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Proceeding Paper

Modeling and Simulation of Traditional Single U-Tube Model and Similar Scaled Model of Underground Storage System Based on Similar Scale Function †

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Abstract: Seasonal thermal energy storage is mostly used to make solar energy more consistent. There are very few research studies available on thermal energy storage mechanisms due to their large size requirements and high computational power. The current research study aims to compare the similar single-tube CFD model with simulation results of the original single-tube model using similarity theory. The temperature field changes before and after the similarity processing of the model are obtained, and the two are compared, so that the accuracy of the similarity functions' relationship can be verified.

Keywords: renewable energy; soil heat storage; similarity theory; temperature field

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1. Introduction

American researchers [1,2] proposed the idea to store heat in soil in the 1960s, and Nordic researchers started work to develop a seasonal heat storage mechanism in the 1980s. At the beginning of the study [3], long-term soil heat storage was only applied in large-scale solar central heating systems or district heating systems. Yumrutas et al. [4] studied a solar-based heating system equipped with a tank containing hot water to analyze the impact of climatic conditions on the operating system. In 1997, Inalli [5] analyzed and discussed solar thermal storage systems with soil regenerative subsystems through computational and modeling simulations. They simulated and predicted soil storage temperatures and collector plates.

In order to perform a complete analysis, Richard A. Beier et al. [6] developed an 18 m-long sandbox test bench. A thermal response test was conducted to investigate various thermal parameters. Sakellariou and Ratchawang et al. [7,8] showed that the long-term storage of solar energy in the heat storage system is relatively more technical and economical, and its operating efficiency is ideal. Z. Abbas et al. [9,10] performed a research study to store cold energy using borehole heat exchangers to fulfill seasonal cooling and heating applications inside domestic and commercial buildings using a similar-scale model. The major issues in performing the research on thermal energy storage include the large storage volume for experimental setup, high computing power, and accuracy of obtained results. Thus, current research work aims to implement the concept of similarity theory to develop a similar-scale model of a soil heat storage mechanism. After establishing an actual-size soil heat storage model and a similar-size model of a single tube, simulations are performed using Ansys Fluent. The temperature field changes before and after the similar processing of the model are obtained, and the two are compared so that the correctness of the similarity function relationship can be verified. The proposed research work aims to establish an accurate relationship between the actual-size model and the similar-size model based on the similar function relationship.

2. Research Methodology

2.1. CFD Foundation

Methods for studying flow problems generally include traditional experimental measurement methods, theoretical analysis methods, and CFD numerical simulation methods. The above three methods can be regarded as a complete set of research method systems. The results obtained by the experimental test method are the basis for the other two methods. However, the construction and measurement of experimental systems are often limited by various practical operations. In the current research study, AnsysFluent simulation software is used to import the fluid flow file. Firstly, single-tube models of actual size and similar size are established. Then, the two single-tube models are used to simulate simple working conditions, and the obtained temperature field distribution is completely consistent, which verifies the correctness of the derived similar function relationship.

2.2. Establishment of a Single-Tube Model

The parameters of the actual-size model and similar-scale-based model are given in Table 1. This paper determines the similar-scale factor as 20 [10]. The surface boundary is set to a constant temperature boundary, and the hourly temperature change data are imported through a user-defined function (UDF).

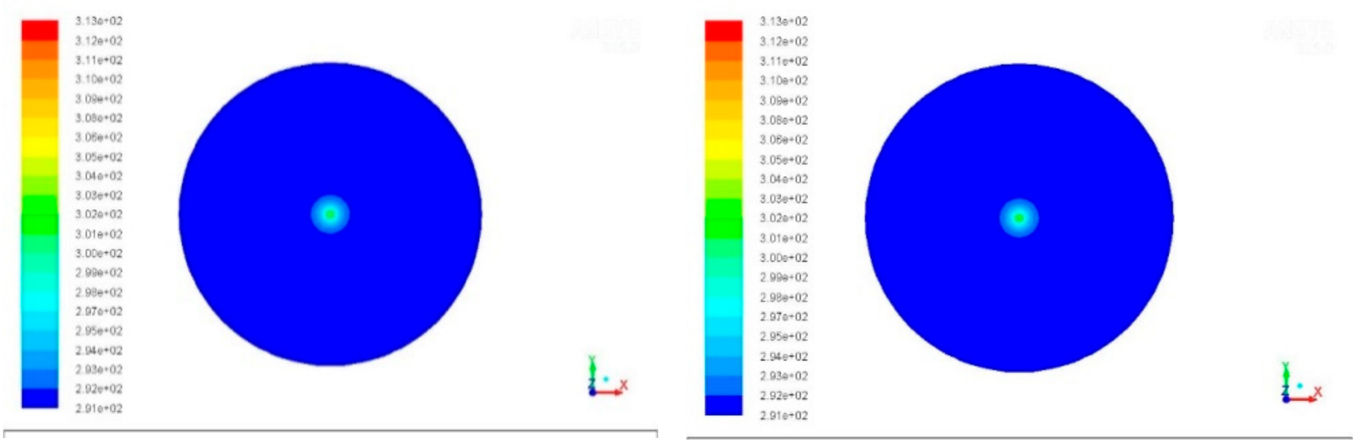
Table 1. Parameter settings in single-tube model.

Model Parameter	Unit	Actual Size	Similar Size
Storage length	m	20	1
Storage width	m	8	0.4
Buried tube length	m	16	0.8
Inlet water temperature	°C	40	40
Inlet flow rate	m/s	0.5	10
Radial far boundary	-	18	18
Surface boundary	-	air temperature	air temperature
Step size	S	10	10
Step count	-	25,920	65
Total length	h	72	0.18

3. Results

Solving Single-Tube Model

The similar-size model and actual model are solved according to the above model size design and operation parameter settings. After the solution, of the obtained results of both models are analyzed from the temperature field distribution and the temperature curve distribution. The cloud map of the temperature field distribution is shown in Figure 1. It can be seen from the temperature field distribution diagram that although the calculated number of steps and duration are different for the two models, the obtained temperature field distribution is basically the same. In order to more clearly compare the temperature fields of the two models, this paper takes a line at the depth of the middle of the model, which is located in the middle of the model and runs horizontally through the model. The temperature data on the line are taken out, and the temperature distribution curve can be drawn, as shown in Figure 2.



(a) (b)

Figure 1. Comparison of temperature field distribution (**a**,**b**) in single-tube model.

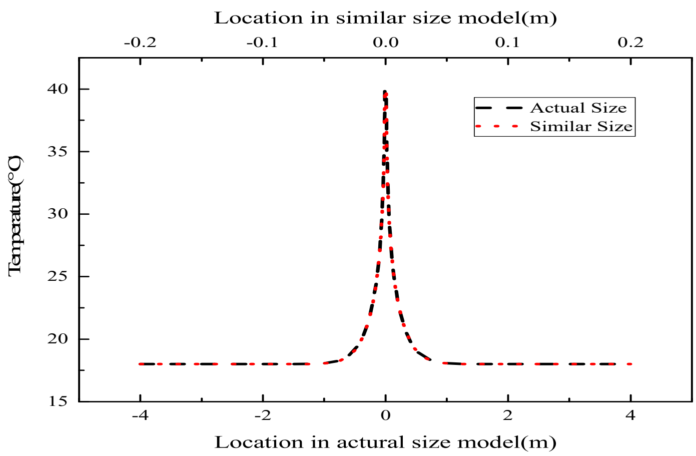


Figure 2. Comparison of temperature curve distribution in single-tube model.

In Figure 2, the horizontal axis at the top represents the position coordinates in the similar-scale model, and the corresponding red dotted line is the temperature distribution; the horizontal axis at the bottom shows the position coordinates in the actual-size model, the corresponding black dotted line is the temperature distribution in the actual-size model. It can be seen from the figure that although the two models are different in spatial scale and the calculated steps and duration are different, the soil temperature distribution calculated by the two models is the same, which fully proves the accuracy of the proposed data.

4. Conclusions

In this research work, the CFD traditional model and similar model of a soil thermal storage system are established for a single tube, and the analysis and verification are carried out step by step. The specific content and conclusions are: Firstly, single-tube models of actual size and similar size are established. Then, the two single-tube models are used to simulate simple working conditions, and the obtained temperature field distribution is completely consistent, which verifies the correctness of the derived similar function relationship. It can be considered that the proposed modeling method can be implemented for a tube group model using complex conditions, and can save a large amount of required computational power.

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