Multifunctional Solar Thermal Collector for Heat Pump Application

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Abstract:- Multifunctional solar thermal collector operates as heat collector and evaporator, which are releasing heat. Heat pump is a system that absorbs heat from low temperature and releases it at higher temperature by using vapour compression system. The moisture in the air can be removed at low temperature during condensation in the evaporator. The heat releases in the condenser can be used for drying of high quality products. Both of these phenomena (reducing moisture content and heating the air) are very important in the drying process. This concept of removing and releasing heat in the heat pump system can be fully utilised for the drying of high quality product. This paper describes the preliminary results of the study on the solar assisted heat pump drying system using these multifunctional solar collector.

Key-Word:- Heat pump dryer, multifunctional solar thermal collector, drying chamber, evaporator, condenser.

1 Introduction

Heat pump can be used as drying system. The heat released from compressor and condenser in the heat pump system can be used to increase the temperature of air in the drying chamber. The heat absorbed in the evaporator through working fluid (air) can be used to remove the moisture content in the air, and hence it acts as dehumidifier. In principle, both components of the heat pump (condenser and evaporator) can be fully utilized during the process of drying. As the result, the COP of the system will be higher. The air in the system can be recycled back from condenser to evaporator in a close loop.

The heat pump system can be set to operate continuously for drying purposes, as such the power consumed by the compressor will increased. This is due to the fact that heat from the condenser causes the temperature of the air in evaporator's temperature increased. The input temperature of the evaporator is low, but the output temperature is high. Therefore, the input temperature into the compressor becomes high. The continuous circulation of the air during will result in increasing air temperature and reducing its humidity. Increasing the air temperature will increase the refrigerant pressure which then increases the power of the compressor to transfer the heat.

The multifunctional solar thermal collector attached to the system will be used to maintain the power in the drying chamber, and also to increase the system efficiency. The collector is similar to ordinary solar thermal collector in collecting heat, but during night time the collector will also absorb the energy from the cold environment, as it acts as cooler or evaporator. Therefore, the solar collector will only be used during daytime to collect energy from the sun.

Hodgett [1] was among earlier researchers who introduced efficient heat pump for drying purposes in 1976. Hawlader et al. [2] studied a solar assisted heat pump dryer with water heater attached to it. Filho and Strommen [3] used heat pump for drying of biomaterials. Okamoto [4] studied heat pump system with a latent heat storage utilizing seawater installed in an aquarium. Argiriou et al. [5] have studied numerical simulation and performance assessment of a low capacity solar assisted absorption heat pump coupled with a sub-floor system.

This paper presents a study on a close loop system of heat pump for drying purposes. The high humidity air due to evaporation of water from the drying material in the drying chamber will be send back to the evaporator, where the water in humid air will be condensed and collected. In tropical country like Malaysia, the climate is warm and humid. During the daytime the humidity is not less than 60%, and during the night-time is more than 95% [6]. The close loop system in the heat pump is to maintain low humidity in the drying chamber.

The heat pump system and the multifunctional solar thermal collector are attached together so that it becomes one unit. The schematic diagram of the system is shown in Fig. 1. The vapour compression heat pump cycle system is the main component of the dryer. The superheated refrigerant of the heat pump is compressed by the compressor. The high temperature and pressure refrigerant then release the heat in the condenser to the air in the drying chamber. Then, the high pressure refrigerant is passed through expansion valve and becomes liquid in super cool form. This super cool refrigerant absorbs heat from evaporator which condenses water in high humidity air in the evaporator. The expansion valve manages the circulation of the refrigerant in the system. With minor modification, the valve can also be used to control the operation of the multifunctional solar thermal collector as a heater, cooler or evaporator.

The multifunctional solar thermal collector designed for the heat pump system is shown in Fig. 2. It consists of aluminium rods and fins to transfer heat to and from the air passing through it. The collector is covered by the transparent plastic sheet on the top, and insulated by rubber foam on the bottom.

2 Research Methodology

The system consists of five main components: vapour compression heat pump system, multifunctional solar thermal collector, drying chamber, air duct and solar collector hot air channel. All the components were made of aluminium except the heat pump system. The capacity of the compressor was half horse power, and the refrigerant used was R134a as specified by the manufacturer. The size of the drying chamber was 0.65m X 0.65m X 0.65m. The collector has an area of 0.65m X 0.65m. The system was a close system.

A solar simulator with 12 halogen lamps, with capacity of 150 Watt each, was used in the experiment. The simulator was set at solar radiation of 440 W/m^2 throughout the experiments.

Four set of experiments were carried out in the laboratory with and without the multifunctional solar thermal collector. The first experiment was conducted with the heat pump as the source of heat for drying purposes without the solar collector. The air was circulated from the condenser in the drying chamber, then to the evaporator to reduce humidity of the air. The second experiment was carried out with the multifunctional thermal collector attached to the system. Hence, extra heat from solar energy was collected to supplement the drying activity. The third experiment was conducted when the thermal collector acted as a cooling system, to cool the air before it entered the evaporator. Finally, the fourth experiment was operated where the thermal collector acted as an evaporator to evaporate drying air before it entered the drying chamber.

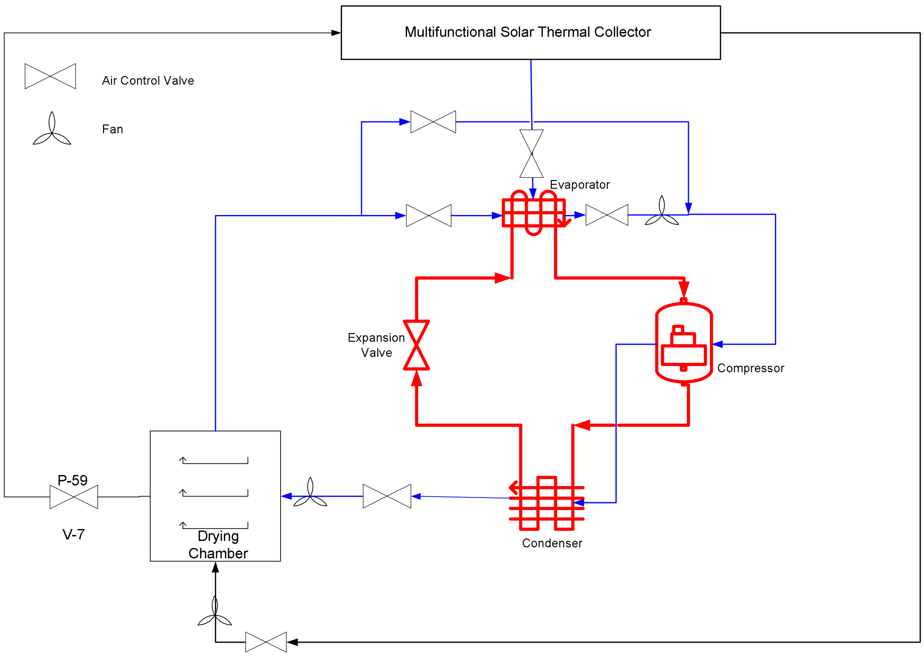

Fig. 1: The schematic diagram of the solar assisted heat pump drying system using multifunctional solar collector.

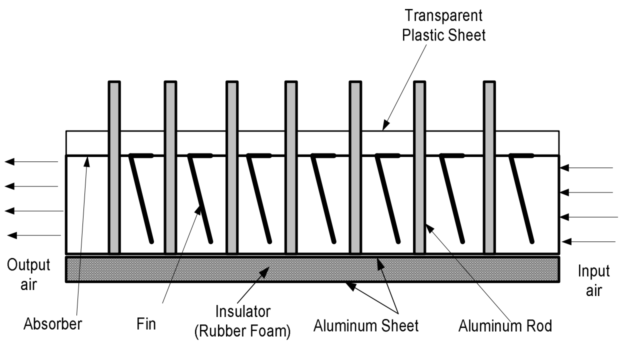

Fig 2: The multifunctional solar thermal collector designed for the experiment.

3 Performance Evaluation of the System

3.1 Heat pump without solar collector.

Heat pump dryer provides a slow drying process, but it was a good dehumidifier. It took 80 minutes to increase the air temperature in the drying chamber from 30ºC to 40ºC. During the period, the humidity decreased from 80% to 45%. After 180 minutes of operation, the humidity of the air in the evaporator decreased to 24%, and the air temperature in the drying chamber increased to 47ºC as shown in Fig. 3. The experiment was performed with no drying load.

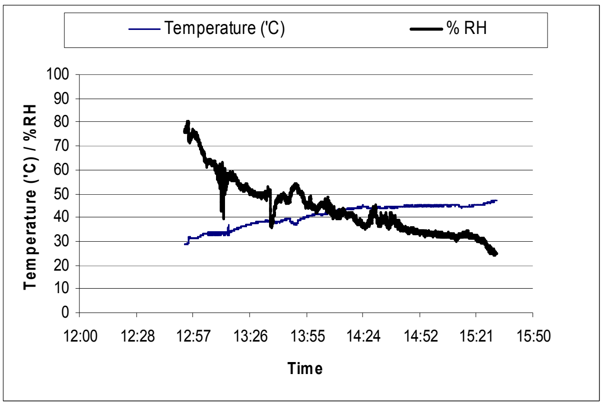

Fig. 3: Heat pump drying capacity: reducing air humidity from 80% to 45%, and increasing air temperature from 30°C to 40°C in 20 minutes

3.2 Heat pump with solar collector.

The experiment was also conducted with the use of the multifunctional solar thermal collector to supplement the heat from the heat pump. A solar simulator with 12 halogen lamps, with capacity of 150 Watt each, was used in the experiment. At constant solar radiation of 440 W/m^2, the air temperature in the drying chamber increased from 34ºC to 38ºC in 20 minutes as shown in Fig. 4. If the system used heat pump only, it took 25 minutes to achieve the same temperature. Combining the two sources of heat will make the drying more efficient, and at the same time, reduces the power used for the heat pump.

The system can also be operated continuously, since by doing so the high compression refrigerant can be maintained at about 20 bar. As the result, the air temperature in the drying chamber can also be maintained. Maintaining the drying temperature will ensure the quality of the dried products.

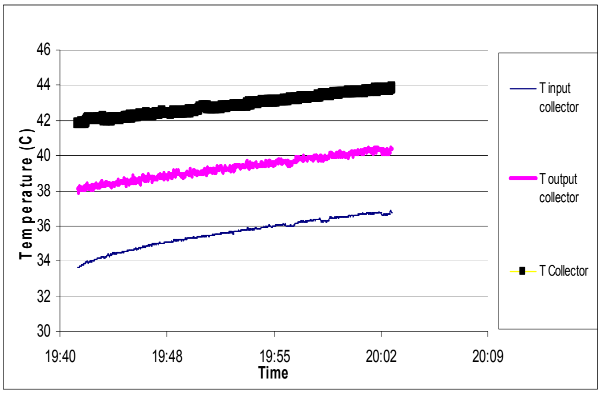

Fig. 4: The variation of air temperature in the drying chamber using multifunctional solar collector at solar radiation of 440W/m^2.

3.3 Solar collector as cooling system.

The multifunctional solar collector system can also be used as cooling system. Fig. 5 shows that the heat pump and multifunctional solar thermal collector operate together at steady state condition. The electric power for the compressor was 410 Watt producing air temperature of 55ºC and humidity of 15% in the drying chamber.

During operation, the multifunctional thermal solar collector was closed not to allow outside air to enter the system, and the solar simulator was shut off. The system worked without additional heat from solar radiation. Therefore only the heat pump maintains the air temperature in the drying chamber as shown in Fig 5. The power of the heat pump started to increase after about 15 minutes of operation started as can be seen in Fig. 6 that. This is due to the fact that the increase of the air temperature in the evaporator where the heat from the drying chamber entered the evaporator. When there was no solar radiation, the multifunctional solar thermal collector attached to it acted as cooler to cool the hot air from the drying chamber before it entered the evaporator. The humidity in the drying chamber was maintained at 15%, and the humidity in the multifunctional solar thermal collector was found to be 20%. This means that the collector removed the heat from the drying chamber and brought it to evaporating chamber for evaporation process.

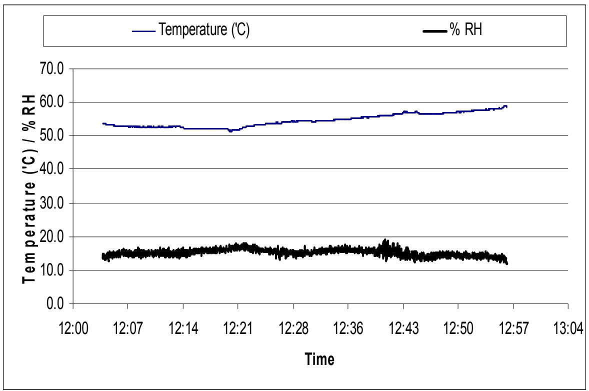

Fig 5: Temperature and relative humidity of the air in the drying when the solar collector acts as a cooler.

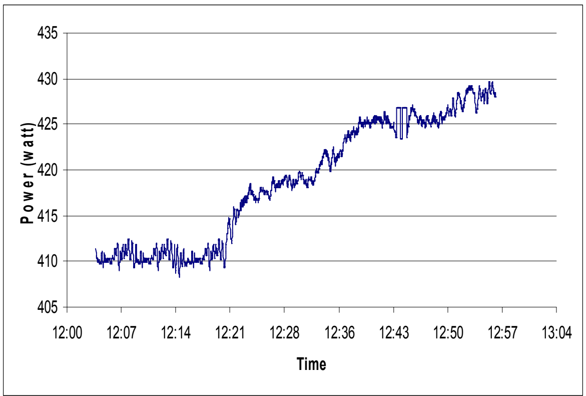

Fig. 5: The multifunctional solar thermal collector as a cooler. Note that the power for the compressor starts to increase after 15 minutes of operation.

3.4 Solar thermal collector as an evaporator.

In this operation, the multifunctional solar thermal collector now functioned as an evaporator. The experiment was carried out at low temperature environment. During drying process, the environment temperature was set at 5ºC to 20ºC. The cooled air outside the drying chamber would cool the aluminium rods and fins in the drying chamber. As such water in hot air with high humidity in the drying chamber would condensate. In other words the thermal collector acted as evaporator to remove part of the water in humid and hot air in the drying chamber. Fig. 6 shows the temperature of the air inside/outside of the collector where the evaporation took place on the aluminium rods and fins. It is clear evidence that the collector can also be used as evaporator.

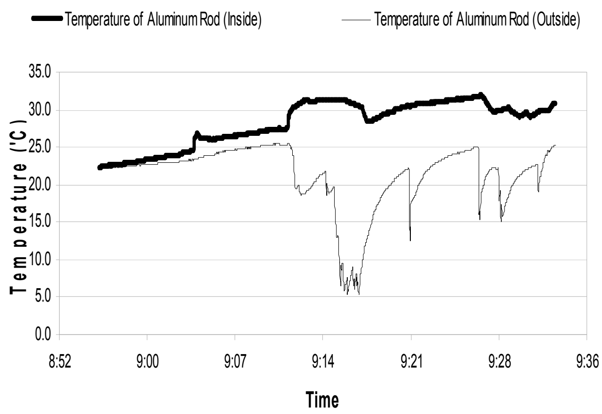

Fig. 6: Multifunctional solar thermal collector acted as evaporator (to condensate water in the drying chamber).

4 Conclusion

The results presented in this paper are the preliminary results. Further experiments are being conduct on the system to study its performance under various conditions. Based on the study conducted, it can be concluded that the air temperature in the drying chamber can be manipulated based on the four types of operations: (a) without the multifunctional solar thermal collector, (b) with supplementary heat from the designed collector, (c) as a cooler to cool drying air before it enters the evaporator, and (d) as an evaporator to condense humid air in the drying chamber.

Based on the results, we believe that the heat pump dryer using multifunction solar thermal collector designed can be used anywhere, regardless of the weather's condition.

The system is environment friendly since it produces no green house gases such as CO, CO_2, H_2S, SO_x, NO_x and haze which bring unknown dangerous various particles. The designed system is very useful for drying activities near populated areas or industrial park which is no longer safe for open drying, even for open loop drying technologies.

For high quality products such as foods and herbs, the priority is to be given to the safety of the environment.

In tropical countries like Malaysia, the problem of humidity, uncertainties of the whether and unpredictable solar radiation intensity are very high. Othman et al. [6] have discovered that the humidity in Malaysia is never below 60%. During night time the humidity can be more than 95%. The solar drying technologies that we introduced previously

[7] had to use auxiliary heater for continuous drying. The current designed drying machine becomes significant considering the above factors.

At sea level the air temperature between 24 ºC to 27 ºC, is considered quit high for multifunctional thermal collector becomes evaporator. So, the designed system is more suitable for a high level land, such Cameron Highland in Malaysia where tea plantation is available. During day time the system can be used to collect solar radiation, but during night time when the ambient temperature is very low (about 15ºC), the system can be used as cooler or evaporator.

The system can also be applied in four season countries, where in winter it can also be used for drying purposes. It is a well known phenomenon that the heating COP of the heat pump is higher than cooling COP. As such the multifunctional solar thermal collector can also be operated as an evaporator.

The preliminary tests on the designed system were already done and the system is ready for various modes of drying for high quality products such as foods, herbs or agricultural products.

Acknowledgement

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