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Performance of a clothes drying cabinet by utilizing waste heat from a split-type residential air conditioner

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ABSTRACT

In the present paper a study on the performance of clothes drying cabinet by utilizing waste heat from a split-type residential air-conditioner (RAC) has been carried out. A drying cabinet with a volume of 1 m^3 has been designed and fabricated. The waste heat from the condenser of the RAC with power of 800 W 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 3.05 kg, 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 to 410 min. For single inlet the averaged drying time, optimum initial weight, optimum drying rate and optimum SMER was 242 min, 6.21 kg, 0.868 kg/h, and 2.345 kg/kW h. 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 min, 8.22 kg, 0.922 kg/h, and 2.492 kg/kW h. Thus, the present drying cabinet should be operated with multi-inlets and the initial weight varies from 6 to 8 kg.

1. Introduction

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 for drying clothes. Typical method of drying clothes in Indonesia is natural drying using solar energy. Several commercial sectors, such as hotels and hospitals, use commercial drying machines for drying clothes. The typical method of commercial clothes dryer is tumbler rotating drum and flowed by hot air of 40–60 °C [3]. Recently, housing in densely populated cities in Indonesia, do not provide sufficient spaces for drying clothes naturally. Thus, several places around the house such as windows, balcony, garage, front gate, etc are used for drying clothes naturally. This method of drying disturbs esthetics of housing. Thus, laundry business is now growing significantly in Indonesia. The commercial drying and laundries in Indonesia use electricity, kerosene, and natural gas as energy source. This sector is predicted will consume fossil fuel

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significantly. On the other hand, due to increase in economic growth and humid climate of Indonesia, the use of split-type residential air conditioner (RAC) is growing significantly, in particular for dense populated cities. As a note, condenser of RAC releases a significant waste heat to the ambient for free. This waste heat can be utilized as heat source for clothes drying. This is the background of the present study.

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]. The heat pump drying has been used to dry several objects such as clothes, agricultural products, food, medicines, etc. In particular for clothes dryer, several works were found in literature. 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. The results showed dryer with heat pump cycle offers up to 40% improvement in energy efficiency over the electric heater dryer. 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. A drying cabinet made of wood was designed and a box cover of condenser was made. In order to drawn the hot air from the box cover of the condenser an auxiliary fan was installed. 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 initial weights of the clothes dried were 1792–1888 g. The results showed that the drying rate for commercial dryer, natural drying, and heat pump dryer was 0.319 kg/h, 0.139 kg/h, and 0.424 kg/h, respectively. The drying time varied from 120 min to 390 min. In order to compare the performance of the dryer, specific energy consumption (SEC) rate in kW h/kg and specific moisture extraction rate (SMER) in kg/kW h 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 m^2 in Hong Kong was used. A drying rack made of 8 moveable hanging bars with a dimension of 760 mm × 450 mm base and 460 mm height was inserted in a 2.5 m long air duct made of polymethyl methacrylate. This rack can be viewed as a drying cabinet with a volume of 0.157 m^3. In the experiments, no auxiliary fan 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. Temperatures of condenser and in the drying cabinet, and change of weight were plotted. 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]. In these two studies, the drying chamber is not practical. It is a drying rack inside a 2.5 m long of wind tunnel.

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. Dimensions of the drying chamber were not reported. The initial weight of the clothes dried was varied from 2.5 kg to 2.8 kg and the moisture removed was from 720 g to 925 g. 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 min to 420 min. The drying rate for the test ranged from 0.56 kg/h to 0.75 kg/h with RACD compared to 0.13 kg/h for indoor drying and 0.18 kg/h for out door drying. The analysis showed that SMER varied from 0.1809 kg/kW h to 0.2205 kg/kW h. 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. A drying chamber with dimensions of 0.5 m × 0.5 m × 1.0 m was designed and fabricated. An auxiliary fan with power of 180 W was installed to draw hot air from the condenser. Load of the drying chamber was varied. The results showed that the drying rate of clothes using waste heat from air conditioner is between 1.1 kg/h and 2.26 kg/h. This was claimed better than commercial dryer and natural drying. The effects of auxiliary fan were evaluated using decreasing COP of the system. However drying characteristics and SMER were not discussed. Recently, Bansal et al. [11] reported a study on the method to determine air leakage in heat pump clothes dryer. In the system, heat pump was employed to produce hot drying air to tumbler dryer instead of using conventional electric heater. It was reported that although heat pump clothes dryers offer higher energy efficiency through air recirculation, it is likely that various components are prone to air leakage and resulting in a loss of efficiency. They suggested and tested a procedure to determine air leakage in heat pump clothes dryers. Mainly the studies related to clothes dryer found in literature dealt with tumble dryer [11–15] and only very limited studies related to cabinet heat pump clothes dryer.

The above reported studies showed that waste heat from split-type RAC can be used as heat source for clothes dryer. The performances of the clothes dryer using waste heat from split-type of RAC, in term of SMER and drying time, were discussed and showed a better performance compared with commercial electric clothes dryer. The focus of the previous studies was mainly on the performance of the system. Only limited study reported the performance of the drying chamber. The present paper focuses on the performance of a drying chamber of clothes dryer using waste heat from a split-type RAC. The effects of drying load and inlet configuration will be analyzed in term of SMER, drying time, and drying characteristics. The results are expected to supply necessary information on development and optimization of RAC clothes dryer.