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Experimental Study of Heat Transfer Performance of the Solar Collector-Automatically Multiple Phase Change Thermal Storage

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Abstract. This paper presents a solar collector-automatic multiple phase change thermal storage. The device achieves the integrated design of Solar Energy Technology (SET) and Phase Change Thermal Storage Technology (PCTST), and it not only can automatically adjust the heat storage temperature and heat storage capacity of Phase Change Materials (PCMs) according to the solar radiation but also can achieve multiple storage and multiple utilization of solar energy. The device consists of a Solar Energy Collecting Layer (SECL), a High Temperature Phase Change Heat Storage Layer (HTPCHSL), an Automatic Adjustable Heat Transfer Coefficient Layer (AAHTCL), a Low Temperature Phase Change Heat Storage Layer (LTPCHSL). Through the experiments, we concluded that the device can store the solar energy in different temperatures. In the heat discharging experiments, the cold water (22℃) can reach a temperature rise about 5℃ through the LTPCHSL, and about 10℃ through the HTPCHSL, which demonstrated that solar energy can be multiple-used. The studies showed the concepts that solar energy multiple-stored and multiple-used, and the integrated design of SET and PCTST is feasible.

1. Introduction:

Solar energy is unstable and intermittent, this takes difficulties in solar energy utilization. But PCMs have the characteristics of good thermal storage capacity and approximately constant temperature during charging and discharging processes, which can reduce the mismatch between solar energy supply and thermal energy demand, so the PCMs have a great potential for solar energy applications. Thus, Many researches were did on solar heating system used PCMs for thermal energy storage, for example, in the form of phase change devices[1-3], numerical simulation[4-6], phase change devices combined with solar energy[7-9], etc.

In this paper, a solar collector-automatic multiple phase change thermal storage is presented. The experimental study is done to study the ability to adjust the participant quality of PCMs, and analyze the performance of multiple heat storage. Temperature change of phase change material and AAHTCL is analyzed. This study also provides a new idea for the usage of SET and PCTST.

2. The Experimental Setting

The experimental system consists of the solar collector-multiple phase change thermal storage device, heat discharging system and data acquisition system. The schematic diagram of the experimental system is shown in Figure 1. The device consists 6 layers: Rubber Plastic Insulation Board (RPIB) layer ($\lambda = 0.034 W/(m \cdot K)$), Rock Wool Insulation Board (RWIB) layer ($\lambda = 0.044 W/(m \cdot K)$), HTPCHSL, AAHTCL, LTPCHSL, RPIB, detailed parameters of the device are listed in the table 1.

Table 1. The compositions and related parameters of the experimental device.

Compositions	Size			Material	Internal Filling Material	The Quality of Internal Filling Material	Melting Temperature
	Length	Width	Height				
	mm	mm	mm			Kg	℃
HTPCHSL	550	50	400	Iron Plate (δ=1mm)	42#Paraffin	7.32	41.8
AAHTCL	550	6	400		Water	1.06	0
LTPCHSL	550	50	400		33#Paraffin	8.34	32.9

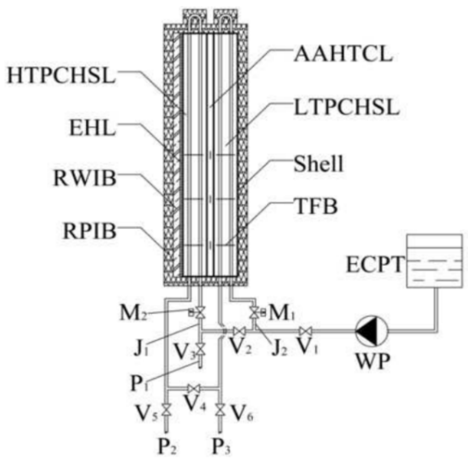
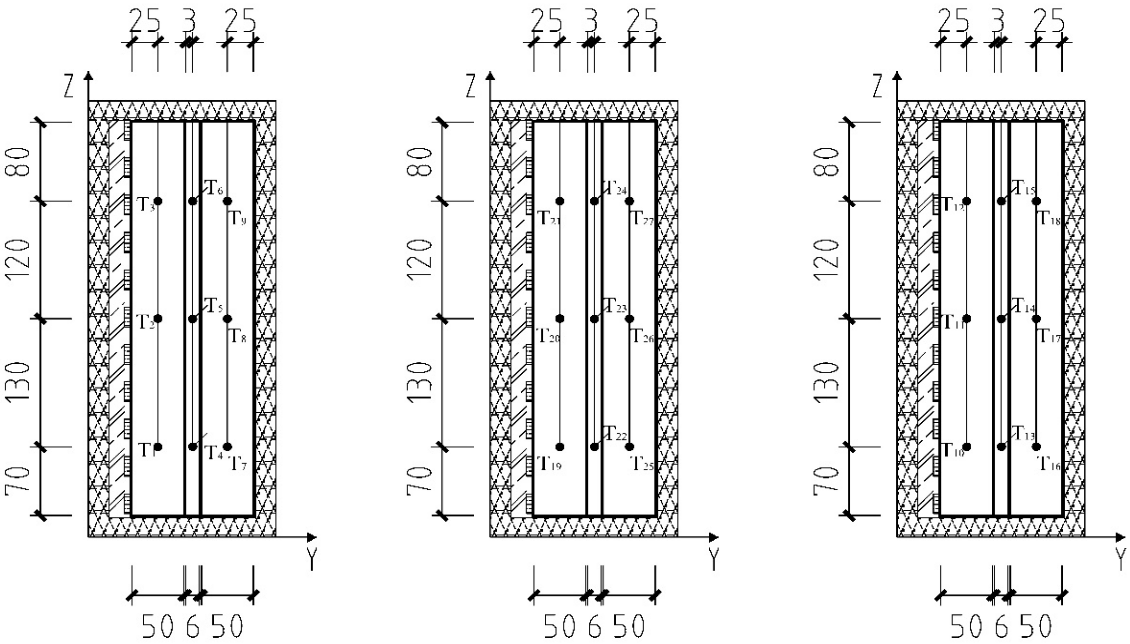


Figure1. Schematic diagram of experimental device.

The temperature measuring points (Figure 2) are arranged in Electric Heating Layer and paraffin. Considering the symmetry of the experimental device, the measuring points are only arranged on the right side of the symmetry line of the experimental device. Three groups of thermocouples (G1, G2 and G3) were set up. Each group of measuring points includes measuring points arranged in the HTPCHSL, AAHTCL and LTPCHSL. G1 is 275 mm from the right edge, G2 is 175 mm from the right edge and G3 is 70 mm from the right edge.



a) G1 b) G2 c) G3

Figure 2. Arrangement of temperature measuring points.

3. Experimental Results

3.1 Heat Charging Process

In the heat charging process, the paraffin temperature change of HTPCHSL to LTPCHSL were analyzed with heat flux density of 634 W/m^2.

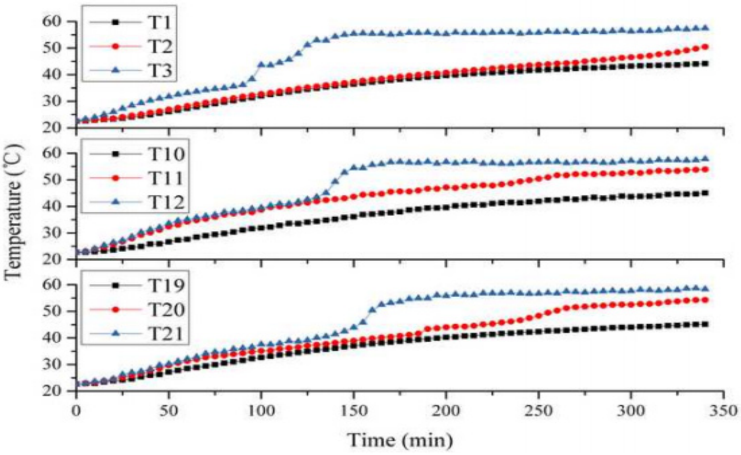


Figure 3. Temperature changing curve of HTPCHSL in vertical.

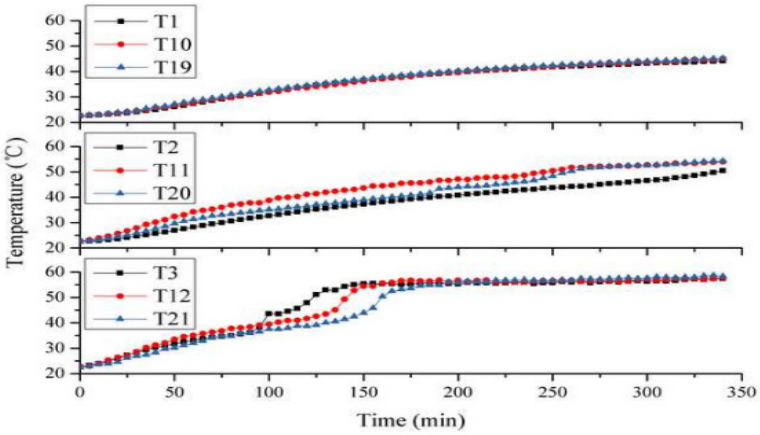


Figure 4. Temperature changing curve of HTPCHSL in horizontal.

From the Figure 4, it is observed obviously that the paraffin absorbs heat and stores it in the form of sensible heat, the temperature rises quickly at the beginning of the charging period, and temperature rises slowly during melting process and increases rapidly during heating of liquid PCM. In vertical direction (Figure 3), the phenomenon of temperature stratification appears. The main reason of this phenomenon is when the paraffin is melted into liquid. The hot liquid paraffin rises up to the top of the HTPCHSL under the influence of buoyancy, which causes the temperature of upper thermocouples (T_3, T_{12}, T_{21}) rise faster. On the contrary, the cold liquid paraffin enter into the bottom of the HTPCHSL, the temperature of paraffin in bottom rises slowly.

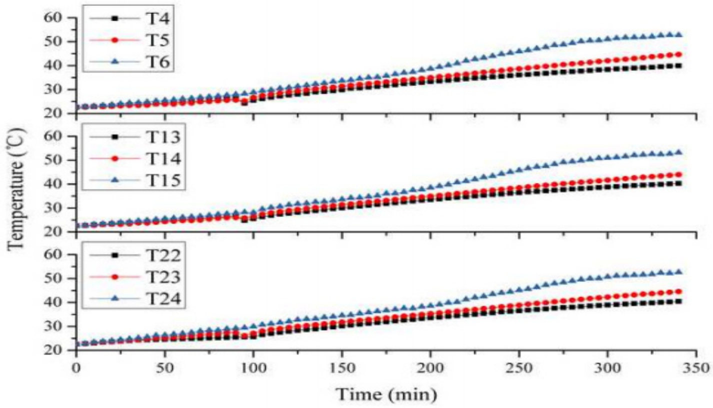


Figure 5. Temperature changing curve of AAHTCL in vertical.

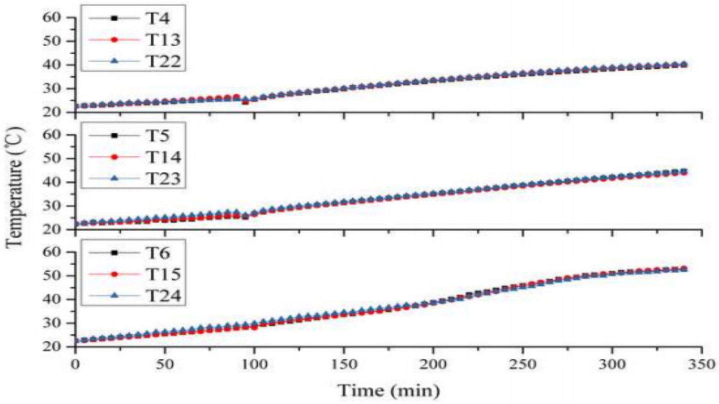


Figure 6. Temperature changing curve of AAHTCL in horizontal.

Figure 5 and Figure 6 describe the temperature histories of AAHTCL. After charging experiment carried out in 100 minutes, the setting temperature was arrived, the AAHTCL begins to add water. From Figure 6, it is observed that before 100 minutes, the temperature rise slowly, after 100 minutes, the temperature rise faster. It is proved that adding water to AAHTCL is feasible to control the heat transfer coefficient of AAHTCL. From Figure 5, the temperature stratification in AAHTCL is observed after 100 minutes. The main reason is that the temperature of HTPCHSL is higher, its temperature stratification is obvious, which has influenced the temperature distribution of AAHTCL.

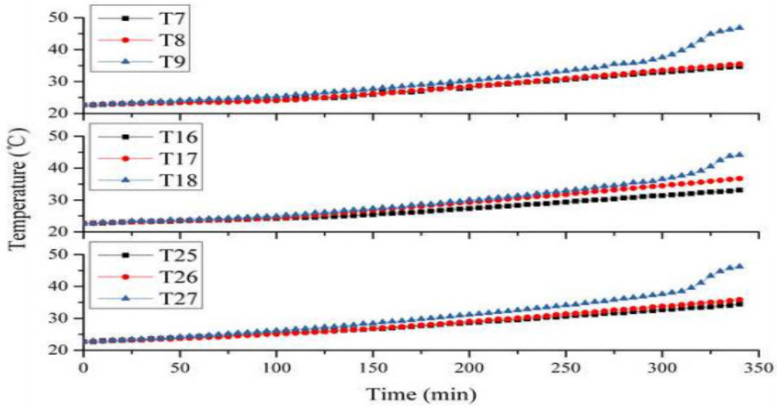


Figure 7. Temperature changing curve of LTPCHSL in vertical.

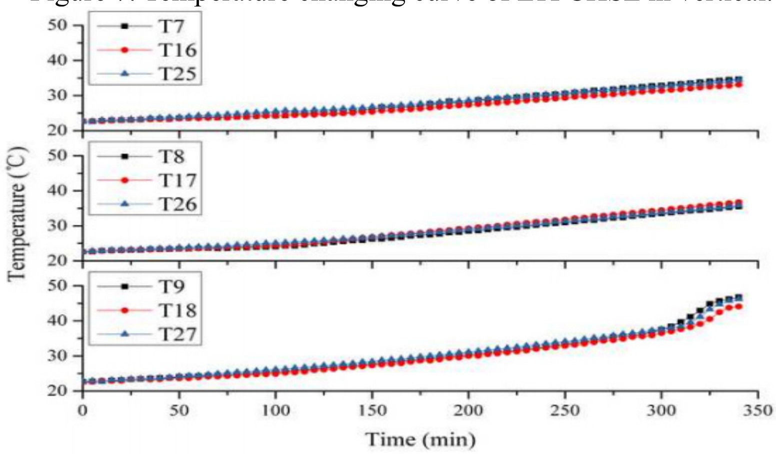


Figure 8. Temperature changing curve of LTPCHSL in horizontal.

From Figure 7 and Figure 8, it is observed that the temperature of LTPCHSL rises slowly before 100 minutes and increases significantly after 100 minutes. The reason is that the heat transfer medium is air before 100 minutes but water after 100 minutes. Because of low thermal conductivity of air, the heat transfer between HTPCHSL and LTPCHSL has been weakened before 100 minutes. And because of high thermal conductivity of water, the heat transfer between HTPCHSL and LTPCHSL has been strengthened after 100 minutes. From Figure 7, Temperature change trend of LTPCHSL in 200~340 minutes is similar to the temperature change trend of HTPCHSL in 25~150 minutes. From Figure 8, it is observed that the temperature difference in horizontal direction is small. Compared with Figure 4, the temperature of LTPCHSL in the middle layer (T_8, T_{17}, T_{26}) does not appear apparent difference and the temperature (T_9, T_{18}, T_{27}) in the top layer also does not appear the phenomenon of temperature delay, the reason of this phenomenon may be the low heating rate of LTPCHSL.

3.2 Heat Discharging Process

The heat discharging experimental data analyzed in the below is based on the heat charging power density is 634W/m^2. The experimental data indicates that the temperature changing curve of PCMs in different condition is similar. The mass flow rate of HTL is 19.78 Kg/h in heat discharging process.

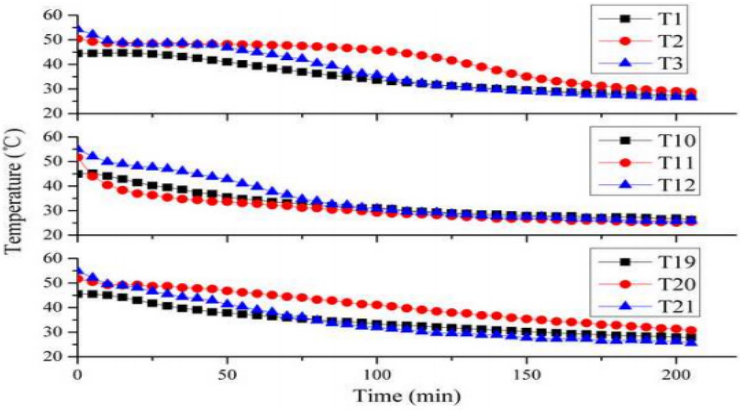


Figure 9. Temperature changing curve of HTPCHSL in vertical.

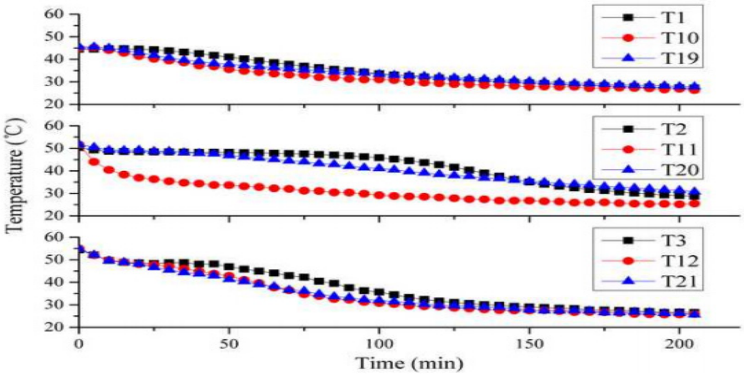


Figure 10. Temperature changing curve of HTPCHSL in horizontal.

From Figure 9, in heat discharging process , the top layer temperature (T_3, T_{12}, T_{21}) of paraffin drops quickly during beginning period, drops gently during melting process, drops rapidly during discharging process and drops slowly in the solid PCM. It is observed that the temperature changes differently and the phenomenon of temperature decay and delay also appears in the vertical direction. Temperature (T_3, T_{12}, T_{21}) in top layer changes quickly, and the paraffin enters into melting process at the same time (about 10 min) with the paraffin (T_2, T_{11}, T_{20}) in middle layer, but the former finishes the melting process of firstly, and its temperature agrees with the temperature in the bottom layer as time goes, while the paraffin in the middle layer has a longer duration in the latent heat discharging process. From Figure 10, it is observed that the temperature also changes differently in the horizontal direction. Temperature (T_1, T_2, T_3) in the bottom layer and temperature (T_3, T_{12}, T_{21}) in the top layer are relatively consistent, while temperature (T_2, T_{11}, T_{20}) in the middle layer is in a large difference.

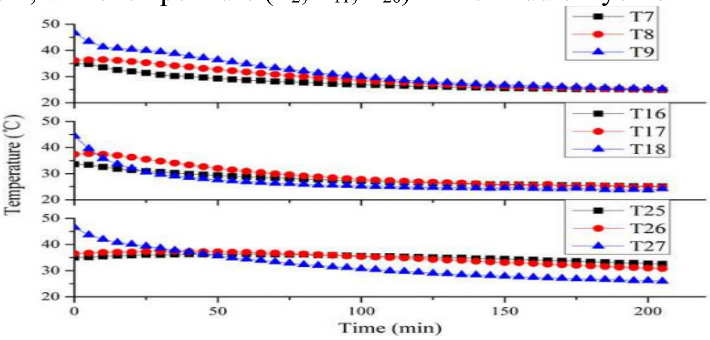


Figure 11. Temperature changing curve of LTPCHSL in vertical.

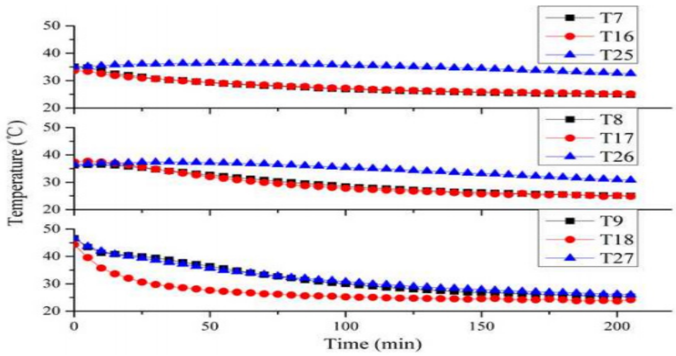


Figure 12. Temperature changing curve of LTPCHSL in horizontal.

From the temperature changing curve in top layer (T_9, T_{18}) of Figure 12, we can find that the paraffin 33# is in the latent discharging process in 41℃~37℃. Comparing the Figure 11 and Figure 12, it is observed that the phenomenon of temperature decay and delay appears in the vertical direction is not obviously, the main reasons have two: The first is the paraffin 33# has not fully melted (about 15% through experimental observation). The second is the cold water in a low initial temperature flows into the LTPCHSL firstly, which lead to a rapid temperature drop in top layer (T_9, T_{18}, T_{27}). The temperature of LTPCHSL in the horizontal direction appear difference, we guess that it is the comprehensive results of the temperature rise of the HTL in the flowing process and the temperature drop of paraffin in the heat discharging process.

4. Conclusion

In this paper, we presents a solar collector-automatic multiple phase change thermal storage based on experiments， some conclusions were obtained: The structure of adding AAHTCL between HTPCHSL and LTPCHSL can achieve the purpose that the device can automatically adjust the heat storage temperature and heat storage capacity of PCMs according to the solar radiation. The way of adding water to adjust the heat transfer coefficient of AAHTCL is feasible, which has a good effect on adjusting the heat transfer between HTPCHSL and LTPCHSL. The device realizes the multiple utilization of solar energy.

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