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Experimental Study of a Heat Pump Assisted General Purpose Tray Dryer with Backup Heater

Nidhin A R
Department of Mechanical Engineering
Mar Athanasius College of Engineering, Kothamangalam

Dr. Jeoju M Issac
Professor
Department of Mechanical Engineering
Mar Athanasius College of Engineering, Kothamangalam

Gokul G Nair
Department of Mechanical Engineering
Mar Athanasius College of Engineering, Kothamangalam

Swagath V Mohan
Department of Mechanical Engineering
Mar Athanasius College of Engineering, Kothamangalam

Feizal Fidus
Department of Mechanical Engineering
Mar Athanasius College of Engineering, Kothamangalam

Abstract

Drying is probably one of the oldest methods of food preservation. The tray dryer is widely used in a variety of applications because of its simple design and capability to dry products at high volume. A drying system incorporating the HP (heat pump) was designed and constructed, along with necessary instrumentation to gather data on the properties of process air as well as real-time weight of the material being dried (mango slices). Drying was carried out in three different temperatures 50, 55 and 600C. The design of the system allowed for conducting drying with recirculation of air as well as use of backup electrical heaters. Comparisons of all three cases were made and it was found that drying time decreases with increase in temperature. Also drying rate increases with temperature. In terms of energy consumption, the process of HP assisted drying is more expensive, but drying time justifies its cost.

Keywords- Heat Pump, Tray Dryer, Drying Uniformity, Drying Rate, Drying Time

I. INTRODUCTION

Drying, a major unit operation in agri-food industry carries a huge environmental cost. The partial or complete removal of water from biological materials is a complex process that requires large amounts of energy. Drying involves the application of heat to vaporize the volatile substances (moisture) and some means of removing water vapor after its separation from the solid. Drying is a complex phenomenon involving simultaneous heat and mass transfer.

Reay and Macmichael (1988), McMullan and Morgan (1981) and Heap (1979) have dealt with the fundamentals of operation and such applications of heat pumps. The agricultural and agri-food processing applications fall within the perspective of the current work and the related Iiterature was reviewed along with other relevant literature pertaining to fundamentals of drying, design and construction of dryers, psychrometrics and energy aspects of drying.

Newbert (1982) comments on the usefulness of heat pumps in recovering waste heat as he takes a sober view of their role in industrial processes. According to this article, heat pumps are desirable only under certain conditions such as operation over long periods within a narrow temperature range, and are to be considered only when other energy saving measures are not practical to achieve. Another paper presented at the same meeting (Oliver, 1982) discusses the use of heat pump dehumidifiers (HPD) in process drying (textile, timber and clay products).

Mujumdar and Menon (1995) also discussed classification, selection and design of dryers. Different experimental techniques for determination of the associated parameters such as moisture content, sorption equilibrium characteristics, thermal conductivity, effective diffusivity etc. are discussed. Focus on drying of food material deals with important factors such as the objectives of drying food, residual moisture content for lengthened storage, properties of foods, optimum drying techniques, types of suitable dryers and changes in food associated with drying.

Hogan et al. (1983) developed a heat pump system for low temperature grain drying. Tested over several seasons, their system was found to be economically desirable when used in open or single pass mode, but they suggested that if exhaust air temperature is taken advantage of through recirculation, the system performance could be improved. Corn was dried from 23% to 14% moisture content, and resistance heaters were used in the control experiments.

The research work related to heat pump dryers at the National University of Singapore is highlighted by Chou and Chua (2001). The paper discusses a general classification of heat pump dryers, their industrial application, comparison of different drying methods and the corresponding energy consumption, and in detail, the use of multi-stage vapour compression systems with multiple condensers and evaporators. An earlier related paper (Hawlader et al., 1998a) provides more details regarding the equipment and drying conditions. The system comprised of two internal evaporators operating at different pressures. The one under higher pressure was used to precool the air (to dew point and below), thus reducing the sensible heat load on the second evaporator (which operated at a lower pressure) to achieve higher dehumidification capacity. An external evaporator was used to make up for low latent heat load during finishing stages of drying. One main condenser, two subcoolers and two economizers were used to achieve proper cooling and to recover heat to the drying air. A simulation model to describe the performance of a heat pump assisted dryer is presented by Hawlader et al. (1998b).

II. MATERIALS AND METHODS

A. *Experimental Setup*

Experimental setup consists of a heat pump dehumidifier unit, an electric heater, a drying chamber contains three trays, a draft fan and an orifice meter to measure velocity of flow. Schematic diagram of the experimental setup is shown below.

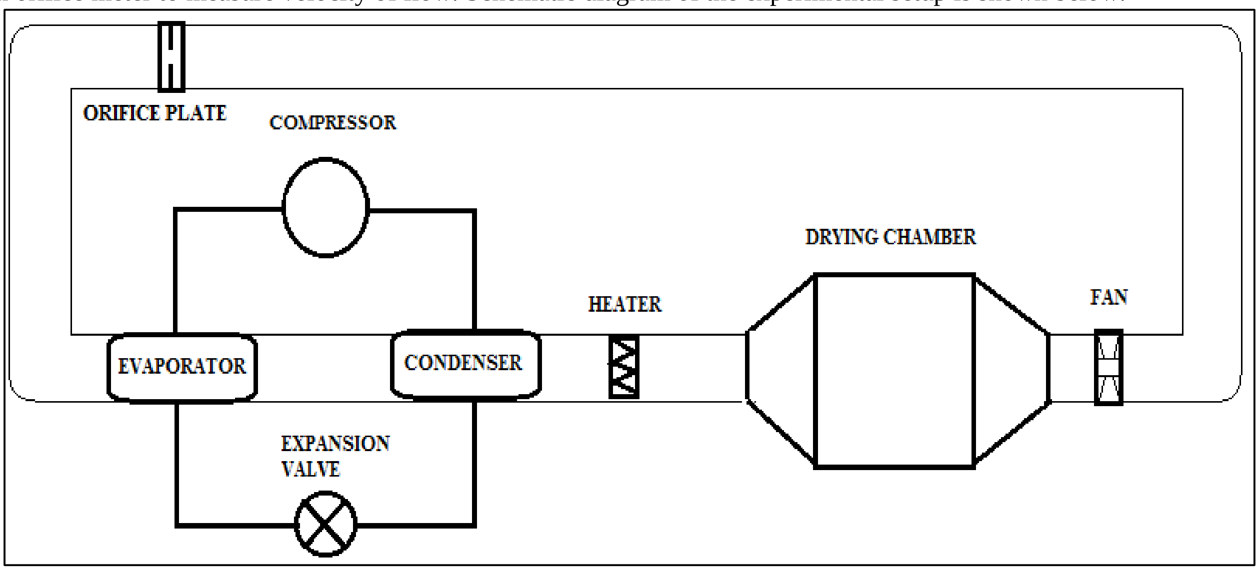

Fig. 1: Schematic Diagram of Experimental Setup

B. *Description of components used*

1) *Heat Pump Dehumidifier*

A heat pump is designed and constructed according to the requirement. Following are assumptions considered in designing the heat pump.

- Atmospheric air at temperature of 32°C and relative humidity of 75% and it is heated to 60°C at the inlet drying chamber
- The evaporating temperature is 10°C below the dew-point temperature
- Condensing temperature is 5°C above the inlet air temperature at dryer inlet
- Compression is isentropic and throttling is adiabatic

With these assumptions following results were obtained,

The evaporating capacity,

$$Q_{ev} = \dot{m}_a \Delta h = \frac{\dot{m}_w}{3600 \cdot \Delta x} \Delta h \quad (1)$$

=1.1715 kW

The refrigerant mass flow rate is determined by,

$$\dot{m}_r = \frac{Q_{ev}}{h_1 - h_4} \quad (2)$$

=0.01098 kg/s

The compressor work and the condensing capacity are determined as,

$$W = \dot{m}_r (h_2 - h_1) \quad (3)$$

=0.4326 kW

$$Q_{con} = \dot{m}_r (h_2 - h_3) \quad (4)$$

=1.6042 kW

Coefficient of performance of the system is given by,

$$COP = \frac{Q_{ev}}{W} \quad (5)$$

= 3.7

As per the design conditions a heat pump dehumidifier is constructed as below,

Fig. 2: Heat Pump Dehumidifier

2) Electric Heater

It consists of an electric heating coil of 1500 Watts. Heater operation is controlled by a thermostat.

3) Drying Chamber

Drying chamber is a 50×50×50 cm cabinet made of GI sheet. Inner side of the chamber was insulated using plastic rexine of 2mm thickness. It consists of 3 trays placed at equal distance. Products to be dried is placed on a wire mesh. Humidity of air entering and leaving the chamber is measured using DHT22 humidity-temperature sensor.

4) Draft Fan

A 60W draft fan of speed 1200 rpm is used. Its air flow rate is 480 cubic feet per minute.

5) Orifice Plate

An orifice plate is manufactured with upstream diameter of 0.6 times diameter of pipe. Provisions for connecting manometer are provided (1.5 times diameter of pipe from upstream side and 0.6 times diameter of orifice to the other side from upstream side).

C. Experimental Procedure

Air first passes through the evaporator coils where it gets dehumidified. Then the condenser itself of the heat pump is used to preheat the air. Air then enters the electric heater where it is heated to the required temperature (50, 55 or 600C). This hot air is supplied to the drying chamber. Draft fan facilitates circulation of air through the system. Orifice plate measures the mass flow rate system using a micro-manometer. Recirculation of air is provided in all cases.

Actual experimental setup is shown below,

Fig. 3: Drying System

III. RESULTS AND DISCUSSION

Mass flow rate through the system is fixed as the fan is running at a constant speed. For drying experiment three cases are considered ie, 50, 55 and 600C. Drying curves for these cases are shown below.

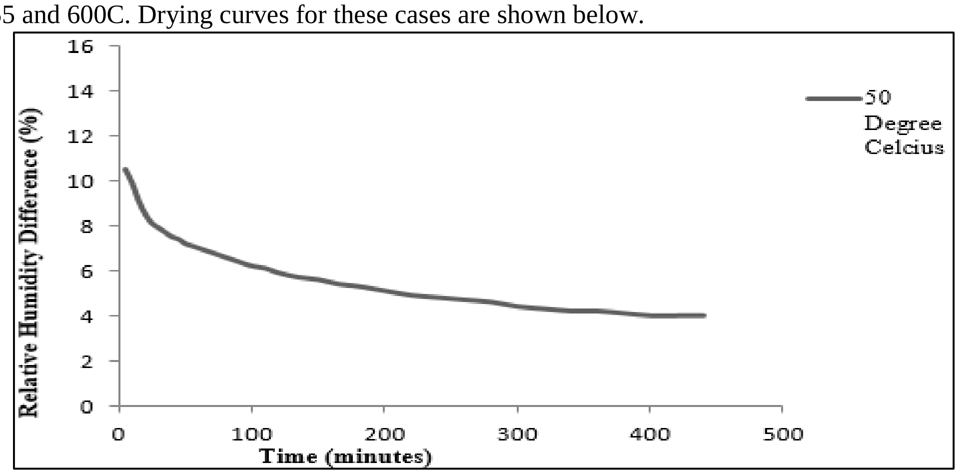

Fig. 4: Drying curve for 50^0C

Figure 4 shows the drying curve for 50^0C. Initial relative humidity difference for 50^0C is 10.5% and it became a constant after 400 minutes. Drying time for this case was 7 hours and 20 minutes. During the first stage humidity difference drops at a faster rate and finally become a constant.

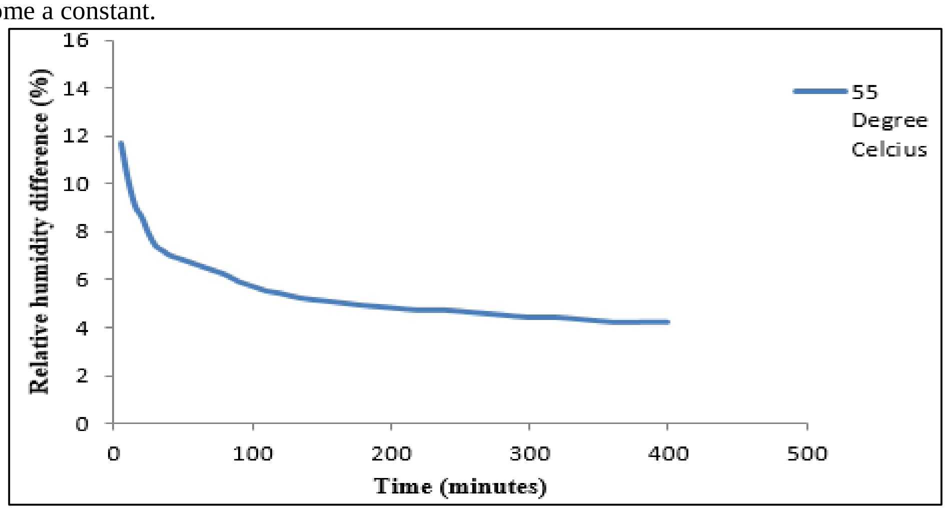

Fig. 5: Drying curve for 55^0C

Figure 5 shows the drying curve for 55^{0}C. Initial moisture removal for this case was 11.7%, clearly more than 50^{0}C. Here humidity difference becomes a constant value from 360 minutes. Drying time required was 6 hour 40 minutes. So drying time reduced in comparison with 50^{0}C.

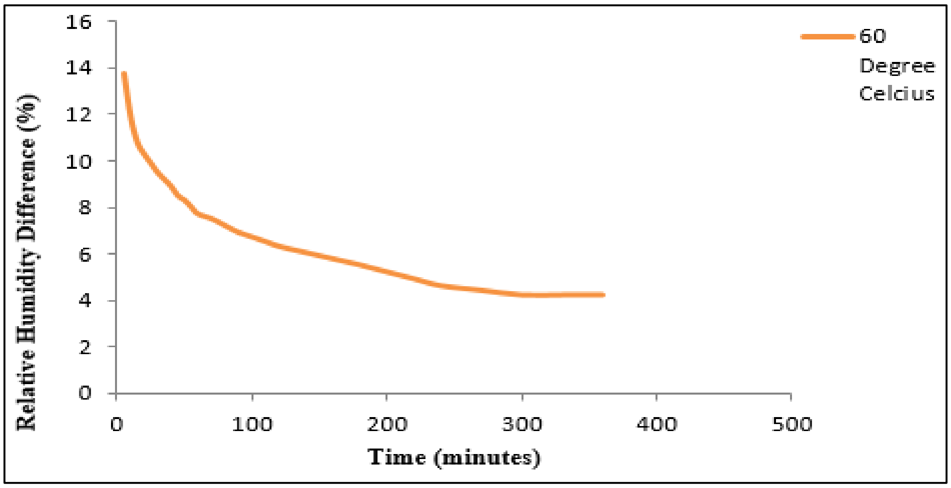

Fig. 6: Drying curve for 60^{0}C

Figure 6 shows the drying curve for 60^{0}C. Initial moisture removal was 14.1% and obviously higher than the other two. Drying time required was 6 hours. So there is a considerable improvement in moisture removal and considerable saving in drying time while comparing with other two cases.

Combinations of all the above cases are shown below.

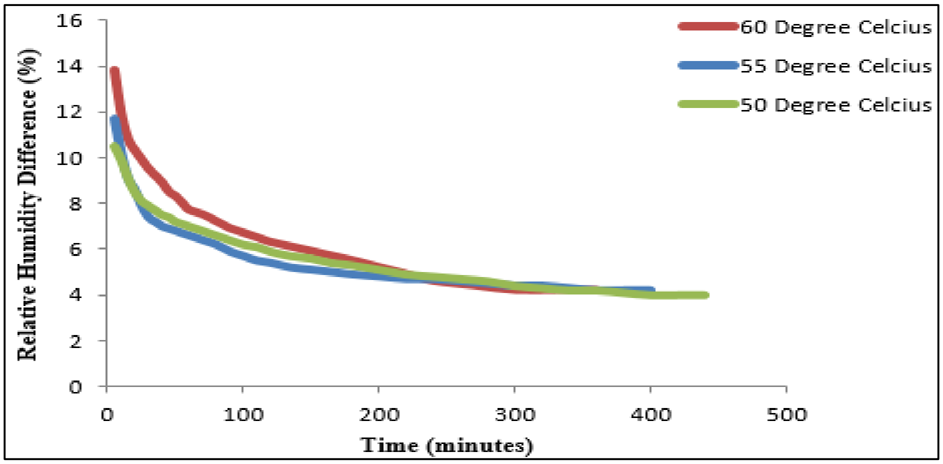

Fig. 7: Combination of 3 cases

Comparisons of drying rate curves are shown below.

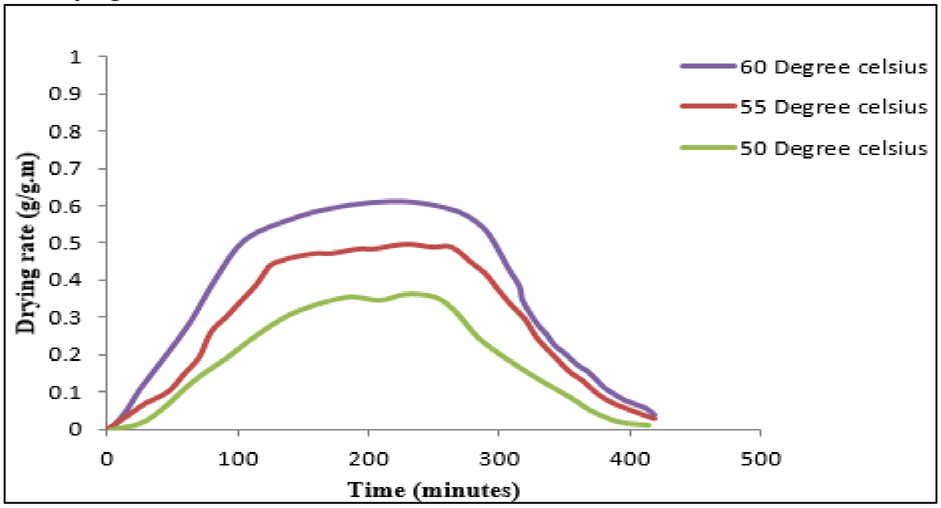

Fig. 8: Drying rate curve

From the drying rate curve, it is clear that drying rate is higher for 60^0C than the other two cases and lowest for 50^0C. So drying rate is directly proportional to temperature ie, drying rate increases with temperature. Each curve consist of three distinct regions.

IV. CONCLUSIONS

An experimental study of a heat pump dehumidifier assisted tray dryer is conducted. Mango slice drying process was simulated three dimensionally for three temperatures (50, 55 & 60^0C). Experimentally, all these parameters such as temperatures along the cabinet, humidity etc. are measured. There is an 11.4% increase in moisture removal for 55^0C compared to 50^0C and 20% increase for 60^0C compared to 55^0C. Drying time is decreased significantly with increase in drying temperature. Drying rate also increases with temperature. Case 3, ie, 60^0C, requires less drying time and shows highest drying rate.

REFERENCES

[1] S. Sokhansanj, and D.S. Jayas, Drying of Foodstuffs. In: Handbook of Industrial Drying, 3rd ed., Mujumdar, A.S. (ed), Taylor & Francis Group, LLC. , 2006, pp. 522-545.
[2] P.K. Adapa,, G.J. Schoenau, and S. Sokhansanj, Performance Study of a Heat Pump Dryer System for Specialty Crops – Part 2: Model Verification. International Journal of Energy Research, Vol 26, 2002, pp. 1-13.
[3] ASHRAE. 1997. ASHRAE Handbook - Fundamentals. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA.
[4] U.S. Pal, and M.K. Khan, Performance Evaluation of Heat Pump Dryer, Journal Food Science Technology, Vol. 47 No. 2, 2010 pp. 230-234.
[5] S.K. Chou, and K.J. Chua, Heat Pump Drying Systems. In: Handbook of Industrial Drying, 3rd ed., Mujumdar, A.S. (ed), Taylor & Francis Group, LLC. , 2006, pp. 1104-1130.
[6] A. S. Mujumdar, “Drying fundamentals,” in Industrial Drying of Foods, C. G. J. Baker, Ed., pp. 7–30, Blackie Academic & Professional, London, UK, 1997.
[7] Mujumdar, AS. and AS. Menon. 1995. Drying of solids: Principles, classification and selection of dryers. In: Handbook of Industrial Drying, Mujumdar, AS. ed., Marcel Dekker, Inc., New York, NY, pp1-39.
[8] M. R. Islam and A. S. Mujumdar, “Heat pump-assisted drying,” in Drying Technologies in Food Processing, X. D. Chen and A.S. Mujumdar, Eds., pp. 190–224, Blackwell Publishing, Oxford,UK, 2008.
[9] S. V. Jangam and A. S. Mujumdar, “Heat pump assisted drying technology—overview with focus on energy, environment and product quality,” in Modern Drying Technology: Energy Savings, Volume 4: Energy Savings, E. Tsotsas and A. S. Mujumdar, Eds., chapter 4, pp. 121–162,Wiley-VCH, 2011.