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Geothermal Energy Use, Country Update for Denmark

Allan Mahler[1], Birte Røgen[1], Claus Ditlefsen[2], Lars Henrik Nielsen[2], Thomas Vangkilde-Pedersen[2]

[1] Danish Geothermal District Heating, Slotsmarken 18, 2970 Hørsholm, Denmark, www.geotermi.dk.

[2] Geological Survey of Denmark and Greenland (GEUS), Øster Voldgade 10, 1350 Copenhagen.K, www.geus.dk.

am@geotermi.dk, br@geotermi.dk

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ABSTRACT

The first geothermal plant in Denmark based on deep wells was established in 1984 in Thisted and later expanded to produce up to 7 MW heat from 200 m3/h of 44 °C, 15 % saline geothermal water with production from and reinjection in Gassum sandstone at 1.25 km depth. The second geothermal plant situated in Copenhagen started production in 2005 designed to produce up to 14 MW heat from 235 m3/h of 73 °C, 19 % saline geothermal water from Bunter sandstone at 2.6 km depth. A new geothermal plant in Sønderborg is designed to produce up to 12 MW heat from 350 m3/h of 48 °C, 15 % saline geothermal water from Gasum sandstone at 1.2 km depth. It is inaugurated 2013 and it has produced the first heat. The heat is transferred to district heating networks using absorption heat pumps with LiBr on all three geothermal plants. The driving heat comes from biomass boilers with or without associated power production. Several more projects all over the country are at different levels of maturation.

Preliminary plans exist to erect a geothermal plant in Copenhagen with 11 wells of which some of the production wells may be prepared for long term heat storage. Such a plant is expected designed to extract around 64 MW from 1000 m3/h geothermal water. Alternative heat pump concepts are considered including absorption heat pumps and compressor based heat pumps using ammonia or an ammonia/water mixture (hybrid heat pump). The heating plan for Copenhagen includes an option to install 400 MW geothermal heating capacity.

The number of smaller heat pumps extracting heat from ground water and topsoil has been assessed to around 27,000 with an average COP of around 3 and a total heat production at around 2-3 PJ/year.

1 INTRODUCTION

Denmark has moderate temperature gradients, but widespread geothermal aquifers and district heating networks in most of the Danish towns supplying heat to 60 % of Danish houses. Aquifers have been identified around many of these towns with sufficient heat to cover 20 – 50 % of their heat demand for hundreds of years.

A recent study has assessed the reserves in a licence for Greater Copenhagen Area to 60,000 PJ or 1/3 of the heat demand for about 5000 years. This study is reported in Magtengaard 2010.

Present plants use absorption heat pumps and produces heat for district heating. Absorption heat pumps can be driven for free if other heat producers such as biomass boilers can supply 160°C driving heat at district heating cost levels.

The Danish legal framework is in place and there is an increasing interest in geothermal energy among district heating companies and municipalities. Geothermal plants receive no funding, but high taxes on fuels and the focusing on CO2 makes it attractive to substitute the burning of fossil fuels on CHP plants with wind turbine power and geothermal heat.

Danish aquifers have not been found suitable for power production as sufficiently permeable layers are too cold. They may, however, be considered used for power production based on stored heat from the sun, excess incineration plant heat etc. or heat pumps driven by excess wind turbine power.

Geothermal plants can be used for long term heat storage with low temperature losses and a study has been initiated to investigate the possibilities and problems.

Geothermal activities in Denmark was up to 2010 mainly driven by DONG Energy, but the company has stopped investing in new plants. In 2011 the district heating companies in Denmark established the cooperative company Danish Geothermal District Heating (www.geotermi.dk) staffed with the former employees from DONG Energy. Together with GEUS this cooperative company holds the central geothermal experience in Denmark. New plants are expected to be owned by district heating companies.

2 DEEP GEOTHERMAL ENERGY

2.1 Geology

The deeper geothermal resources in Denmark are mainly related to two deep, low-enthalpy sedimentary basins, the Norwegian-Danish Basin and the North German Basin, and pronounced temperature anomalies are absent. Instead a fairly consistent temperature gradient of 25-30˚C/km dominates primarily depending on variations in thermal conductivity of the geological strata. The two basins are separated by a series of high-lying basement blocks with a thin sedimentary cover of approx. 1 km forming the WNW-ESE trending Ringkøbing-Fyn High. The Norwegian-Danish Basin to the north of the high constitutes the major part of the Danish subsurface, whereas the northern rim of the North German Basin constitutes the subsurface in the southernmost part of Denmark south of the high (Fig. 1).

Comprehensive research based on seismic and well data primarily from previous hydrocarbon exploration campaigns have shown that the fill of the Norwegian-Danish Basin contains several lithostratigraphical formations with sandstones of sufficient quality and temperature to serve as geothermal reservoirs. These are primarily the Lower Triassic Bunter Sandstone Formation, the Triassic Skagerrak Formation, the Upper Triassic–Lower Jurassic Gassum Formation, the Middle Jurassic Haldager Sand Formation and the Upper Jurassic–Lower Cretaceous Frederikshavn Formation. Of these formations especially the Gassum and Bunter Sandstone Formations are widely distributed at appropriate depths. The two formations are dominated by marginal marine and fluvial sandstones, respectively. The Skagerrak Formation is widely distributed along the northeastern basin margin, but its quality as geothermal reservoir is yet less understood owing to its heterogeneous nature. The Haldager Sand and Frederikshavn Formations occur mainly in northern to mid-Jylland, where they form good reservoirs at relatively shallow depths. In addition to these formations, Lower Jurassic, Lower Cretaceous and various mid-Cretaceous sandstones are present along the northeastern basin margin and especially in the eastern part of the basin on Sjælland they seem have a good potential.

In the North German Basin straddling southern Denmark the Bunter Sandstone Formation constitutes the principal geothermal reservoir as the Gassum Formation is only sporadically preserved at fairly shallow depths and the younger formations are completely absent. On the Ringkøbing-Fyn High sandstones are sparse due to non-deposition and erosion, and the few sandstones preserved are shallowly buried and thus of low temperature.

2.2 Geothermal resources

The distribution of the identified geothermal reservoir, their quality, temperature, and pore water chemistry is highly variable owing to different burial depths and deformations such as faults, folds, salt diapirs and pillows. The general trends and variations of these factors are relatively well understood and huge geothermal resources are documented in the subsurface below most of the Danish cities (Mathiesen et al. 2009). However, the geological variations are less constrained on a local scale and need to be thoroughly investigated prior to major decisions and investments. In most areas a preliminary local geological model can be established based on existing data from deep wells and seismic surveys obtained from previous explorations activities, as data, information, samples etc. are stored and kept at GEUS in accordance with the Danish Subsurface law. The local models need in most cases to be followed by the acquisition of new seismic data to supplement the existing data. In order to optimize the exploration and appraisal efforts and minimize the costs, GEUS has defined a stepwise maturation process with a number of decision gates that serves to avoid unnecessary investments in new exploration wells in areas with a limited geothermal potential.

2.3 Geothermal concessions

Exploration for and production of geothermal energy requires a licence pursuant to the provisions of the Danish Subsoil Act. In Denmark, several licenses have been awarded (Fig. 2) and projects are at different levels of maturation. The Danish Energy Agency administers licenses and monitoring.

2.4 Deep geothermal for district heating

Three plants are in operation in Denmark. The Thisted Plant has been in operation since 1984, and the HGS plant in Copenhagen at Margretheholm started production in 2005. A plant in Sønderborg has started test production. Locations are shown on figure 2.

The annual heat extracted in 2012 from geothermal water and used for district heating is at about 300 TJ. Around € 110 million, hereof approximately 90 % private, has been invested in the use of geothermal heat for district heating.

2.5 Geothermal plant in Thisted

A geothermal pilot plant transferring heat to the district heating network in Thisted from 35 m^3/h geothermal water through an electrically driven heat pump was erected by DONG in 1984. It was enlarged using absorption heat pumps to extract 4 MW from 150 m^3/h geothermal water in 1988 and 7 MW from 200 m^3/h geothermal water in 2001.

Annual corrosion rates in carbon steel exposed to the geothermal water are at 0.06 mm and good productivity and injectivity has been maintained.

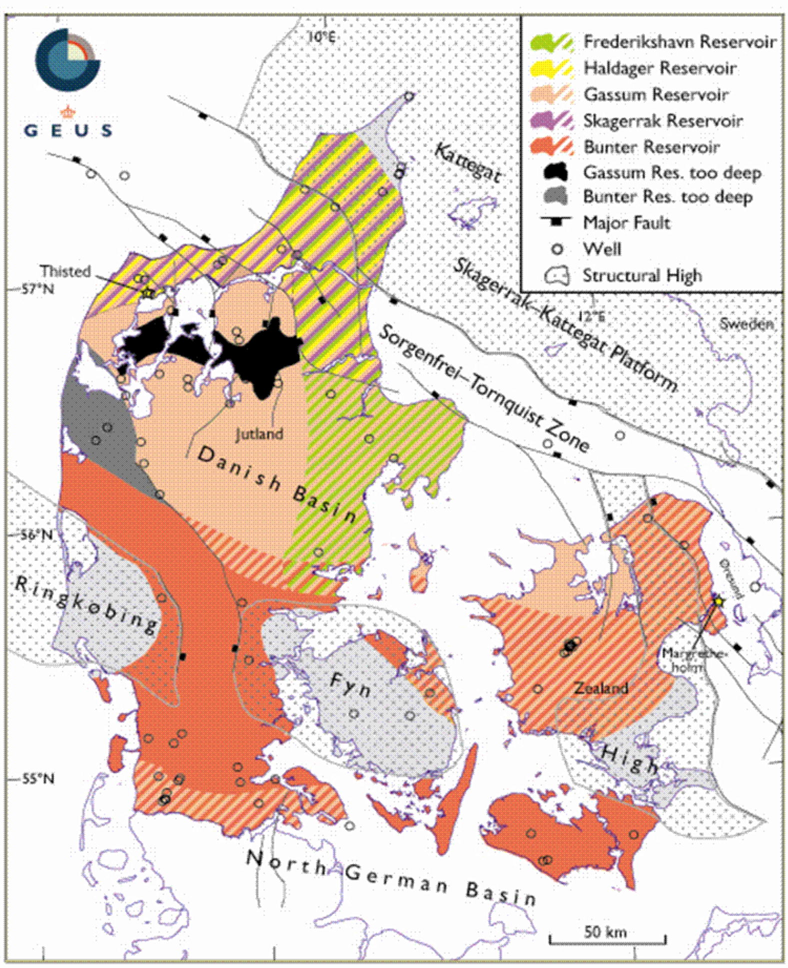

Figure 1: Map of potential geothermal reservoirs in Denmark.

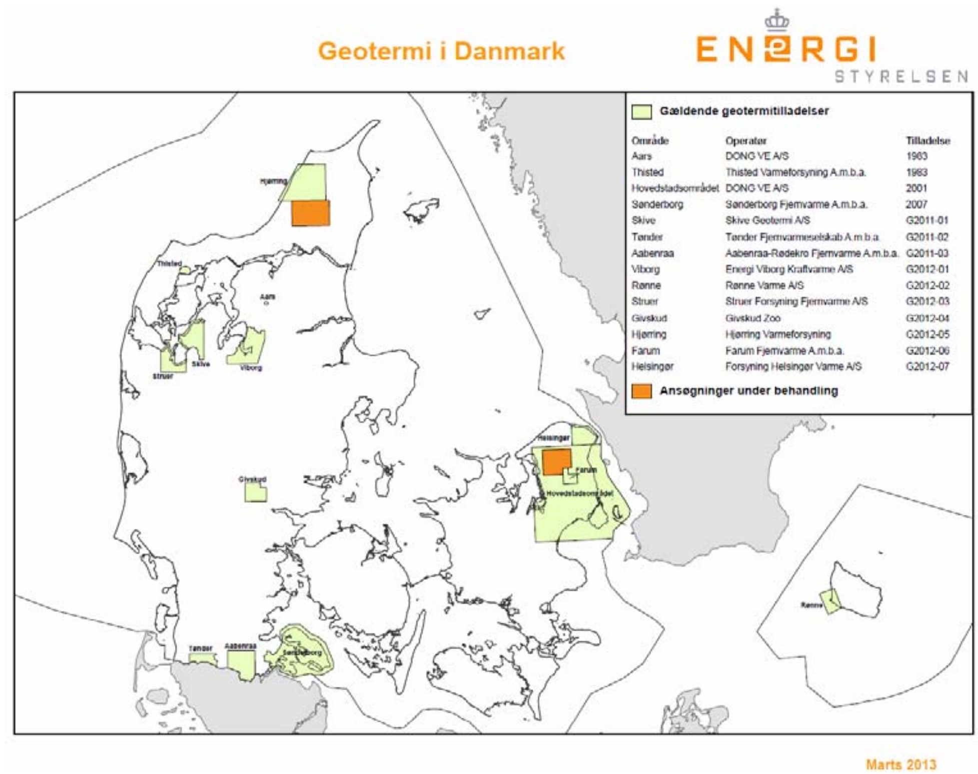

Figure 2: Map of geothermal licences.

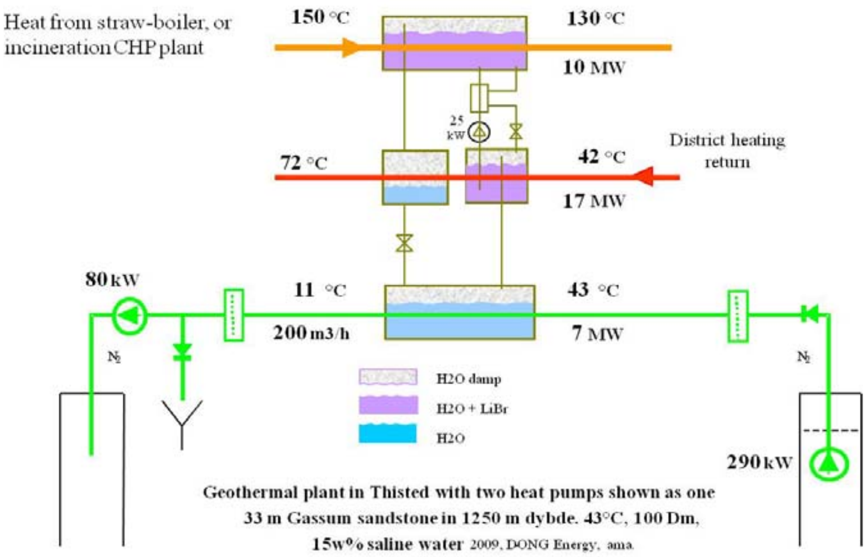

Figure 3: Geothermal plant in Thisted.

43 °C warm, 15 % (weight) saline water is produced from a high permeable Gassum sandstone aquifer at 1,250 m depth filtered to about 2 micron in bag filters before the heat extraction and to about 1 micron in cartridge filters before reinjection. The wells are vertical and located 1.5 km apart with injection pump and cartridge filters facilities at the injection site.

The plant has carbon steel piping with 3 mm corrosion allowance and AISI 316 moving parts in valves. It is protected towards air ingress into the saline geothermal water by nitrogen bottles maintaining an overpressure, when the plant is stopped, and furthermore by an operating system avoiding low pressures when the plant is operating and stopping. The water in the system is flushed to the sea at restarts.

The heat is transferred to the district heating network through absorption heat pumps driven by a straw based boiler. They are driven for free as the boiler uses the same amount of straw when producing heat through the absorption heat pumps to the district heating network as it does, when producing directly to the network. The local incineration CHP plant can also drive the heat pumps. The power to heat ratio (COP) for the geothermal plant in Thisted is at 15 - 20 depending on the load.

The total investment costs were € 11.1 million including costs for the Pilot Plant and the deep explorative production well.

Table 1: € million invested in the period 1982 – 2001 (1 € = 7.5 DKK).

Explorative 3.3 km production well	3.8
1.3 km reinjection well	1.4
30 m^3/h surface plant	1.8
Geothermal loop expansion to150 m^3/h	0.4
Surface plant expansion to 4 MW	2.2
Plant expansion to 7 MW	1.5
Total	11.1

More information on this plant can be found in earlier Danish WGC papers (Mahler 1995a &b, Mahler 2000, Mahler & Magtengaard 2005, Mahler & Magtengaard 2010).

2.6 Geothermal plant in Copenhagen

In 1999 DONG Energy formed a group (HGS) with heat and power producers and district heat transmission companies to establish a geothermal plant in Copenhagen. More detailed information about this plant has been included in earlier Danish WGC papers (Mahler & Magtengaard 2005, Mahler & Magtengaard 2010, Magtengaard & Mahler 2010).

A site next to the sea at the Amager CHP plant was chosen. The first well was drilled vertically to the basement situated in 2.7 km depth in 2002.The Bunter Formation at 2.6 km depth could be produced at acceptable rates and a second deviated well was drilled in 2003 with a 1.3 km step-out .

The construction of the surface plant to extract 14 MW heat from 235 m^3/h of the 74 °C, 19 % (weight) saline geothermal water started in 2003.

A heat pump plant with absorption heat pumps driven by up to 13 MW from steam is placed close to the steam supply and district heating net about 800 m from the geothermal loop. Three heat pumps in series cool district heating return water at about 50 °C to 15 °C to be heated to 71 °C in the heat exchanger at the geothermal loop plant.

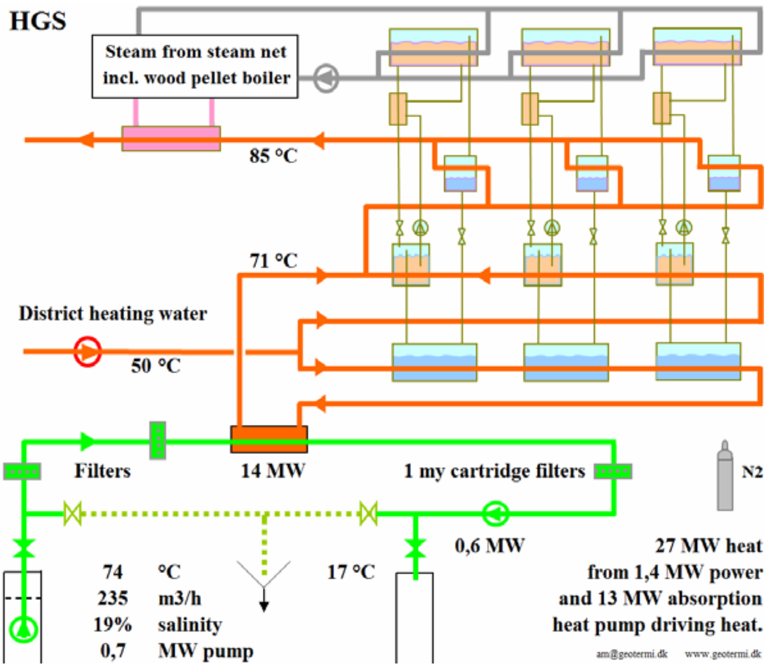

Figure 4: Geothermal plant in Copenhagen producing heat using heat exchangers and absorption heat pumps.

The geothermal water in the Copenhagen plant has a higher gas content including CO_2 and salinity than in Thisted. The geothermal loop with carbon steel piping is designed with 5 mm corrosion allowance, AISI 316 bag and cartridge filter houses with corrosion protection rods - and titanium plate heat exchangers.

When starting up the plant it was found that the bubble point was higher than calculated from water/gas samples. The production wellhead pressure was therefore increased to 15 bar(a) requiring the removal of two submersible pump steps to gain speed and thereby more horsepower in the pump. The high bubble point (at around 20 bar) has also required a system for removing gasses at the plate heat exchanger top. Measured corrosion rates in the carbon steel are at about 0.2 mm annually. The injection well needed a clean-up and it was pumped clean using the pump from the production well. The particle production was higher than expected and a self-cleaning filter (scraped and back-flushed) was installed.

The geothermal water is pumped to the surface by the 700 kW submersible pump located at 650 m depth, pre-filtered to 30 micron in the self-cleaning filter unit, filtered in 2 layered bag filters to first 10 then 1-2 micron, cooled from 74 °C to 17-18 °C in the tall ttitanium plate heat exchangers, filtered to 1 micron in cartridge filters and reinjected at up to 70 bar using a 700 kW injection pump.

Figure 5: Installation of a heat pump bottom part with common absorber & evaporator vessel.

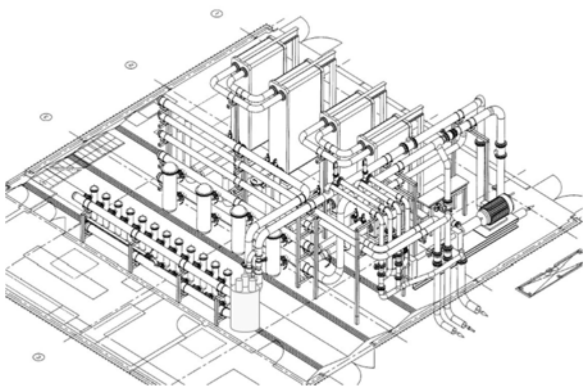

Figure 6: Geothermal loop in building

When starting the plant water is for some hours pumped to the cooling channel at the CHP plant to avoid plugging up the filters with sand and corrosion products from the well and to be sure not to inject air contaminated water.

Table 2: Investment costs: € million invested in the period 1999 – 2005 (1 € = 7.5 DKK).

Exploration including 314 km seismic	2.3
2.7 km vertical well & tests	6.3
2.7 km TVD production well	6.8
Surface plant	12.9
Total	28.3

The highest average daily production since the inauguration in 2005 has been at 13.5 MW. The plant seem able to run with a high stable heat production capacity and avoid capacity reduction from precipitations increasing the injection pressure if the injection temperature is kept low (below around 20°C) and both the flow rate and wellhead pressure is high.

Regretfully the injection pressure have been increased from plant stops from missing steam supply, summer periods with no heat demand and frequency converter failures etc. together with periods with low injection pressures from injection without injection pump and increased injection temperatures from insufficient cooling in the heat pumps e.g. from insufficient vacuum pumping, low stem pressures or internal leaks.

A container with a small acid pump and an acid / inhibitor mixing tank has been installed next to the injection well too ad some acid when needed.

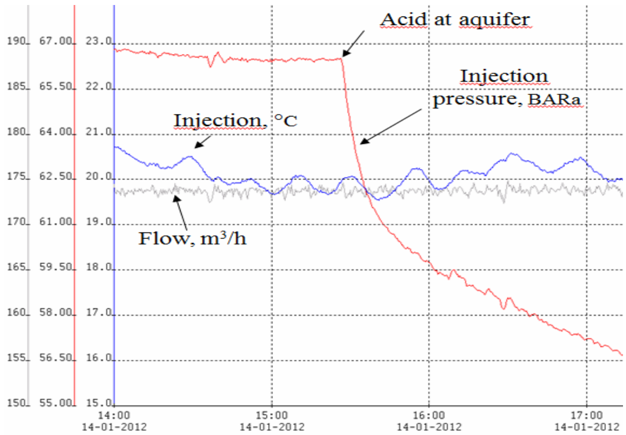

Figure 7: 10 bar injection pressure drop mixing 250 l of 15 % HCl into injection water

More acid has and will be injected to reduce the injection pressure, but the well completion with perforations instead of a gravel pack carries a risk of perforation collapses if too much acid is injected. Some effort will thus be put into systems to avoid new pressure increases from high injection temperatures or low injection pressures before more substantial amounts of acid is injected and a full clean-up of the well is carried out.

2.7 Geothermal plant in Sønderborg

A license for the area was granted in 2007 and a seismic survey was made the same year. The conclusion from the survey was that the wells should be placed outside the town and a production well and an injection well, both deviate, was drilled in 2009-2010.

The primary target was the Bunter sandstone expected to be found at 2.1 km. The Bunter formation was not found, and it was decided instead to test and install a gravel pack in the Gassum sandstone at 1.2 km depth.

The well tests showed that the well communication transmissivity was high, but regretfully also, that the skin factor was high in both wells. It was concluded that the mud cake removal in the gravel pack with enzymes should be supplemented by acid injection.

When surface facilities with filters etc. were ready in 2013, this acid injection was successfully carried out using the acid injection unit from the Copenhagen plant. The test pump was installed in the injection well pumping geothermal water first to a basin and afterwards through the filters together with the acid into the production well. The test pump was then removed and the production pump was installed in the production well to clean up the injection well the same way.

The surface facilities were installed in 2012-2013 with a separate heat pump plant next to the district heating net some kilometers from the geothermal wells. The plant is designed to produce up to 12 MW from the 48°C, 15 % (weight) saline geothermal water using absorption heat pumps, and the first heat from the geothermal water was produced early 2013.

The geothermal surface loop at the well site includes pumps, filters and a basin to collect geothermal water from well clean-up, filter drains and removal of air contaminated water. The basin is emptied by pumping the water to the sea mixing it with fresh water from a sewage water cleaning plant.

The heat pump plant has 4 absorption heat pumps cooling district heating water to about 12°C before it is pumped to the geothermal heat exchangers heating the water to about 45°. Driving heat for the heat pumps is provided by 2 wood chip boilers and the cooled water is also used to increase the heat extraction from the boiler flue gas.

The heat pumps and the geothermal pumps has been tested at the factory and the geothermal loop has shortly produced and reinjected more than 250 m^3/h, but the plant is still in the startup phase when this text is written.

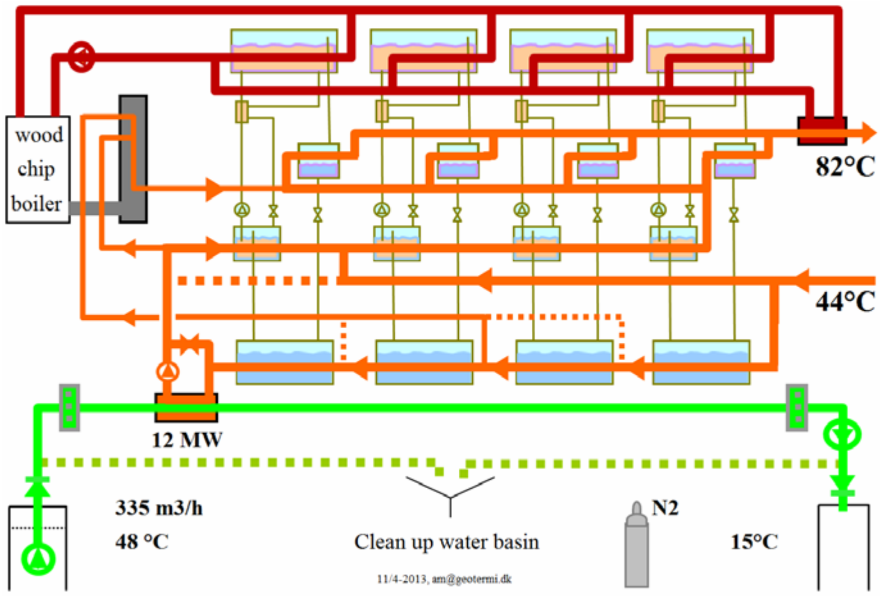

Figure 8: Geothermal plant in Sønderborg.

Figure 9: Picture with cartridge filters from geothermal loop in Sønderborg

2.8 New initiatives

A number of Danish district heating companies are considering establishing geothermal plants and seismic surveys and preparations for more have been made. Preliminary plans exist to erect a geothermal plant in Copenhagen with 11 wells.

The receivers of the heat from the existing plant in Copenhagen are investigating the possibility to establish a large geothermal plant with 11 wells deviating in all directions to an individual distance in the reservoir exceeding 1 km.

The large scale star-plant concept has been adopted in scenarios in the climate plan as well as in the heating plan for Copenhagen. If the plans are realized up to 3 star-plants able to extract a total of up to around 200 MW heat from the geothermal water could be erected before 2050 with a long term perspective to reach 400 MW.

The design in figure 10 use absorption heat pumps, but Denmark has an increasing power production from wind turbines etc. and electrical driven heat pumps may be chosen instead.

Such heat pumps may be ammonia based. Some or all heat pumps may alternatively be hybrid heat pumps working with an ammonia/water mixture reducing the condenser pressure and provide a different inlet and exit temperature through the condenser and evaporator. This can remove the need to establish a number of heat pumps in series to minimize the power consumption.

In an attempt to speed up the process of establishing new geothermal plants and avoid costly explorations activities in areas where the subsurface or the infrastructure are unsuitable, the Ministry of Climate, Energy and Buildings has initiated a number of new activities. As an important part of these initiatives, GEUS has commenced the establishment of a new Web-based GIS database with existing and quality-controlled data relevant for assessment of the geothermal potential. A screening exercise including both evaluation of the subsurface and the infrastructure in a number of Danish cities will be started later in 2013. In addition the preparation of a comprehensive manual describing the full project from the subsurface investigations to the construction of the plant from birth to grave will be initiated. Matters related to insurances and reductions of the economic risks are also expected to be mapped and described. It is expected that these new initiatives will fertilize and stimulate further interest in the utilization of the great geothermal resources in Denmark.

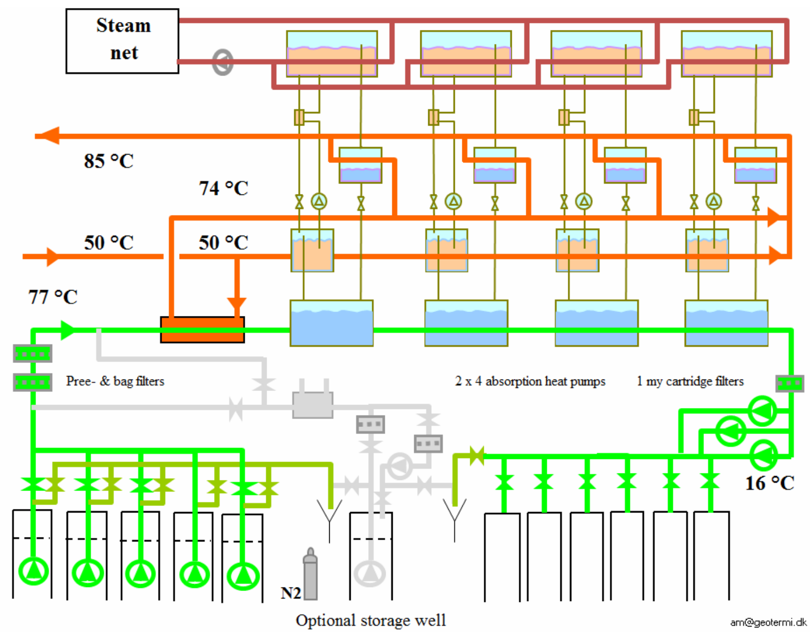

Figure 10: Possible concept for new large geothermal plant in Copenhagen

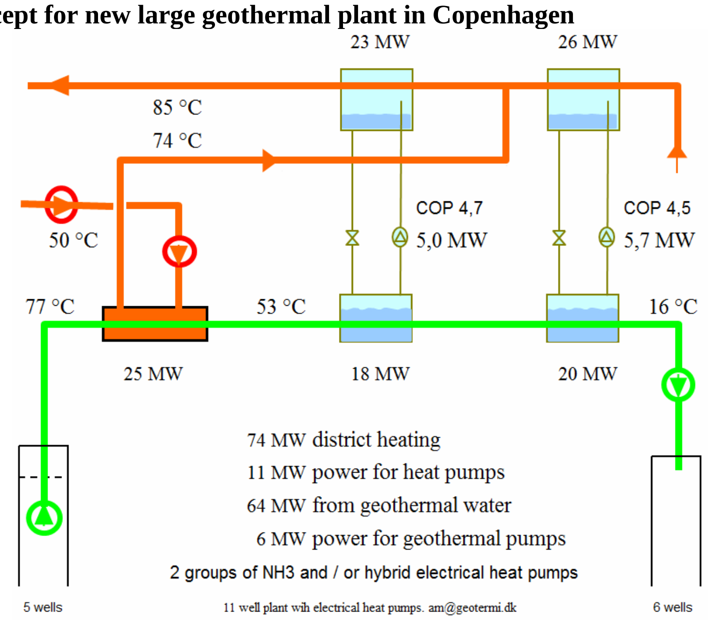

Figure 11: Alternative using electrical heat pumps at a new large plant in Copenhagen

3 SHALLOW GEOTHERMAL ENERGY

In Denmark shallow Geothermal Energy is commonly described as Ground Source Heating and Cooling which covers horizontal collectors as well as borehole heat exchangers (vertical or inclined) and groundwater based open loop systems.

Energy extraction by heat pump technology from shallow geological formations is beginning to play a significant role in Denmark in the transition towards a sustainable heat supply, especially in areas without district heating.

3.1 Geology

The shallow geology is dominated by soft sediments and characterized by a variable depth to the groundwater table. The sediments consist of glacial sand and clay deposits of variable thickness. To the west they are found on top of Miocene fluvio-deltaic sands and marine silts and muds. To the east and northeast the glacial deposits overlay relatively soft limestones from the Danien and Cretaceous.

The energy extraction from shallow installations depends on the thermal properties of the sediments surrounding the heat collectors, (e.g. Vangkilde-Petersen et al., 2011). However only few investigations of thermal properties of Danish sediments have been carried out (Balling et al. 1981; Porsvig 1986), and thermal conductivity values for different rock and sediment types published by e.g.

VDI (2010) show large variations for sediments relevant in a shallow geological context.

3.2 Legislation and administration

Ground Source Heating and Cooling is regulated pursuant to the Danish environmental protection act and permissions are issued by the Municipalities, who must include groundwater interests in their considerations.

Protection of the groundwater is normally not a limitation for horizontal collectors, but for borehole heat exchangers 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 against contamination. 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.

The regulation of groundwater based open loop systems is rather strict and specifies investigations and documentation regarding the geology and hydrogeology of the aquifer as well as the hydraulic and hydrothermal properties and the chemical and microbiological conditions. Furthermore, numerical modelling is required in order to document that the temperature of the groundwater in existing catchments will not increase more than 0.5 degree Celsius. For “areas of specific drinking water interests” it is required, that the groundwater resource must be exploitable again 10 years after the closing of the installation, which should also be documented by numerical modeling. These requirements are rather costly and imply that only larger installations are economically feasible.

3.3 Extent and distribution

Despite a large potential, the application of shallow geothermal energy in Denmark is relatively limited compared to e.g. Sweden or Germany. Today, the total number of ground source heat pumps in Denmark is around 27.000, and currently increasing with around 5000 per year. Most of the existing installations are horizontal collectors. Only a few hundred are borehole heat exchangers and some tens are groundwater well open loop systems. During the last couple of years the number of borehole heat exchangers has increased significantly with more than a hundred boreholes constructed each year, see figure 12.

Some open loop systems were installed in the eighties for house heating, later installations were primarily for industrial cooling and now large systems are applied with alternating operation (heating in winter and cooling in the summertime). One local district heating company has established a borehole heat storage (48 boreholes, 45 m deep) in combination with a solar heat installation, while another has established a pit storage also combined with solar energy.

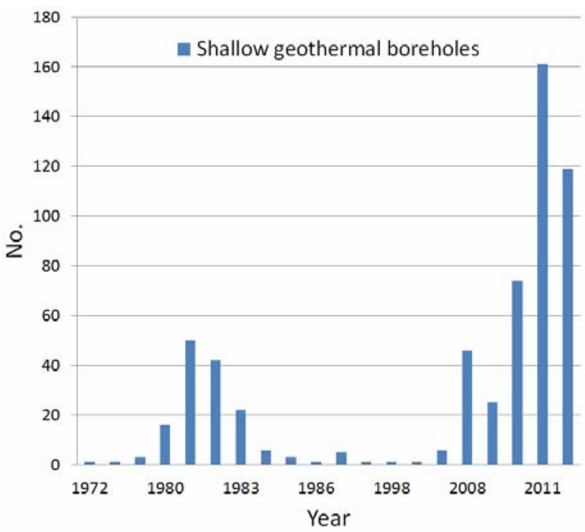

Figure 12: Number of shallow geothermal boreholes reported to the national borehole database Jupiter.

3.4 New initiatives

A three year project supported by the Danish Energy Agency aims to pave the way for a wider use of borehole heat exchangers by acquisition and dissemination of know-how and developing tools and best practice for the design and installation of systems.

Figure 13: Installation of borehole heat exchanger at test site, photo Inga Sørensen VIA UC.

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

A program to investigate the thermal properties of common shallow sediments has been initiated. The results will be accessible from a public database and will serve as input for numerical modeling of relevant scenarios with different geology and operating conditions. The results will serve as guideline for Danish planners of shallow geothermal installations.

The project is described in more detail in Ditlefsen et al. (this volume). Results from the project can be seen on the homepage www.geoenergi.org.

4 CONCLUSIONS

Assessment of the geothermal resources in Denmark indicates a great potential in large parts of the country. It has been proved possible to produce geothermal heat for district heating from deep Danish geothermal aquifers at 3 plants with a total design rate at 33 MW heat extraction from the 15-20 % saline geothermal water and a number of district heating companies are conducting exploration and are considering establishing a geothermal plant.

Shallow geothermal energy is expected to become more widespread in the future especially in areas with no district heating or natural gas supply. Most of the present ground source systems are using horizontal collectors.

REFERENCES

Balling, N., Kristiansen, J.I., Breiner, N., Poulsen, K.D., Rasmussen, R. & Saxov, S: Geothermal measurements and subsurface temperature, modelling in Denmark. GeoSkrifter 16, 176 pp. Aarhus University, Denmark (1981)

Ditlefsen, C., Sørensen, I., Bjørn, H., Balling, I.M., Højberg, A.L. and Vangkilde-Pedersen, T.: GeoEnergy – a national shallow geothermal research project. European Geothermal Congress 2013.

Magtengaard, J. & Mahler, A. 2010: Geothermal reserves and sustainability in the Greater Copenhagen Area. Proceedings World Geothermal Congress 2010.

Mahler, A. 1995a. Geothermal Plant with absorption heat pump in Thisted. Integration with heat and power plant and use for heat storage and removal of CO_2. Proceedings World Geothermal Congress 1995.

Mahler, A. 1995b. Geothermal Plant in Thisted with absorption heat pump and 10 years operation without corrosion or reinjection problems in sandstone for 15% saline water. Proceedings World Geothermal Congress 1995.

Mahler, A. 2000. Geothermal plant with efficient absorption heat pumps driven by incineration chp plant. Successful injection in sandstone aquifer. Country Update Denmark. Proceedings World Geothermal Congress 2000.

Mahler, A. & Magtengaard, J. 2005: Geothermal Development in Denmark, Country Update WGC 2005. Proceedings World Geothermal Congress 2005.

Mahler, A. & Magtengaard, J. 2010: Country Update Report for Denmark. Proceedings World Geothermal Congress 2010.

Mathiesen, A., Kristensen, L., Bidstrup, T. & Nielsen, L.H. 2009: Vurdering af det geotermiske potentiale i Danmark. Danmarks og Grønlands Geologiske Undersogelse Rapport 2009/59, 30.

Porsvig, M.: Varmeovergangsforhold omkring jord-slanger. Energiministeriets varmepumpeforsk-nings-program 33, 56 pp. (1986).

Vangkilde-Pedersen, T., Ditlefsen, C. and Højberg, A.L: Shallow geothermal energy in Denmark. Geological Survey of Denmark and Greenland Bulletin 26, 37–40. GEUS 2012.

VDI (Verein Deutscher Ingenieure) 2010: Thermische Nutzung des Untergrundes: Grundlagen, Genehmigungen, Umweltaspekte. Richtlinie 4640, Blatt 1, 33 pp. Dusseldorf: Verein Deutscher Ingenieure. 2010.

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TABLES A-G

Table A: Present and planned geothermal power plants, total numbers*

*Geothermal power plants are not available in the country.

Table B: Existing geothermal power plants, individual sites*

*Geothermal power plants are not available in the country.

Table C: Present and planned geothermal district heating (DH) plants and other direct uses, total numbers

	Geothermal DH Plants		Geothermal heat in agriculture and industry		Geothermal heat in balneology and other	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2012	21	300	-		-	
Under construction end of 2012	12		-		-	
Total projected by 2015	33		-		-	

Table D: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commiss.	Is the heat from geo-thermal CHP?	Is cooling provided from geo-thermal?	Installed geotherm. capacity (MW_{th})	Total installed capacity (MW_{th})	2012 geo-thermal heat prod. (GWh_{th}/y)	Geother. share in total prod. (%)
Thisted		1984	Yes	No	7		22	
Copen-hagen	GDA *	2005	Yes	No	14		58	
Sønder-borg		2013	Yes	No	12			
Total					33		80	

* Geotermisk Demonstrationsanlæg Amager

Table E: Shallow geothermal energy, ground source heat pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New GSHP in 2012		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2012	27000		2-3 PJ	5000		
Projected by 2015	42000					

Table F: Investment and Employment in geothermal energy

	in 2012		Expected in 2015	
	Investment (million €)	Personnel (number)	Investment (million €)	Personnel (number)
Geothermal electric power	-	-	-	-
Geothermal direct uses	200			
Shallow geothermal				
total				

Table G: Incentives, Information, Education

	Geothermal el. power	Geothermal direct uses	Shallow geothermal
Financial Incentives – R&D	No	REQ (First time in 2013)	No
Financial Incentives – Investment	No	No	No
Financial Incentives – Operation/Production	No	No	No
Information activities – promotion for the public	No	Yes (Danish Energy Agency and GEUS)	Yes (Danish Energy Agency and GEUS)
Information activities – geological information	No	Yes (Danish Energy Agency and GEUS)	Yes (Danish Energy Agency and GEUS)
Education/Training – Academic	No	No	No
Education/Training – Vocational	No	No	No

Key for financial incentives:

DIS	Direct investment support	RC	Risc coverage	FIP	Feed-in premium
LIL	Low-interest loans	FIT	Feed-in tariff	REQ	Renewable Energy Quota