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Effect of natural cold source on groundwater source heat pump according to laboratory and field geotechnical thermal physical tests

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ABSTRACT

This paper uses the numerical method and laboratory and field tests to determine the effect of cold source on groundwater source heat pump (GWHP) in Jiagedaqi. Cold sources are distributed in a scattered pattern, with temperatures ranging from 0 °C to 1 °C according to temperature field test results. Laboratory tests show that the thermal physical parameters of pebbles and grit present discrete phenomenon with depth and that the parameters of sandstone and granite undergo minimal change. By considering the correlation and discrepancy of laboratory and field tests and by modifying the parameters of the laboratory test via the analytic hierarchy process, this paper selects formation thickness, moisture content, density, and permeability as the main factors that influence the difference in thermal physical parameters. Basing on the geological conditions of the region, this paper constructs a numerical model with the data from modified laboratory tests and in-situ thermal response tests. The model analyzes heat breakthrough and influence radius of cold source in the producing/injecting system of multiple wells. Simulation results show that the influence range of cold source on GWHP is 150 m and that heat breakthrough is observed when the influence radius is less than 85 m.

1. Introduction

Shallow geothermal energy refers to energy at a certain depth (generally 200 m) below the ground surface with a temperature of 25 °C or lower. This energy can be developed and utilized as a valuable energy source by using current technology. The dwindling amount of conventional energy, the emphasis on environmental protection, and the maturation of ground source heat pump (GSHP) technology all contribute to the popularity of shallow geothermal energy technology in developed countries. Approximately 1.3 million GSHPs have been installed in 33 countries and regions by 2005, with an annual growth rate of 24.4%. On the basis of the statistics of the 2010 World Geothermal Congress, energy using GSHPs reached 33,134 MWt around the world, showing an increase of 2.15 times within five years and an average annual growth rate of 23.1% compared with the 2005 statistical data [1]. The above data show that GSHP has been attracting increasing attention from countries worldwide.

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The Chinese government began to advocate the scientific use of shallow geothermal energy in the 1980s to build an energy-saving society. The engineering specifications for GSHP systems have been published by China's Ministry of Construction in 2006 [2]. Currently, the systems are geographically distributed in almost all Chinese province [3].

Many problems are encountered in the practical application of GSHP stemming from the need for an accurate measurement of the thermal physical parameters of rock and soil layers before developing and utilizing shallow geothermal energy. Two methods have been studied by many researchers and are available in determining the thermal physical parameters: laboratory test and thermal-response test (TRT) [4–6]. For instance, Yavuzturk and Zeng [7,8] examined the theoretical models of the tests. Wang et al. and Raymond and Lamarche [9,10] improved and developed field testing instruments by considering different influencing factors. Lim and Witte [11,12] conducted uncertainty analysis based on their test results. Signorelli and Wagner [13,14] analyzed and evaluated in-situ TRT results, and Cho et al. [15,16] studied the influence of water content and porosity on the thermal conductivity. Other studies focused on the effect of temperature and pressure on thermal conductivity in the laboratory [17–19]. However, only several researchers pointed out the differences between the two testing

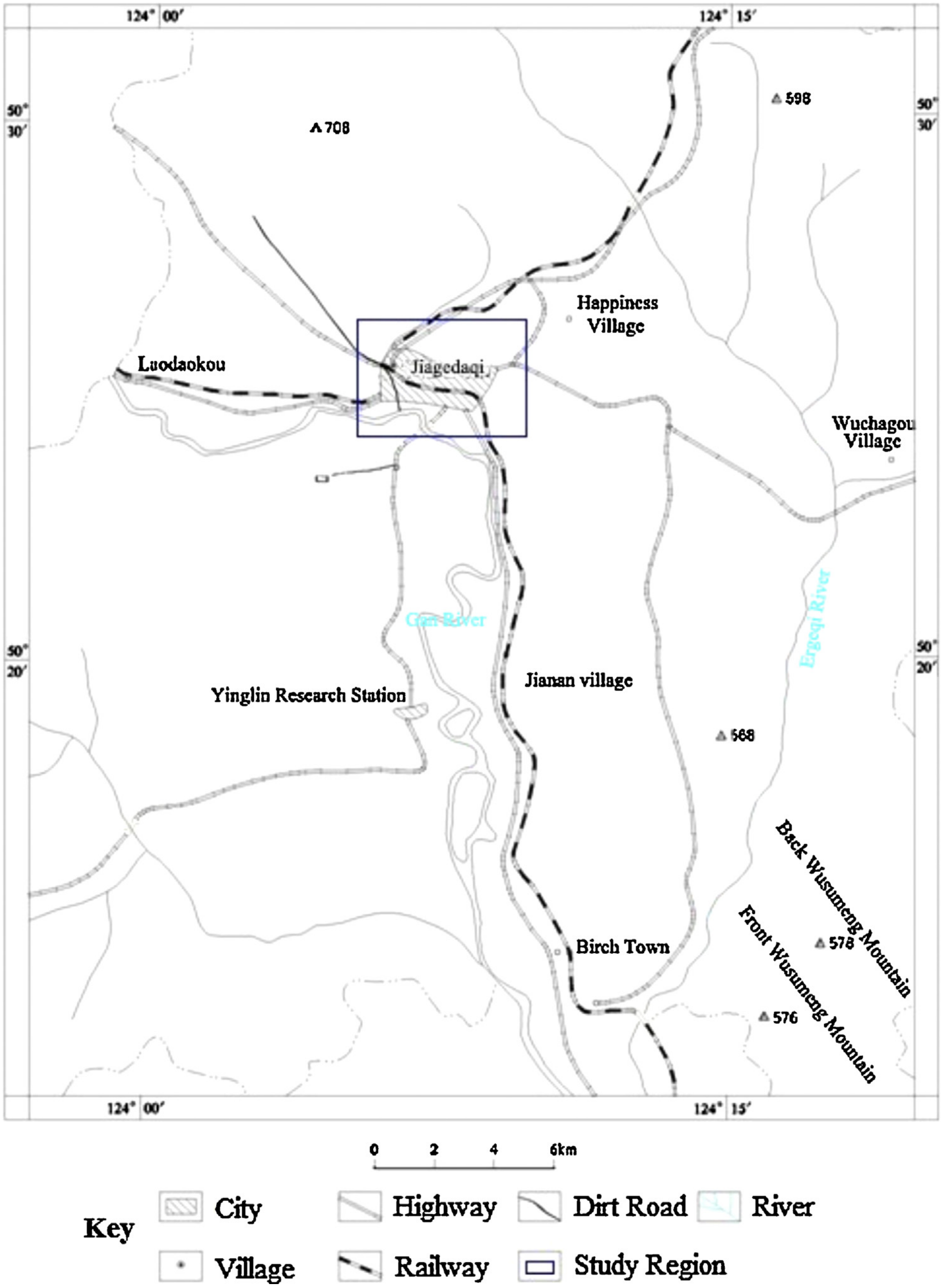

Fig. 1. Transportation location of the study region.

methods [6,13,20]. The correlation of the two methods has not been studied. Moreover, many problems exist in the process of using shallow geothermal energy. Among these problems, the accumulation of underground heat after several years of operating the GSHP system, influence of groundwater flow on the thermal performance of the heat exchanger [21–25], testing accuracy of thermal physical parameters [26,27], and effect of stratigraphic configuration [25,28] are studied.

Many researchers have studied the development and utilization of shallow geothermal energy, but literature on the influence of cold source is rare. Cold source naturally exists in the normal temperature zone as a kind of underground resources, and its temperature was lower than the average temperature of the layer obviously. It has a large influence on the performance of the GSHP. Lim [11] and Gao [29] conducted research on the working principle and application conditions of ground water heat pumps (GWHPs); however, the cold source was ignored in their actual projects. This paper mainly researched the influence of the cold source on the GWHP according to the actual conditions of the study region. In the current paper, the characteristics of thermo-physical parameters and distribution law of the cold source in the Jiagedaqi region were studied through laboratory and field tests, then the influence of cold sources on GWHP was explored. Analytic hierarchy process (AHP) was adopted to modify the thermo-physical parameters of rock and soil samples in the laboratory to take advantage of these testing results. A numerical model was then built based on the data from the modified laboratory tests and in-situ TRTs. The influence of cold sources on the key parameters of a multi-well pumping irrigation system was studied by comparing two sets of simulation results. The feasibility that TRT was replaced by using the