Renewable Heat Supply through the Seasonal Coordinated Combination of Solarthermal and Geothermal Systems

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Abstract

Solarthermal plants can be supplemented with a seasonally operating geothermal deep probe and a heat pump, thus creating an energy supply system in which these devices support each other in an ideal manner. The system promises high shares of renewable energy and high efficiency of the solar and the geothermal system at the same time.
This report introduces the concept of the system, explains its interesting technical properties, presents the simulation model and describes its economic characteristics.

KEYWORDS

solar energy - geothermal energy - Deep Probe - simulation - seasonal storage - local heating

INTRODUCTION

To achieve substantial contributions of regenerative energy sources to the overall energy supply, systems must be able to cover high shares of heat demand by regenerative sources. Unfortunately, these sources are characterised by seasonal fluctuations, low energy densities and stochastic production patterns. If only one renewable source is used, these shortcomings often lead to high costs that can be avoided by combined systems.
With support from the German Ministry of Education and Research (BMBF), the heat supply company EKT has been working in cooperation with the Technical University Berlin (TUB) on a feasibility study for the local heating system *Gesotherm S*. This is a combination of a solarthermal installation with a newly developed geothermal Deep Probe. It enables high regenerative fractions, synergism effects of the combined operation and acceptable costs per kWh heat delivered to the customer. The Deep Probe is not only applicable in particular geological locations, but in most areas.

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SYSTEM DESIGN

The local heating system *Gesotherm S* consists of a collector field and a thermal buffer, combined with a Deep Probe and a gas-driven heat pump with waste heat utilisation. It is designed to cover about 50% of the heat demand through renewable sources, while the remaining demand is covered by a peak boiler (Fig. 1).

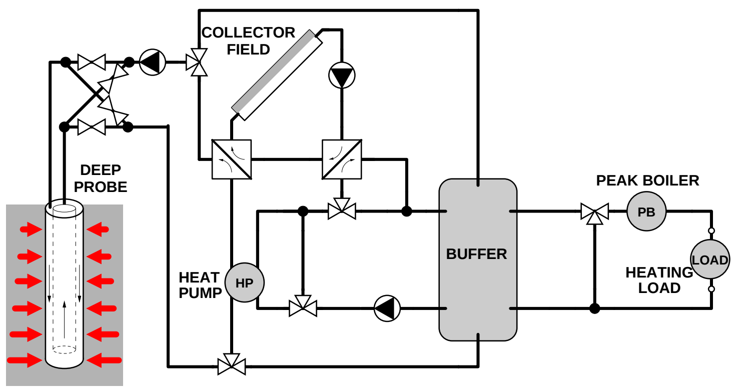

Figure 1: *Gesotherm S* - flow scheme

In contrast to usual geothermal plants (aquifer, hot-dry-rock systems, etc.) the newly developed Deep Probe is a closed system requiring no filtering, no subsurface installations of pumps and little pump energy. However the output is restricted by the natural underground heat flow.
While ordinary probes used as temperature reservoirs for heat pumps or storages have a depth of ca. 100 m, the Deep Probe has a depth of ca. 3'000 m, allowing extraction of geothermal heat at ca. 65 °C outlet temperature.
Only a single borehole of ca. 17 cm diameter is necessary, in which a tube-in-tube system is installed. During normal operation cold water is pumped through the outer tube and heated on its way down, returning up through the insulated inner tube. This closed circuit is filled only once with conditioned water. Energy flow and outlet temperature of this ground heat exchanger are controlled by the mass flow. A heat pump raises the temperature to the level required by the heating network. The system is truly regenerative as heat is continuously conducted to the probe from the earth's core, replacing the extracted heat. A Deep Probe plant of the type described here has been in operation in Prenzlau (Germany) since 1994. The probe works all year in a base load range with a capacity of up to 600 kW and covers 21% of the annual heat demand of the district heating company (Kraft,1996). The geological situation at this location is not special and is comparable to that of more than half of Germany. The installation of the Deep Probe in Prenzlau was honoured with the Innovation Prize of the European Thermie Program in 1995.
In the planned project the Deep Probe and the solar system are operated in seasonal coordination. Heat flow into the probe is limited by the heat conductivity of the ground. Extracting more energy out of the ground than can be recovered through instant heat flow enables an operation of the Deep Probe depending on the season. In Figure 2 the varying contributions to the heat production can be seen:
In wintertime as much geothermal heat is extracted from the ground as possible. If necessary, the heat pump or the peak boiler is used. Due to the heat extraction, the temperature of the ground surrounding the probe is lower at the end of the winter. At this time the power output of the Deep Probe is reduced, and the output of the collector field rises. In summertime the solar system covers the energy demand, while the earth around the Deep Probe can warm up again. Surplus solar energy is used to fasten the regeneration in the lower ground layers around the probe or can be stored in layers closer to the surface. At the end of the summer period, collector output declines and increasingly more stored energy has to be used. With falling outdoor temperatures the contribution of the collector gets smaller, and the contribution of the Deep Probe rises until the cycle is closed.

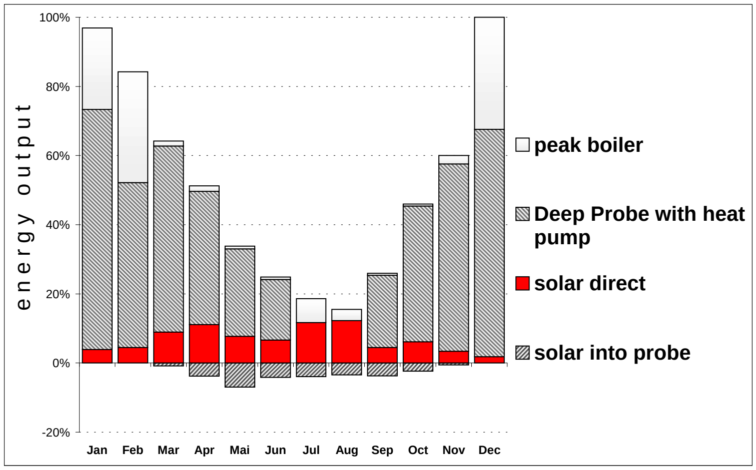

Figure 2: *Gesotherm S* - seasonal energy output

SIMULATION

To optimize configuration and to analyse the time-dependent behaviour of the combined system, the computer modelling software SMILE is used. SMILE is a simulation environment as well as an equation- and object- oriented language for dynamic simulation. It has been used for research in energy engineering since its development at the TU Berlin. Modelling is convenient, because experiment description, modelling language and numerical solvers are separated in SMILE. The program offers a numeric library with different solvers for differential-algebraic equations and a technical data base containing components in the field of high and low temperature engineering (collector, heat pump, storage, building, pipeline network, turbine, etc.)(Bartsch,1997).
The Deep Probe model is built from submodels of the tube-in-tube system and the soil layers. The object-oriented structure of the model enables the implementation of different truncation levels and geological circumstances. In the first step, radial symmetry and pure conductive heat transfer are assumed. The model is validated with other geological simulation tools and data measured at the plant in Prenzlau.
This model determines the correlation between the heat flow in the ground and the potential energy output of the probe. The output depends on construction, operation and geological parameters (tube depth and diameter, mass flow, inlet temperature, ground conductivity, etc.). The simulation facilitates analysis of a number of questions, differing in their time scale:

- What is the long-term behaviour of the probe? What mass flow has to be chosen to avoid a continuous decrease of the ground temperature and to establish a stationary operation?

- For an optimal combination with solar energy, the seasonal variation is crucial. How much can the temperature of the ground be lowered during winter and how long does it take to regenerate it in summer? Furthermore, can the yearly output be increased by variation of the temperature gradient in the ground?

- How should the probe be coordinated within the complex overall system? For quick regulations the thermal inertia of the ground and the time delay in this long buffer with up to 30 m^3 have to be considered.

To study the questions concerning the long-term behaviour of the ground, a stand alone model is used. To study the short-term behaviour of the complete *Gesotherm S* system, the model is connected with components from the data bank and is used to determine:

- the contributions and efficiencies of the different components;
- optimal system parameters, design and control strategies;
- synergism effects through the combination of solarthermal and geothermal energy: How far can the regeneration be influenced by surplus solar energy and how much energy can be stored in the underground? Buffers often are uneconomically large, in order to prevent collectors from boiling. To which extent can the combination with the Deep Probe avoid this stagnation? How much can the collector output be augmented when the fluid from the cold outlet of the heat pump enters into the collector?

ECONOMY OF THE SYSTEM

Preliminary calculations show that local heating systems with an overall connected heat load of 1-5 MW and a regenerative energy share of 30-60% achieve the best economic results. The economic attractiveness of the *Gesotherm S* system results from the following elements:

- The costs of drilling have declined considerably in recent years, thus reducing the geothermal heat price to a level comparable to standard solarthermal systems.
- The seasonal operation leads to synergetic effects which enhance the economy of the Deep Probe.
- There is only a minimal drilling risk.
- Additional economic aspects of the Deep Probe are a long life expectancy and low overhead costs.

A local heating system with a heating load of 4 MW and a 45% renewable share of heat demand was projected in Berlin. Based on offers from equipment suppliers the cost of heat production was determined to be no more than 188 DM/MWh (heat price of the regenerative energy: 211 DM/MWh).
The Deep Probes is, in contrast to other geothermal systems, independent from local geological anomalies and represents no risk to ground water. Sufficient geological conditions are found in wide parts of Europe and the world. Deep probes can be installed in inner cities.
The diffusion of the system will increase its efficiency and achieve economies of scale for drilling and solar panel costs. A potential of 30-50% cost reduction can be expected in the near future. The goal of the competitiveness of regenerative energy seems to be reached under these conditions.

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