Energy 109 (2016) 679–693

Contents lists available at ScienceDirect

Energy

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

Applicability of thermal response tests in designing standing column well system: A numerical study

Jun-Seo Jeon [1], Seung-Rae Lee*, Woo-Jin Kim

Department of Civil and Environmental Engineering, KAIST, Daejeon, 305-701, South Korea

ARTICLE INFO

Article history:
Received 11 December 2015
Received in revised form
6 April 2016
Accepted 9 May 2016

Keywords:
Standing column well
Thermal response test
Parametric study
Thermal diffusivity
Enhanced thermal conductivity
Finite element method

ABSTRACT

The thermal performance of a standing column well system is sensitive to geological and hydrogeological conditions and is maximized in the conditions of stable groundwater temperature, high well yield, and shallow water level. Intricate heat transfer phenomena in the standing column well system leads to difficulties in establishing unified detailed guidelines for the design, installation, and operation of the standing column well system, and consequently a variety of guidelines exist in different countries. According to the guidelines for the design, installation, and operation of a standing column well system, thermal response tests are conducted in Korea and thermal properties such as thermal conductivity and thermal diffusivity which are essential for the design step are obtained. This article investigated the applicability of thermal response tests in the design of a standing column well system based on a numerical study. Based on the developed standing column well model, a total of 420 scenarios were simulated by varying the thermal, hydraulic, and operation properties, and bleeding rates to evaluate their effects on an enhanced factor. The results show that the applicability of thermal response tests in designing a standing column well system mainly depends on the magnitude of hydraulic conductivity.

1. Introduction

The importance of renewable energy is strengthened by the need to reduce the consumption of fossil energy, to reduce greenhouse gas emission, and to address increasing global energy consumption. According to the Renewables 2015 Global Status Report, renewable energy accounts for 19.1% of global energy consumption, and its share continues to grow every year [1]. Renewable energy such as hydro, wind, solar, biomass, or geothermal energy, originating from environment-friendly sources, is mainly being used for power generation, heating and cooling. Among the various types of renewable energy, geothermal energy can be utilized through the use of GSHP (ground source heat pumps) for cooling and heating buildings [2].

The GSHP systems can be categorized into open or closed types based on the contact method with the heat transfer medium. As the open-type GSHP is in direct contact with the heat transfer medium, the overall performance of the open-type GSHP is higher than that of the closed type that has no direct contact with the medium [3]. The high performance in the open-type reduces the total design length of BHEs (borehole heat exchangers), and consequently leads to a lower initial cost. As a SCW (standing column well) system is one of the open type of GSHP system, its ground heat exchanger has a deep vertical borehole that is filled with groundwater up to the water table (Fig. 1). The heat injection/extraction through ground heat exchanger is performed by re-circulating the groundwater between well and the heat pump. In addition, bleeding is an operation that imposes the imbalance between the amount of water injected and extracted in the borehole to create a drawdown that induces a higher water flow into the borehole. Consequently, it enhances heat exchange with the surrounding ground by heat transport mechanism including the conduction and advection and helps maintain the outlet fluid temperature within operation temperature limits of the heat pump. Along with the general advantages of the open-type GSHP like low initial cost, and high performance, the requirement of less land area than closed type of GSHP makes the SCW systems attractive more in urban areas [4].

However, the performance of the SCW system is largely affected by geological and hydrogeological conditions. Fortunately, the hydrogeological conditions in Korea are suitable for adopting the SCW system due to stable groundwater temperatures, shallow

* Corresponding author. Tel.: +82 42 350 3617; fax: +82 42 350 7200.
E-mail address: srlee@kaist.ac.kr (S.-R. Lee).
[1] Current address: Department of Civil and Environmental Engineering, KAIST, 291, Gwahakro, Yuseong-gu, Daejeon, 305-701, South Korea.

http://dx.doi.org/10.1016/j.energy.2016.05.023
0360-5442/

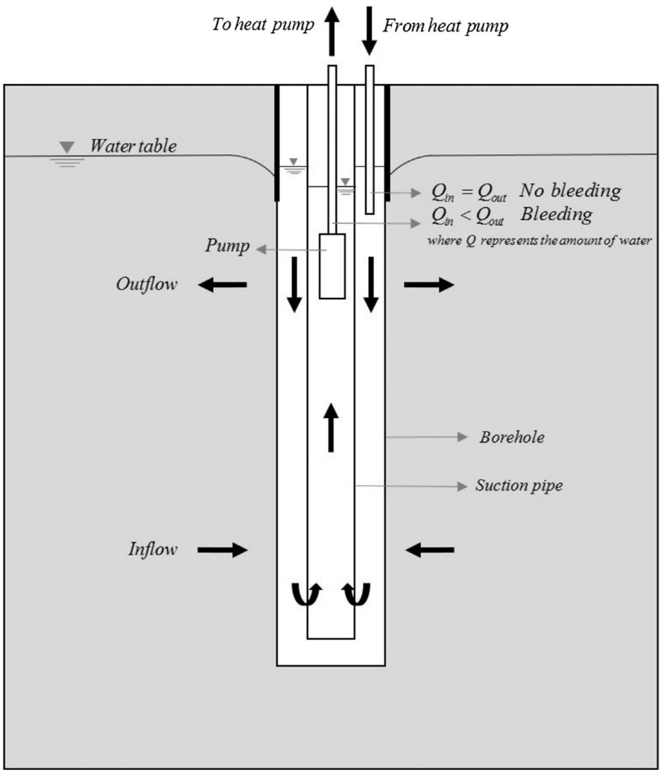

Fig. 1. Illustration of a SCW (Standing Column Well) system.

water levels, and high well yields [5].

Despite these optimum conditions, the share of the SCW system has reduced from 29% to 16% during last 3 years. In contrast, the closed type GSHP system in Korea occupied 68.6% in 2009, and 75% in 2012 [6,7]. These trends reflect that most GSHP system studies focused on the closed type. This consequently led to the development of more precise and efficient design technology for the closed type. Additionally, the specifications for the closed type were widely used as a standard in practice.

Recently, several studies were also conducted for the SCW system of GSHP through field experiments [8–17], and numerical studies [4,18–21]. Experimental studies indicated the superior performance of various types of well systems. These include cased systems [8], concentric well pipe systems [9], thermal well systems with concentric pipe [11,12], and standing column well systems [10,13–17]. Various numerical models were also developed from simplified models (using the finite difference method [4]) to complex models (using the finite volume method [18–21]), to investigate the parameters affecting the overall performance of the SCW system. Nevertheless, an efficient design technology, or a related commercial program for the design of SCW system is still rare.

Based on various prior research results, a variety of guidelines for the design, installation, and operation for the SCW system were established in different countries. Thus, there are no unified detailed guidelines for the design, installation, and operation of the SCW system. Korea also established its own guidelines for the design, installation, and operation of the SCW system. The design procedure follows certain steps. First, a well testing is conducted to identify the aquifer properties such as storage coefficient, hydraulic conductivity and well pumping capacity. Second, the TRTs (thermal response tests) are performed in accordance with the guidelines listed in Table 1 to investigate the enhanced thermal conductivity of the ground formation. These hydraulic and thermal properties of the aquifer are used as input parameters for designing a SCW system. The guidelines recommend the use of GLHEPro software to determine the total length of the SCW system and to predict the long-term effect on the performance. Although the mechanism of the SCW system is quite different from that of the closed system, the SCW system is considered as a closed system with a concentric tube shape in the design software.

TRTs (thermal response tests) are essential for the design of the closed type GSHP to measure the ground thermal conductivity and borehole thermal resistance. In general, constant power is injected to the borehole by circulating heated fluid. Then the difference in fluid temperatures between the inlet and outlet is measured to calculate the ground thermal conductivity based on the line-source model. This model assumes that the heat exchanger is considered as the infinite line source, and only conduction is considered in the radial direction in a homogenous medium. Because of the simple equation form, the line-source model in the TRTs interpretation was commonly used in practice. Since, the TRTs were originally suggested for considering the conduction phenomena, a different test method was necessary for the proper design of the open-type GSHP [22].

A typical standing column well system is installed at approximately 300–500 m below the ground in Korea. The bedrock is commonly located at depths less than 30 m from ground level. Additionally, the hydraulic conductivity is quite low (in an average value of 1.1554E-08 m/s) compared to that of other countries where many standing column wells have been installed. This implies that the effect of advection should also be taken into account in the various hydraulic conditions.

This study investigated the hydraulic and thermal properties used in the design of already installed SCW systems. A numerical study was adopted to evaluate the applicability of TRTs in designing the SCW system. The factors affecting the results of TRTs were described, and the enhanced effect and correlations between factors were discussed. These findings enable the development of more optimal design and operation phases of the SCW system. This paper is divided into three parts. First, the results of the well pumping test and the thermal response test used in the design of

Table 1
Guidance of the practice regulations of TRT for SCW system in Korea (Korean Ministry of Trade, Industry and Energy [39]).

Control item	Recommendations
Start-up time after boring	72 h
Exception time	2 h
Total test period	24 h
Maximum data acquisition interval	10 min
Power injection range	200-500 W/m
Temperature difference between the inlet and outlet fluid	3.5–7.0 $°C$
Input power fluctuation limit	± 3%
Resume condition of TRT for fluid temperature	0.3 $°C$ to initial ground temperature