International Refrigeration and Air Conditioning Conference

School of Mechanical Engineering

2014

The Effects of Fin Spacing and Tube Outer Diameter of Evaporator on System Performance in Heat Pump Tumble Dryers

Cenk Onan
Yildiz Technical University, Turkey, conan@yildiz.edu.tr

Serkan Erdem
Yildiz Technical University, Turkey, serdem@yildiz.edu.tr

Derya Burcu Özkan
Yildiz Technical University, Turkey, tumer@yildiz.edu.tr

Hasan Alpay Heperkan
Yildiz Technical University, Turkey, heperkan@yildiz.edu.tr

Onan, Cenk; Erdem, Serkan; Özkan, Derya Burcu; and Heperkan, Hasan Alpay, "The Effects of Fin Spacing and Tube Outer Diameter of Evaporator on System Performance in Heat Pump Tumble Dryers" (2014). *International Refrigeration and Air Conditioning Conference.* Paper 1457.
http://docs.lib.purdue.edu/iracc/1457

The Effects of Fin Spacing and Tube Outer Diameter of Evaporator on System Performance in Heat Pump Tumble Dryers

Cenk ONAN[1]*, Serkan ERDEM[2], Derya B. OZKAN[3], Hasan H. HEPERKAN[4]

[1]Yildiz Technical University, Department of Mechanical Engineering, Istanbul, Turkey
Phone: 0090 212 383 29 16, Fax: 0090 212 261 66 59, E-mail: conan@yildiz.edu.tr

[2]Yildiz Technical University, Department of Mechanical Engineering, Istanbul, Turkey
Phone: 0090 212 383 29 16, Fax: 0090 212 261 66 59, E-mail: serdem@yildiz.edu.tr

[3]Yildiz Technical University, Department of Mechanical Engineering, Istanbul, Turkey
Phone: 0090 212 383 29 11, Fax: 0090 212 261 66 59, E-mail: tumer@yildiz.edu.tr

[4]Yildiz Technical University, Department of Mechanical Engineering, Istanbul, Turkey
Phone: 0090 212 383 28 11, Fax: 0090 212 261 66 59, E-mail: heperkan@yildiz.edu.tr

* Corresponding Author

ABSTRACT

In heat pump tumble dryers, moisture separates from the laundry and leaves the dryer system at the evaporator. Moist air goes out the drum and enters the evaporator whose outer surface is below the dew point temperature. Air cools and then leaves its moisture. At the airside of the evaporator the wet surface develops and simultaneous heat-mass transfer occurs. Fin-and-tube heat exchangers are used as evaporators in household heat pump tumble dryers. In addition to optimum operating conditions, optimum evaporator geometry can significantly affect system performance. In this study, a model was developed for household heat pump tumble dryer. The model was validated by experimental data collected from the literature. MATLAB software was used in programming, and fluid properties were taken from Refprop software. The model was run with different fin spacing (2–5 mm) and tube outer diameter (6–12 mm) for evaporator, whereas operating conditions and all other geometrical parameters stayed the same. Then, coefficient of performance (COP), moisture extraction rate (MER), and specific moisture extraction rate (SMER) were calculated. As a result, the effects of fin spacing and tube outer diameter of evaporator were determined depending on the input characteristics of the dryer model. In the working range, SMER was changed up to 20% and 15% depending on the fin spacing and the tube outer diameter of evaporator, respectively.

1. INTRODUCTION

Developing technology is increasingly extending the use of heat pump tumble dryers. Literature has various studies on both heat pump tumble dryers and evaporators that are the components through which the moisture extracted from clothes is condensed and vented from the system.

Horuz *et al*. (1998) did theoretical and experimental studies on air-cooled and plain fin-and-tube evaporators. They concluded that the more the tube diameter increases, the more the heat transfer coefficient inside the tube decreases, whereas the heat transfer rises because of the increase in air-side heat transfer and total heat transfer coefficient.

Wang *et al*. (1999) experimentally studied the air-side of herringbone wavy fin-and-tube heat exchangers in wet conditions. They researched the impact of the number of tube rows, fin pitch, and tube diameter on heat transfer and pressure loss. They concluded that the more the number of tubes increases, the more the friction factor decreases because of the herringbone wavy shape of fin. According to their research, the effect of the number of tube rows on heat transfer is partially low when the fin pitch is 3.1 mm. Wang *et al*. also found that as the number of tubes increases, the more the heat transfer decreases when the fin pitch is 1.7 mm and $Re_{Dc}<1000$.

Klöcker *et al*. (2001, 2002) bought a commercial dryer with electrical heating capacity of 12 kW and closed air cycle, detached its heating element, and replaced it with the gas cooler of a heat pump operating with CO_2. They showed the transient characteristics of the drying process. As a result of their studies, Klöcker *et al*. revealed that the heat pump dryers provided considerable energy saving (between 53–65%) when compared to electrical heating.

In their experimental study, Pirompugd *et al*. (2008) analyzed the air-side of wavy fin-and-tube heat exchangers in the cases of fully and partially wet surface formation. They developed suitable correlations for heat and mass transfer, Colburn factors j_h and j_m. They showed that j_h and j_m decrease depending on the increase of the Reynolds number.

Liu *et al*. (2010) experimentally studied the air-side of plain fin-and-tube heat exchangers with large-diameter tubes (D_c=15.88 mm) in wet conditions. They analyzed the effect of the number of tube rows and fin pitch on heat transfer. They found out that as the number of rows increase, the more the impact of fin pitch on Colburn j factor decreases.

Literature has various studies on the heat-mass transfer and air-side pressure loss in evaporators. This study puts forward the effect of fin spacing and tube outer diameter of fin-and-tube evaporator on the performance of heat pump tumble dryer. To that end, a model of heat pump tumble dryer operated by the transcritical CO_2 cycle was developed. The model was then validated by the appropriate experimental data collected from the literature. Also, the effects of the fin spacing and the tube outer diameter on the system were determined.

2. HEAT PUMP DRYERS

As shown in Figure 1, heat pump dryers have two cycles: air cycle and refrigerant cycle. In the air cycle, air is heated in the gas cooler and is sent to the drum. Then, air gets moisture from the laundry and comes to the evaporator. Air leaves moisture on the evaporator’s outside surface, and comes back to the gas cooler. The refrigerant side is a vapor compression cycle that uses CO_2 in this study.

2.1 Model

To generate a heat pump drying system simulation model, all components shown in Figure 1 were modeled separately. Then, they were combined to work together. Thus, all components affect the others. Inputs and outputs of the model are shown in Table 1.

Table 1: Inputs and outputs of the heat pump dryer model

Inputs	Outputs
Gas cooler geometry	Coefficient of performance
Evaporator geometry	Moisture extraction rate
Compressor specifications	Specific moisture extraction rate
Drum specifications	Drying time
Fan specifications	Energy consumption
Ambient air specifications	Airside conditions of every point of cycle
Operating parameters	CO_2 side conditions of every point of cycle

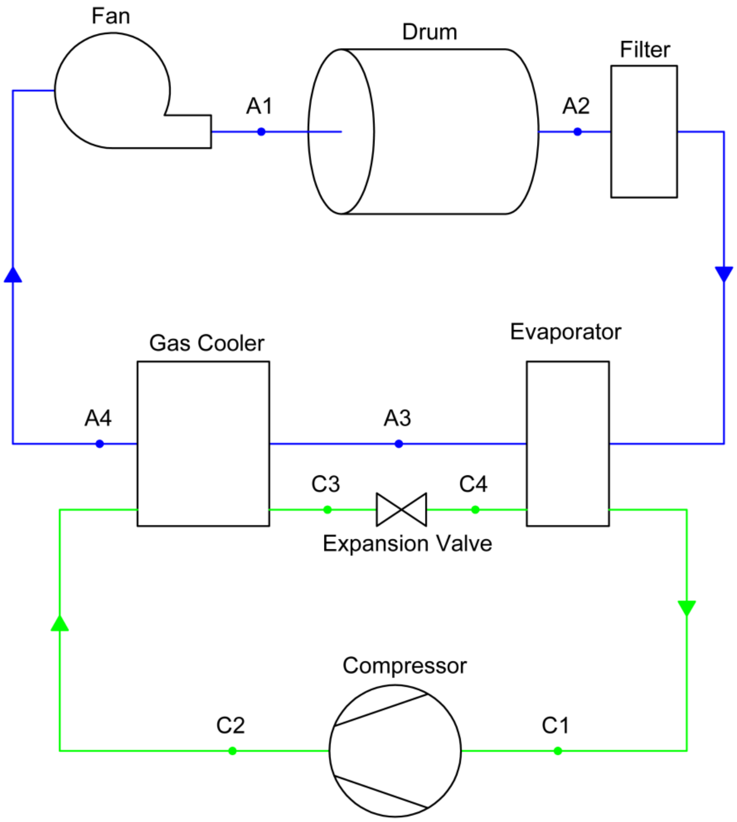

Figure 1: A schematic view of heat pump drying system

The modeling study was made by using MATLAB R2011b software. To determine thermophysical properties of the air and CO_2 in the calculations, Refprop V7 software was used. The properties of water, copper, stainless steel, and aluminum that could be used as pipe and fin material were determined using EES V9 software.

Optimum operating parameters and heat exchanger geometries can be determined by using the model in design stage of the heat pump laundry dryers. Thus, the design stage can be accelerated and operating costs can be reduced by producing more effective dryers.

2.2 Validation of Model

For validation of the general dryer model, the experimental study of Klöcker *et al*. (2001, 2002) was taken into consideration.

Among the criteria used for comparison, coefficient of performance (COP), moisture extraction rate (MER), and specific moisture extraction rate (SMER) are expressed with equations (1), (4), and (5), respectively.

$$COP = \frac{\dot{Q}_{gc}}{\dot{W}_c} \tag{1}$$

$$\dot{Q}_{gc} = \dot{m}_r(h_{C2} - h_{C3}) \tag{2}$$

$$\dot{W}_c = \dot{m}_r(h_{C2} - h_{C1}) \tag{3}$$

$$MER = \dot{m}_a(\omega_{A2} - \omega_{A1}) \tag{4}$$

$$SMER = \frac{MER}{\dot{W}_c + \dot{W}_f} \tag{5}$$

$$\dot{W}_f = \dot{m}_a(h_{A1} - h_{A4}) \tag{6}$$

Sarkar *et al*. (2006a, 2006b) validated their steady-state simulation model with the experimental results at the 50th min. of Klöcker *et al*. (2001, 2002). In this study, these 50th min. experimental results were used for validation. The results of Klöcker *et al*. (2001, 2002) are given in Table 2 by comparing the results obtained from dryer model. Deviations are calculated with equation (7).

$$\text{Deviation} = \frac{|\text{Experimental Results} - \text{Model Results}|}{\text{Experimental Results}} \times 100 \tag{7}$$

Table 2: Comparison of the experimental study by Klöcker *et al*. (2001, 2002) and results of the model

		Experimental Results Klöcker *et al*. (2001, 2002)	**Model Results**	**Deviation (%)**
Cooling Load	kW	10.15	10.7	5.4
Heating Load	kW	12	13.0	8.3
Compressor Power	kW	1.85	2.28	23.2
COP	-	6.5	5.70	12.3
MER	kg/h	5	5.90	18.0
SMER	kg/kWh	2.05	1.99	2.9

3. THE EFFECTS OF CHANGING GEOMETRY OF EVAPORATOR

3.1 The Effects of Fin Spacing of Evaporator

In heat pump tumble dryers, outer geometric limitations for heat exchangers are certain because heat exchangers are installed in a fixed place. Consequently, total outside surface heat transfer area of evaporator decreased when fin spacing increased (2–5 mm), as seen in Figure 2.

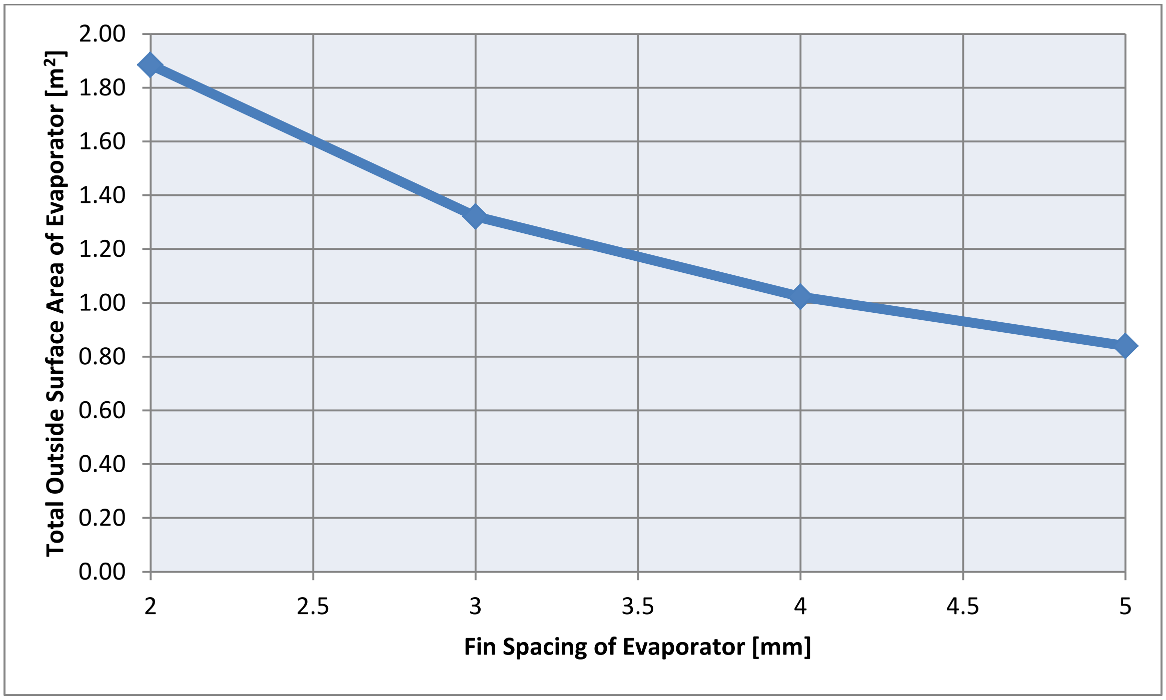

Figure 2: Total outside surface heat transfer area of evaporator depending on fin spacing of evaporator

This decrease in the heat transfer area in the evaporator yield decrease heat transfers in both the evaporator and gas cooler. These results and the COP of heat pump dryer are given in Figure 3.

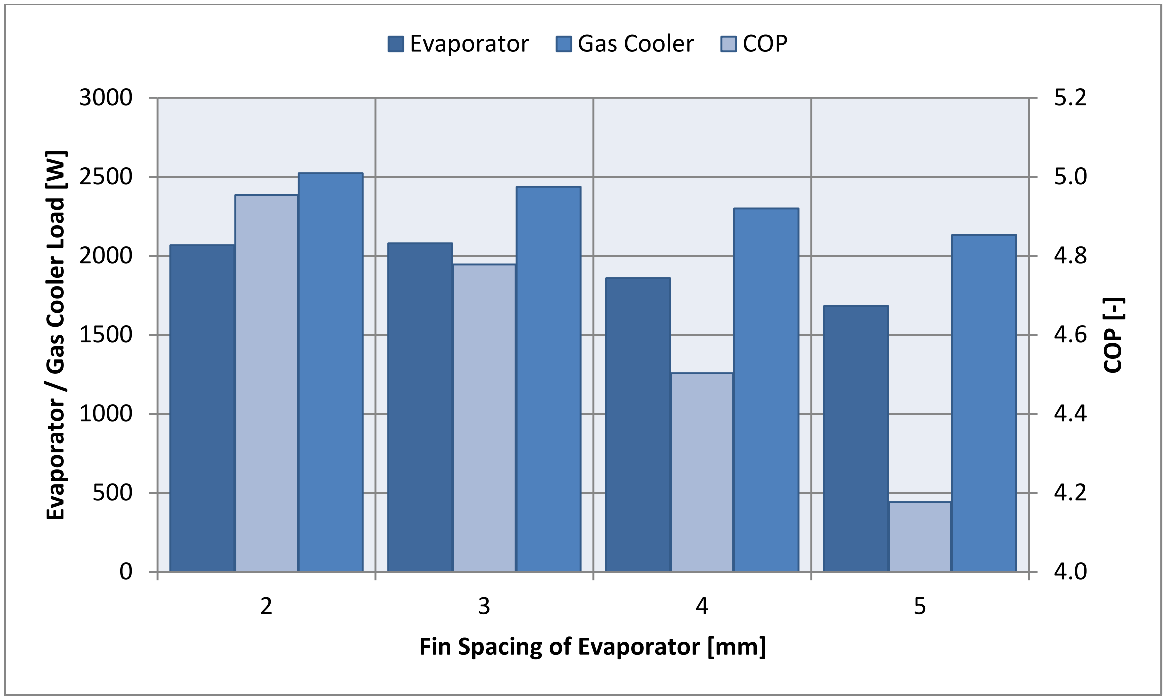

Figure 3: Evaporator / gas cooler load and COP of heat pump dryer depending on fin spacing of evaporator

Compressor power was relatively constant because it was highly related with inlet-outlet pressures. So, the decrease in evaporator capacity and constant compressor power yield decrease both SMER and MER as seen in Figure 4.

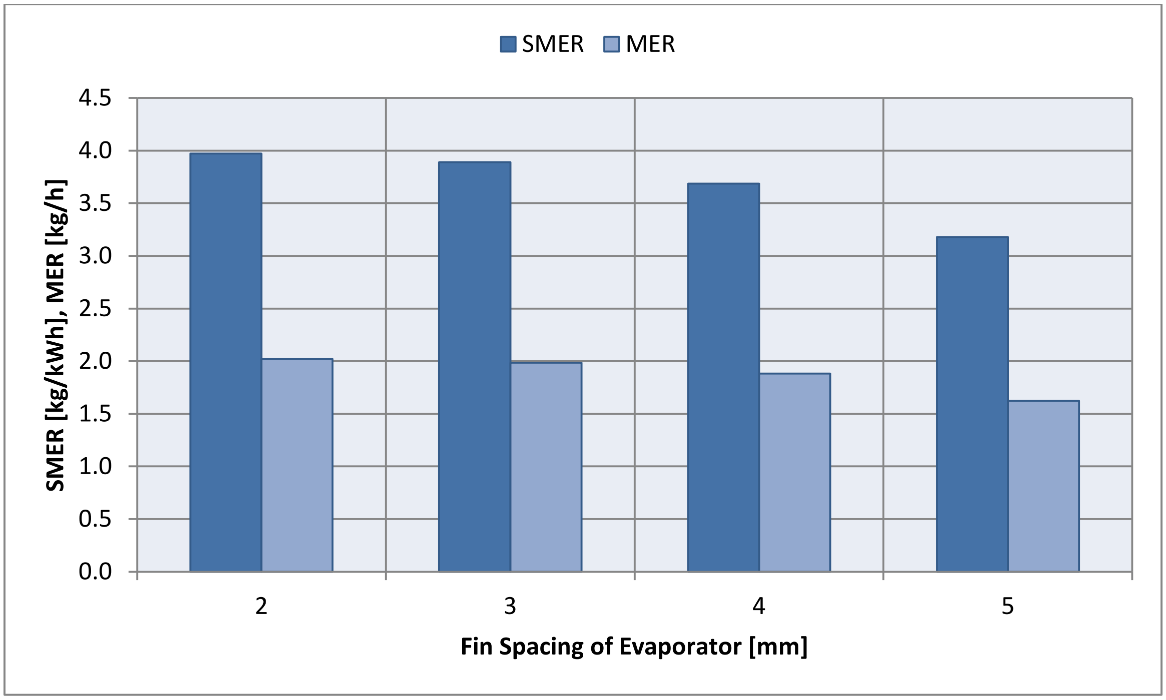

Figure 4: SMER and MER of heat pump dryer depending on fin spacing of evaporator

As a result, decrease in fin spacing of the evaporator decreased drying time and energy consumption.

3.2 The Effects of Tube Outer Diameter of Evaporator

The cross-sectional area that air passes through is decreasing with increasing tube outer diameter in fin-and-tube heat exchangers. This contraction, which occurs in area, yields increase in maximum air velocity. The change of maximum air velocity in evaporator depending on tube outer diameter (6–12 mm) is given in Figure 5.

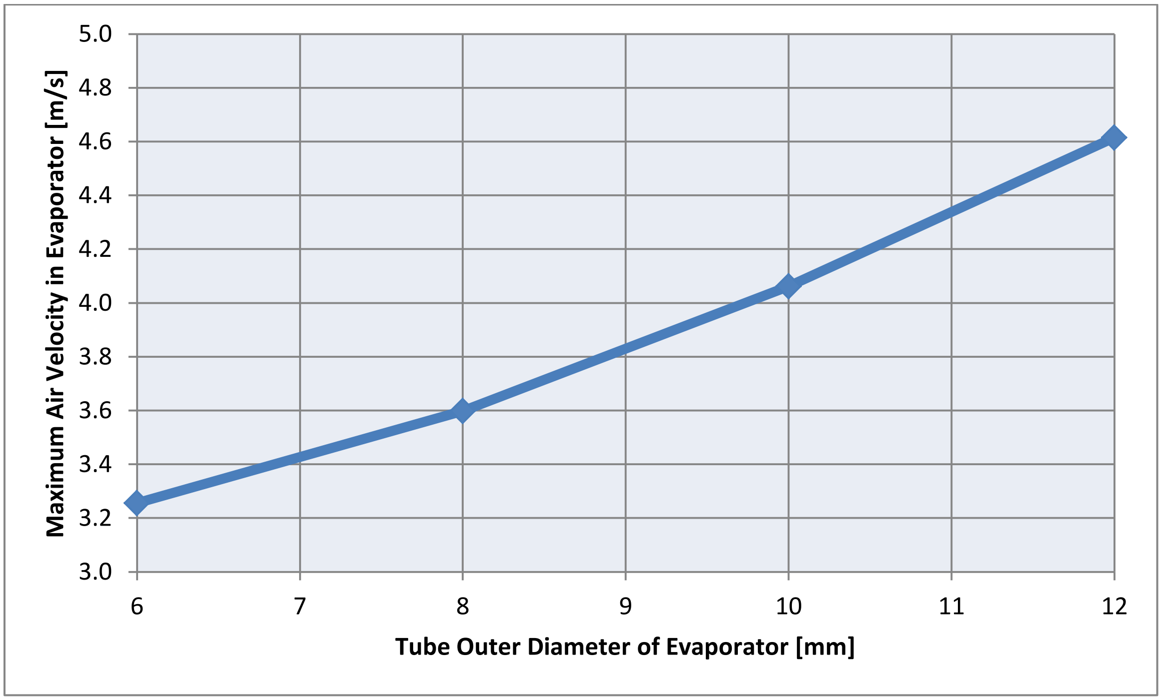

Figure 5: Change of maximum air velocity in evaporator depending on tube outer diameter of evaporator

This increase in maximum air velocity in the evaporator increased the Reynolds number based on collar diameter (Re_{Dc}). Hence, heat and mass transfer Colburn factors j_h and j_m decreased with the increasing Reynolds number. Eventually, heat transfers in both the evaporator and gas cooler decreased with increasing tube outer diameter of the evaporator. These results were given in Figure 6 with COP.

SMER and MER decreased with increasing tube outer diameter of the evaporator because of decreasing evaporator capacity and constant compressor work (Figure 7). Consequently, drying time and energy consumption decreased when the tube outer diameter of the evaporator in heat pump tumble dryers decreased.

6. CONCLUSIONS

Evaporator geometry is highly related with energy consumption and drying time in heat pump tumble dryers. In this study, a heat pump laundry dryer simulation model working with CO_2 was developed. The model was validated with experimental results obtained from literature. Effects of fin spacing (2–5 mm) and tube outer diameter (6–12 mm) of evaporator were determined.

- COP increased 16% when fin spacing of evaporator decreased from 5 mm to 2 mm.
- SMER and MER increased 20% when fin spacing of evaporator decreased from 5 mm to 2 mm.
- COP increased 7% when tube outer diameter of evaporator decreased from 12 mm to 6 mm.
- SMER and MER increased 15% when tube outer diameter of evaporator decreased from 12 mm to 6 mm.

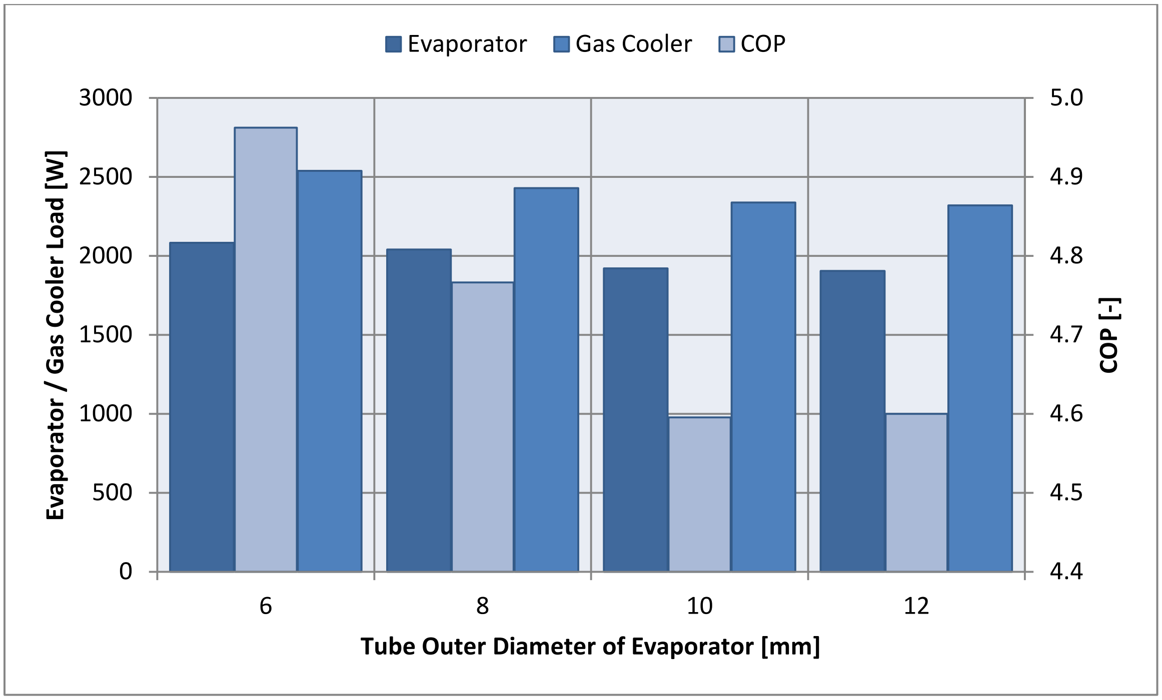

Figure 6: Evaporator / gas cooler load and COP of heat pump dryer depending on tube outer diameter of evaporator

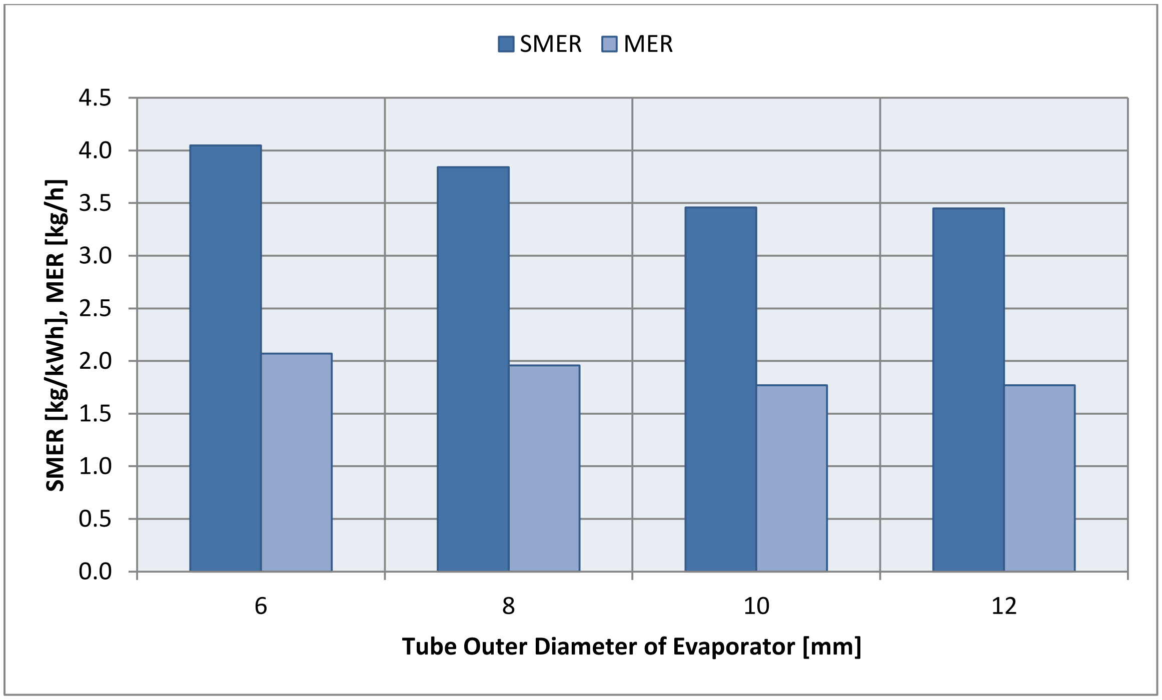

Figure 7: SMER and MER of heat pump dryer depending on tube outer diameter of evaporator

Depending on the results given, the importance of evaporator geometry in heat pump tumble dryers was put forward. So, in the design and manufacturing stage, it is important to choose right geometrical properties in the evaporator. The developed model calculates the process as steady state, but the drying process has transient characteristics. Thus, the model will be able to improve to give the effects of transient process for a next stage.

NOMENCLATURE

COP	coefficient of performance	(-)
h	enthalpy	(kJ/kg)
j	Colburn factor	(-)
$\dot{m}$	mass flow rate	(kg/h)
MER	moisture extraction rate	(kg/h)
$\dot{Q}$	heat transfer rate	(W)
Re	Reynolds number	(-)
SMER	specific moisture extraction rate	(kg/kWh)
T	temperature	(^{o}C)
W	power	(W)
ω	absolute humidity for air	(kg_w/kg_{da})

Subscript

a	air
A	air cycle
C	CO_2 cycle
c	compressor
D_c	collar diameter
f	fan
gc	gas cooler
h	heat
m	mass
r	refrigerant
sat	saturation

REFERENCES

Horuz, I., Kurem, E., Yamankaradeniz, R., 1998, Experimental and theoretical performance analysis of air-cooled plate-finned-tube evaporators, *Int. Commun. Heat Mass Transf.*, 25, 6:787–798.

Klöcker, K., Schmidt, E.L., Steimle, F., 2001, Carbon dioxide as a working fluid in drying heat pumps, *Int. J. Refrig.*, 24, 1:100–107.

Klöcker, K., Schmidt, E.L., Steimle, F., 2002, A Drying Heat Pump Using Carbon Dioxide As Working Fluid, *Dry. Technol.*, 20, 8:1659–1671.

Liu, Y.C., Wongwises, S., Chang, W.J., Wang, C.C., 2010, Airside performance of fin-and-tube heat exchangers in dehumidifying conditions – Data with larger diameter, *Int. J. Heat Mass Transf.*, 53, 7–8:1603–1608.

Pirompugd, W., Wang, C.C., Wongwises, S., 2008, Finite circular fin method for wavy fin-and-tube heat exchangers under fully and partially wet surface conditions, *Int. J. Heat Mass Transf.*, 51, 15–16:4002–4017.

Sarkar, J., Bhattacharyya, S., Gopal, M.R., 2006a, Transcritical CO_2 Heat Pump Dryer: Part 1. Mathematical Model and Simulation, *Dry. Technol.*, 24, 12:1583–1591.

Sarkar, J., Bhattacharyya, S., Gopal, M.R., 2006b, Transcritical CO_2 Heat Pump Dryer: Part 2. Validation and Simulation Results, *Dry. Technol.*, 24, 12:1593–1600.

Wang, C.C., Du, Y.J., Chang, Y.J., Tao, W.H., 1999, Airside performance of herringbone fin-and-tube heat exchangers in wet conditions, *Can. J. Chem. Eng.*, 77, 6:1225–1230.

ACKNOWLEDGEMENT

Thanks for Republic of Turkey Ministry of Science, Industry and Technology for their support.