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DESIGNING OF A HEAT PUMP DRYER FOR DRYING OF PLUM

Summary

Traditional drying ways for drying of agricultural products and consumption of large amount of energy in conventional dryers result in reducing of quality and increasing of final cost of products. Utilizing of Heat Pump Dryers can improve the quality of products as well as decreasing the final production costs by means of energy saving. In the Heat Pump Dryer a high quantity of heat needed for drying of products can be shed off or saved from the latent and sensible heat of air leaving the drying chamber. In this article primary data of configuration such as relative humidity of air, input power of compressor, power of fan, recirculation air ratio (RAR) was obtained. Regarding to this primary data and dehumidifying specifications of plum, an experimental model of dryer was designed. The results indicated that the optimum temperature of drying for plums is in vicinity of 70-80ºC; also specific moisture extraction rate (SMER) of designed dryer was notably more than conventional types of dryers in respect to saving the energy.

Introduction

Heat pump has been studied for use on farms since the early 1950s and has found some applications in various sectors like dairy, grain drying, fruit and etc. Heat pump dryers have many advantages compared to the conventional systems like improved product quality, reduced energy consumption and reduced environmental incidence [1]. Various agri-products such as apple, onion and etc were dried in this method. The products obtained by the process were of exceptionally high quality. The color degradation was negligible and the flavor was free from any process-induced aberrations [2]. Heat pump dryers are attractive for the processing of heat sensitive materials since the drying conditions are easily controlled. Aside from being able to save energy this dryer design is based on an environmentally friendly technology [2, 3].

In a HPD air carries moisture from drying chamber and in its own way has to pass through evaporator coils. Now refrigerant through the HP undergoes a double fast change from fluid to vapor and makes drying air cool and dried. During this process the air is first cooled sensibly to its dew point and further cooling results in water being condensed from air. The evaporator for boiling of the refrigerant then absorbs latent heat of vaporization. The recover heat is pumped to the condenser. The cooled and dried air then absorbs heat at condenser moving between its coils and then is directed towards drying chamber again. This cycle will be continued as long as products get optimum moisture content [3].

At the same time air with low relative humidity (RH) extracts moisture. Quality of dried products in hot air dryers strongly depends upon mass and heat transfer and exposing time to the heat. Hence designing of a good dryer based on physical and chemical properties of products is posed as a major problem. Regarding to this that color, flavor and nutritive value of products (Fruit) are important factors so designing of a good dryer system seems notable [3].

Plum (Prunus Domestica) has low consumption, as it is fresh. The waxy skin of plum prevents removing of moisture. From one hand prunes are sensitive to color change while they are drying and on the other hand neglecting this can spoil market of that. In this paper a heat pump dryer is designed for dehumidifying of plum utilizing from technology of HPD. For drying of plum maintains the quality of products as well as saving energy by recovering heat from outlet of drying chamber because energy costs during drying process account for major portion (25-30%) of total production costs [4].

Materials and methods

Primary data on designing

For designing of heat pump dryers' fundamentals of heat pumps and different kinds of dryers should be well understood. Finding the best cultivars of plum also is needed. Some factors involve: temperature of drying, residence time, circumstances of inlet and outlet air (Relative Humidity, Absolute Humidity, air mass flow rate and so on) and quality of products are necessary. These data were obtained from psychometric chart and thermo dynamical equations and previous researches. The best drying temperature was 70-80°C [4, 5].

Choosing the suitable cultivars of plum

Researches indicate that the best cultivars plum is three known Stanley, Empress, and Angeleno. From these three varieties, Stanley has a higher final sugar content and Sorbitol and drying times for Stanley cultivars is lower than the other cultivars [4]. So Stanley prunes were selected as the best cultivars for drying. Therefore In this paper used data is based on data reported for Stanley prunes.

Selecting the kind of HPD

Considering to the results of 5 different convention kinds of HPD, partially closed HPD was selected [4]. In this combination before evaporator and condenser two adjustable dampers for adjusting the RAR (Recirculation Air Ratio) exist .RAR depends on ambient temperature and moisture content of fruits. It's alternative for achieving the best SMER independent of ambient circumstances. Generally this system for lower ambient temperatures was near to close (higher RAR) and in higher ambient temperature was near to open statue (lower RAR). Then near to open statue (lower RAR). Then after determining this rate as a function of ambient temperature, dampers were adjusted for keeping internal circumstances to provide the best SMER [7, 8, 9].

Results and discussion

Primary specifications of drying

Designing of this dryer was for drying of Stanley prunes with total weight of 48.5gr per one fresh fruit and moisture content of 78.8%. The optimum and desire final moisture content was 20%. With using of the equations 1, 2 weight of water in the fresh plum and after drying were calculated.

$$W_{\omega} = W_t \times \omega \tag{1}$$

$$W_d = W_t \times 20\% \tag{2}$$

Regarding to both above equations weight of water in the fresh plum was 38.22gr and weight of residual water after drying was 9.7gr.

This dryer was designed for 50 prunes with a mean weight of 2425gr. Amount of water in these prunes from eq.1 was approximately 1911gr and residual water after getting optimum moisture from eq.2 was approximately 435gr. Amount of removal water was equal to subtraction of mentioned amount of water.

Designing of dryer components

Select of size of drying chamber

A leading role of drying chamber consists of surrounding internal circumstances of chamber, maintaining temperature, pressure and velocity of air constant. Hence chamber should have a special shape so that pressure and velocity of inlet air do not change. However chamber was designed cylindrical with diameter of 30cm that was located a place for a fruit tray in it. Fruit tray was made of steel mesh, which could hold 50 prunes. Length of chamber was 70cm and length of mesh was 60cm.The mesh was located horizontally in the chamber.

Designing of heating system of working air

This system had various elements such as evaporator, condenser, compressor, throttle valve and auxiliary heater. Usually the coefficient of performance (COP) for heat pumps are higher than 3[7]. By assuming that temperature of flowing air at the outlet will be decreased about 5ºC and its relative humidity will increased about 2% , amount of needed energy for operation of system was obtained by equation (3).

$$q_{ai} = \Delta h \times m_{ai} \tag{3}$$

Using equation (4), primary data and psychometric chart the air mass flowing rate of inlet air was obtained from equation (5).

$$T_{ai} = 70\,^{\circ}c$$

$$T_{ao} = 65\,^{\circ}c$$

$$H_o = 5\%$$

$$h_{ai} = 78\ {}^{kj}\!/_{kg}$$

$$h_{ao} = 86\ {}^{kj}\!/_{kg} \qquad \Rightarrow \Delta h = 8\ {}^{kj}\!/_{kg}$$

$$Q_{ai} = V \times A \tag{4}$$

$$m_{ai} = \frac{Q_{ai}}{v_{ai}} \tag{5}$$

Inlet air mass flowing rate and heat needed for heating of inlet air using above equation were obtained 21.85 kg/min and 174.8 kj/min equal to 2.9 kj/s, respectively.

Regarding to loss of heat from components reliability coefficient of system was assumed 1.5. So utilized heat and energy was 4.35 kj/s. By using a heat pump with COP of 3, input power compressor was obtained 1.45kw.

Calculating of pressure reduction

For determining of exact energy needed for running an appropriate fan, reduction of pressure at different parts of system should be known. Regardless to pressure reduction at the bends and within fruits at the drying chamber, pressure reduction between fan’s vanes based on height of air from equations 6, 7 were obtained 20.39m (air).

$$V_{tra} = \frac{Q_{ai}}{A_w} \tag{6}$$

$$V_{tra}^2 = 2gh_{air} \tag{7}$$

After changing of mentioned value to height of water from equation 8 it was 0.0229m (water).

$$h_{air} \times \gamma_{air} = h_w \times \gamma_w \tag{8}$$

Power of fan

Using results of equations 5, 8 and 9 for computing of power, the input power was obtained 0.294kw. By supposing

$$P = m_{ai} \times h_t \tag{9}$$

$h_t = h_w$.

Designing of control system

Because of choosing a partially closed type for HPD also for obtaining exact graphs for building of industrial apparatus, designing of a control system seemed necessary. Components of this system were temperature and relative humidity probes, electronic balance, adjustable dampers and a few currents for controlling of fan's speed. Locating of temperature and relative humidity sensors at the inlet and outlet ports and after and before condenser as well as attachment of fruits tray to the accurate balance for giving weight exchange of products during drying could give valuable information continuously.

Conclusions

Results of previous calculations and equations number 10, 11 showed the time needed for drying of 50 fresh prunes about 16.31 minutes.

At the following equation f=1426gr and it was total moisture load. According the inlet and outlet tem.(70 , 65) the absolute humidity 0.003 for inlet and 0.007 for outlet that was obtained from psychometric chart the time of drying is obtained from equ.10,11.

$$HA_{ai} = 0.003$$

$$\Rightarrow \Delta\mathrm{HA} = 0.004\ {}^{\mathrm{kg}}\!/_{\mathrm{kg}}$$

$$HA_{ao} = 0.007$$

$m_w = \Delta HA \times m_{ai}\left({}^{kg}\!/_{\min}\right)$ = 0.004 kg/kg * 21.85 kg/min = 0.0874 kg/min (10)

$T_d = \dfrac{f}{m_w}$ =1426/0.0874 =16.31 min (11)

Total performance of dryers is lower about 50-60%, thus this time increased to 22 minutes.

SMER of this dryer regarding to equation 12 was obtained 3.

$$SMER = \frac{m_w\left({}^{kg}\!/_{h}\right)}{P_t\left(kw\right)} \qquad (12)$$

Analyzing of balance data at different stages of drying and drawing diagram based on weight-time and removed moisture-time can give valuable information's.

Nomenclature

$W_w =$ Weight of water in the fresh plum
$W_t =$ Total weight of plum
$\omega =$ Moisture content of fresh plum
$W_d =$ Weight of water in the dried material
$T_{ai} =$ Temperature of inlet air
$T_{ao} =$ Temperature of outlet air
$H_t =$ Relative humidity of inlet air
$H_o =$ Relative humidity of outlet air
$h_{ai} =$ Enthalpy of inlet air
$h_{ao} =$ Enthalpy of outlet air
$\Delta h =$ Changes of enthalpy
V = Velocity of flowing air
A = Area of inlet port of drying chamber
$Q_{ai} =$ Volume flowing rate of inlet air
$v_{ai} =$ Specific volume of inlet air
$m_{ai} =$ Mass flowing rate of inlet air
$q_{ai} =$ Heating load
$V_{tra} =$ Transparent velocity
$A_w =$ Area of vanes
$h_{air} =$ Pressure reduction basis on height of air
$h_w =$ Pressure reduction basis on height of water
$\gamma_{air} =$ Density of air
$\gamma_w =$ Density of water
P = Power of fan
$HA_{ai} =$ Absolute humidity of inlet air
$HA_{ao} =$ Absolute humidity of outlet air
$m_w =$ Mass flowing rate of water
f = Total removed moisture load
$T_d =$ Time of drying
$P_t =$ Total input power

References

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

[2] Raghavan, G.S., Valerie, O. (2004). Drying of agro-products and grains. Proceeding of IWSID 2004,Mumbi, India

[3] Mujumdar, A.S. (2001). Drying Technology in agriculture and food science. Science Publishers, Inc, Enfield, USA.313 p.

[4] Cinquanta, L., M.D. Matteo, M. Esti. (2002). Physical pre-treatment of plum (*prunus domestica*). Part2.Effect on the quality characteristics of different prune cultivars. Food Chemistry, 79:233-238

[5] Lambertotten, J.S, Gotthardova,J., P. Homola.(1999).Model comparisons of equilibrium moisture content of prunes in the temperature range of 15-45 ºC . Stored products Research, 35:27-36

[6] Henry T. Sabarez, William E. Price. (1999). A diffusion model for prune dehydration. Stored products Research, 45:167-172

[7] Jangam.,S.V., Waje,S., Thorat.B. (2004).Heat Pump Drying: Some Design Aspects.Proceeding of IWSID 2004.Mumbi, India

[8] Swensabai, P. and Prasertsan, S. (2003).Effects of component Arrangement and Ambient and Drying conditions on the performance of Heat Pump Dryers. Drying Technology.21 (1): 103-127

[9] Sosle,V., Raghavan,G. and R. Kittler. (2003). Low-Temperature Drying Using a Versatile Heat Pump Dehumidifier. Drying Technology.21 (3): 539-554.