Geothermal Heat PipeBorehole Heat-Exchangers: Computational Simulation and Analysis of Measurement Data

Échangeurs thermiques à thermosiphon utilisés en géothermie : simulation numérique et analyse des mesures

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ABSTRACT: Shallow Geothermal Energy is a very promising alternative to fossil fuels, especially in the Residential and Commercial sectors, both including the heating and cooling of buildings. Among the available technologies in Shallow Geothermics, the Geothermal Borehole Heat-Exchanger equipped with a Heat Pipe is a particularly efficient optimization in comparison to conventional borehole heat-exchanger systems for two main reasons: Due to the gravity and buoyancy driven energy transport in the borehole heat-exchanger there is no need for a circulation pump. Hence, the consumption of by-energy is significantly reduced. Furthermore, the temperature distribution within the borehole heat-exchanger is advancing a high energy withdrawal rate much more than conventional systems. A method has been developed to estimate the heat transport of a Geothermal Heat Pipe Borehole Heat-Exchanger as computational simulations are used to determine the expected energy withdrawal rate. Furthermore, long-term measurement data have beencollected from a Geothermal Heat Pipe Borehole Heat-Exchanger installation. The analysis of measurement data allows proving the functionality.

RÉSUMÉ : L'énergie géothermique de surface comme alternative aux énergies fossiles est une source d'énergie prometteuse, en particulier dans les secteurs résidentiels et commerciaux incluant le chauffage et la climatisation des bâtiments. Parmi les technologies disponibles, les sondes géothermiques équipées d'un thermosiphon (conduite de chaleur) sont une solution particulièrement efficiente en comparaison des traditionnelles sondes géothermiques pour deux raisons principales. Il n'est d'abord pas nécessaire de disposer d'une pompe de circulation, à cause de la gravité et du transport d´énergie par la flottabilité dans la sonde, diminuant ainsi l'énergie d'alimentation. Ensuite, la distribution de température dans la sonde géothermique montre une consommation d'énergie moins importante que pour les systèmes conventionnels. Une méthode a été développée afin d'estimer le transport de chaleur assuré par un échangeur thermique sur le principe du thermosiphon utilisé en géothermie et des simulations numériques ont été effectuées afin de déterminer la consommation énergétique du système. Les données ont été collectées à long terme sur une installation utilisant une sonde géothermique à thermosiphon. L'analyse des données collectées permet de montrer la fonctionnalité de ce type d'installations.

KEYWORDS: shallow geothermal energy, heat pipe, thermosiphon.

1 INTRODUCTION

Geothermal Energy is a very promising alternative to fossile fuels, especially in the residential and commercial sectors, both including the heating and cooling of buildings: Almost 50% of the overall final energy consumption are being unsed for the tempering of buildings. As using the so-called "Shallow Geothermal Energy" – the thermal use of soil and groundwater in the uppermost spoil region for low-temperature applications – is almost everywhere applicable, decentral and in perfect conjunction with electirc power from other renewable sources, various applications scenarios in differenct climate regions, operational modes and building types in new construction and the existing building stock allow a wide range and large number of applications. Among the available technologies in Shallow Geothermics, the conventional geothermal borehole heat-exchanger, usually consisting of a double-u loop to circulate the energy carrying medium is most common. In order to optimize the overall energy performance of the heat exchanger and thereby of the entire geothermal facility a heat pipe is being used as main energy transport element of the borehole heat exchanger.

A heat pipe is a particularly efficient technology in comparison to conventional borehole heat-exchanger systems for two main reasons:

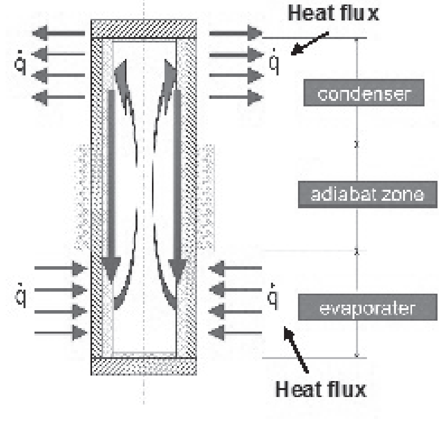

Figure 1: Heat Pipe: Working Cycle

Due to the gravity and buoyancy driven energy transport in the borehole heat-exchanger a high density of energy transport can be archived even without using a circulation pump.

Accordingly, the consumption of by-energy is being significantly reduced.

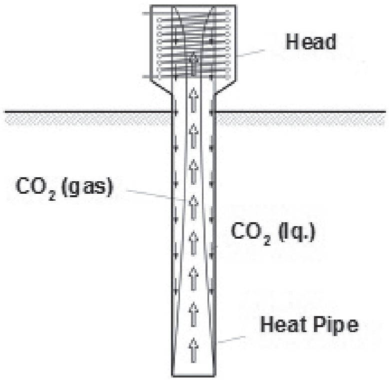

Figure 2: Heat Pipe: Geothermal Heat Pipe: Configuration

Furthermore, the temperature distribution within the borehole heat-exchanger is advancing a high energy withdrawal rate much more than conventional systems: The overall energy withdrawal rate is predominantly governed by the temperature difference between borehole heat-exchanger and ambient ground temperature, which by itself is limited in terms of its lower margin. Hence, a heat pipe borehole heat-exchanger is exploiting the usable temperature more efficient than conventional borehole heat-exchanger systems.

2 SIMULATION OF GEOTHERMAL HEAT PIPE OPERATION

The thermal performance of a heat pipe is dependent on a number of influencing parameters, e.g. driving temperature difference, mechanical and thermal properties of the heat carrier fluid – in the present case CO_2 – such as evaporation enthalpy, heat conductivity and capacity, viscosity, the energy withdrawal rate on the condenser side, the geometric dimensions and particularly the inside pressure and the amount of filling medium respectively, compare to Dunn and Reay (1993) and Lee and Mital (2003).

Based on a numerical algorithm and accounting for the conduction-governed energy transport from the soil to the cylinder and the convection-governed energy mechanism within the cylinder in vertical direction and considering both surface evaporation and boiling evaporation, an extensive number of computations were conducted in order to investigate the sensitivity to various parameters such as overall length, diameters of heat pipes and boreholes. The resulting specific power for a given set of parameters for a constant saturation pressure is plotted in Figure 3.

The exceptionally efficient energy transport within the heat pipe and the obsolete circulation pump in comparison to conventional borehole heat exchangers allow a relative increase of the coefficient of performance (COP) of up to more than 10°% (percentage).

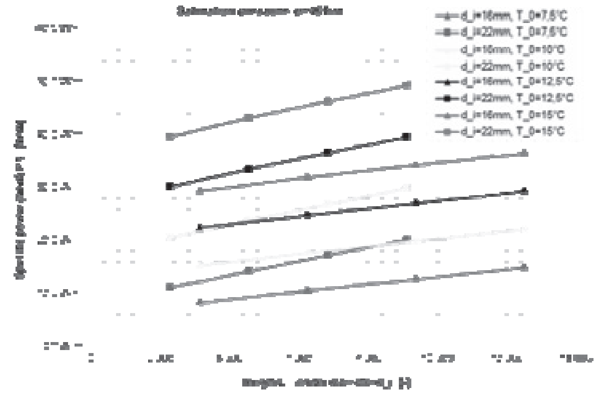

Figure 3: Simulated heat pipe performance: Energy withdrawal rate(specific power: heat)

During the operation of such a Two-Phase-Heat Pipe the thermal transfer resistance in film evaporation or condensation is significantly smaller in comparison to a system without phase change. Accordingly, a significantly smaller driving temperature difference between soil temperature and heat pump evaporator is necessary to archive the same overall heat flux density.

The relation between length and diameter has large influence on the specific power (heat). Accordingly, it is desirable to optimize this geometric relation during dimensioning and design.

3 CASE STUDY OF APPLICATION

Within a pilot project, a new-construction one-family home has been equipped with a ground-coupled heat pump in combinations with geothermal heat pipe borehole heat exchangers. These have been instrumented for long term measurements of ground temperatures and heat pump parameters(see Figure 4).

Figure 4: Measurement installation

The obtained temperature records (Figure 5) can be used to investigate the overall performance of the energy supply system as well as to analyse the operation and to control the functionality of the installation.

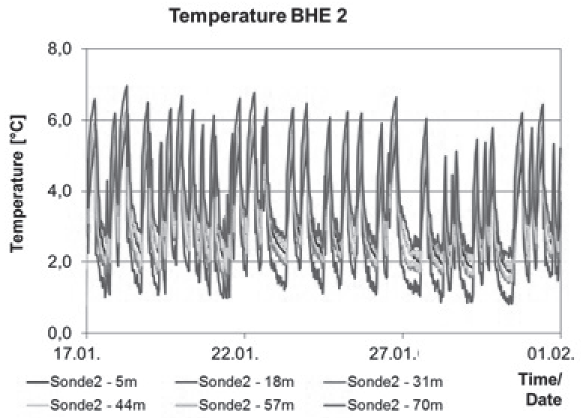

Figure 5: Temperature records

Especially the temperature distribution in depth and time along the heat-pipe borehole heat exchangers allows to identify the operation of the heat-pipes in detail:Figure 6 shows the temperature distribution at a specific borehole heat exchanger at different states of operation. One can observe that the temperature distribution is not linear. From this distribution information on the state of operation (bath or film evaporation) can be derived.

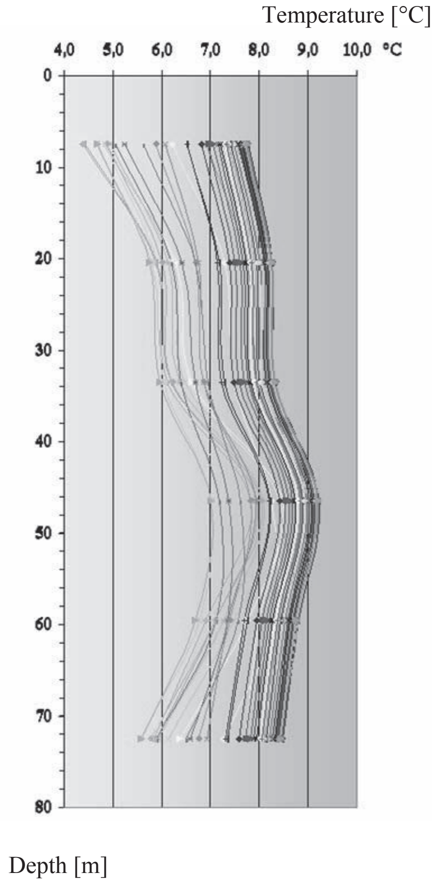

Figure6: Temperature profiles of a particular heat pipe borehole heat-exchanger within 24 h (30 min interval, the colors ranging red-yellow-green-blue-black)

4 SUMMARY

Geothermal Borehole Heat Exchangers using geothermal heat pipes for convective energy withdrawal and transport from and with the soil are a particularly efficient technology.

A method has been developed to compute the heat transport of a Geothermal Heat Pipe Borehole Heat-Exchanger.

Furthermore, long-term measurement data have been collected from a Geothermal Heat Pipe Borehole Heat-Exchanger installation. They have been successfully used to compute the expected heat power output and the systems' operation.

5 REFERENCES

Dunn, P.D.; Reay, D.A. (1993). Heat Pipes. University of Reading, Reading UK, Heriot-Watt University, Edinburgh, UK. Fourth Edition.

Lee, Y.; Mital, U. (2003). A two-phase closed thermosyphon. Department of Mechanical Engineering, University of Ottawa 2, Ottawa, Canada.