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Numerical simulation of single spiral heat storage tank for solar thermal power plant

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ABSTRACT

Thermal energy storage is a key technology for the solar thermal power plants. This paper set up a single spiral heat storage tank using concrete as heat storage material and Cu-water nano-fluid as heat transfer fluid. In this paper, temperature distribution and the effects of the parameters i.e., inlet temperature and inlet velocity, on the charge time of the storage tank have been investigated based on numerical simulation. The results show that the charge time of the storage tank is about 72,000 s before the other factors have been changed. The charge time of the storage tank increases with the decrease of the inlet temperature and inlet velocity.

Introduction

The data coming from National Bureau of Statistics of the People's Republic of China show that in the energy consumption structure, the proportion of coal tends to decline, the proportion of high-quality clean energy increased gradually. Among them, the proportion of solar energy increased by 27.5% and it is one of the most potential energy. However, the intermittence of solar energy has stunted its development [1]. Therefore, the study of solar energy has been widely concerned. Concentrating power plant coupling with thermal energy storage system is a popular technology during the solar application process, and researches of the performance of thermal energy storage for concentrating solar power plant have been carried out for past four decades and are ongoing. Concentrating solar thermal power, more commonly referred to as CSP that the sunlight hits the surface of the earth and concentrates on the receiver, where the fluid is heated by the energy [2–5]. In recent years, a multitude of advancements have taken place in an effort to make CSP more cost effective. Hence, the development and design of economical and efficient thermal energy storage systems are of vital importance. The development of energy storage technique is significant and necessary.

The advantage of solar thermal power plant has also got a great deal of research and approval. A multitude of scholars have done a great deal of work and achieved a series of research results. Stückle et al. [6] have presented a methodology of the heat conduction process inside the single module, and numerical simulation and experimental study have been

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both conducted, and the design of a 1000 MWh_{th} storage system was presented. Madaeni et al. [7] have estimated the capacity value of concentrating solar power plants with thermal energy storage (TES) in the southwestern U.S. The results showed that incorporating TES plants significantly increases their capacity value. Sciacovelli, Bejan and Castell et al. [8–10] have studied the heat storage tank, and improved the thermal performance of the storage system by expanding the heat transfer surface. Sciacovelli et al. [11] developed a numerical model for researching the performance of tree shaped fins in a shell-and-tube LHTES unit. The results showed that an increase of 24% of the system efficiency can be achieved by the optimized unit. Hadiya et al. [12] have studied a shell and tube with four-pass heat exchanger unit of 1 MJ storage unit, paraffin wax as phase change material, and the main method of it was experimental study. The results showed that the charging as well as discharging cycle time decreases with increase in mass flow rate of HTF, fall in cycle time during discharge is around three times faster than charging, and the same is attributed to fissure crack developed in the lump mass. Rahimia et al. [13] have studied the process of solidification and melting of a phase change material in fin and tube heat exchanger, and the main method of it was experimental study. The results showed that utilizing fins increases fin average temperature regardless of flow regime. While reduction in fin pitch does not affect this parameter sensibly for both regimes. Adriano et al. [14] have studied a single vertical shell-and-tube latent heat thermal energy storage, and the main method of it was numerical simulation study. Wang et al. [15,16] and Qi et al. [17,18] have studied the heat transfer performance of the receiver in solar energy plant based on numerical method. Wu et al. [19,20] and Yuan et al. [21–24] have done some works about the solar optical-chemical and particle distribution in solar energy field.

It can be seen from the reported works that most of the researchers focus on the use of straight tube heat transfer. However, there is a lack of research on the optimization the charging tube used in concrete based on the charge time. Hence, in this paper, the storage time of the storage tank has been investigated by using a single spiral heat exchanger tube. The influence of inlet velocity and inlet temperature on the charge time have been discussed using the simulation tool FLUENT. The results can provide reference for the design of solar energy storage system.

Introduction of the model

Governing equations

The single spiral heat storage tank is simulated with Fluent Software, and the influence of different parameters on the charge time of the heat storage tank has been studied. Boundary conditions are as follows: outflow, velocity inlet. The governing equations are as follows:

Continuity equation:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{1}$$

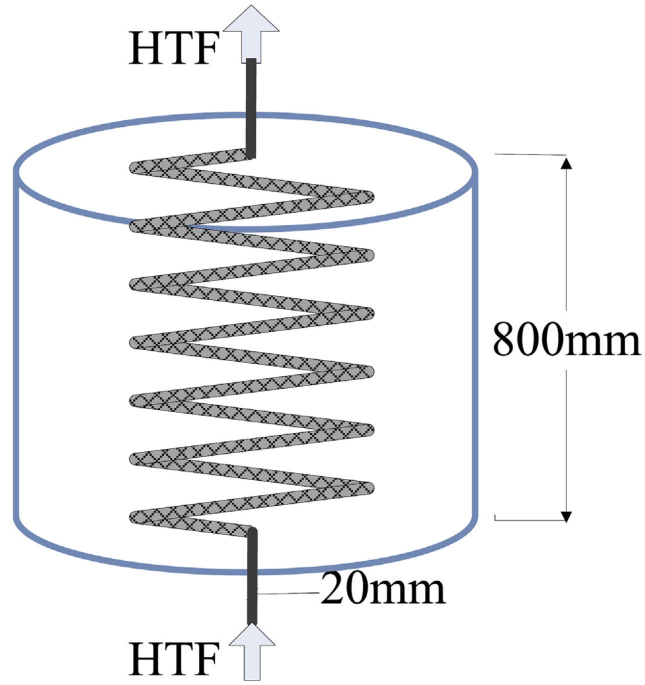

Fig. 1 – Model of single spiral heat storage tank (system diagram).

Momentum equation:

$$\begin{aligned}
\rho\left(\frac{\partial u}{\partial \tau}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)&=F_x-\frac{\partial p}{\partial x}+\eta\nabla^2 u\\
\rho\left(\frac{\partial v}{\partial \tau}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)&=F_y-\frac{\partial p}{\partial y}+\eta\nabla^2 v\\
\rho\left(\frac{\partial w}{\partial \tau}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)&=F_z-\frac{\partial p}{\partial z}+\eta\nabla^2 w
\end{aligned} \tag{2}$$

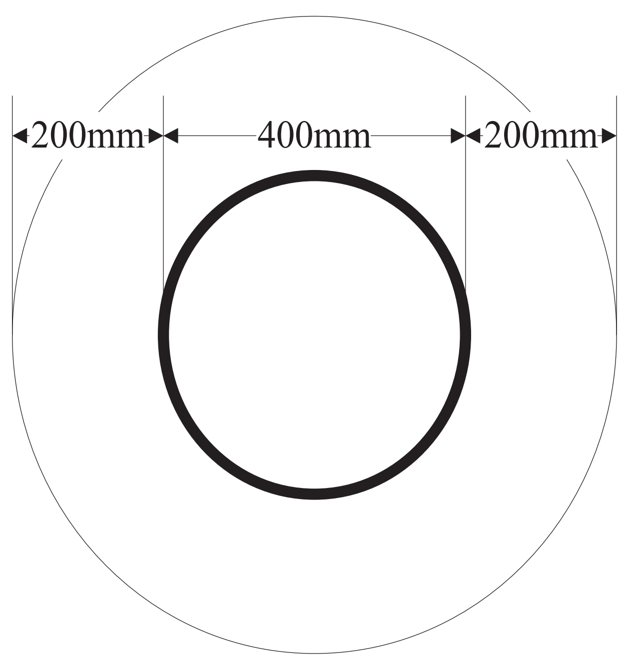

Fig. 2 – Model of single spiral heat storage tank (vertical view).