Geothermics 55 (2015) 99–107

Contents lists available at ScienceDirect

Geothermics

journal homepage: www.elsevier.com/locate/geothermics

Numerical investigation of the performance of a partially wetted geothermal thermosyphon at various power demand schemes

Frank Hartmann[a], Ralph Behrend[b], Andreas Hantsch[c,*], Thomas Grab[b], Ulrich Gross[b]

[a] *TU Bergakademie Freiberg, Institute of Energy Process Engineering and Chemical Engineering, G.-Zeuner-Str. 7, 09596 Freiberg, Germany*
[b] *TU Bergakademie Freiberg, Institute of Thermal Engineering, G.-Zeuner-Str. 7, 09596 Freiberg, Germany*
[c] *Institute of Air Handling and Refrigeration gGmbH, Bertold-Brecht-Allee 20, 01309 Dresden, Germany*

ARTICLE INFO

Article history:
Received 6 December 2013
Accepted 29 January 2015

Keywords:
Geothermal heat pipe
Thermosyphon
Wetting behaviour
Falling liquid film flow
Soil
Grout
Operation model
Steel
Polyamide (PA)

ABSTRACT

Geothermal thermosyphons utilise the latent heat of a working fluid in order to extract heat from the subsurface without the requirement of any further mechanical energy. Earlier visual observations showed that the inner pipe area is often not fully wetted by the liquid film. This fact raised the question of the influence on the overall heat transfer of the imperfect wetting in conjunction with the materials of borehole filling (grout) and thermosyphon, and the operational modes. In order to facilitate the discussion, a quasi-three-dimensional model has been developed and solved numerically. The results agree well with experiments and it can be discovered that the choice of the pipe and grout material becomes increasingly important for lower wetting ratios and shorter extraction times. Furthermore, it could be illustrated that a well-wetted polyamide plastic pipe with a thermal conductivity larger than 2 W/(m K) would be a possible alternative to steel pipes.

1. Introduction

The costs for heating have risen fast during the past 25 years, and many experts on the field predict an ongoing rising in the future. To counteract these rising costs and the depletion of conventional resources, the utilisation of renewable energy sources has largely increased. Utilising wind and water energy as well as deep geothermal electrical energy is only cost efficient in large-scale installations and hence very expensive. The application of small-scale installations, such as for single households or smaller complexes, solar and shallow geothermal energy are contrary to large-scale installations already increasingly employed. Both technologies have in common the relatively large specific investment costs compared to oil- or gas-fired heating systems, but contrary to solar thermal energy, geothermal energy is always available at almost constant rate. Geothermal energy is mostly extracted by employing ground-source heat exchangers, such as double-U pipes with some fluid circulating. Opposing to those installations utilising the sensible heat of the fluid, there are geothermal thermosyphons existent, which will be in the focus of the present contribution.

A geothermal thermosyphon consists of two main parts: a vertical pipe and an attached condenser yielding a closed system as illustrated in Fig. 1(a). This system is filled with a pure two-phase working fluid, which is initially separated into a liquid pool at the bottom of the pipe, some liquid wetting the inner pipe surface, and the vapour phase filling the remaining space. As soon as the condenser is activated, heat is withdrawn, and hence some vapour is liquefied in the condenser. In reaction of the decreasing pressure, the liquid film at the inner surface evaporates immediately and the liquid pool starts to boil. Due to the ongoing liquefaction process, liquid is supplied to the upper end of the inner surface of the pipe, where it is driven down by gravity. Due to the temperature difference between fluid, pipe, and borehole filling (grout), a heat flux is induced into the liquid and thus the liquid is heated. As soon as the liquid exceeds its saturation temperature it evaporates and the vapour begins to rise, due to buoyancy. The fluid is liquefied at the condenser and the cycle starts again. For further details see Grab et al. (2011).

As stated above, geothermal thermosyphons have large initial costs, which are directly related to the size of the borehole, and both the pipe and filling materials. The borehole diameter cannot be varied freely due to drilling restrictions and the availability of standard

---

* Corresponding author. Tel.: +49 351 4081 684; fax: +49 351 4081 655.
E-mail addresses: andreas.hantsch@ilkdresden.de (A. Hantsch), thomas.grab@iwtt.tu-freiberg.de (T. Grab).

http://dx.doi.org/10.1016/j.geothermics.2015.01.014
0375-6505/

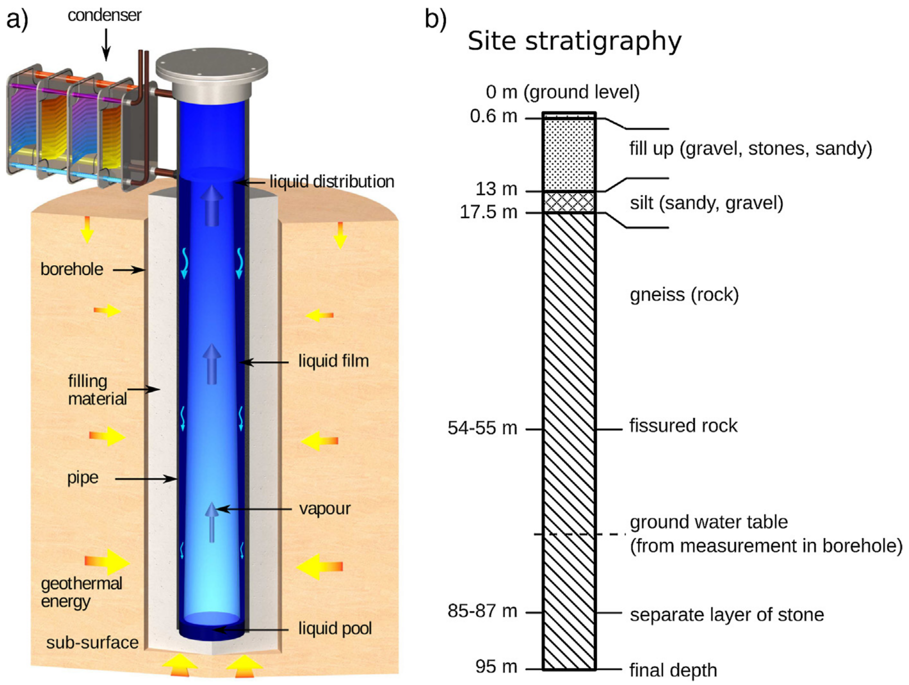

Fig. 1. (a) Schematic representation of a geothermal thermosyphon. Not to scale. Typical dimensions for common systems are 50, ..., 250 m length, up to 55 mm pipe diameter, and approx. 150 mm borehole diameter and (b) site stratigraphy of experimental test site.

Source: Adopted from Storch (2015).

drilling tools. Steel pipes, which are required to be welded at the building site, may be replaced by plastic pipes made, for instance, of polyamide (PA) or polypropylene, which can be delivered to the building site as coils with the required length. Furthermore, the filling material can be varied in order to improve the heat transfer. Due to the difficult measurement conditions in such a geothermal thermosyphon, numerical methods should be applied in order to facilitate performance evaluations.

Modelling the temperature in the surrounding sub-surface is a field where a lot of effort has been made, especially for ground source heat exchangers (see Hantsch and Gross, 2013; Peterlunger et al., 2009, and references therein for an overview). Lee and Lam (2008) presented three-dimensional finite difference simulations employing an irregular, rectangular grid around the borehole. They pointed out, that during a regeneration period, the heat flow to the surroundings is small, but not negligible. A two-dimensional transient model for the simulation of ground heat exchangers was developed by Yavuzturk et al. (1999) using an implicit finite volume approach. The simulation was set up to employ a parametric polar grid and it demonstrated good agreement with analytical solutions for short time scales. The probably most complex model so far was presented by Al-Khoury et al. (2005) and Al-Khoury and Bonnier (2006). A finite element method was applied together with a three-dimensional model of the sub-surface including coupled processes of heat transfer and ground water flow. For this case the borehole heat exchanger was modelled as an one-dimensional element. The simulation has been carried out for steady-state and transient operation.

The present authors carried out a lot of investigations, both in the field and in the laboratory. The performance of a geothermal thermosyphon using propane has been measured and analysed, see Grab et al. (2011), and transient temperature distributions along a 100 m pipe have been reported. Storch et al. (2012) utilised the same test facility for visual observations of the falling liquid film flow by application of a specially designed camera system being descended inside the pipe down to its lower end. Whilst the test facility has been installed in gneissic bedrock, the first 20 m are drilled in local tailings (see Fig. 1(b)). One characteristic feature has been observed, which is critical to the correct simulation of geothermal thermosyphons. Whilst the afore-mentioned studies assumed complete wetting over the full length of the evaporation zone, this is not necessarily the case in reality. Over the length of the pipe, especially in the lower half, a decreasing area of the inner surface is wet and it is numerically described as wetting ratio B in %.

Based on these observations, Hantsch and Gross (2013) performed a two-dimensional numerical study in order to investigate the influence of pipe materials, thermal conductivities of both borehole filling and sub-surface, and the wetting ratios on the geothermal thermosyphon performance assuming permanent extraction.

In the present study, however, the emphasis lies on the short-time behaviour at various wetting ratios, material parameter values and operation modes including regeneration periods. Objective is to focus on the influence of the outer thermal resistances in the pipe, borehole filling, and surrounding sub-surface at partial wetting. The fluid flow itself is not considered here in detail, but the wetting conditions are imposed as boundary condition in terms of wetted perimeter divided by total perimeter (i. e., wetting ratio B). By means of numerical modelling and simulation, the following points will be considered:

1. thermal conduction through pipe material (P), borehole filling (F), and sub-surface (S),
2. fluid flow including the wetting ratio inside the pipe using algebraic equations for the local heat transfer and
3. mode of operation (temporal characteristics of extraction and regeneration, wetting conditions).

These simulations were carried out in order to investigate the substitutability of steel (ST) pipes by polyamide (PA) pipes due to the simpler bore hole installation. Besides the pipe material, also the filling material of the borehole is of importance for the