrastructure for research both for the university scientists and for the national and international geothermal community. For this purpose, a monitoring system will be installed with partners from research and industry. In the planning process of the project, several studies into the geology and performance characteristics of the reservoir, the economics of the system, the co-injection of CO₂ and into advanced drilling and casing options for the wells have been performed and published.

Aspects to be investigated in the installation of a well doublet and the operation of the geothermal heating system include the use and installation of innovative composite casing for drilling and well completion, scaling from the geothermal brine, which often causes problems with reinjection, and geophysical monitoring techniques to be tested in a busy and “noisy” environment on the surface prior to drilling and downhole for reservoir monitoring during operations. The paper gives an overview about past and future studies around the DAP wells.

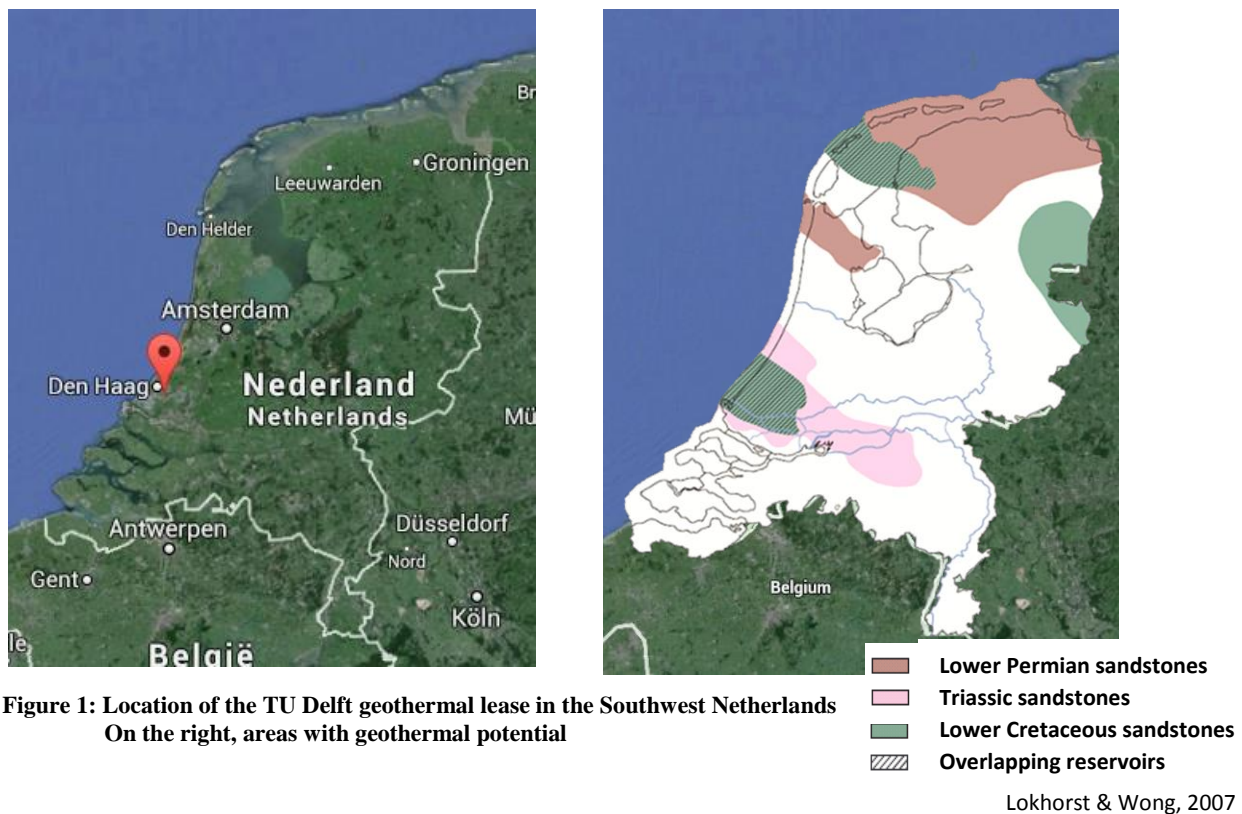
1. INTRODUCTION

Geothermal energy is receiving growing attention in the Netherlands. Deep geothermal projects, primarily for the supply of heat for greenhouse farming, have been initiated in several part of the country and accessing various geological units. In the Southwestern part of the country, including the cities of The Hague, Rotterdam and Delft (Fig.1), there is a high density of greenhouse farms and also a high density of licenses granted or requested for the development of geothermal heating systems for these greenhouses. The subsurface geology of the area is fairly well known, as a result of extensive oil & gas exploration.

Most geothermal wells in the region target Cretaceous sandstones of the West Netherlands Basin (WNB). The WNB was formed during several rift phases and existed from the Late Permian to the Late Cretaceous. During the middle and late Triassic tectonic movement, large-scale half-graben structures formed. The strongest rifting occurred during the Late Jurassic to Early Cretaceous. This rifting event led to the formation of NW-SE fault patterns with tilted fault blocks. Syn-rift deposition of fluvial and later marine sediments filled the graben structures with some intervals of local uplift until the Late Cretaceous. During the Late Cretaceous and early Tertiary tectonic phases compressive forces (Alpine compression) caused strong uplift and reactivation of Jurassic faults (Den Hartog Jager, 1996). This resulted in the formation of complex inversion structures and NNW-SSE fault patterns. In these structures most of the oil and gas fields of the WNB are found (De Jager, 2007). Erosion of Cretaceous sediments was most severe in the Northern part of the basin where uplift was strongest. Syn-rift terrestrial deposits concentrated in the lower fault blocks. Marine middle and Late Cretaceous deposits can be found extensively across the basin. While these deposits are often several hundred meters thick, their distribution throughout the WNB is quite heterogeneous, due to the geologic history and the change between marine and terrestrial/deltaic depositional environments. A detailed study of these sedimentary units, their distribution and properties including their potential for geothermal developments is part of a separate study presented at the WGC2015 (Willems et al., 2015).

For the development of geothermal energy, three main stratigraphic units are identified as promising zones: the Permian Rotliegend sandstones, the Lower Triassic sandstones and the Lower Cretaceous sandstones (Fig. 1). Most operative geothermal projects in the WNB use the Cretaceous Delft Sandstone as a reservoir. There have been attempts, however, to access sandstones of the Lower Triassic, which are usually below 3000m depth and therefore potentially interesting for the co-generation of heat and electricity. Generally, the reservoir interval in the Lower Triassic contains enough thick sequences of porous sandstones with sufficient permeability. But the occurrence and properties of the Triassic units are not as well determined as the Cretaceous. Primary porosity

and permeability are low in some Triassic rocks that were accessed by deep wells, but it is expected that permeability and connectivity are enhanced locally through fracturing.



Oil & gas development is focused on the structural highs. Prospective areas for geothermal exploitation occur in lows. The lows have no well penetrations and are usually considerably deeper than the much shallower oil fields. It is, however, suspected that structuration and formation of highs and lows occurred relatively late and that diagenesis predates structuration. This would imply that the shallow oil fields have porosities representative of much greater depths. Generally, tectonic events led to a strong compartmentalization of the WNB, which has a strong effect on groundwater flow velocity.

The geothermal project of the Technical University of Delft (DAP – Delft Aardwarmte Project) is planned to support the campus heating system with renewable heat from a geothermal reservoir. The two stratigraphic units introduced above – the lower Cretaceous Delft Sandstone and the Lower Triassic sandstones – provide the target horizons for this project. Two scenarios have been discussed for the development of the DAP: One involves a well doublet into the Delft sandstones to depths of 2200 – 2500 m (Fig. 2), where temperatures of 70-75°C are expected. This approach is well constrained by two already existing geothermal well doublets north of Delft, serving greenhouse farmers. The other scenario, involving the Triassic sandstones at 4000m depth, is less mature. This scenario involves a stronger research component, as the Triassic sandstones have not been accessed for geothermal energy projects in The WNB so far. The greater depth makes it an attractive target for co-generation of heat and electricity. The limited knowledge about this target at the location and the resulting economic risks make public funding for prior investigation of these rocks a likely path of development.

2. BACKGROUND

Started as student initiative in cooperation with the Mijnbouwkundige Vereniging (the Delft mining student association) and some of its alumni in 2007, the realization of the DAP doublet is now progressed through a committee (Transitie Warmtenet TU Delft) with representatives of TU Delft and several external parties. Aim is to develop a business case for a 70GJ/yr hot water source to partly replace the natural gas-powered boilers that are currently used for heating the TU Delft buildings through an existing campus-wide heat piping network. Part of the business case involves modification of the heating infrastructure in existing buildings and/or equipping new buildings such that they can cope with the lower entrance temperature of geothermally heated water (70 °C compared to the current 120 °C). In parallel DAP has evolved into a multi-company-sponsored consortium that supports a research and development program into geothermal energy at the TU Delft. Further support for the drilling of a geothermal doublet on campus and the development of an associated research and educational program is obtained through the Delft Energy Initiative (DEI).

The initiation of the DAP has triggered a broad range of research activities, addressing topics related to subsurface and surface aspects of geothermal energy production. Several reservoir modelling approaches investigated the potential both the Cretaceous and the Triassic rocks. Other topics include

- Reuse of suspended oil and gas wells for geothermal energy.
- Optimal well placement related to the profitability of the geothermal project.
- Unconventional well completions and drilling for geothermal wells (Composite casing and casing while drilling, optical-fiber temperature sensing technique).
- Lower Cretaceous geothermal reservoir modelling.
- Mineral scaling in geothermal wells.
- Triassic age reservoir properties in the West Netherlands Basin.

In addition, the simultaneous geothermal energy production and CO₂ injection has been at the focus of intensive studies, one of them is also presented here at the WGC2015 (Nick et al., 2015).

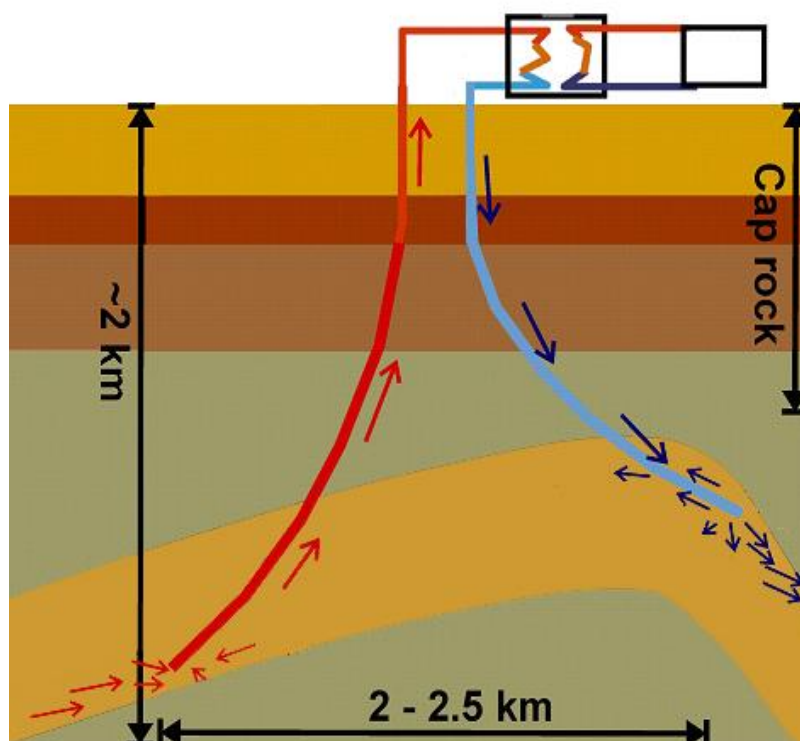


Figure 2: Planned DAP well trajectories into the Delft sandstone

2.1 Research specific to the TU Delft campus doublet

2.1.1 Geological characterization

A considerable number of wells have been drilled in the Netherlands for the exploration and production of oil and gas. Much of the information gathered in these wells through coring, wire-line logging and cuttings analysis is also relevant to characterize the potential of subsurface layers for geothermal energy production. The study of Willems et al. (2015, this volume) is an assessment of the geothermal potential of depleted Triassic and lower Cretaceous sandstone reservoirs in the West Netherlands basin. Unfortunately, much of the available information stems from decades ago and is no longer of the quality required for modern formation evaluation methods. Moreover, all the existing wells have been drilled in structural 'highs', i.e. potential hydrocarbon accumulations in porous and permeable rock close to an impermeable 'cap rock'. However, for geothermal reservoirs we need to focus on the structural 'lows' where the water-bearing rock has the least chance to contain hydrocarbons (which float on water). The drilling of the DAP doublet therefore offers an opportunity to obtain a set of high-quality data at the relevant part of a geothermal reservoir. Such a data set will be of major importance for the characterization of similar subsurface formations in the West of the Netherlands, and to quantify the potential for geothermal energy production.

2.1.2 Casing drilling

Another innovation that will potentially be used for the DAP doublet is the 'casing drilling' technology. In traditional drilling, the borehole is created with aid of a rock-crushing tool, the drill bit, connected to surface with the aid of drill pipes to transmit torque to the bit and to provide a conduit for drilling fluids. After completion of (a section of) the well, the drill string is removed. Next a larger diameter casing is run in the hole (also consisting of connected steel tubes) and cemented in place. The idea of casing drilling is to replace this two-step operation by a one-step operation in which the casing is also used to drill the well, and not just to line the borehole afterwards. The combination of casing drilling with the use of composite casing would be a logical, but technically challenging, next step. At present these developments are driven by the consortium of companies, but using the material for drilling of the DAP wells further testing will address fundamental understanding of the loading conditions, the material properties, and the dynamic behavior of the equipment involved.

2.1.3 Well completion

The material of the glass-fiber epoxy (GRE) or glass fiber PA6 (APA6 composite) will be used for casing instead of conventional steel casing to line the borehole wall. Although more expensive than steel, composites have the advantages of being corrosion-resistant, and, most importantly, much lighter than steel. Therefore, the necessary drilling equipment will also be much lighter than usual which leads to considerable cost savings. (The hoisting capacity, and therefore the size, weight and costs of a drilling rig, are determined by the maximum weight of the casing). The development of composite casing technology for the DAP doublet is pursued by a consortium of companies, with the aid of various subsidies. The first step involves the use of composite casing with conventional steel couplings (threaded connections), glued to the composite. (Note: The latest base plan is to use all composite connections, glued on the rig floor.) The Faculty of Aerospace Engineering is involved in this development, and in particular performs the following research activities:

- Development of test set-ups for composite pipe testing
- Testing of composite pipes
- Mechanical characterization of APA6 composites
- Development of the production technology for APA6 composite pipes
- Durability of GRE and APA6 composites in geothermal wells
- Behavior of composites in dynamic loading in drilling operations

The innovative use of composite casing will allow for a repetition of the running of ‘open-hole’ logs (which would not function inside a steel casing) after periods of production and injection (say yearly) to monitor the reservoir behavior (and the quality of the composite casing) over time. The well completion with the composite material will require and initiate the test of novel monitoring techniques for composite casing. The resin used in the casing may be mixed with, for example, semi-conductive materials to enable new cost efficient logging techniques. The usage of the fiber material in the casing may be a solution for continuous well integrity monitoring

For the geothermal doublet it would allow for monitoring of

- Long-term effects of fluid, temperature and pressure on the composite casing.
- Production damage (sand production or reservoir collapse) in the producing zones
- Clogging/cementation in the injection zones

The installation of a fiber-optic cable for the long-term monitoring of temperature, acoustic signals and strain is planned in one of the two wells.

2.1.4 Well testing

Pressure and temperature transient testing

Pressure transient testing (also known as ‘well testing’) is a technique to infer near-well reservoir properties from pressure data recorded in a well (preferably at the bottom) after shutting-in production. Repeated pressure transient tests (e.g. every half year) can give insight in the development of near-well ‘formation damage’, i.e. the precipitation of salt, scale or fines blocking the flow of water. Additional information can be obtained by employing an array of pressure sensors (instead of just a single one) over the entire producing interval to observe the response of the individual layers. In addition it is possible to monitor the temperature transient after shut in. In particular, with the aid of ‘distributed temperature sensing’ (closely spaced temperature sensors) in the injector, a ‘warm-back’ of the cold well can provide additional information about the flow capacity of the various layers in the reservoir.

Interference and pulse testing

Measuring the pressure response in the production well as a result of shutting-in the injection well, or vice-versa, can give additional information about the reservoir properties in-between the wells. Further information can be obtained by manipulating the flow rates in the wells to increase the frequency content in the data (pulse testing). This requires facilities to measure the flow rates in the wells (in addition to the pressures) and remotely controlled valves (at surface) to control them. Just as for ordinary pressure-transient testing, the use of multiple pressure sensors, and the creation of time-lapse signals by repeating the measurements over time will result in additional information, in particular about the long-term effects of water injection and production on the reservoir performance.

Tracer testing

Releasing tiny amounts of (inert) chemical or (very mildly) radioactive tracers in the injection stream allows for the detection of ‘water breakthrough’ in the production well. Note that such injection water break-through significantly precedes the arrival of the cold front because the mass transport through the reservoir occurs at a much higher velocity than heat transport. It is nowadays possible to install multiple permanent tracer sources at various depths along the part of the injection well in contact with the aquifer. Using different types of tracers it is thus possible to detect which layers have the highest permeability and/or provide ‘short cuts’ between the injector and producer. Moreover, the development of small-scale chemical sensors, e.g. on chips or in the form of coated fiberglass, allow for a detection of chemicals breaking through in the production well, and if employed at multiple points along the producing interval, give an additional means to characterize the heterogeneity of the reservoir.

2.1.5 Surface monitoring

Active seismics

The noise generated by the drill bit during drilling will be used as a source. For this purpose, a seismic network will be installed prior to drilling. The network will also be used for passive seismic monitoring during operations.

Passive seismics

With passive seismics the reservoir is monitored using continuously recording receivers. Injection of cold water and production of hot water will change the equilibrium in the reservoir and overburden. Differential pressure changes along faults might lead to slip. The seismic energy released during a slip can be recorded with seismic sensors and back-projected to its source location. Thus, the location of fractures and pressure changes can be monitored. Since the seismicity released is typically very small it is advantageous to have the sensors close to the source, i.e., in the well. At the Earth's surface, the energy released near the reservoir will be recorded with only small signal to noise, which prevents usual location algorithms to work. A advanced method that will be applied is the ambient noise correlation method, which allows the use of various sources of ambient noise (cars, trams) to monitor in their own right, or produce additional information about subsurface heterogeneities.

The passive array can best be constructed prior to drilling. The drill-noise recording allows the creation of an impulsive seismic source and a virtual receiver at the position of the drill bit. This data can be used to get valuable information on the location of fractures and lithological contrasts near the well.

Electromagnetics

Electromagnetic (EM) methods, and magnetotellurics (MT) in particular, have been applied very successfully in a variety of geothermal systems around the world (see e.g. Muñoz 2013 and references therein). Movement of the cold front could also be monitored by EM methods as it is expected that cool water has higher resistivity than hot water. EM has a low vertical resolution but quite a good lateral resolution. MT uses naturally occurring electromagnetic fields as its sources. This has many advantages but also the disadvantage that in highly populated areas the presence of man-made electromagnetic signals (e.g. power lines, generators, geothermal power plants) distort the natural signals and negatively affect the quality of the measured data. In order to remedy this, a number of techniques are applied (although not routinely) like remote reference processing, delay line filtering, etc. The application of controlled-source electromagnetics (CSEM) represents another step in order to further improve the quality of the data. By using controlled sources it is possible to inject currents into the ground of comparable (or higher) amplitude to the electromagnetic noise. Furthermore, MT and CSEM have different resolution capabilities with respect to conductive and resistive structures which are complementary.

CSEM measurements are currently being developed for (among others) monitoring processes occurring during the engineering phase of an enhanced geothermal system (EGS) or during the exploitation phase. Electromagnetic (EM) monitoring is aimed at detecting changes in the reservoir electrical resistivity signature that can be produced by the activity in the geothermal reservoir. Changes such as the level of the water table produce a signature in electrical resistivity that can be detected by a proper distribution of monitoring stations.

Electromagnetic measurements will involve determination of the background resistivity model. This could be done using existing Electrical tomography resistivity (ERT) and with new data acquired prior to drilling. Once drilling commences, Syn-Drilling determination of the reservoir characteristics will make use of borehole-to-surface, surface-to-surface or (if possible) cross-borehole CSEM measurements. After well completion, reservoir characteristics will be determined using the same techniques as for the previous stage. This constitutes the monitoring component and can help determine the influence of the geothermal activities on the reservoir.

2.2. Performance monitoring and modelling – subsurface

2.2.1 In-well sensing

One of the operational risks in geothermal energy production is the reduction in near-well permeability because of the deposition of salt, scale or fines. Other operational problems could result from strong geological heterogeneities (high-permeability layers, non-sealing faults, large fractures or fracture corridors) leading to unexpected early cold water breakthrough in the producer. Monitoring of the production performance of the DAP doublet will therefore form an important research topic. To this effect is necessary to equip the wells with sensors, which could be done at various levels of sophistication:

- In the simplest case only pressure and temperature sensors at surface are installed, which would, however, severely limit the monitoring options.
- A better solution is the use of sensors at surface and down hole ('permanent down hole gauges' or PDGs) – at least a single pressure and a single temperature sensor at the bottom of each well.
- A next level of sophistication would be the use of multiple downhole sensors, distributed over the entire producing (injecting) interval. Whether this would be possible also depends on the completion details of the well (e.g. sand screens). Pressure and temperature sensors could be optical (using fiber glass) or electrical. A particular attractive option is the use of glass fiber in combination with surface-mounted laser technology for 'distributed' temperature sensing, in which case the fiber is not only a means for transmitting signals but also forms the sensor.
- State-of-the-art down hole sensing technology involves the use of chemically coated fiberglass, which makes it sensitive to particular chemical components, e.g. tracer components. Alternatively chips with particular chemical component detection capacities are currently being developed.

2.2.2 Fracture monitoring

An important issue in geothermal wells is the potential occurrence of pressure-induced and/or temperature-induced fractures in the injector. Monitoring of fracture growth is possible with different techniques. In particular the use of passive seismics makes it sometimes possible to 'listen' to the propagation of the fracture (the cracking of the rock). However, this would involve the use of in-well acoustic sensors, which are probably outside the financial scope of the DAP doublet. Alternatively it is sometimes possible to monitor fracture growth with the aid of acoustic waves (pressure pulses) that are sent into the borehole through. The signature of the reflected wave can then be used to obtain information about the fracture.

2.2.3 Reservoir simulation and data assimilation

Apart from monitoring the production performance with just observations, it is also possible to compare the measured data with ‘simulated data’ obtained from numerical simulation. This technique, known as ‘data assimilation’ in meteorology and oceanography, and as ‘history matching’ in the oil industry, offers the opportunity to combine physical understanding (as captured in the numerical simulations) with measurements of the real system. If correctly applied it results in simulations models that cannot only explain the data, but that may also have (some) predictive capacity.

Numerical simulations of mass and heat transport in the DAP reservoir below the TU Delft campus are already being performed as part of MSc and PhD research, and there is ample scope for the development of further numerical simulation models of near-wellbore and wellbore flow. The use of real, measured data from the DAP wells in combination with these models is a very promising aspect of the DAP doublet, both for research and education purposes. Note that the slightly tilted orientation of the reservoir implies that the produced water will exhibit a small change in temperature right from the start of production.

2.3. Performance monitoring, modelling and optimization- surface

To justify the business case for the DAP doublet it is necessary that the temperature of the water returned to the injection well is around 30°C, i.e. that it is cooled with about 40°C. This requires a careful design and operation of the campus-wide heating system. As part of the technical solution TU Delft participates in a multi-company demonstration. Aim is to develop and implement an intelligent control system on the TU Campus for heat and cold supply. The challenge is to combine multiple sources and storage mechanisms such that the system can cope with a varying demand at a minimal energy costs.

2.3.1 Temperature modelling and monitoring

Distributed temperature sensing with fiber optics is a rapidly emerging technology in the upstream oil and gas industry. It provides a relatively cheap means of high-resolution (in space and time) monitoring of the temperature in wellbores using Raman backscatter of laser light in a simple glass fiber run inside oil and gas wells. A single laser unit suffices to monitor a large number of wells. In addition glass fiber optical pressure sensors are gaining rapid popularity. Similar temperature and pressure monitoring technology could be applied in the surface heat network of the TU Delft. In addition to temperature, seismic signal can now be recorded by fiber optic methods (DAS – distribute acoustic sensing) as well as strain/deformation in the well.

2.3.2 Geochemical modelling and monitoring

Sampling and detailed analysis of the changes in composition and mineralogy of the produced water, and modelling of these properties as a function of temperature and pressure, will allow to for a better understanding and remediation of the fouling that is known to occur in surface piping systems, wells and the near-well reservoir. Especially precipitation of minerals (scaling) near the injection well may lead to serious injectivity decline and threaten the viability of a geothermal doublet. Improved fundamental understanding of the mechanisms involved may lead to assessment methods and mitigation techniques, which will help to reduce the risk in future geothermal projects.

2.3.3 Heat/cold supply-and-demand modelling, monitoring and interaction with electricity supply on the campus

The TU Delft possesses various heat/cold sources for building climate control and sub-soil thermal storage systems. The majority of the heat demand is still covered with classic boilers on natural gas, followed by a recently installed new central combined heat and power (CHP) unit. Some campus buildings have their own local heat and cold storage in sub-soil aquifers in combination with a heat pump for low temperature heating. Introduction of geothermal heat (medium temperature) is an important step to phase out the gas fired boilers in the longer term, without the need to transform all buildings in a costly operation to the low temperature level in the next decade or so.

An important question is how the overall TUD system can be optimally controlled for minimum energy use (including cooling and electricity generation) and maximum performance. (On-line) monitoring of the various energy flows is important for dynamic modelling and as a basis for optimal control. Such a district based approach is most relevant for the transition towards sustainable heat/cold supply, and the TUD is in a unique position with its various opportunities for early stage developments, with its scientific challenges and with great interest from commercial parties.

3. CONCLUSIONS

The DAP has established a great amount of preliminary studies on the use of a geothermal well doublet for campus heating and perhaps even for co-generation of electricity. The use of the wells, however, will not be limited to commercial heat supply for the refurbished campus buildings. The well doublet will serve as a major national infrastructure for geothermal research on all aspects of geothermal development. Some of the most relevant research institutions (TNO, University of Utrecht, University of Groningen) support the development of the well as a research infrastructure, as well as the industry consortium supporting the DAP from the start in 2007. The research possibilities arising from this development are enormous, as the infrastructure will also allow long-term monitoring of the impact of operations on the reservoir and on well and surface installations. It will thus provide the basis for national as well international research projects and allow commercial provision of heat to the customers at the same time.

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