Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2014, 6(6):1620-1624

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

The impact of velocity on thermal energy storage performance of tube type thermocline tank

Yongping Yang, Jingxiao Han and Hongjuan Hou

School of Energy Power and Mechanical Engineering, North China Electric Power University, Beijing, China

---

ABSTRACT

Established an indirect contact thermocline single tank heat storage two-dimensional mathematical model, its thermal energy storage properties has been studied. Using Fluent software to perform CFD simulations on tubular accumulator, the thermal storage medium used for the model was sand, heat transfer fluid was air, two types of media were separated by a stainless steel tube in the middle. The simulation results agreed well with the existing small-scale test bed regenerative results. The results showed that for a 6m long heat storage tank, when the flow rate changes in the range of 4,6,8 m/s, the heat storage efficiency was 0.708, 0.534, 0.425,respectively. High flow rates, temperature distribution inside the tank tends to uniform, which is not conducive to the formation of thermocline..

Keywords: solar energy, thermocline, thermal energy storage, efficiency, CFD, air, sand.

INTRODUCTION

Solar thermal power[1] plants using thermal energy storage(TES) Technology, can help achieve continuous plant operation even at a lower intensity of sunshine or night, without relying on a natural gas or diesel back-up generator. However, the high cost of existing storage technology has restricted the development of large-scale solar thermal power. Therefore, to find out suitable heat storage materials and regenerative mode are important issues in solar thermal utilization field.

The California SEGS trough power plants use thermal oil[2] as the heat transfer fluid, the Hitec molten salt as the storage media, heat exchange is accomplished through a heat exchanger, thus the heat can be remained in the molten salt. To further reduce the cost of the heat accumulator, the use of porous rock or similar heat storage medium as the filler, so that heat transfer fluid flows through the thermal storage medium in direct contact with the heat storage mode attracted attention in recent years [3].Compared with other heat-accumulating material, such as the molten salt and phase change material (PCM), the biggest advantage of the rock is cheap and easy to obtain. Despite its regenerative properties less than the former one, when increased in volume, you can still get good results. Sandia National Laboratories created a single thermocline tank using molten salt for thermal storage[4], the tank body using quartz and silica sand as the thermal storage medium to transfer heat with molten salt[5]. Flueckiger et al[6] established a thermocline heat storage solar tower power plant level model, the pebble bed in the molten salt contact heat transfer model.

Within a thermocline tank, during the heat storage process, the a stratified temperature layer inside the tank body will be formed, high temperature layer at the top of the tank, and the low temperature region at the bottom end, between which exists a middle temperature gradient region which is called thermocline. Xu et al[7] investigated the packed bed heat storage system using molten salt as the heat transfer fluid, the two-dimensional simulation results showed that, with the exothermic process, while the thermocline region moving upward, a slight expansion of the thermocline region phenomenon will occur. To improve heat transfer and heat storage effect of the molten salt in the solid particles, smaller solid particles should be used[8].

Since the heat-transfer fluid needs to flow all through the heat storage area, the pressure loss is relatively large; in addition, for larger solar power regenerative demanding, a need for the construction of a huge volume of the heat storage tank arises, thereby increasing the cost of. Laing et al[9] considered using concrete as the storage material, a heat-transfer fluid flowing through the pipe embedded in the concrete, as the heat transfer fluid passing through the tunnels, tank body investment can be reduced. However, the effect of the poor thermal conductivity of concrete [10], make it necessary for heat transfer enhancement, and after repeated use, the concrete becomes easy to crack, resulting in poor heat transfer.

In this paper, gravel was used as a sensible heat storage material because it's similar thermal conductivity to rocks. And the air was used as heat transfer fluid, heat transfer is achieved through the heat conduction to the stainless steel pipe in the heat storage tank. The aim of this paper was to study the effect of the flow rate on the heat storage properties. If large-scale seasonal heat storage can be realized, which can be achieved by directly embedding the regenerative modular in the desert, the construction costs will see a significant reduction.

EXPERIMENTAL SECTION

Mathematical Model

Reference [11] gives the model description. Using ANSYS Fluent@ 6.3software,the model assumed that the heat transfer and flow inside the heat storage tank is transient, with incompressible fluid, constant properties within the flow rate ranges from 4-8m/s, the Reynolds number in the range of 1000-2000, the flow is laminar. The involved governing equations, momentum, continuous and energy equations are：

$$\nabla \cdot \vec{V} = 0 \tag{1}$$

$$\frac{\partial \vec{V}}{\partial t} + \left(\vec{V} \cdot \nabla\right)\vec{V} = -\frac{1}{\rho}\nabla p + \nu \nabla^2 \vec{V} \tag{2}$$

$$\frac{\partial T}{\partial t} + \left(\vec{V} \cdot \nabla\right)T = k \nabla^2 T \tag{3}$$

Since the thermocline effects (the hot fluid floats on top ofthe cold fluid), generally natural convection is not considered. Single pipe calculation area boundary conditions are as follows:

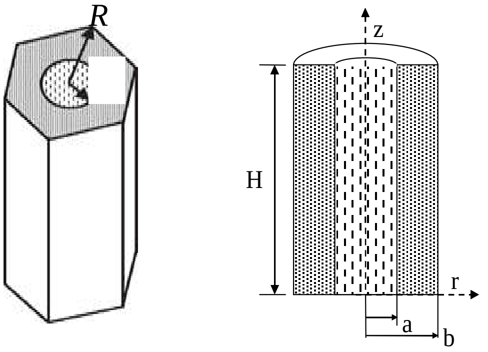


Fig.1 Transformation of hexagon into 2D control volume

In the pipeline centerline, $u_r = 0$,$\frac{u_z}{\partial r} = 0$,$\frac{\partial T}{\partial r} = 0$.

Along the r direction, outside boundary,$u_z = 0$, $u_r = 0$,$\frac{\partial T}{\partial r} = 0$.

At the solid wall where $z= 0$and $z = H$, $u_z = 0, u_r = 0$,$\frac{\partial T}{\partial z} = 0$.

At the outlet boundary,$u_r = 0, \frac{\partial u_z}{\partial z} = 0, \frac{\partial T}{\partial z} = 0$.

Experimental Validation

To validate the simulated results, one simulation was compared to previous experimental results. The experimental setup is constructed as follows:

Heat storage tank is cylindrical, processed with low carbon steel. Its diameter D = 203mm, height H = 600mm, the tunnels are formed with stainless steel tube (1010 low carbon steel, density 7.86 g/cm3 , the thermal conductivity of

51.9 W/(m K), specific heat capacity 448J/(kg °C), gravel heat 733 J/(kg K), thermal conductivity 0.15W/(m K). Wherein the pipe out diameter dout =12.7mm, inside diameter din=9.4mm, its height is the same to the tank's height, namely 600mm. Inside the tank, carbon steel tubes are arranged in hexagonal honeycomb arrangement. From the center to the outside of the tank along horizontal direction, the tubes are arranged in three layers. For any two adjacent tubes, the distance between two tubes center spacing is 40.6mm. So for the inner ring of tube, the heat transfer can be seen as well thermal insulated. Using Omega company produced K-type thermocouples, whose thermocouple diameter is 3mm, and length is 152mm, the temperature does not exceed 0.2 ℃of the absolute measurement error.

From Fig.2 we can easily come to the conclusion that the results converges well. So in the future we will use the model to simulate larger TES units.

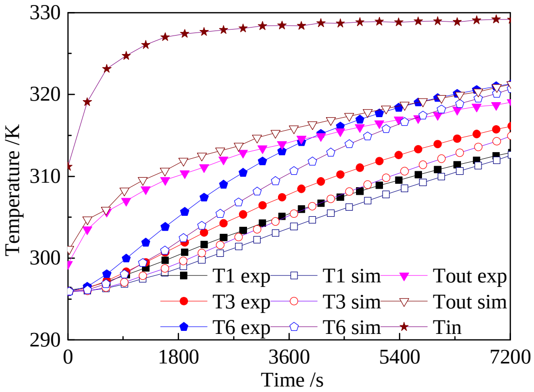
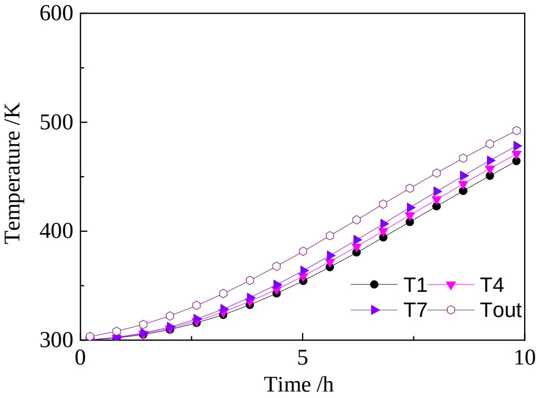


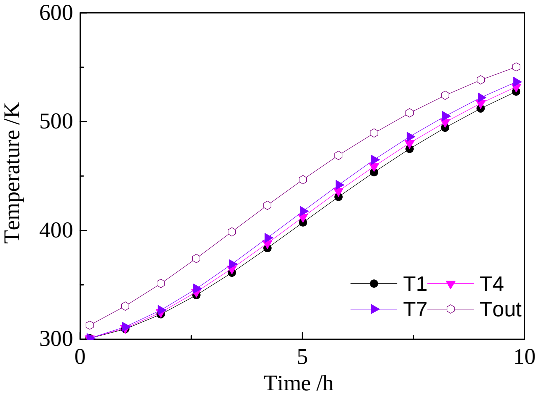
Fig.2 Comparison of sand experiment and 2D simulation

RESULTS AND DISCUSSION

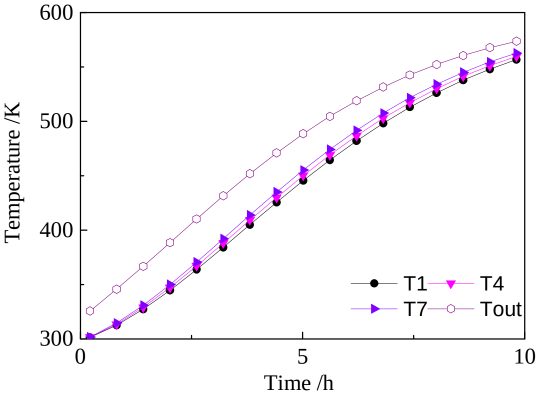
According to the properties mentioned in the previous section, a larger TES tank was simulated. The length of the tank is zoomed out to 6m, but each tube diameter and its relative relation remains the same. Here we come to investigate regenerative properties of different air flow rates. Air flow rate was set to be 4, 6 and 8m/s, respectively. The initial temperature of the tank was set to be 300k, and air inlet temperature was 600k.



(a) 4m/s



(b) 6m/s



(c) 8m/s

Fig.3 Temperature profiles of TES tank under various inlet velocity

Figure 3 shows the temperature distribution of thetank at different locations. The impact of flow rate on heat storage tank's thermal energy storage properties is presented. The simulation results are indicated by the temperature of thermocouples embedded in the tank. From the bottom of the tank to the top, altogether 7 thermocouples was placed, and there are called T1-7. Their distance to the bottom of the tank are 0.72, 1.48, 2.24, 3, 3.76, 4.52, 5.28 m. Easy to see that, under different flow rates, the temperature inside the tank tends to be uniform, indicating that the temperature inside the tank under high velocity distribution, is not conducive to generating thermocline.

To evaluate the performance of different types of gravel, from the perspective of the energy input and output, we get thethermal energy storage efficiency η

$$\eta = \frac{Q_{TES}}{Q_{Ideal}} = \frac{\int \dot{m}_f C_{p,f} (T_f^{in} - T_f^{out})dt}{\int \dot{m}_f C_{p,f} (T_f^{in} - \overline{T}_s^{t_0})dt} \quad (4)$$

This equation represent for a certain period of thermal storage process, if the heat transfer fluid can actually pass all of its energy to the thermal storage medium and its temperature is lowered to the initial temperature of the tank, we get the theoretical maximum heat transfer. Under this assumption, the thermal storage medium in the process of thermal storage will not rise its temperature, here we can getQ_{Ideal}. Then the actual heat transfer is Q_{TES}. After calculation, thermal energy storage efficiency for different flow rates, are η=0.708, 0.534, 0.425. We may reach the conclusion that thermal energy storage efficiency at low flow rates can be greatly increased.

CONCLUSION

Efficiency of thermal storage tank's under different air flow rates showed that: at low flow rates, the heat transfer between the heat transfer fluid and the thermal energy storage media is good. With high flow rates, the temperature inside the tank tend to converge, which is not conducive to the formation of thermocline. If we want to obtain good thermal energy storage, the thermocline should be maintained at low air flow rate.

Acknowledgements

All of the authors are grateful to the financial support bythe National Natural Science Foundation of China (Grant No. 51025624,51206049), National High-tech R&D Program of China (863 Program) (Grant No.2012AA050604) and State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources(LAPS13002).

REFERENCES

[1]D Barlev; R Vidu; P Stroeve. *Solar Energy Materials and Solar Cells*, **2011**,95(10), 2703-2725
[2]TE Boukelia; M Mecibah. *Renewable and Sustainable Energy Reviews*, **2013**, 21, 288-297
[3]DLZhao; Y Li; YJ Dai; RZ Wang.*Energy Conversion and Management*, **2011**,52(6), 2392-2400
[4]JE Pacheco; SK Showalter; WJ Kolb.*ASME Journal of Solar Energy Engineering*, **2002**,124, 153-9
[5]L Heller; PGauché. *Solar Energy*, **2013,**93, 345-356
[6]SMFlueckiger; BD Iverson; SV Garimella; JE Pacheco.*Applied Energy*, **2014**,113, 86-96
[7]C Xu;ZFWang;YLHe;X Li;FWBai. *Applied Energy*, **2012**,92, 65-75
[8]C Xu;X Li;ZF Wang;YL He;FWBai.*Applied Thermal Engineering*, **2013**,57(1-2), 69-80
[9]Laing D, Steinmann W, Tamme R, Richter C, Solid media thermal storage for parabolic trough power plants[J],

Solar Energy, 2006, **80**(10):1283-1289

[10]D Laing;W Steinmann;M Fiß;R Tamme;T Brand;C Bahl. *Journal of Solar Energy Engineering*, **2008**, 130(1), 1-5

[11]P Li;B Xu;JXHan;YPYang.*Solar energy*,**2014,** 105, 71–81