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QUALITY AND TECHNO-ECONOMIC ANALYSIS OF NUTMEG OIL DISTILLATION USING NUTMEG OIL DISTILLATION MODEL HH1 (1 BOILER WITH 2 KETTLE DISTILLERS)

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Abstract

This study aimed to analyze the quality and techno-economics of the distillation of nutmeg oil obtained from Nutmeg plant techno-economics parts using a steam distillation distiller. The research method analyzes the production of essential oils from nutmeg plant parts using a distillation apparatus model, with 1 boiler and 2 kettle distillers with a capacity of 200 kg for each kettles distiller. The procedure of this research starts from the preparation of raw materials (dried nutmeg leaves, young nutmeg seeds, old nutmeg seeds, and nutmeg mace), drying of raw materials, destruction of dried nutmeg with a crusher, distillation for 6-8 h, oil quality analysis according to the Indonesian National Standard (SNI) nutmeg oil, and oil packaging on the dark-colored conductor. Furthermore, a techno-economic analysis of the feasibility of this nutmeg oil distillation business was carried out for 20 years. The results showed that the nutmeg oil produced had met the quality of SNI nutmeg oil (*SNI 06-2388-2006*). The total needs funds needed is 10,504,336,633 IDR. consisting of a fixed cost of 15,176,633 IDR. and variable cost of 9,689,160,000 IDR. with a % Profit Estimated at 13%, results show that Break Even Point (BEP) was achieved after producing 4,233.14 kg nutmeg oil. Return on Investment (ROI) of 2.44 times and the return time of the investment issued (Pay Out Time) 0.394427841 or 1/39.44 = 2.54 years. Does it can be concluded that nutmeg oil distillation activities using steam distillation model 1 boiler with 2 kettle distillers is quite profitable and feasible to implement.

Keywords**:** Nutmeg oil, Steam distillation method, Techno-economic.

1. Introduction

Essential oils from nutmeg plants have significant economic value. Therefore, optimal development measures with strict quality control are required, referring to applicable quality standards, such as the Indonesian National Standard (SNI) 06-2388-2006 for nutmeg oil. Competition in the market is influenced by many factors, including the quality of the nutmeg oil produced. Pala Bogor is a type of nutmeg variety Nurpakuan Agribun has oval-shaped leaves, the upper leaves are green, the bottom of the leaves are light green, and the skinned fruit is greenish yellow, round, and oval. The shell of old seeds is shiny brownish-black, and fresh fruits are red [1].

The distillation technique that is widely used is steam distillation due to its effectiveness in terms of the speed, duration, and higher yield of essential oils. The extraction pressure of nutmeg oil through steam distillation must be below atmospheric pressure to maintain the purity of nutmeg oil because pressure above atmospheric can damage the quality of nutmeg oil [2]. The marketing prospects for nutmeg oil are still wide open, therefore a review of its techno-economic aspects is required. Based on our previous study [3, 4], this study aimed to explore the potential of all parts of the nutmeg plant to be produced into nutmeg oil. The uniqueness of this research is that all parts of the nutmeg plant, including fallen leaves, young nutmeg, old nutmeg, and nutmeg, can be used as raw materials for making nutmeg oil.

2. Literature Review

This distillation equipment consists of heating boilers, distillation boilers, condensers, oil separators, nutmeg seed crushers, ovens, digital scales, measuring cups, plastic conductors, and for quality testing of nutmeg essential oils using laboratory equipment. The distillation equipment used is steam distillation model HH1 (1 boiler with 2 kettle distillers) with a capacity of 200 kg/kettle. The advantage of this HH1 model distiller is that this tool can distill several essential commodities at once without worrying about being contaminated with other essential oils [5]. In addition, it is more efficient in the use of firewood and labor [6].

The main components in the distillation process, namely, boiler, kettle, a condenser (cooler), and a separator tool that separate the oil [5]. The research flow chart of nutmeg oil distillation using model 1 boiler distillation with 2 kettle distillers can be seen in Fig. 1.

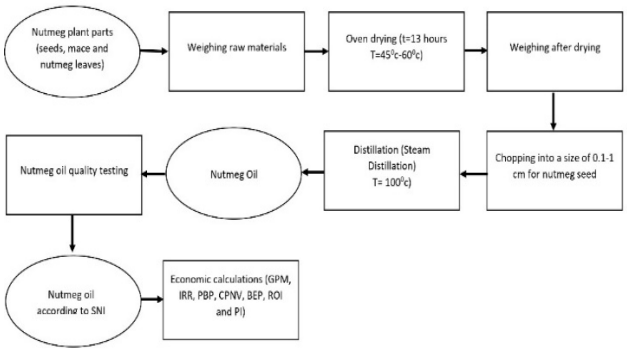

Fig. 1. Nutmeg oil distillation flow chart.

3. Method

Nutmeg oil produced from various nutmeg plants were then analyzed for quality following the Indonesian national standard (SNI) nutmeg oil (specific gravity, refractive index, residual evaporation, solubility in ethanol, color, aroma, and yield), SNI 06-2388-2006 [7]. Techno-economic analysis was analyzing the materials and equipment price for nutmeg oil distillation using average price of commercial products online. All data is calculated using simple mathematical analysis in Excel. Several economic evaluations (i.e.; gross profit margin (GPM), internal rate of return (IRR), pay back period (PBP), cumulative net present value (CNPV), break even point (BEP), break even capacity (BEC), return on investment (ROI) and provability index (PI) were analyzed to inform the production potential of nutmeg oil from nutmeg plant parts. Detailed information for the calculation is explained elsewhere [8, 9].

4. Results and Discussion

4.1 Measurement results of physicochemical properties of nutmeg oil, SNI 06-2388-2006

Physicochemical properties of nutmeg oil from the nutmeg plant, SNI 06-2388-2006 can be found in Table 1.

Table 1. Physicochemical properties of nutmeg oil from the nutmeg plant.

Physicochemical Properties	Parts of Nutmeg Plants (A)				SNI 06-2388-2006
	Nutmeg leaf(A1)	Young nutmeg seed(A2)	Old nutmeg seed(A3)	Nutmeg mace(A4)	
Spesific Gravity (g/mL)	0.888± 0,001a	0.890± 0,001a	0.888± 0,001a	0.890± 0,001a	0.880-0.910
Refractive Index	1.477± 0,0015[a]	1.475± 0,0000[b]	1.475± 0,0000[b]	1.477± 0,0005[a]	1.470-1,497
Residual Evaporation (%)	1.320± 0,030[a]	1.333± 0,015[a]	1.300± 0,026[a]	1.360± 0,020[a]	Maks. 2.0%
Solubility in Ethanol	clear	Clear	clear	clear	1 : 3 clear, so on clear
Color	4,801 ° 0.516[a]	4,833 ° 0.414[a]	4,856 ° 0.432[a]	4,815° 0.401[a]	Colorless, pale yellow
Aroma	8.200± 1,155[a]	8.200± 0,943[a]	8.200± 0,933[a]	8.100± 1,109[a]	Nutmeg oil specialties
Yield (%)	1.300± 0.360[c]	5.507± 0.467[b]	10.36± 0.52[ab]	15.167± 1,.58[a]	

It can be seen that all measured parameters have met the Indonesian national standard (SNI), includes:

(i) Specific Gravity

The specific gravity of nutmeg leaf oil obtained from the distillation process is higher than that of previous research [10], where the essential oil produced from nutmeg leaves has a specific gravity of 0.8543 g/mL. This aligns with other

research [11], where nutmeg leaf essential oil has a specific gravity of 0.8862 g/mL. This can be due to differences in the type of nutmeg crop, regional origin, and the distillation method used [12]. Specific gravity value and fraction weight of components in essential oils are often associated, where the value of the particular gravity of nutmeg essential oil is low, indicating a low weight fraction in essential oil with the value of the specific gravity at distillation hours to 6 the value of 0.902 g / mL [13]. The specific gravity of nutmeg mace from the research that has been done has an average of 0.890g / mL, where the results are relatively lower than the other research [14], the average yield of nutmeg mace specific gravity is 0.937 g/mL.

(ii) Refractive Index

Nutmeg essential oil produced in this study has a refractive index of 1.477. The results are based on the quality standards of nutmeg oil and align with previous research [11], where the refractive index of nutmeg leaf essential oil is 1.4779. The refractive index value produced from the essential oil of young and old nutmeg seeds is the same, which is 1.475. These compounds have longer carbon chains than other molecules and contain many hydroxyl groups [15]. The refractive index value of nutmeg mace essential oil is 1.477, determined through three replications. These findings are consistent with other research [16], where the refractive index value of nutmeg mace essential oil is 1.481. The higher the refractive index of the essential oil, the better its quality [13, 17].

(iii) Residual Evaporation

The percentage of residual evaporation in nutmeg essential oil samples fell within the range of 1,300% to 1,360% on average, further confirming the adherence to these quality standards. Volatile compounds should not contain vaporization residues, which consist of non-volatile substances and include fats, solid oils, and other molecular weight components [15]. The high or low percentage of residual evaporation in essential oils may be due to poor quality of raw materials or high distillation temperatures during the distillation process, which causes material polymerization, making it difficult or even impossible to evaporate [18].

(iv) Solubility in Ethanol

Essential oil of nutmeg plant nutmeg leaves, young nutmeg seeds, old nutmeg seeds, and mace on the solubility in ethanol showed a transparent appearance. When the essential oil dissolves completely in ethanol, more non-polar compounds are present in the oil. Conversely, if an essential oil contains more non-polar compounds, its solubility in ethanol, which is a polar substance, will be affected [19]. These findings are consistent with the opinion who proposed that essential oils containing high levels of polar compounds dissolve quickly in ethanol because they have similar properties [20].

(v) Color

Research studies reveal that the essential oils obtained from various parts of the nutmeg plant, such as leaves, young seeds, old seeds, and mace, mostly have a colorless appearance. Nutmeg oil is considered good quality if it has a colorless or pale yellow appearance. The reason the essential oil changes color to brownish

yellow could be due to the presence of β-caryophyllene, which is a type of terpene hydrocarbon found in essential oils [21]. Exposure of these compounds to air and light can cause oxidation, affecting the color of essential oils.

(vi) Aroma

Various researchers have also shown that nutmeg leaf essential oil, nutmeg seed oil, and nutmeg mace oil all have a strong characteristic of nutmeg aroma [22]. The characteristic aroma of nutmeg essential oil is the result of a combination of various chemical components, including monoterpene hydrocarbons, myristicin, monoterpenoid alcohols monoterpenoid, and other components such as eugenol and methyl eugenol [23]. The main contents of nutmeg essential oil are β-pinene 18.74%, myristicin 14.26%, α-terpinene 13.71% [24].

(vii) Yield

A material's yield is the percentage of the number of parts used divided by the total weight of a material [25]. Nutmeg oil yield can be calculated by comparing the weight of nutmeg oil with the weight of the nutmeg plant used [26]. This study revealed that the yield of nutmeg leaf essential oil was 1.3%, which is consistent with the previous research statement [27] that the yield of essential oil from nutmeg leaves usually does not exceed 1.7%. Smaller nutmeg particles yield a higher yield, a yield of 39.61% obtained from seeds with a mesh size of 60 [28].

4.2 Techno-economic calculations

The Techno-economic calculations was shown in Table 2.

Table 2. Results of techno-economic calculations

Component	Parameter	Cost (IDR)
Fixed Cost	Capital related cost	751,131,249.75
	Depreciation	64,045,383.75
	Total fixed cost	815,176,633.50
Variable Cost	Raw material	8,769,000,000.00
	Operating labor (OL)	48,000,000.00
	Labor related cost	32,160,000.00
	Sales related cost	840,000,000.00
	Total variable cost	9,689,160,000.00
% Profit Estimated	Sales	12,000,000,000.00
	Manufacturing cost	10,440,291,249.75
	Investment	686,478,712.50
	Profit	0.13
	Profit to sales	2.27
BEP	Unit	12000
	Fixed cost	815,176,633.50
	Variable cost	9,689,160,000.00
	Sales	12,000,000,000.00
	BEP	4233.144485
	Percent profit on sales	0.129975729
	Return on investment	2.435317987
	Pay out time	0.394427841

From Table 2, the amount of funds needed is 10,504,336,633 IDR. which consists of a Fixed Cost of 815,176,633 IDR. and Variable Cost of 9,689,160,000 IDR. with an estimated % profit of 2.27% with a percentage gain of 13.0%, the results of the business analysis showed that the BEP was achieved after producing 4233.14 kg of nutmeg oil. IRR of 2.44 times and ROI 0.394427841 or 1/0,394 = 2,54 year.

Curve CNPV/TIC

CNPV is a value that predicts the condition of a production project in the form of a production function in years [29]. Curve CNPV/TIC can be seen in Fig. 1.

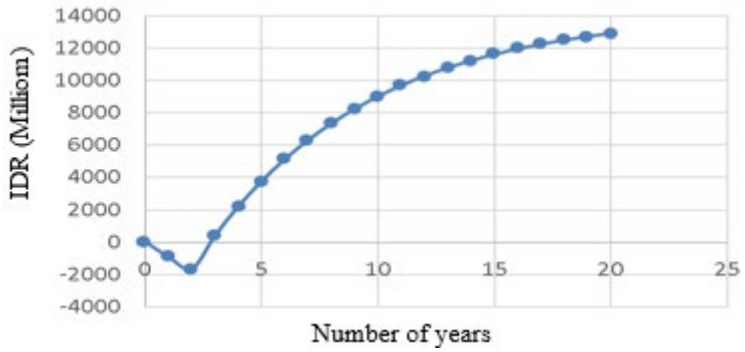

Fig. 2. Yield curve CNPV/TIC.

From the curve in Figure 2, the profit until the second year is still negative, and only in the third year (2.54 years) began to have positive gains. With a profit percentage of 13.0%, the trend continues to increase until the 20th year.

5. Conclusion

Nutmeg oil produced from nutmeg plant parts using distillation method 1 boiler with 2 distiller boilers has produced nutmeg oil that meets SNI 06-2388-2006. The total funding needed is 10,504,336,633 IDR. consisting of a fixed cost of 815,176,633 IDR. and variable cost of 9,689,160,000 IDR. with an estimated % profit of 13.0%. The results of the business analysis showed that the BEP was achieved after producing 4233.14 kg of nutmeg oil. IRR of 2.44 times and ROI 0.394427841 or 1/0,394 = 2,54 year. So it can be concluded that nutmeg oil Distillation activities using steam distillation model 1 boiler with 2 distiller boilers is quite profitable and feasible to implement.

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References

1. Pinontoan, M. (2022). Livelihood education of candied nutmeg business for pkk mothers in Klabat village, Dimembe district, North Minahasa

regency. *Dikmas: Journal Pendidikan Masyarakat dan Pengabdian*, 2(1), 159-170.

2. Asfiyah, S. (2020). Deanstark modification is an effort to increase the efficiency of the steam distillation process of nutmeg seed oil in organic chemistry practicums. *Indonesian Journal of Laboratory*, 2(1), 10-15.
3. Hudaefi, D.; Roestamy, M.; and Adiwijaya, A.J.S. (2021). Legal certainty of halal certification for medicines linked to halal product guarantees. *Journal Ilmiah Living Law*, 13(2), 122-131.
4. Haris, H.; Sudarsah, A.S.; Puti, A.M.; Ningsih, S.R.; Septiani, B.; Rahmah, W.A.; Akim, R.; and Rachmasari, A. (2024). Bojongmurni village, achieving hope through the fragrance of essential oils. *Devosi*, 5(1), 24-35.
5. Mahlinda, M.; Arifiansyah, V.; and Supardan, M.D. (2019). Modification of steam distiller to increase patchouli oil yield and quality (pogostemon cablin benth). *Jurnal Rekayasa Kimia & Lingkungan*, 14(1), 28-35.
6. Polii, F.F. (2016). Research of nutmeg oil distillation "Siauw" pressurized steam method and quality characteristics of nutmeg oil. *Journal of Industrial Technology Research,* 8(1), 23-34.
7. Maryati, M. (2023). Isolation, characterization, and identification of chemical compounds from Papua nutmeg essential oil (myristica argentea warb). *Journal Teknologi Pertanian Gorontalo*, 65-73.
8. Fiandini; and Nandiyanto, A.B.D. (2024). How to calculate economic evaluation in industrial chemical plant design: a case study of gold mining using amalgamation method. *ASEAN Journal for Science and Engineering in Materials*, 3(2), 75-104.
9. Nandiyanto, A.B.D. (2018). Cost analysis and economic evaluation for the fabrication of activated carbon and silica particles from rice straw waste. *Journal of Engineering Science and Technology*, 13(6), 1523-1539.
10. Puspa, O.E.; Syahbanu, I.; and ibowo, M.A. (2017). Phytochemical and toxicity test of nutmeg leaf essential oil (myristica fragans houtt) from Lemukutan Islands. *Equatorial Journal of Chemistry,* 6(2), 1-6.
11. Rastuti, U.; Kartika, D.; and Ningsih, R. (2013). Antibacterial activity of nutmeg leaf essential oil from Banyumas against staphylococcus aureus and escherichia coli and the identification of its constituent compounds. *Scientific Journal of Chemistry,* 8 (2), 197-203.
12. Tabaika, R.; Taher, T.; and Anfin, I. (2023). Analysis of yield and chemical components of nutmeg essential oil from Ternate and Tidore cities. *Journal Bionatural*, 10(1), 89-97.
13. Rangkuti, F.R.; Agustina, R.; Mustaqimah; and Mustafril (2018). The effect of long distillation on the quality yield of essential oil on nutmeg (*Myristica fragans Houtt*). *Rona Teknik Pertanian,* 11(1), 51-58.
14. Ismiyarto; Ngadiwiyana; and Mustika, R. (2009). Isolation, identification of essential oil of nutmeg mace (myristica fragrans) and activity test as larvicide. *Journal of Science and applications*, 12(1), 23-30.
15. A'Mun, A. (2013). Oil characteristics and isolation myristicin Papua nutmeg seeds (myristica argentea). *Littri Journal*, 19 (2), 72-77.

16. Saputro, M.A.; Andarwulan, N.; and Faridah, D.N. (2016). Physical characterization and properties of essential oils from mace and nutmeg from West Sumatra (myristica fragrans houtt) at various harvest ages. *Journal Farmakognosi dan Fitokimia*, 5(6), 371-376.
17. Ospina, J.D.; Tovar, C.D.G.; Flores, J.C.M.; and Orozco, M.S.S. (2016). Relationship between refractive index and thymol concentration in essential oil of lippia origanoides Kunth. *Journal pertanian dan ilmu hewan Chili* , 32 (2), 127-133.
18. Suprihatin; Ketaren, S.; Ngudiwwaluyo, S.; and Friyadi, A. (2007). Isolation of myristicin from nutmeg oil (myristica fragrans) by steam distillation method. *Journal Of Agricultural Industrial Engineering*, 17(1), 23-28.
19. Loppies, J.E.; Wahyudi, R.; Fortune, E.S.; and Winaldi, A. 2021. The quality of clove leaf essential oil resulting from various distillation times. *Journal Of The Plantation Industry*, 16(2), 89-96.
20. Noble, S.S.; Ayu, D.F.; and Zalfiatri, Y. (2022). Long distillation on the physico-chemical properties of kecombrang flower essential oil (nicolaia speciosa horan). *SAGU*, 19(1), 40-47.
21. Shahidi, F.; and Hossain, A. (2018). Bioactives in spices, and spice oleoresins: Phytochemicals and their beneficial effects in food preservation and health promotion. *Journal of Food Bioactives*, 3, 8-75.
22. Ibrahim, M.A; Cantrell, C. L; Jeliazkova, E.A; Astatkie, T.; and Zheljazkov, V.D. (2020). Utilization of nutmeg (myristica fragrans houtt.) seed hydrodistillation time to produce essential oil fractions with varied compositions and pharmacological effects. *Molecules*, 25(3), 565.
23. Lanari, D.; Zadra, C.; Negro, F.; Njem, R.; and Marcotullio, M.C. (2022). Influence of choline chloride-based NADES on the composition of *Myristica fragrans Houtt*. essential oil. *Heliyon*, 8(5), 1-8.
24. Hasmita, I.; Mistar, E.M.; and Redha, F. (2019). Effect of temperature on the isolation of myristicin from nutmeg oil using rotary evaporator. *Biopropal Industri*, 10(1), 41-48.
25. Miao, X.Y.; Zhan, H.L; Zhao, K.; Li, Y.Z.; Sun, Q.; and Bao, R.M. (2016). Characterization of oil yield based on anisotropy in optical parameters of oil shale. *Energy and Fuels*, 30 (12), 10365-10370.
26. Al-Rawi, S.S.; Ibrahim, A.H.; Majid, A.S.A.; Majid, A.M.A.; and Ab-Kadir, M.O. (2013). Comparison of yields and quality of butter obtained by extractin of nutmeg rind by soxhlet and supercritical carbon dioxide (SC-CO2). *Journal of food engineering*, 119(3), 595-601.
27. Damayanti, R.; Fahmi, C.N.; and Efendi, R. (2015). Physical properties of nutmeg leaf essential oil (myristica fragrans houtt) South Aceh. *Biolink*, 1 (2), 76-80.
28. Saranaung, A.; Sangi, M.S.; and Katja, D.G. (2018). Effect of material size on yield and quality of nutmeg seed oil (myristica fragrans houtt) by soxhletasi method. *Journal of Mathematics and Natural Sciences Online*, 7 (1), 39-43.
29. Filip, S.; Vidović, S.; Adamović, D.; and Zeković, Z. (2014). Fractionation of non-polar compounds of basil (ocimum basilicum l.) by supercritical fluid extraction (sfe). *The Journal of Supercritical Fluids*, 86, 85-90.