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Charge time of the storage material of the tank for a solar power plant

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ABSTRACT

Concentrating power plant coupling with thermal energy storage system is a popular technology during the solar application process or solar power plant, and researches for the performance of thermal energy storage for concentrating solar power plant have performed over the past four decades and are ongoing. In this paper, temperature distribution and the effects of the parameters i.e., heat conductivity, heat transfer length, inlet velocity, and the diameter of the tube, on the charge time of the storage tank have been investigated based on numerical simulation. The results show that the charge time for the storage tank is about 23 600 s before changing the parameters of the model. The charge time of the storage tank increases with increasing the heat transfer length and decreasing the heat conductivity, inlet velocity, and the diameter of the tube. The results can provide a reference to the state-of-the-art design of solar storage system.

Introduction

Rising energy costs and the adverse effect on the environment caused by the burning of fossil fuels have triggered extensive research into alternative sources of energy. Due to the abundance of solar energy, it has been one of the most attractive energy alternatives. Concentrating solar power (CSP) is regarded as an effective way to make use of solar energy [1,2]. The main idea of CSP is that the sunlight hits the surface of the earth and concentrates on the receiver, where the fluid is heated from the energy [3–6]. As green energy, solar energy can not be widely used because of its intermittency. Concentrating solar power system will not work during night and rainy days and solar energy can not instead of fossil fuels completely. Thus, energy storage technique is needed and of great significance.

A multitude of advancements have taken place in recent years in heat transfer characteristics of different storage tanks for CSP plant. Longeon et al. [7] have studied a round latent heat energy storage unite, RT35 paraffin as the medium, and the main methods of it are numerical simulation and experimental study. The results showed that the system performance has certain function relation with energy storage structure and heat transfer medium. Liu et al. [8] have presented the experimental results of solidification process of stearic acid in the energy storage system. The main parameters of the cylindrical tank are as follows: length of cylindrical tank of 600 mm, diameter of cylindrical tank of 91 mm, length of phase-change material tube of 550 mm, diameter of phase-change material tube of 46 mm. Xu et al. [9] have a detailed study and introduction on a 1 MW solar energy plant in Badaling Great Wall, located in Beijing. There are two subsystems in the energy storage system. They are high and low temperature energy storage systems, respectively, consisting of heat exchanger, heat pump and storage tank. Vailudh et al.

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[10] have taken experimental research on high-temperature energy storage system, adopting vertical and spiral tubes. Results showed that the system get the maximal efficiency 0.631 when the mass flow of heat transfer fluid is 0.1 kg/s. Hosseini and Manenti et al. [11,12] have studied the heat transfer process of melting and solidification of RT35 paraffin by experimental and numerical methods. The main parameters of the tank are as follows: length of horizontal cylindrical tubes of 1000 mm, inner diameter of 85 mm, wall thickness of 2.5 mm. Castell et al. [13] have performed experiments on phase-change materials to explore the performance of low-temperature energy storage system. It is a typical tube-in-shell cylindrical storage tank, of which the main parameters are as follows: diameter of two tanks of 290 mm, height of 350 mm, heat transfer area of 0.173 m^2. The results showed that heat transfer efficiency of the system remains unchanged with the change of the time and decreases with the increase of flow rate. Yazici et al. [14] have conducted experiment on the solidification process of paraffin in a horizontal tube-in-shell storage system. During the experiment, the inlet temperature and flow rate of the fluid kept constant and changed the eccentricity of tube. The eccentricities are −10, −20, −30, 10, 20, 30. López-Navarro et al. [15] have presented the experimental results of a versatile latent heat storage tank capable of working with organic phase-change materials. Enthalpy-temperature curves, specific heat capacity curves and density curves of paraffin have been tested. The main parameters of storage tank are as follows: length of tube of 13300 mm, inner diameter of 12 mm, external diameter of 16 mm.

In recent years, fins have been used in energy storage systems in order to enhance the heat transfer. Sciacovell et al. [16] have proposed a tree-shaped fins tank to enhance the performance of a latent heat energy storage system. Results showed that tree-shaped fins can improve the efficiency of the system apparently, and the discharged efficiency increased of 24% by using optimal fins with two bifurcation. Medrano et al. [17] have conducted experiments and tested efficiency of heat exchangers of 5 new types. Cui et al. [18] have proposed a convenient heat absorber, based on three different temperature conditions, to improve the efficiency of solar power plant. In the system, fluid flow through three different phase-change materials. Besides, recent researches have suggested the advantage of capsule storage system, but it has not been widely used [19,20]. The research works focus on pake-bed [21–25], the method [26–28], and fluidized bed [29,30].

In this paper, the temperature distribution of thermal storage of sensible heat using concrete material by numerical method has been investigated, and the effect of the parameters on the charge time is also discussed. The aim of this paper is to knowledge the temperature distribution and the effect order of solar storage tank. The results can provide a reference to the state-of-the-art design of solar storage system.

Model

Fluent

In this paper, Fluent software is used to simulate the heat transfer process in the tank. The main equations are given as:

Continuity equation:

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

Momentum equations:

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

Energy equation:

$$\rho c_p\left(\frac{\partial t}{\partial \tau}+u\frac{\partial t}{\partial x}+v\frac{\partial t}{\partial y}\right)=\lambda\left(\frac{\partial^2 t}{\partial x^2}+\lambda\frac{\partial^2 t}{\partial y^2}\right) \tag{3}$$

In the above equations, the symbol ρ is the density with the unit of kg/m^3. μ, ν are the fluid velocity of different directions with the unit of m/s, respectively. P is the pressure with the unit of Pa.

Physical model of the storage tank

In order to study on the heat transfer process of the tank, a physical model of the tank is essential firstly. Fig. 1 shows the schematic diagram of a tank designed in this paper. It can be seen from this figure that the cylindrical tank consists of a cylindrical tube and concrete module.

The main parameters of the storage tank

Relative parameters of the physical model are as follows: hot water is as heat transfer medium, concrete is as sensible heat storage, the dimension of the tank is the height of 640 mm, the diameter of 260 mm; the thermal properties of concrete is the density of 2250 kg/m^3, thermal conductivity of 1.44 W/(m K), specific heat conductivity of 735.7 J/(kg K), initial temperature of 313.16 K; the parameters of the inner tube is diameter of 60 mm; the parameters of the fluid is inlet temperature of 353.16 K, the flow rate of 0.5 m/s. In the numerical simulation, the external surface of the tank is insulated.

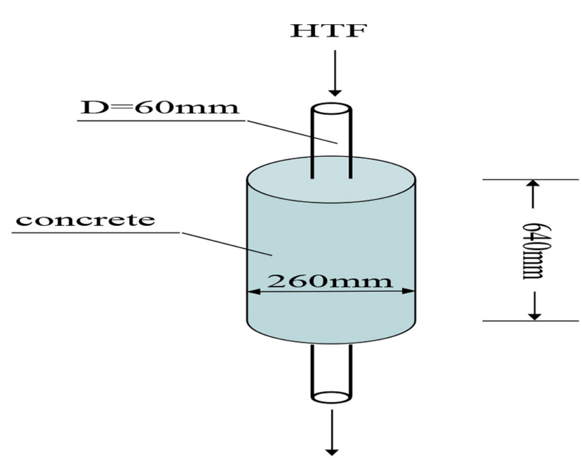

Fig. 1 – Schematic diagram of the storage tank.