Applied Thermal Engineering 94 (2016) 99–110

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research Paper

Towards the increased utilisation of geothermal energy in a district heating network through the use of a heat storage

Sotirios A. Kyriakis *, Paul L. Younger

School of Engineering, University of Glasgow, James Watt Building, Glasgow G12 8QQ, United Kingdom

HIGHLIGHTS

- The application of heat storage in geothermal district heating networks was studied.
- Integrated algorithms for the sizing and operation of the installation were built.
- Heat losses in the pipelines decrease substantially with the developed algorithm.
- The proposed solution is cheaper and more environmentally friendly.
- The effect of a financial subsidy in a renewable project was highlighted.

ARTICLE INFO

Article history:
Received 20 August 2015
Accepted 23 October 2015
Available online 29 October 2015

Keywords:
Geothermal energy
District heating
Heat storage
Heat network
Energy utilisation

ABSTRACT

Geothermal energy is a renewable energy source which can provide base-load power supply both for electricity and direct uses, such as space heating. In this paper, district heating systems that are fed by geothermal energy, the so-called geothermal district heating systems, are studied. It is proposed to apply a hot water storage tank in these systems to store hot water in times of low-load and release it to the system during peak load periods in order to minimise the use of peak-up boilers.

In this paper, two different models are presented and the results are shown for three different cases of heat demand coverage by geothermal energy. First, a model for the sizing of these systems is developed. The main findings highlight the importance of the insulation both for the storage tank and the pipelines of the network. Secondly, a model that studies the daily and the annual operation of the installation is developed followed by an integrated economic and environmental analysis of the proposed solution. The results indicate that the proposed solution is financially beneficial compared to the traditional case without use of the storage tank as all the financial indices and cash flows are improved. More specifically, the levelised cost of heating decreases by 4.3–14.9% leading to an increased potential income of £87,000–241,000 per year, while the NPV, the IRR and the BCR all increase. Furthermore, the emissions decrease by up to 54.2% and the load factor increases by up to 3.86%. Therefore, the proposed solution is proved to be beneficial from an economic, environmental and energetic point of view as more geothermal energy is utilised in a more economical way with subsequent environmental benefits.

1. Introduction

Geothermal energy is the energy contained within Earth's crust and it originates from the processes that occur within Earth and heat conduction taking place to the upper layers [1]. Depending on the temperature of the source, geothermal energy can have many uses, such as electricity production, space heating, aquaculture, agriculture, snow melting, drying, and distillation. [2,3] Theoretically, temperatures higher than 15 °C can be utilised through the use of heat pumps [4]. Geothermal energy is a fairly mature technology and is in use in many countries worldwide, with Iceland, Turkey, USA, New Zealand, Indonesia and Philippines being the pioneers of geothermal development [5]. It can be stated that geothermal energy is a proven, cheap [6] and renewable energy source [7] that its main advantage compared to the other renewable energy sources is that it can produce base-load energy and does not depend on the weather conditions [8]. On the other hand, geothermal energy depends a lot on the geological conditions onsite and has a high risk of uncertainty in the first levels of exploration. These factors together with the poor financial support have lagged the overall development of geothermal energy [9].

In general, district heating refers to the production of heat in a central plant and its distribution to the end-users via a pipeline network. A district heating network can have many heat sources, such as combined heat and power plants, which is the most common source; conventional boilers; waste incinerators; industrial waste heat source; solar collectors; heat pumps and geothermal energy

* Corresponding author. Tel.: +44 1413305042.
E-mail address: s.kyriakis.1@research.gla.ac.uk (S.A. Kyriakis).

http://dx.doi.org/10.1016/j.applthermaleng.2015.10.094
1359-4311/

[10]. The main advantages of district heating compared to local provision of heating in each building are well summarised in [11,12] and include the higher efficiency of the whole procedure, the reduction of emissions, the facility of waste heat recovery and the high level of reliability amongst others. The development of district heating is connected with the available waste heat from power plants [13,14]. In the majority of the cases, a district heating network is fed by the waste heat of a power plant and the heat production is a by-product of the process. Heat production only stations which feed a district heating system have been rarely used and are not studied extensively. Concerning geothermal energy, the locations where electricity can be produced are limited by the high temperature needed, while in the case of heat production the possible locations are more widespread since a lower temperature is needed. In the case of heat production units, geothermal energy usually has a temperature which is quite close to the requirement of the heat users [15]. For all the aforementioned, a purely heat-production geothermal system which feeds a district heating network seems a very valuable solution. These systems, the so-called geothermal district heating systems (GDHS), are studied in this paper. The studied systems combine all the aforementioned advantages offering an efficient, cheap and environmentally friendly solution to the environmental and energetic problem of nowadays [8,16]. It should be noted that in the cases of higher temperatures of geothermal water, a CHP plant can be used in which the cooled water used for electricity production is then fed in the district heating network, but these systems will not be studied in this paper as they are limited by the higher temperatures needed.

The most typical users on a district heating system are dwellings and the current research is based, but not limited, on these users. Their heat demand within a day is not constant and a typical profile can be seen in Fig. 1. The published research on the operation of a GDHS is very limited. In [18], the authors develop a model for the operational optimisation of an existing GDHS with the objective of minimising the running costs, while in [19] the authors develop a novel control strategy of the system with the objective of maximum exergetic efficiency. In reality, the general approach to cover the heat demand is to fluctuate the geothermal production according to the heat demand until its maximum capacity and when the heat demand is higher than the maximum geothermal production, fossil-fuel peak-up boilers will cover

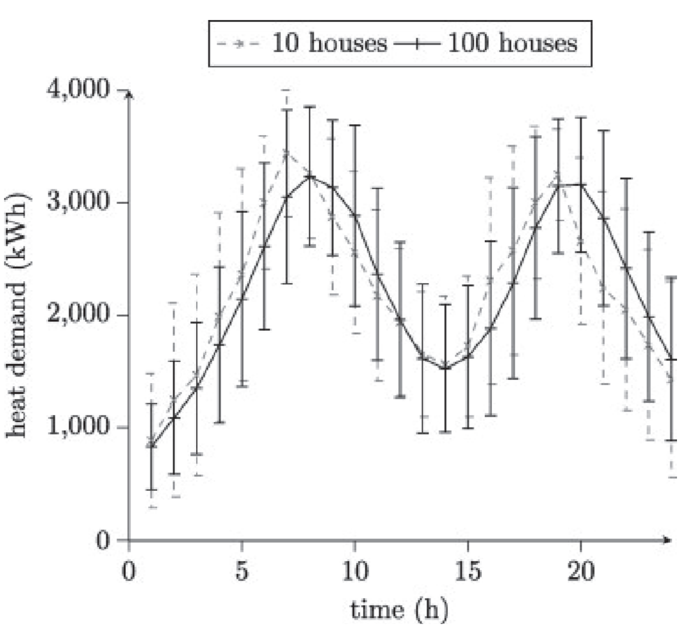

Fig. 1. The average heat demand for a set of houses [17].

the excess heat demand. In this paper, a different approach for the coverage of the heat demand is proposed. More specifically, it is proposed to keep the geothermal production constant each day and add a hot water storage tank, where hot water will be stored in times of low-load, and this stored hot water will be released in the network to cover the peak demands. With this approach, more geothermal energy will be utilised, while less fossil fuel will be used with subsequent environmental benefits. The financial viability of this proposal is crucial and will be studied in detail. Furthermore, it should be made clear that it is not attempted to totally phase out the peak-up boilers, but to minimise their use, as there would be some boilers anyway in the installation for back-up purposes, but also this would lead to an over dimensioning of the whole installation which would turn the investment to unfeasible.

In general, the concept of storing energy in a sensible heat storage has been extensively studied [20–22]. In the majority of the cases, stratified water tanks are used [23,24]. This happens because the inlet temperature of the storage tank is usually variable coming from a CHP plant [25,26] or from solar collectors [27]. On the other hand, the end-users need a specific temperature for their requirements. So, a stratified tank with a high degree of stratification has a maximum possible temperature on its top, which is sent to the users, and a minimum temperature on its bottom which is sent in the production unit [28,29]. A novelty of this paper is that it is proposed not to use a stratified water tank, but a fully mixed storage tank instead. More specifically, two storage tanks will be used, one on the supply and one on the return lines of the system that will store hot and cold water, respectively. The hot water storage tank will be studied in detail as the cold water storage tank will be used as a regulator of the flow to the geothermal heat exchanger. For the sake of simplicity, in the rest of the text the word “tank” will refer to the hot water storage tank unless otherwise stated. In a GDHS, the production temperature is almost constant compared to the aforementioned cases, so it is expected to operate more smoothly in this way. Furthermore, in a GDHS the flow rates are quite high as will be seen in the results, so it is quite hard to maintain the stratification within the tank.

The novelties of this paper are the following: The first and most basic novelty is the new way of operation of the GDHS which is proposed and studied. Based on this direction, two integrated models for the sizing and design of the system as well as for the in-advance knowledge of the operation of the system are built and presented. Finally, as referred previously, the use of a fully mixed tank instead of a stratified tank is another novelty of this paper.

The structure of the paper is as follows: In this section a general introduction in the concept of a GDHS was given; the second section analyses the methodology of the whole approach; the third section provides the results of the analysis together with the discussion and the last section concludes the paper.

2. Methodology

A simplified scheme of the studied installation is shown in Fig. 2. The geothermal fluid is pumped in the surface through the production well (P.W.) and its heat is transferred to water through a geothermal heat exchanger (G.H.E.) in order to avoid scaling and corrosion to the main network. The heated water is then distributed to the end users through a transmission and distribution network and returns to the GHE to be reheated and continue its cycle. Finally, the cooled geothermal water is pumped in the underground through a re-injection well (R.W.).

The study is divided into two main parts. In the first part, an integrated algorithm for the sizing of the installation is built. It should be noted that the installation will operate on daily cycles. In the second part, an algorithm which provides details for the daily operation of the installation is built and then this algorithm is extended in order to study the annual operation of the installation. By study-