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Selection of Non-Thermal Technology for Honey Pasteurization Machine Using Multi-Criteria Decision Making

Muhammad Dani Setiawan[1a◆], Lobes Herdiman[1b], Taufiq Rochman[1c]

Abstract. *Honey is a natural food product from a sweet viscous substance formed from flower nectar by honey bees. Honey processing using the pasteurization method has limitations, one of which is temperature. As a result, fungi and spores present in honey have not been eliminated. Non-thermal technology (NTT) is a solution to this limitation, because NTT is a process that applies little or no heat, with the aim of food receiving microbial inactivation, and can extend life, maintain physical quality, nutrition and sensory freshness. NTT is commonly used in industry, namely in High-Pressure Processing (HPP), Pulsed Electric Field (PEF), Pulsed Light, Cold Plasma (CL), and Ultra Sound (US). Adjustment to the characteristics of honey is the reason for choosing non-thermal technology. The selection was carried out using the MCDM method, which integrates AHP-TOPSIS. The result is PEF being the selected NTT with a relative closeness of 0.773.*

Keywords: *MCDM, AHP, TOPSIS, Honey Pasteurization, NTT*

I. INTRODUCTION

Honey is a naturally sweet substance produced by honey bees from plant nectar or secretions from living plant parts. Honey contains a complex mixture of 82.0% carbohydrates (sucrose, fructose, maltose), 0.3% protein, 17.0% water and antioxidants. In addition to sugar, honey contains vitamin B complex, vitamin C and various minerals (Commission., 2019). The condition of honey taken from beehives still contains several ingredients that can affect honey's quality and shelf life, namely pollen, beeswax and other materials that must be removed.

Improving honey quality is usually done through filtration, preheating, straining, heating, cooling and packing. Filtration and heating are the essential processes in honey processing. The heating process aims to remove microorganisms that cause spoilage and reduce the water content to inhibit fermentation (Subramanian et al., 2007). One of the heating process methods is pasteurization, where pasteurization is the most common heating process used in the honey industry (De & Arnaut De Toledo, 2010). Pasteurization is the process of applying heat to food to destroy foodborne pathogens. Pasteurization for honey has a temperature limit of not exceeding 80 C; if it exceeds this temperature, it can reduce honey's reducing sugar content. However, when honey is heated to a temperature not exceeding 80°C, there are still active microorganisms and fungi. This limitation can be overcome by using non-thermal technology (NTT) (Soleha et al., 2015).

NTT is a process where food receives microbial inactivation without or with little direct heat application and can prolong life and maintain fresh physical, nutritional and sensory qualities (Troy et al., 2016). Several non-thermal technologies commonly used in industry are High-Pressure Processing (HPP), Pulsed Electric Field (PEF), Pulsed Light, Cold Plasma (CL), and Ultra Sound (US).

High-Pressure Processing (HPP) is a food processing method in which food is subjected to high pressure (up to 87,000 psi or about 6,000 atm), with or without the addition of heat, to achieve microbial inactivation or change food attributes to achieve the desired quality (Dhineshkumar et al., 2016). Pulsed Electric Field (PEF) applies a high electric field which is in

[1] Industrial Engineering Department, Faculty of Engineering, Universitas Sebelas Maret, Jl. Ir. Sutami No.36, Kentingan, Surakarta, 57126, Indonesia

[a] email: daniset354@gmail.com
[b] email: lobesh@gmail.com
[c] email: taufiqrochman@staff.uns.ac.id
◆ corresponding author

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contact with the material between the two electrodes in a short time (Rahmah et al., 2020). PEF can be applied to liquid and semi-liquid products; it can produce liquid food with high microbial safety, sensory and nutritional qualities, and extended shelf life (Soltanzadeh et al., 2020).

Pulsed Light is a non-thermal method that involves a comprehensive, short but highly energized pulsed circuit of white light's broadband, consisting of ultraviolet (UV) light, visible and infrared radiation (Dong et al., 2020). Cold plasma is an ionized semi-neutral gas that combines ions, UV photons, electrons, reactive species and charged elements. Cold plasma is claimed to be able to inactivate all microbes, including viruses, fungi and bacteria (Charoux et al., 2021). Ultra Sound is a non-thermal technology involving pressure waves with a frequency range between 20 and 100 kHz. This method is an application of ultrasound in food technology (Chandrapala et al., 2012).

The selection of non-thermal technology for the honey pasteurization machine needs to consider several important criteria. The purpose of the selection is so that the selected alternative can match the characteristics of honey. An alternative selection is made using Multi-Criteria Decision Making (MCDM). The MCDM method aims to choose the best alternative from several mutually beneficial exclusive alternatives based on the general performance of several criteria determined by the decision maker (Tzeng & Huang, 2011). In this paper, the MCDM method that will be used is the integration between AHP and TOPSIS. The AHP method is used to determine the weight of the criteria, while TOPSIS is used to select alternatives. This study aims to choose a non-thermal technology for a honey pasteurization machine using AHP-TOPSIS.

II. RESEARCH METHOD

This research focuses on selecting non-thermal technology for the honey pasteurization machine. Selection of non-thermal technology using MCDM by integrating AHP-TOPSIS. AHP is used to determine the weight of the criteria, and TOPSIS provides alternative rankings. Figure 1 shows the non-thermal technology selection flowchart methodology:

- Step-1: Identify non-thermal technology selection criteria obtained from literature, expert experience and questionnaires.
- Step-2: Establish a hierarchy of non-thermal technology selection criteria. Then calculate the weight of the criteria using AHP.
- Step-3: Calculate alternative ranking with TOPSIS to get the final ranking result

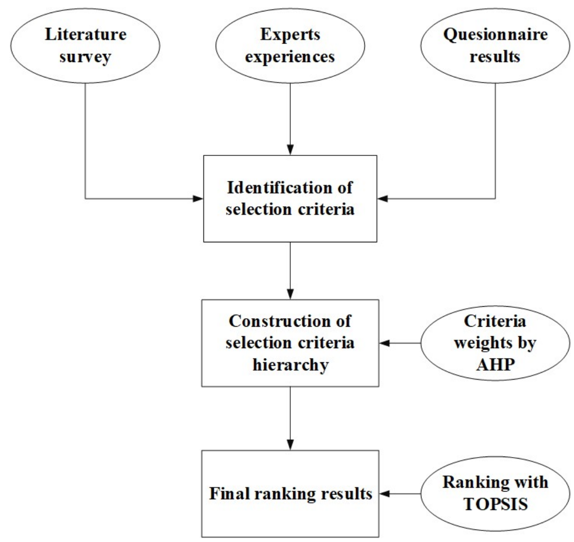

Figure 1. Flowchart methodology of non-thermal technology selection

The AHP Metodhology

AHP is a multi-criteria decision-making method (MCDM) developed by Thomas L. Saaty around 1970. AHP is a measurement theory through pairwise comparisons based on expert judgment to obtain a priority scale for criteria. Comparisons are made using an absolute rating scale representing how much one criterion dominates another concerning a given alternative (Thomas L Saaty, 2008). AHP is a method that is widely used in solving multi-criteria decision-making problems because this method is easy to understand and very applicable to various complex decision-making problems (Emovon & Oghenenyerovwho, 2020). The following are the steps for implementing AHP.

The first step of AHP is to describe the decision-making problem in a hierarchy with the 'objective' at the top, followed by criteria with many levels, and the lowest hierarchy is the alternative. The hierarchy of decision-making problems is shown in Figure 2.

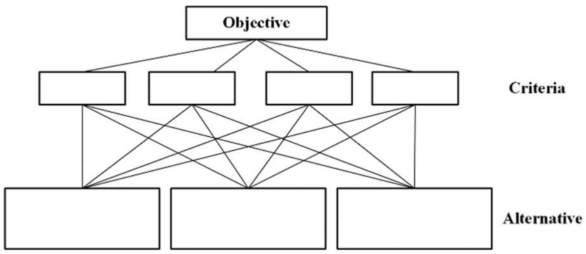

Figure 2. Hierarchy of decision-making problems

The second step is to create a decision matrix. The decision matrix is filled in based on the fundamental scale or 9 scale developed by Saaty. The fundamental scale contains 9 scales that represent the importance of one criterion to another. Fundamental scale as shown in Table 1.

Table 1. Fundamental scale

Intensity of Importance	Definition
1	Equal importance
3	Moderate importance
5	Strongly importance
7	Very strongly importance
9	Extremely importance
2, 4, 6, 8	Intermediate values

If the decision-making problem contains n criteria, namely $A_1, A_2, \dots A_n$, where if the criteria A_1 is compared with A_2, the resulting comparison value is a_{12}. The results of the comparison between criteria will produce an $n \times n$ matrix A as described in Equation 1.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

Next, create a pairwise comparison matrix a_{ij} represents the preference scale of criterion i to criterion j, where $a_{ij} = w_i / w_j = 1/a_{ji}$ and $a_{ii} = 1$ with $i, j = 1, 2, \dots, n$. Pairwise comparison matrix as described in Equation 2.

$$A = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} \quad (2)$$

Then the pairwise comparison matrix is normalized. Normalization begins by adding up the weights in each column j. S_{ij} represents the total weight in each column. The calculation of the total weight of each column is described in Equation 3.

$$S_{ij} = \sum_{i=1}^{n} a_{ij} \quad (3)$$

After that, each column value is divided by the total weight of each column, which V_{ij} represents. Calculation of V_{ij} as described in Equation 4.

$$V_{ij} = \frac{a_{ij}}{S_{ij}} \quad (4)$$

Then calculate each criterion's priority vector or weight by calculating the average row i for each criterion; Q_{ij} represents the total weight of row i. The weight of the i-th criterion is represented by W_i, as described in Equation 5

$$W_i = \sum_{i=1}^{n} \frac{Q_1}{n} \quad (5)$$

The next step is to calculate the consistency rate (CR). Consistency rate (CR) is the consistency of the decision maker's judgment at the evaluation stage. CR is calculated by dividing the value of CI (consistency index) by RI (random index). To calculate CI, it is necessary to calculate the maximum eigenvalue (λmax) as described in Equation 6.

$$A.x = \lambda max \quad (6)$$

Where, A is a pairwise comparison matrix and x is the criterion weight matrix. After getting the max value, calculate the CI value, as described in Equation 7.

$$CI = \frac{\lambda max - n}{n - 1} \quad (7)$$

Where, n is the number of criteria. The next step is to calculate CR by dividing CI by RI. RI is obtained by looking at Table 2 and adjusting to n criteria at the evaluation stage.

Table 2. Random index

n	RI	n	RI	n	RI
1	0,00	6	1,24	11	1,51
2	0,00	7	1,32	12	1,48
3	0,58	8	1.41	13	1,56
4	0,90	9	1.45	14	1,57
5	1,12	10	1,49	15	1,58

After knowing CI and RI, the next step is calculating CR, as described in Equation 8.

$$\mathrm{CR}=\frac{\mathrm{CI}}{\mathrm{RI}} \tag{8}$$

The CR value considered consistent is not more than 0.1 or 10%. If the CR value exceeds the limit or is inconsistent, then the evaluation or appraisal stage from the decision maker needs to be repeated.

TOPSIS Approach

TOPSIS is a decision-making method developed by Hwang and Yoon in 1981. This method was developed based on the premise that the best solution has the smallest distance from the positive ideal solution and has the farthest distance from the negative ideal solution (Chakraborty, 2022). TOPSIS has been applied to decision-making problems in many areas such as educational selection applications (Nanayakkara et al., 2019), product selection (Akgül et al., 2021), strategy evaluation (Ture et al., 2019), mission-critical planning (Tavana & Hatami-Marbini, 2011) and technology selection (Sohaib Khan et al., 2021). Here are the steps for applying TOPSIS.

The first stage is to create a decision matrix. The decision maker's preference for each alternative A_i against each criterion C_j is known as the performance rating (x_{ij}). The performance rating for each alternative against each criterion can be displayed as a decision matrix (X). The decision matrix is shown in Equation 9.

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1J} \\ x_{21} & x_{22} & \cdots & x_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ x_{I1} & x_{I2} & \cdots & x_{IJ} \end{bmatrix} \tag{9}$$

The second stage is to calculate the normalization of the performance rating. The performance rating on the decision matrix is normalized to obtain a normalized performance rating y_{ij}. Calculation of normalization of performance rating as shown in Equation 10.

$$y_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \tag{10}$$

The normalized performance rating y_{ij} can be represented as a Y normalized decision matrix. The normalized matrix as shown in Equation 11.

$$Y = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1J} \\ y_{21} & y_{22} & \cdots & y_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ y_{I1} & y_{I1} & \cdots & y_{IJ} \end{bmatrix} \tag{11}$$

After that, create a weighted normalized decision matrix. The normalized performance rating y_{ij} on the Y normalized matrix multiplied by the criterion weight W_j makes the normalized weighted performance rating v_{ij}. Calculation of the normalized weighted performance rating is shown in Equation 12. The normalized weighted performance rating of v_{ij} can be represented as a normalized weighted decision matrix Y. The matrix is normalized as shown in Equation 13.

$$v_{ij} = y_{ij} \times w_j ; (i = 1, 2, \ldots, I; j = 1, 2, \ldots, J) \tag{12}$$

$$V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1J} \\ v_{21} & v_{22} & \cdots & v_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ v_{I1} & v_{I2} & \cdots & v_{IJ} \end{bmatrix} \quad \textbf{(13)}$$

The next step is to determine the positive and negative ideal solutions. Positive and negative ideal solutions are represented by A^* and A^-, respectively. Determination of positive and negative ideal solutions, respectively, as shown in Equations 14 & 15.

$$A^* = \left[v_1^*, v_2^*, \ldots, v_J^* \right] \quad \textbf{(14)}$$

$$A^- = \left[v_1^-, v_2^-, \ldots, v_J^- \right] \quad \textbf{(15)}$$

where,

$$v_j^* = \begin{cases} \max v_{ij}, \text{ if } j \text{ benefit criteria} \\ \min v_{ij}, \text{ if } j \text{ cost criteria} \end{cases}$$

$$v_j^- = \begin{cases} \min v_{ij}, \text{ if } j \text{ benefit criteria} \\ \max v_{ij}, \text{ if } j \text{ cost criteria} \end{cases}$$

Next, calculate alternative distances with positive and negative ideal solutions. Calculating alternative distances with positive and negative ideal solutions is based on Euclidean distance theory. Calculation of alternative distances with positive (S_i^*) and negative (S_i^-) ideal solutions as shown in Equations 16 & 17, respectively.

$$S_i^* = \sqrt{\sum_{j=1}^{J} (v_{ij} - v_j^*)^2} \quad \textbf{(16)}$$

$$S_i^- = \sqrt{\sum_{j=1}^{J} (v_{ij} - v_j^-)^2} \quad \textbf{(17)}$$

The final step is to calculate the relative closeness to the ideal solution. The alternative is closer to the positive ideal solution and further from the negative ideal solution when the relative closeness value (C_i^*) is close to 1. Calculation of relative closeness as shown in Equation 18.

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \quad \textbf{(18)}$$

III. RESULT AND DISCUSSION

This study uses 5 main criteria, 12 sub-criteria and 9 sub-criteria obtained from literature studies and expert opinions. And 5 alternative non-thermal technologies, namely High-Pressure Processing (HPP), Pulsed Electric Field (PEF), Pulsed Light, Cold Plasma (CP), and Ultra Sound. Criteria. The non-thermal technology selection model hierarchy is shown in Figure 3.

The researcher prepared a questionnaire that

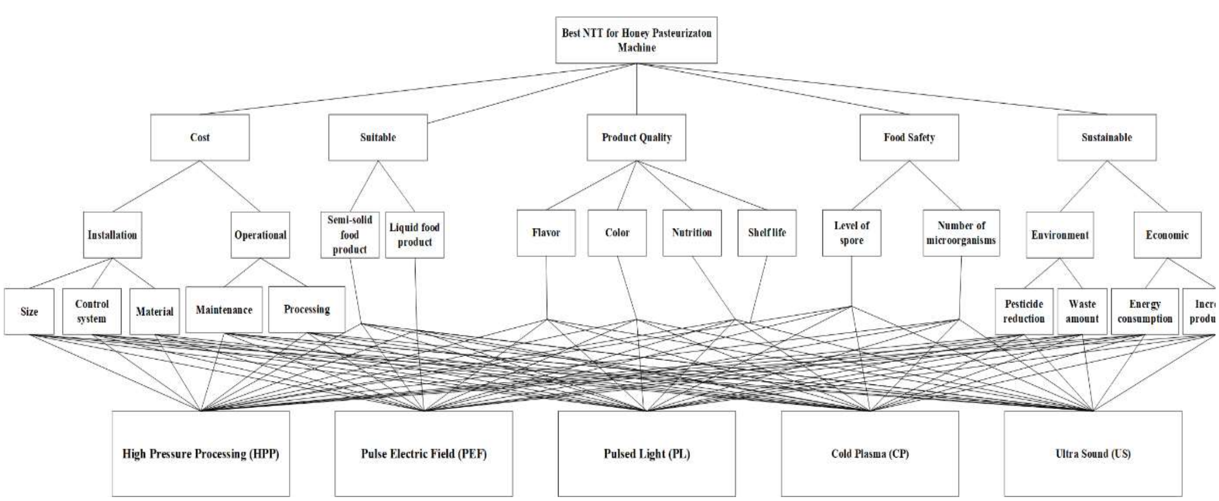

Figure 3. Hierarchy model of selection NTT

Table 3. The weight of AHP criteria

Criteria	Weight between the criteria	Sub-criteria	Weight between the Sub-criteria	Sub-subcriteria	Weight between the Sub-subcriteria	Global weight criteria
Suitable	0,37	Semi-solid food product	0,26	-	-	0,096
		Liquid food product	0,74	-	-	0,273
Product Quality	0,30	Flavor	0,18	-	-	0,055
		Color	0,14	-	-	0,043
		Nutrition	0,28	-	-	0,086
		Shelf life	0,40	-	-	0,121
Food Safety	0,16	Number of microorganisms	0,35	-	-	0,057
		Level of spore	0,65	-	-	0,104
Cost	0,10	Installation	0,30	Size	0,30	0,009
				Control system	0,52	0,015
				Material	0,18	0,005
		Operational	0,70	Maintenance	0,28	0,018
				Processing	0,72	0,048
Sustainable	0,07	Environment	0,47	Pesticide reduction	0,65	0,021
				Waste amount	0,35	0,012
		Economic	0,53	Energy consumption	0,61	0,023
				Increased productivity	0,39	0,015

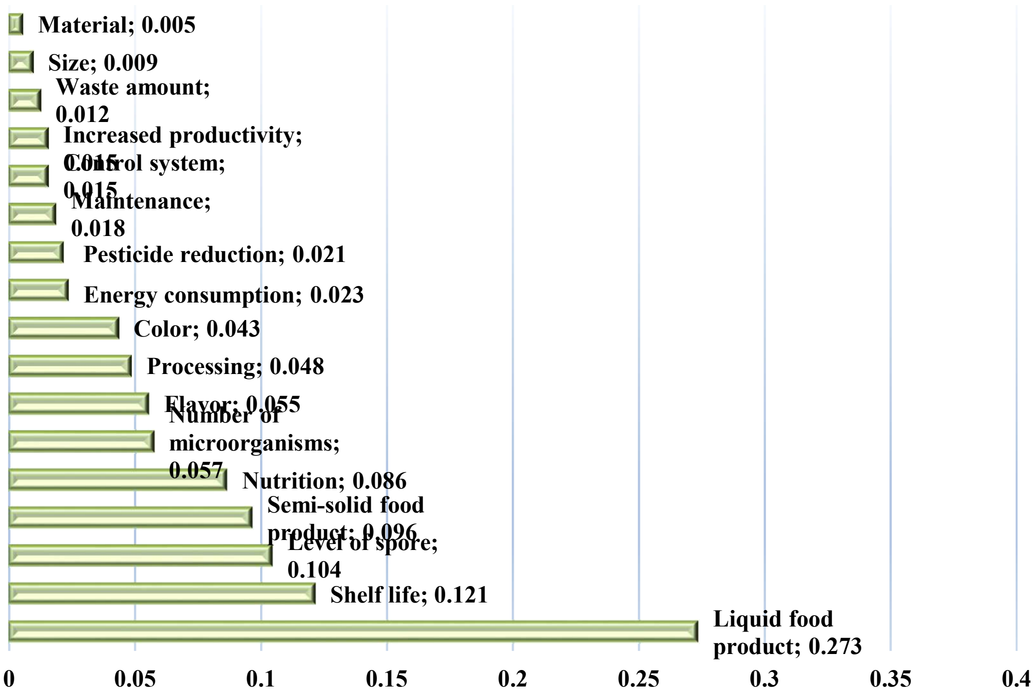

Figure 4. The weight of global criteria

had to be filled out by the expert, and some experts proposed some additions. The first questionnaire was made based on the Saaty Fundamental Scale. Then the expert filled out the questionnaire, and then the results were processed using AHP to determine the weight of the criteria. AHP processing is done using Microsoft Excel Software. The weight of the criteria is calculated at each criterion level, starting from the main criteria, sub-criteria and sub-sub-criteria. The results of the criteria weights for each level are then converted into global

Table 4. The normalized decision matrix

Weight	0,096	0,273	0,055	0,043	0,086	0,121	0,057	0,104	0,009	0,015	0,005	0,018	0,048	0,021	0,012	0,023	0,015	0,096
Alternative	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	16	C17	C1
HPP	0,435	0,413	0,462	0,370	0,452	0,479	0,476	0,489	0,417	0,473	0,429	0,470	0,481	0,465	0,443	0,410	0,456	0,435
PEF	0,479	0,483	0,517	0,439	0,490	0,463	0,476	0,460	0,417	0,517	0,414	0,420	0,420	0,489	0,481	0,451	0,496	0,479
PL	0,458	0,462	0,383	0,348	0,353	0,427	0,386	0,489	0,392	0,410	0,429	0,446	0,487	0,418	0,402	0,451	0,436	0,458
CP	0,435	0,462	0,470	0,407	0,476	0,468	0,476	0,412	0,510	0,423	0,502	0,489	0,443	0,437	0,443	0,471	0,436	0,435
US	0,428	0,413	0,390	0,619	0,452	0,393	0,415	0,374	0,488	0,402	0,456	0,406	0,398	0,422	0,463	0,451	0,408	0,428

Table 5. The weighted normalized decision matriks

Alternative	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	16	C17	C1
HPP	0,119	0,040	0,025	0,016	0,039	0,058	0,027	0,051	0,004	0,007	0,002	0,009	0,023	0,010	0,005	0,009	0,007	0,119
PEF	0,130	0,046	0,028	0,019	0,042	0,056	0,027	0,048	0,004	0,008	0,002	0,008	0,020	0,010	0,006	0,010	0,007	0,130
PL	0,125	0,044	0,021	0,015	0,030	0,052	0,022	0,051	0,003	0,006	0,002	0,008	0,023	0,009	0,005	0,010	0,006	0,125
CP	0,119	0,044	0,026	0,017	0,041	0,057	0,027	0,043	0,005	0,006	0,003	0,009	0,021	0,009	0,005	0,011	0,006	0,119
US	0,117	0,040	0,021	0,026	0,039	0,048	0,024	0,039	0,004	0,006	0,002	0,007	0,019	0,009	0,005	0,010	0,006	0,117

Table 6. The weighted normalized decision matriks

Solution	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	16	C17	C1
A^8	0,119	0,044	0,026	0,017	0,041	0,057	0,027	0,043	0,005	0,006	0,003	0,009	0,021	0,009	0,005	0,011	0,006	0,119
A^-	0,117	0,040	0,021	0,026	0,039	0,048	0,024	0,039	0,004	0,006	0,002	0,007	0,019	0,009	0,005	0,010	0,006	0,117

weights. From the results of the calculation of the weight of the AHP criteria, as shown in Table 3, it is known that at the level of the main criteria, the 'suitable' criterion has the highest weight, which is 0.37. As shown in Figure 4, the criteria for 'liquid food products' is the criterion with the highest global weight, which is 0.273. Then the 'material' and 'size' criteria became the criteria with the lowest global weights, namely 0.005 and 0.009. Global weight criteria are used as the weight of the criteria at the alternative selection stage with the TOPSIS approach.

The TOPSIS approach to selecting alternatives uses input from the second questionnaire. The results of the global weights obtained from the AHP are used as criteria weights for TOPSIS. TOPSIS calculation is done with Microsoft Excel Software. Table 4 shows the normalized matrix. Next, the weighted normalized decision matrix is shown in Table 5. Then, the Determination of positive and negative ideal solutions as shown in Table 6. The results of calculating the Euclidean distance and relative closeness of the ideal solutions for each alternative are shown in Table 7.

Results of the study This shows that the NTT applied to the honey pasteurization machine is PEF as shown in Figure 5.

Table 7. Euclidean distance and relative closeness

Alternative	Si^*	Si^-	Ci^*
HPP	0,018	0,020	**0,524**
PEF	0,009	0,025	**0,733**
PL	0,021	0,016	**0,440**
CP	0,018	0,017	**0,495**
US	0,024	0,014	**0,375**

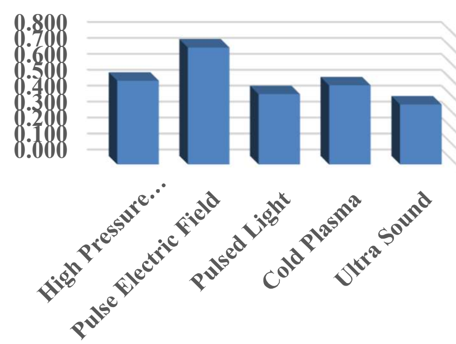

Figure 5. Relative closeness

IV. CONCLUSION

The model hierarchy is shown in Figure 1. Explains that there are 3 levels of criteria, namely the main criteria, sub-criteria and sub-criteria, in which each level has a total of 5,12 criteria and 9 criteria, with 5 alternatives, namely High-Pressure Processing (HPP), Pulsed Electric Field (PEF), Pulsed Light, Cold Plasma (CP), and Ultra Sound

(US). The selection of NTT was carried out with a combination of AHP-TOPSIS.

The weighting of the criteria is calculated using the AHP method. Based on Figure 4, it is known that the 'liquid food product' criterion is the criterion with a weight of 0.273. Meanwhile, the 'Material' and 'Size' criteria are in the lowest ranking with weights of 0.005 and 0.009, respectively.

An alternative selection is made by applying the TOPSIS method. Alternatives are selected based on the results of the weighted criteria using AHP. Alternatives with relative closeness to 1, become the chosen alternative. Based on Figure 5, it is found that Pulsed Electric Field (PEF) is the chosen alternative. Based on the relative proximity values, they can be sorted as follows: PEF > HPP > CP > PL > US. So it can be concluded that PEF is applied to the honey pasteurization machine.

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