Specific Energy Consumption comparative study of Hot Air dryer and Heat Pump dryer for highland drying process

Sayompon Srina†
Department of Mechanical Engineering, Faculty of Engineering,
King Mongkut's University of Technology Thonburi,
126 Prachauthit rd., Bangmod, Thungkru, Bangkok 10140, THAILAND
Tel: +66 08 6230 0620, E-mail: sayompon.sri@hotmail.com

Atikorn Wongsatanawarid
Department of Mechanical Engineering, Faculty of Engineering,
King Mongkut's University of Technology Thonburi,
126 Prachauthit rd., Bangmod, Thungkru, Bangkok 10140, THAILAND
Tel: +662 470 9265, E-mail: atikorn.won@kmutt.ac.th

Abstract

This research study is developing alongside with Royal project in Chiang-Rai province. The objective is exactly aim to reduce the energy usage and production cost of drying process which is used typically for several products of highland area for example flower teas, fruits and vegetables. The study evaluates the drying performance of the conventional drying oven of 60 kg batch size, rather than that we introduce the developing of drying oven designed for better velocity distribution using computational fluid dynamics model in enhancing performance of the oven. The heat sources are performed by indirect heating hot water to air using fin-tube heat exchangers in comparison to a heat pump combined heat pipe system. The oven sizes of 0.4 m in width, 0.45 m in height and 0.6 m long with 6 trays. Drying process is controlled for finished products with 6-7 moisture percentages in dry basis. The results showed that evaporation rate of the indirect hot air dryer and the heat pump dryer were 0.15 and 0.72 kg of moisture/hr with specific energy consumption of 147.3 and 168 MJ/kg respectively. The oven design and developed configuration of the system could be discussed further in details.

Keywords: Hot Air Dryer, Heat Pump Dryer, Energy Consumption

1. Introduction

Sa-Ngo Royal Project Development Center locates at Mount Sa-Ngo, Sridornmoung, Chiangsan, Chiang-Rai Province was initiated by His Majesty King Bhumibol Adulyadej in 1969. It was introduced to encourage hill-tribe villagers to shift from the cultivation of opium poppies to alternative crops. Recently, the Sa-Ngo Royal Project supports farmers to plant Chamomile and Chrysanthemum as majority products. They harvest the fresh products from farmers to produce Chamomile tea and Chrysanthemum tea using drying processes.

The old fashion oven size shown in Figure 1 was 1 m long, 2 m wide and 1.6 m high, with 10 trays and a loading capacity of about 60 kg of fresh flower per batch. The Chamomile flower drying program has 2 steps. First drying step that Chamomile flowers are heated up to

† Corresponding author

80 °C and holing for 4 hours then they are kept at 40 °C for another 8 hours. Chrysanthemum flower drying process is also run by the same oven size. The Chrysanthemum flower drying is carried out by 2 methods. One Chrysanthemum flowers is dried at 40 °C for 12 hours. The second method is that Chrysanthemum flowers are grouped in disc shape then they are steamed for 10 seconds in believing that short steam heating will rush up their color. Then wet bunches of Chrysanthemum are dried at 40 °C for 24 hours.

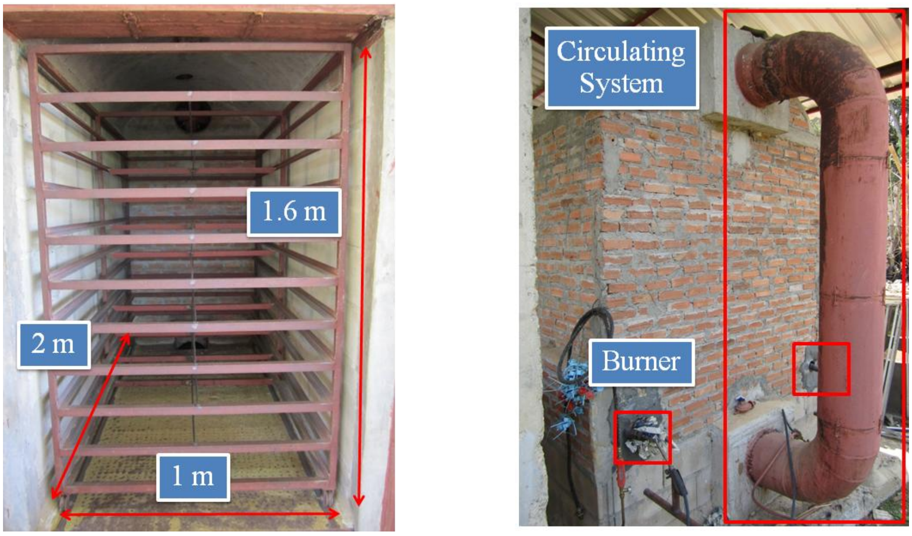

Figure 1: Drying Oven of Sa-Ngo Royal Project Development Center.

Basically, the oven was simply built without any engineering design that leads to high energy consumption and takes very long time for processing. During the drying process, they have to open the oven to rearrange the trays due to a big variation of temperature in the chamber. Therefore opening the door could drop the temperature in the chamber this consumes more fuel in compensate.

Computational fluid dynamics (CFD) have been widely used for predicting the fluid flow pattern in drying chambers (Norton and Sun, 2006). To design a fruit cabinet dyer with obtaining a uniform distribution of drying air flow and temperature, Amanlou and Zomorodian (2010) used CFD for predicting the air velocity and temperature in drying chamber. Rujininnat (2001) had designed and evaluated drying performance of a cabinet dryer using LPG as a direct heat source for drying air. The drying conditions were the drying air temperature 60 °C, the airflow rate of 0.95 m^3/s and air recycle of 81.6 %. To improve the energy utilization and reduce the energy cost per unit mass in traditional longan fruit drying, Tippayawong et al (2009) introduced a novel forced draft and recirculating air dryer. It was found that the same mass of dried longan fruit produced, specific energy utilization, fuel cost and operating cost were reduced by more than 42 %, 45 % and 27 % respectively. Teeboonma, Tiansuwan and Soponronnarit (2003) recommended the most important factors when examining the optimum conditions of heat pump fruit dryers (HPD) and for minimizing HPD cost are recycle air ratio, evaporator bypass air ratio, airflow rates and drying air temperature. Nirubon and Tul (2003) studied the performance of a combined heat pump-heat pipe dryer and compared the difference between a drying process using heater and a combined heat pump-heat pipe.

Nomenclature

DR	drying rate, kg/h
SEC	specific energy consumption, MJ/kg
LHV	lower heating value for fuel, J/kg
m_f	mass of fuel used, kg
m_w	mass of moisture lost, kg
h	drying time, hour

The objectives of this research were to design the new drying oven by using CFD and evaluated drying performance of new drying oven that the heat sources are performed by indirect heating hot water to air using fin-tube heat exchangers in comparison to a heat pump combined heat pipe system.

2. Methodology

2.1 Design improvement

The new drying oven was newly designed based on; (i) Heat source: A new drying oven is designed in compatible with various heat source such as LPG burning, Agriculture waste burning and also hot air from heat pump system using indirect heating method, however, in this study LPG burning is our priority. (ii) Fluid dynamics: Hot air in a dryer chamber is designated flow and direction by means of force convection which give higher drying rate than the present oven. (iii) Thermal insulation: Drying cabinet and connecting hot water pipes are well insulated to prevent excessive heat loss. With a well insulated system, a narrower temperature fluctuation inside the dryer could be obtained, as well as variation of temperatures in a layer can be greatly reduced; and (iv) Air side control: Thermocouples were installed at inlet and exit to measure the temperature and relative humidity of drying air. This was simpler and more convenient to allow control of the drying conditions and process fine tuning.

2.2 Indirect hot air dryer system

Figure 2 illustrates the new system design. It consisted of a hot water system and a drying chamber. The hot water system consisted of two fin-tube heat exchangers, a heat exchanger direct heated with firing of LPG using high efficiency self-respirating burner. A hot water pump of 1 hp electrical motor flows hot water through the second heat exchanger installed at upstream of drying chamber. There was a 0.5 hp of centrifugal fan generated hot air flow throughout the oven size of 0.4 m in width, 0.45 m in height and 0.6 m long with 6 trays. The piping lines were all insulated with 25 mm-thick of EPDM rubber. All ducts were tightly insulated with 25 mm-thick cellular glass insulation cladding with galvanized sheets.

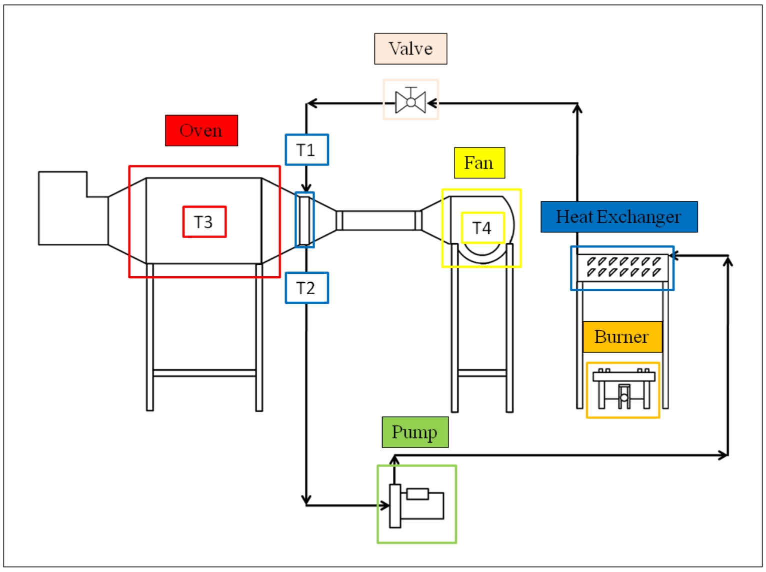

Figure 2: An indirect hot air dryer.

2.3 Heat pump combined heat pipe heating system

In figure 3, the heat pump system was using reverse refrigeration cycle of 36,000 Btu/hr combined with a heat pipe in front of the condenser. With normal operation of the R-22 cycle it can generated maximum of hot air at condenser outlet of 52 °C. The heating system was installed to the oven size of 1 m in width, 1.7 m in height and 1.4 m long with 24 layers of tray. This is comparative study of drying process in identical of inlet condition of the oven in terms of drying rate and energy consumption. The system piping and ducting were also well insulated with EPDM close cell rubber in preventing heat loss in the same level.

2.4 Test procedure and evaluation

The experimental program includes the influences of various operating parameters on the dryer performance and drying characteristics of the marigold flower as an example. The target point is reducing the product moisture to 6 % in a dry basis. Table 1 lists the conditions of the experimental carried out in the present work.

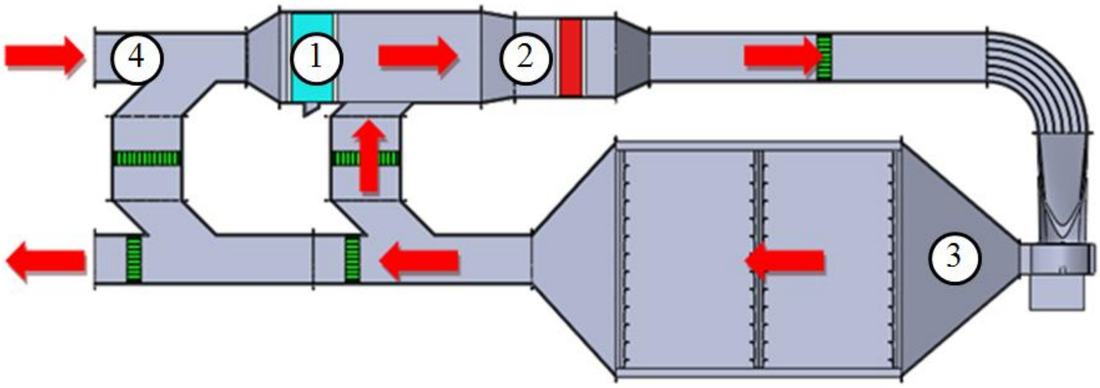

Figure 3: A heat pump combined heat pipe dryer.

Table 1: The experimental conditions for marigold drying in comparative study.

Investigating parameters	Indirect hot air dryer	Heat pump-heat pipe dryer
Surface load (kg/m^2)	3	3
Ambient temperature (^{o}C)	33.2	32.6
Ambient relative humidity (%RH)	63.5	62.3
Inlet drying air temperature (^{o}C)	51.7	51.3
Inlet drying air relative humidity (%RH)	22.9	19.7
Average air velocity (m/s)	1.64	0.91
Bypass air (%)	0	80

Drying rate is defined as the evaporation mass of moisture from the products divided by the drying time.

$$DR = \frac{m_w}{h} \tag{1}$$

Specific energy consumption is defined as the summation of energy used including electrical and thermal energy used per unit mass of evaporation moisture. As for the LPG burning, the SEC could be obtained by;

$$SEC = \frac{m_f \cdot LHV}{m_w} \tag{2}$$

3. Results and discussion

3.1 Drying characteristic

The experimental results of the indirect hot air dryer showed that the average temperature of inlet hot water (T1) was 94.2 ^{o}C, the outlet hot water (T2) was 77.2 ^{o}C, the drying (T3) was 51.7 ^{o}C and the e ambient (T4) was 32.6 ^{o}C as shown in figure 4. In figure 5 demonstrated the variations of relative humidity at inlet and outlet of the drying chamber in comparison with ambient as a function of drying time.

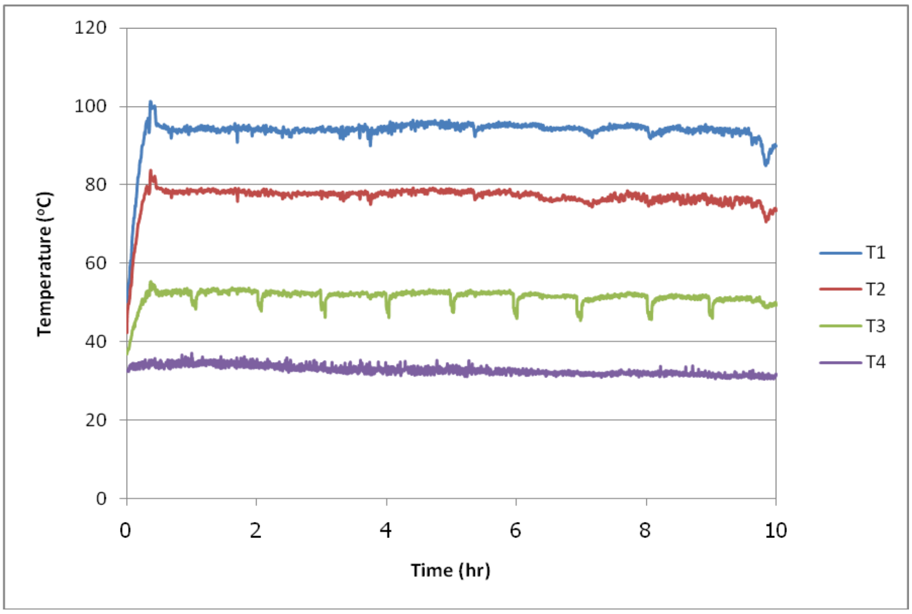

Figure 4: Experimental inlet and outlet temperatures of the indirect hot air dryer.

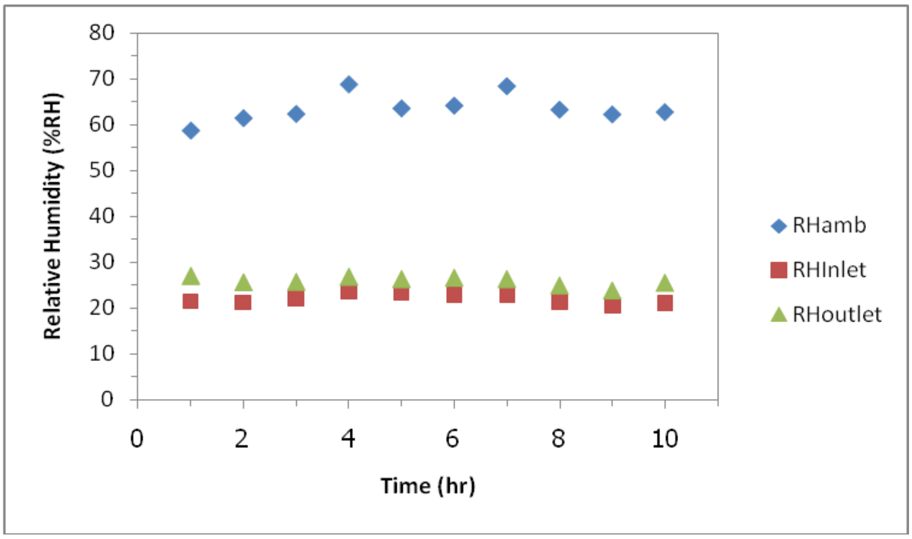

Figure 5: Inlet and outlet relative humidity of the indirect hot air dryer in the experiment.

The experimental results of the heat pump combined heat pipe dryer of the average temperature of air at evaporator inlet (T1), condenser inlet (T2), drying temperature (T3) and ambient temperature (T4) were 23.5, 35.2, 51.3 and 33.5 in degree centigrade respectively. The temperature plots with time as shown in figure 6.

Figure 7 shows the variations of relative humidity at inlet and outlet of the drying chamber as a function of drying time.

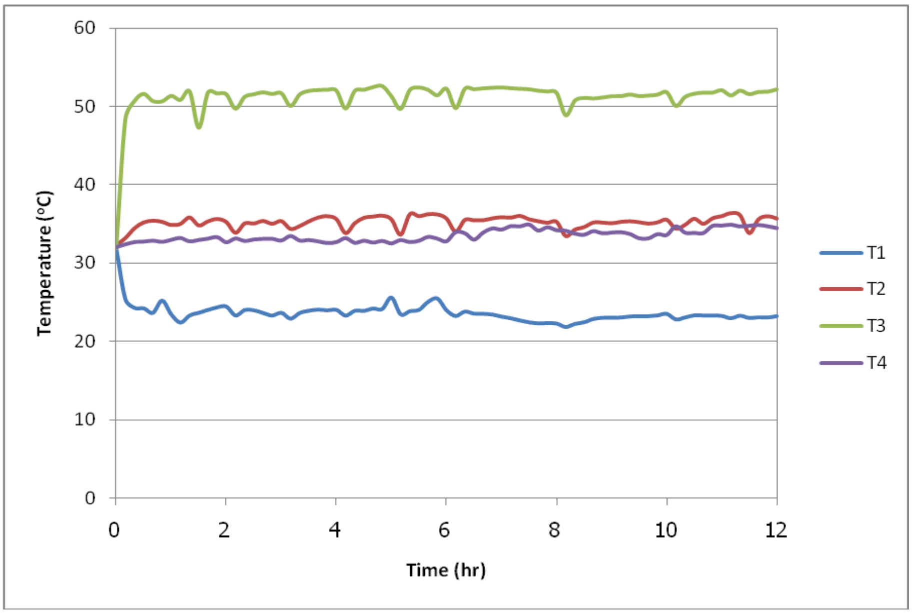

Figure 6: Experimental inlet and outlet temperatures of the heat pump-heat pipe dryer.

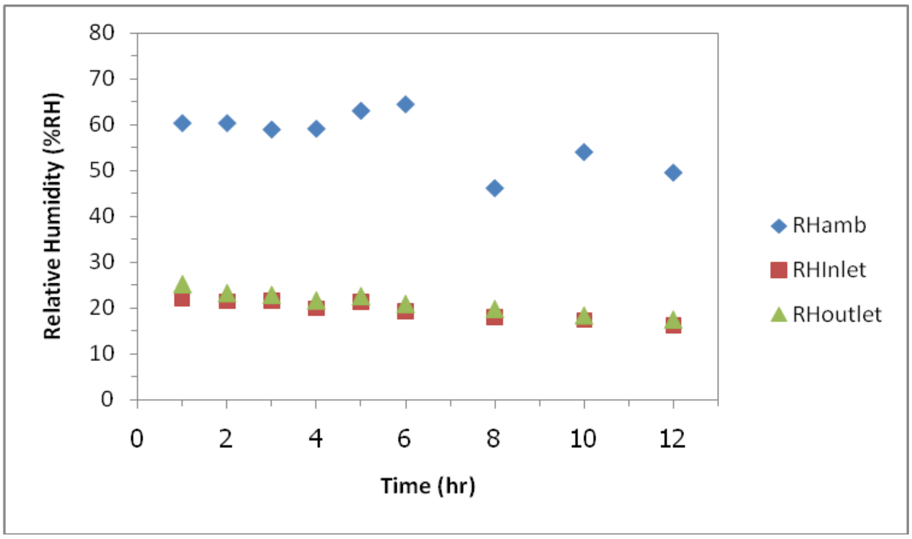

Figure 7: Inlet and outlet relative humidity of the heat pump-heat pipe dryer in the experiment.

The drying rate data was collected during the process for fix amount of the sample. The sampling was taken at every hour from each tray during the process. The results data were tabulated for indirect hot air dryer and heat pump combined heat pipe dryer in table 2 and 3 respectively. The highlighted data was showing that it was achieved to the target weight.

Table 2: The marigold was dried by using the indirect hot air dryer.

Time (hr)	Marigold weight (kg)					
	1	2	3	4	5	6
0	0.288	0.290	0.290	0.290	0.290	0.302
1	0.220	0.216	0.210	0.218	0.238	0.248
2	0.172	0.166	0.158	0.176	0.198	0.212
3	0.132	0.132	0.122	0.146	0.170	0.186
4	0.104	0.102	0.094	0.124	0.144	0.162
5	0.080	0.078	0.072	0.096	0.122	0.144
6	0.062	0.058	0.056	0.080	0.104	0.118
7	0.052	0.048	0.040	0.066	0.090	0.106
8	0.044	0.036	0.034	0.056	0.072	0.088
9	0.030	0.030	0.022	0.046	0.058	0.074
10	0.030	0.026	0.022	0.040	0.056	0.068

Table 3: The marigold was dried by using the heat pump-heat pipe dryer.

Time (hr)	Marigold weight (kg)			
	1	2	3	4
12	0.459	0.420	0.739	0.718
14	0.359	0.340	0.579	0.558
16	0.339	0.330	0.479	0.458
18	0.319	0.320	0.379	0.358

3.2 Specific energy consumption

Table 4 presents comparison of the indirect hot air dryer and the heat pump combined heat pipe system dryer. From our findings, the average drying time of the indirect hot air dryer was 8 hours, the average drying time of the heat pump combined heat pipe system dryer was 12 hours, the drying rate of indirect hot air dryer and the heat pump combined heat pipe system dryer were 0.15 and 0.72 kg of evaporated water/hr respectively, the specific energy consumption of the indirect hot air dryer was found to be 147.3 MJ/kg water evaporated and the specific energy consumption of the heat pump combined heat pipe system dryer was found to be 168 MJ/kg water evaporated. It should be noted that the energy consumption of heat pump combined heat pipe system was electricity then the conversion here was not include any consideration of second law of thermodynamics then the energy quality was not taken into account.

Table 4: The comparison of the indirect hot air dryer and a heat pump-heat pipe dryer.

Title	Indirect	Heat pump
Average drying time (h)	8	12
Drying rate (kg/h)	0.15	0.72
Specific energy consumption (MJ/kg)	147.3	168

4. Conclusion

In this study, the developing of drying oven designed for better velocity distribution using Computational Fluid Dynamics model in enhancing performance of the oven. The performance of the indirect hot air dryer was compared with the heat pump combined heat pipe system dryer. Improvement in drying time was successfully demonstrated. However, the complexity of the system design was not discussed here. The batch size of experimental study was also largely difference. Regarding to the experimental resulted, we would inform that the hot air dryer using LPG burning was performed comparably to the heat pump combined heat pipe system in the view point of energy consumption.

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