A Study on Optimizing Technological Parameters of Honey Concentration on a Tube Vacuum Evaporator with a Conduction Ring

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Abstract: The VLUTE-1 honey concentrator, designed and manufactured by the research team of Vinh Long University of Technology Education, Vietnam, is used to concentrate honey and some solutions with similar physical and chemical properties. This type of concentrator has the advantage of using a liquid conduction ring and an ultrasonic transmitter to increase the ability to evaporate water and break up sugar crystallization in honey, contributing to improving the quality of honey products during the concentration process. Applying the multi-factor experimental research method to study the simultaneous influence of concentration temperature, liquid conduction ring height, and ultrasonic emission time on the total score of honey quality. The experimental research results have determined the optimal value of the input factors when the optimal value of the total score of honey quality reaches its extreme. The above research results are an important basis for completing the design and manufacturing of concentrator sizes with different capacities suitable for the scale of each production facility.

Keywords: Honey concentrator, concentration temperature, liquid conduction ring height, ultrasonic emission time, total score of honey quality

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1 Introduction

The beekeeping industry plays an important role in global food production [1]. Currently, there have been many studies related to the farming, collection, and processing of honey [1], [2], [3]. Honey is a saturated sugar solution, which, after concentration, can be recrystallized within 3-12 months of storage at room temperature [4], [5]. When crystallized, honey is susceptible to mold growth (due to high humidity), which greatly affects the nutritional value, sensory value, viscosity, and processing ability of honey products [6], [7]. Therefore, the research and design of improved concentration equipment, ensuring product quality according to export requirements, with a simple structure, low cost for wide application in domestic honey processing facilities, is an urgent issue. For the optimization of honey products, Najwan Osman-Ali and Junita Mohamad-Saleh used the grasshopper optimization algorithm (GOA), adaptive average GOA (AAGOA) [2]. The problem is to determine a comprehensive optimal value, which serves as a basis for refining the technological process and improving the system design.

The VLUTE-1 honey concentrator system is being researched and applied to concentrate honey and some solutions with similar physical and chemical properties. This type of concentrator has the advantage of using a liquid conduction ring and an ultrasonic transmitter to increase the ability to evaporate water and break up sugar crystallization in honey, contributing to improving the quality of honey products during the concentration process. To improve product quality, reduce concentration time and electricity costs for the concentration process, it is necessary to find optimal parameters as a basis for perfecting the design to manufacture concentrators of different capacities for widespread application in production facilities.

The article presents some research results to determine the optimal parameters of the structure and working mode of the tube-type honey concentrator system with a liquid conduction ring combined with ultrasonic crystallization VLUTE-1.

2 Materials and research methods

2.1 Materials, equipment, and research tools

The research material is honey taken from Viet Y Honey Bee Joint Stock Company, Hai Phong City. This is lychee honey, harvested annually in February and March with a moisture content of 26,2%, a density of $1367{,}8\ \mathrm{kg/m^3}$, and crystallization begins after 2 months of storage. The mass of each concentrated batch is 16 kg. Honey is concentrated to a safe moisture content of 18%, meeting export requirements. At the end of each experiment, samples are taken to analyze the HMF content, sugar content, mold, yeast, microorganisms, and the time of re-crystallization of honey after concentration during storage [8].

The research equipment is a tube-type honey concentrator system with a liquid conduction ring combined with ultrasonic crystallization, $16\ \mathrm{kg/batch}$ capacity (symbol VLUTE-1), designed and manufactured at the research group of Vinh Long University of Technology Education, Vietnam. The structure of the equipment system includes 5 main parts (Figure 1).

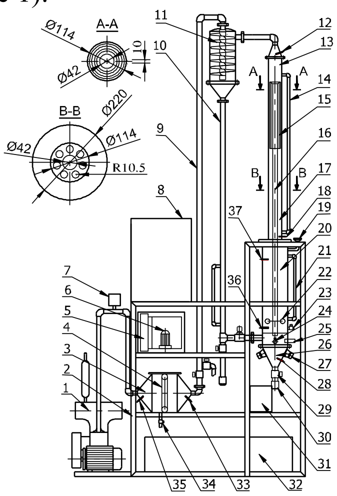


Fig. 1. Honey concentration equipment system VLUTE-1 "*Source: created by the authors.*"

1) The concentration unit (17) is a vertical cylindrical tube. The lower part is cylindrical, and the bottom is a truncated pyramid, which is the place to supply and discharge materials. At the top, boiling tubes and honey circulation tubes are installed, separated by flanges. These tubes are surrounded by hot water, which is heated by electric resistance heaters. The middle part is a boiling chamber, also cylindrical (smaller diameter), which is the place to develop the size of the foam particles by receiving more steam in the bile. The top part is the foam breaking chamber (with a diameter equal to the diameter of the boiling chamber), inside this chamber is installed a liquid conduction ring, which is a combination of concentric cylindrical tubes with gradually smaller diameters to create narrow, ring-shaped slots, breaking the foam particles to release steam and gas in the foam particles, while also creating many thin layers of film to increase the evaporation surface area and increase the speed of movement of the bile in the narrow slots from bottom to top to increase the driving force of the evaporation process in the bile.

2) The screw-type secondary vapor separator (11) is connected to the upper part of the concentrator and has the function of separating the secondary vapor and recovering the remaining honey that evaporates with the secondary vapor to avoid waste.

3) The secondary vapor condenser (3) is a box-shaped unit, one end of which is connected to the secondary vapor separator, and the other end is connected to the vacuum pump. Inside the secondary vapor separator, there are 2 parallel cooling systems whose task is to condense the secondary vapor into liquid form to create dry air before entering the vacuum pump to both reduce.

The load on the vacuum pump avoided water condensation in the pump.

4) The ultrasonic transmitter consists 27 of 9 transmitters with a total capacity of 900 W, frequency of 28 kHz installed at the bottom of the cone of the condenser, with the task of generating ultrasonic waves to destroy harmful microorganisms while breaking crystallization during the concentration process and preventing re-crystallization of honey during storage.

5) The control unit (8) is responsible for controlling technological parameters during the concentration process, including: controlling the water temperature in the heating zone is done by a thermal relay, controlling the boiling temperature of the honey solution is done by adjusting the vacuum pressure by changing the number of revolutions of the vacuum pump by an inverter, controlling the secondary vapor condensation temperature in the condenser is done by adjusting the evaporator temperature.

The research parameters of the concentrator were determined:

- Condensation temperature, determined by digital electronic thermometer model CH 402 (China), measuring range $0°\mathrm{C} - 1.300°\mathrm{C}$, error $\pm 0.5°\mathrm{C}$.
- The moisture content of honey is determined by a digital Brix meter (ATAGO, Japan), measuring range $0\% - 93\%$, error $\pm 0.1\%$.
- Recrystallization time is determined by the storage time of honey from after concentration until sugar crystals begin to appear.
- The total score of honey quality is determined according to the scoring method, National Standard TCVN 12401-2018 [9].

2.2. Research method

Apply the multi-factor experimental planning method to study the simultaneous influence of 3 input factors. The experimental matrix is built according to Box-Wilson's second-order experimental planning method [10], [11]. The number of experiments according to this method is calculated according to the formula:

$$N = N_{td} + N_{\alpha} + N_o \quad (1)$$

In which: N_{td} - number of experiments at upper and lower levels, m - number of influencing factors; N_{α}- number of experiments at sub-levels called "star" points, $N_{\alpha} = 2m$; N_0- number of experiments at the central level. With the number of input factors m = 3, the total number of experiments is N = 20 experiments, in which: number of experiments at upper and lower levels N_{td} = 8, number of experiments at sub-levels called "star" points N_{α} = 6, number of experiments at central level No = 6 (Table 1).

Table 1. Variation of input factors "Source: created by the authors."

The levels	T (°C)	H (mm)	τ (min)
Star level below	39	410	11
Lower level	41	480	15
Base level	44	580	20
Upper level	47	680	25
Star level above	49	750	29

To determine the main technological parameters, such as concentration and temperature x_1, t (^0C), liquid conduction ring height x_2, H (mm), ultrasonic emission time x_3, τ (minutes), and the same values at different levels, the study considered the technical characteristics of the equipment, consulted relevant literature, and conducted preliminary experiments with each of these factors (Table 1). The mathematical model of functions Y is represented by regression equations [10], [11].

$$Y = b_o + \sum_{i=1}^{m} b_i x_i + \sum_{i=1}^{m=1} \sum_{j=i+1}^{m} b_{ij} x_i x_j + \sum_{i=1}^{m} b_{ii} x_i^2 \quad (2)$$

The regression coefficients of equation (2) are calculated according to the formulas (3), (4), (5), and (6) [10], [11], [12]. In this case, b_i- the main influence coefficient of the variables x_i, b_{ij}- coefficient of interaction between variables, b_{ii}- the second-order influence coefficient of the variable x_i.

$$b_o = a_1 \sum_{u=1}^{N} Y_u - a_5 \sum_{i=1}^{m} \sum_{u=1}^{N} x_{iu}^2 Y_u \quad (3)$$

$$b_i = a_2 \sum_{u=1}^{N} x_{iu} Y_u \quad (4)$$

$$b_{ij} = a_3 \sum_{u=1}^{N} x_{iu} Y_u x_{ju} \quad (5)$$

$$b_{ii} = a_4 \sum_{u=1}^{N} x_{iu}^2 Y_u - a_5 \sum_{u=1}^{N} Y_u + a_6 \sum_{i=1}^{m} \sum_{u=1}^{N} x_{iu}^2 Y_u \quad (6)$$

3 Results and discussion

Table 2. Results of the honey concentration experiment "Source: created by the authors."

Run	T (°C)	H (mm)	τ (min)	Q (score)
1	41	480	15	17.94
2	47	480	15	15.09
3	41	680	15	18.29
4	47	680	15	15.89
5	41	480	25	17.14
6	47	480	25	16.80
7	41	680	25	19.43
8	47	680	25	18.29
9	39	580	20	19.09
10	49	580	20	15.20
11	44	410	20	16.57
12	44	750	20	18.63
13	44	580	11	17.26
14	44	580	29	18.51
15	44	580	20	18.74
16	44	580	20	18.74
17	44	580	20	18.06
18	44	580	20	19.31
19	44	580	20	18.63
20	44	580	20	19.20

Conduct a honey concentration experiment according to Box-Wilson's second-order experimental planning scheme with 20 experiments. The experimental results are shown in Table 2.

With the number of input factors m = 3and the number of experiments $N = 20$, the coefficients a_j

Are determined: $a_1 = 0.16627$, a_2 =0.07322, $a_3 = 0.125$, $a_4 = 0.0625$, $a_5 = 0.05676$, a_6 =0.00678.
After determining the regression coefficients, check the significance level of the regression coefficients according to the Student standard. Compare the Student standard with the significance level $\alpha = 0,05$, degree of freedom, f = N–p, look up the table t^b. The regression coefficients of the equation are significant when the opposite coefficients $t_{b0} > t^b, t_{bi} > t^b, t_{bij} > t^b, t_{bii} > t^b$are not significant and proceed to remove that coefficient.
Check the suitability of the mathematical model according to the Fisher criterion. Compare with the Fisher criterion, look up the table for $F^b$and $\alpha = 0,05$ degrees of freedom, f_1 = N-p (p- number of regression coefficients); f_2 = p-1. Looking up the table, we can determine F^b if $F < F^b$ Yes, then the second-order model is suitable. If no, $F > F^b$ then the second-order model is not suitable, then move to a higher-order solution.

Table 3. Coded regression coefficients of the function Y "Source: created by the authors."

Regression coefficient	**Student coefficient**
$b_0 = 18.784^c$	$t_{b0} = 102.918^c$
$b_1 = -0.972^c$	$t_{b1} = 8.024^c$
$b_2 = 0.615^c$	$t_{b2} = 5.076^c$
$b_3 = 0.48^c$	$t_{b3} = 3.962^c$
$b_{12} = -0.044^k$	$t_{b12} = 0.277^k$
$b_{13} = 0.471^c$	$t_{b13} = 2.978^c$
$b_{23} = 0.329^k$	$t_{b23} = 2.078^k$
$b_{11} = -0.602^c$	$t_{b11} = 5.098^c$
$b_{22} = -0,441^c$	$t_{b22} = 3,732^c$
$b_{33} = -0,34^c$	$t_{b33} = 2,877^c$

Because the functions Y have extreme values corresponding to the values of different input factors x_i It is necessary to find the general optimal value of the input factors x_i For all output parameters Y. Apply the method of solving the general optimization problem according to the method of establishing the "desirable function" of E. C. Harrington [12].
The calculation determines the regression coefficients in the form of Student standard coefficients, as in Table 3.
c- significant coefficient; k- non-significant coefficient

Look up the Student standard table with significance level $\alpha = 0.05$, degrees of freedom, f = N–p = 20–10 = 10, and find t^b = 2.228 [13], [14]. The regression coefficients of the equation are significant when the coefficients are $-> t^b, t_{bi} > t^b, t_{bij} > t^b, t_{bii} > t^b$ Otherwise, they are not significant and proceed to eliminate that coefficient.
The mathematical model of the component function Y (after removing the non-significant regression coefficients) in coded form is as follows:

$$Y = 18.784 - 0.972x_1 + 0.615x_2 + 0.48x_3 + 0.471x_1x_3 - 0.602x_1^2 - 0.441x_2^2 - 0.34x_3^2 \qquad (7)$$

After eliminating the non-significant regression coefficients, the mathematical model Y of the real components can be determined as follows:

$$Q = -94.5341 + 4.9328\,T + 0.0572H - 0.7427\tau + 0.0314\,T\tau - 0.0668T^2 - 0.0001H^2 - 0.0136\tau^2 \qquad (8)$$

The results of the calculation to test the fitness of the mathematical model according to the Fisher criterion are shown in Table 4.

Table 4. Testing the suitability of the mathematical model "Source: created by the authors."

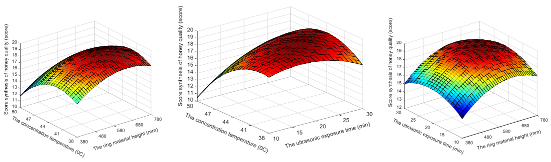
F value according to the criterion Fisher standard	**Y**
Calculate F	0.50
Look up the table F^b	3.02
Conclude	Adaptive model

Based on degrees of freedom: f_1 = N – p = 20 –10 = 10 và f_2 = p - 1 = 9. Looking up the table, we can determine F^b = 3.02 [15].
The calculated values $F$of the functions Y are all smaller than the table values F^b. Therefore, the above mathematical models ensure adaptability, meaning that the simulated mathematical models are compatible with the experimental values.
Determine the optimal values of the functions Y by taking the partial derivative for each input factor and setting that derivative to 0, to get a system of linear equations. Solve this system of equations to get the optimal values of the input factors x_i. Substitute these values into the function Y to get the optimal values of the output parameters. The code and real values of each factor $x_i$and function Yare obtained as in Table 5.

Table 5. Optimal values of input factors x_i and Y
"Source: created by the authors."

	Y (*score*)
- Encoded value:	
x_1	-0.7289
x_2	0.6977
x_3	0.2009
- Real value:	
T (^oC)	41.81
H (mm)	649.77
τ (min)	21.01
Target out Q (score)	19.4006

Represent the 3D influence of the function Y according to the factors, as in Figure 2



a) b) c)

Fig 2. 3D graph showing the influence of parameter pairs on the function Y "Source: created by the authors."

a) The influence of the pair of factors $T(^0C)$ and $H(mm)$;
b) Influence of the pair of factors $T(^0C)$ and τ(minute);
c) The influence of the pair of factors $H($ mm)and τ(minutes).

From the 3D graph in Figure 2, it can be seen that when the concentration temperature $x_1$fluctuates from $39°C - 49°C$, the height of the liquid conduction ring $x_2$fluctuates from 410-750 mm, and the ultrasonic emission time fluctuates from 11-29 minutes. The function Y is the maximum function, at the same time, the coordinates of the optimal points of the function Y lie within the research domain of the factors x_i (i $= 1 - 3$).

4 Conclusion

Applying the experimental planning method combined with the general optimization research method, Harrington EC determined the optimal values of the input factors: concentration temperature $T = 41.81°C$, liquid conduction ring height $H =$ 649.77 mm, ultrasonic emission time $\tau = 21.01$in minutes, and the optimal values of the output parameters: the total quality score of the concentrated product $Q = 19.4006$ score.

Compared to the standards of honey produced in Vietnam and the standards of Vietnamese honey exported to the US, EU, and Japan, honey concentrated on the VLUTE-1 device ensures the prescribed standards of nutritional value, sensory value, and food hygiene and safety standards, meeting the requirements of domestic consumption and export.

The above research results are an important basis for completing the design and manufacturing of honey concentrators of different capacities suitable for the scale of each production facility.

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References:

[1] Mudiyanselage, Sarasie, Apan, Armando, Maraseni, Tek, and Altarez, Richard Dein D, Decoding the impacts of space and time on honey bees: GIS based fuzzy AHP and fuzzy overlay to assess land suitability for apiary sites in Queensland, Australia, *Applied Geography*, 2023. doi.org/10.1016/j.apgeog.2023.102951.

[2] Najwan Osman-ali, Junita Mohamad-Saleh, An Adaptive Average Grasshopper Optimization Algorithm for Solving Numerical Optimization Problems, *WSEAS transactions on systems and control*, Volume 18, 2023, pp. 121-135. doi: 10.37394/23203.2023.18.13.

[3] Jonathan A. Ladapo, Abdul K. Mohammed, Veronica C. Nwosu, Review of GenX Pollution: GenX Pollution of the Cape Fear River in North Carolina, USA, *WSEAS Transactions on Environment and Development*, E-ISSN: 2224-3496, Volume 15 pp. 144-152, 2019.

[4] Karabournioti S and Zervalaki P., The effect of heating on honey HMF and invertase, *Apiacta*, 4, pp. 1-4, 2001.

[5] Tosi EA, Ciappini M., Ré E., and Lucero H, Honey thermal treatment effects on hydroxymethylfurfural content, *Food Chemistry*, Vol 77(1), 2002, pp. 71-74. doi.org/10.1016/S0308-8146(01)00325-9.

[6] Tosi EA, Ré E., Lucero H., and Bulacio L., Effect of honey high-temperature short-time heating on parameters related to quality, crystallization

phenomena, and fungal inhibition. LWT, *Food Science and Technology*, Vol 37(6), 2004. Pp. 669–678. doi.org/10.1016/j.lwt.2004.02.005.

[7] Ajlouni S. and Sujirapinyokul P.S., Hydroxymethylfurfuraldehyde and amylase contents in Australian honey, *Food Chemistry*, Vol 119(3), 2009, pp. 1000-1005. doi.org/10.1016/j.foodchem.2009.07.057.

[8] Das S, Uddin M. N, Haque M. S, Chakraborty D, Mostafa M, Hasnaine A, Das S.K, Hydroxymethylfurfural Content and Sugar Profile of Honey Available in Bangladesh Using Validated HPLC-PDA and HPLC-RID, *Journal of Food Quality and Hazards Control*, Volume 9, Issue 3, pp. 160-168, 2022. doi: 10.18502/jfqhc 9.3.11154.

[9] National Standard TCVN 12605: 2019-Honey, Directorate for Standards, Metrology and Quality, *Ministry of Science and Technology*. Link Accessed Date: 15/12/2025.

[10] Angela Dean, Max Morris, John Stufke, Derek Bingham, *Handbook of Design and Analysis of Experiments*, *Department of Biostatistics, Harvard School of Public Health*, Boston, MA, USA, 2015. https://doi.org/10.1201/b18619.

[11] Okwunodulu F. U., Umoh A. E., & Ufearoh S. M. Utilization of Box-Wilson Experimental design matrix in biogas production: a response surface approach, *Journal of Chemical Society of Nigeria*, Vol. 47, No. 6, pp 1285 – 1295, 2022. doi.org/10.46602/jcsn.v47i6.830

[12] Harrington E. C, The desirability function, *Industrial quality control*, 21(10), pp. 494-498, 1965.

[13] Student's t Table Published on April 29, 2022 by Shaun Turney, *Scribbr*. Revised on June 21, 2023. https://www.scribbr.com/statistics/students-t-table/, Accessed Date: 02/02/2026.

[14] Dr. Mathias Jesussek, Statistics made easy, 6th edition, DATAtab e.U, t-distribution Table, *Numiqo*, 2025. https://numiqo.com/tutorial/t-distribution, Accessed Date: 02/02/2026.

[15] F Distribution Tables, Critical values of t for two-tailed tests Significance level (α), *Socr*. http://www.socr.ucla.edu/Applets.dir/F_Tabl.htm, Accessed Date: 02/02/2026.

Contribution of Individual Authors to the Creation of a Scientific Article

- *Dang Thanh Son* organized and performed the experiments and was responsible for Statistics.
- *Le Hong Ky* performed the simulation and optimization.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.