Energy Conversion and Management 52 (2011) 2919–2924

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Feasibility analysis of heat pump dryer to dry hawthorn cake

D.C. Wang *, G. Zhang, Y.P. Han, J.P. Zhang, X.L. Tian

College of Electromechanical Engineering, Qingdao University, Qingdao 266071, PR China

ARTICLE INFO

Article history:
Received 22 April 2010
Received in revised form 28 February 2011
Accepted 8 April 2011
Available online 4 May 2011

Keywords:
Heat pump dryer
Drying
Hawthorn cake
Feasibility analysis

ABSTRACT

A heat pump dryer (HPD) would be an economic, environmentally friendly, hygienic drying machine used to dry some food, such as hawthorn cakes. Based on the production process of the hawthorn cake, a HPD is proposed and its basic principle is introduced. The experimental drying curves of the hawthorn cake using the heat pump drying method and the traditional hot air drying method are compared and analyzed. The drying process of hawthorn cakes is similar to that of the other drying materials. The higher drying temperature causes a faster drying process. But in the initial stage of the heat pump drying process, the water content of the hawthorn cake is not sensitive to the drying temperature, so a lower drying air temperature can be available in order to get a higher coefficient of performance (COP) of the heat pump (HP). The experimental results and the economic analysis indicate that the HPD is feasibly used to dry hawthorn cakes.

1. Introduction

The hawthorn cake, is one kind of healthy food which is rich in nutrition. The hawthorn cake is made from hawthorn, a fruit which is widely planted in the north of China, as shown in Fig. 1. In the production process of the hawthorn cake, drying is one of the most important production processes. The traditional drying method is air forced drying in an open cycle of the hot air, named as hot air drying. In the cycle, air is heated by a coal-fired or gas-fired furnace and then its temperature increases, when the lowest relative humidity and the strongest drying capacity of the air yield. The hot air blows into the drying chamber to dry the materials and then discharged into the atmospheric environment. In the hot air drying cycle, a furnace with low efficiency and low power is employed. The utilization efficiency of the primary energy resources (such as coal, oil and gas) reduces and the atmospheric pollution badly yields. Meanwhile, all the air heated in the open cycle is from the atmosphere so that its purity is very difficult to be controlled. As a result, the food dried in the open cycle is easy to be polluted. At present, almost of all the food companies in China use the coal-fired furnace to dry hawthorn cakes, that is hot air dryings method. Therefore, it is necessary to find one energy saving and sanitary drying method for hawthorn cake drying. A HPD would be the best choice.

A HPD can be powered by the electric energy. And in a HPD system, a closed cycle is available so that the sanitary condition in food drying process can be firmly controlled. At the same time, the COP of the HP is generally much larger than 1.0. Compared with the dryers driven by the low power coal-fired furnace or the conventional steam heated dryer, a HPD could save 58% or 75% energy respectively [1]. Compared to conventional dryers incorporating electric coil heaters, a re-circulating heat pump continuous bed dryer system could save more than 22% energy and 65% drying time [2]. The experimental results also proved that a HPD was more efficient than a conventional gas-fired dryer when the shelled corn and grain sorghum were dried [3]. Additionally, the product quality of the drying material would be also focused on. According to the experimental results of the drying green sweet pepper [4], more chlorophyll and ascorbic acid were preserved when a HPD was used because a lower drying temperature was adopted.

A HPD is composed of a HP subsystem and a drying subsystem. Due to the advantages of the energy saving potential and the ability to control the drying temperature as well as the air humidity, the HPD technology has attracted much interest of researchers. Since the first HPD patent applications in 1973, a lot of work to study HPD technology were reported in the literatures [5–7].

The HP used in the drying system is usually a vapor-compressed type or an absorption type. Using a vapor compressed HP or an absorption HP resulted in a energy recovery of more than 70% or 40% respectively from the exhaust moist air [8]. Brice et al. [9] pointed out that using an absorption HP to dry wood is feasible especially when an industrial waste heat recovery system was available. The heat released from the condenser is commonly more than that absorbed by the evaporator in one HP. The superfluous heat in the closed-loop HPD system could be removed by two effective methods: heat rejection with

* Corresponding author. Tel./fax: +86 532 859 505 12.
E-mail address: wdechang@163.com (D.C. Wang).

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doi:10.1016/j.enconman.2011.04.002

Fig. 1. Photo of hawthorn and hawthorn cakes.

external condenser [10] and heat rejection with desuperheater [11]. Another method to keep the thermal equilibrium of the HPD system [12] is that a part of moisture hot air is discharged into the environment and the same amount of dryer cold fresh air is imported. Therefore the auxiliary condenser used in the closed-loop system could be saved, and the investment would decline. Certainly, the structure of the open-loop system is simpler. But the fresh air imported into system should be filtrated by a certain set.

For the sake of energy saving, other efforts to develop HPD technology also ware made. The combination of HPD and the solar dryer was considered to be more efficient because the solar dyer and the HPD could alternately work in the daytime and at night [13]. When a heat pipe was used in a HPD system, the claimed reduction in energy consumption of HP was 12–20% [14]. Minea [15] researched on methods to fix some common design errors and to suggest original control strategies of high temperature HPD in order to avoid the system malfunction and equipment failures. The investigation of an air heat pump (reversed Brayton) cycle for tumbler clothes dryers indicated a 40% improvement in energy efficiency over the electric dryer [16]. According to the Ref. [17], the intermediate moisture food was much suitable for being dried by a HPD. And the hawthorn cake was one kind of intermediate moisture foods. But HPD technology had not used in hawthorn cake drying process at present. And little research about using HPD to dry materials like hawthorn cakes was reported. In this work, a HPD for hawthorn cake drying was designed and tested in order to estimate the feasibility of a HPD to dry hawthorn cakes. Compared to a hot air dryer, the HPD was more efficiency. The analysis of the data obtained from the experiments indicated that the feasibility of a HPD used in the hawthorn cake drying process was validated.

2. Production process of hawthorn cakes

Different production process of drying materials causes a different influence on the performance of the HPD. In the drying process, the slimy pulp of the hawthorn becomes solid slices. In order to maintain the hawthorn cake flat and smooth appearance, the hawthorn pulp must be spread on the smooth surface of glass-likely materials before the fixed state is formed in the drying process. At this stage, the moisture in the hawthorn pulp is just transferred in one way because the glass plate is airtight. Therefore the hawthorn slices will be difficult to be quickly dried before they are peeled off from the glass plate. In addition, the suitable temperature and moisture content are necessary for the hawthorn slices so that they can be inextenso peeled from the glass plate. The drying process of hawthorn cakes is closely related to its production process. The main production process of hawthorn cakes is introduced as follows:

(1) Beating Pulp: The hawthorns are carefully selected by hands. After being cleaned, the hawthorns are cooked. The pulp of the hawthorn is removed seeds and then mixed with sugar and other food additives in a certain proportion. Then this mixture is beaten into pulp by a strip engine.
(2) Strickling: The hawthorn pulp mixture was flatted and strickled on the smooth glass plates into thin layers (the hawthorn pulp slices) whose thickness is not more than 2 mm, depending on the customs' requirements.
(3) Pre-drying: The glass plates together with the hawthorn pulp slices are put into the dryer. The inlet air temperature of drying chamber is 60–65 °C that is needed by next process. After a certain time of baking in the dryer, about half moisture of the hawthorn slices is lost, then the surface of the slices is not sticky and the shape of the slices is fixed. Then the hawthorn slices on the glass plates are carried out of the dryer.
(4) Peeling and drying: The hawthorn slices after being predried are peeled from the glass plates, and turned over on the wire meshes. Then they return into the dryer again. In this drying process, the moisture can be transferred through both two sides of the hawthorn slices so that the hawthorn slices can be dried more quickly. When the moisture content in the slices meets the requirements for products, this process is finished.
(5) Stewing slices: All the dried hawthorn slices are separated by papers and then stacked in the stewing chamber with temperature of about 45 °C. As a result, the sugar is melt fully and spreads uniformly in the slices.
(6) Slicing up and packing: The stewed slices, hawthorn cakes, are packaged into various specifications, depending on the choices of per buyer' s requests.

3. System descriptions

3.1. Traditional hot air drying system

Fig. 2 shows the schematic diagram of a traditional hot air drying system for drying hawthorn cakes used in the food factory at present. The heat source is provided by a coal-fired furnace. In this system, the Import door A is the inlet of the wet hawthorn slices and the Exit door B is the outlet of the dried hawthorn cakes. The Exit door A and the Import door B are the outlet and the inlet of the pre-dried hawthorn slices with semi-moisture content respectively. After being carried out through the Exit door A and before being put into Chamber B through the Import door B, the hawthorn slices are peeled from glass plates and turned over on the wire meshes. The primary function of drying Chamber A is pre-drying in order to fix the shape of the hawthorn slices and ensure them easy to be peeled from glass plates. Therefore, the humidity of the air flowing out of Chamber A is very high and its temperature is quite low. The drying Chamber B is the place where the semi-moisture hawthorn slices are further dried for the production requirement. In this system, air flows in an open cycle. After being heated by the furnace, the circulating air mixed with the fresh air is distributed into Chamber A and Chamber B by the Shunt. Almost all the air from Chamber A and a part of air from Chamber B will be discharged through Exhaust air port because of its highest humidity especially in the pre-drying process in Chamber A. The Exhaust air port is located on the front top of the wet material inlet (Import door A). The moisture content of the hawthorn slices will meet the requirements of the products when they are carried out of the Chamber B through the Exit door B.