



Techno-economic Review of Isolation of Eugenol from Clove Oil with Batch Distillation

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Abstract

All parts of the clove plant (*Syzygium aromaticum* L.), including roots, stems, leaves and flowers, can be processed into clove oil. One of the important compounds in clove oil is Eugenol. Pharmaceutical grade eugenol has a very high selling value, however conventional refining without a purification process only produces clove oil with a eugenol content of 78-80%. This study aims to compare the efficiency of eugenol purification from clove oil processed by clove farmers using two different methods: reactive extraction and batch distillation. Analysis of the final products from both processes was carried out by GC-MS. The eugenol isolation process using a reactive extraction method with various variations in NaOH purity obtained optimum results at 2 N NaOH levels where clove oil was produced with a eugenol content of 75.33% with a product recovery of 40%. Meanwhile, eugenol was isolated using batch distillation with constant reflux and atmospheric pressure to obtain pure clove oil with a eugenol content of 97.02% with a product recovery of 28.25%. The main component other than eugenol detected in both methods was beta-Caryophyllene.

Keywords: clove oil, eugenol, extraction, batch distillation, techno-economy

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1. Introduction

Indonesia is one of the producers and exporters of essential oils with high export value, where the export value in 2019-2020 reached approximately US\$400 million (Mahlinda et al., 2019). Cloves (*Syzygium aromaticum*) are plants from the myrtaceae group whose flowers, leaves and stems can be processed into essential oil (Frohlich et al., 2019). Clove oil is an aromatic oil liquid that is used in the food, cosmetic and pharmaceutical industries because of its functional properties. Apart from being used directly as a cooking ingredient, cloves can be further processed for their medicinal properties. As medicine, clove buds need an extraction process to obtain essential oil. Several researchers, namely Romani et al. (2019) have studied the application of cloves in dental care. Clove oil is also included in the edible coatings and coatings industry, as a substitute for synthetic preservatives. Clove essential oil also has anti-inflammatory activity as well as anodyne, namely the properties listed in clove oil as a natural remedy for toothache. The potential activity of this oil comes from the abundance of phenolic compounds it carries including eugenol, eugenol acetate and gallic acid (Karunamay et al., 2022).

In clove oil there is the compound eugenol which is the main constituent component. The quality and price of clove oil is largely determined by the eugenol content in it. On average, clove oil produced by farmer distillers has a eugenol content of between 70% - 80% with a cloudy color so it is in the low category with a price range of IDR 200,000 - IDR 400,000 (Moemenbellah et al., 2020). Meanwhile, pure eugenol has very high economic value. Pure eugenol, United States Pharmacopoeia (USP) eugenol, with a purity of at least 97% has a price of around IDR 1,500,000 to IDR 3,000,000 per kg.

Research on the isolation of eugenol from clove oil, especially on a pilot plant scale with different process innovations, still needs to be carried out, because it can be implemented in industry, especially Small and Medium Enterprises (SMEs). Refining processes that have been studied in previous studies include: The influence of packing type on refining clove oil by vacuum distillation. Purification by saponification and distillation processes. Purification by extraction process using NaOH. However, the pure clove oil produced still has a eugenol content of less than 90%. Therefore, research has been carried out on

refining clove oil using batch distillation where a simulation study has been carried out to obtain a batch distillation operation scenario by (Sugiharto, 2008). Through this experimental study, it is hoped that eugenol with levels above 90% can be produced and it is necessary to carry out an economic study by comparing reactive extraction methods so that it can be applied on an MSME scale.

This research aims to isolate eugenol from clove oil using the batch distillation method, while to carry out an economic study, research was also carried out using a reactive extraction method. It is hoped that the techno-economic study of both methods can be implemented by clove oil refining MSMEs to produce products with higher economic value.

2. Methodology

2.1. Materials

All reagents, namely NaOH, HCl, and 96% Ethanol used in this research, are technical-grade. Clove oil samples were obtained from Cepogo, Boyolali Regency, Central Java.

2.2. Extraction Method

At this stage, clove leaf oil is mixed 3 times with 0.9 N NaOH solution; 1.5 N; 2 N was mixed for 10 minutes, 15 minutes, and 20 minutes. Then let it sit for 120 minutes, 180 minutes, and 360 minutes, until two layers form. The bottom layer is Na-eugenolate and the top layer is other organic compounds, then separated and the Na-eugenolate solution is added with 1 N HCl solution.

2.3. Batch Distillation Method

Isolation of eugenol from clove oil was carried out using a batch distillation process using a fractionation column consisting of 7 ideal plates with an operational plan scenario according to research in (Sugiharto, 2008). Distillate and residue samples were taken at 10, 30 and 50 minutes after steady state tower conditions. During the process of taking the distillate, changes in the temperature of the top and bottom of the tower are recorded. This distillation process was carried out within 1 hour, by taking 3 sets of samples. Samples were analyzed by Gas Chromatography-Mass Spectrometry (GC-MS) to obtain the eugenol concentration for each.

2.4. Analysis

Analysis of the eugenol raw material, extraction results and purification results was

carried out using the GC-MS method, to determine the eugenol content and all the components that make up clove oil before and after the process. The column used is Rtx – 5MS, length 30 m, ID: 0.25 mm. Meanwhile, the analysis conditions were carried out in a gradient at a temperature of 60-200°C with a constant pressure of 36.2 Kpa. Then the carrier gas used is Helium with a flow rate of 0.75 mL/minute.

3. Results and Discussion

3.1. Physico-Chemical Characteristics of Clove Oil

The characteristics of clove oil from clove leaf distillation in the Cepogo Boyolali area are blackish brown. Analysis of the eugenol content in clove oil raw materials was carried out qualitatively and quantitatively. The components of clove oil were analyzed quantitatively using GC-MS. Based on the results of GC-MS analysis of clove oil raw materials, there are 5 components shown in Table 1. Eugenol is the main component of clove essential oil which gives it a strong and distinctive aroma and taste. In addition, clove essential oil contains flavonoids, polyphenols and antioxidants which contribute to various health benefits. This compound has anthelmintic, antifungal, antibacterial and antioxidant activity (Pessoa et.al,2002, Pinto et.al,2009).

Table 1. Composition of clove oil from GC-MS analysis

No	Description	CAS	Peak area (%)
1.	Eugenol	97-53-0	69.74
2.	beta-	1139-30-6	26.24
3.	Caryophyllene	6753-98-6	2.67
4.	Alpha-humulene	3856-25-5	0.40
5.	Alpha-Copaene	87-44-5	0.43
	Caryophyllene		0.53
	Others component		

From Figure 1, it can be seen that there are 5 components of clove oil identified by the Gas Chromatography instrument. Each component can be separated due to differences in the distribution or interaction of compounds in the sample with the column of the instrument. Differences in interactions occur due to differences in the chemical structure of each component in clove oil. The results of these differences in interactions will be represented as the retention time of the chromatogram.

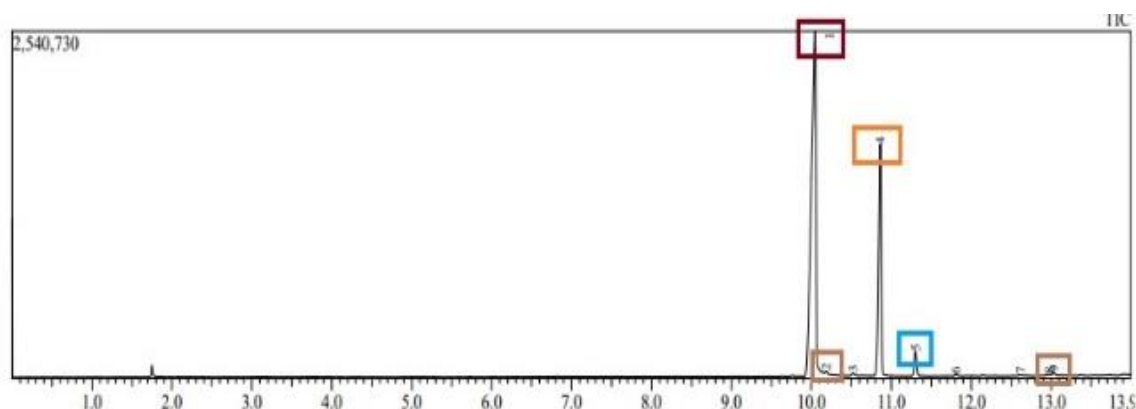


Figure 1. Chromatographic spectrum of clove oil raw materials

Retention time is also a value that can be used to initially identify types of compounds whose structures are unknown in a mixture. By looking at the MS data and the retention time of each chromatogram peak, the types of components that make up clove oil can be determined.

The quality of clove oil is determined by its levels of eugenol and caryophyllene. The eugenol and beta-caryophyllene content in clove oil from Cepogo were 69.74% and 26.24%, respectively, which did not meet the SNI 06-2387-2006 standards requiring a minimum of 78% eugenol and a maximum of 17% beta-caryophyllene. In comparison, clove oil from Java showed eugenol levels ranging from 55.6% to 74.6% and beta-caryophyllene levels from 12.7% to 14.8%. Meanwhile, clove oil from the Ambon area has eugenol levels of 52.53% and caryophyllene 37.25% (Tales et al., 2021).

Table 2. Comparison of standard specifications for clove oil according to SNI 06-2387-2006

No	Test Type	Unit	Condition	Raw Material
1.	Specific gravity 20°C/ 20°C	g/mL	1.025 – 1.049	1.034
2.	Refractive index at 28°C	-	1.528 – 1.535	1.529
3.	Eugenol content (v/v)	%	Minimum 78	69.74
4.	Beta caryophyllene content (v/v)	%	Maximum 17	26.24

As presented in Table 1, the evaluation of the raw materials indicated that, in comparison to

the quality parameters specified in SNI 06-2387-2006, the specific gravity and refractive index of the raw material samples, outlined in Table 2, complied with the SNI standards. Meanwhile, the eugenol content of the sample was 69.74%, still below the SNI quality standard, namely 78%. Another compound mentioned as a parameter in SNI, namely beta caryophyllene, still has a percentage of 26.24%, exceeding the maximum criterion set at 17%.

3.2. The Liquid-Liquid Extraction Performance

Clove oil samples were extracted using NaOH with varying concentrations of 0.9; 1.5 and 2 N. The stirring time was set for 10, 15 and 20 minutes while the standing time was 120, 180 and 360 minutes. The results of the water phase and organic phase obtained are shown in Figure 2a, b and c. The addition of NaOH with various concentrations and stirring times has an influence on the volume of the water phase and organic phase. The volume of the water phase is greater than the organic phase.

The eugenol in the sample will react with the added NaOH to form eugenolate salt so that it is more easily distributed into the water solvent. At variations in NaOH concentrations of 0.9 N and 1.5 N there was an effect of stirring and the length of residence time on the volume of the water phase and organic phase, however at variations of 2 N the length of stirring time and the residence time had no effect on the volume of the water phase and organic phase. This happens because the amount of NaOH available is in excess. A NaOH concentration of 1.5 N is equivalent to a concentration of 6% NaOH.

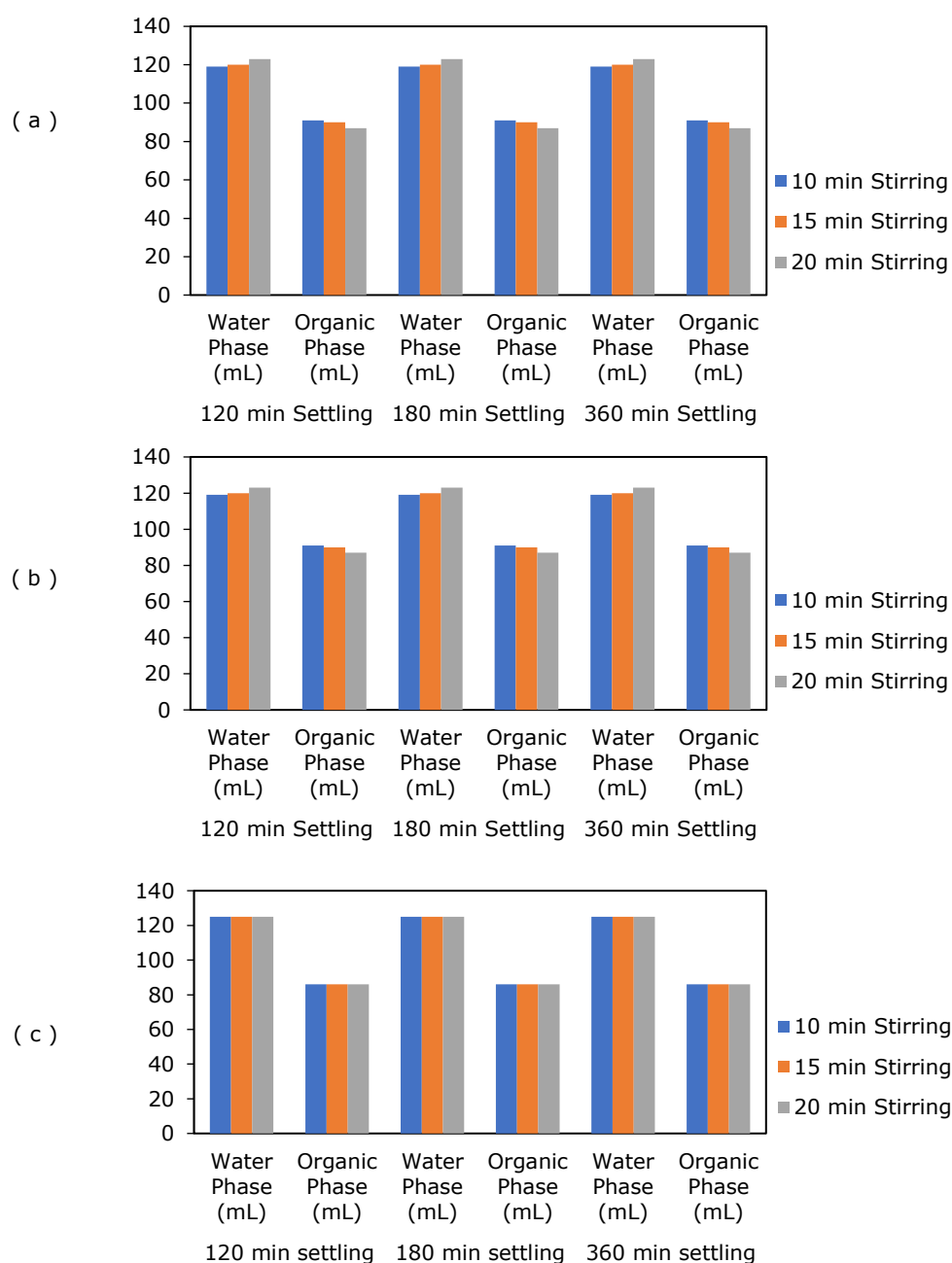


Figure 2. Volume of water and organic phase extraction results: a (0.9 N), b (1.5 N), c (2N).

According to Nurdin (2020) NaOH of more than 5% provides good separation between terpenes (organic phase) and Na-eugenolate. However, the 2N NaOH concentration was chosen for the saponification process in this experiment because the eugenol conversion was complete and the remaining NaOH was not excessive. Meanwhile, Hasim et al., (2016) obtained an organic phase percentage of 57% and a water phase of 15% in extraction using 1 N NaOH. Figures 3 and 4 show that the volume of the water phase is directly proportional to the normality of NaOH while the organic phase is inversely

proportional. This shows that there is a saponification reaction of eugenol resulting in the formation of eugenolate salt which is more distributed in the water solvent. This is the basic principle for increasing eugenol levels in clove oil.

This is in accordance with research conducted by Lutfi et al. (2013) that the higher the NaOH content, the greater the water phase formed. All of this is because one of the reactants, namely NaOH or clove oil, has not yet been used up to react. This is also supported by research conducted by Nurdin (2020)

explaining that NaOH with a concentration of 3% in the formation of Na-eugenolate is not perfect, where the top layer and bottom layer (Na-eugenolate) have not been separated into 2 layers or 2 layers cannot be seen forming. Therefore, to get a visible layer of 2 layers, the NaOH concentration must be increased again to 5%. Even for a NaOH concentration of 10% the separation is very clearly visible and quickly becomes 2 layers. The concentration of NaOH also affects the purity of the eugenol obtained.

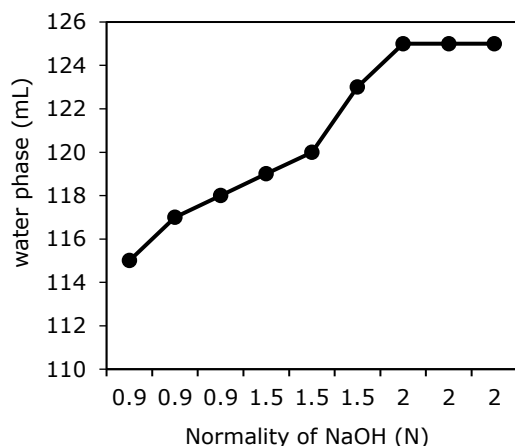


Figure 3. Relationship of N NaOH with the water phase

The eugenol saponification reaction can be seen in Figure 5. In a solution, NaOH will form into Na^+ and OH^- , this OH^- group will attract one H atom from eugenol and will be replaced by a free Na^+ ion in the solution. Eugenol salt has high solubility in water solvents so it can be used as a method of purifying eugenol in clove oil.

Neutralization is carried out by adding HCl to the water phase (Figure 6). The liquid-liquid extraction method process with NaOH is then neutralized with HCl, samples are taken at a

NaOH concentration of 2 N. The NaCl salt formed at the end of the reaction will be in the form of its ions which will dissolve in the water phase so that Eugenol will be separated from other organic compounds in the mixture. This separation principle can be carried out if the compounds in a mixture have different polarities or solubility in several solvent systems. In this test, water solvent is used which has polar properties. So eugenol which has been reacted with NaOH can be distributed in the water phase while other compounds such as caryophyllene, copaene or other organic compounds remain in the organic phase so that separation occurs.

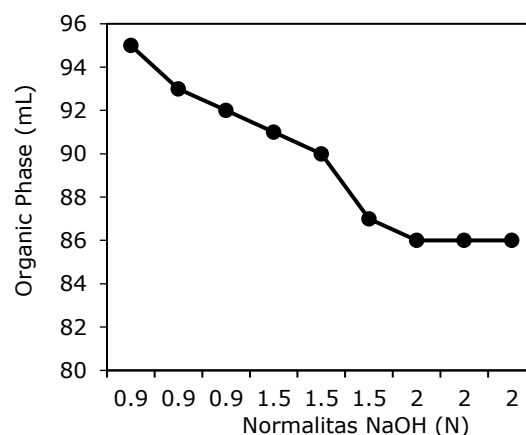


Figure 4. Relationship of N NaOH with the organic phase

Table 3 shows that after the liquid-liquid process the eugenol concentration is higher when compared to the initial clove oil eugenol content. Eugenol levels increased from 69.74% to 75.33%. This process is one of the steps if you want to increase eugenol levels in clove oil samples. Meanwhile, levels of other compounds generally did not change much. Beta-Caryophyllene content is 19.63% so it still does not meet SNI 06-2387-2006 standards.

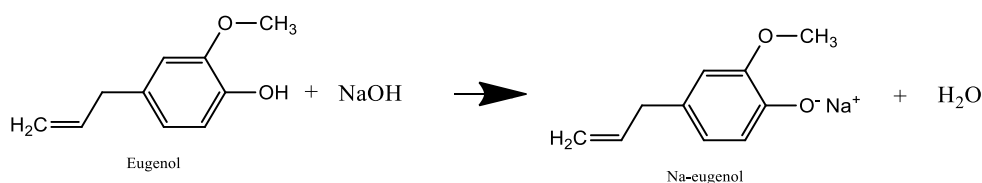


Figure 5. Saponification reaction of eugenol with NaOH

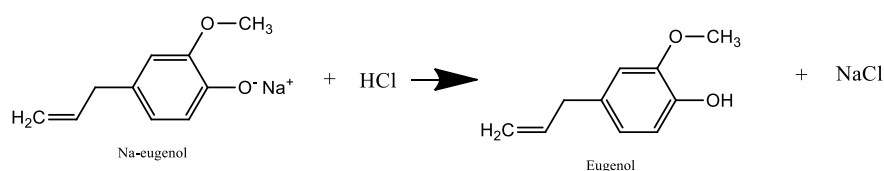


Figure 6. Eugenol neutralization reaction with HCl

Table 3. Chemical composition of extracted clove oil

No	Description	CAS	%
1.	Eugenol	97-53-0	75.33
2.	Beta-	1139-30-6	19.63
3.	Caryophyllene	6753-98-6	2.63
4.	Alpha-humulene	3856-25-5	0.19
5.	Alpha-Copaene	87-44-5	0.30
	Caryophyllene		1.92
	Others component		

The extraction process carried out by previous researchers at a temperature of 40°C for 30 minutes produced 51.07% eugenol (Daryono, 2015). Meanwhile Hasim et al., (2016) obtained a eugenol content of 84.8% after the extraction process with NaOH and then neutralization with 1N HCl of 3.5% of the total weight. The reactive extraction process in purifying eugenol is quite effective if the right concentration of NaOH is used, however this method requires several process stages, namely extraction and reaction followed by distillation to purify the final product.

3.3. Batch Distillation Process Results

At the beginning of the process, when the volatile components of eugenol are distilled, the distillate is collected in the by-product tank. In the next process, after the composition of the eugenol distillate starts to get high, the distillate is diverted to the main product tank. This process in batch distillation is called cut-off. In order to obtain maximum product recovery, the operating reflux setting is the best. Product recovery is the amount of distillate obtained divided by the initial feed amount of clove oil. The results of product recovery based on time are shown in Table 4.

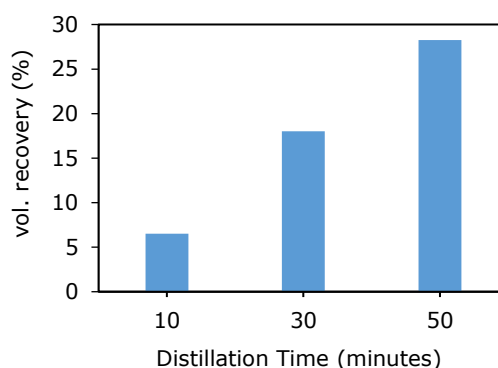
Table 4. Product recovery results in percent

Distillation Time (minutes)	Distillate product recovery (%)
10	6.5
30	18
50	28.25

In the batch distillation process, the first step is that the researcher carries out the High Equivalent Theoretical Plate (HETP) experiment to determine the number of theoretical plates that are equivalent to the packing height in the batch distillation tower. Based on the calculation results, the number of theoretical plates obtained is 7 stages. This is in accordance with simulations carried out

by previous researchers Sugiharto (2008). After that, 2000 mL of clove oil sample was put into a flask. The temperature is set to reach 250°C, close the reflux tap until it reaches steady state or constant temperature. The choice of temperature of 250°C was based on the boiling point of eugenol.

Figure 7 shows the relationship between distillation time and product recovery volume. Based on the relationship between product recovery and distillation time, there is a comparable correlation, meaning that the longer the sampling duration, the greater the volume of product recovery.


Figure 7. Comparison between time and recovery volume

In Figure 7, it can be seen that the pattern of increasing product recovery values as the distillation time increases. The 10th minute produces the smallest product recovery of around 6.5%, while the 30th minute is around more than 18%. Then, 50 minutes of distillation time gives results of around 28.25% product recovery. So the amount of product recovery produced at the 50th minute is with the largest value, namely 28.25%.

Table 5. Eugenol content in distillate

Distillation Time (minutes)	Distillate product recovery (%)	Eugenol content in distillate (%)
10	6.5	99.93
30	18	98.04
50	28.25	97.02

The results of the distillate analysis for each time variation gave results in the form of eugenol levels from each sample. The respective levels were 99.93% then 98.04% and 97.02% respectively from variations of 10, 30 and 50 minutes (Table 5). With the amount of distillate (product recovery)

increasing from 6.5% then 18% and 28.25% as shown in Figure 7. According to Ratri et al. (2020) used steam hydro distillation as a method to isolate cloves, producing eugenol levels of 80%, without any explanation of product recovery. Then, analysis of Clove Bud

Oil (CBO) with steam distillation or steam distillation using GC-MS by researchers (Tuslinah et al., 2023) obtained eugenol levels of 79.98% - 84.86%, without any explanation regarding product recovery.

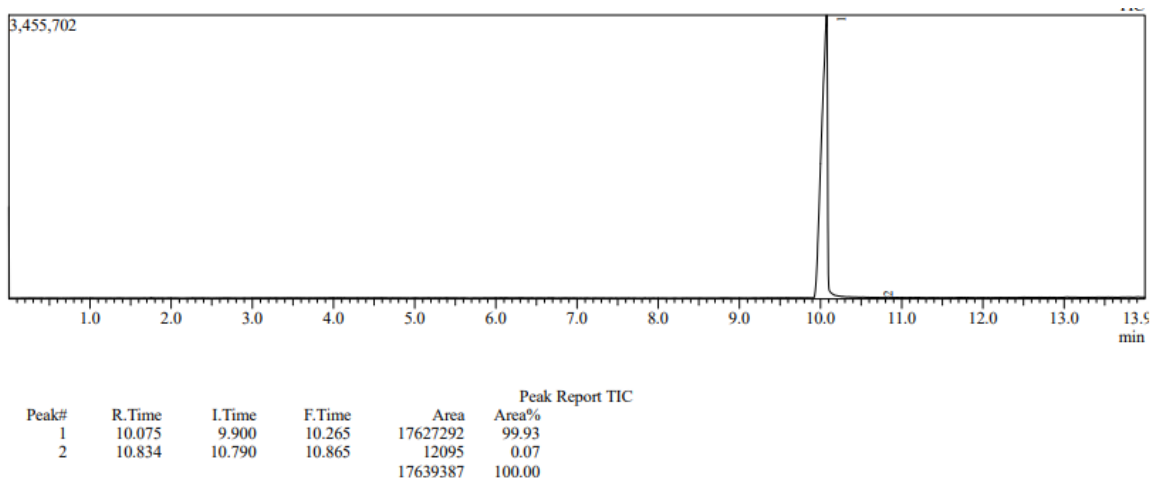


Figure 8. Chromatogram of 10 minute batch distillation

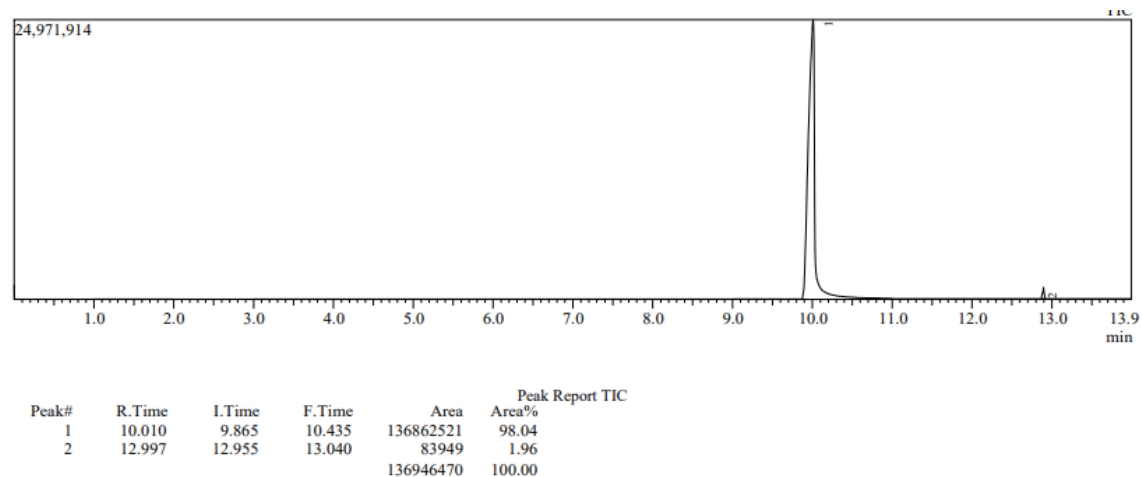


Figure 9. Chromatogram of 30 minute batch distillation

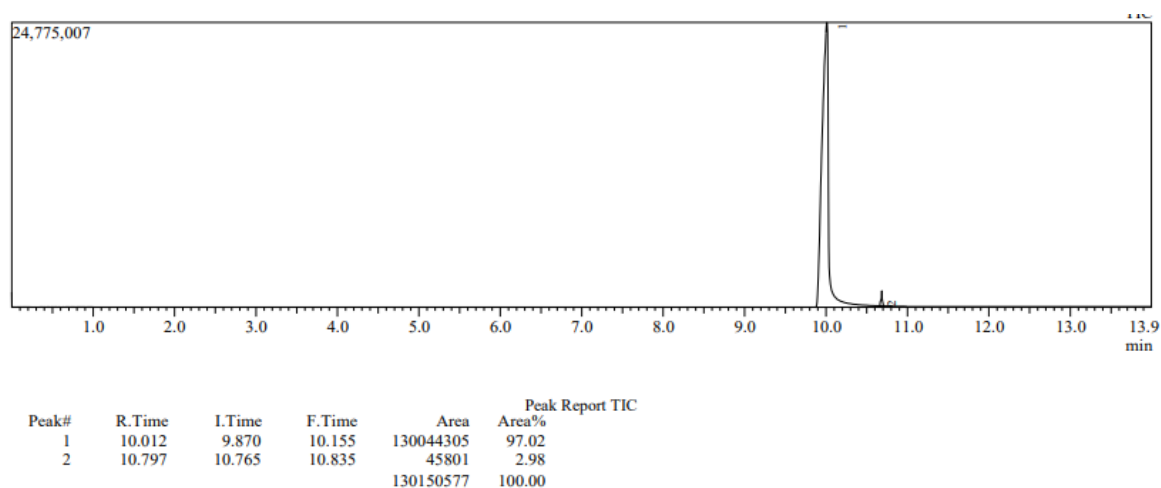


Figure 10. Chromatogram of 50 minute batch distillation

Meanwhile (Sugiharto, 2008) succeeded in simulating increasing eugenol levels in clove oil samples by distillation up to 99%.

In Figures 8, 9 and 10 it can be seen that the 10-minute distillate has the highest purity of the other 2 variations in distillation time. The first 10 minutes of distillation time produces the highest eugenol content, namely 99.93% with beta-Caryophyllene as a contaminant, then the third 10 minutes or 30 minutes produces a eugenol content of 98.04%, with a beta-Caryophyllene contaminant of 1.98%. After that, it continued with the fifth distillation time of 10 minutes, producing a eugenol content of 97.02%, with beta-Caryophyllene contamination of 2.98%. During the 50 minute distillation, the only components that were distilled were eugenol and beta-Caryophyllene.

From these three processes, results were obtained in the 50th minute with a recovery of 28.25% and a eugenol content of 97.02%. This was confirmed by the results of simulations carried out by Sugiharto (2008), obtaining a recovery of 46.56% with a eugenol content of 99%. This contamination occurs because after the eugenol is evaporated, the system will leave behind beta-Caryophyllene as a volatile compound so that it also evaporates and condenses in the distillate.

3.4. Techno-economic Analysis of Clove Oil Refining

Based on the economic analysis, eugenol production using batch distillation is more economical than the reactive extraction method, especially if the distillation is carried out under vacuum conditions, this is because the distillation operating temperature is lower so it is more energy efficient. Based on Table 6, the use of technology for refining clove oil into eugenol provides a very high potential revenue value. This is because the price of Pharmacopeia grade eugenol is around 10 times the price of unrefined clove oil. This technology can provide much greater market

potential for Indonesian SMEs to reach the world pharmaceutical industry market.

Table 6. Comparison of NPV and Net B/C Ratio values

Technology Applications	Net PV (Rp)	Net B/C Ratio
Conventional	12,084,975,000,000	15.54
Liquid Extraction	35,646,442,436,738	42.36
Batch Distillation	44,788,243,045,923	54.58

3.5. Investment Criteria Analysis

For the Investment Criteria Analysis, several assumptions are used in economic studies if the investment is made in Central Java Province. The assumptions in question are as follows:

1. The effective production period is 1 (one) year
2. The economic life of a farming project is 5 (five) years.
3. Total oil production based on the annual yield of clove flowers from the 2020-2022 national plantation statistics report is 7,673 tons.
4. Investments were made in several distillation equipment, saponification machines and batch distillation machines. The investment for implementing extraction-distillation technology is IDR 53,475,000.00 while for the batch distillation system IDR 465,000,000.00. Below are presented estimates of Variable Costs, Fixed Costs and Revenues from the technology implementation model for several purification systems.

Total Variable Costs consist of 3 components, namely: energy requirements, raw material costs, and supporting chemicals. Based on Table 7, it can be seen that the Total Variable Cost of extraction-distillation shows a higher value than the conventional method and batch distillation. This is due to the use of reagents for extraction in the form of NaOH and HCl for the liquid-liquid extraction process.

Table 7. Potential to increase the value of clove oil to Eugenol Pharmaceutical Grade (National plantation statistics 2020-2022).

Technology Applications	Product Yield (L/Year)	Product Price/Liter	Potential Revenue (Rp)	Percentage without application of technology (%)
Conventional	95,375,390	150,000	14,306,308,500,000	-
Liquid-Liquid Extraction	19,075,078	2,250,000	40,223,922,680,412	181.1
Batch Distillation	22,346,623	2,250,000	50,279,903,350,515	251.4

Table 8. Estimated fixed costs, variable costs and revenues from each system.

Technology Applications	Variable Costs (Rp)		Total Variable Costs (TVC) (Rp)	Total Fixed Costs (TFC) (Rp)	Total Revenue (TR) (Rp)
	Direct cost	Application Fee			
Conventional	920,760,000,000	0	920,760,000,000	0	14,306,308,5
L-L Extraction	920,760,000,000	28,658,941,08	949,418,941,080	53,475,000	00,000
B. Distillation	920,760,000,000	0	920,760,000,000	46,500,000	40,223,922,6
		0			80,412
					50,279,903,3
					50,515

In Table 7 it can also be seen that the total fixed costs for liquid-liquid extraction compared to batch distillation show a higher value due to investment in equipment in the form of a distillation tower and saponification tower. Even though both liquid-liquid extraction and batch distillation processes have higher variable and fixed costs (initial investment), the potential income (potential income) shows a much higher value, resulting in the difference in profits that will be obtained is also higher. A comparison of the NPV and Net B/C Ratio values can be presented in Table 8.

Net Present Value shows the net profit that will be obtained, based on Table 6, it can be seen that the liquid-liquid extraction method shows the Net Present Value (NPV) value at the 10% Discount Factor level of IDR 35,646,442,436,738. Meanwhile, the batch distillation method has a Net PV value of IDR 44,788,243,045,923. Judging from the level of business feasibility, it can be seen that the use of batch distillation method technology in clove farming is feasible, where the Net B/C Ratio obtained is 54.58.

4. Conclusion

In this research, clove oil was successfully purified into eugenol with levels reaching 97.02%. The batch distillation method provides higher product yields with a recovery percentage reaching 28.25% at the time of distillate collection in the 30th minute. This method has economic advantages because pharmaceutical grade eugenol has a high selling value and a wide market with technology that is very likely to be realized. This research can be implemented for MSME actors refining clove oil so that they have better quality products with better economic value. Further studies of eugenol purification by batch distillation can be carried out mainly using operating conditions under vacuum pressure. The use of a vacuum press has many advantages, including greater energy

savings because the boiling point of clove oil is lower and the purity of the product is better because it avoids the use of high temperatures which can damage the aroma of the pure eugenol produced.

Author contribution statement

Conceptualisation, A.S.,; Formal analysis, E.S.,; Investigation, T.W.,; Project administration, T.W.,; Supervision, A.S.,; Writing – original draft, K.H.,; Writing – review and editing, A.S.

Data availability statement

Available on request to the corresponding Author.

Declaration of Competing Interest

The author declares that there is no conflict of interest regarding the publication of this manuscript.

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