Air Source Heat Pump System for Drying Application

R. DAGHIGH, M.H. RUSLAN, A. ZAHARIM AND K. SOPIAN
Solar Energy Research Institute,
Universiti Kebangsaan Malaysia (UKM),
43600, Bangi, Selangor
Malaysia
ronak_d@eng.ukm.my,azami.zaharim@gmail.com,ksopian@eng.ukm.my

Abstract: - This paper investigates the performance of an air source heat pump for drying purpose. In order to evaluate the performance analysis; a simulation study has been done. The results of simulation of heat pump dryer for different evaporator temperatures and condenser temperatures have been calculated. Simulation results are obtained for this system indicated the coefficient of performance (COP) of this heat pump dryer system increases with decreasing condenser or increasing evaporator temperatures and the compressor work decrease. It is also observed that heat rejected from condenser increases with increasing evaporation temperature.

Key-Words: Evaporator temperature, Air source Heat Pump, Dryer, Coefficient of Performance (COP), Condenser Temperature and Compressor Work.

1 Introduction

The heat pump receives higher-grade energy to low-grade heat from a low-temperature source and provides more a high-temperature sink. It seemingly “pumps” heat from the low-temperature source (at or near ambient temperature) to the high-temperature sink. Therefore, it is called a heat pump [1]. Following the general trend to improve product quality and reduce energy consumption, many researcher have acknowledged the specific features of heat pumps, which has resulted in the rapid growth of both theoretical and applied research on air source heat pump drying. The main objective of any drying process is to produce a dried product of desired quality at minimum cost and maximum throughput and to optimise these factors consistently [2]. Drying is an energy intensive operation, therefore most researchers have been tried to find energy efficient systems and save energy in drying heat processes. In drying process the air leaving the dryer has almost the same enthalpy which it had on entering the system, hence a considerable part of the enthalpy used on drying can be regained by condensing the absorbed water vapour. Utilizing energy efficient heat pump in drying system can achieve this goal and recover both latent and sensible heat which would otherwise be wasted. One of the most efficient and controllable ways of drying moist materials is by using a heat pump drying. For years heat pumps have been known as an efficient method of energy recovery. Heat pump for drying is difference, of the hot heat produced by condenser and cold heat by the evaporator will be use concurrently during the operation. The heat from the condenser will produced hot and will use to heat the material and the cold heat from the evaporator will be use in dehumanization process. Their ability to convert the latent heat of vapour condensation into the sensible heat of an air stream passing through the condenser makes them attractive in drying applications especially when combined with the ability to produced well-controlled drying conditions [3]. For these reasons heat-pump drying has been used for decades in wood kilns to dehumidify air and lumber quality. Following the general trend to improve product quality and reduce energy consumption, many researcher have acknowledged the specific features of heat pumps, which has resulted in the rapid growth of both theoretical and applied research on heat pump drying (Table 1).

The key advantages and limitations of heat pump dryers are as follows [4]:

Advantages:

- Higher energy efficiency with controlled temperature profile to meet product requirements

ISSN: 1792-507X 404 ISBN: 978-960-474-230-1

Table1 Some studies in heat-pump drying

Source	Location	Application (s)	Conclusions
(Theerakulpisut, 1990) [5	Australia	Grain	An open cycle HPD performed better during the initial stage when the product drying rate is high.
(Meyer, and Greyvenstein, 1992) [6]	South Africa	Grains	The HPD is more economical than other dryers.
(Rossi et al.,1992) [7]	Brazil	Vegetable (Onion)	Better product quality and energy saving of the order of 30% was obtained.
(Mason and Blarcom, (1993) [8]	Australia	Macadamia nuts	---
(Strommen and Kramer 1994) [9]	Norway	Marine products (fish)	The high quality of the dried products was Highlighted as the major advantage of HPD.
(Prasertsan et al., 1997); (Prasertsan and Saen-saby, 1998)[10-11]	Thailand	Agricultural food drying (bananas)	HPD is economically feasible and for drying high moisture materials is so appropriate.
(O'Neill et al., 1998) [12]	New Zealand	Apples	Modified atmosphere heat pump (New Zealand) heat pump system drying (MAHPD) produces products with a high level of open pore structure, contributing to the unique physical properties
(Strommen et al. 1999) [13]	---	---	HPD with hydrocarbon and natural working fluids can save significant amounts of energy. With comparison the performance of several refrigerants, they found that ammonia was the most favourable refrigerant in the temperatures: 30-80°C.
(Chou et al., 1998, 2001);(Chua et al., 2000) [14,15,16]	Singapore	Agricultural and marine products	With scheduled drying conditions the quality of products can be improved
(Oktay et al., 2003) [17]	Turkey	Wool	The SMER was between 0.65-1.75 kg/kWh. COP was between 2.47-3.95.
(Teeboonma et al.,2003) [18]	Thailand	Fruits (papaya and mango glace)	Mathematical models of fruits drying using HPD are developed and validated experimentally. The optimum criterion is minimum annual total cost per unit of evaporating-water. The effects of initial moisture content, cubic size and effective diffusion coefficient of products on the optimum conditions of HPD are also investigated. exergy and energy analysis was made.
(Kohayakawa et al., 2004) [19]	Brasil	Mango	The energy efficiency improved compared with an electrical resistance dryer.
(Hawlader et al., 2006) [20]	Singapore	Apple, guava and potato	Modified atmosphere heat pump dryer produced better physical properties.
(Chegini et al., 2007) [21]	Iran	Plum	The optimum temperature of drying for plums is in vicinity of 70-80ºC; also (SMER) of designed dryer was notably more than conventional types of dryers in respect to saving the energy
(Phoungchandang et al., 2009) [22]	Thailand	Garlic and White mulberry	Computer simulation model of the heat pump dehumidified drying shown to be in good agreement with experimental results.
(Aktaş et al., 2009) [23]	Turkey	apples	A system which is composed of the combination of both dryers is considered to be more efficient

- Better product quality with control temperature profile to meet product requirements

- A wide range of drying conditions typically from -20ºC to 100ºC (with auxiliary heating) is feasible
- Consistent output of products
- Excellent control of the environment for high value products and reduced electrical consumption for low- valued products
- Suitable for both high-value and low-value products
- Aseptic processing is possible.

Limitations:

- Auxiliary heating may be required for high-temperature drying due to the critical pressure level of some refrigerants
- Initial capital cost may be high due to many refrigerant components. Requires a steady state period for system to attain desired drying conditions.
- Required regular maintenance of components
- Leakage of refrigerant to the environment if cracking of pipes occurs due to pressurized systems

2 Mathematical Modeling

Figure 1 represents the schematic diagram of this system. The system consists of two heat exchangers as condenser and evaporator, an expansion valve a compressor, dryer, supporting structure and casing. The heat pump system and the dryer are attached together so that it becomes one unit. The heat from the condenser will produced hot and will use to heat the material in dryer and the cold heat from the evaporator will be use in dehumanization process.

2.1 Theoretical performance Analysis of heat pump drying system

In general, simulation can be used to study variations in system or component configurations in order to identify critical parameters [24].The starting point of a heat pump model is the description of the operation of a heat pump in terms of mathematical relationships.

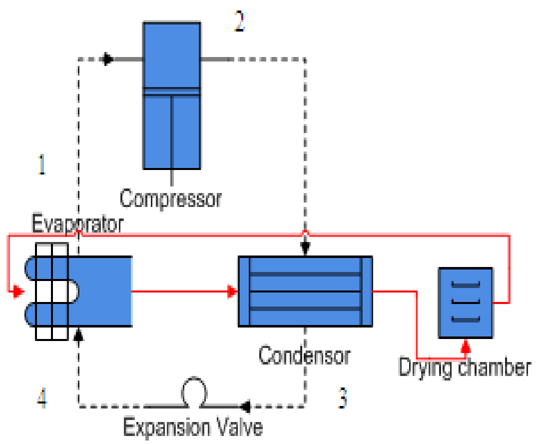

Fig.1 Schematic Diagram of heat pump dryer

The main parameters of the compressor are volumetric efficiency (η_{vol}), refrigerant mass flow rates (m_r) and compression power (W) [25].

$$\eta_{vol} = 1 - C\left[(CR)^{\frac{1}{n}} - 1\right] \quad (1)$$

$$m_r = V_{st} N_i \left(\frac{1}{v_1} \right) \eta_{vol} \quad (2)$$

$$W = m_r (h_2 - h_1) \quad (3)$$

Applying the energy equation for a mass m of refrigerant in the evaporator yields:

$$Q_1 = m.(h_1 - h_4) \quad (4)$$

The heat rejection in the condenser is given by:

$$Q_{Cond} = Q_{Desuperheating} + Q_{Condensetion} \quad (5)$$

For a mechanical vapor compression system, the net energy supplied is usually in the form of work, mechanical or electrical, and may include work to the compressor and fans or pumps. Thus, the coefficient of performance is:

$$COP = \frac{Q_{cond}}{W} \quad (6)$$

3 Results and discussion

In this work, the simulation study of an air source heat pump dryer has been done. Four different operating modes with condenser temperature at 45°C, 50°C, 55°C and 60°C, respectively were considered.

The coefficient of performance and heat rejected from condenser calculated for these range of condensing and evaporating temperature.
Figure 2-5 show the effect of evaporating temperature on COP for fixed condenser load temperatures.

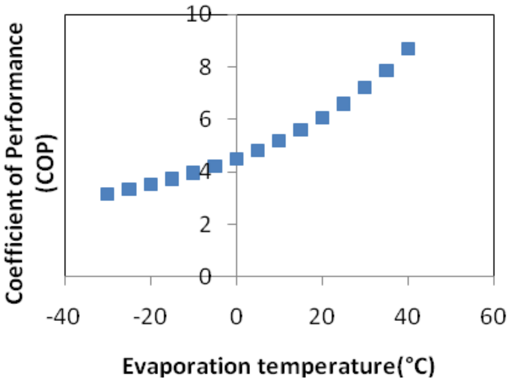

Fig. 2 Variation of COP with evaporator temperature (Condenser=45°C)

Decreasing condenser temperature or increasing evaporator temperatures will decrease the compressor work and increase the COP.

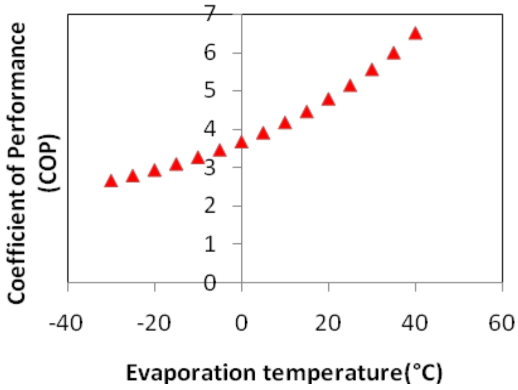

Fig. 3 Variation of COP with evaporator temperature (Condenser=50°C)

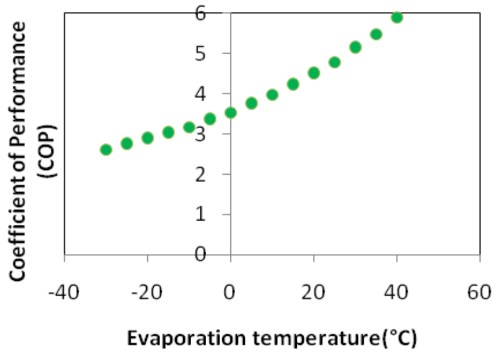

Fig. 4 Variation of COP with evaporator temperature (Condenser=55°C)

If the evaporating temperature remains constant, the COP declines as the condensing temperature increases.

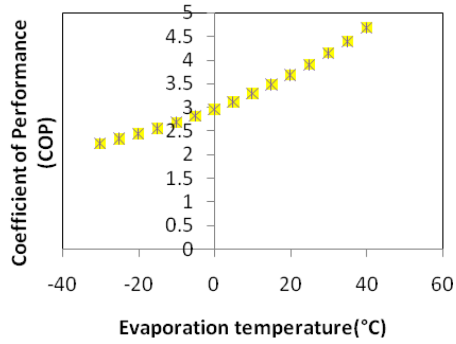

Fig. 5 Variation of COP with evaporator temperature (Condenser=60°C)

As evaporation temperature considers constant, the amount of hear rejected from the condenser increases as condenser temperature decline.
The effect of increasing condensing temperature on coefficient of performance of heat pump is the exact opposite of the raising the evaporator temperature. Whereas increment of evaporator temperature reduces the work of compressor, increasing of the condensing temperature increases the work of compressor.

Figure 6 shows the variation of the condenser heat load against evaporator temperature. It is observed that heat rejected from condenser increases with evaporation temperature. This is due to this fact that the large rate of the increase in refrigerant mass flow rates that overcomes the rate of decrease in the enthalpy differences between inlet and outlet of condenser. Due to the increase in heat load of condenser by increasing the evaporator temperatures the COP rise as shown in figure 2-5.

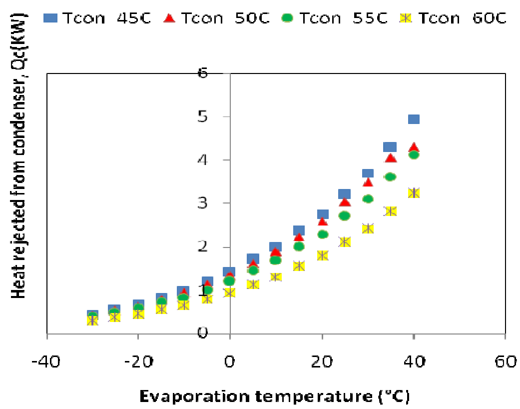

Fig.6 Variation of heat rejected from condenser with evaporator temperature

4 Conclusion

The main objective of any drying process is to produce a dried product of desired quality at minimum cost and maximum throughput and to optimise these factors consistently. Following the general trend to improve product quality and reduce energy consumption, the specific features of heat pump dryers have been studied.

In this study the performance of an air source heat pump for drying purpose has been investigated. A series of parametric studies have been performed to analyze the effects of different variables on the performance of the system and the parameters which affect the COP. The influence of the evaporator temperature on COP is of sufficient importance. The value of the COP of the system improves as evaporator temperature rise or condensing temperature decrease. The heat rejected from condenser increases with increasing evaporation temperature.

Acknowledgment

The authors would like to thank the Solar Energy Research Institute (SERI), University Kebangsaan, Malaysia, for their invaluable support.

Nomenclature

C	Clearance Percentage
COP	Coefficient of Performance
CR	Compression Ratio
h	Specific enthalpy, KJ/Kg
m	Mass flow rate, Kg/s
Q	Rate of heat transfer, kw
T	Temperature,K
ν	Specific volume, m^3/kg
V	Displacement volume, m^3
W	Work
Greek letters	
η	Efficiency

References:

[1] Kent, E.F. Performance evaluation of a compact ait-to-air heat pump. Energy Convers. Mgmr 38(4) “(1997): 341-345.

[2] Chua, K.J. Mujumdar, A.S.Hawlader, M.N.A.Chou, S.K. Ho,J.C. "Batch Drying of Bannana Pieces-Effect of Stepwise Change in Drying Air Temperature on Drying Kinetics and Product Colour." Food Res Int 34, no. 721-31 (2001).

[3] Kudra, T. and Mujumdar, A.S., Advanced Drying Technologies,Marcel Dekker, New York, 2001, 457 pp.

[4] Chou S.K and Chua K.J. Heat Pump Drying Systems. In:Mujumdar, Arun S. (3rd Ed.), 2006,Handbook of Industrial Drying.

[5] Theerakulpisut, S. (1990). Modeling heat pump grain drying system. PhD thesis, University of Melbourne, Australia, Melbourne.

[6] Meyer, J.P Greyvenstein, .G.P. (1992). The drying of grain with heat pumps in South Africa: A techno-economic analysis. Intl, J Energy Research 16:13-20.

[7] Rossi, S.J. Neues, C.Kicokbusch T.G. (1992). Thermodynamics and energetic evaluation of a heat pump applied to drying of vegetables. In Drying ’92 (Mujumdar AS, ed.). Amsterdam: Elsevier Science.

[8] Mason, R.L. Blarcom, A.V. (1993). Drying macadamia nuts using a heat pump dehumidifier. In Development and Application of Heat Pump Dryer, at Brisbane, Australia,1-7.

[9] Strommen, I. and Kramer, K. (1994). New applications of heat pumps in drying process. Drying Technology 12 (4):889-901.

[10] Prasertsan, S. Sean-saby, P. Prateepchaikul, G. (1997). Heat pump dryer.Part 3:Expriment verification of the simulation. Intl. J Energy Research 21:1-20.

[11] Prasertsan, S. and Saen-saby, P., 1998, Heat pump drying of agricultural materials, Drying Technology, 16(1&2) pp.235-250.

[12] O’Neill, M.B. Rahman, M.S. Perera, C.O. Smith, B. Melton, L.D. (1998). Colour and density of apple cubes dried in air and modified atmosphere. International Journal of Food Properties 1 (3): 197–205.

[13] Strommen, I., Eikevik, T.M. and Odilio, A-F. (1999) 'Optimum design and enhanced performance of heat pump dryers', Proceedings of the first Asian-Australian Drying Confrence, at Bali, Indonesia, Abudullah,K., Tamaunan, A.H., and MAUJUMDAR, a.s. (Eds.),68,1999.

[14] Chou, S.K. Chua, K.J. Hawlader, M.N.A. Ho, J.C. (1998). A two-stage heat pump dryer for

better heat recovery and product quality. Journal of the Institute of Engineers, Singapore 38:8–14.

[15] Chou, S.K. Chua, K.J. Mujumdar, A.S. Tan, M. Tan, S.L. (2001). Study on the osmotic pre-treatment and infrared radiation on drying kinetics and colour changes during drying of agricultural products. ASEAN Journal on Science and Technology for Development 18 (1):11-23.

[16] Chua, K.J. Mujumdar, A.S.Chou, S.K. Hawlader, M.N.A. Ho,J.C. (2000). Convective drying of banana, guava and potato pieces: Effect of cyclical variations of air temperature on convective drying kinetics and colour change. Drying Technology 18 (5):907–936.

[17] Oktay, Z. Hepbasil, A. "Performance Evaluation of a Heat Pump Assisted Mechanical Opener Dryer." Energy Conversion & Management 44 (2003): 1193-207.

[18] Teeboonma, U. Tiansuwan, J. Soponronnarit, S. "Optimization of Heat Pump Fruit Dryers." Journalof Food Engineering 59 (2003): 369–77.

[19] Kohayakawa, M.N. Silveria-Junior, V. Telis-Romero, J. "Drying of Mango Slices Using Heat Pump Dryer." Paper presented at the Proceedings of the 14th International Drying Symposium, Sao Paulo, Brazil, 22-25 August 2004.

[20] Hawlader, M.N.A. Perera, C.O. Tian, M. (2006). Properties of modified atmosphere heat pump dried foods. Food Engineering 74:392-401.

[21] Chegini, G.Khayaei, J. Rostami, H.A. Sanjari, A.R. "Designing of a Heat Pump Dryerfor Drying of Plum." Journal of Research and Applications in Agricultural Engineering 52, no. 2 (2007): 63-65.

[22] Phoungchandang, S. "Simulation Model for Heat Pump-Assisted Dehumidified Air Drying for Some Herbs." World Journal of Agricultural Sciences 5 no. 2 (2009): 138-42.

[23] Aktas, M., CeylaN.i.,Yilmaz, S. "Determination of Drying Characteristics of Apples in a Heat Pump and Solar Dryer." Desalination 239, no. 1-3 (2009): 266-75.

[24] Pendyala, V.R., Devotta, S., Patwadhan, V.S. "Heat Pump-Assisted Dryer Part 1: Mathematical Model." International journal of energy research 14 (1990): 479-92.

[25] Abou-Ziyan, H.Z., Ahmed, M.F.,Metwally, M.N, Abd El-Hameed H.M. "Solar-Assisted R22 and R134a Heat Pump Systems for Low-Temperature Applications." Applied Thermal Engineering 17, no. 5 (1997): 455-69.