Design and Research of a New Type of Solar Energy Heat Collection and Heat Exchange System Based on Oil-water Graded Heat Conduction

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Abstract. A low-carbon society and a low-carbon economy have become a new target for development. In China, construction, industry, and transportation energy consumption take up the major role in the overall energy consumption. In addition, the present heating technology has a low efficiency with large coal consumption and heavy damage to the environment and damage. Investigation shows that northern China boasts rich solar energy resource, making it suitable for promoting solar heating system, which can bring better economic and social benefits. Research found out a new solar heat collection and exchange system based on oil-water grading heat conduction. It can effectively reduce the conventional energy consumption of the building to achieve low carbonization and even zero energy consumption.

1. Preface
Solar energy, as an important clean energy source, is becoming increasingly important in heating northern China as treating pollution, changing energy structure, and ecological civilization are advocated nowadays. However, the current hot water heating system using solar heating are mainly traditional solar collector system with water as the heat collecting medium, which has the problems such as low efficiency, easy evaporation, easy freezing, easy blocking in the vacuum tube, leakage, pipe corrosion, complicated circulation lines, and poor stability. Faced with those, this paper proposes a new type of solar heat collection and exchange device and designs a new solar heat collection and exchange system based on oil-water grading and heat conduction by using the heat transfer oil with high heat transfer efficiency, fast heat dissipation and high thermal stability as the heat transfer medium.

2. Idea of the new solar heat collection and exchange system based on oil-water grading and heat conduction
This system is mainly composed of two subsystems: solar collector system and oil-water heat exchange and temperature control system, which helps to realize the application of solar energy in the heating system, further improve the solar-thermal energy conversion efficiency, which is favorable for combining and upgrading various low-carbon or zero-carbon heat sources.

The solar collector system absorbs solar energy and heats the heat-conducting oil to provide heat energy to the system. Then, it transmits the heat energy to the oil-water heat exchange and temperature control system for heat exchange and temperature control. In this way, the heat-conducting medium
can efficiently and stably collect, conduct, and dissipate heat in the sealed pipeline circulation system, thereby meeting the needs of heating through the water system.

Figure 1. Composition diagram of a new type of solar energy heat collection and heat exchange system based on oil-water fractional heat conduction

Figure 2. Schematic diagram of a new type of solar heat collection and heat exchange system based on oil-water fractional heat conduction

3. Structural design of the new solar heat collection and exchange system based on oil-water grading and heat conduction

3.1. Solar collector system
This system uses solar energy as a heat source and maximizes its utilization by adopting parabolic trough, solar tracking technology, new heat collecting tube and application of heat transfer oil self-circulation technology.

3.1.1. Design of parabolic trough reflector
The focal line of the parabolic trough is on the same line as the axis of the heat collecting tube. The reflector can concentrate the parallel beams of the sun on the heat collecting tube to maximize its utilization. Its structure is shown in the following figure.
3.1.2. Design of collector circulatory system
It includes two aspects. First, natural circulation system which works by the density difference caused by the temperature difference of the heat transfer medium. Oil temperature monitoring is adopted to ensure a stable hot oil temperature. Second, mechanical circulation system which is relied on the mechanical power of the circulating oil pump to force the oil to circulate in the collector. The two are combined in application to satisfy different working conditions.

3.1.3. Design of tracking system
The tracking system has the following characteristics. First, it adopts single-axis tracking design scheme, making it simple and easy to install. Second, it adopts north-south horizontal axis tracking, north-south axis tracking, and east-west horizontal axis tracking, which can be used to maximize the utilization of solar energy in different seasons and regions.
3.2. Oil-water heat exchange and temperature control system

This system takes the oil-water heat exchanger as the main body, and adds an auxiliary heat device and an energy storage box to ensure a stable heat supply. The oil-water heat exchanger adopts tubular heat exchange method to maximize the heat exchange efficiency. Meantime, it uses auxiliary heating device and energy storage box to control temperature.

3.2.1. Design of oil-water heat exchanger

Its design should be based on the functions of oil-water heat exchange, temperature control, and energy storage. The layout design is shown in the following figure.

The heat transfer oil from the solar collector is sent to the heat exchange station and is divided into two or three parts by the oil separation cylinder. The first part produces 65 °C hot water for shower through two volumetric oil-water heat exchangers; the second part produces 95 °C/70 °C hot water as heating medium through two semi-instantaneous oil-water heat exchangers. An electric three-way split regulating valve is arranged on the oil inlet pipe of the heating heat exchanger to control outlet water temperature by adjusting the ratio of the amount of oil entering the heat exchanger to that of bypass oil.
At the same time, an auxiliary heating system at the outlet can also help with temperature control. If there is long-time direct sunlight and the energy of heat transfer oil can meet the requirements of the first two parts, then use the third part of the oil to produce 95 °C/90 °C hot water through a water-oil heat exchanger as the energy stored in the outside tank.

3.2.2. Design of oil-water heat exchanger
The geometric model based on the oil-water tubular heat exchanger structure commonly used in engineering is initially established, as is shown in Figure 8.

![Figure 8: Geometric model of oil-water cooled tubular heat exchanger](image)

1 Head; 2 Cooling water inlet; 3 High temperature oil inlet; 4 Cylinder; 5 Bundles; 6 Tube plate; 7 Folding; 8 Cooling water outlet;

The heat exchanger is made of 6063 aluminum alloy with cooling water in the tube and lubricating oil on the shell pass. There are 10 heat exchange tubes in total, which are arranged into an equilateral triangle. For other geometric parameters, see Table 1.

| Shell diameter | Tube pitch | Diameter of inlet and outlet |
|---------------|------------|------------------------------|
| 159           | 32         | 19                           |
|               |            | 750                          |
|               |            | 40                           |
|               |            | 35                           |

The heat exchanger parameters are calculated as follows:

1. Amount of heat transfer Q:
   \[ Q = W \times C_p \times (T_1 - T_2) \]

2. Effective heat transfer temperature difference \( \Delta T \); logarithmic mean temperature difference \( \Delta t_m \):
   \[ \Delta t_m = \frac{\ln((T_1 - t_2) - (T_2 - t_1))}{\ln(T_1 - T_2)} \]
   \[ \Delta t_m = \frac{\ln((T_1 - t_2) - (T_2 - t_1))}{\ln(T_1 - T_2)} \]

3. Set the total heat transfer coefficient \( K \) and the required heat transfer area \( A \) based on the nature of the heat exchanger and the process conditions:
   \[ A = \frac{Q}{\Delta T \times K} \]

3.2.3. Design of auxiliary heating system
It has two temperature sensors. When the solar energy is insufficient, the sensor on the solar panel allows the A primary and secondary coils to work, and closes switch 1; when the water is not hot enough, the other sensor allows the B primary and secondary coils to work, and closes switch 2. With switch 1 and switch 2, the electric heater power switch is turned on and the single-chip control action is effective. The auxiliary electric heating controller is composed of a temperature detecting circuit, a
signal conditioning circuit, an A/D conversion circuit and a singlechip, as shown in Figure 9. Its working principle is as follows: convert the temperature measured by the temperature sensor into an electrical signal; amplify it using the signal conditioning circuit; convert it into the digital signal using the A/D conversion circuit and send it to the singlechip; the singlechip judge whether or not to turn on the auxiliary heater by comparing the signal with the preset temperature; display the temperature on LED in real time.

![Figure 9. Overall design block diagram of the system](image)

### 3.2.4. Design of energy storage tank

A new solar stratified tank is adopted in this paper, as is shown in Figure 10. Hot water from the oil-water heat exchange station enters the water tank from the top of the right side and enters the middle and left chambers through the diversion trench formed by the heat-insulating partition. The left outlet re-pumps the returned low-temperature water to the oil-water heat exchange station, while the right outlet delivers the high-temperature water to the user. The diversion trench introduces the water at the bottom of each chamber into the top of the next chamber, forming respective layers of water, thereby improving the energy utilization.

![Figure 10. Schematic diagram of layered solar water tank structure](image)
4. Conclusion
Recent years have seen the rapid development of fossil fuels and the development of new energy. Nowadays, solar heat collection and exchange technology has gradually replaced the traditional heat collecting technology. Together with the oil-water grading heat transfer technology, achievements will be made in energy conservation and emission reduction.

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