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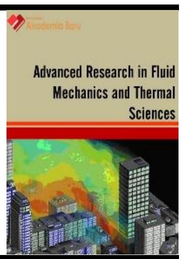

Comparative Assessment of Closed Loop Heat Pump Dryer and Direct Solar Dryer System for Banana Drying

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ABSTRACT

The comparative assessment of direct solar dryer system (DSDS) and closed loop heat pump dryer (CLHPD) for drying of banana has been investigated. This study was carried out with 3 drying methods including DSDS, CLHPD without preheating and CLHPD with preheating for 30 minutes to determine the performance and drying characteristics of banana dryer from the initial mass of 8 kg to evaporate of moisture content of 3.2 kg. The results showed that the drying time of banana using CLHPD with preheating (30 minutes), CLHPD without preheating and DSDS are 255 minutes, 305 minutes and 720 minutes, respectively. The CLHPD drying time with pre-heating was faster than CLHPD without pre-heating and it was the fastest compare to DSDS. The higher value of Specific Moisture Extraction Rate (SMER) of banana using CLHPD with preheating (30 minutes), CLHPD without preheating and DSDS were 1.29 kg/kWh, 1.18 kg/kWh and 0.35 kg/kWh, respectively. The SMER of CLHPD with pre-heating was higher than that CLHPD without pre-heating and it was the highest compared to DSDS. The CLHPD with preheating showed a better performance in comparison with CLHPD without preheating and it was the best performance compared to DSDS.

Keywords:
Direct solar dryer system; closed loop heat pump dryer; banana drying; heating; performance

1. Introduction

Drying is a process of dehumidification in which moisture is removed from a solid using thermal energy [1]. The use of sunlight in open space for drying has been existed since ancient times. But it has not been widely integrated in home or the industrial sector. In principle, the drying process involves the process of heat and mass transfer that occurs simultaneously, in most cases will change products properties. First, the heat must be transferred from the heating medium to the material. And then, after water evaporation occurs, the moisture content must be moved through the material structure to the surrounding medium. This process involves fluid flow where the water content must be transferred through the material structure during the drying process. The length of drying time

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process depends on the material being dried and the method of heating used [2-5]. Drying is one of the most common ways to extend the storage time of agricultural products including fisheries and other food products. The process of drying product after post-harvest is important so that the growth of bacteria or micro-organisms that caused decay stops growth and the product can be stored in longer time before consumption [6].

The energy as heat for drying supplied in various sources (solar energy, natural gas, fossil fuel, biomass etc.). Although solar dryers are used for drying various commodities, it has not yet been widely commercialized because of high investment cost, time-consuming operation, human habit etc. [7]. The evaluation and review on the use of solar dryer for drying of various commodities have been presented by many researchers [2,4,8-12]. Kumar *et al.,* [3] reported a review of solar dryer in various types namely, direct solar dryers, indirect solar dryers, hybrid solar dryers and their drying applications for various commodities. Hedge *et al.,* [13] reported design and fabrication of solar dryer and performance evaluation of solar dryer for banana and reported their performance for banana drying. They found that the drying rate increase when wooden skewers were used instead of conventional trays. The total difference is found to be 3.1% for moisture content which is considerable knowing that the rate of drying drastically decreases with time at the end of the day.

Many dryer technologies have been developed over the past years such as freeze drying, vacuum drying, hot air drying, heat pump dryer etc. Many researchers found that the quality of the dried product is strongly dependent on the processes and methods of drying involved because drying is a complex operation and could be degraded during operation [14]. Heat pump technology has been used in residential, domestic and industrial sectors in most developed countries for cooling space using air conditioning. However, heat pump technology for drying of commodities like food, fruits and vegetables has been largely unexploited in Indonesia. Very little literature studies about heat pump technology conducted in Indonesia [15-17]. Fayose *et al.,* [18] Reported that heat pump technology for drying of fruits and vegetables had been used in domestic and industrial sectors in Sub Sahara Africa including South Africa. Several studies of heat pump technology have been performed by many researchers, including applying heat recovery process [19,20] and drying technology [21-23]. Liu *et al.,* [24] conducted the design and thermal analysis of an air source heat pump dryer for food drying. Their results showed that the open and semi-open heat pump dryers were greatly affected by ambient temperature and humidity. The closed heat pump drying system was greatly affected by the bypass air rate. Heat pump dryer uses a closed loop and fully recovers energy. The amount of heat recovered in a heat pump dryer depends on heat transfer area, refrigerant properties and moist air recirculation.

In this study, closed loop heat pump dryer (CLHPD) compared to direct solar dryer system (DSDS) for banana drying was designed, constructed and tested. The experimental result was performed on the system to determine the optimum performance and drying characteristic between CLHPD and DSDS. This study was carried out with 3 drying methods namely DSDS, CLHPD without preheating and CLHPD with preheating for 30 minutes from the initial mass of 8 kg to evaporate of moisture content of around 3.2 kg.

2. Methodology

The experimental apparatus of closed loop heat pump dryer (CLHPD) and direct solar dryer system (DSDS) were designed, constructed and tested at the Thermal Engineering Laboratory (Faculty of Engineering, Universitas Riau) as shown in Figure 1 and 2, respectively. CLHPD apparatus consists of heat pump system and dryer room. Table 1 shows the specifications of the heat pump used in this study that modified from a split type of residential air conditioning.

CLHPD has dimension of dryer room with size 1500 mm x 750 mm x 1800 mm (length x width x height) and heat pump dryer package has dimension size 730 mm x 600 mm x 550 mm (length x width x height), where net volume of dryer volume is 1.78 m^3. DSDS has volume 1.5 m^3 and dimension size 970 mm x 1000 mm x 1030 mm (length x width x height) with slope angle 45° and consist of V type corrugated black aluminum absorber plate with 0.4 mm thick and 1.344 m^2, glass cover 0.5 mm, isolator 17 mm plywood, fan for air circulation with power 4W from solar cell.

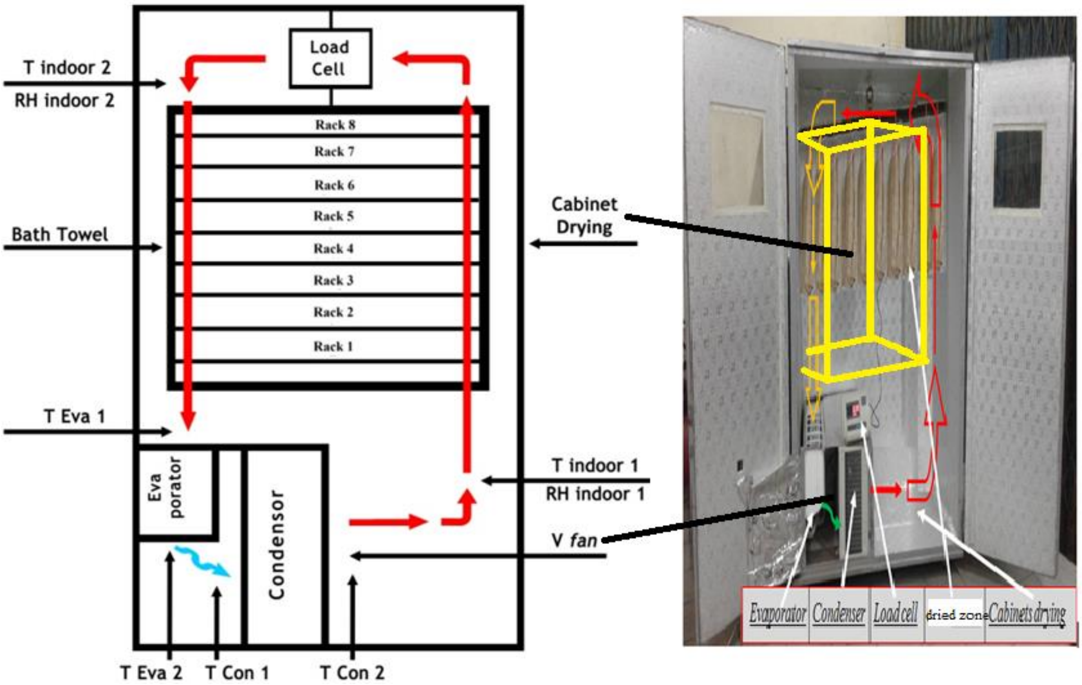

Fig. 1. The schematic of Closed Loop Heat Pump Dryer (CLHPD) apparatus

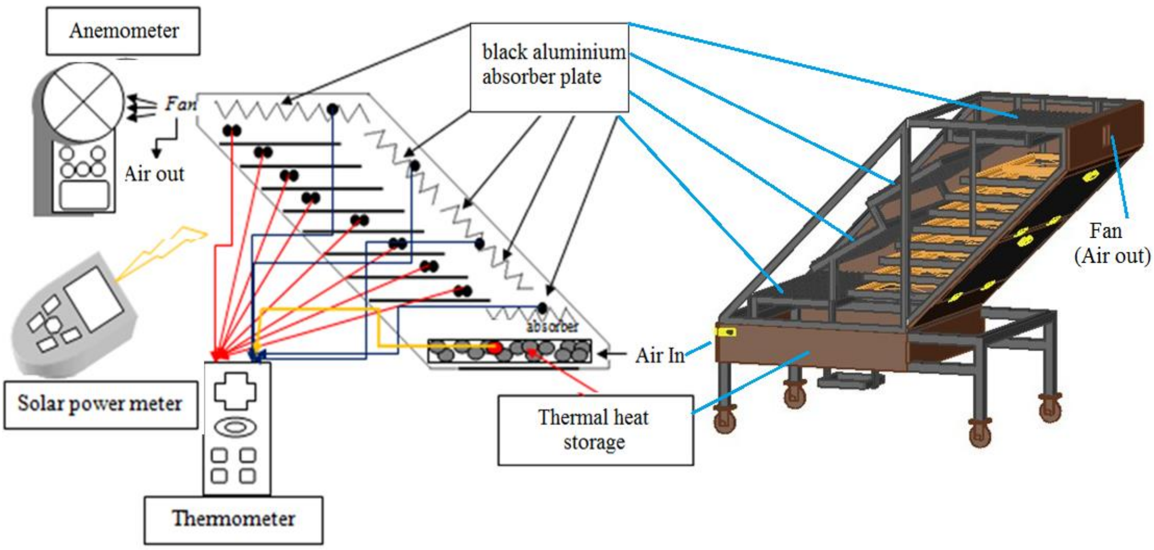

Fig. 2. The schematic of Direct Solar Dryer System (DSDS) apparatus

Table 1
Specification of heat pump

Characteristics	Technical Description
Type	Split Unit
Volt/Phases/Hz	220V/1/50 Hz
Power (averaged)	305 W
Nominal Ampere	1.3 A
Cooling Capacity	1465 W
Refrigerant/mass	R22/320 g
Pipe size, Liquid/Gas	06.35 mm / 9.53 mm
Dimension of indoor unit	770 mm x 260 mm x 320 mm
Dimension of outdoor unit	790 mm x 340 mm x 490 mm

K-type thermocouple with data acquisition was used for measurement of temperatures from apparatus with accuracy 0.2% (± 0.5°C) and resolution 0.1°C. The electric current input and voltage input (Hioki DT4211) were measured by ampere-meter (accuracy ± 2.0 percent and 3 digits) and voltmeter (accuracy ± 1.0 percent and 3 digits), respectively. The mass of banana was measured by digital weight scale (HY12 *weighing indicator*) with accuracy ±10 gram using type-S Load cell. The intensity of direct solar radiation measured by solar power meter (Tenmars TM-206) with resolution 0.1 W/m^2 and accuracy 10 W/m^2 or ± 5.0 percent.

The experimental drying data of banana was analyzed using the moisture ratio, where the moisture ratio (MR) is the amount of water content remaining in the banana sample compare to the initial water content of banana [5,17,25]. Where *m*, *mo* and *me* are the mass of the banana dried at measured time, at initial time and at equilibrium, respectively. It was calculated using Eq. (1).

$$MR = \frac{m-me}{mo-me} \tag{1}$$

Specific moisture extraction rate (SMER) was used in this study as drying performance of CLHPD, which defined as number of water content removed from the banana dried per unit consumption of energy [5,17,25,26]. SMER is indicated as energy effectiveness use in drying banana. Thus, SMER [kg/kWh] is calculated using Eq. (2).

$$SMER = \frac{\Delta m}{\dot{W_{in}} \times \Delta t} \tag{2}$$

where Δm (kg) total of water content removed from the banana during the drying time, W_{in} the power consumption (kW) and Δt is the drying time (h).

3. Results

Figure 3, 4 and 5 show the moisture ratio, average temperature of drying chamber (*Tin*) and surrounding temperature (*Tout*) during drying time (minutes) of banana at CLHPD without preheating, with preheating (30 minutes) and DSDS, respectively. During the drying process at CLHPD as shown in Figure 4 and 5 the temperature of the drying chamber during drying process increase with the enhancement of drying time. This is because of the effect of the closed loop heat pump (CLHPD). Heat rejection from condenser was used for heating air in the drying chamber so that the water content of banana will be reduced because of evaporation. The temperature distribution of the drying chamber with DSDS reaches the maximum temperature 57.1°C at 360 minutes then continues to decrease gradually following the daily solar radiation pattern in the form of a parabolic curve with time. The hot air was circulated back through the evaporator and condenser until the evaporation of water content evaporation achieved 3.2 kg.

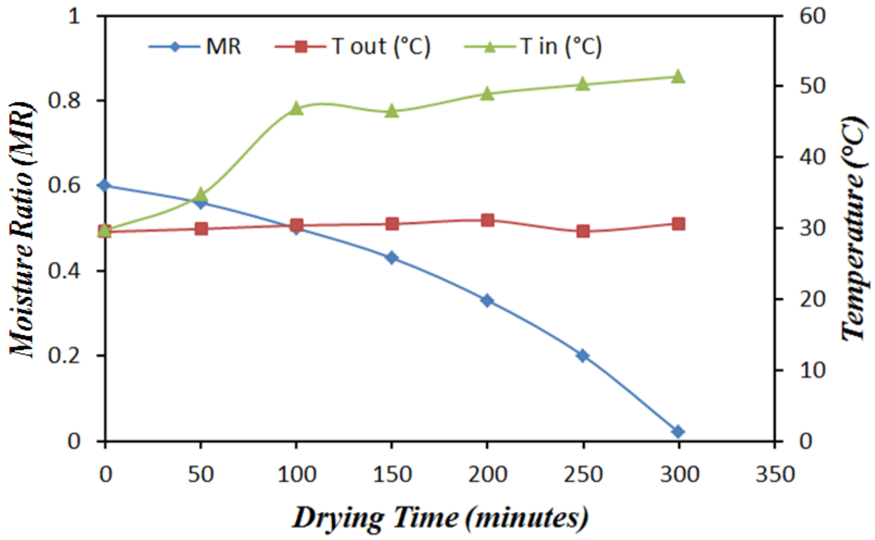

Fig. 3. Moisture Ratio, average temperature of drying chamber (*Tin*) and surrounding temperature (*Tout*) in drying time (minutes) of CLHPD without preheating

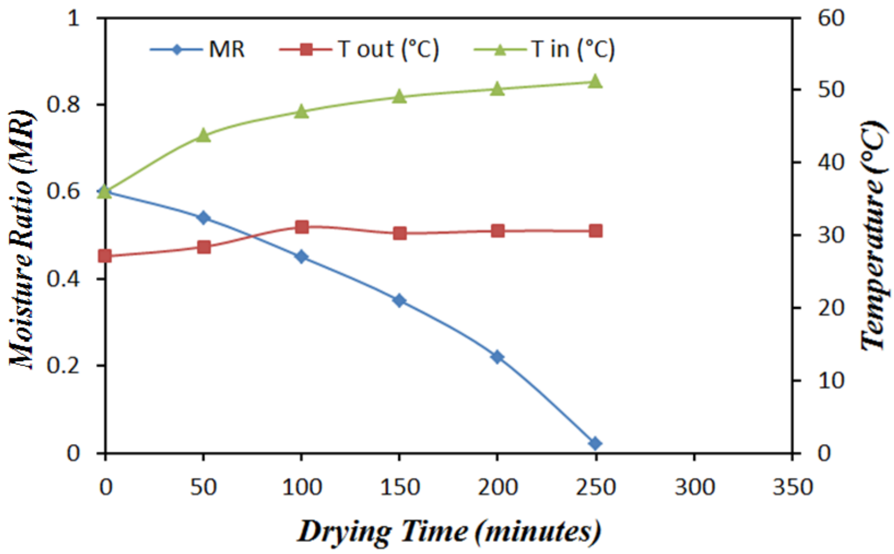

Fig. 4. Moisture Ratio, temperature average of drying chamber (*Tin*) and surrounding temperature (*Tout*) in drying time (minutes) of CLHPD with 30 minutes preheating

CLHPD with preheating 30 minutes is faster than CLHPD without preheating around 55 minutes, because average temperature of CLHPD with preheating higher than average temperature without preheating. The average drying temperature of CLHPD with preheating 30 minutes and without preheating is around 47^{o}C and 44.5^{o}C respectively, where average drying temperature of DSDS is around 43.8^{o}C. The CLHPD with preheating provides the highest average temperature.

In the drying process, moisture ratio (MR) decreases with increasing temperature of drying chamber, where the temperature drop using CLHPD with or without preheating, faster than using DSDS. Banana drying using CLHPD with preheater 30 minutes requires 255 minutes while CLHPD without preheating requires 305 minutes and DSDS requires 720 minutes. The results show that banana drying when viewed on MR and drying time using CLHPD with 30 minutes preheater was better than using CLHPD without preheater and DSDS.

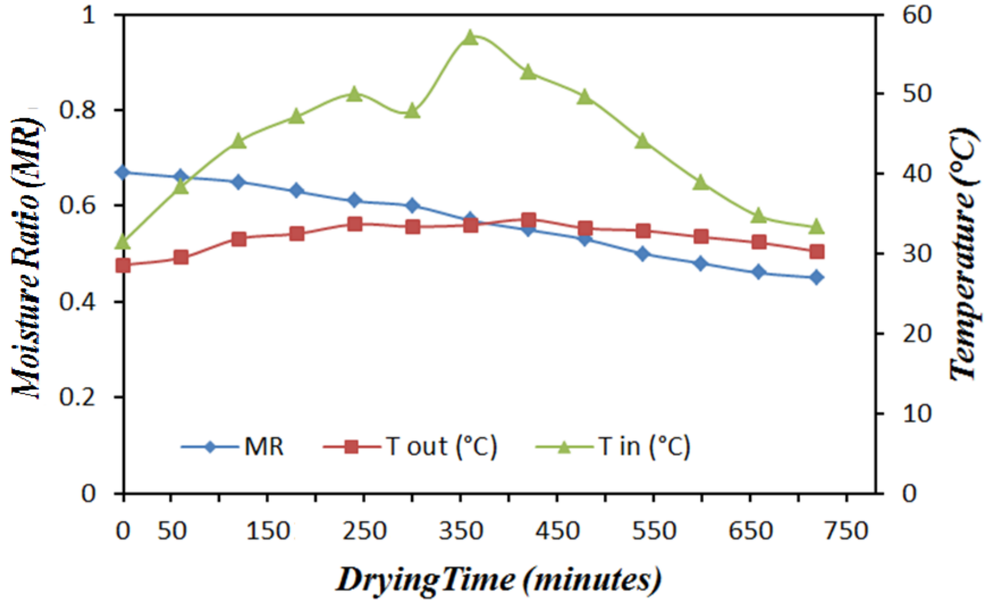

Fig. 5. Moisture Ratio, temperature average of drying chamber (*Tin*) and surrounding temperature (*Tout*) in drying time (minutes) of DSDS

Figure 6 shows the solar radiation intensity (W/m^2) and collector efficiency (%) of DSDS. The highest radiation intensity achieved after 360 minutes (at 2.00 PM) from starting time (at 8.00 AM) similar to collector efficiency around 38.4% at 2.00 PM (360 minutes). As shown in Figure 6, the highest solar radiation intensity of DSDS, the highest the collector efficiency.

Figure 7 shows the mass reduction of banana drying versus drying time comparison using DSDS, CLHPD without preheating, with preheating 30 minutes. It can be seen in Figure 7, that the mass reduction of banana that dried directly using CLHPD preheating of drying chamber 30 minutes faster than CLHPD without preheating and DSDS. This is because the temperature average of drying chamber using CLHPD with preheating 30 minutes highest than CLHPD without preheating and DSDS. The DSDS need around three times drying time for mass reduction of banana (lowest value) compared to CLHPD with and without preheating.

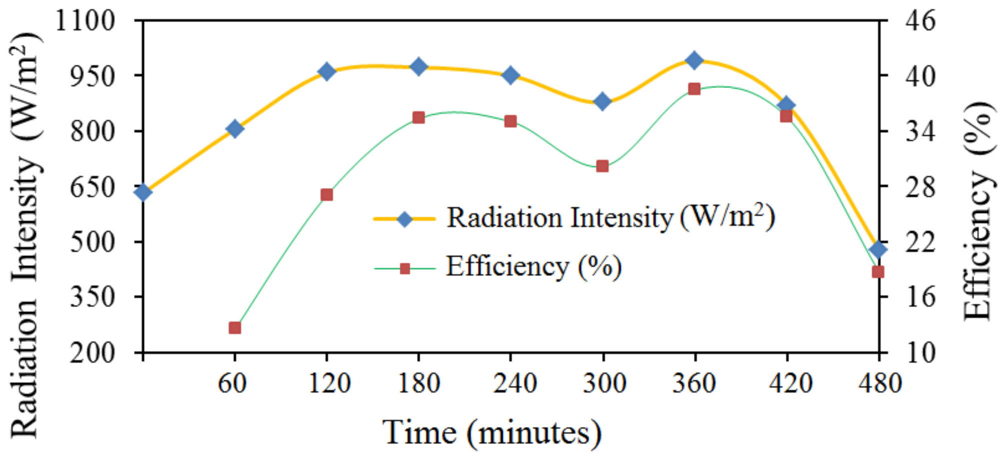

Fig. 6. Solar radiation intensity (W/m^2) and collector efficiency (%) in time (minutes) of DSDS

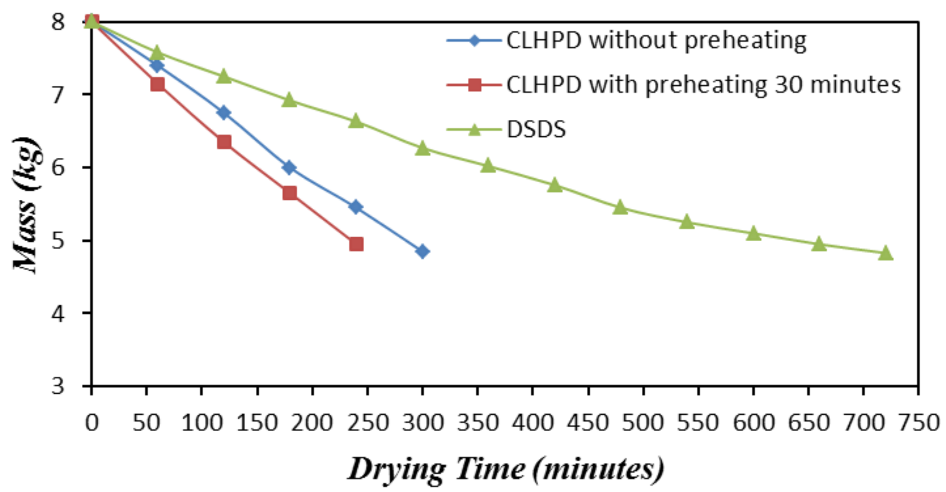

Fig. 7. Mass reduction of banana versus drying time comparison using CLHPD without preheating, with preheating 30 minutes and DSDS

The variation of Specific moisture extraction rate (SMER) of banana with drying time comparison of CLHPD without preheating, with preheating 30 minutes and DSDS is shown in Figure 8. As shown in Figure 8 the SMER value in this study using a heat pump (CLHPD) is higher than the test using a solar dryer (DSDS). The highest SMER value in the heat pump (CLHPD) without preheating is 1.18 kg/kWh and the lowest SMER is 0.83 kg/kWh. The highest SMER value with preheating 30 minutes is 1.29 kg/kWh and the lowest SMER is 0.87 kg/kWh. The highest SMER value in the solar dryer is 0.35 kg/kWh and the lowest SMER is 0.21 kg/kWh. This result was showed that time required for banana drying is faster using a heat pump (CLHPD with preheating 30 minutes) when compared to banana drying using a solar dryer (DSDS).

Figure 9 shows the drying chamber temperature versus drying time comparison of heat pump (CLHPD) without preheating, with preheating 30 minutes and solar dryer (DSDS). Drying temperature in the drying chamber with a heat pump (CLHPD) is higher than the drying temperature using a solar dryer (DSDS), but CLHPD with preheating 30 minutes drying temperature was highest than CLHPD without preheating. This condition similar to the drying temperature chamber, where temperature of CLHPD higher than DSDS.

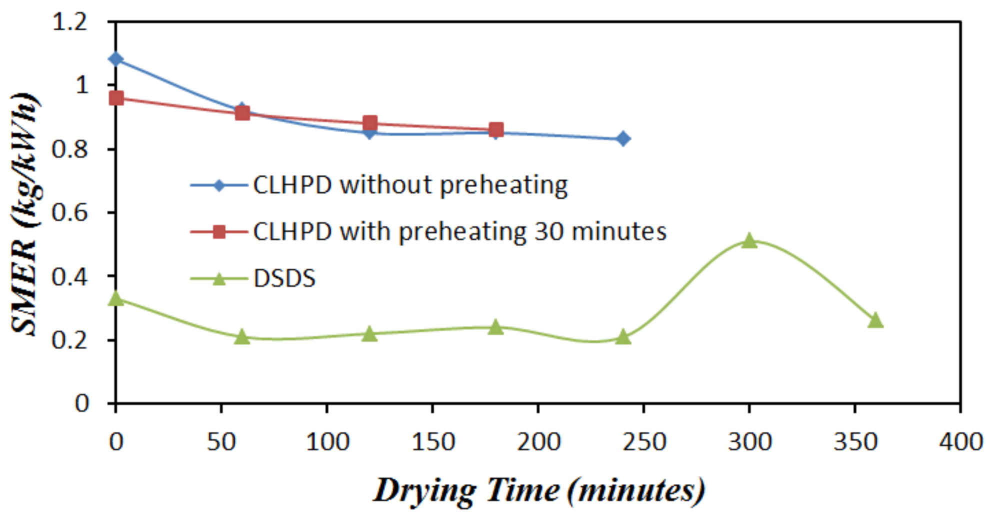

Fig. 8. SMER of banana versus drying time comparison of CLHPD without preheating, with preheating 30 minutes and DSDS

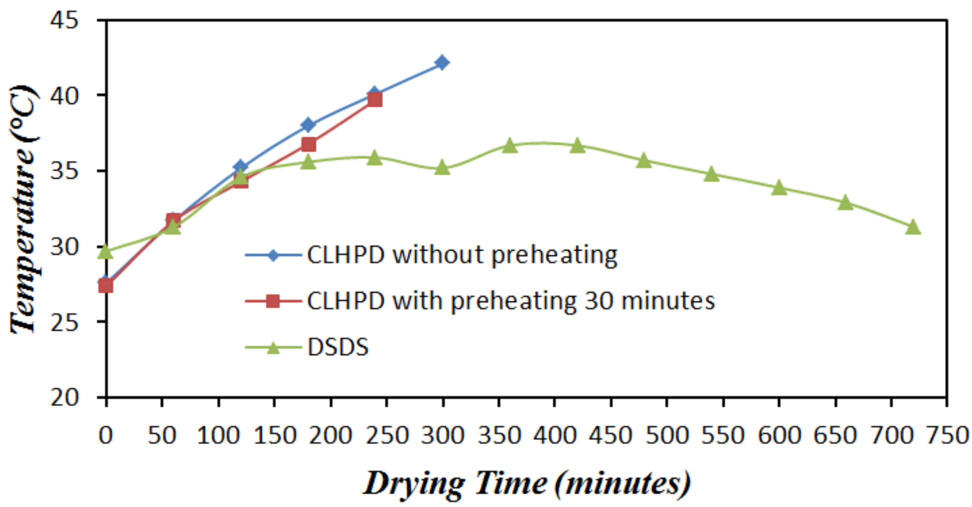

Fig. 9. Drying chamber temperature versus drying time comparison of CLHPD without preheating, with preheating 30 minutes and DSDS

4. Conclusions

The performance and drying characteristic of 3 drying methods including direct solar drying system (DSDS), closed loop heat pump dryer (CLHPD) without preheating and CLHPD with preheating for 30 minutes of banana dryer from the initial mass of 8 kg to evaporate of moisture content of 3.2 kg have been reported. The drying time of banana drying using CLHPD with preheater 30 minutes requires 255 minutes while CLHPD without preheating requires 305 minutes then DSDS requires 720 minutes. The results were showed that banana drying of MR and drying time using CLHPD with 30 minutes preheater was better than using DSDS and CLHPD without preheater. The highest SMER value is 1.18 kg/kWh in the heat pump (CLHPD) without preheating while the lowest SMER value is 0.21 kg/kWh in the DSDS. It was concluded that the time required for banana drying is faster using a heat pump (CLHPD) when compared to a solar dryer (DSDS).

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