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Research Article

Novel Solution for High Efficiency Bee Pollen Heat Pump Dryer

Nguyen Hay[1]*, Le Quang Huy[2] and Vo Tan Phuong[3]

[1]Faculty of Engineering and Technology, Nong Lam University, Ho Chi Minh City, Vietnam

[2]Cao Thang Technical College, Ho Chi Minh City, Vietnam

[3]Tien Giang College, Tien Giang Province, Vietnam

***Corresponding Author:** Nguyen Hay, Faculty of Engineering and Technology, Nong Lam University, Ho Chi Minh City, Vietnam.

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Abstract

The study was conducted to calculate, design, fabricate and test a bee pollen heat pump raking device assisted dryer with a yield of 10 kg/batch. The aim of mixing material is to increase the contact of pollen with drying air, thus, increasing heat exchange, drying efficiency and drying rate. Besides, it reduces energy consumption and increases product uniformity. Experimental planning was carried out to determine the influence of operating parameters of the drier on the quality of the dried bee pollen. A set of mathematical equations represents the dependence of electrical energy consumption of the drying process, vitamin C content in the dried pollen and product recovery rate on drying temperature and the raking cycle was determined. The result showed that, at the drying temperature of 38.40C and raking cycle of 10 minutes, the drier operates at optimal working condition with the minimum electrical energy consumption Armin = 0.96 kWh/kg, maximum vitamin C content C_{max} = 72.11% (256.7 mg/kg) and maximum product recovery rate M_{max} = 75.46%.

Keywords: Pollen Heat Pump; Bee Pollen; Vitamin C

Introduction

Bee Pollen, the food of bees, is also a product of the beekeeping sector. It is considered one of nature's most nourishing foods. It contains all the essential components of life, such as proteins, free amino acids, and vitamins. In oriental medicine, bee pollen has been used as a kind of medicine and tonic for thousands of years. Due to the high moisture content in composition (between 20 - 30%) of bee pollen, which causes fermentation and rapid deterioration, a drying out process is necessary to extend its shelf life. In some places, the sun drying of bee pollen is used, which is inappropriate because of the considerable process time, increased microbial spoilage during the drying process and lower sanitary conditions.

Heat pump drying technology is a suitable drying method for heat-sensitive food products like bee pollen. This drying method has some enormous/great/huge/significant advantages, including improved microbial safety, better colour, vitamin C retention, and a reduction of energy consumed in the process. Up to now, most studies on the heat pump drying technique have been focused on static drying methods. There is very little research focused on dynamic drying methods. In the dynamic drying methods, drying materials are mixing in a drying chamber. Therefore, it intensifies the contact of the material with drying air and increases the heat transfer rate and drying speed. This research aims to study the effect of drying temperature and rake cycle on the quality of the dried bee pollen using a heat pump raking device assisted dryer.

Materials and Methods

Material

The bee pollen was obtained from Cho Gao District - Tien Giang Province. Pollen exists in the form of pellets and has a bright yellow powder and mixes some golden brown particles.

The moisture content of the bee pollen before and after drying is 30% wb and 10% wb, respectively.

Method

Many parameters affect the technical and economic indicators of the dryer. Therefore, the black-box testing method is used in the experimental planning to reduce the number of experiments.

Pollen vitamin C is determined by the AOAC method.

Specific energy consumption is determined by measuring the electrical energy consumption on each batch and divided by the total pollen volume of the batch [10].

The product recovery rate is determined by measuring the remaining weight of the pollen after sieving with 1.2 mm diameter orifice screen to remove the pollen powder.

The analysis of variance (ANOVA), Statgraphics software ver. 7.0 and Microsoft Excel are used in experimental design and data processing. Based on the regression equation found in the experimental planning process, the optimal working condition for the dryer is determined.

Following up on the research results of Vietnamese and foreign authors in the field of drying granular materials, drying pollen is used to supplement the research process in order to save time and research costs on a scientific basis.

Based on approaching and learning about previous and current technology, equipment and professional experiences, the method of selective acquisition leads to both advantages and disadvantages as the most convincing learning curve. This method is also proven to be efficient for research time and costs.

Experimental measurement methods determine selected data. Direct measurement data is regulated by measuring tools. A detailed calculation formula decides the rest of technical data after the direct measurement of the component data.

Results and Discussion

Bee pollen heat pump raking device assisted dryer

A bee pollen heat pump raking device assisted dryer with a yield of 10 kg/batch was calculated, designed and fabricated (Figure 1). The drying chamber and drying tray were made of stainless steel SUS 304. The parameters of the dryer are as follows:

Drying chamber dimension: 0.9 x 0.7 x 0.6 m (length x width x height).

Tray size: 0.8 x 0.6 x 0.025 m (length x width x height).

In the dryer, there are 5 trays with a gap between each tray of 60 mm. Two comb rake blades were alternatively arranged on each tray. The distance between two tooth peaks of the rake blades is 10 mm.

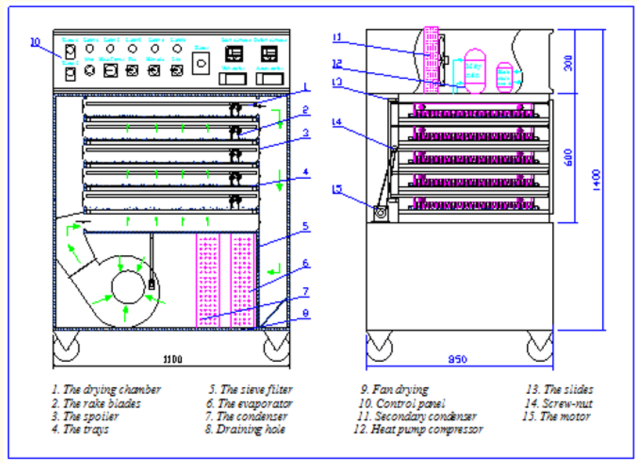

Figure 1: Bee pollen heat pump dryer model.

Figure 2: Installed pollen dryer on heat pump drying principal in the combination of stirring and mixing.

The pollen is loaded into the trays. The trays are placed in the drying chamber [1]. After dehumidifying in the evaporator [6] and heating up in the condenser [7], the drying air passes through the drying chamber to exchange heat with pollen and remove the moisture in the bee pollen. The sieve filter [5] retains the pollen dust in drying air. The dryer can work at two different operating modes by adjusting the spoiler [3] to change the drying-air flow direction: horizontal flow direction and vertical flow direction (up-flow and down-flow). Two comb rake blades [2] with reciprocating linear motion are alternatively arranged on each tray for raking and mixing the bee pollen. The moving period of rake blades is controlled by adjusting the rotational speed of the motor [15].

Experimental results

A set of experiments was conducted with different operating modes of the dryer: horizontal flow direction, vertical flow direction. These tests were carried out with and without mixing pollen using the rake blade. The results show that the dryer meets the drying time requirement of 4 hours at the operating modes of vertical flow direction with mixing pollen using the rake blade. Therefore [1,2], the operating mode was chosen for conducting experimental research.

Black box testing model

The black box testing model was described as follows:

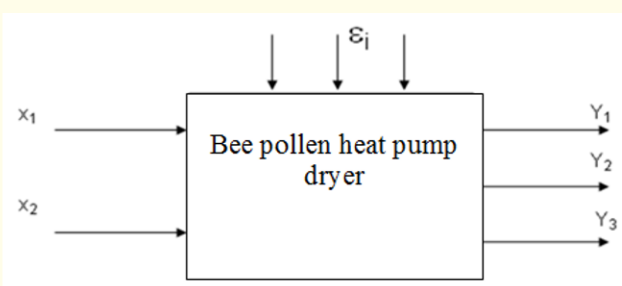

Figure 3: The black box testing model.

Input parameters

X_1: Drying air temperature (t, ^{0}C). The drying air temperature is selected in the range of t = 35 ÷ 45^{o}C.

X_2: Raking cycle (tg, min). Using the result of exploratory testing, the raking cycle is chosen as tg = 10 ÷ 30 min.

Output parameters

Y_1: specific energy consumption (Ar, kWh/kg)

Y_2: vitamin C content C (%C, %).

Y_3: product recovery rate (%M, %).

The experiment was conducted using two-level factorial designs with quadratic effects. Table 1 shows the level and variability for the two-level factorial designs with quadratic effects.

The experiments were carried out based on the established experimental matrix. The results of the experiment are presented in table 2.

Factors / Level	x_1 (°C) Drying air temperature	x_3 (min) Raking cycle
+1,414	47,07	34,14
+1	45	30
0	40	20
-1	35	10
-1,414	32,93	5,86
Variability Δ	5	10

Table 1: Level and variability for the two-level factorial experiment.

run	t	tg	Ar	%C	%M
1	40.0000000	20.000000	0.96	64.61	76.45
2	32.9289322	20.000000	1.26	80.34	76.00
3	40.0000000	20.000000	0.98	65.45	76.40
4	40.0000000	20.000000	0.97	64.04	76.35
5	40.0000000	34.142136	1.19	63.20	77.50
6	47.0710678	20.000000	0.89	56.18	76.50
7	40.0000000	5.857864	0.94	75.28	75.00
8	45.0000000	10.000000	0.92	62.36	75.45
9	45.0000000	30.000000	1.06	61.52	77.35
10	35.0000000	30.000000	1.29	75.56	76.55
11	35.0000000	10.000000	1.04	76.69	75.35

Table 2: Experimental matrix and experimental results.

Treatment of experimental data

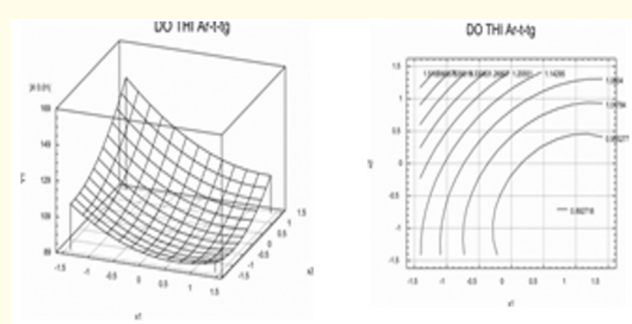

Figure 4: Ar-t and Ar-tg relations.

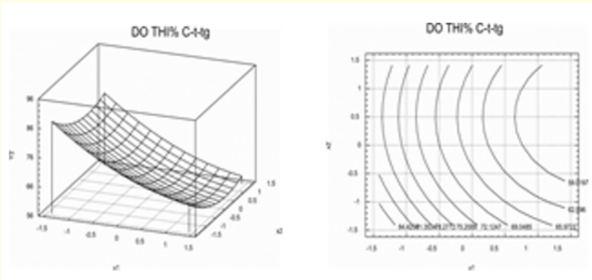

Figure 5: %C-t and %C -tg relations.

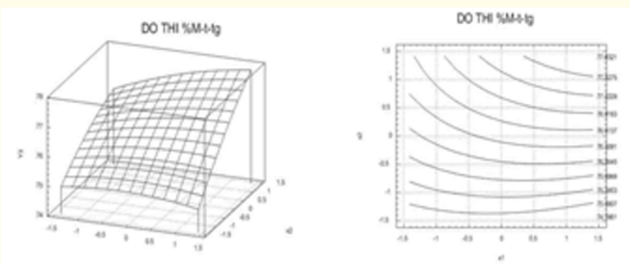

Figure 6: %M-t and %M -tg relations.

Based on the results of the experimental data treatment, a set of regression equations describing the relationship between the specific energy consumption (Ar); the vitamin C content C (%C); the product recovery rate (%M) and drying air temperature (t); raking cycle (tg) were established as follows:

$$Ar = 4,89487 - 0,184831.t + 0,0115444.tg - 5,5.10^{-4}.t.tg + 2,175.10^{-3}.t^2 + 4,9375.10^{-4}.\ tg^2\ (R^2 = 0,978)$$

$$\%C = 259,803 - 7,48544.t - 1,17442.tg + 0,074025.t^2 + 0,0234062.tg^2\ (R^2 = 0,944)$$

$$\%M = 69,559 + 0,270178.t - 0,0195558.tg + 3,5.10^{-3}.t.tg - 3,75.10^{-3}.t^2 - 9,375.10^{-4}.\ tg^2\ (R^2 = 0,992)$$

Determination of the dryer optimal working operations [12]

Based on the research purposes, optimization problems are formed and solved to determine the optimal working conditions for the dryer. Four optimization problems are formed as follows [1,2].

Problem 1

Objective function: Ar→ min

$$Ar = 4,89487 - 0,184831.t + 0,0115444.tg - 5,5.10^{-4}.t.tg + 2,175.10^{-3}.t^2 + 4,9375.10^{-4}.\ tg^2$$

Constraints: $47,07 \geq t \geq 32,92$ and $34,14 \geq tg \geq 5,85$.

Problem 2

Objective function: %C → max

$$\%C = 259,803 - 7,48544.t - 1,17442.tg + 0,074025.t^2 + 0,0234062.tg^2$$

Constraints: $47,07 \geq t \geq 32,92$ and $34,14 \geq tg \geq 5,85$

Problem 3

Objective function: %M → max

$$\%M = 69,559 + 0,270178.t - 0,0195558.tg + 3,5.10^{-3}.t.tg - 3,75.10^{-3}.t^2 - 9,375.10^{-4}.\ tg^2$$

Constraints: $47,07 \geq t \geq 32,92$ and $34,14 \geq tg \geq 5,85$

Problem 4

Objective function: %C→ max and Ar→min and %M → max

$$Ar = 4,89487 - 0,184831.t + 0,0115444.tg - 5,5.10^{-4}.t.tg + 2,175.10^{-3}.t^2 + 4,9375.10^{-4}.\ tg^2$$

$$\%C = 259,803 - 7,48544.t - 1,17442.tg + 0,074025.t^2 + 0,0234062.tg^2$$

$$\%M = 69,559 + 0,270178.t - 0,0195558.tg + 3,5.10^{-3}.t.tg - 3,75.10^{-3}.t^2 - 9,375.10^{-4}.\ tg^2$$

Constraints: $47,07 \geq t \geq 32,92$ and $34,14 \geq tg \geq 5,85$.

In problem 4, the specific energy consumption (Ar) is selected as the objective function.

Objective function: Ar → min

Constraints: $\%C \geq Cs$ and $\%M \geq Ms$ and $47,07 \geq t \geq 32,92$ and $34,14 \geq tg \geq 5,85$

where: Cs is required vitamin C value; Ms is required product recovery rate.

After solving, the results for the multiple objectives optimization problems is obtained as follows:

+ Optimal parameters

Optimal drying air temperature: 38,40C

Optimal raking cycle: 10 minutes

+ Optimal specific energy consumption: 0.96 kWh/kg

+ Optimal vitamin C content: 72.11%.

+ Optimal product recovery rate: 75.46%.

Calculation of economic efficiency in production

The total cost of products upon delivery: VND 338,884/kg of the final product (Including the cost of buying fresh pollen, the fixed cost of electricity, renting, equipment, labor costs and equipment depreciation, etc)

Surveys conducted at companies Viethoney, Highlandhoney, Ong Tam Dao Co., Ltd., show that the price of final bee pollen products in the market is 350,000 ÷ 400,000 VND/kg.

Interest earned: 11,116 VND/kg of final product

Payback period: 12 months.

Formulating a theory of designing pollen dryers by the equivalent technique

Using the same method to rebuild the basic parameters for a pollen dryer with a capacity of 50 kg/batch for the industrial production deployment. The result is, as shown in table 3.

#	Basic parameter	10 kg machine	50 kg machine
1	Productivity (kg/ batch)	10	50
2	Compressor capacity (kW)	1,5	13,3
3	The thickness of drying material layer δ (mm)	10	15
4	The diameter of filter hole (mm)	0,2	0,3
5	Stirring cycle (minute)	10	10
6	Drying temperature (^{o}C)	38,4	38,4
7	Fan speed v (m/s)	1,3	1,7
8	Drying tray are S (m2)	0,3	0,7
	Drying tray size d x r x c (m)	0,8x0,6x0,025	1,0x0.8x0,025
	Drying chamber size d x r x c (m)	0,9x0,7x0,6	1,2x1,0x0,6
9	Drying fow (m3/s)	0,04	0,12
	Fan power (kW)	0,6	1,7

Table 3: Basic parameters of a pollen dryer of 50 kg/batch.

Discussion

In this dryer, on each tray, there will be 2 toot-shaped blades arranged alternately with each other to perform vertically and horizontally, to execute the movement back and forth of scraping, stirring and mixing pollen. With this method, drying the pollen becomes hugely time-saving. Last but not least, thanks to the above set-up layout, it does not only help save the size of the installation area but also ensures the lasting drying time for material such as pollen.

The high-frequency rake (many times in one batch), and early scratching while the initial moisture in the pollen is still high can help the pollen to dry quickly, but it will easily make the pollen shattering, causing the loss of pollen value. Therefore [10], it is essential to set appropriate starting time for the first stirring performance. In order to avoid the broken pollen due to the high initial moisture during harvest seasons, the fresh pollen should be dried on the surface in about 10 minutes to assure the pollen no longer has high adhesion. This method is also adaptable for conducting a scratch every time after 10 minutes (as testing results).

The biggest advantage of this stirring and scratching method is the capacity to dry the pollen thoroughly with a thicker layer of pollen, rather than a single-layer drying method on the tray. Consequently, it will lead to high productivity for the final products. Besides, regarding the cleaning stage afterward, this scratching technique supports is less expensive and less time-consuming than the traditional conveyor mixing method.

Considering the profile of the pollen layer when performing static drying (Figure 7), the efficiency of evaporating through the fixed thickness layer is not as competent as the efficiency of evaporating by stirring and scratching execution. Used scratching and stirring back and forth, pollen grains also switch laying position so that pollen surface is exposed to get dried faster and more evenly. From this experiment, we realized that when using a heat pump drying method in combination with stirring rake, it will increase the heat exchange between pollen and drying sources. As a result, the stirring procedure supports speeding up drying speed and increasing the efficiency of the drying process.

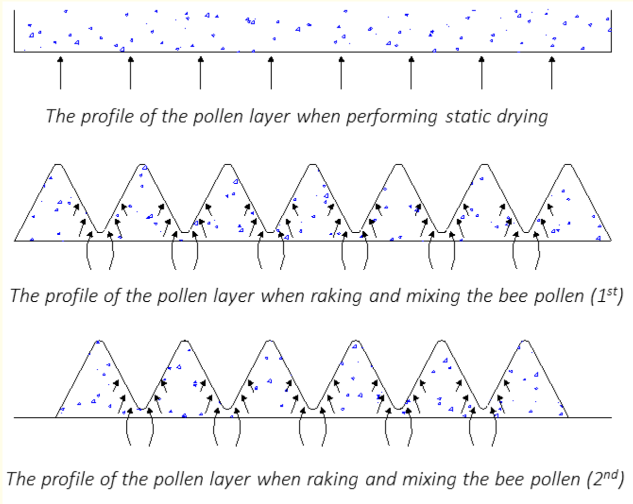

Figure 7: The profile of the pollen dryer after stirring and scratching.

Conclusion

In this study, a bee pollen heat pump raking device assisted dryer with a yield of 10 kg/batch was designed, manufactured and tested. Using the experimental planning method, a set of regression equations describing the relationship between the specific energy consumption, the vitamin C content, the product recovery rate and drying air temperature, the raking cycle was established. The optimization problems were formed and solved. The result showed that, at the drying air temperature of 38.4 ^{0}C and the raking cycle of 10 minutes, the optimal operating conditions for the dryer was found to be Ar_{min} = 0.96 kWh/kg; $\%C_{max}$ = 72.11%; $\%M_{max}$ = 75.46%.

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