

# Performance analysis of solid heat accumulator used in tower solar thermal power generation system

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2023 8th International Conference on Advances in Energy and Environment Research & Clean Energy and Energy Storage Technology Forum, Shanghai Electric Power University, No.2588 at Changyang Road in Yangpu Area, 200090 Shanghai, China.

**Abstract**—In recent years, solar energy, wind energy and other new energy sources have been highly praised, especially solar energy, which is considered as one of the cleanest renewable new energy sources, and solar thermal power stations have been built in many countries. Tower solar photothermal power generation is a heat absorber that reflects sunlight to the top of the tower through heliostat field. Molten salt absorbs heat through the heat absorber, heats water supply and promotes thermal power generation. However, solar energy is intermittent and unstable, so the tower solar thermal power station is equipped with heat storage molten salt tank. Solid heat storage technology has the advantages of cheap heat storage medium, no harm to the environment, strong reliability and operability of the system, and can provide cost-effective heat storage solutions for industrial process heat energy and power generation. In this paper, the molten salt tank is replaced by a solid heat accumulator. After the molten salt absorbs heat during the day, part of it heats the heat accumulator through the unit tube in the heat accumulator to store the heat in the heat accumulator, and the other part heats the water to promote the steam power cycle. At night, the heat accumulator heats the molten salt to release heat, which continues to promote the steam power cycle. In this paper, CFD software will be used to numerically simulate the change of temperature characteristics inside the solid regenerator with the time of heat storage and release, and draw the temperature nephogram and change curve.

## 1. Preface

Solar photothermal power generation has the characteristics of strong regulation ability, high safety, suitable for large-capacity energy storage and bidirectional connection to power grid. The Tenth Five-Year Plan for Modern Energy System points out that solar thermal power generation should be actively developed, especially in Qinghai and Xinjiang. So that solar photothermal power generation combined with wind power, photovoltaic and other renewable power generation energy sources can develop harmoniously and jointly promote<sup>[1]</sup>.

As a centralized solar power generation mode with the most stable development and large-scale commercial operation, the tower solar thermal power station is rich in research. Different from parabolic trough, tower solar thermal power station has many variants in receiver type, working fluid, power cycle, heliostat size and so on. Although it can be traced back to the end of 1980s, in the past decade, it has been observed that the number of tower solar thermal power stations has increased considerably<sup>[2]</sup>.

Thermal energy storage technology has become a potential solution to intermittent problems related to solar thermal systems in industrial applications. In addition, the thermal storage system can play a key role in improving the effective utilization of thermal energy by recovering the waste heat generated during operation<sup>[3-5]</sup>. Sensible heat

storage is the cheapest technology, so it is the most commonly used in other types of thermal energy storage. At present, it is mainly used in residential hot water tanks, space heating and thermal storage systems (molten salt) of solar thermal power plants. Sensible thermal energy storage has the lowest energy density, which means that they are larger than latent heat and thermochemical thermal energy storage systems. Although latent heat and thermochemical thermal energy storage technologies are expensive, they provide promising performance improvement due to their high energy density, but these two technologies are still mainly in the research stage, especially thermochemical thermal energy storage systems.

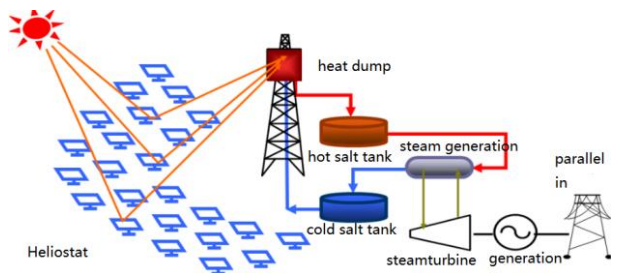
Solid heat storage is one of the most potential sensible heat energy storage technologies. Solid heat storage technology has the advantages of cheap heat storage medium, no harm to the environment, strong reliability and operability of the system, and can provide cost-effective heat storage solutions for industrial process heat energy and power generation. According to the form of heat storage, it can be divided into hybrid heat storage and porous solid heat storage<sup>[6-8]</sup>.

## 2. System model

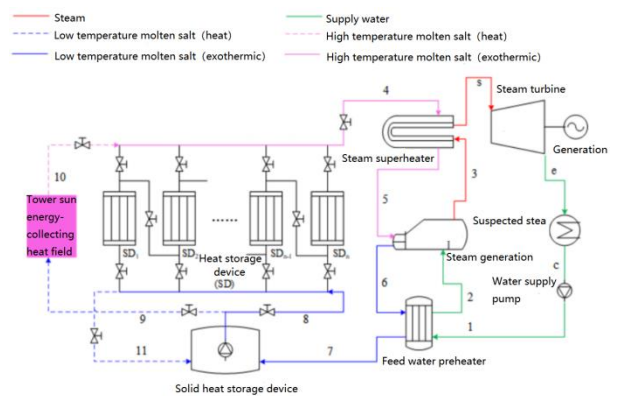
Figure 1 shows the workflow of the power generation system in the thermal power station. The power generation system consists of two parts, including the light gathering

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and heat collection part and the power circulation part. The work flow of the light-gathering and heat-collecting part is: fix the position where the helioscope captures the sun, and reflect the light of the sun to the top of the heat absorption tower, and the receiver at the top can heat the pipeline after absorbing the heat. The heat transfer medium can be heated to about 600°C after flowing through the pipeline. In the steam generator, the heat transfer medium transfers heat to the steam, and the high-parameter steam then pushes the steam turbine to do work and generate electricity. The photothermal power generation system with solid heat storage discussed in this paper mainly involves mirror field model, heat collection model, heat absorber model, heat accumulator model and thermal system model. The working principle of the system is shown in Figure 2.



**Figure 1** Schematic diagram of tower solar photothermal power generation system



**Fig. 2** schematic diagram of solar photothermal power generation system with solid heat storage.

As shown in Figure 2, when the solar energy is surplus, the molten salt flows out of the cold salt tank and then enters the heat absorber to absorb heat, and the absorbed molten salt not only drives the Rankine cycle, but also heats the heat accumulator to store heat. When the solar energy is insufficient, the molten salt will be heated by the heat accumulator, and the heated molten salt will transfer heat to steam, which will drive the steam turbine to generate electricity.

3. Regenerator model

In this paper, solid heat storage is used, and the molten salt partially enters the heat storage body after absorbing heat through the heat absorber, and the absorbed heat is stored in the heat storage body for continuing to release heat at night to maintain the system operation<sup>[9]</sup>. When there is solar radiation in the daytime, the molten salt absorbs heat,

stores part of the heat in the heat accumulator, and the other part exchanges heat with water, and the water absorbs heat and vaporizes into steam for power circulation. During the daytime heat absorption process, molten salt flows through the regenerator, which releases heat and the heat absorption temperature of the regenerator increases; At night, the heat accumulator releases heat, the temperature decreases and the heat absorption temperature of molten salt increases.

There are many kinds of materials for heat storage, including mullite, cordierite, clay and corundum. By comparison, concrete is more suitable for heat storage, and the volume of heat storage is basically controllable. Metal tubes are inserted into the unit holes, which are arranged in a serpentine manner, and each tube pass is connected by a U-shaped tube. During the whole process of heat storage and heat release, the temperature at the cold end and the hot end of the regenerator changes, and the initial design and calculation parameters are shown in Table 1.

**Table 1** Initial Parameters of Design Calculation

| physical quantity                                          | numerical value        | unit              |
|------------------------------------------------------------|------------------------|-------------------|
| Molten salt specific heat                                  | 1499                   | J/(kg·K)          |
| Molten salt density                                        | 1923                   | kg/m <sup>3</sup> |
| Number of main pipes in regenerator                        | 3600                   | —                 |
| Number of tubes per row                                    | 60                     | —                 |
| Row number                                                 | 60                     | —                 |
| Inner diameter of regenerator tube                         | 19                     | mm                |
| Tube spacing                                               | 0.1                    | m                 |
| Inlet molten salt temperature during heat storage          | 520                    | °C                |
| Outlet molten salt temperature during heat storage process | 200                    | °C                |
| Inlet molten salt temperature during exothermic process    | 190                    | °C                |
| Outlet molten salt temperature during exothermic process   | 450°C                  | °C                |
| Molten salt kinematic viscosity                            | 1.654×10 <sup>-6</sup> | m <sup>2</sup> /s |
| thickness of pipe wall                                     | three                  | mm                |
| Pipe wall material: cast steel                             |                        |                   |
| Thermal conductivity of pipe wall                          | 20.2                   | W/(m·K)           |
| Regenerator material: concrete                             |                        |                   |
| Thermal conductivity of regenerator material               | 2.2                    | W/(m·K)           |
| Specific heat of regenerator material                      | 1050                   | J/(kg·K)          |
| Material density of regenerator                            | 2500                   | kg/m <sup>3</sup> |
| Thermal storage time                                       | 6                      | h                 |

#### 4. Analysis and summary of calculation results

The line spacing of the text is set to single line spacing, and the distribution of heat storage and release process under three working conditions is numerically simulated, and the temperature nephogram of heat storage and release

under three working conditions is drawn, and the change curves of molten salt and solid temperature and the change curve of heating rate at molten salt outlet are drawn. The temperature nephograms of molten salt and concrete during heat storage under three working conditions are shown in Figures 3, 4 and 5, and those during heat release are shown in Figures 6, 7 and 8.

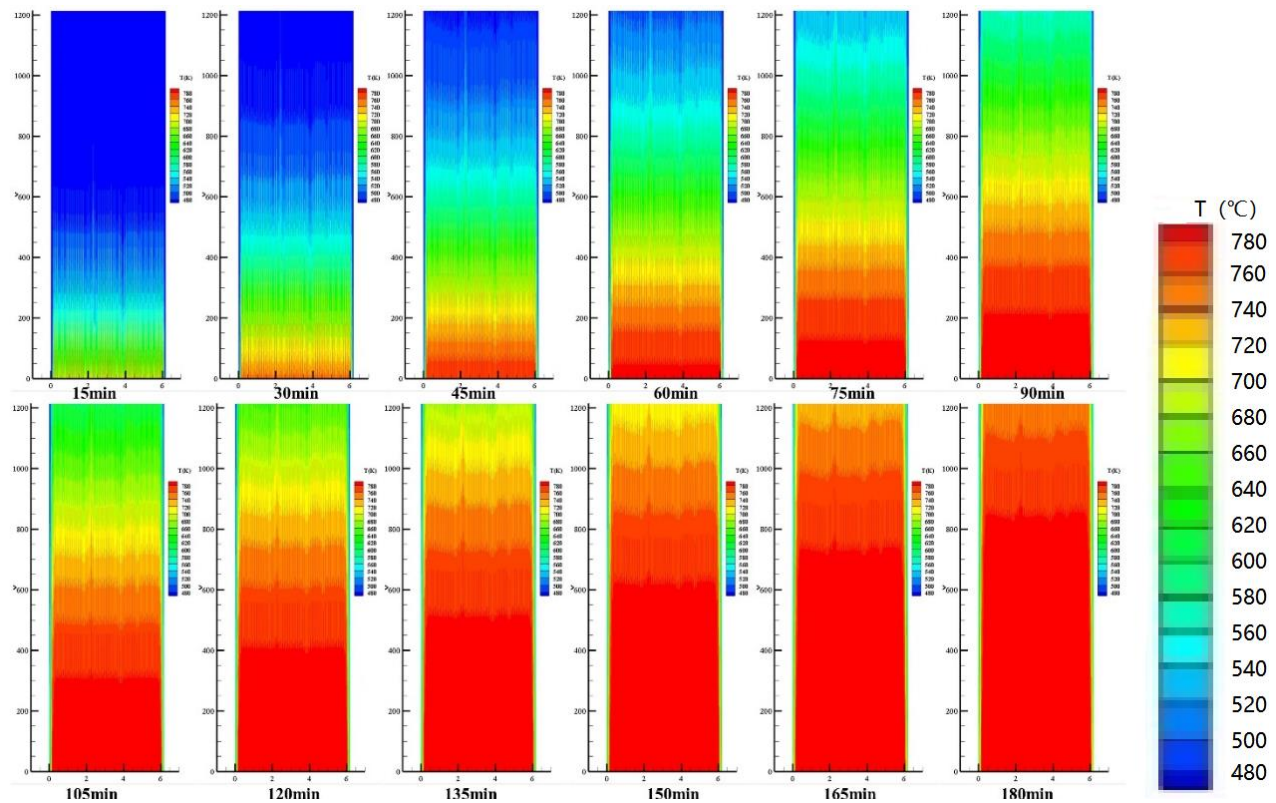
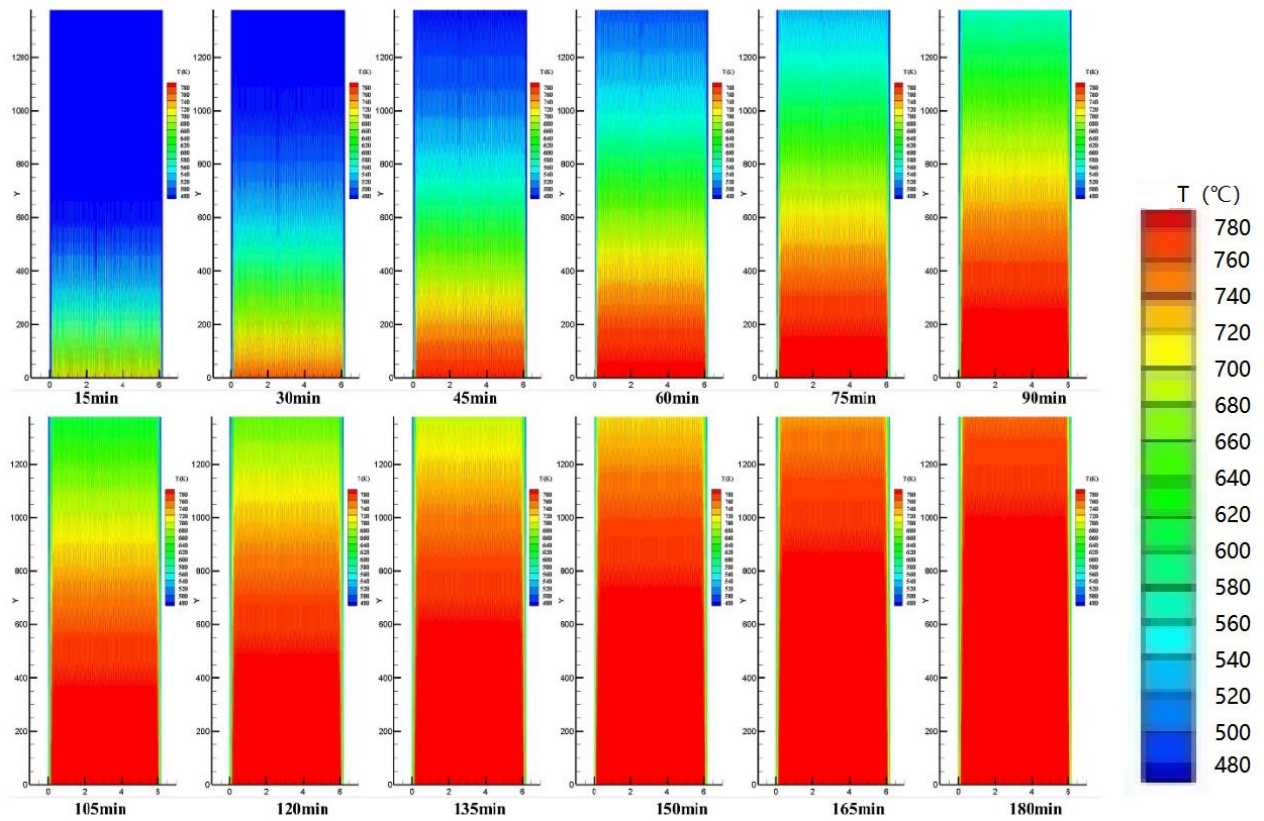
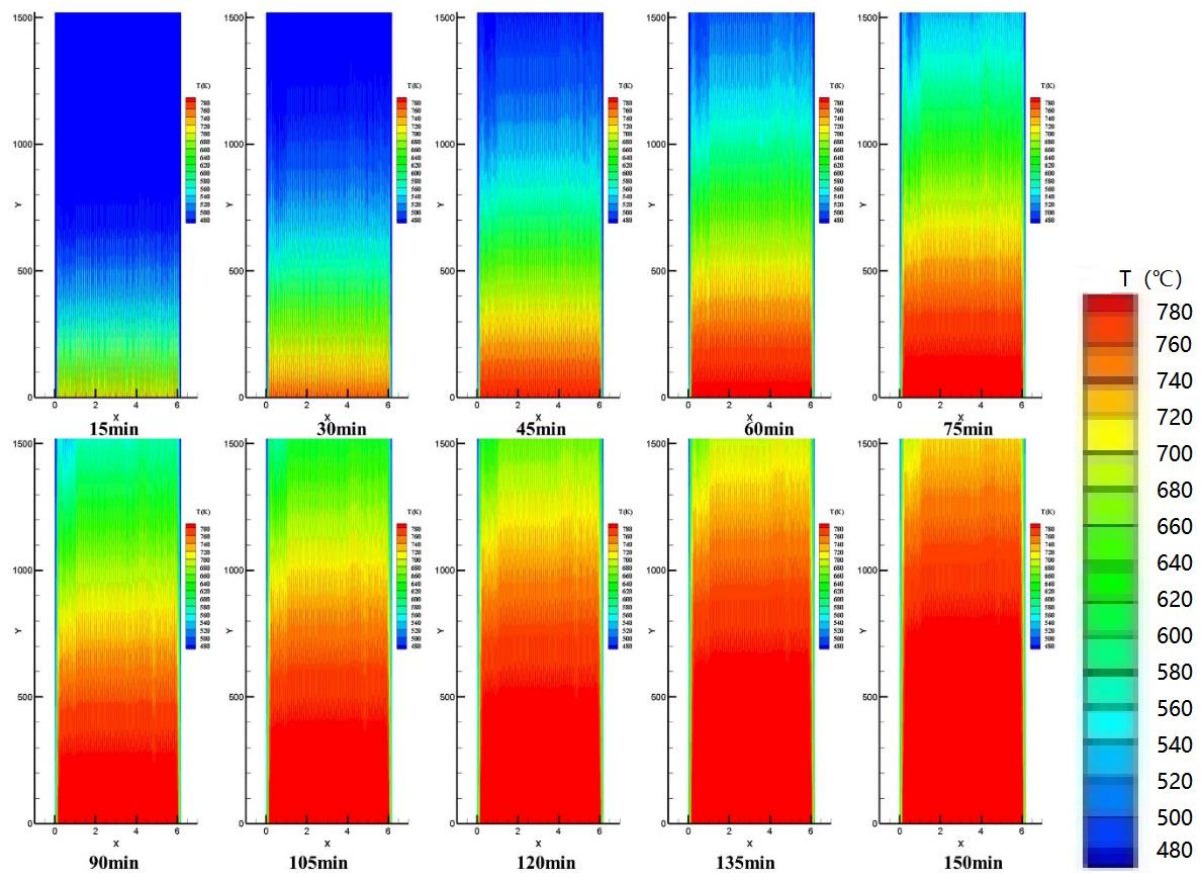


Fig. 3 Temperature nephogram of concrete and molten salt during heat storage under working condition 1.



**Fig. 4** Temperature nephogram of concrete and molten salt during heat storage in Condition 2.



**Fig. 5** Temperature nephogram of concrete and molten salt during heat storage under working condition 3.

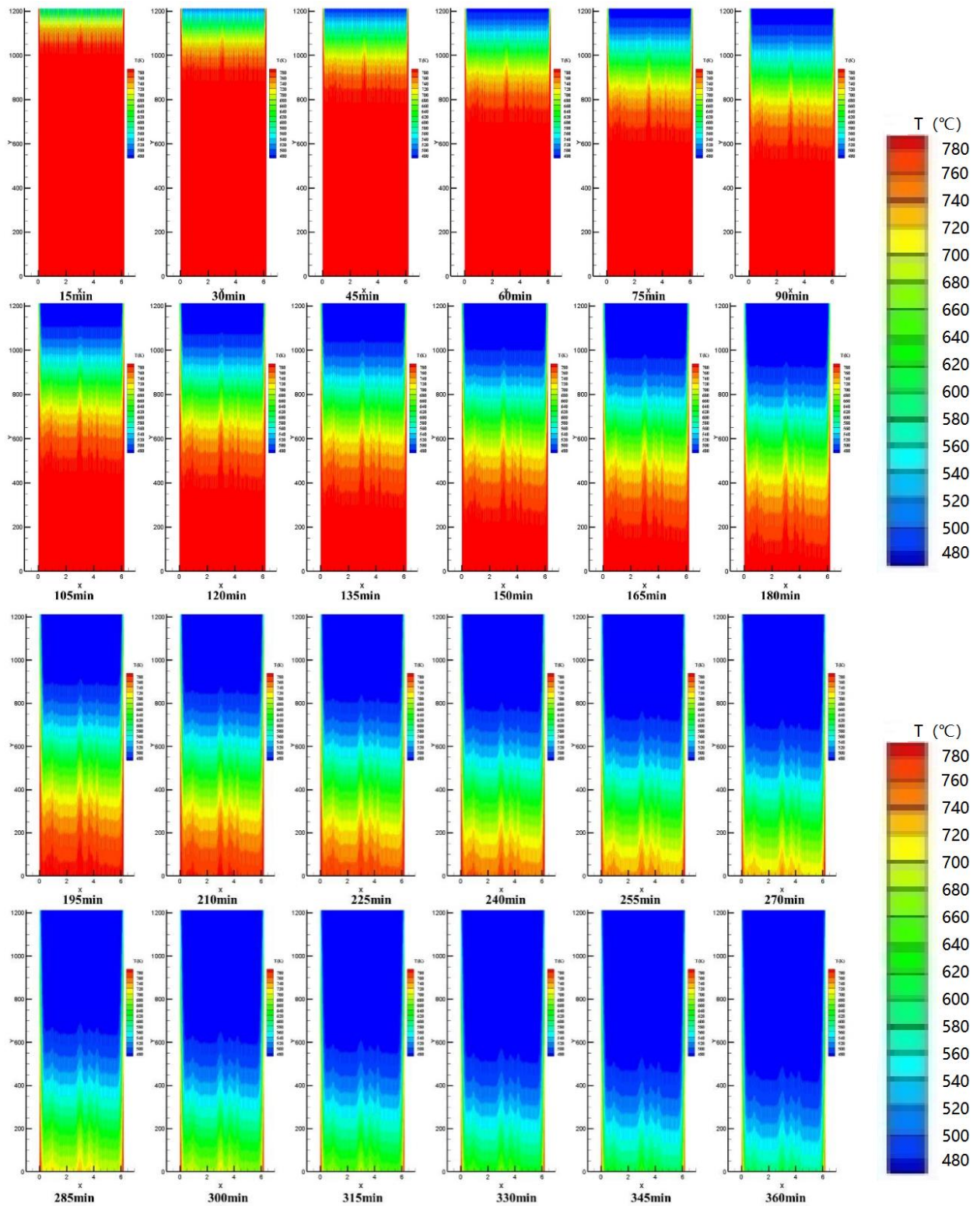
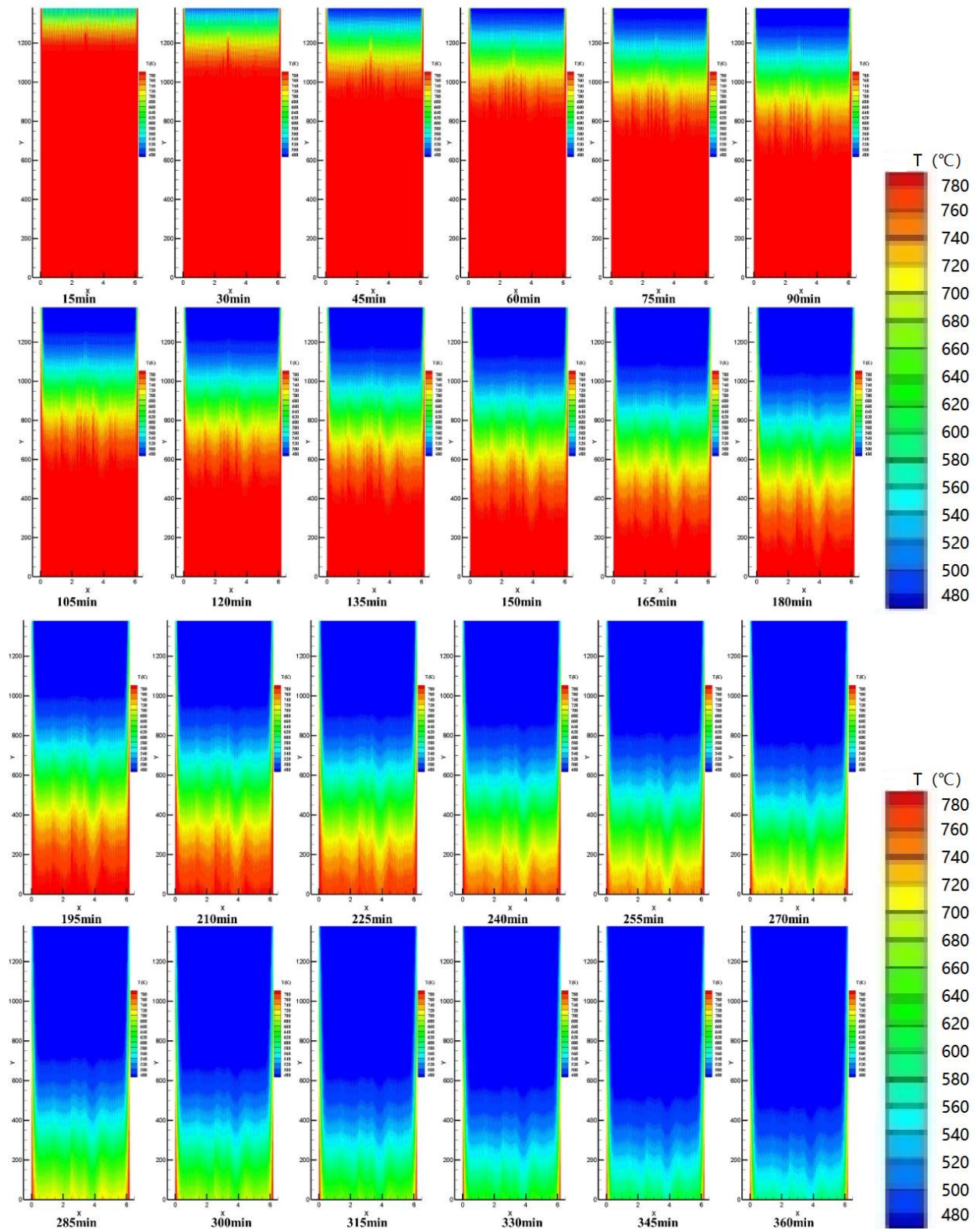
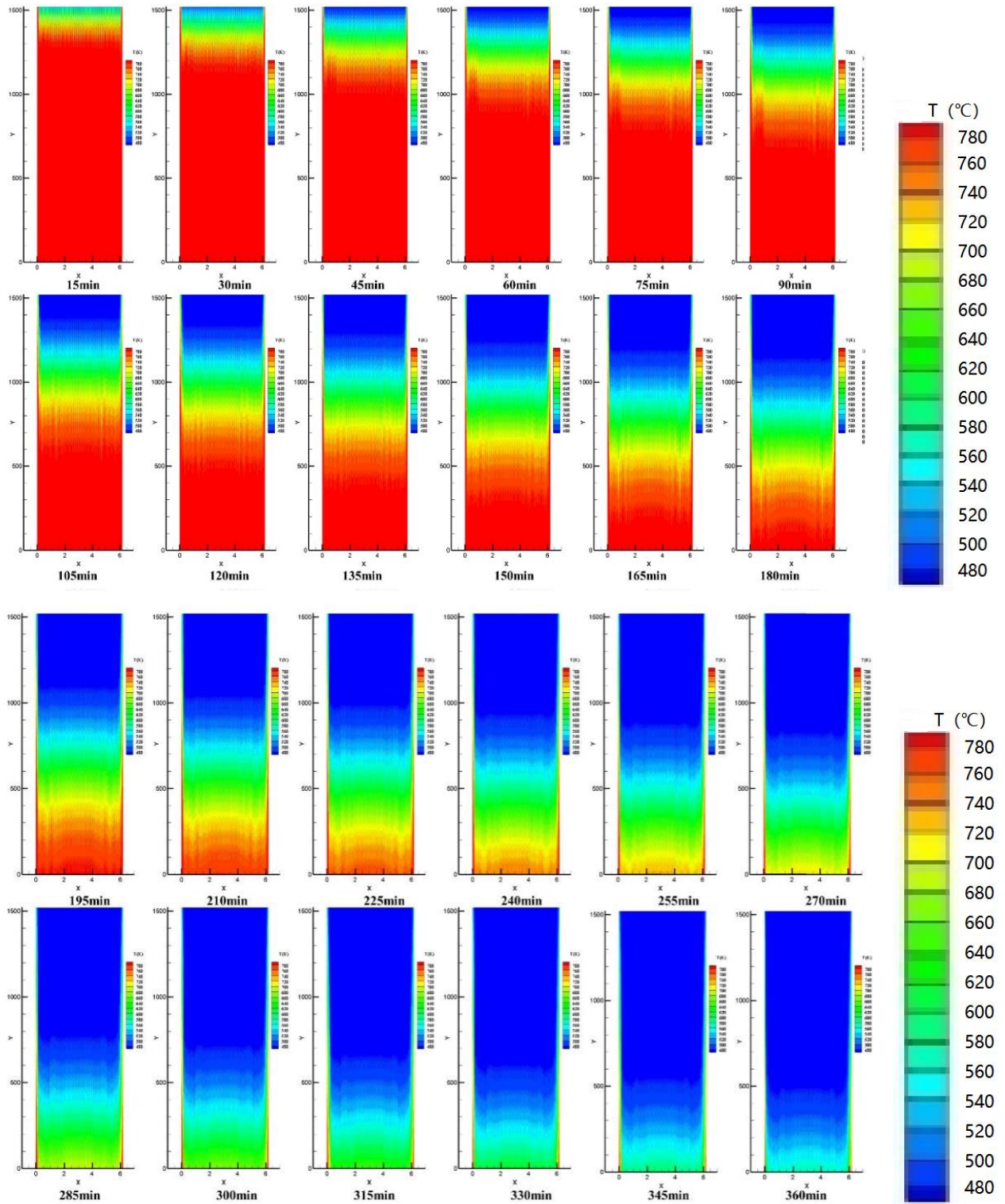


Fig. 6 Temperature nephogram of concrete and molten salt during working condition-exothermic process.



**Fig. 7** Temperature nephogram of concrete and molten salt during exothermic process in Case 2.



**Fig. 8** Temperature nephogram of concrete and molten salt during exothermic process under working condition 3.

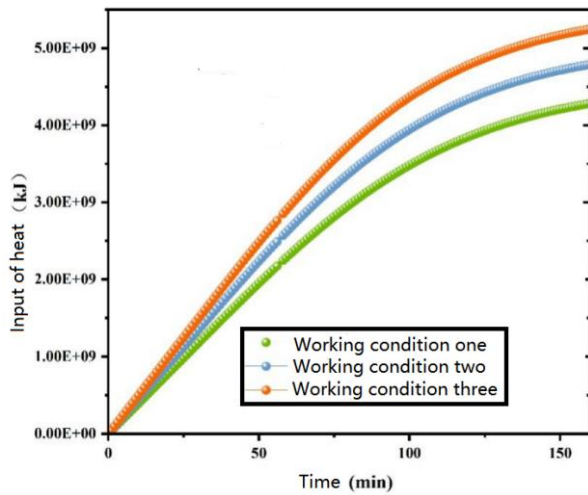
The amount of energy stored in the process of charging and discharging can be calculated according to Formula (1):

$$E_c = \int \frac{c_{p, in} + c_{p, out}}{2} (T_{out} - T_{in}) q_m dt \quad (1)$$

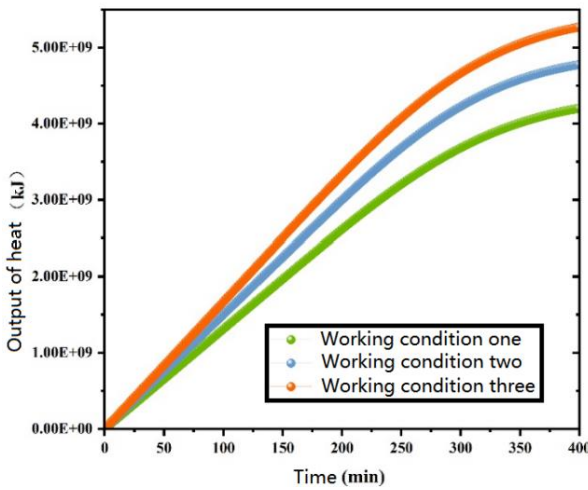
Wherein,  $c_{p, in}$  -it represents the specific heat capacity of imported molten salt, kJ/(kg°C);  $c_{p, out}$  -Represents the specific heat capacity of molten salt at the outlet, kJ/(kg°C);  $T_{in}$  and  $T_{out}$  respectively represent the inlet and

outlet temperatures of molten salt, °C;  $q_m$  -Represents the mass flow, kg/s.

According to the CFD calculation results, the curves of heat storage and heat release of the regenerator with time under three weather conditions are shown in Figures 9 and 10.



**Fig. 9** Thermal storage of concrete during thermal storage



**Fig. 10** Heat release in concrete exothermic process

Tables 2 and 3 summarize the calculation results of heat storage process and heat release process under three working conditions respectively.

**Table 2** Summary of Calculation Results of Thermal Storage Process

|                                                       | Working condition 1 | Working condition 2 | Working condition 3 |
|-------------------------------------------------------|---------------------|---------------------|---------------------|
| Initial temperature of molten salt (°C)               | 520                 | 520                 | 520                 |
| Total length of heat exchange tube (m)                | 1214                | 1379                | 1522                |
| Mass flow (kg/s)                                      | 1379                | 1579                | 1755                |
| Flow velocity (m/s)                                   | 0.70                | 0.80                | 0.89                |
| Molten salt outlet temperature after 160 min (°C)     | 466                 | 474                 | 475                 |
| Average temperature of molten salt after 160 min (°C) | 507                 | 509                 | 509                 |

|                                                    |                    |                    |                    |
|----------------------------------------------------|--------------------|--------------------|--------------------|
| Average temperature of concrete after 160 min (°C) | 490                | 494                | 494                |
| Inflexion point of molten salt heating rate (min)  | 92                 | 94                 | 88                 |
| Maximum heating rate of molten salt (°C/min)       | 3                  | 3                  | 3.1                |
| Time for molten salt to start flowing out (min)    | 30                 | 29                 | 28.5               |
| Heat storage energy after 160 min (kJ)             | $4.28 \times 10^9$ | $4.79 \times 10^9$ | $5.25 \times 10^9$ |

**Table 3** Summary of Calculation Results of Exothermic Process

|                                                  | Working condition 1 | Working condition 2 | Working condition 3 |
|--------------------------------------------------|---------------------|---------------------|---------------------|
| Initial temperature of molten salt (°C)          | 190                 | 190                 | 190                 |
| Total length of heat exchange tube (m)           | 1214                | 1379                | 1522                |
| Mass flow (kg/s)                                 | 459.5               | 526.4               | 584.9               |
| Flow velocity (m/s)                              | 0.23                | 0.27                | 0.30                |
| 400 min molten salt outlet temperature (°C)      | 266                 | 257                 | 258                 |
| Average temperature of 400 min molten salt (°C)  | 203                 | 201                 | 202                 |
| Average temperature of concrete for 400 min (°C) | 213                 | 211                 | 212                 |
| Time for molten salt to start flowing out (min)  | 98.8                | 98.7                | 98.8                |
| 400 min exothermic energy (kJ)                   | $4.2 \times 10^9$   | $4.78 \times 10^9$  | $5.27 \times 10^9$  |

## 5. Conclusions

In the process of heating the regenerator with molten salt, the hot molten salt fills the regenerator around 30 min, and at this time, the outlet temperature of molten salt starts to rise synchronously, and the solid heating rate reaches its peak around 35 min, and the molten salt heating rate reaches its peak around 94 min. The increase of DNI has little effect on the above data, but the peak time of molten salt heating rate and regenerator heating rate is only delayed slowly, and the starting time of molten salt outlet temperature rises slowly ahead of schedule, which is due to the increase of molten salt flow rate. The process of

heating molten salt by regenerator is more complicated than that of heat storage. Under the conditions of low, medium and high DNI, the outlet temperature of molten salt began to decrease around 150min, and the temperature decrease rate of molten salt began to decrease around 306min, respectively, and the temperature decrease rate of regenerator increased before that, and then the temperatures of molten salt and regenerator decreased steadily. Under the three DNI working conditions, the time for cold molten salt to fill the regenerator is basically the same. With the increase of DNI during the day, the time for the temperature of molten salt at the outlet to start to drop is slightly delayed, but there is a delay of 45~57min between them. This is because the molten salt may be heated to the highest temperature in the middle of the flow, and the system can collect a certain amount of molten salt with constant temperature.

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