Experimental Analysis through Heat Pump Assisted Dryer

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Abstract - *Drying is one of the most common preservation methods to prolong the shelf life of agricultural and bio-origin products. It is an energy intensive process. Therefore, the need to develop efficient and cost effective drying processes remains important. Most industrial dryers used in industries are of conventional type where the energy efficiency is low. The heat pump assisted dryer is one of the efficient methods to reduce the energy. It is widely used in many industries because of its capabilities to dry products at high volume. This investigation presents the design of heat pump assisted dryer. The drying kinetics of green peas was studied by using fluidized bed dryer in different configuration. The performance of all systems were evaluated and compared in terms of energy consumption, drying time and MER. The influence of temperature on the drying parameters was analyzed for each configuration. The experimental results show that the use of heat pump is advantageous in the drying process of green peas, mainly in relation to energy consumption, drying time and MER. The drying time is mainly affected by drying temperature. Drying time decreases with increase in temperature for all configurations. Among all the dryer configurations heat pump assisted dryer with vertical arrangement is the optimum one with minimum energy consumption and maximum drying rate.*

Key Words: **Drying rate, Drying time, Heat pump, Moisture extraction rate, Relative humidity**

1. INTRODUCTION

Drying the crops after harvest is essential for longer preservation. The drying process takes out the humidity of the crops and prevents the growth and reproduction of microorganisms. The energy required for drying can be provided from various sources, namely, electricity, fossil fuels, natural gas, wood and solar. The use of solar radiation for drying exists since ancient times. However, it has not been widely integrated in the industrial sector. Number of drying technologies has been developed over the past years such as freeze drying, vacuum drying, hot air drying etc. It is obvious that the quality of the dried product is strongly dependent on the drying methods and drying processes involved. Drying is a complex operation involving combined heat and mass transfer. It is an energy intensive process. Product quality could be degraded during drying operation

When a solid body containing moisture is subjected to thermal drying, two processes occur simultaneously:

1. Transfer of energy (mostly as heat) from the surrounding environment to evaporate the surface moisture

2. Transfer of internal moisture to the surface of the drying substance and its subsequent evaporation due to process 1

Drying rate is governed by the rate at which the above two processes proceed. Wet drying substance gets heat from the surroundings in the form of conduction, convection or radiation and in some cases a combination. The developments on dryers are generally about i) improvements of efficiency, ii) sustainability impact, iii) safety, and iv) product quality. Conventional dryers applied in the manufacturing of dried products consume a large amount of energy. A better solution to this problem is to apply heat pump drying because it is a ready to use technology. It operates well at low temperatures as well as high temperatures applications for preheating. A heat pump dryer recovers heat from the drying exhaust vapour that is lost in open conventional dryers. Heat pump dryer uses a closed loop and fully recovers energy. The amount of heat recovered in a in a heat pump dryer depends on the area available for heat transfer and on the properties of refrigerant and moist air.

Experimental investigation of heat pump for low-temperature grain drying by Hogan and Muller [1] revealed that best performance; both in terms of drying time and energy saving is attained with pure recirculation of air, a heat pump dehumidifier and supplementary resistance heating. The economics of heat pump assisted drying systems by Pendyala [2] voiced that the sensitivity of the economics of heat pump assisted dryers to various factors such as design, economic and operational variables can be evaluated for Indian conditions when payback period approved as a criterion. For the specific, typical conditions and the current charges of electricity and steam in India, a heat pump assisted dryer has a payback period in the range of two to 3 years. Second law limits in convective heat pump driers by Carrington and Liu [3] studied the encouragement of an evaporator economizer and liquid sub cooler on the operating parameters and performance of a heat pump dehumidifier and found out that the drying capacity and efficiency were most substantial at low relative humidity, but further growths were limited by thermal effectiveness of the economizer. Mujumdar [4] has acknowledged and proposed for the first time the use of multiple modes of variable levels of heat input, simultaneous or consecutive, as nicely as cyclical editions in speed or operating strain as technologies of the future for batch and continuous warmness pump drying tactics. it is possible to speed up drying kinetics without adversely affecting the quality of dried products by using multiple modes of heat input. Rossi et.al [5] equated the performance of an electrical heating drying with and without heat pump assisted drying for onion and they reported that the drying time can be saved by 40.7%.According to Best et.al [6], the low temperature and better control in the heat pump assisted drier showed several advantages. So, heat pump assisted drying is an excellent alternative to traditional drying systems and drying rate increased. According to Alves-Filho et.al [7], this set-up can produce drying temperatures from 20 to 60 °C and air humidity ranging from 20 to 90%. The advantages offered by heat pump fluidized bed dryer are: low energy consumption due to high specific moisture extraction rate (SMER), high coefficient of performance (COP), drying temperature can be regulated within the range of −20°C to 110°C, environmental friendly and high product quality. Vázquez et.al [8] recommended that the use of heat pump assisted dryer as an alternative method to dry fruits and vegetables with lower values in consumption of energy, relative humidity and temperatures and electrical energy by 40% in heat pump assisted drying. Prasertsan *et.al* [9] studied the dried products quality compared between the heat pump dried and hot air dried products, and proved that the color and aroma of the first ones are better. Chua *et.al* [10] found that heat pump drying produce a dried product of desired quality at minimum cost and maximum throughput. Utilizing power efficient heat pump in drying gadget can obtain this goal and recover both latent and sensible heat which would otherwise be wasted.

From the literature review, it is clear that no studies have been conducted previously for a heat pump assisted simple tray dryer system and investigate the influence of direction of flow and effect of recirculation on drying rate of the product. Thus, the objective of the present work is experimentally investigating the influence of direction of flow and effect of recirculation on drying rate of the product.

2. EXPERIMENTATION

2.1 Experimental Setup

Experimental setup consists of a heat pump unit, a heater, drying chamber and a fan. Incoming air is dehumidified by cooling it below the dew point temperature in the evaporator. Then the condenser itself of the heat pump is used to preheat the air which is further heated by the heater to the required temperature. Dehumidified, heated air enters the drying chamber. Draft fan forces the air through the network. Schematic diagram of the experimental setup is shown below.

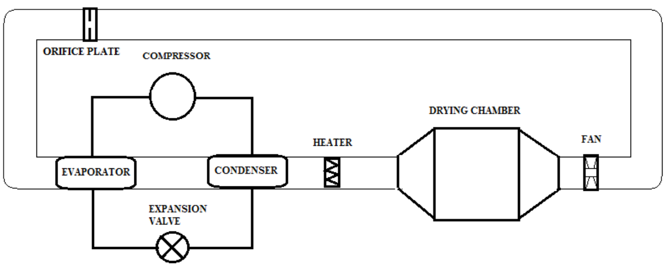

Fig. 1: Schematic Diagram of Experimental Setup for horizontal flow

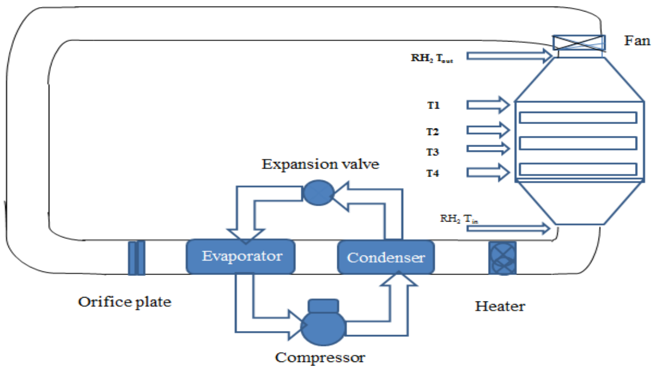

Fig. 2 : Schematic Diagram of Experimental Setup for vertical flow

2.2 Description of components used

(i) Heat pump dehumidifier

Specifications of heat pump as per design are given in table 4.1.

Evaporating capacity	1.1715 kW
Refrigerant mass flow rate	0.01098 kg/s
Compressor work	0.4326 kW
Condensing capacity	1.6042 kW
Coefficient of performance	3.7

Table 1: Specifications of heat pump

(ii) Electric Heater

It consists of an electric heating coil of 1500 Watts. A thermostat controls the operation of the heater. That means power supply to the heater will cut off when air temperature exceeds the preset temperature and turn on supply when temperature drops below the required value.

(iii) Drying chamber

Drying chamber is a 50cm×50cm×50cm cabinet made of GI sheet with a door. Inner side of the chamber was insulated using plastic rexine of 2mm thickness. It consists of 3 trays made of wire mesh, placed at equal distance. Products to be dried are placed on this wire mesh.

(iv)Draft fan

Draft fan facilitates the circulation of air through the system. Specification of the draft fan used is given below:

- Power: 60W
- Speed: 2400 RPM
- Air flow: 480 CFM

(v) 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).

2.3 Experimental Procedure

In experimental procedure, drying experiment is conducted by placing the experiment set up in horizontal flow arrangement with recirculation initially and later the same experiment conducted for vertical flow arrangement with recirculation. Compared the measured values such as relative humidity, exit temperature, weight of dried product and calculated the drying rate and moisture extraction rate for each case and compared the rates. Next the previous experiment conducted for vertical flow arrangement with open cycle and compared the energy consumption and drying time with closed cycle (with recirculation).

Drying experiment was conducted at three temperatures ie, 50°C, 55°C and 60°C. Product to be dried was taken as green peas. Mass flow rate through the system is fixed as the fan is running at a constant speed. During experiments; temperature, velocity and relative humidity of drying air were recorded. Relative humidity sensors (DHT22) are located at upstream and downstream of the drying chamber. Four temperature sensors are placed along chamber to record temperature. Product weight is measured after certain time interval in order determine drying rate. Drying is terminated when the relative humidity difference reaches a constant value.

Instantaneous drying rate is calculated by,

$$\text{Drying rate, } D_R = \frac{W_{i-1} - W_i}{W_d * (t_{i-1} - t_i)}$$

Where,

W_i = Weight of product at any instant „i", (g).

t_i = Time at which weight is taken(minutes).

W_d = Weight of dried product (g).

Instantaneous moisture extraction rate is calculated by,

$$Moisture\ extraction\ rate = \frac{w_{i-1} - w_i}{t_i - t_{i-1}}$$

Where

W_i = Weight of product at any instant „i", (g).

t_i = Time at which weight is taken (minutes).

Fig. 4 (a) Experimental setup in horizontal flow arrangement

Fig. 4 (b) Experimental setup in vertical flow arrangement

3. RESULTS AND DISCUSSIONS

Drying experiment is conducted using green peas as the product to be dried for three temperatures (50°C, 55°C, and 60°C) and corresponding parameters are measured. Under various drying temperatures relative humidity difference (RH1 and RH2), temperatures along the drying chamber (T1 to T6) and drying rate (obtained by instantaneous weighing) is determined depending on drying time. Moisture extraction rate also calculated. Comparison of parameters of vertical flow arrangement and horizontal flow arrangement given below;

3.1 Comparison of Drying Rate Curves

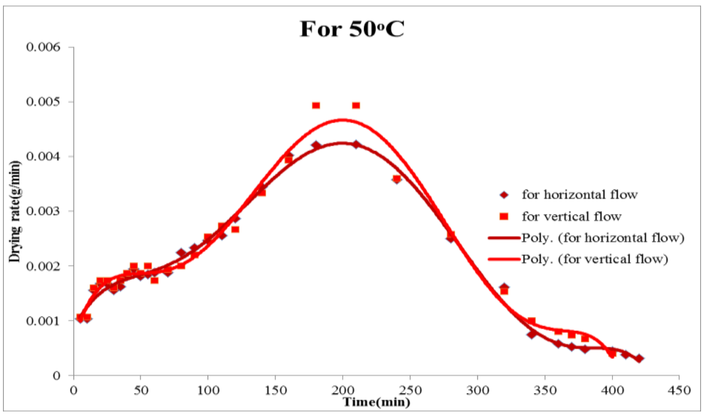

Fig 5 variation of drying rate for 50°C

From figure 5, for both horizontal and vertical flow trend of variation of drying rate is similar. First stage is rapid increasing of drying rate. Second stage is constant rate stage and third stage is falling period stage. Comparing drying rate curve average drying rate for vertical flow is higher than that of horizontal flow. Average drying rate for horizontal flow is 0.0023 and that of vertical flow is 0.0024. Percentage increase in drying rate for vertical flow is 4.34%. Increase in drying rate for vertical flow is because of the gravitational effect due to the nature of air flow. Due to low flowing velocity of air process is basically mixing of natural convection and forced convection. Due to this moisture extraction rate is high ineffectively increase in drying rate.

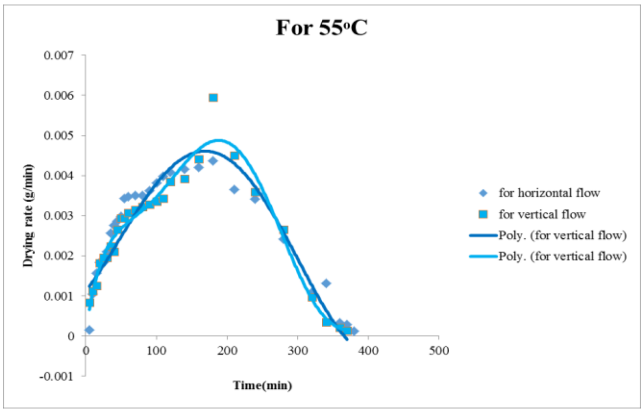

Fig 6: variation of drying rate for 55°C

From figure 6, for both horizontal and vertical flow trend of variation of drying rate is similar. First stage is rapid increasing of drying rate. Second stage is constant rate stage and third stage is falling period stage. Comparing drying rate curve average drying rate for vertical flow is higher than that of horizontal flow. Average drying rate for horizontal flow is 0.0025 and that of vertical flow is 0.0030. Percentage increase in drying rate for vertical flow is 20%. Increase in drying rate for vertical flow is because of the gravitational effect due to the nature of air flow. Due to low flowing velocity of air process is basically mixing of natural convection and forced convection. Due to this moisture extraction rate is high ineffectively increase in drying rate. Comparing drying curves for 50°C, for 55°C average drying rate is higher for both horizontal and vertical flow. Percentage of variation of drying rate is also more for vertical flow arrangement. For horizontal flow percentage variation is 8.6% and that of vertical flow is 25%.

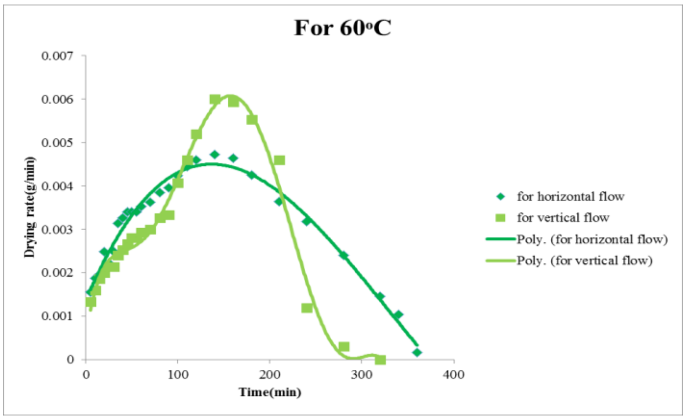

Fig 7: variation of drying rate for 60°C

From figure 7, for both horizontal and vertical flow trend of variation of drying rate is similar. First stage is rapid increasing of drying rate. Second stage is constant rate stage and third stage is falling period stage. Comparing drying rate curve average drying rate for vertical flow is higher than that of horizontal flow. Average drying rate for horizontal flow is 0.0028 and that of vertical flow is 0.00323. Percentage increase in drying rate for vertical flow is 15.35%. Increase in drying rate for vertical flow is because of the gravitational effect due to the nature of air flow. Due to low flowing velocity of air process is basically mixing of natural convection and forced convection. Due to this moisture extraction rate is high ineffectively increase in drying rate. Percentage of variation of drying rate is also more for horizontal flow arrangement. For horizontal flow percentage variation is 12% and that of vertical flow is 7.6% while comparing with average values of drying rate for 55°C. Even though values of average drying rate for vertical flow is still high for vertical flow.

3.2 Variation of Drying Time

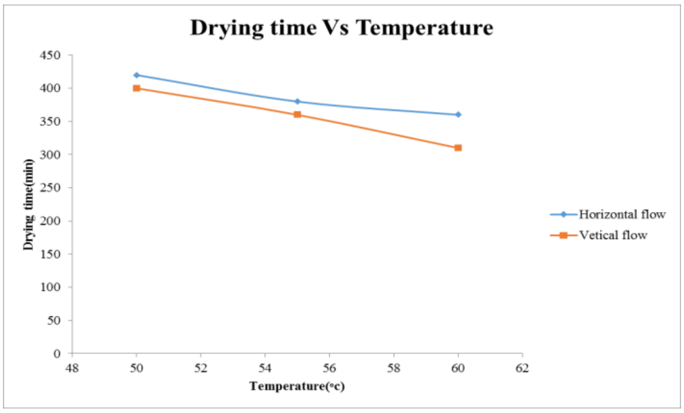

Fig 8: variation of drying time

From figure 8, it is obvious that drying time and temperature are inversely proportional, ie, as the temperature increases drying time decreases and vice versa. For horizontal flow drying time for 50°C is 420 minutes, that for 55°C is 380 minutes and that for 60°C is 360 minutes. For horizontal flow drying time for 50°C is 400 minutes, that for 55°C is 360 minutes and that for 60°C is 310 minutes. While comparing horizontal flow and vertical flow, percentage decrease in drying time is 5% for vertical flow, that for 55°C is 5% for vertical and that for 60°C is 16.13 %.Comparing all operating temperatures 60°C having highest percentage reduction in drying time. Since when temperature increases drying rate and moisture extraction rate increases, it will reduce the time for drying. While comparing direction of air flow in all cases vertical arrangement having lowest value of drying time in all temperatures, because of the high values of drying rate and MER.

3.3 Variation MER

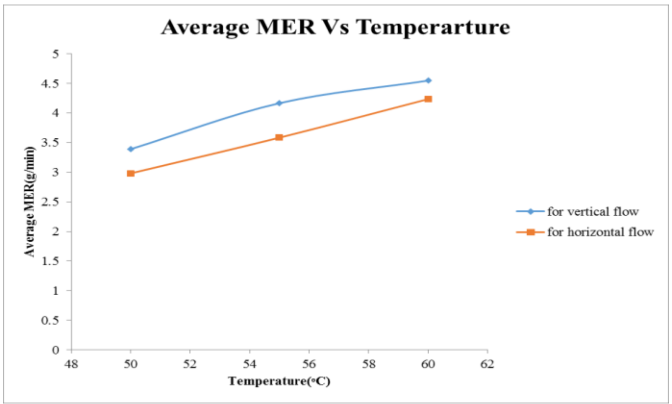

Fig 9: variation of MER

In MER contours of both horizontal and vertical, there is an increase in MER initially; it can be explained on the basis of moisture condensation rate. During the initial stages moisture condensation rate was high because of high relative humidity of air at dryer exit. As the drying progresses, relative humidity of process air at dryer exit decreases thereby reducing MER. For horizontal arrangement moisture extraction ratio varies from 0.5g/min to 5g/min. For vertical arrangement moisture extraction ratio varies from 0.8g/min to 5.5g/min. For both case when value of MER increases drying rate increases. There for maximum drying rate occurs for 60°C. While comparing horizontal flow and vertical flow, percentage increase in MER is 13.72% for 50°C, that of 55°C is 16.26% and that of 60°C is 7.3%.

4. CONCLUSION

Experimental investigation of heat pump assisted dryer is done with parallel flow arrangement and vertical flow arrangement in order to check the influence direction of flow and effect of recirculation on drying rate of the product. A green pea drying is carried out for temperatures of 50°C, 55°C and 60°C. Drying time is decreased significantly with increase in drying temperature. There is a 10.52% decrease in drying time for 55°C compared to 50°C and 5.56% less drying time required for 60°C compared to 55°C for horizontal flow. Drying time is decreased significantly with increase in drying temperature. There is a 11.11% decrease in drying time for 55°C compared to 50°C and 16.13% less drying time required for 60°C compared to 55°C for vertical flow. When the temperature is increased from 50°C to 60°C, increase in drying rate is 21.74% for horizontal flow and 34.58% for vertical flow. Range of average MER for horizontal flow is 2.98- 4.24 g/min and that for vertical flow is 3.39 – 4.55 g/min. Range of average drying rate is 0.0023 - 0.0028 for horizontal and 0.0024 - 0.00323 for vertical. Comparing drying time, drying rate and MER vertical flow arrangement is more efficient than horizontal. Comparing open cycle and closed cycle of vertical flow, closed cycle consuming less amount of energy than open cycle. From the analysis, vertical flow arrangement with recirculation is one of the best methods for drying.

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