Research Article

Study and Test of Cold Storage Heat Recovery Heat Pump Coupled Solar Drying Device

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Abstract: In this study, we design the recovery of a heat pump combined solar drying device. Then, with this device, drying experiments of aquatic product, tilapia, were conducted, indicating that the newly designed device functions are well in temperature adjusting and controlling performance and showing that drying time is closely related to energy consumption and drying conditions. Heat recovery heat pump combined solar energy drier can improve the drying quality of aquatic products, but also can greatly reduce the drying energy consumption, which provides theoretical support to the design and processing of heat recovery heat pump of refrigeration system coupled solar drying device.

Keywords: Cold storage, dehumidification evaporator, drying devices, heat pump, heat recovery, solar collectors

INTRODUCTION

Cold storage is the important facility for frozen food processing, storage and distribution. It has played a very active role in adjusting the distribution of food and balancing food supply, so it plays an important role in the national economy.

Refrigeration system must continue to discharge heat to maintain the local continuous low temperature. Recovering heat from refrigeration system and applying it to heat consumers can greatly improve energy efficiency. Wasted heat recovery has great application potential in various systems and has gained increasing attention currently due to serious energy situation. Early in Hubbard Commercial Products Ltd (1981), analyzed the heat recovery of refrigeration system. Rajesh (1986) analyzed heat recovery feasibility of ground source refrigeration and air-conditioning. Stinson *et al*. (1987) analyzed the performance and economics of a dairy refrigeration heat recovery unit. More and more studies are focused on waste heat recovery recently (Mustafa *et al*., 2009).

Leena and Pekka (2009) studied Energy efficiency improvement of dryer section heat recovery systems in paper machines, the result showed the investments carried out have resulted in 12% lower fuel use and 24% lower CO_2 emissions. Condensing heat recovery technology of air-conditioning have been applied widely, Jaime and Per (2006) studied heat recovery and floating condensing in supermarkets, Wang *et al*. (2007) designed the waste heat recovery system for cold storage, Guangcai *et al*. (2008) studied a new heat recovery technique for air-conditioning/heat-pump system. These above heat recovery program were basically the heat pump recovery system. Secondly, there were also a lot of reaches of the waste heat recovery by using waste heat recovery adsorption refrigeration. Li *et al*. (2008) carried out experimental study on an innovative multifunction heat pipe type heat recovery two-stage sorption refrigeration system, Li *et al*. (2007) carried out performance study of a high efficient multifunction heat pipe type adsorption ice making system with novel mass and heat recovery processes. Wang *et al*. (2007) complete d a comparative evaluation of two different heat-recovery schemes as applied to a two-bed adsorption chiller.

There are special heat recovery units in air-condition water chiller, which are used to recover heat from condensers and supply consumers healthy hot water. Therefore, there are more studies about air-conditioning condensing heat recovery, mainly including double condenser heat recovery, heat pump recovery and phase change materials heat recovery. Heat recovery and floating condensing in supermarkets were studied (Jaime and Per, 2006). Heat pump technology is adequately mature, Li *et al*. (2009) had designed and analyzed the programs of large-scale aquatic products processing plant's energy recovery system and analyzed the influences of different heat recovery ways to the efficiency of energy recovery; but the programs have not been penetrated and concretely implemented as yet. Above based on heat recovery refrigeration systems' energy-saving research is not related to recover waste heat directly used to food drying process. This article is about the use of heat pump recovery condenser heat of cold storage and its application to aquatic product drying process, in terms of the drying stage requirements, added the solar drying

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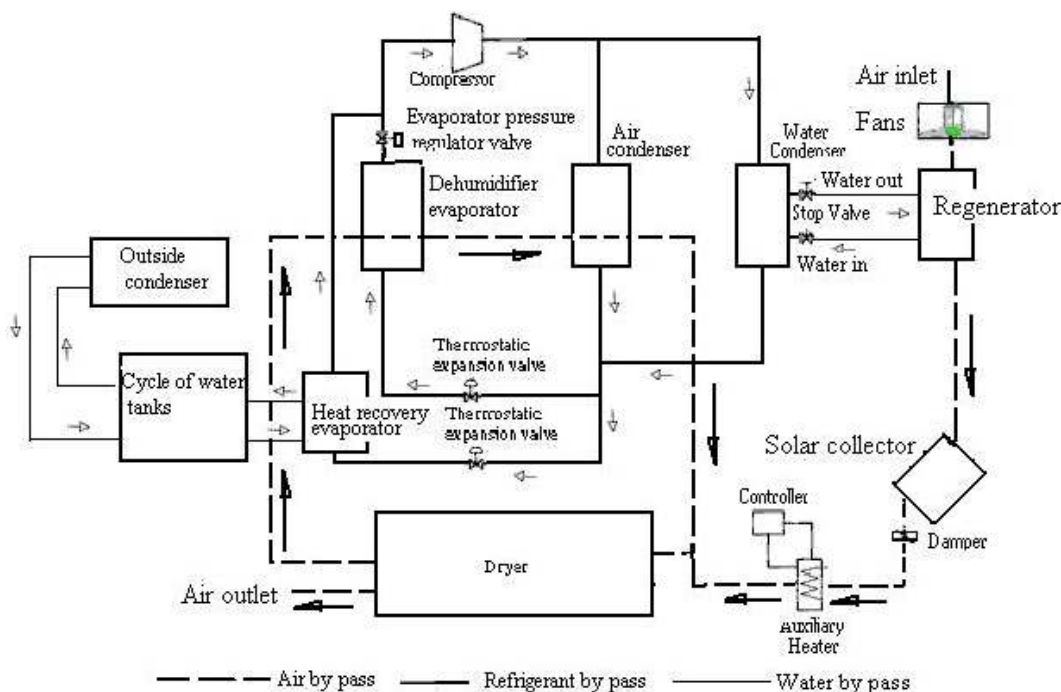
Fig. 1: Schematic diagram of heat pump heat recovery combined with solar drier

link and to improve drying device deployment performance accordingly.

A heat pump combined solar drying device is designed, which copes with energy saving of solar drying and high efficiency and stability of heat pump drying. Also, the device applies convertible-stage drying to satisfy aquatic produce drying demands. It can be adjusted according to energy efficiency, quality control and drying process characteristic in usage. Tilapia drying experiment was performed to test operation and regulation performance.

DESIGN OF HEAT RECOVERY HEAT PUMP SOLAR DRYING DEVICE

Figure 1 illustrates the system diagram. The heat pump system is composed of a compressor, two evaporators (one is used for heat recovery and the other is used for dehydration of drying air), two condensers and a thermostatic expansion valve and steam mixer, in which the parallel water-cooled condenser serves as auxiliary one to regulate condensing temperature of air condenser according to the temperature of the dry box. The main part of solar assisted heating is a serial opened circuit consisted of an air collector, an auxiliary heater and a water regenerator. Solar assisted heating is used to control temperature of drying air entering into the drying box.

Analysis on operation mode and coupling performance: The heat recovery heat pump device showed in Fig. 1 receives higher energy efficiency and

improves temperature and humidity controlling. Heat recovery evaporator's recoveries external refrigeration system condenser's heat. A dehumidifier evaporator is used to remove high humidity air moisture. This equipment can supply air of lower humidity radio and different drying condition for dried products. The auxiliary water-cooled condenser regulates condensing temperature and it also transfers heat into water heat accumulator to preheat air entering solar collector as well.

Air by pass: Air flows along the broken line in Fig. 1. The drying process is divided into convertible-stages: in terms of drying requirement. The air can be cyclically open, closed and semi-open loop; the closed loop only use for heat pump system, the open cycle use for solar or auxiliary heating device or heat pump system, semi-open can work for heat pump-solar energy for combined drying.

Air out of drier is divided into two ways. One goes by the turn way into the air desiccant, air condenser and air mixture from the solar collectors to return to the oven, another is discharged outside the box. It need adjust damper for bypassing because of requirement on humidity. Way to the outdoor air preheating by the hot water accumulator enters into solar collector.

Heat pump refrigerant circulation: The high temperature and high pressure refrigerant from compressor is divided into two ways to throttle after condenser. One way enters the heat recovery
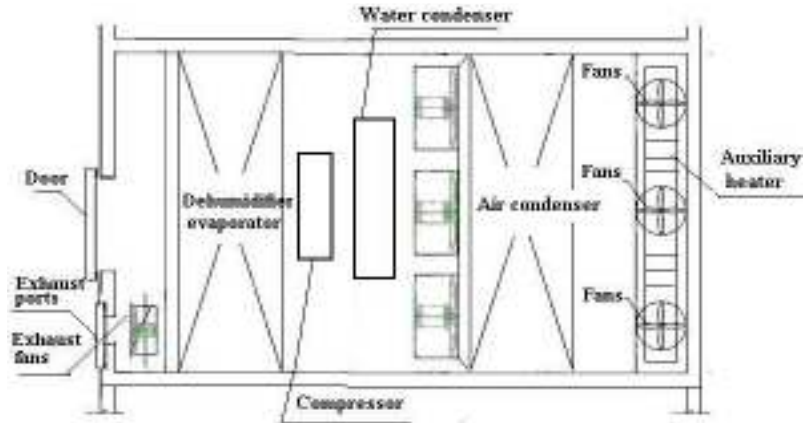
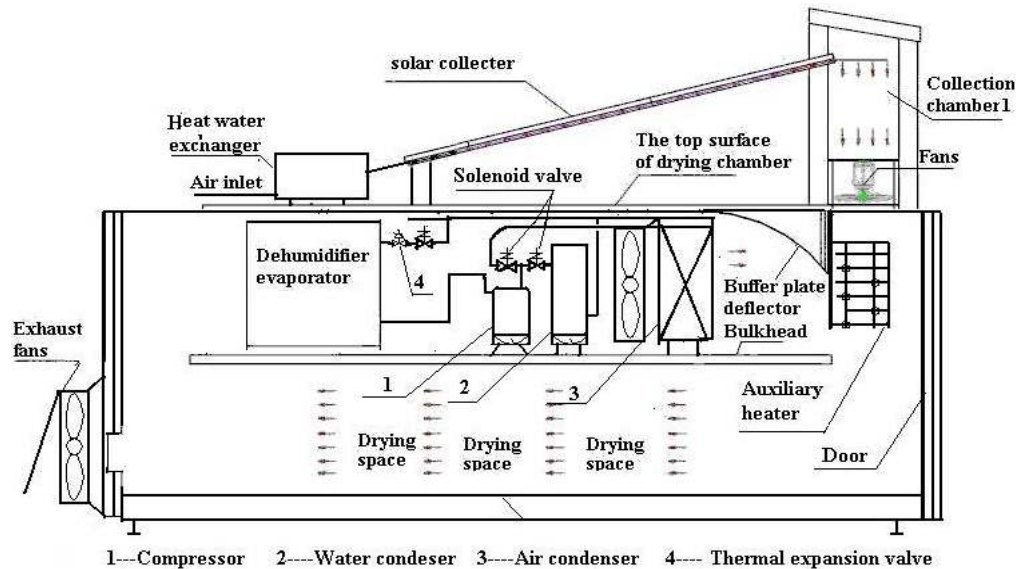Fig. 2: The floor plan of drying chamber's upper device

Fig. 3: Profile layout of the drying chamber's device

evaporator while another one enters the dehumidier evaporator. Gasified refrigerant from two evaporators will then get together in the mixer and be inhaled into compressor for the next circulation. In order to adjust the air pressure and temperature of the condenser, the system set up a parallel auxiliary water-cooled condenser and hot water into the regenerator.

Product drying process: After pretreatment, fresh materials are firstly processed in the first stage of drying to remove surface moisture under low temperature and gain balanced water content. Then they will reach the second stage of drying and be processed to the wanted water content. According to product demand, it is flexible to apply sole low temperature drying, sole high temperature drying or circulating temperature drying.

Operation mode and coupling performance analysis: The designed device can realize four separate operation modes according to product characteristics and requirements for drying quality:

- **Heat pump drying mode:** This mode needs to cut the solar collector. It performs well enough on condition that products require low temperature drying. Either open-mode drying or closed-mode drying is applicable.
- **Solar collector drying mode:** This mode is applicable when products can be dried without low temperature stage.
- **Combined drying of heat pump and solar collector:** This mode realizes convertible-sage drying. It is a flexible mode guaranteeing both drying quality and drying speed.
- **Combined drying of heat pump and solar collector with auxiliary electric heater:** This mode realizes continuous temperature control and maintains constant drying conditions, regardless of the influence of season and time.

THE DEVICE'S ASSEMBLY AND THE DESIGN AND FABRICATION OF SPECIAL PARTS

This drying device's layout and facade arrangement shown in Fig. 2 and 3.

The figures demonstrate the heat pump heat recovery coupled solar and auxiliary heating drying device formed an entirety via. Drying chamber is divided into two layers by the clapboard shown in Fig. 2. The upper part is installed with the major equipment: dehumidifier evaporator, heat pump system, air condenser, auxiliary heater and the fans; the lower part stores the material for drying, which coupled a complete system via the throttle and duct. The calculation of the drying system's capacity is based on the cold storage refrigeration system's condensing heat's releasing quantity, so as to determine the heat pump heat recovery system's capacity and the dry volume of the materials in the drying chamber, solar collector (Hawlader *et al*., 2008) area can be determined by the amount of dried material; during the summer time, it can heat air to 60ºC when working independently, as a result of which, this is used for the design conditions using the local solar radiation as a reference data calculated the solar heat collector area. Then the appropriate heater collector is selected and built on the top of the drying chamber with incline the same as the local latitude accordingly. Dehumidification evaporator unit is selected by matching the device's dehumidification rate and combined with its working temperature conditions to determine; so that it uses finned coil structure. In accordance with the requirement of phase control and temperature regulation, the system is installed with a perfect temperature, humidity control, testing device and procedure to run control device.

Test on drying performance of the device: A data acquisition system is equipped to the designed heat pump solar drying device. Online measurement system
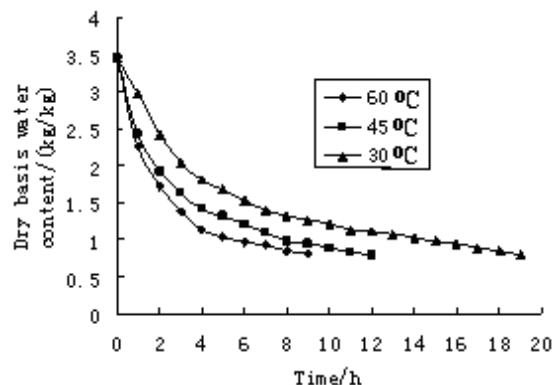

Fig. 4: The drying curves under different temperature conditions

and temperature and humidity control devices of Aquatic sample can work under required condition. In order to test the device performance, tilapia primary drying experiment was performed.

EXPERIMENTAL STUDY OF THE HEAT PUMP DRYING TILAPIA

On condition that wind speed (v) was 2.0 m/s and fillet thickness (h) were 7 mm, setting drying temperature to be 30, 45 and 60ºC, respectively as example and performing tilapia drying experiments. Contribute to the results shown in Fig. 4. And dry basis moisture content was at 0.8 kg/kg end of test.

As shown in Fig. 4, the required drying-time reduces while the temperature of drying medium ascents under drying to the same dry base moisture content.

As the drying medium temperature rising up, the material interface temperature rise in mass transfer driving force to improve and accelerate the rate of water vapor escaping from the interface, so that the moisture content of tilapia fillets declined faster and drying time shorten. The test also illustrates the better performance of heat pump running independently.
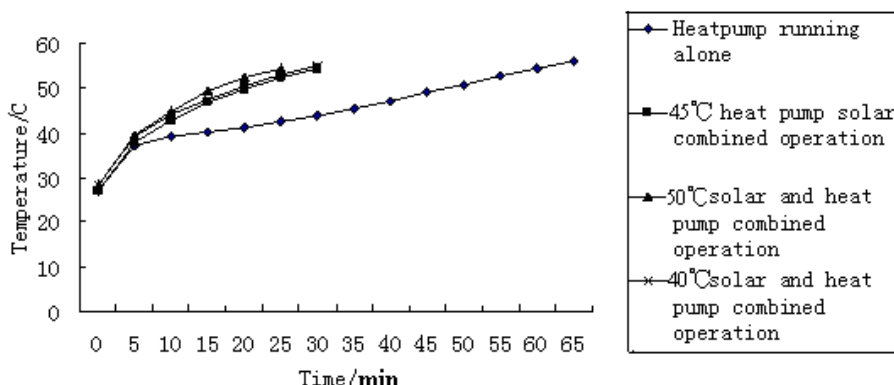

Fig. 5: Temperature of drying air changes as solar heat pump combined operation

The performance of solar heat pump combined operation: As shown in, temperature of drying air outlet of the solar collector is different, as the air of dier box is heated to a certain temperature and the required time is also different. For amount of air in dier (calculation showed), the solar collector outlet temperature is respectively 40, 45 and 50ºC, solar heat pump combined operation system for thermal coefficients was 5, 6, 7 and 8, far more than heating coefficient of heat pump running individually. And the higher the temperature, the more obvious effect is. However, when the temperature rises to 45ºC above, the range of the increasing is smaller.

Analysis shows that the higher the temperature of dry air through the solar collectors is, the faster drying air heat up, which is in good agreement with the actual situation, indicating that the device has the better regulation performance.

CONCLUSION

- A heat recovery heat pump solar drying device is designed and its operation mode and coupling performance are analyzed. The device cans recovery cold storage refrigeration system condensing heat for material drying Fig. 5. It designed the solar auxiliary heating, which provides energy for the drying process via heat recovery and solar auxiliary heating device's coupling. The device possesses advantages of both solar drying and heat pump dehumidification, improving drying quality, realizes continuous operation and saving energy and reduces carbon emission.

- Combined with the advantages of cold storage refrigeration system and the needs of drying function conversion, this device matched with dehumidification evaporator, which has dehumidification features, so the device's low-temperature drying performance is greatly improved.

- Experiments of the drying performance and adaptability of the dry materials of joint drying device show that the device can provide dry conditions for multiple loading conditions on the basis of constant temperature drying experiment on tilapia. Results indicate the increase of drying temperature and drying speed.

- In the experiments, influences of drying temperature on system energy consumption are analyzed. Results suggest that higher drying temperature means shorter drying time and less energy consumption, which advices that adjustable drying temperature can save energy with damaging drying quality.

- Experimental analysis of drying performance and energy consumption under different conditions will be further performed.

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