# Research on Solar Energy Underground Seasonal Storage Device and Its Parameters Measuring System

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***Abstract*—In order to improve the availability of solar energy, this paper introduces a new solar energy storage device and its parameters automatic measuring system. The device puts the heat which was gathered by synchronous tracking solar collector into underground concrete storage pile. Meanwhile, the system could simultaneously measure the temperature, pressure and flow of the device, etc. Some derived parameters such as thermal energy storage and thermal storage effectiveness can be obtained by calculation. According to the experimental results, the device is able to store the solar energy for seasons in the underground, and automatic measuring system could display the parameters and real-time curves on monitor and draw the history curves of all parameters. The data base of parameters could be built during the energy storage process. Furthermore, the energy storage report can be generated to obtain an automatic and digital energy storage process.**

***Index Terms*—solar energy; underground concrete storage pile; parameters measuring system; configuration software**

## I. INTRODUCTION

With the increasing depletion of conventional energy, humans pay more attention to utilization of renewable resources. As a kind of renewable energy, solar energy is abundant. The research and application of solar energy will be used to deal with alterative energy [1]. But solar irradiation has some disadvantages, such as low energy density, large random and long intermittent [2]. It only can be used effectively through energy storage. In the energy development project which formulated by International Energy Agency (ECES-IA) [3], the energy storage technology was a key development field.

The heating method of long-term underground energy storage combined with heat pump is a very energy-efficient heating mode. Its economic performance is better than some usual heating modes. Thus, it is considered as the most development scheme on long-term energy storage [4-5]. The underground thermal energy storage pile could make full use of underground space; so many countries pay more attention to this technology. Most of existing underground solar energy storage ways make use of artificial underground water tank or underground caverns to store. Because of the restriction of geological conditions, it is difficult to insure the underground thermal insulation and anti-seepage treatment. The loss of energy storage is serious and efficiency is very low [6-8].

For above reasons, a new experimental device of solar energy underground seasonal storage was developed. In the ground, a temperature withstanding concrete pile was built to store solar energy which was gathered by synchronous tracking solar collector, so the solar energy could be stored for seasons. Therefore, the intermediate-low temperature solar energy could be stored in any formation of cold region in summer （or daytime）, then the energy was used to heating supply of the surface buildings in winter （or night）. An energy storage parameters automatic measuring system by means of industrial computer has been also devised. The system can real-timely measure the temperature, pressure and flow of the device, etc. Some derived parameters such as thermal energy storage and thermal storage effectiveness can be obtained by calculation. All the parameters and the real-time curves can be displayed on monitor at the same time. History curves of all the parameters can be drawn by computer automatically. A database of the parameters can be built during the energy storage process. Furthermore, the energy storage report can be generated.

## II. SYSTEM OF UNDERGROUND CONCRETE ENERGY STORAGE PILE

### A. The composition of experimental device

This experimental device is composed by synchronous tracking solar collector, underground concrete energy

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storage pile and parameters automatic measuring system. The overall composition of experimental device is shown in Figure 1.

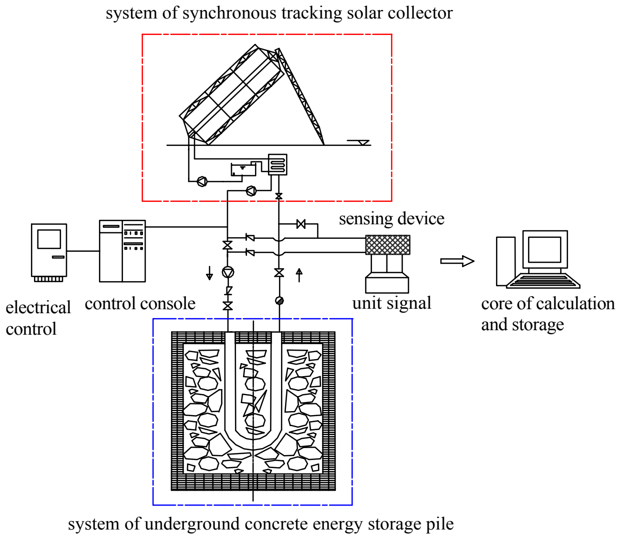



Figure1. The overall composition of experimental device

### B. *The principle of energy storage*

The circulation medium was heated by synchronous tracking solar collector and injected into the heat exchanger which was set in concrete pile with the help of circulation pump. After heat exchanging between the heat exchanger and concrete pile, circulation medium was pumped to synchronous tracking solar collector, so forms the circulation. And then, the solar energy which was gathered by synchronous tracking solar collector was stored constantly in the underground concrete energy storage pile. The circulating principle is shown in Figure 2.

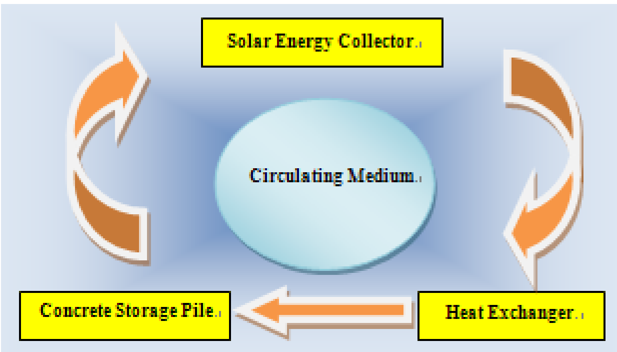



Figure2. The circulating principle of solar energy

## III. THE SYSTEM OF SYNCHRONOUS TRACKING SOLAR COLLECTOR

In order to make use of solar energy effectively and acquire more collector temperature and heat collecting efficiency, it is necessary to improve the energy density and make the solar heat focus on a smaller collector surface, so the focus warhead solar collector is selected. Because any point in the earth varied with the sun, the focus warhead solar collector must be equipped with tracking system. The position of focus warhead solar collector should be adjusted according to position of the sun to ensure the opening surface of the concentrating collector and solar radiation always perpendicularly and the focusing sunlight can be irradiated rightly in the absorption. Therefore, the stable and reliable synchronous tracking device is the core components of solar collector.

The concept of solar visual operation track was introduced into the development of focus warhead synchronous tracking solar collector. In addition, the method of simultaneous linear tracking was proposed. Using the clock function to track the apparent right ascension (hour angle) of the sun trace, adopts modified sine function to track the apparent right ascension (latitude angle) of the sun trace, contacts the clock function with modified sine function by linear transmission chain. By using one electric motor could be achieved the goal of tracing simultaneously, continuously, high precision and low power consumption. The physical graph of synchronous tracking solar collector is shown in Figure 3.

Figure3. The physical graph of synchronous tracking solar collector

The main technical performance parameters are as follows:

(1) Dimension: effective area 17m$^2$ , focal length 1500mm
(2) System capacity: 78.2%（max）
(3) Output power: 11.43kw（max）
(4) Heat transfer medium: transformer oil or ethanediol
(5) Weight: complete appliance 960kg, drive fraction 740Kg
(6) Drive capacity: 8w（DC12V）
(7) Wind resistance capacity: 550N/m$^2$
(8)Anti-corrosion coating: galvanizing by dipping＞60um.

## IV. THE SYSTEM OF UNDERGROUND CONCRETE ENERGY STORAGE PILE

The system mainly consists of concrete energy storage pile, heat exchanger and impermeable insulation layers.

### A. *Concrete energy storage pile*

According to the design requirements of solar energy storage, acuminate cement [9-10], gravel-cobble and quartz sand are selected to prepare the concrete, which maximum heat resistant temperature is up to 1300□. Graphite powder and activated carbon aggregate are mix in it to enlarge thermal conductivity and specific heat capacity. Addition amount is respectively 4% and 6%. The preparation flow is shown in Figure 4.

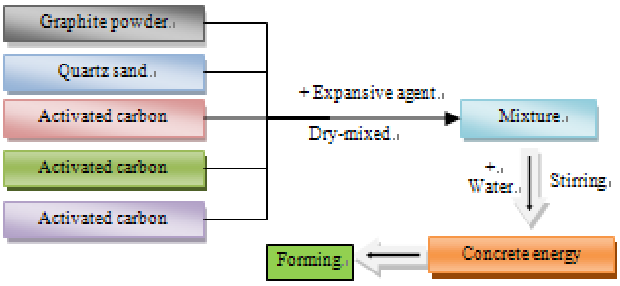



Figure4. The preparation flow of Concrete

The main parameters of underground concrete energy storage pile are: diameter 2m, height 25m, density 2320 kg/ m$^3$, specific heat capacity 3700 J/（kg·℃）, thermal conductivity 2.2 W/（m·℃）. According to the principle of energy storage and specific heat definition [11], the thermal calculation of concrete pile is as follows:

$$Q = \int_{T_1}^{T_2} C_P \gamma dT \tag{1}$$

Where,

Q——heat storage per unit volume, (KJ/ m$^3$);

T ——temperature, (℃);

Cp——specific heat capacity of heat retainer, (J/(Kg·℃));

Γ——specific gravity of heat retainer, (Kg/ m$^3$)

Strictly speaking, Cp and γ are functions of temperature, but during simple calculation, they are regarded as constant in the temperature range of heat retainer. Therefore, the above formula changes:

$$Q = C_p \gamma \Delta T \tag{2}$$

Where, △T——temperature difference of heat retainer

The underground average temperature of stratum in Changchun is about 8℃. The concrete energy storage pile was heated to 88 ℃; temperature difference was 80℃, so the concrete pile could storage 5.39×10$^7$KJ.

### B. The heat exchange

Galvanized iron pipes with a diameter of 25mm were used to make heat exchanger, which is single-U form.

### C. The impermeable insulation layers

Seepage control and thermal insulation are closely related to the quality of underground heat storage. The thermal conductivity of polyurethane is less than 0.025w/mk. As good results of thermal insulation and anti-seepage, polyurethane was selected to material of impermeable insulation layers. According to the design guidelines of equipment and piping insulation, the economical thickness is 20cm.

## V. THE ENERGY STORAGE PARAMETERS MEASURING SYSTEM

### A. Automatic control system

#### 1) Solar energy collector system

Solar energy collector system [12-13] is mainly to ensure that synchronization tracking device and circulating pump automatically switch the appropriate state of operation according to the different conditions and pipe temperature. The controlling principle diagram is shown in Figure 5.

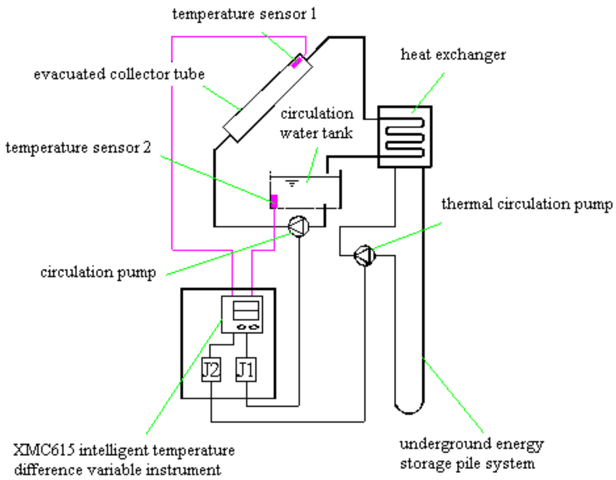



Figure5. The controlling principle of solar energy collector system

The main function of control system is as follows:

Manual controls the synchronous tracking device and circulating water pump running.

According to the data of the two temperature sensors, to estimate the sunshine conditions of the day, the circulating pump automatically started to work when sunshine, if not it closed.

According to the temperature of circulation water tank, the running state of thermal circulation pump was switched automatically.

When the circulating water pump failure to work or the temperature of circulating pipe was too high due to gas, the running state of synchronization tracking device would be switched automatically to making evacuated collector tube avoiding the focusing spot.

#### 2) Underground concrete energy storage pile controlling system

With a view to making the whole device to work automatically and switch the different state between solar energy collector system and underground concrete energy storage pile system, two relative independent console were set to the sub-systems. The physical graph of underground energy storage system is shown in Figure 6.


Figure6. The physical graph of underground energy storage system

### *B. Automatic measuring system of energy storage parameters*

The automatic measuring system of experimental device collects circulation line temperature, pressure and flow. Then, these parameters will be sent to the core of control and data calculation and storage though signal processing unit [14]. And heat storage and thermal storage power can be obtained by calculation.

*1) Signal acquisition*

Sensors and transmitters that include temperature sensor, flow transducer and pressure transmitters are used to collect the energy storage parameters.

*a) Temperature measurement*

The experimental device needs to detect the temperature of circulation medium, the internal temperature of concrete energy storage pile and the external temperature of soil. The sensors would work in poor conditions for long time and need to withstand a certain formation pressure. Thus, pt100 platinum resistance temperature sensors as using of special processing were selected [15-16]. After the whole armor and waterproof treatment of the sensor probe and traverse, it reduced the impact of external factors effectively and prolonged the service life of sensors. The range of temperature is 0～150□, measurement accuracy is 0.2%, the output signal is 4 mA. The temperature measuring points of underground concrete energy storage pile include: circulating water temperature of internal and external pile, pile center, pile edge, the edge insulating layer and soil. The measurement point position temperature is as shown in Figure 7.

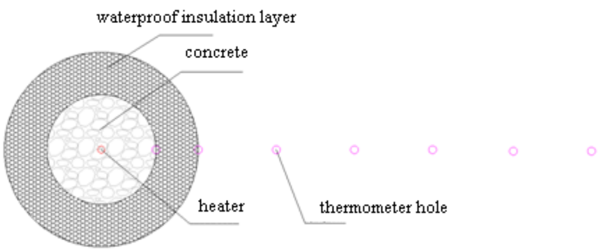



Figure7. The measurement point position temperature

*b) Flow measurement*

The experimental device required small flow and flow stability. Therefore, the type of LRS25-6 turbocharged pump was selected, which capacity is 46/67/100W, work temperature is 0～150□, maximum flow is 60 L/min.

*c) Pressure measurement*

Pressure transmitter of JYB-KO-HAG-T type is adopted in the pressure measurement. Its supply voltage is 12～24V DC, and measuring range is 0～5MPa. Its output signal is electric current signal of 4～20mA DC. This kind of signal has advantages of strong anti-interference ability, and non-attenuation. And its signal quality will be not influenced by length of conducting wire. The measuring accuracy of this transmitter is 0.5%, working temperature range is -20～+85℃.

*2) Signal processing unit*

The parameters signals are sent to the signal processing unit to be made signal conditioning and analog-digital conversion after signal acquisition. Because the signals are standard direct current signals, the signal conditioning circuit converts the electric current signal into voltage signal, and filters the wave only. And then the signals will be sent to analog-digital conversion module. The module is industrial level equipment. It has advantages of reasonable interface and strong anti-interference ability. It communicates with the core of control and data calculation and storage though RS485 serial port interface. The performance of the module is stable and reliable.

*3) Core of control and data calculation and storage*

In order to meets the requirements of underground energy storage experiment, of which the environmental condition is terrible for electronic equipment, industrial computer is adopted as the core of control and data calculation and storage. Its anti-shake performance is excellent. And it has strong ability to restrain electromagnetic interference of power supply equipment and motors. The industrial computer's system integration technique is perfect. They become the key technologies of industrial computer which are integration of control software, optimization software and soft-sensing technique, and integration of functions of measurement, control, scheduling, management and decision-making et al [17-19]. Moreover, industrial computer can be installed various configuration software which can be programmed to realize functions of monitoring changing situation of the parameters, drawing real-time and history curve diagram, generating data report, and saving data.

## VI. NUMERICAL SIMULATION ON HEAT STORAGE OF UNDERGROUND CONCRETE PILE

### *A. Heat-transfer model of the heat exchanger*

*1) Model assumed conditions*

During the period of energy storage, the circulation medium carried on heat exchange with surrounding concrete though the wall of heat exchanger. This was a 3 D unsteady heat transfer process. Because of complex influencing factors, it was difficult to solve exactly by using analytical method. In order to obtain the heat-transfer model conveniently, the finite element method was used to numerical simulate. The assumed conditions were as followed:

a) Neglected vertical direction, the heat-transfer model was simplified as two-dimensional.

b) The thermal properties of concrete, insulation layer and formation were uniform and not changed along with the temperature and depth.

c) In the entire solution region, the initial temperature of heat exchanger, concrete, insulation layer and formation was the same, and it was not changed along with the depth.

d) Neglected the influence of surface temperature.

*2) Physical model*

The physical model of double U heat exchanger was shown in Figure 8. In the entire solution region, there were concrete, heat exchanger and formation from inside to outside. The radius of soil solved region was far boundary radius. Based on the far boundary theory which was proposed by Bose in 1984, it could obtain that:

$$R_\infty \geq 4\sqrt{a_s t} \tag{3}$$

The far boundary radius was thermal influence radius in t time. Its temperature maintains invariable before t time, so it is initial temperature.

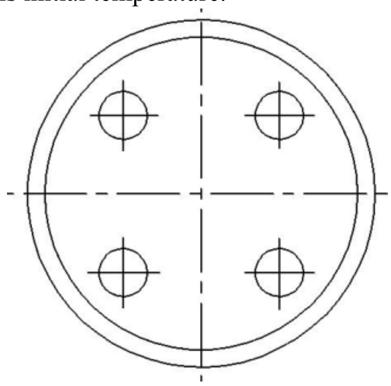


Figure8. Physical model of double U heat exchanger

*3) Mathematical model*

According to the assumed conditions, the heat conduction differential equation between exine of heat exchanger and concrete was:

$$\frac{\partial T_g}{\partial t} = \frac{\lambda_g}{\rho_g c_g}\left(\frac{\partial^2 T_g}{\partial r^2} + \frac{1}{r}\frac{\partial T_g}{\partial r}\right) \left(r_e \leq r \leq r_b\right) \tag{4}$$

Where,

$T_g$ —— transient temperature of concrete (℃)

$\lambda_g$ ——thermal conductivity of concrete pile (W/m k)

$\rho_g$ ——density of concrete pile (kg/m$^3$)

$c_g$ ——specific heat capacity of concrete pile (kj/kg.℃).

$r_e$ —— radius of single buried pipe (m)

$r_b$ —— radius of concrete pile (m)

*4) Initial and boundary conditions*

*a) Initial temperature*

According to the assumed conditions of model, the initial temperature of concrete pile was used as initial temperature of solved region.

$$T\big|_{t=0} = T_\infty \tag{5}$$

*b) Heat flux of pipe wall was fixed value*

Neglected the influence of cycling medium, heating power Q was approximately regarded as to exert uniformly on entire inner wall of heat exchanger. And the average temperature of inner wall was equal to that of cycling medium.

$$Q = -\lambda_s \frac{\partial T}{\partial n}\bigg|_\Gamma \tag{6}$$

Where,

n——normal unit vector of isotherm of passing through the point

Γ——Object boundary, inner wall of heat exchanger in this model

c) *The initial temperature of border soil kept invariant*

Exterior boundary of solved region was adiabatic. It was not influenced by internal heat flow, so its temperature was equal to initial temperature of soil.

$$T\big|_{r=r\infty} = T_\infty \tag{7}$$

## *B. ANSYS numerical simulation analysis*

This paper simulated the underground heat transfer of concrete pile by using ANSYS finite element method. ANSYS is a multipurpose computer analysis program, and particularly applied to heat conduction which had certain shape and boundary conditions.

*1) Model selection and mesh generation*

The unit type of model was quadrilateral unit, which was used for modeling of two-dimensional heat conduction. Each node of unit has only one degree of freedom, and that is temperature. The heat flow could be regarded as surface load input of unit. The output data of unit included node temperature and unit data. In order to control mesh quality, the precision setting was 3 and the maximum control side length of mesh was 0.2 meter. With a view to using computer resource reasonably and having no influence on calculation accuracy, the mesh was divided closely in interior region of concrete pile, while the thick mesh by way of proportional division was selected in surrounding soil.

2) Thermophysical parameters

The numerical simulation based on physical parameters of double U heat exchanger. In the entire solution region, there were concrete, heat exchanger and formation from inside to outside. Their thermal physical parameters were shown in table 1.

TABLE I.
SOME THERMAL PHYSICAL PARAMETERS

| | Thermal conductivity W/(m k) | Specific heat capacity kJ/（kg℃） | Density kg/m$^3$ |
|---|---|---|---|
| Concrete pile | 1.5 | 1150 | 2100 |
| Insulating layer | 0.022 | 1100 | 50 |
| soil | 1.2 | 1200 | 1400 |

*3) Simulation and analysis*

Simulated conditions: the diameter of concrete piles was 1 meter; the inner diameter of heat exchanger was 0.025 meter; the thickness of insulating layer was 0.01 meter; the average heat flux of the solar energy collector approximately is 40 W/m; the flow of circulating medium was 0.55m$^3$/h. The efficient period for heating underground concrete piles with the energy collecting from solar power collector was 8 hours each day; also it stopped heating the piles during the other time of the day. The system kept heating back and forth for 120h.

The Figure 9 and Figure 10 shows the changes of heating and energy storing assorting with the temporal variation. From the figures, we can see that the highest temperature is at where the solar energy collector is and the further away from the center the lower the temperature it is. The Figure 11 shows the temperature changes of the center, the edge of concrete pile and insulating layer as the time goes on. From the picture we can see that when the temperature of piles rises to 43 ℃, the temperature of center is higher than the edge area, and also because the heat is transferred from the center to the edge area, so the temperature between the center area and the edge area is getting closer and closer until the temperature is the same. As the insulating layer wasn't absolutely insulating the transfer of energy, the diffusion of heat will slowly get through the insulation, however, as the temperature getting lower, the speed of diffusion gets slower as well. Here we can get a conclusion that underground concrete can store significant amount of heat energy, and also is able to store the energy for a long period.

With the numerical simulation of the underground heat transfer of concrete pile by using ANSYS finite element method, we can get the conclusions:

a) With setting of concrete piles storing heat energy is possible from the aspect of theories, the underground create pile not only stored heat energy effectively, but also made full use of underground space.

b) During the progress of storing energy, the temperature field is uneven between the energy carrier and concrete piles, it is unstable.

c) The further away from the center the lower the temperature it is.

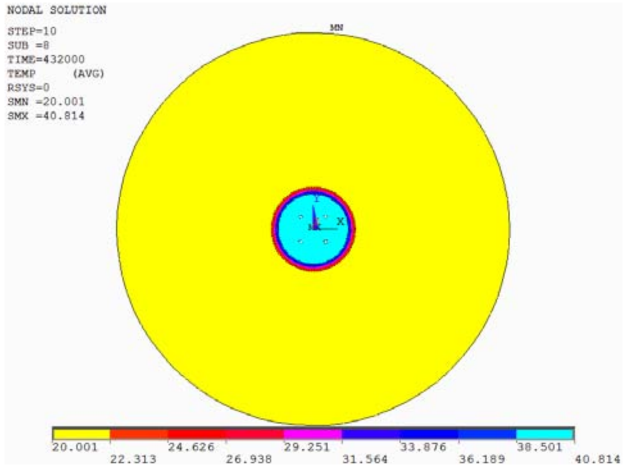



Figure9. The temperature simulation in heating stage

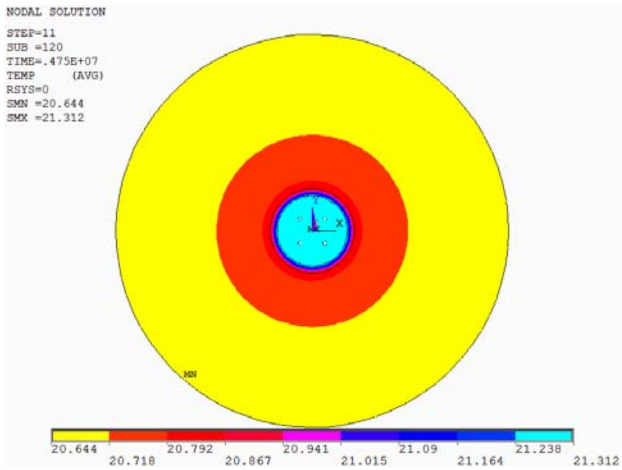
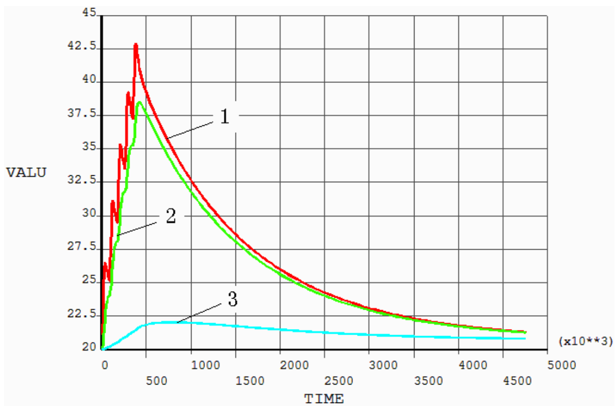



Figure10. The temperature simulation in heating storage




1- temperature in the center of concrete pile;
2- temperature at the edge of concrete pile;
3- temperature of insulating layer

Figure11. The cure of temperature simulation of concrete pile

## VII. SOLAR ENERGY UNDERGROUND SEASONAL STORAGE EXPERIMENTS

After completing the experimental device, the solar energy underground seasonal storage experiment has been carried out. The automatic measuring system of experimental device collects circulation line temperature, pressure and flow, drawing real-time and history curve diagram, generating data report, and saving data. The real-time display picture is shown in Figure12, and historical data display and report picture is shown in Figure13. The heat storage of underground concrete pile is $5.2\times10^{7}$KJ and thermal transfer efficiency of synchronous tracking solar collector is 65% by calculation.

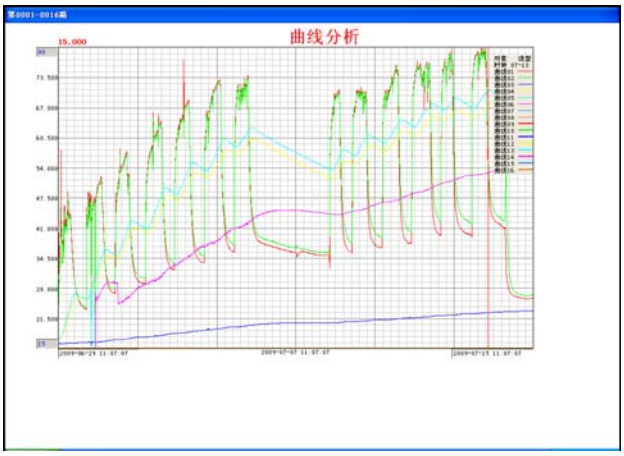



Figure12. The real-time display picture

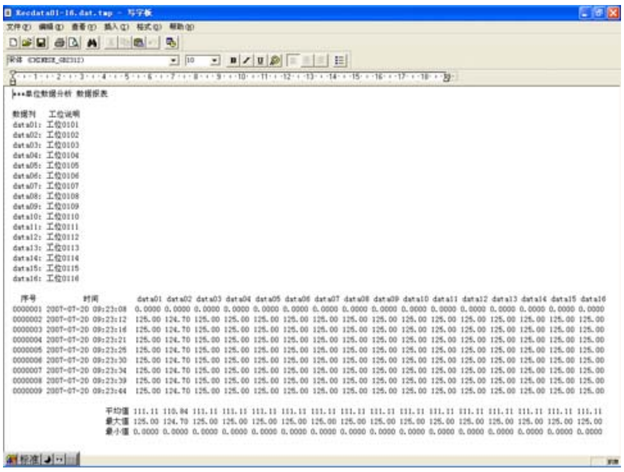


Figure13. The historical data display and report picture

## VIII. Conclusions and Recommendations

In this work, some import conclusions can be made. The main conclusions are listed below.

1) The experimental device provides a new method of underground solar energy storage technology. It is beneficial to give full play to the source of advantage and the use of underground space. It provides a new heating mode for north area. In addition, it receives good economic and social benefits from reducing pollution and carbon dioxide.

*2)* Through the development of this device, it can solve the key technical issue of current underground solar energy storage. Meanwhile, the combination of advanced measurement and control technology obtains an automatic and digital energy storage process.

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