DESIGN AND PERFORMANCE ANALYSIS OF A HEAT PUMP SYSTEM FOR MOTOR PHASE CHANGE THERMAL STORAGE

by

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Along with the rapid economic development and social progress, the problem of energy and environment is becoming more and more outstanding. Therefore, it is very important to use new energy saving techniques to increase energy consumption and reduce energy consumption. In this paper, we have developed a hot water system, which is based on solar energy technology, gas-source heat pump, and phase change energy storage technology. The system was designed and constructed, and its performance was tested in various control conditions, with an emphasis on the analysis of the influence of phase change heat supply on heat storage properties. In this paper, the effect of the heat storage property is analyzed. Studies have shown that compared to a conventional tank that does not have a phase change heat storage device, the heat storage tanks equipped with phase change energy storage devices have longer discharge time, higher discharge temperature, better temperature, and better operation efficiency. In addition, the data show that flow rate control is also an important factor in optimizing the thermal storage characteristics of the system.

Key words: *motor phase change thermal storage, heat pump system, performance analysis, solar energy*

Introduction

Entering the 21st century, the global population and economic scale continue to expand, and the economy and society are developing rapidly. Energy, as a driving force for human social progress and development, has been widely applied [1]. With the increasing depletion of global non-renewable resource, the destruction of the ecological environment, environmental pollution and other problems, the contradiction between energy supply and demand is extremely prominent. At the same time, the problems caused by the utilization mode and utilization rate of energy pose serious challenges to the way of human survival and economic development. At present, the domestic society is in the stage of industrialization transition, the rapid growth of the economic scale and the increasing energy consumption of residents need to consume a large amount of primary energy, and the relationship between energy supply and demand has also had an important impact on social and economic development [2]. China's energy structure has been dominated by coal for a long time. The proportion of coal in the production and consumption of primary energy in China has been around 70% for a long time, of which 76% of the energy consumption of fuel power generation, 70% of the energy consumption of steel industry, 80% of the energy consumption of civil use, and 60% of the chemical fuel all come

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from coal. The total domestic coal consumption in 2007 was 2.51 billionns, an increase of 8% compared to 2006, and a year-on-year decrease of 0.1% in growth rate. Since 2005, China's real industrial economy has entered a rapid development track, resulting in an annual growth rate of 8% in coal consumption. It is expected that by the mid-20th century, China's total energy consumption will reach 3-3.75 billionns of standard coal, accounting for about 20% of the world's total. Traditional fossil fuels generate a large amount of pollutants during their extraction, transportation, and utilization, posing a serious threat to air, groundwater resources, and the ecological environment. In China, coal smoke pollution caused by coal combustion is the main cause of severe atmospheric pollution, about 80% of the pollutants discharged into the atmosphere every year are soot, 87% of SO_2 and 67% of NO_x from the combustion of coal. The massive emission of pollutants will further lead to serious environmental pollution problems, such as acid rain, summer smog, nationwide haze weather*, etc.* in recent years [3, 4]. In view of the aforementioned two major issues of energy and environment, saving existing resources, developing new energy and improving the utilization efficiency of primary energy are the development trends in the global energy field today. According to China's existing energy structure, coal will still be dominant in the medium to long term. Therefore, the development of China's energy structure must be based on reality and adhere to sustainable development strategies. Heat pump is a technology that can extract energy from low grade sources into high grade energy, such as the large amount of low grade thermal energy present in natural air, water, or soil. By consuming a certain amount of electrical energy through the heat pump, people can provide the high quality thermal energy they need. Taking the steam compression heat pump cycle system as an example, briefly introduce the working principle of the heat pump [5]. Its working principle: The evaporator absorbs heat from surrounding environment and transforms it into refrigerant, while the vapor refrigerant is compressed into high temperature and high gas by the compressor. Then, it condenses and exchanges heat with water in a heat tank through a condenser, and undergoes secondary transformation become a liquid. Finally, it returns to the evaporator through the expansion valve, and this process is repeated in a cyclic manner. The working principle of the heat pump is the same as that of the air conditioner. Both accord with the principle of reversing Carnot cycle, but their operation temperature is different. With the increase of population and public housing in China, heat consumption has been increasing year by year. According to surveys, building energy consumption accounts for about 30% of China's total energy consumption, and the energy consumption of hot water supply in building energy consumption is as high as 20%. In recent years, the solar heat pump complex system has been a hotspot in the field of heating technology. The system is a combination of the heat pump and the solar energy technology, and the combination of the advantages and disadvantages of the two technologies is solved. On the basis of the technology of solar energy heat pump and phase change energy storage, a solar energy gas source heat pump with energy storage is designed.

Methods

System design and working principles

The purpose of the heat storage solar heat pump is to supply hot water to S small or independent buildings, with a standard daily water consumption of 1 ton. The system uses the non-direct-current expansion solar air source heat pump. The system is made up of solar energy collecting module, air source heat pump module, and heat storage water tank module [6]. The system consists of three types of heat exchangers, and the specific process is shown in fig. 1 [7].

The heat box includes two heat sources: heat source and phase change heat source. The phase selective thermal storage material (PCM) is a composite organic phase transfer ma-

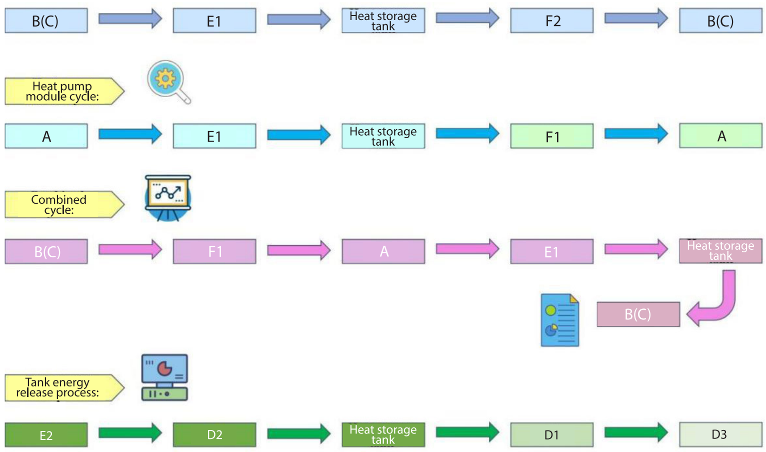

Figure 1. Process of different operation modes

terial, and its thermophysical properties are shown in tab. 1. At present, the mature packaging technology in the domestic market is to encapsulate thermal storage materials using capsules. Therefore, the author uses this technology to package the energy storage materials into approximately spherical shapes, with a total of 43 pieces laid flat on perforated shelves one-third of the distance from the bottom of the thermal storage tank.

Table 1. Thermophysical parameters of phase change energy storage materials

Latent heat [kJkg^{-1}]	Specific heat capacity [kJkg^{-1}K^{-1}]	Thermal conductivity [Wm^{-1}K^{-1}]	Phase transition temperature [°C]	Density [kgm^{-3}]
164.5	2.719	0.8	48-52	1520

System thermal evaluation indicators

Heat pump efficiency (COP) is the main evaluation index of heat pump, and the COP of this system is:

$$COP = \frac{Q_k}{W} \tag{1}$$

where Q_k is the heat generated by the heat pump and W – the power consumption of the heat pump. A collector is the heart of a solar module, and its performance determines the quality of a hot water system. Instantaneous efficiency can be used as its evaluation indicator, and its instantaneous efficiency can be expressed as:

$$\eta = \eta_0 - UT^* = \frac{\eta_0 - U\left(t_a - t_e\right)}{G} \tag{2}$$

where η_0 is the instantaneous efficiency intercept, reflecting the heat absorption efficiency of the collector under zero heat dissipation, U [Wm^{-2}°C^{-1}] – the total heat loss coefficient, which reflects the collector's average heat transfer coefficient to the surrounding air, T^* [m^2°CW^{-1}] – the normalized temperature difference, t_a [°C] – the inlet temperature of the working fluid of the collector, t_e [°C] – the ambient temperature, and G [Wm^{-2}] – the solar irradiance. According to eq. (2), when selecting the collector, η_0 and U are determined, and their instantaneous efficiency is linearly related to T^*. The heat storage tank module is an important component of the experiment, and the main measuring parameters are the heat discharge rate and the inclined heat flow. During the energy release phase, the water in the tank is mixed with the cold water, and the temperature changes at the exit and interior are recorded by measuring points. This project is an actual engineering project that is closely related to the user's experience. Therefore, attention should be paid to the continuous discharge of hot water exceeding 45 °C from the energy storage tank. The hot water discharge rate is defined as the ratio of the effective use of hot water volume V_u to the total volume V_{tank} of the tank:

$$\eta_V = \frac{V_u}{V_{\text{tank}}} \tag{3}$$

During the heat release process of the heat storage tank, due to the difference in density between cold water and hot water, a state of upper heat and lower heat will be formed, and the area with temperature changes in the middle range is the inclined temperature layer. In practical applications, the thinner the inclined temperature layer, the greater the temperature change within its range, and the better the layering situation. Conversely, the greater the mixing effect of water, and the worse the layering.

Operation results and data analysis

Operation of solar modules and heat pump modules

Select typical spring climate days in A city for experiments, and study the overall performance of each module and system using three operating modes [8]. According to the actual engineering situation, the solar module selects a vacuum tube collector for testing to test the daily heat collection efficiency of the vacuum tube collector. Select a cloudy day as the testing day, and the system will be connected to municipal water with a circulating water volume of 19 Lpm. The experiment time lasted from 12:40 p. m. to 16:05 p. m., when the irradiance was the highest. The change curve of the solar irradiance on that day was recorded as shown in fig. 2. The test ambient temperature was maintained at about 22 °C. The heat collection efficiency curve in fig. 3 is obtained from eq. (2). Thus, the variation of solar irradiance is similar to that of the Sun, with a maximum of 0.61 and then a gradual decline.

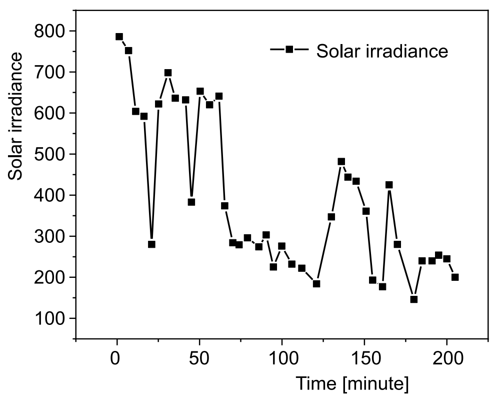

Figure 2. Solar irradiance

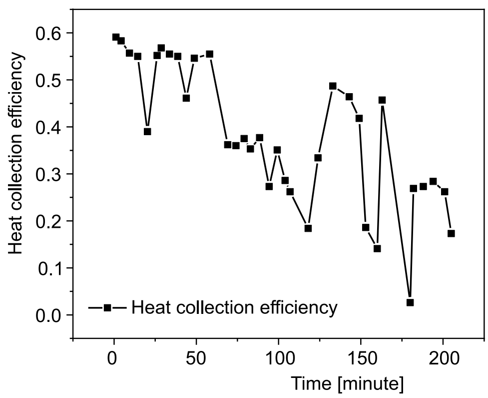

Figure 3. Collector heat collection efficiency

In the unfavourable weather (such as rain, fog, night, *etc.*) and low temperature conditions, heat pump can be used separately to provide hot water. Select a cloud day for heat pump and energy storage tank module test date. Circulating pump flow rate is 26.5 Lpm. The inlet and outlet temperature of the heat pump after cycle heating is shown in fig. 4.

From fig. 4, it can be seen that the heat transfer temperature difference of the heat pump is normal around 8 °C. The maximum outlet temperature can reach 61.79 °C, and after about 155 minutes, the heat exchanger reaches the temperature of 55 °C. When the solar module and heat pump module are combined for operation, the solar module is first used to increase the temperature of the water tank, and then the heat pump module takes over the operation and fills the energy storage tank with hot water. First, according to the user's use behavior, add water to the solar module and fix it for 2 hours. Cycle and begin to heat the water in the energy reservoir at 30 °C. Total time is 31.5 minutes. Then, shut down the solar module, turn on the heat pump, and heat it up to 55 °C.

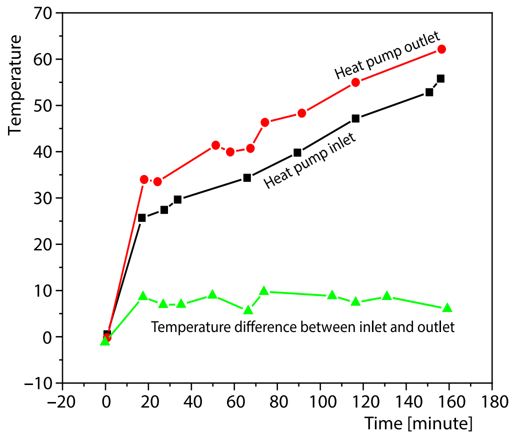

Figure 4. Heat pump inlet and outlet temperature

Operation of the heat storage water tank module

Add PCM to the heater box, set the temperature, and calibrate it every 15 meters. From the first layer to the tenth layer, there are all 10 layers from the top down. The water tank is filled with urban water, and then the heat pump is turned on heat the water in the tank. When the water tank temperature reaches 55.9 °C, the heat pump is shut down, and the water cooler is turned on. The heating rate is 10 Lpm, and the initial heat release property of the heater up to the exit temperature the water heater's temperature is equal to that of the outcome. During this time, the water tank's inlet and outlet temperature should be recorded every 5 minutes. Under the same experimental conditions, the PCM free heat storage water tank and the PCM equipped heat storage water tank with a makeup flow rate of 13.4 Lpm were tested and compared with the original test. The variation of the temperature within the tank is illustrated in figs. 5-7. From figs. 5-7, the continuous hot water discharge time of the PCM free-water tank

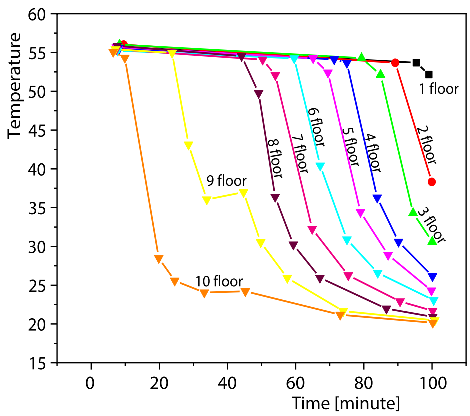

Figure 5. Shows the temperature change curve inside the heat storage tank with PCM 10 Lpm

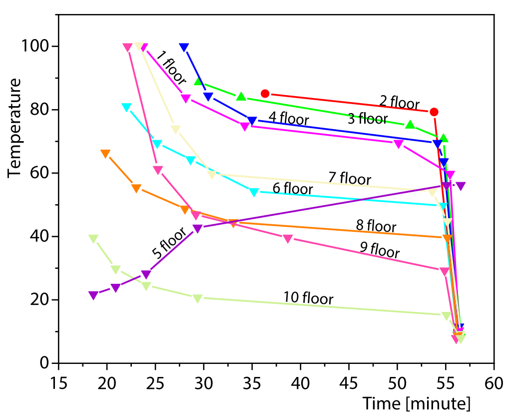

Figure 6. Internal temperature change curve of heat storage tank without PCM 10 Lpm

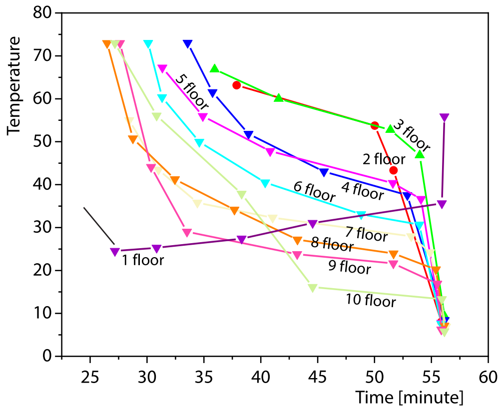

Figure 7. Shows the temperature change curve inside the heat storage tank with PCM 13.4 Lpm

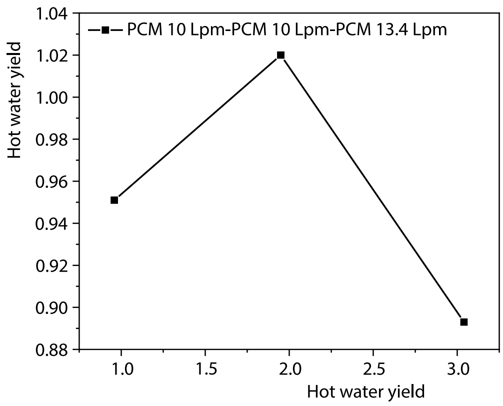

Figure 8. Hot water discharge rate

is reduced in comparison with that of the PCM. There is an obvious heat release in the vicinity of the PCM layer of the PCM free water tank, which releases heat and accelerates the temperature mixing state near that time. However, overall, its performance is improved compared to a PCM free water tank. Under high flow conditions, the performance of the PCM water tank is the worst, and the continuous hot water discharge time is significantly reduced to within 70 minutes, resulting in good mixing effect. It can be seen that in addition adding energy storage materials to optimize the performance of the unit, further optimization is also needed for flow control.

In engineering applications, users are most concerned about whether there is a continuous hot water supply, so the hot water output rate is the most important indicator in practical applications. According to national standards, this indicator is defined as the continuous output of hot water above 45 °C, according to eq. (3), the hot water yield under three different operating conditions can be calculated as shown in fig. 8. According to the temperature changes of each layer during the energy release process, the hot water yield under each operating condition reaches over 80%. The addition of PCM is of great help for the supply of hot water. Under the same low flow condition, the hot water yield of a PCM water tank can be increased by 8.33% compared to a PCM water tank, but under the high flow condition, the temperature stratification during the energy release stage is poor, the hot water output rate has also significantly decreased.

The indicator of inclined temperature layer reflects the quality of the stratification effect in the heat release process of the water tank. In theory, a water tank with excellent stratification state can produce more hot water than a water tank with good mixing effect [9, 10]. From the temperature contour maps at various times, it can be seen that the distribution status of the inclined temperature layer is generally the smallest during the heat release process of PCM water tanks with low flow rates, while the distribution status of the inclined temperature layer is larger under high flow rates. The inclined temperature layer in the PCM free water tank gradually increases, indicating that the temperature stratification state inside the tank gradually deteriorates, and water will gradually become severely mixed. The PCM water tank with low flow rate has a period of time before and after PCM energy storage when the inclined temperature layer is thickened and heavily mixed, while the temperature stratification is good at other times, which is conducive to users' continuous use of hot water. The mixing of large flow phase change energy storage tanks is more severe than the first two, which reduces the user's hot water utilization rate and is detrimental to system performance.

Conclusion

The effective current is in direct proportion solar irradiance, and the radiation temperature is in accordance with the change of solar irradiance. When combined with the solar heat pump system, the COP of the heat pump system decreases a little. However, it is possible to save 17 minutes and 2.03 kWh by heating the water tank from 18-55 °C. Under the same Initial condition, under the flow rate of 10 Lpm, the continuous hot water delivery time of PCM thermal storage tank is increased by about 10% compared with that without PCM thermal storage tank, the hot water delivery rate can be increased by 8.33%, and the temperature stratification is better. In general, its performance is improved compared with that of PCM thermal storage tank. In the same Initiation, PCM heater box has obvious difference under two flow rates of 10 Lpm and 13.4 Lpm. Because the latter has good mixing effect, its hot water outlet time is reduced by 30 minutes compared with the former, and the temperature stratification effect is poor, and the hot water outlet rate is reduced by 11.7%

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