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Method to Increase Efficiency of Heat Pump Dryer with Infrared Radiation by Loop Thermosyphone Technique

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Abstract

This research aims to study the efficiency of the loop thermosyphon with header used as an energy-saving in the heat pump-infrared radiation dryer system. The loop thermosyphon consists of a series-type evaporator and a set of condensation in the same size which is 1 kW made of copper pipe, continuous aluminium fin cross-sectional area sized 330x420 mm, vapour pipe and fluid pipe cross-sectional area sized 2.98 cm2 and 1.57 cm2, respectively. R-134a is used as working fluid with filling ratio 25, 50, 75 and 100 % of the evaporator section. The heat pump-infrared radiation dryer system includes drying chamber with stainless steel belt conveyor 300 mm in width, 1,500 mm in length and 5 mm. s-1 of belt conveyor speed, centrifugal fan with motor 1.2 kW, 13 m3 .min-1 of air flow, scroll type compressor 1.75 kW, a set of condensation 4.0 kW, 8 sets of infrared lamp 500 W. The results show that the working fluids have a significant effect the performance of the loop thermosyphon heat exchanger. Which the working fluid filling ratio of 100 % of evaporator capacity, It results in the highest heat transfer of 3 kW, 45 % of efficiency. So, it can be increase the efficiency of this system.

Keywords: Heat Pump dryer, Loop Thermosyphon, Infrared Radiation.

1 Introduction

A drying process is a significant method for processing agricultural products after harvesting. In general, sun drying is largely practiced because of the low operating cost. However, the process takes time and is likely to be contaminated causing low quality of dried products. To resolve the problem, A hot-air drying process is utilized among large scale industries and agriculturists who process agricultural products by themselves. Nowadays, the low-temperature heat pump dryer is an efficient method greatly used due to energy saving, good quality of drying air and drying condition control. In addition, the dehumidification of agricultural materials using infrared radiation which is a form of an electromagnetic wave is another method widely applied to agriculture. The process consumes low energy and is able to create heat rapidly. The combined processes of heat pump and infrared were assumed to reduce energy consumption and acquire good quality of dried products.

The loop thermosyphon is also considered in this study in order to increase ability of heat exchanging.

Waikluan (1997) conducted a study of thermosyphon coil typed and sealed tubes with continuous fins, there are 2 cases including 4 and 8 loops. The condensing and evaporating coils of the loop thermosyphon are 580x203 mm. The outer and inside smooth copper tubes are 10.0 mm and 9.3 mm respectively. There are 12 aluminium fins per inch, 0.15 mm in width. The installation of the coil loop thermosyphon is placed at 58^{o} blocking the evaporator of the air conditioner.

It was found that the average value of the energy efficiency ratio of room condition controlling for 4 loop and 8 loop equals 4.66 and 5.87 BTU.hr^{-1}. Welec^{-1}.respectively.

Phaphuangwittayakul (2000, 2003) studied on the loop thermosyphon made of copper pipe with aluminium fins, the condensing and evaporating tubes sized 9.53 mm inside diameter and 10.0 mm outside diameter. The bevel thermal resistant pipe is at 20 ^{o} and 1,200 mm in length. The working fluid is filled 75 % of evaporator section. Evaporating uses R123 as working substance compared with a mathematic model and a computer program with the basic conditions comprising of cooling capacity of the heat pump dryer at lowest specific energy and highest efficiency. It was found that the efficiency increases from 13% to 45 %, it is compatible with the model. It reveals that the loop thermosyphon is used for energy saving in the heat pump dryer. The percentage is between 12 to 20 % depending on working condition.

Wongsai (2011) studied on the influences of pipe diameter, ratio of working fluid filling and liquid tube which affects the heat of the loop themsyphon with header. The fluid tube and the vapour tube are 19.05 mm in diameter. Evaporating and condensing parts are circular tube with continuous wavy – fin coil. The length of fins and the height of coil are 330 mm and 420 mm, respectively. The coil tubes are smooth copper 10.0 mm in outside diameter. The distance between the midpoint of coil tubes in vertical alignment and flowing is 25.4 mm. the aluminium coil fins are 0.15 mm in depth with 12 fins per inch. The fins are staggered aligned in the coil. The result shows that the diameters of vapour and fluid tubes, filling ratio and types of working substance affect the performance of the loop thermosyphon heat exchanger. For the heat transfer rate, with 19.05 mm in diameter of vapour tube, it results in the highest rate. With the 19.05 mm in diameter of fluid tube, the inlet vapour temperature 80 ^{o}c and the inlet condensing temperature 20 ^{o}c using ethanol as working fluid with filling ratio 75% of evaporator capacity, it reveals the maximum value of the efficiency equals 16.4 %.

The research is to apply the loop thermosyphon with header as an energy saver in the heat pump drying system.

2 Materials and Methods

2.1 Materials

The materials of this reseach consist of heat pump-infrared radiation dryer with loop thermosysphon. Shown in figure1.

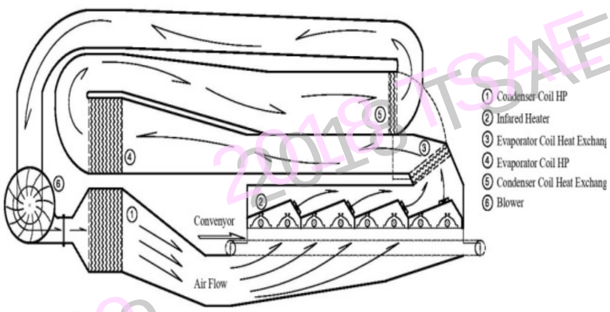

Figure 1 Heat pump-infrared radiation dryer with loop thermosyphom

2.1.1 Drying chamber

The drying chamber consist of 50 litres of capacity, stainless steel conveyor 300 mm in width, 3,000 mm in long, and moving rate between 5-14 mm.s^{-1}.

2.1.2 Heat pump system

The heat pump system consiste of scroll type compressor 1.75 kW, evaporator 2.0 kW, condenser 4.0 kW, working substance circuit with a pressure relieve valve.

2.1.3 Centrifugal fan

The controlled by electric frequency between 0-100 Hz, 1.2 kW motor, maximum air flux 13 m^{3}.min^{-1}.

2.1.4 Infrared radiation

The infrared radiation consiste of 500 W 8 units, temperature controlled by digital thermometer with electric current controller, maximum temperature 380 °C at surface. The frequency range of infrared wavelengths is between 1,011 – 1,014 hertz which is in the same length as microwaves. The infrared wave ranges between red radiation and radio wave, and does not deviate in electromagnetic field. In addition, the radiation energy is direct variation with frequency. Higher frequency results in higher energy.

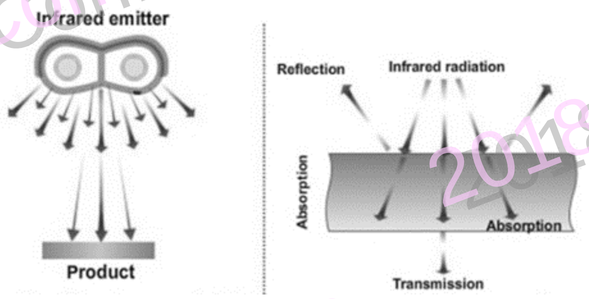

Figure 2 Infrared Transmissions and Absorption

2.1.5 Loop thermosyphon

The loop thermosyphon with headers, adapted from the circular tube – continuous wavy – fin coil 1 kW, 330x430 mm in cross sectional area, smooth inside and outside copper pipe, 10 mm in diameter 4 rows with 13 pipes in each row, staggered aligned pipes connecting to header tubes sized 19 mm in diameter equally for condenser and evaporator, vapored working substance pipe 19 mm in diameter, 2 liquid working substance pipes 10 mm in diameter, R-13a as working substance.

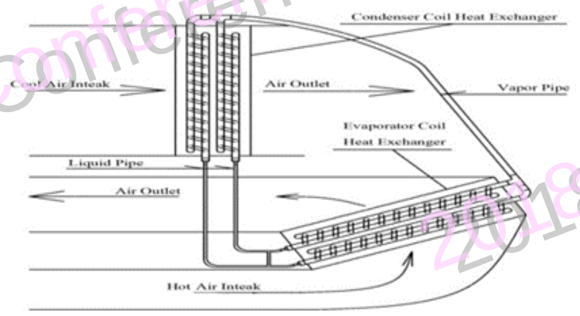

Figure 3 Loop thermosyphon for heat exchanger with headers

2.2 Methods

Operate the heat pump-infrared radiation dryer and collect data in every 2 minutes with the following steps.

Step 1 Operate the fan to flow the air after that turn on the heat pump and set the condenser temperature of the controller at 60 ºC and 13 ºC in the evaporator.

Step 2 Start the infrared radiation system with inside temperature at 60 ºC in the drying chamber.

Step 3 Experiment with altered working fluid filling ratio to 25, 50, 75, and 100 % of evaporator section..

Step 4 Collect all data, and analysing the results from 25, 50, 75 and 100 % examination of the evaporator and then re-examine.

The performance of the loop thermosyphon with headers is examined from evaporater section heat exchange rate to pre-cool air entering the evaporater of heat pump and condenser section heat exchang rate to re- heat air entering dryer. Turn on the main electric system and inspect the system.

The loop thermosyphon is high potential device to use for heat transfer. It consists of evaporator and condenser sections with vapour and liquid pipes. The function of the system is when a working substance in the evaporator is heated by a high temperature resource. The working fluid is vapored condensing to liquid which returns to evaporator forced by the gravity. The vaporing and condensing processes are exothermic and endothermic reactions generating heat transfer. There are pre-cool phase before entering the evaporator and re-heat phase before entering the condenser in the heat pump dryer system.

The outer air is entered the system by a fan through the heat pump condensing part. The temperature of air increase is using for drying process. The hot air is capable of absorbing moisture from agricultural products in the drying room. The humidity hot air enters the evaporator section of the loop thermo syphon resulting to decrease of temperature (pre-cool). The air then moves to the evaporator of the heat pump which causes more condensed air reducing temperature and humidity. Afterwards, the cool air enters the condenser section of the thermo syphon causing higher temperature (re-heat) before moving into the fan and the condenser, respectively. This process can increase the efficiency of heat pump –radiation dryer system.

2.3 Relevant Theories

2.3.1 Heat exchanger

The cross-flow heat exchanger operates when a liquid flows crossing another liquid. The capacity of the exchanger is as following equation.

Efficiency of the heat exchanger

$$Eff = Q/Q_{max} \quad (1)$$

$$Q = \dot{m}C_p(\Delta T) \quad (2)$$

$$Q_{max} = (\dot{m}C_p)_{max}\Delta T_{max} \quad (3)$$

$$\Delta T_{max} = T_{(h,in)} - T_{(c,in)} \quad (4)$$

Where,

Eff= Efficiency of heat exchanger(decimal)

Q = Heat transfer (W)

Q_{max} = Maximum heat transfer (W)

$\dot{m}$ = Mass flow rate (kg.s^{-1})

C_p= Specific heat capacity of fluid (J/kg•K)

ΔT = Temperature difference (K)

ΔT_{max}= Maximum temperature difference (K)

$T_{(h,in)}$ = Temperature of inlet hot fluid in evaporator (K)

$T_{(c,in)}$=Temperature of inlet cool fluid in condenser (K)

$\dot{m}_h$= Mass flow rate of hot fluid (kg/s)

$\dot{m}_c$ = Mass flow rate of cool fluid (kg/s)

C_{ph} = Specific heat capacity of hot fluid (J/kg•K)

C_{pc} = Specific heat capacity of cool fluid (J/kg•K)

$T_{(h,in)}$= Temperature of inlet hot fluid in evaporator (K)

$T_{(h,out)}$=Temperature of outlet hot fluid in evaporator (K)

$T_{(c,in)}$= Temperature of inlet cool fluid in condenser (K)

$T_{(c,out)}$= Temperature of outlet cool fluid in condenser (K).

3 Result and discussion

Evaporator and condenser temperatures of loop thermosyphon as showed in Table 1, it can be concluded that the average of different inlet and outlet temperatures of the evaporator and the condenser section at 100% of the evaporator capacity, yields maximum value. With the large area of working fluid, it absorbs more heat and resulting in to change from liquid to vapour a large amount which can transfer a maximum of heat.

Table 1 Average temperature difference of evaporator and condenser of loop thermosyphon with 25, 50, 75 and 100% of working fluid filling ratio of evaporator.

Filling Ratio.	25%		50%		75%		100%	
Part of LTS	Evap.	Cond.	Evap.	Cond.	Evap.	Cond.	Evap.	Cond.
Temp Diff. degrees Celsius	6	11.8	8.8	10.4	8.7	13.3	11.2	20.1

From table 1 when the filling ratio increase the average temperature difference of evaporator section and condenser section increase together but condenser section more than evaporator section all of filling ratio. The average temperature difference maximum at 100% filling ratio. It can be said that the maximum averages temperature difference of evaporator and condenser is 11.2 and 20.1 °C, respectively.

Results of working fluid filling ratio and heat transfer in pre-cool and re-heat phase of 25, 50, 75, and 100% of evaporator section show in figure 4.

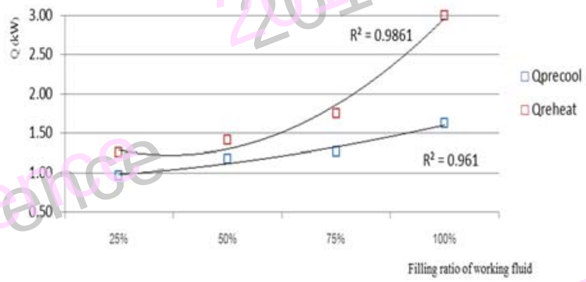

Figure 4 Filling ratio with condenser and evaporator heat transfer of loop thermosyphon.

From figure 4,. it can be said that when filling ratio increases from 25, 50, 75 and 100% of evaporator capacity, the condenser and evaporator heat transfers rate to 1.2, 1.4, 1.7, 3.0 and 1.0, 1.2, 1.3, 1.6 kW ,respectively.

Furthermore, it reveals that the heat transfer rate of the condenser is higher than the evaporator in all filling ratio as the condenser heat transfer works better than the evaporator. At the 100% of filling ratio, it results show that the maximum heat transfer rate of 3 kW.

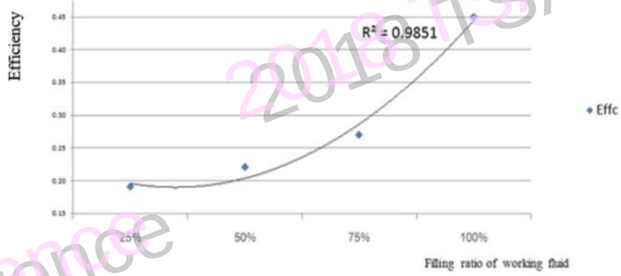

Figure 5 Filling ratio of working fluid and Efficiency of loop thermosyphon.

According to Figure 5, it indicates that the increasing filling ratio of working fluids from 25, 50, 75 and 100% of the evaporator capacity affects the efficiency which increases from 0.19, 0.22, 0.27 and 0.45, respectively. The filling ratio of 100% reflects the highest efficiency of 45%. Thus, it can be summarized that the filling ratio of 100% has the optimum efficiency of the heat exchanger in this experiment.

4 Conclusions

The filling ratio of working fluids provided significant effects the performance of the loop thermosyphon heat exchanger. The filling ratio of 100% of evaporator capacity, it resulted in the highest heat transfer of 3 kW, 45% of efficiency. So, the loop thermosyphon can increase the efficiency of heat pump dryer system.

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