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Operation and Control Analysis of Dual Evaporator Heat Pump-solar Drying System

Hanling Xue[1*], Yuting Yan[1], Yehao Wu [1], and Xuening Wan[1]

[1]School of Energy, Xi'an University of Science and Technology, Xi'an, Shaanxi, 710054, China

[*]Corresponding author's e-mail: szt2001718@xust.edu.cn

Abstract. In order to meet the new environmental requirements of drying technology and reduce energy consumption costs, this paper uses solar energy and air energy to combine multiple heat sources to propose a heat pump-solar drying system for crop drying. Among them, the heat pump system is a dual evaporator parallel mode, and the solar energy adopts the form of comprehensive application in the system. The operation principle of the system is analyzed, and the operation effect of the vacuum tube hot water collection system is obtained through Trnsys simulation, and a multi-energy complementary control method is proposed for the system, which makes the system operation more energy-saving and flexible.

1. Introduction
Drying technology is widely used in agriculture and industry. In recent years, solar heat pump drying technology has been greatly developed. Practice has proved that solar-heat pump drying technology can save energy by 36.7%-41.1% or more than traditional coal-fired drying, and has the advantages of saving time, environmental protection and improving product quality [1~3]. The heat pump drying device uses the principle of reverse Carnot to absorb low-temperature heat energy in the ambient air, raises the temperature of the heat energy, and then uses it to heat the drying medium in the drying room, and at the same time cools the moisture in the dryer exhaust gas to condense into liquid water The energy efficiency ratio (COP) value of heat pump drying is about 4, which is more than 3 times higher than the thermal efficiency of the traditional direct electric heating method [4].

The best harvest time for most crops is from July to September, and there are abundant solar resources that can be used. Based on a heat pump-solar drying system, this paper analyzes the operating principle of the system and proposes an operating control method for the system.

2. System construction
The system is composed of heat pump system, solar energy collection system and drying room air system. As shown in Figure 1, the drying medium air is open cycle (without return air).

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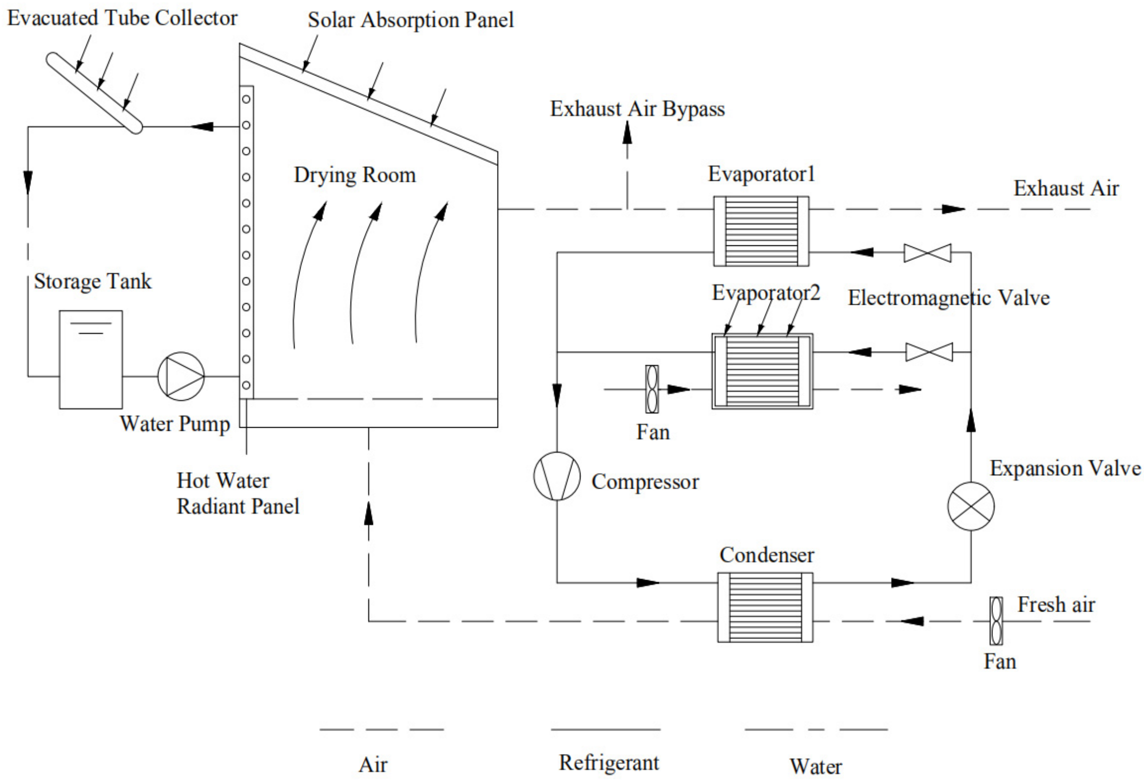

Figure 1. Schematic diagram of solar-air source heat pump drying system.

This system uses dual evaporators in parallel. Evaporator 1 is a heat recovery evaporator. After the dehumidification process, the hot air in the room will take away the excess water on the surface and inside of the material and turn it into a high-temperature and high-humidity gas, which is cooled and dehumidified by the dehumidifier . The evaporator 2 is a wind-solar evaporator (external evaporator), which only exchanges heat with the outdoor environment. The double evaporator helps to better control the environmental conditions required for drying and reduce energy consumption during the operation. In the initial stage of drying, the temperature in the drying room is lower than the set temperature value, which requires a lot of heat to heat the material and the drying environment. The wind temperature is also low. At this time, the evaporator 2 works, and the evaporator 1 does not work. The evaporator 2 absorbs outdoor wind and solar radiation heat to evaporate the refrigerant. After drying, the indoor temperature is relatively high. When the indoor temperature and humidity reach the set mode, the dehumidification starts, the evaporator 1 is turned on, and the evaporator 2 is turned off, and the circulating heat of the system is exhaust heat, thereby achieving the purpose of heat recovery.

This system can realize the multi-level utilization of solar energy. In the solar water system, water is heated by solar collectors and enters the hot water storage tank. When the water temperature is higher than 75℃ and the temperature in the drying room is lower than the set temperature, the water pump is turned on. Hot water radiation panels are laid on the side walls of the drying room. The water enters the hot water radiator panel after being pressurized by the water pump, and performs convection, radiation, and heat transfer with the indoor air. Perform radiation heat exchange with indoor materials. So as to achieve the purpose of heating the drying chamber. In addition, the top of the drying chamber uses a metal plate as the top plate, and the surface of the metal plate is coated with selective absorbing materials, which improves the solar energy absorption rate and directly uses solar radiation to heat the indoor environment.

In addition to the above, the evaporator 2 is a wind-solar evaporator. As shown in Figure 2, the surface of the evaporator is coated with a solar absorbing coating, which is located in the interlayer between the glass and the insulation board. The two sides are the inlet and outlet of outdoor wind , Absorb outdoor wind heat and solar radiation heat at the same time.

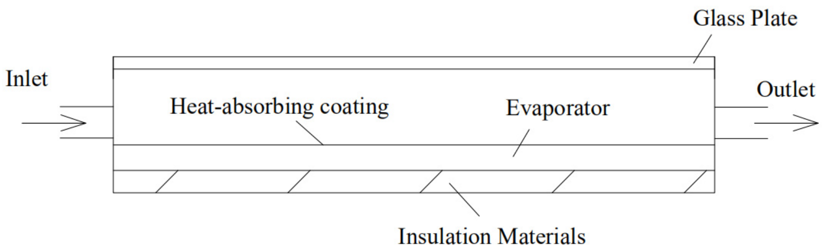

Figure 2. Schematic diagram of wind-solar evaporator.

3. Analysis of heat collection performance of solar water heating system

3.1.Model building

In order to optimize the heat collection performance of solar water heating system, this paper analyzes the heat collection performance of vacuum tube solar collector system with the help of TRNSYS software, and determines whether the solar collector can meet the temperature requirements of hot water radiant panel in drying room. The size of the vacuum tube collector is 2 m2 and the volume of the water tank is 0.3 m3. Taking Xi'an as an example, the longitude and latitude of Xi'an are 108.93e and 34.27n respectively. The best harvest season is from July to September, and the simulated period is from July to September. Since the heat storage tank is a lower inlet and upper outlet tank, the outlet water temperature of the water tank is determined according to the top temperature of the water tank.

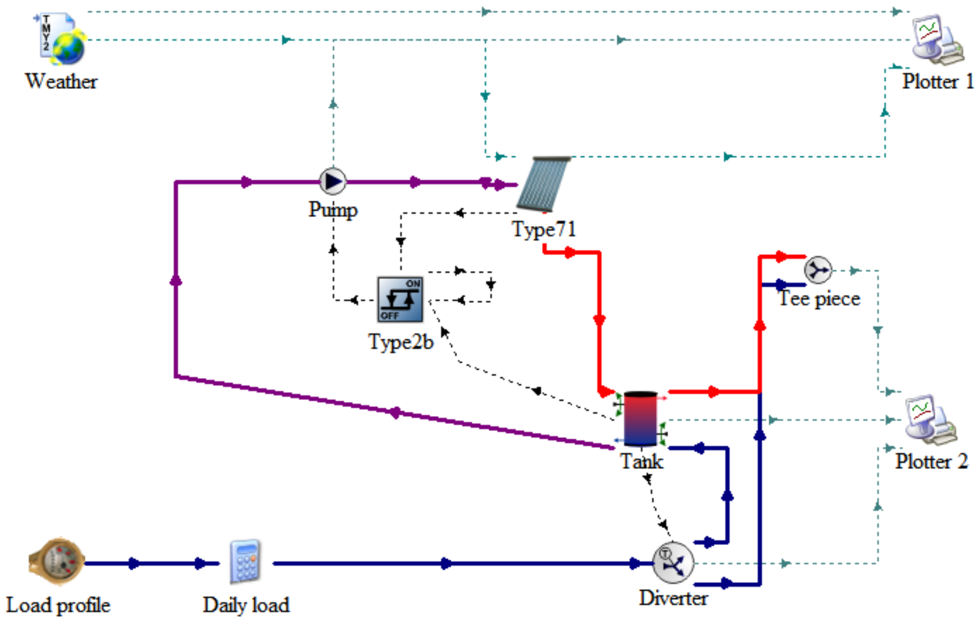

Figure 3. Solar collector system model established in Trnsys.

3.2. Result analysis

From the water outlet temperature curve of the evacuated tube collector, Figure 4 shows that the evacuated tube collector has a high heat collection efficiency, and the local time temperature can reach above 160℃. It can be seen from Figure 5 that the temperature of the water tank cannot reach the required 75℃ in early July, but the evacuated tube collector solar heat collection system can reach the set temperature in other periods. Therefore, an electric heating auxiliary device can be added to the hot water storage tank. The temperature curve diagram of the top layer o`f the water tank with the electric heating device is shown in Figure 6, so that the temperature of the solar heat collection system can reach the temperature demand of the drying room during the working time.

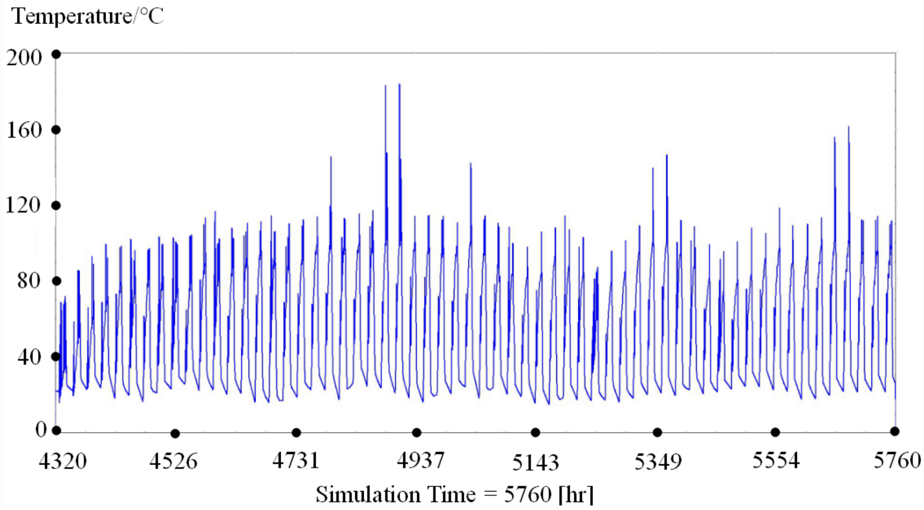

Figure 4. Water outlet temperature of evacuated tube collector.

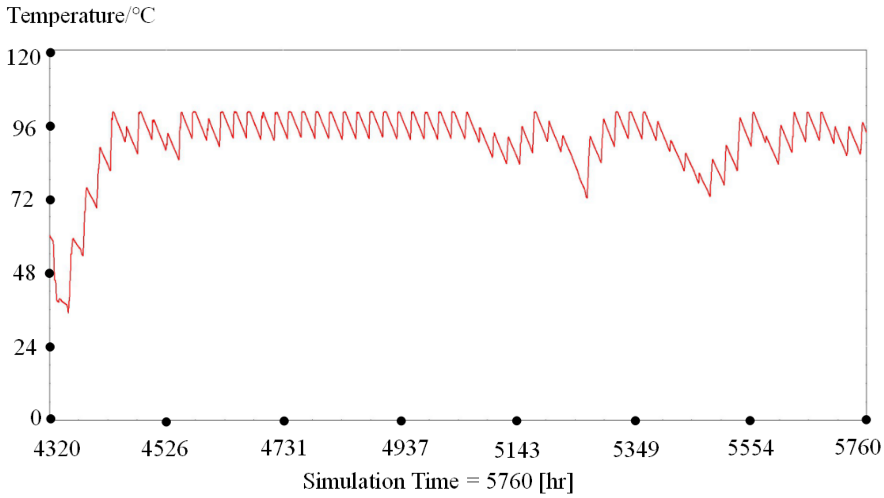

Figure 5. Top temperature of water tank.

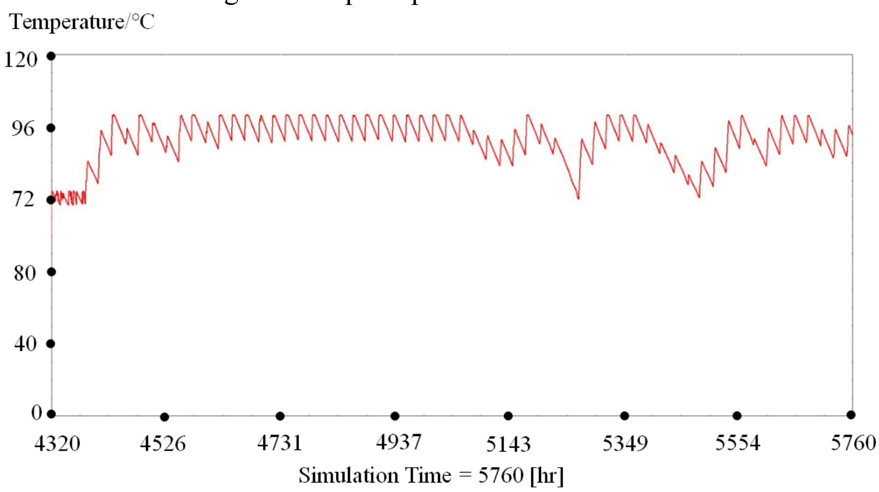

Figure 6. Auxiliary electric heating water tank top temperature.

4. Control logic

4.1 .Staged control
There are two main stages in the drying process, the constant speed phase and the deceleration phase. In the constant speed stage (5 hours), it is easier to remove the surface moisture of the material. In order to reduce energy consumption, so that the drying medium can take away more moisture, control the relative humidity in the room to 50%. Taking 65℃ air supply as an example, according to the principle of isenthalpy humidification, the outlet air temperature in the control room is determined to be 41℃. In the deceleration phase (3 hours), the surface moisture of the material has been dried, and the water content is low, and the bound water inside the material is difficult to evaporate, resulting in a higher specific energy consumption value (SEMR) and a lower energy efficiency value (COP)[5] . Therefore, a large water vapor partial pressure difference is required in the deceleration stage, and the relative humidity in the control room is 20%. It is determined that the outlet air temperature of the control room is 54℃ in this stage.

Table 1. Control parameters at different stages.

Stage	Time(hr)	Temperature(℃)	Relative humidity(%)
drying constant speed stage	5	41	50
Drying down stage	3	54	20

4.2. Heating process
When the outlet air temperature of the drying chamber is lower than the set outlet temperature of the corresponding stage, the system is supplemented with heat. The external evaporator of the heat pump system works: the valve in front of the heat recovery evaporator is closed, and the valve in front of the external evaporator is opened. The refrigerant throttled by the expansion valve enters the external evaporator, exchanges heat with the outdoor wind, and absorbs solar radiation heat for evaporation. Solar water system part: When the temperature of the hot water storage tank is greater than 75℃, the circulating water pump of the solar hot water system is turned on, and heat is supplied to the room through the hot water radiation panel in the drying room. When the temperature of the hot water storage tank is less than 75℃, the electric auxiliary heating device is turned on until the water supply temperature of 75℃ is met, and then the cycle is performed.

4.3. Dehumidification heat recovery process
When the outlet air temperature of the drying chamber is 0~5℃ higher than the set outlet temperature of the corresponding stage, the heat recovery process will be carried out. The heat recovery evaporator of the heat pump system works: the valve in front of the external evaporator is closed, and the valve in front of the heat recovery evaporator is opened. The refrigerant after throttling by the expansion valve enters the heat recovery evaporator, absorbs the heat in the exhaust air, and evaporates. The circulating water pump of the solar water system is closed and does not participate in the heating process of the drying system.

4.4. Heat removal process
When the air temperature at the outlet of the material chamber is 5℃ higher than the set drying temperature, the heat recovery evaporator and the exhaust air bypass are turned on at the same time, and part of the excess heat in the drying system is discharged into the environment. The other part of the heat is exchanged with the refrigerant through the heat recovery evaporator, so that this part of the heat can be reused.

5. Conclusions
(1) The heat pump drying system with double evaporators can facilitate the adjustment of the

operation mode during the drying process; different drying system operation modes are adopted for different drying stages to achieve the effect of energy saving.

(2) Different drying parameters are used for drying at different stages. Not only the drying effect is good, the energy-saving effect is obvious, but it also conforms to the law of moisture migration inside the dried material, and has less damage to the internal structure of the dried material.

(3) In order to improve the utilization rate of solar energy, solar radiation heat absorption devices are used in the three parts of the system. The solar radiation absorption panel on the top of the drying chamber and the external evaporator can absorb solar radiation during the day and provide heat to the system. The heat pipe collector and the hot water storage tank with heat preservation can not only supplement the heat of the drying room intermittently during the day, but also use the hot water in the hot water storage tank at night, achieving the effect of multi-level utilization of solar energy.

(4)With the help of Trnsys, the heat collection effect of the evacuated tube collector solar collector is simulated, and the working mode of the electric heating auxiliary solar collector is determined, so that the solar water system can meet the temperature requirement of the drying room at every time.

Acknowledgments
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