CHAPTER 5

Discharged Fluid Temperatures From a Thermal Storage System—The Key Parameter for Utilization of Stored Thermal Energy

Contents

Abstract

One of the important objectives of the investigation into the behavior of a thermal storage system is to understand the variation of the temperatures of the fluid when discharged from the thermal storage system. It is the discharged fluid temperature that indicates whether the thermal storage system is fully charged or fully discharged in the respective processes. This chapter will discuss the scenarios of the discharged fluid temperature from single medium (HTF alone) and dual-media thermal storage systems under different operating conditions.

Keywords: Dual media thermal storage, Heat transfer fluids, Latent heat thermal storage, Sensible thermal storage, Discharged fluid temperature

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5.1 EXAMPLE OF FLUID ALONE SENSIBLE THERMAL STORAGE

When a fluid alone is used for thermal storage, the situation is rather simple: during the energy storage process the fluid pumped out from a cold tank will get heat (from a heat collector) and is then stored in a hot tank; and during the energy discharge process the fluid pumped out from a hot tank will release heat (to a heat sink or thermal energy user) and is then stored in a cold tank. Therefore, for these processes we can assume that the temperature of the discharged fluid from a tank is approximately constant.

5.2 EXAMPLE OF PACKED BEDS BY SOLID FILLER MATERIAL FOR SENSIBLE HEAT STORAGE

The so-called dual media thermal storage system uses a solid packed bed as the primary energy storage material, and a heat transfer fluid flows through the packed bed to deliver or withdraw thermal energy to/from the solid materials. Under this circumstance, the heat transfer between the packed-bed solid material and the heat transfer fluid makes the temperature of the discharged fluid vary during the entire energy charge or discharge process.

Having an accurate prediction of the time-dependent temperature of the fluid flowing out from the dual-media thermal storage tank is critical to the size design of thermal storage tanks and operation of a thermal power plant utilizing the stored thermal energy. For example, when below a certain temperature, the discharged fluid will not be acceptable by the power plant. Therefore, the size design for a thermal storage system needs to consider this requirement.

Fig. 5.1 shows schematically the time-dependent variation of the fluid temperature flowing in and out from a dual-media thermocline sensible thermal storage system. Fig. 5.1A is for a thermal storage/charging process and Fig. 5.1B is for a thermal discharging process [1].

For the thermal discharging process, it is easy to understand that theoretically the temperature of the discharged hot fluid will start to decrease once the original hot fluid in the voids of the packed bed moves out. If the time to fill up a tank volume with fluid is t_{full} and the void fraction of the packed bed is ε, then the time instance that the temperature of the discharged hot fluid

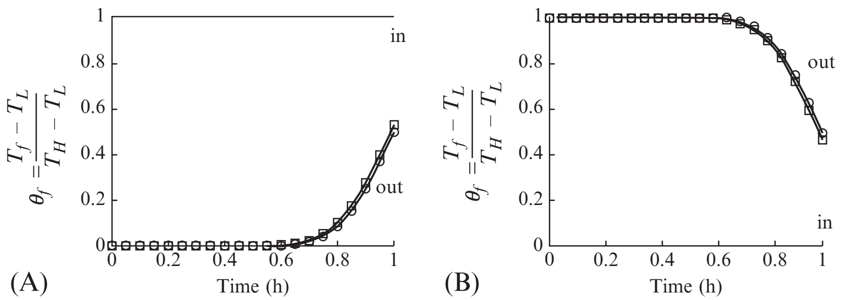

Fig. 5.1 Temperature of fluid at inlet and outlet of thermal storage tank during charging and discharging processes. (A) Thermal charging, (B) thermal discharging.

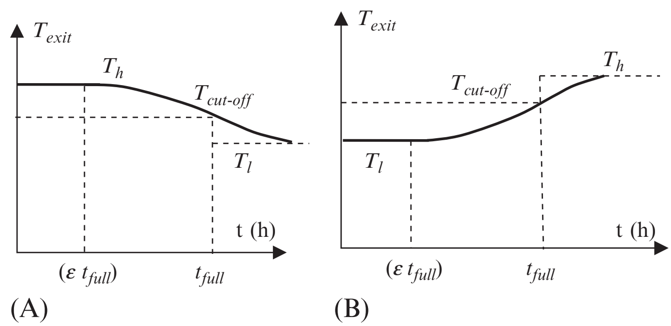

Fig. 5.2 Illustration of the time-dependent outflow fluid temperatures in discharging and charging processes of a dual-media sensible thermal storage system [2]. (A) Discharging, (B) charging.

starts to decrease is $\varepsilon \cdot t_{full}$ as shown in Fig. 5.2A. Similarly, as shown in Fig. 5.2B, in a thermal charging process, the temperature of the cold fluid flowing out of the tank will start to increase at the moment of $\varepsilon \cdot t_{full}$ at which the original cold fluid in the voids of the packed bed moves out.

In the discharging process, a cut-off temperature, as shown in Fig. 5.2A, is typically set as the lowest fluid temperature that is acceptable by the user of the thermal energy. The discharging process stops once the temperature of the fluid out from the tank is below the cut-off temperature. Similarly, it is also important to observe the temperature of the flowing-out fluid in a charging process to control the operation of the thermal charging process. When the flowing-out fluid has a sufficiently high temperature, $T_{cut-off}$, it becomes difficult to charge more energy into the system due to the minimized temperature difference between the solid and the fluid, and the charging process stops.

5.2.1 Multiple Energy Charges and Discharges to Approach Cyclic Steady-State Operation

When a thermal storage system is subjected to operation, the thermal storage tank is initially cold. The thermal charge and discharge operation will repeat for multiple times or days (if one charging and one discharging are made in one day's operation) and then the system comes to a so-called cyclic steady-state operation, if the fluid temperature respectively fed to the charging and discharging processes do not change from one to another time. Typically, after several to 10 charging/discharging cycles, the system will reach a cyclic steady-state. Fig. 5.3 schematically shows the evolution of the dimensionless temperature distribution of the filler material in a tank at the end of each charging and discharging in total six runs of energy storage and withdrawn

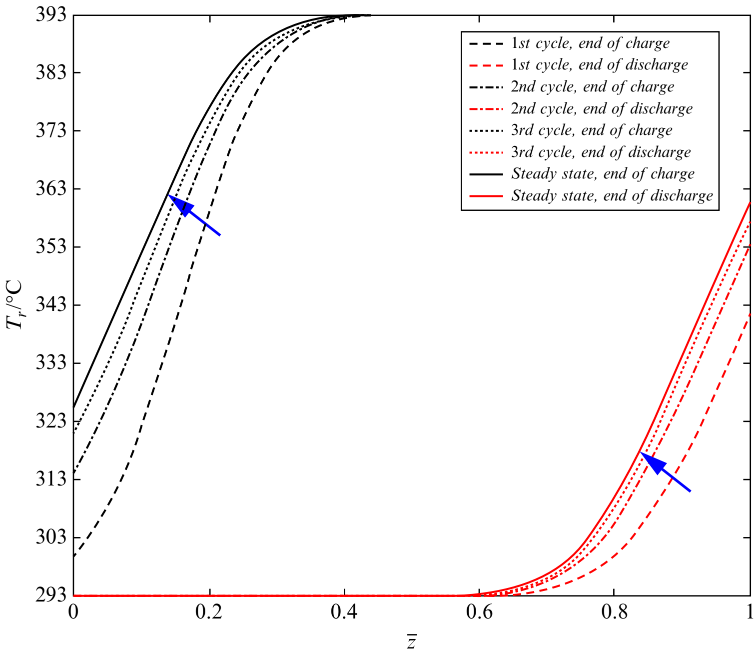

Fig. 5.3 The filler material temperature distribution in a sensible thermal storage tank in six runs of thermal charging and discharging with the tank initially cold [3].

operation. One can see that after three runs of charging/discharging, the temperature distribution in the tank after a charging and a discharging becomes the same as that of the next operation.

5.3 PACKED-BED BY ENCAPSULATED PCM FOR LATENT HEAT THERMAL STORAGE

PCM-based latent heat thermal storage is characterized by a section of constant temperature of fluid flowing out of the storage tank, which is due to the large heat capacity of PCM at the melting or freeze point. Fig. 5.4 shows a typical scenario of the fluid temperature flowing out from a PCM storage tank during a heat discharging process. The first short period shows a quick temperature drop, which is due to the sensible heat in the PCM above the freeze point. The section with a long period of constant temperature is related to the freezing temperature where the release of large latent heat keeps the temperature of fluid constant for a relatively long time. After the section of freezing process, the sharp drop of the temperature of the outflow fluid is due to the relatively low sensible heat capacity of the PCM.

Obviously, if we view the large latent heat as an equivalent of a large heat capacity at the freeze point, we may pack multiple sections of different PCMs with different freeze points in one storage tank, which will allow us to have the advantage of multiple small steps of temperature drop and overall to have small storage volume.

5.3.1 Multiple Energy Charge and Discharges to Approach Cyclic Steady-State Operation for Latent Heat Thermal Storage

In a similar way to that of sensible thermal energy storage, thermal charge and discharge operation for a latent heat thermal storage system will also repeat for multiple times or days (if one charge and one discharge are made in one day's operation) until the system comes to a so-called cyclic steady-state operation. This is assumed that the fluid temperatures respectively fed to the charging and discharging processes do not change each time. Fig. 5.5 schematically shows the evolution of the dimensionless temperature distribution of the filler material in a tank at the end of each charging and discharging in total six runs of energy storage and withdrawn operation. One can

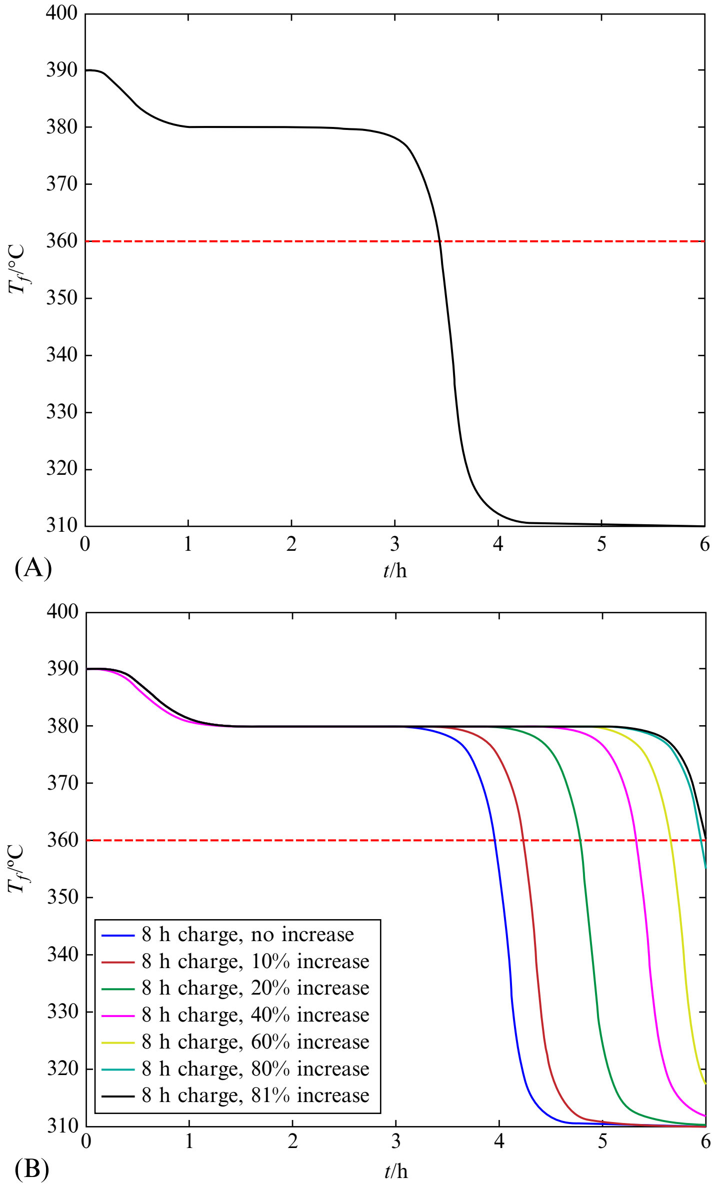

Fig. 5.4 Examples of the temperature of outflow fluid during a discharging process in a PCM thermal storage system [4] (A) A basic case of same charging and discharging time, (B) a case with longer charging time and increased volume on the basic case.

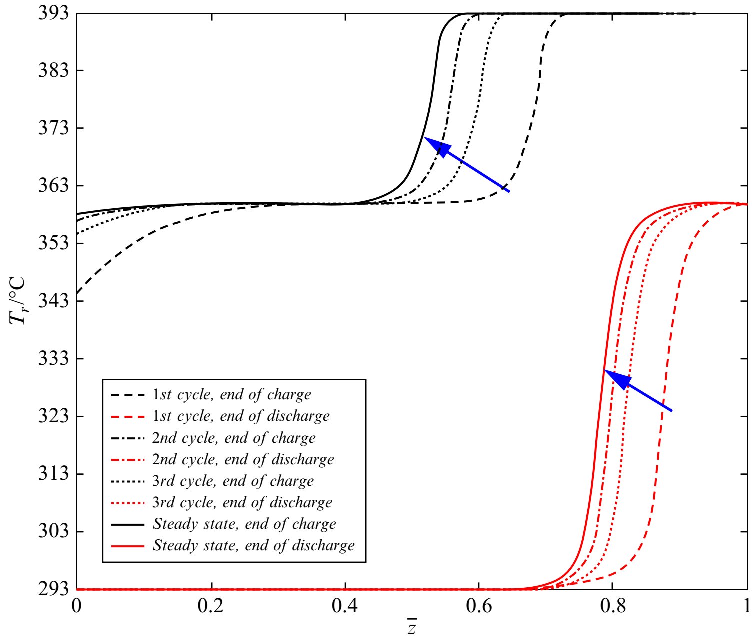

Fig. 5.5 The filler material temperature distribution in a latent heat thermal storage tank in six runs of thermal charging and discharging with the tank initially cold [3].

see that after three runs of charging/discharging, the temperature distribution in the tank becomes the same as that of the next operation.

5.4 MULTIPLE LAYERS OF PACKED BED WITH DIFFERENT PCM OF DIFFERENT PHASE CHANGE TEMPERATURES

Because of the great difference between latent heat and sensible heat, one can see a quick drop of the discharged heat transfer fluid (HTF) once the phase change is complete. For the system to rely more on latent heat thermal storage, the idea of multiple PCM sections with a cascade melting point in one tank has been proposed [5,6], such as is shown in Fig. 5.6. Because each zone in the packed bed has a different PCM material with different melting points, the discharged fluid temperature profile can be different from that of using single PCM. Fig. 5.7 shows the scenario of the fluid temperature measured at the top of PCM-1, PCM-2 and PCM-3 during a discharging process [6].

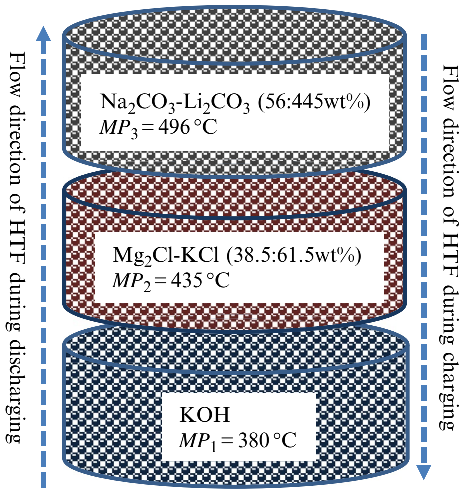

Fig. 5.6 Multiple zones of packed PCM capsules in different melting point and properties [5].

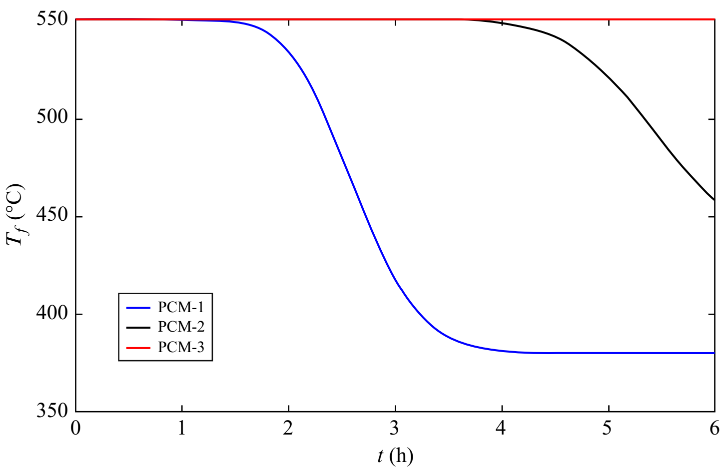

Fig. 5.7 Schematic illustration of the fluid temperature taken at the top of each PCM zone during a discharging process for the PCM packed bed shown in Fig. 5.6 [6].

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