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Designing and Manufacturing a Vacuum Frying System with Intelligent Controlling

Chau Thanh Tuan[1], Do Thuy Khanh Linh[2], Nguyen Tan Dung[2*]
[1]*Institute of Food and Biotechnology, Can Tho University, Vietnam*
[2]*Hochiminh City University of Technology and Education, Vietnam*

[*]Corresponding author. *Email: tandzung072@hcmute.edu.vn*

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ABSTRACT

Vacuum frying is one of the advanced technologies for food processing to make high-quality fried products by decreasing smoked temperature of oil. In this study, the vacuum frying system was calculated, designed, and manufactured using potato slices as material. The system was successfully manufactured using shortening as the frying oil and the optimal frying conditions were 105ºC, 150 mmHg for 10 minutes. The frying process was automatically controlled and measured by computer-programmed software. The system consists of a heat power (6.33 kW), a cylinder frying tank (400 mm diameter × 750 mm height), a vacuum pump (0.75 kW, a condensing equipment (0.45 kW, 30mm diameter × 440 mm length), and a freezing compressor (1.12 kW). The frying capacity of the system is 24 kg material for 4 hours, consisting of 12 frequencies (20 minutes of frying time for 2 kg material for each). After manufacturing, the system was used for frying potatoes to test and assess the effectiveness and adjust the optimal conditions. The fried potato indicated the required moisture, suitable quality, typical color and taste, and low energy costs. This result can help to master vacuum frying manufacturing technology for domestic engineering.

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1. Introduction

Frying, the water-separating process occurring at the boiling temperature of the heat-transferring substance, cooking oil, makes products lose water, leads to loss of bacteria living environment, kills the bacteria, changes initial material rheological properties, produces the porous, crispy, soft, and elastic structure, and increases the sensory properties of the products. Thus, the process helps extend the preservation and prolong the fried product's self-life [1], [2]. However, at the atmosphere or residual pressure, the smoking temperature of oil is commonly higher than 100°C [2]-[4]. During the frying process, oil always reacts to oxygen in the air, and then the oxidization reactions occur rapidly at high temperatures [1], [5]. This changes the natural properties of lipids, carbohydrates, and protein. Thus, the oils, at high temperatures, can be oxidized to create free radicals (R*) and some peroxide substances [6], which can soak into the fried products. Although after frying, the products can be centrifuged to separate the substances and collect the frying oil, the oxidized oils cannot be wholly removed from the products. In this case, fried products containing high amounts of R* and peroxide could cause problems for consumers by causing some diseases related to cardiovascular, blood pressure, obesity, liver, kidney, and cancer [7]. If the frying oils can be reused several times, it leads to the increase of unexpected substances and causes fried products to be unsafe. If the frying oils can be reused several times, it leads to the increase of unexpected substances and causes fried products to be unsafe [5]-[7]. Therefore, the frying process occurring in the atmosphere and residual pressure, the reuse oils, and its products must be controlled carefully to prevent the loss of product quality.

There are several ways to reduce the reaction with oxygen and the smoking temperature of the oil; the usual way is that the frying must be carried out in a vacuum condition called vacuum frying [1], [5]. In the vacuum condition, the oil smoking temperature is reduced, and oxidization cannot occur. When the frying process is finished, the rest oil is lightly oxidized. The R* and peroxide substances are generated in the minimum amount. Thus, it can be reused several times without treatment [5]. Besides,

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the product nearly does not decrease in quality, colors, porous, crispy, soft, and elastic structure, and does not contain any unexpected substances that can harm consumer health [1], [8]. Although vacuum frying supplies several advantages, the vacuum frying equipment has not been attended to study and manufactured. In Viet Nam, no studies have been published relating to calculating, designing, and manufacturing the vacuum frying system that works automatically under the frying technology setting of programs controlled by a computer [2], [9]. Therefore, this study was carried out to calculate, design, and manufacture the vacuum frying system DVF-3, which is automatically controlled the frying process such as measuring and controlling all technology's parameters (oil temperature, environment pressure, frying time) to make high-quality product and reduce energy cost and product prices [10]-[12].

2. Materials and Methods

2.1. Materials

- Fried materials: to calculate, design, and manufacture the vacuum frying system, potato was used as the fried material, which was identified, such as initial and post-fried moisture, specific mass, and material input capacity (input capacity) as described previously [10], [13], [14]. The material chemical composition is shown in Table 1. Potato was washed, peeled, cut into a 4 mm thick slice and used for frying.
- Frying oil: shortening was used as the heat-transferring substance containing less than 0.1% free fatty acid and 1% saponification substances.

2.2. Calculating methods

2.2.1. Initial parameters for calculating and designing

- Potato's initial moisture: W_1 (%),
- Fried product moisture: W_2 (%),
- Input capacity of the vacuum frying equipment: G kg material/batch,
- Time of a frying batch: τ (h), Number of frying frequency in a batch: T,
- Apparent frying degree: b (%),
- Shortening initial temperature: t_1 (°C), Shortening temperature during frying: t_2 (°C),
- Sliced potato initial temperature: t_0 (°C), Sliced potato temperature during frying: t (°C).

2.2.2. Material balance calculating

Each frying batch was divided into some frequency; and a frequency longs 20 minutes, including 3 minutes for vacuuming, 3 minutes for heating, 13 minutes for frying, and 1 minute for oil separating centrifugal. Time for a frequency was τ_T = 0.3 (hr) = 20 mins [9], [13], [14].

Number of frequencies per batch:

$$T = \frac{\tau\times 60}{\tau_T} \quad (1)$$

Input capacity for each frequency:

$$G_1 = \frac{G}{T}\ (kg) \quad (2)$$

Apparent frying degree:

$$b = \frac{G_1 - G_2}{G_1}\times 100\ (\%) \quad (3)$$

Fried product mass accounted by apparent frying degree:

$$G_2 = G_1 - \frac{G_1\times b}{100}\ (kg) \quad (4)$$

Some nutrients, such as vitamin A, E, D and K, could be solved in the oil during frying. Mass of the nutrients is $m_{ct} = a_1$ (a_1 = 1%)

$$m_{ct} = 1\%\times G_1 \text{ (kg)} \quad (5)$$

Mass of oil-soaking potato is a_2 (a_2 = 11%)

$$G_{os} = M = 11\%\times G_1 \text{ (kg)} \quad (6)$$

Moisture evaporates from the material during frying:

$$W = G_1\times\frac{W_1 - W_2}{100 - W_2} \text{ (kg/s)} \quad (7)$$

Actual drying degree:

$$g = b + M' = \frac{G_1 - G_2 + M}{G_1}\times 100\% \quad (8)$$

2.2.3. Frying chamber Calculating

Potato volume in the frying chamber:

$$V_p = A\times\frac{G_1}{\rho_p} \text{ (m}^3\text{)} \quad (9)$$

Where: A, filling up coefficient; ρ_p (kg/m^3), specific mass of potato

Necessary oil in the frying chamber to submerge material:

$$V_d = B\times V_p\times\tau_T \quad \text{(m}^3\text{)} \quad (10)$$

Where: B, submerging coefficient of material for frying

The equation determines the size of the frying chamber:

$$V_d = \frac{\pi D^2_{t(\text{frying chamber})}}{4} H_d \ (m^3) \quad (11)$$

2.2.4. Energy balance calculating

Heat used to increase the material temperature from t_0 to t:

$$Q_1 = G_1\times C\times(t - t_0) \text{ (kJ)} \quad (12)$$

Heat used to evaporate moisture in the material:

$$Q_2 = W\times r\times\tau_T \quad \text{(kJ)} \quad (13)$$

Where: evaporating latent heat of moisture: $r = 2392.9\times 10^3\ J/kg$; or W' (kg/s)

Heat used to increase oil temperature:

Oil specific heat at t_1 = 30°C: C_1 = 1.94 kJ/(kg.K); Oil specific heat at t_2 = 120°C: C_2 = 2.209 kJ/(kg.K). Average specific heat of the oil:

$$C_{tb} = \frac{C_1 + C_2}{2} \ (\frac{kJ}{kg.K}) \quad (14)$$

Amount of required oil during frying:

$$m_d = \varphi\times\rho_d\times V_d \text{ (kg)} \quad (15)$$

Heat used to increase oil temperature from t_1 (=30°C) to t_2 (= 120°C):

$$Q_3 = m_d C_{tb}(t_2 - t_1)\text{(kJ)} \quad (16)$$

Heat consumed during frying:

$$Q' = Q_1 + Q_2 + Q_3 \text{ (kJ)} \quad (17)$$

Heat lost to the ambient: calculated as φ = 5% of proper heat:

$$Q_4 = \varphi \times Q' \text{(kJ)} \quad (18)$$

Total heat of a frequency per batch:

$$Q = Q_1 + Q_2 + Q_3 + Q_4 \text{ (kJ)} \quad (19)$$

Necessary resistor power:

$$P_w = \frac{Q}{\tau_T} \text{ (kW)} \quad (20)$$

2.2.5. Air pipe Calculating

Air pipe diameter of the equipment was determined the equation:

$$d = \sqrt{\frac{V_s}{0{,}785w}} \quad (m) \quad (21)$$

Where: V_s (m^3/s) –air flowing inside pipe; w (m/s) – optimal rate of air flowing inside the pipe

2.2.6. Vacuum pump calculating

Capacity of the vacuum pump was calculated by equation [10], [12], [14], [15]:

$$Q_p = \beta_1 \beta_2 \frac{V}{t_d} \ln\left(\frac{B - P_{gh}}{P_{bck} - P_{gh}}\right) \left(\frac{m^3}{h}\right) \quad (22)$$

Where: Q (m^3/h) – capacity of a vacuum pump; V (m^3) – a volume of a vacuum chamber; t_d (s) – time of vacuum suction; B (mmHg) – atmosphere pressure; P_{gh} (mmHg) – critical pressure generated by a vacuum pump, selected P_{gh} = 100 mmHg; P_{bck} (mmHg) – working pressure of a vacuum chamber, selected P_{bck} = 150 mmHg; β_1 = 1.2 ÷ 1.5 – Leaking coefficient of a vacuum chamber; β_2 = 1.12 ÷ 1.15 – Safety coefficient of a vacuum pump.

Machine power of the vacuum pump was calculated by equation [10], [15]:

$$N = \beta \frac{\Delta P_b \times Q_p}{1000 \eta_H \eta_v \eta_{ck}} \text{ (kW)} \quad (23)$$

Where: ΔP_b (Pa) –pressure generated by a vacuum pump; β = 1.12 ÷ 1.15: Safety coefficient of a vacuum pump; η_H = 0.97 ÷ 0.98 hydraulic efficiency; η_v = 0.95 ÷ 0.99 volume efficiency; η_{ck} = 0.95 ÷ 1.0 transmission efficiency of a vacuum pump.

2.2.7. Calculating the cooling capacity of the freezing system condensing the amount of evaporated moisture from the material during frying

Before the vacuum pump sucked the amount of the evaporated water (W (kg/s) from the material at frying temperature t_2 (ºC), the water had been condensed at the temperature t_w (ºC). Then, the heat removed by the evaporator of the freezing system was calculated by equation (24).

$$Q_{comp} = Q_{11} + Q_{12} + Q_{13} \text{ (kW)} \quad (24)$$

Where: Q_{comp} (kW) – heat power of the condensing equipment

Heat was removed to decrease the temperature, from t_2 to t_w, of moisture and air flowing into the frying chamber:

$$Q_{11} = W \times C_{pn}(t_2 - t_w) + G_k(h_2 - h_w) \ \text{(kW)} \quad (25)$$

Where: Q_{11} (kW) – removed heat decreases the temperature from t_2 to t_w; G_k (kg/s) – a mass of the air; C_{pn}(kJ/(kg.K)) – specific heat of water; h_2, h_w(kJ/kg) – enthalpy of the air at t_2 (ºC) and t_w (ºC).

Heat was removed to condense the evaporated water at t_w (ºC):

$$Q_{12} = W \times r_{cond} \ \text{(kW)} \quad (26)$$

Where Q_{12} (kW) – removed heat condenses the evaporated water at t_w (ºC); r_{cond} (kJ/kg) –latent condensing heat of water at t_w (ºC).

Heat lost through a pipe and condensing equipment walls:

$$Q_{13} = K \times F \times \Delta t_a \ \text{(kW)} \quad (27)$$

Where: Q_{13} (kW) – Heat lost through a pipe and the condensing equipment wall; F (m^2) – heat transferring area of the condensing equipment; Δt_a (°C) temperature logarithm difference between inside and outside environment of the condensing equipment.

Cooling power of a refrigerating compressor of the condensing equipment:

$$Q_o = k_a \times Q_{comp} \ \text{(kW)} \quad (28)$$

Where: Q_o (kW) – cooling power of a refrigerating compressor of the condensing equipment; k_a loading safety coefficient.

2.3. Designing and manufacturing a vacuum frying system

In this study, the AutoCAD software version 2018 (Autodesk Inc., US) was used to build an assembly and detailed technical drawings for each piece of equipment of the vacuum frying system. Besides, several mechanical processing methods were used – milling, planing, bending, grinding, mounding, welding, and drilling – to make the system [10], [12], [15].

2.4. Assessing the quality of the vacuum frying system by experimental methods

The quality of the fried product is one of the most essential critical for assessing the frying system's effectiveness and for optimal correcting. In this study, the two outcome indicators were the energy cost of a kilogram fried potato y1 (kWh/kg) and the moisture of fried product y2 (%) [10], [14]. The income parameters were the thickness of the potato and frying time.

3. Results and discussion

3.1. Initial parameters needed for calculating and designing the vacuum frying system

The system's actual design drawings were needed and built from calculating and designing parameters, and then the vacuum frying system was manufactured. Calculating and designing the vacuum frying system had to be carried out before the system was manufactured. Thus, the necessary initial parameters used to solve the design problems had to be first identified. In this study, the material, potato, was used to simplify the vacuum frying system design since the initial parameters of the potato had been identified by experiments. The system capacity and the other parameters are shown in Table 1 and Table 2. Table 1 showed that potato contains high nutrient content. Thus, producing potato chips could increase the agricultural value and adapt user consumption [10], [15].

Table 1. *The chemical composition of potato*

Component	Water	Carbohydrates	Cellulose	Lipid	Protein
content (%)	75	18.2	2.4	0.3	2.1

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Table 2. *Necessary initial parameters for calculating and designing*

No.	Parameter	Symbol	Unit	Value
1	Material input capacity	G	kg material/ batch	24
2	Time of a frying batch	τ	h	4
3	Time of a frequency in a batch	τ_T	h	0.3
4	Heat source	-	-	Resistor
5	Vacuum frying material	-	-	Potato
6	Chemical component of potato	-	-	Table 1
7	Specific heat of potato	C_p	kJ/(kg.K)	1.86
8	Specific mass of potato	ρ	kg/m^3	1034
9	Thermal conductivity coefficient	λ	W/(m.K)	0.59
10	Moisture of input material	W_1	%	75
11	Moisture of fried product	W_2	%	5
12	Apparent frying degree	b	%	50

3.2. Calculating and designing the vacuum frying system

Figure 1 displayed the principal diagram of the smart vacuum frying, which was designed and manufactured with a material input capacity of 24 kg/batch. The system was automatically measured and controlled by a computer program optimally controlling and assessing the frying process.

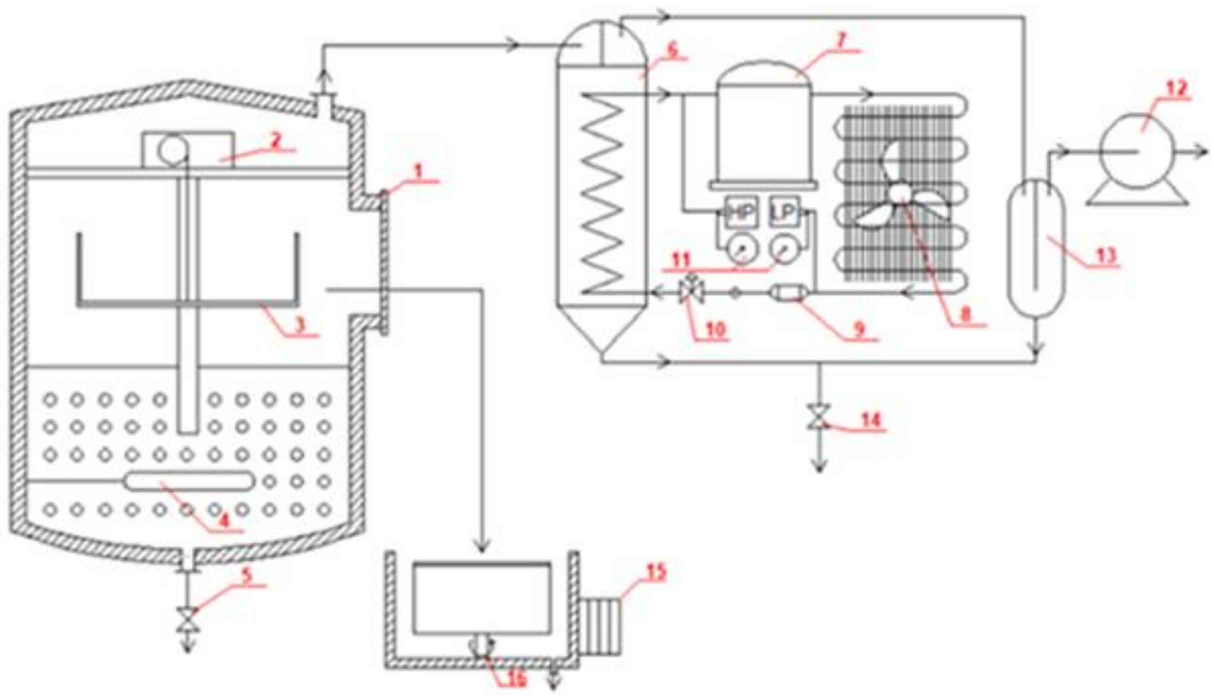

Figure 1. *The principal diagram of the smart vacuum frying*

(1): Frying chamber door; (2): The motor of the frying basket; (3): Frying basket (3); (4): Heat supplement (Resistor); (5): Oil drain valve; (6): Moisture condensing equipment; (7): Freezing compressor; (8): Refrigerant condensing equipment; (9): Filter; (10): Expansion valve; (11): High and

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low-pressure gauge; (12): Vacuum pump; (13): Liquid separator; (14): Water drain valve; (15): Oil centrifugal equipment; (16): Centrifugal motor shaft.

Based on the calculating methods mentioned in 2.2 and the initial parameters in Table 1 and Table 2, the intelligent vacuum frying system was calculated and designed (Table 3).

Table 3. *Results of calculating and designing the vacuum frying system with a capacity of 24 kg/batch*

Parameter	Equation	Unit	Result
Number of frequency per batch	(1)	-	12
Material input capacity of a frequency per batch, G_1	(2)	Kg	2
Fried product mass accounted by apparent frying degree of a frequency per batch, G_2	(3) and (4)	Kg	1
Mass of the nutrients in oil of a frequency per batch, m_{ct}	(5)	Kg	0.02
Mass of oil-soaking potato of a frequency per batch, M	(6)	Kg	0.22
Moisture evaporates from the material of a frequency per batch, W	(7)	Kg/s	1.47
Actual drying degree, g	(8)	%	61
Potato volume in the frying chamber, V_p	(9)	m^3	0.019
Necessary oil in the frying chamber to submerge material, V_d	(10)	m^3	0.046
Size of frying chamber:			
- Diameter, D_t	(11)	mm	400
- Height, H_d	(11)	mm	370
- Height of frying equipment, including height of frying chamber, material input chamber, and equipment cover.	(11)	mm	1220
Heat used to increase material temperature, Q_1	(12)	kJ	297.6
Heat used to evaporate moisture in the material, Q_2	(13)	kJ	3517.56
Average specific heat of the oil, C_{tb}	(14)	kJ/(kg.K)	2.07
Amount of required oil, m_d	(15)	kg	18.4
Heat used to increase oil temperature, Q_3	(16)	kJ	3427.92
Heat consumed during frying, Q’	(17)	kJ	7243.15
Heat lost to the ambient, Q_4	(18)	kJ	362.15
Total heat of a frequency per batch, Q	(19)	kJ	7605.28
Necessary resistor power, P_w	(20)	kW	6.33
Air pipe diameter of the equipment, d	(21)	mm	18
Capacity of vacuum pump, Q_p	(22)	m^3/h	13.32
Machine power of the vacuum pump, N	(23)	kW	0.75
Cooling power of refrigerator condensing moisture from frying material, Q_0	(24), (25), (26), (27), (28), (29)	kW	0.45
Machine power of the compressor, N_{dc}	-	kW	1.118kW

3.3. Manufacturing the intelligent vacuum frying system

Based on the results shown in Table 3, the AutoCAD software was used to design technical drawings of the system, which was needed for manufacturing. Besides, the automatic measurement and control system was also made to adapt to technological requirements.

After the vacuum frying system was designed, mechanical methods such as welding, bending, and pressing were carried out to manufacture. Besides, software for the measurement and control systems was designed and installed in a computer to control frying and adapt to the technology process. As a result, the vacuum frying system was successfully manufactured, as shown in Figure 2.

Figure 2. *The manufactured vacuum frying system, DVF-03, with the initially designed requirement*

The manufactured vacuum frying system – DVF-03 with the technical parameters:

- Equipment capacity: maximum 24 kg material/ batch.
- Adjustable temperature of frying environment: 80 ÷ 120°C.
- Adjustable frying time of 12 frequency in a batch: 4 ÷ 6 hrs.
- Shortening was used as the frying factor.

The automatic controlling of technological parameters, such as temperature and pressure of the frying environment and time of frying, was programmed by a computer and applied IoT to remote control the frying process. Thus, energy costs could be minimal during frying can reduce production costs and increase competition in commerce.

3.5. Assessing the quality of the vacuum frying system by experiment

In this study, the stability and the operating ability of the frying system were assessed by using several optimal frying parameters, which were conducted before. Temperature, pressure, and time of the frying process were 105ºC, 150 mmHg, and 10 mins, respectively; frying time and quantity of material of a frequency per batch were 20 mins and 2 kg/batch, respectively; the 75% moisture material was cut in three sizes, 4 mm, 6 mm, and 8 mm. The energy costs for a kilogram of product, y1 (kWh/kg product), was identified and shown in Table 4 or Figure 3.

Table 4. *Energy cost for a kilogram of product depended on time of the vacuum frying time*

Time (mins)	0	1	2	3	4	5	6	7	8	10	thickness
y_1 (kWh/kg product)	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	2	4mm
	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	3	6mm
	0	0.4	0.8	1.2	1.6	2	2.4	2.8	3.2	4	8mm

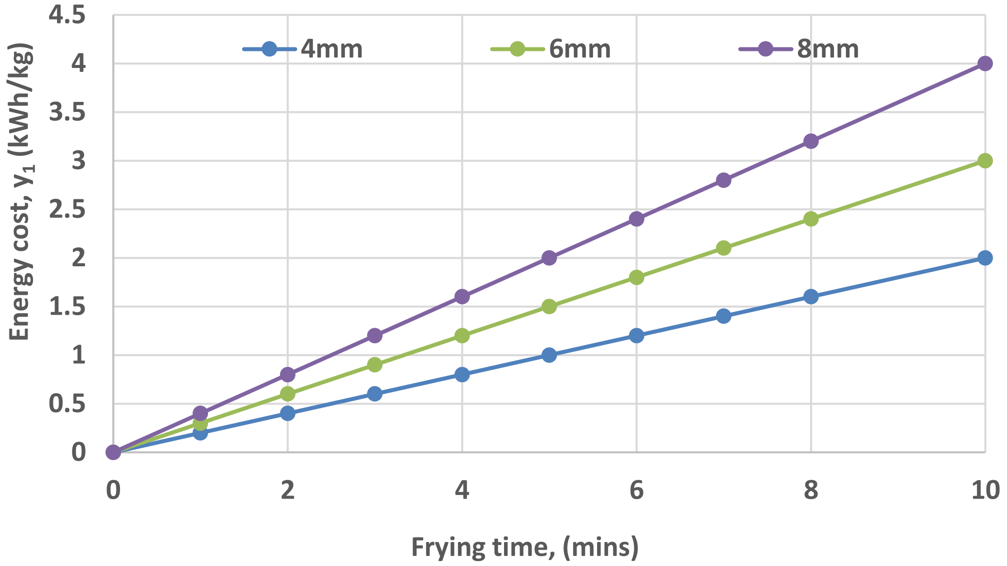

Figure 3. *Energy cost for a kilogram of product depended on time of the vacuum frying time*

Vacuum-fried product moisture y_2 (%) was calculated and shown in Table 5 or Figure 4.

Table 5. *The moisture of a kilogram vacuum-fried product depended on the time of frying*

time (mins)	0	1	2	3	4	6	7	8	10	thickness
	0.75	0.2497	0.0831	0.0277	0.0092	0.0010	0.0003	0.0001	0.0001	4mm
y_2 (%)	0.75	0.3370	0.1514	0.0680	0.0306	0.0062	0.0028	0.0012	0.0003	6mm
	0.75	0.4549	0.2759	0.1673	0.1015	0.0373	0.0226	0.0137	0.0051	8mm

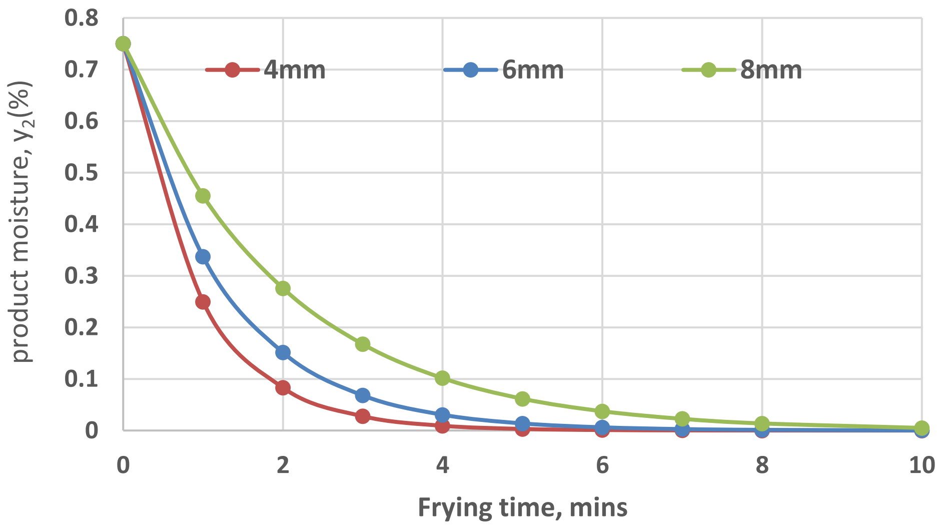

Figure 4. *The moisture of vacuum fried product depended on the frying time*

Table 4, Table 5, Figure 3, and Figure 4 showed that when the 4 mm thickness material was fried at the optimal conditions, the temperature of 105°C, pressure of 150 mmHg, and duration of 10 mins, energy costs reached the lowest, and moisture rapidly decreased to the required value nearly equal 0; the product had the spongy and crispy structure.

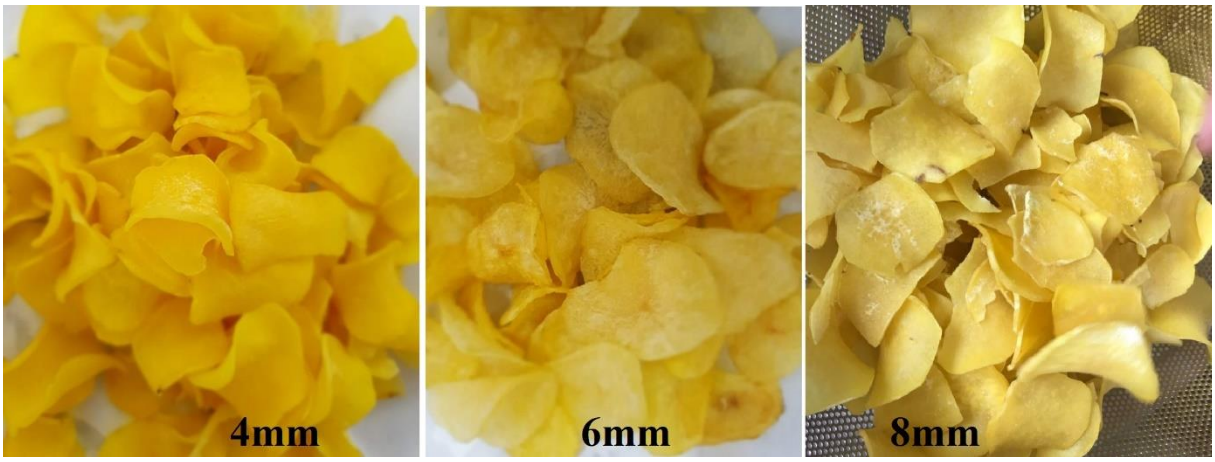

Figure 5. *Fried potato products with the thickness of 4 mm, 6 mm, and 8 mm*

Experimental results showed that after frying, the 4 mm thick potato presented the natural color of bright yellow as the raw potato (see Figure 5). The 6 mm and 8 mm thick potatoes indicated a darker yellow. Their spongy and crispy levels were less than those of the 4 mm product, and the high thickness caused the ripe on the outside but not on the inside. Besides, during frying, water on the surface of the large-thickness potato was evaporated early, creating a thin dried surface, which prevented the inside water from evaporating. Thus, the 6 mm and 8 mm potatoes contained higher moisture at the same frying time. The experiments showed that if the potato was lower than 4 mm thick, the product could be broken because of too spongy and crisp; some others showed darkening due to over-dehydration.

Generally, the experiments indicated that the 4 to 8 mm thick potatoes, which were fried at the optimal condition by the vacuum frying system, showed suitable quality. Among them, the 4 mm potato indicated the best quality, lowest moisture, spongy, crisp properties, bright yellow, and natural odor; and the energy costs were lowest. It means that the vacuum frying system was successfully manufactured. Its parameters were correctly set; the frying was controlled and measured by the intelligent controller. It can make high-quality food products, which can serve for consuming, trading, and exporting.

4. Conclusions

The intelligent vacuum frying system was successfully manufactured with the adjustable frying temperature from 80 to 120ºC, frying time of a batch from 4 to 6 hrs, and using shortening as a frying oil. The vacuum frying system was controlled and measured by software programmed into a computer, which can control and monitor the frying process optimally and effectively. The result of this study is mastering the vacuum frying technology, which can help manufacture the intelligent vacuum frying system for the need of processing and manufacturing agricultural products in Viet Nam. Moreover, the technology can reduce production costs and increase product quality and financial value for producers. Acknowledgments

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REFERENCES

[1] A. A. Bello *et al.*, "Vacuum Frying: An Alternative to Obtain High-Quality Dried Products," *Food Engineering Reviews,* vol. 3, no. 2, pp. 63-78, 2011.

[2] D. S. Ahmad, L. Sugiyarto, B. Solichatun, and A. Susilowati, "Review: Physical, physical chemistries, chemical and sensorial characteristics of the several fruits and vegetable chips produced by low-temperature of vacuum frying machine," *Bioscience,* vol. 5, no. 2, pp. 86-103, 2013.

[3] F. D. Gunstone, *Vegetable Oils in Food Technology: Composition, Propertiesand Uses,* Hoboken, New Jersey, U.S.: John Wiley & Sons, 2011.

[4] “Smoke Point of different Cooking Oils.” ChartsBin.com. http://chartsbin.com/view/1962 (accessed Mar. 30, 2011).

[5] S. Manzoor, F. A. Masoodi, R. Rashid, and T. A. Ganaie, "Quality changes of edible oils during vacuum and atmospheric frying of potato chips," *Innovative Food Science & Emerging Technologies*, vol. 82, p. 103185, 2022.
[6] E. Choe and D. B. Min, "Chemistry of Deep-Fat Frying Oils," *Journal of Food Science*, vol. 72, no. 5, pp. R77-R86, 2007, doi: 10.1111/j.1750-3841.2007.00352.x.
[7] A. Negre-Salvayre *et al.*, "Pathological aspects of lipid peroxidation," *Free Radical Research,* vol. 44, no. 10, pp. 1125-1171, 2010.
[8] J. Garayo and R. Moreira, "Vacuum frying of potato chips," *Journal of Food Engineering,* vol. 55, no. 2, pp. 181-191, 2002.
[9] L. T. T. Long *et al*., "Modeling the freezing process of turmeric starch to determine the rate of freezing water," *Journal of Technical Education Science,* no. 46, pp. 1-9, 2018.
[10] N. T. Dzung and N. D. M. Duyen, "Multi-objective optimization to determine the cold drying mode of gac (momordica cochinchinensis spreng)," *Carpathian Journal of Food Science & Technology,* vol. 12, no. 3, pp. 23-34, 2020.
[11] V. D. Phuong and N. T. Dzung, "The Multi-objective Optimization by the Restricted Area Method to Determine the Technological Mode of Cold Drying Process of Carrot Product," *Research Journal of Applied Sciences, Engineering and Technology,* vol. 13, no. 1, pp. 64-74, 2016.
[12] D. T. H. Hai and N. T. Dzung, "The Multi-objective Optimization by the Utopian Point Method to Determine the Technological Mode of Infrared Radiation Drying Process of Jackfruit Product in Viet Nam," *Research Journal of Applied Sciences, Engineering and Technology,* vol. 13, no. 1, pp. 75-84, 2016.
[13] N. T. Dzung, T. V. Dzung, and T. D. Ba, "Building the method to determine the rate of freezing water in penaeus monodon of the freezing process," *Carpathian Journal of Food Science & Technology,* vol. 4, no. 2, pp. 243-248, 2012.
[14] L. T. K. Vu, P. Q. Pham, D. T. A. Phan, and N. T. Dung, "Building and solving the mathematical model of transient heat transfer during the peanut roasting process to determine the roasting parameters," *Carpathian Journal of Food Science & Technology,* vol. 14, no. 4, 2022, doi: 10.34302/crpjfst/2022.14.4.6.
[15] N. T. Dzung, H. V. Chuyen, L. V. T. Khanh *et al*., *Freeze Drying*, Ho Chi Minh City, Vietnam: HCMC-VNU Press, 2022, p. 592.

Chau Thanh Tuan, PhD.
Department of Food Technology, Institute of Food and Biotechnology;
Cần Thơ University;
Campus II, 3/2 Street, Ninh Kieu Ward, Can Tho City, Viet Nam;
Phone: 0989298529;
Email: chautuan@ctu.edu.vn

Linh Thuy Khanh Do, Msc.
Department of Food Technology; Faculty of Chemical and Food Technology;
HCM City University of Technology and Education, Viet Nam;
No 01, Vo Van Ngan Street, Thu Duc District, HCM City.
Phone: 0936699563
Email: dtklinh@hcmute.edu.vn

Nguyen Tan Dzung,, Associate Professor. PhD.
Department of Food Technology; Faculty of Chemical and Food Technology;
HCM City University of Technology and Education, Viet Nam;
No 01, Vo Van Ngan Street, Thu Duc District, HCM City.
Phone: 0918801670
Email: tandzung072@hcmute.edu.vn; tandzung072@yahoo.com.vn