

Performance and Characteristics of Heat Pump Clothes Drier

H Ambarita¹, D M Nasution^{2*}, S Gunawan³, A H Nasution¹

¹Mechanical Engineering, University of Sumatera Utara, Medan 20155, Indonesia

²Mechanical Engineering, Sekolah Tinggi Teknik Harapan, Medan 20216, Indonesia

³Mechanical Engineering, Sekolah Tinggi Teknologi Sinar Husni, Medan 20373, Indonesia

*dianmorfinasution@gmail.com

Abstract. In this paper, a study of clothes drying using a heat pump drier has been carried out. The objective is to examine the performance and drying characteristics of the heat pump clothes dryer. The result of performances and drying characteristics were compared with waste heat drying system of split-type residential air conditioner (RAC). A drying chamber with volume 1 m³ integrated with heat pump component had been designed and fabricated. The heat pump operated by vapor compression cycle with power input of 800W and refrigerant R22 as a working fluid. The clothes dried made of pure cotton with initial weight varied from 3.00 kg, 5.25 kg, and 6.38 kg, respectively. The results shown that the drying time and drying rate of heat pump drier are faster than waste heat drying system. The average total performance of heat pump clothes drier is 6.56. On the other hand, SMER which is obtained 1.492 kg/kWh. These values are lower than the SMER of waste heat drying system which shown the average value of 2.492 kg/kWh. In the case of drying clothes, waste heat drying of RAC shows a better performance in comparison with heat pump drying system.

1. Introduction

Drying is a process that uses amount of energy (typically heat) to evaporate water from the moist object. There are several treatment/products that use drying in their process, such as industrial drying, agricultural product drying and clothes drying. In daily life activities, drying clothes is one of the biggest sectors that consume huge amount energy. Based on a study in USA, electricity consumption for drying clothes is estimated as 71 Terawatt hours (TWh) per year it is up to 9% of electricity consumption in the USA [1, 2]. For Indonesian case, to the best knowledge of the authors, there is no report on energy consumption of electricity for drying clothes. However, there is an increasing number of commercial laundry business which use commercial drying instead of typical natural drying. In the commercial sector tumbler rotating drum and flowed by hot air of 40-60°C is the most used system [3].



The method of using the heat from a condenser of vapor compression cycle is known as heat pump drying. Several researchers have published their work related to heat pump drying [4]. Braun et al [5] reported a study on energy efficiency analysis of air cycle heat pump dryers. Two types of cloth dryers were compared the first one is conventional tumbler dryer using electric heater and the second one is using reversed Brayton cycle. Ameen and Bari [6] investigated the feasibility of drying clothes using waste heat from a condenser of a typical split-type RAC used in high rise urban apartments. Three methods drying clothes were compared, they are drying with commercial dryer using 1 kW electric heater, natural drying of the clothes indoors, and drying clothes using condenser heat (heat pump dryer). The results showed that the drying rate for commercial dryer, natural drying, and heat pump dryer was 0.319 kg/hr, 0.139 kg/hr, and 0.424 kg/hr, respectively. The drying time varied from 120 minute to 390 minutes. In order to compare the performance of the dryer, specific energy consumption (SEC) rate in kWh/kg and specific moisture extraction rate (SMER) in kg/kWh were proposed. Here the mass of the clothes dried were not varied and the characteristics of the drying cabinet were not discussed.

Deng and Han [7] performed experimental study on clothes dryer using rejected heat from split-type RAC. A laboratory experimental rig has been purposely set up. The RAC with specification of 6.4 kW of cooling capacity a typical RAC size applicable to a room of up to 30 m² in Hongkong was used. The initial weight of clothes dried was about 3 kg. Two methods of drying were compared, electricity clothes dryer and the method proposed. The electricity consumption and drying time were compared. The results showed that the additional electric use of RAC was only 1.2%. A further study on a new termination control method for clothes drying process in their previous clothes dryer has also been reported [8]. Mahlia et al [9] reported an experimental study on using heat wasted from split-type RAC for drying clothes. The system proposed consists of a drying chamber and a moveable unit of RAC. The study compared the effectiveness of the drying system proposed to a conventional one in terms of drying time and energy consumption. The results showed that drying time was from 70 minutes to 420 minutes. The drying rate for the test ranged from 0.56 kg/hr to 0.75kg/hr with RACD compared to 0.13 kg/hr for indoor drying and 0.18 kg/hr for out door drying. The analysis showed that SMER varied from 0.1809 kg/kWh to 0.2205 kg/kWh. The RAC clothes dryer is claimed more efficient way to dry clothes and in term of time it is also more effective. However, the increase of fan capacity due to air resistance was not taken into account. Suntivarakorn et al [10] reported a study on clothes dryer using waste heat from split-type RAC. The results showed that the drying rate of clothes using waste heat from air conditioner is between 1.1 kg/hr to 2.26 kg/hr. This was claimed better than commercial dryer and natural drying.

Recently, Ambarita et al [11] reported an experimental study on performance of a clothes drying chamber by utilizing waste heat from a split-type residential air conditioner. A room chamber with a volume of 1 m³ has been designed and fabricated. The waste heat from the condenser of the RAC with power of 800W was utilized as a heat source. In the experiments the RAC was operated to keep a conditioned space at 20°C. The clothes dried made of pure cotton with initial weight varied 3.05kg, 5.25 kg, 6.21 kg, 8.22 kg, and 10.22 kg. Two different inlets, single inlet and multi inlets, has been tested. The results show that the drying time varies from 80 minute to 410 minutes. For single inlet the averaged drying time, optimum initial weight, optimum drying rate and optimum SMER was 242 minutes, 6.21 kg, 0.868 kg/hr, and 2.345 kg/kWh. On the other hand, the drying chamber with multi inlets the averaged drying time, optimum initial weight, optimum drying rate and optimum SMER was 222 minutes, 8.22 kg, 0.922 kg/hr, and 2.492 kg/kWh.

The above reported studies showed that there are two type of systems that employ vapor compression refrigeration cycle for drying clothes. They are pure heat pump system [5] and waste heat system [6-11]. In those study the comparisons have been made for natural drying, electricity clothes drying, and RAC heat rejected drying. The comparison of vapor compression cycle as pure heat pump system and waste heat system for drying clothes has not been reported. In this study the performance and characteristics of clothes drying using pure heat pump drying system is investigated. The main focus will be the comparison of heat pump system and waste heat drying system of RAC. Here, the

heat pump clothes drier is optimized by adding a cross-flow flat plate heat exchanger assigned as a heat recovery. The effect of drying load will be analyzed in term of total performance, SMER, drying time, and drying characteristics. The results of this study provide important information related to the advantages and disadvantages of both systems in drying clothes.

2. Methods

2.1. Experimental apparatus

In order to perform the experimental, a lab scale model of heat pump drier with dimensions of 3000 mm × 1000 mm × 1800 mm has been designed and fabricated. The main components is the compressor, condenser, expansion valve, evaporator, fan, flat plate heat exchanger, and drying chamber. The drying chamber has a volume of 1 m³ with dimensions of 1400 mm x 1000 mm x 1080 mm. Heat pump installed in a dryer is a modification of a split-type of RAC by commercial name is Samsung and model AS09TUQX. The specifications of the heat pump used in this study are shown in Table 1. The fan used on drying system has a power input of 105 W. Flat plate heat exchanger has dimensions of 400 mm × 400 mm × 400 mm using a zinc plate material with a thickness of 0.35 mm, the distance between the flat plate 4 mm, and the number of gap 92.

Table 1. Specification of heat pump

Parameter	Value
Power (Averaged)	800 W
Operation	Vapor Compression Cycle (VCC)
Voltage/Frequency	220 -240 V/50 Hz
Current (Maximum)	4.7 Ampere
Dimension of Condenser Unit	660 mm × 470 mm × 240 mm
Dimension of Evaporator Unit	820 mm × 283 mm × 210 mm

Data acquisition unit installed on the experimental apparatus as a measurement tool. The temperature and humidity of the drying air was measured using a Portable Thermohygrometer with accuracy 1.0°C and 5% RH. Measurement of the temperature and humidity are 5 points, namely the drying chamber, enter the heat exchanger, evaporator entrance (exit heat exchanger), exit the evaporator (air reentry into heat exchanger), and out of heat exchanger (condenser sign). The velocity of the hot air was measured using a DT-8880 Hot wire anemometer with speed measuring range and accuracy of 0.3 to 30 m/s and ± 3%, respectively. Weight measurements of clothes dried using type-S Load cell with an

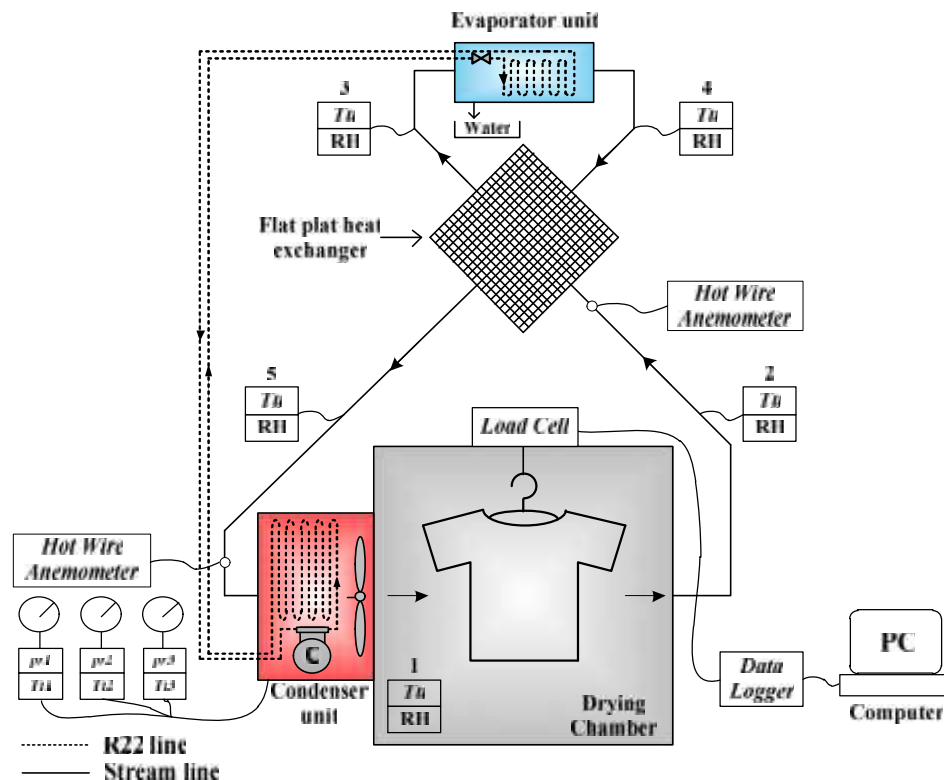


Figure 1. Experimental apparatus and data acquisition unit.

accuracy of 1.0 grams which is placed on the outside of the drying chamber. The pressure of R22 is measured using a pressure gauge on the 3 position, namely the compressor suction side, discharge of the compressor and the condenser exit. The schematic diagram of the heat pump drier and data acquisition unit is shown in Fig. 1.

Drying air moves in through the drying chamber at point 1 and absorbs moisture from clothes. The air that contains high moisture content at point 2 is then directed past the heat exchanger (2 to 3) and then across the evaporator coil (3 to 4). Heat exchanger works as a heat recovery to air at 4 to 5 points. During the dehumidification process (the humidity) from point 3 to point 4, the first time the air conditioning cooled the sensible until the dew point (dew point). The cooling process will produce condensation of water vapor contained in the air dryer. Latent heat of evaporation of water is then absorbed by the evaporator to boil the refrigerant. Heat is recovered will be pumped to the condenser. The air cooled and lowered the humidity will absorb the heat that is released condenser from point 5 to point 1 as heating sensible to raise the temperature of the drying air.

2.2. Performance parameters

As mentioned above, in the experiments the temperatures, weights, and air velocity in the drying cabinet will be read and recorded by a data acquisition unit. The voltage, electric current, and pressure of the heat pump will be measured. These measured parameters will be used to analyze performance parameters. The performance parameters used in this study are explained as follows.

In this study, parameter of performance of specific moisture extraction rate (SMER) will be used. This parameter is defined as number of moisture removed from the clothes divided by energy consumed. Here, the energy used for removing the moist from clothes consists of heat release from condenser and energy to power the auxiliary fan (W_f). Since the heat released from condenser is the

generated heat of vapor compression cycle by power input of compressor (W_c) [12]. Thus, SMER [kg/kWh] will be calculated using the following equation:

$$\text{SMER} = \frac{\dot{m}_d}{W_c + W_f} \quad (1)$$

The drying rate, $\dot{m}_d$ [kg/hr or gr/minute] of the clothes dried is calculated by the following equation:

$$\dot{m}_d = \frac{m_i - m_d}{\Delta t} \quad (2)$$

where m_i and m_d is the mass of the clothes at initial time (wet) and at dry, respectively. Δt is interval measurement in hr or minute of wet clothes and dry mass (kg), and t is the drying time (hours). Heat pump dryer performance expressed in total achievement (TP), which is calculated by the equation:

$$\text{TP} = \frac{Q_k + Q_e + Q_h}{W_c + W_f} \quad (3)$$

where Q_k and Q_e each the amount of heat that is released condenser and evaporator heat absorbed (kW). Q_{he} is a total heat generated of heat exchanger (kW) in the form of sensible heat summation (Q_s) with latent heat (Q_L) is calculated by:

$$Q_h = Q_s + Q_L = [\dot{m}_h C_{p,h} (T_{h,i} - T_{h,o})] + [\dot{m} \times h_{fg} \times (w_{hi} - w_{do})] \quad (4)$$

where $\dot{m}_h$ the mass flow rate of air in kg/s, $C_{p,h}$ is the specific heat of air (kJ/kg.°C), $T_{h,i}$ and $T_{h,o}$ each temperature of air in and out of heat exchanger, h_{fg} the heat of vaporization enthalpy (kJ/kg) and w_{hi} , w_{do} is the humidity ratio of air temperature and relative humidity.

2.3. Clothes dried and drying method

The clothes dried in the present experiments were several shirts made of cotton. The experiments were carried out for three different initial weights as load for drying chamber. The weights of the clothes when dry are 1.96 kg, 3.42 kg, and 4.15 kg. The clothes are wetted and preliminary dried using spinner for 3 minutes. Here the wet weights are 3.00 kg, 5.25 kg, 6.38 kg, respectively. These will be known as initial weights to be dried. Thus there are three samples will be dried in the drying chamber where each sample is dried for 3 times. Then the total drying has done as much as 9.

In the beginning the heat pump drier will be operated with empty drying chamber for 30 minutes, named as idle time. After the idle time, the wet clothes placed by hanging inside the drying chamber. The experiment begins and all of the temperatures, weight, current, and hot air velocity were measured and recorded using the data acquisition unit.

3. Result and Discussions

Three different initial weights to each of the three drying were studied experimentally. Thus a total of 9 cases were carried out. The experiment results will be analyzed in terms of performance, drying characteristics, SMER, and comparison drying system.

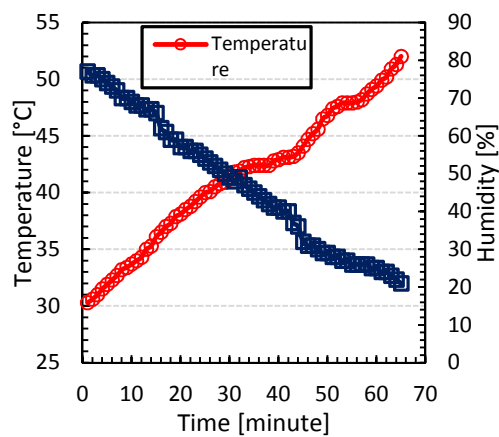
3.1. Performance

In measuring the performance of the dryer, drawn 3 optimum drying results from 9 drying has been done. Each initial weights has one optimum results. Performance heat pump drier for the third drying are shown in Table 2. The main performance of the heat pump dryer is a total achievement (TP) is

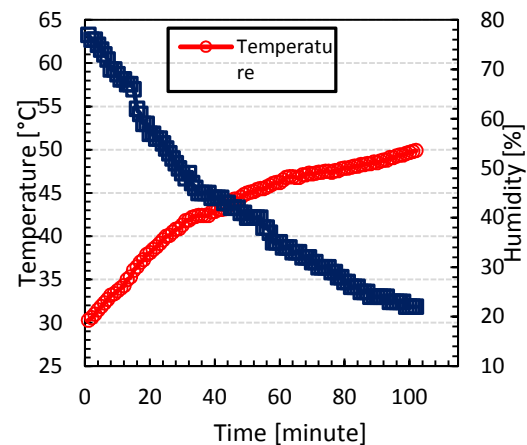
calculated using equation (3). TP value obtained for an average of 6.56 means that for every 1 kWh of electrical energy required dryers can produce 6.56 kWh of energy to heat up, restore, and cools the air for drying clothes. The average air temperature in the drying chamber for drying is obtained 44.7°C with RH average fell up to 30%. Velocity of air flowing into the system is set constant for all drying at 0.64 m/s and R22 pressure increases with increasing temperature of the air in the drying chamber.

Table 2. Performance of heat pump drier

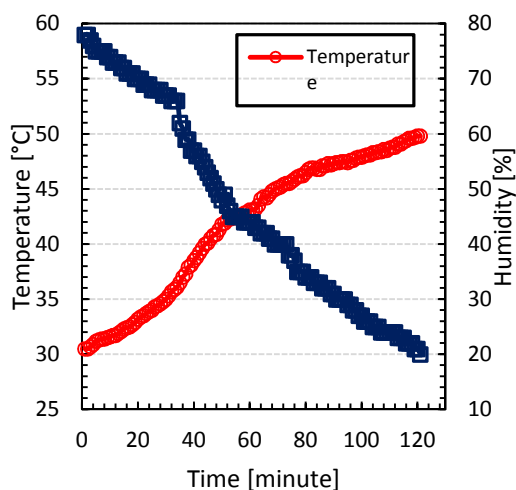
No	Initial weight (g)	Drying chamber		Condenser (kW)	Evaporation (kW)	Heat exchanger (kW)	TP
		Temp (°C)	RH (%)				
1	3.00	45.7	27	1.127	0.861	0.365	6.91
2	5.25	43.6	31	0.990	0.753	0.274	6.47
3	6.38	44.9	32	0.982	0.746	0.231	6.29
	Average	44.7	30				6.56



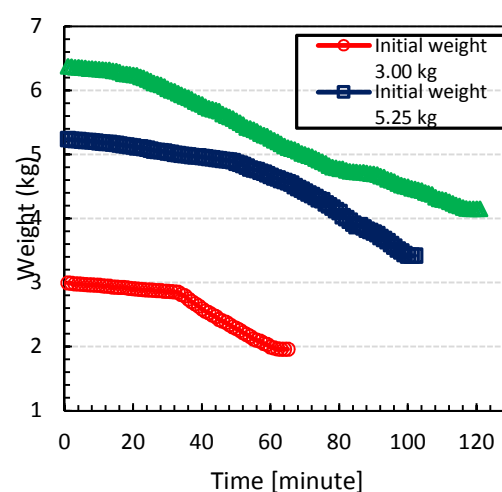
(a) Initial weight 3.00 kg



(b) Initial weight 5.25 kg



(c) Initial weight 6.38 kg



(d) Weight loss clothes

Figure 2. Typical temperatures and weight loss of the clothes dried in the drying chamber

3.2. *Drying characteristics*

All of the drying characteristics such as SMER, drying time, and averaged drying rate for all experiments are presented in Table 3. Clothes drying time is measured for initial weight of 3.00 kg, 5.25 kg, and 6.38 kg is 65 minutes, 102 minutes, and 121 minutes, respectively. Conditions of temperature, humidity, and weight of clothing in the drying chamber for the three initial weights were presented in Fig. 2 (a) - (d). As a note, the volume of drying chamber is constant at 1 m³. More clothes in the drying cabinet results in more water to be evaporated. This results in increasing drying rate. However, too many clothes in the drying chamber results in decreasing space for drying air to flow. This will make drying rate lower. The drying rate in every measurement was calculated using equation (2), with dimension in gram/minute.

Table 3. Drying characteristics and comparison

Drying system	Initial weight (g)	Drying time (min)	Average drying rate (kg/h)	SMER (kg/kW)
Heat pump drier	3.00	65	0.965	1.374
	5.25	102	1.076	1.533
	6.38	121	1.101	1.569
		Average	1.047	1.492
Waste heat of RAC (Ambarita et al [11])	3.04	80	0.704	1.903
	5.25	170	0.868	2.346
	6.21	195	0.895	2.418
		Average	0.822	2.222

3.3. *Specific moisture extraction rate*

In term of energy use, the performance of the drying chamber will be analyzed using specific moisture extraction rate (SMER). This parameter was defined with equation (5), in the above section. SMER can be viewed as how effective the energy consumed to remove the moist from material dried. Table 3 shows that SMER for all initial weights varies from 1.374 kg/kWh to 1.569 kg/kWh with an averaged value of 1.492 kg/kWh. Ambarita et al [11] reported that SMER obtained from waste heat system is 2.492 kg/kWh. This fact suggests that SMER in the present study is lower than the results of Ambarita et al [11]. This is because in this system the sum of the energy consumed in the form of energy for auxiliary fan for heat and energy released by the condenser. While the waste heat system of the energy consumed in the drying chamber is only energy for auxiliary fan.

3.4. *The comparison between clothes drying by heat pump drier and waste heat of RAC*

Heat pump dryer and waste heat drying system of the RAC is the real form of the findings that are both reliable in terms of drying. If it takes a drying products that require a short time by not reducing energy consumption is greater then the heat pump drying system is the right application is used for generating a high drying rate. On the contrary, if the need for drying a product requires a significant reduction in energy consumption, the waste heat drying system of RAC is a suitable solution. The comparison between the two systems for the initial drying approaching weight can be seen in Table 3. The table shown that the drying time and drying rate of heat pump drier are faster than waste heat drying system but do not apply to the value of SMER. In the case of drying clothes, waste heat drying of RAC shows a better performance in comparison with heat pump drying system.

4. Conclusion

A lab scale model of heat pump drier with drying chamber volume of 1 m³ has been designed and fabricated. The heat pump drier was tested to dry the clothes made of pure cottons with 3 initial weights. The average total performance of heat pump clothes drier is 6.56. The main conclusion of this study is that heat pump drying system and waste heat drying system of RAC is a form of real findings that are both reliable according to his needs. Heat pump clothes drier can produce a high drying rate because there is a role evaporator as lowering humidity. In contrast to the waste heat drying system of RAC which rely solely on heat released by the condenser. The experiments show that the drying time varies from 65 minute to 121 minutes and the value of SMER varies from 1.374 kg/kWh to 1.569 kg/kWh.

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