

Extraction of Java Lemongrass (*Cymbopogon citratus*) Using Microwave-Assisted Hydro Distillation in Pilot Scale: Parametric Study and Modelling

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Abstract. This study aims to extract oil from Java lemongrass (*Cymbopogon citratus*) using the pilot-scale Microwave-Assisted Hydro distillation method (distiller volume 10,000 mL). The operating variables of this research are the extraction time, the microwave power, and the ratio of the mass of the material to the solvent (F/S ratio). The results showed an increase in the yield of lemongrass oil along with the increase in extraction time using the Microwave-Assisted Hydro distillation (MAHD) method, and this trend will continue to occur as microwave heating is selective and volumetric. Thus, there is a tendency to increase yield with increasing power. In general, it follows that the higher the power, the higher the yield. The energy received by the material to be converted into heat has caused the essential oil yield to be more abundant, with the highest yield being obtained at 800 W. The increase in the material to solvent ratio increased the oil yield up to a certain point. However, the yield started declining after the F/S ratio of 0.08 was reached. The first order kinetic model well represents the extraction process at a pilot scale. The pilot scale's oil yield is slightly lower than the laboratory scale MAHD. Compositional analysis of the result suggests that the main components of Java lemongrass oil are Geranial (30.06%), Z-Citral (25.88%), Eugenol (12.88%), and Beta-Myrcene (12.84%).

Keywords: Java Lemongrass, *Cymbopogon citratus*, Extraction, Microwave-Assisted Hydro Distillation, Pilot Scale

INTRODUCTION

Indonesia is known to have diverse natural resources, most of which are yet to be optimally utilized. Some resources are

essential oils-producing plants, whose utilization and development could have been improved over time. There has been an increased trend in using essential oils for various purposes, such as food flavors,

cosmetic industries, pharmaceuticals, and fragrances. Indonesia is one of the mega-biodiversity centers that has produced 40 out of 80 types of essential oils traded on the world market (Abdelhadi et al., 2015; Ministry of Trade of the Republic of Indonesia, 2011). Most of the essential oils are produced from the extraction of aromatic plants. One of the aromatic plants producing essential oils in Indonesia is *Cymbopogon citratus*, commonly known as lemongrass. Lemongrass essential oil (*Cymbopogon citratus*) is widely used for cooking spices and is also commonly used as a mosquito repellent. People call it lemongrass oil because of its distinctive smell and lemon-like odor.

Lemongrass oil has been reported to have antimicrobial properties (Jafari et al., 2012; Mukarram et al., 2021), antifungal activities (Mukarram et al., 2021; Tzortzakis and Economakis, 2007), anti-angiogenic agent (Piaru et al., 2012), and antioxidant properties (Mukarram et al., 2021). The *Cymbopogon citratus* oil was also tested for anti-cancer activity (Mukarram et al., 2021; Piaru et al., 2012; Trang et al., 2020). The active components of lemongrass can be grouped into 3, citral-a (geraniol), citral-b (neral), and myrcene. Citral-a and citral-b have anti-bacterial activities in essential oils (M. et al., 2014; Mukarram et al., 2021). Furthermore, the components of citral-a and citral-b individually act on gram-positive and gram-negative bacteria. Meanwhile, citral-c does not show activity as an anti-bacterial. However, the anti-bacterial activity increases when myrcene meets one or both of the components of citral-a (geraniol) and citral-b (neral) (Jafari et al., 2012; Onawunmi et al., 1984).

Essential oil extraction of lemongrass is typically carried out using conventional methods such as hydrodistillation (HD) and

steam distillation. Essential oils produced using these methods typically result in low yields, a relatively long extraction time, large solvent requirements, high energy requirements, and thus, making the process highly capital intensive (Clain et al., 2018). Therefore, a novel environmentally friendly technology is needed for the essential oil extraction process that can minimize the consumption of solvents, energy, and time. Several methods have been developed in the essential oil extraction process. One of them is the use of microwaves as a heating medium.

The microwave extraction method has been applied for microwave-assisted hydrodistillation (MAHD), which combines the HD method with microwave energy (Heri Septya Kusuma and Mahfud, 2017; Stashenko et al., 2004). Several studies have been conducted, including one comparing the extraction of essential oils from *Apium graveolens* L. using HD and MAHD methods. This study suggests that extracting essential oils from *Apium graveolens* L. using MAHD required less solvent, produced a higher yield, and required a shorter extraction time than conventional methods (Moradalizadeh et al., 2013). Other related studies maintain that microwave extraction is an alternative that can be developed over conventional methods. This is due to the high level of product purity, minimal use of energy and solvents, and short extraction time (Chemat et al., 2019; Ferhat et al., 2006; Heri Septya Kusuma and Mahfud, 2017).

Some authors have extracted lemongrass essential oil using the MAHD method (Bhuana et al., 2021). However, the extraction process was conducted on a laboratory scale using a 1L flask, leaving room for improving the yield of the essential oil obtained. Scaling up the laboratory-sized extraction into a pilot

scale is considered technically favorable to make the oil extraction process more efficient. Extraction on a large scale requires modification of the equipment so that it can accommodate a larger quantity of materials and other related parameters.

Several studies have been conducted to produce more essential oils using different materials. This is specifically done by increasing the capacity of the distiller in an HD system using a microwave (Filly et al., 2014; Masum et al., 2019). Consequently, this study's essential oil extraction will be carried out in a larger distiller. By scaling up the apparatus, the optimum operating conditions can be determined, will give the optimum quality of the lemongrass oil as well. By considering all the above factors, this study aims to determine the effect of extraction time, microwave power, and feed to liquid volume ratio on the yield of lemongrass oil using the pilot-scale MAHD. The data obtained will then be used to explain the kinetic model of the extraction process accordingly.

Some researchers have previously attempted to study the kinetics of essential oil extraction from various plants using different extraction methods. A study investigated the kinetics of obtaining essential oil from lemongrass using the steam distillation method (Amenaghawon et al., 2014). Furthermore, there is also research on the kinetics of essential oil extraction from sandalwood using microwave hydro-distillation (Kusuma and Mahfud, 2018) while another study investigated the kinetics of citronella oil the MAHD method (Ma'sum et al., 2021).

However, a kinetics study on java lemongrass oil extraction on a pilot scale has yet to be conducted. In studying the kinetics of the lemongrass oil extraction using MAHD,

we compared the suitability of two simple kinetic models and figured out which model would better represent the results. Thus, the efficiency of each model was checked by comparing the experimental data with calculated parameters such as rate constant, coefficient of determination, equilibrium extraction capacity, and initial extraction rate of lemongrass oil.

MATERIALS AND METHODS

Materials

The lemongrass leaves were obtained from Mojokerto, East Java. The leaves and outer stem layer of java lemongrass were used in this research. The materials had been dried indoors for 2 days.

Experimental Apparatus

Figure 1 shows an apparatus scheme of pilot-scale microwave-assisted hydro distillation, with the main equipment components of distillation, microwave, condenser, and Clevenger. The Electrolux EMM2308X microwave oven with the following specifications: Voltage 220 V, Power 1000 W, Magnetron frequency 2450 MHz (2.45 GHz), Microwave dimensions: Length = 48.5 cm, Width = 37.0 cm, and Height = 57 cm. The distiller was made of Pyrex glass with a volume of 9000 ml. It was equipped with a Clevenger condenser reflux, condensate reservoir, and a separator funnel to separate oil and water.

Experimental Procedure

The java lemongrass as a raw material was dried in atmospheric conditions, then cut into 2 parts, i.e., the leaves and the stems. The experiment was carried out at atmospheric pressure. The following variables were applied in this study: The mass of the

lemongrass sample was 300, 500, and 700 g; the volume of the solvent was 2, 4, and 6 L; the extraction time was 30, 60, 90, 120, 150, 180, 210, 240 min, and the microwave power was 400, 600, 800 W. The % yield was calculated from the resulting oil, and the composition was analyzed using Gas Chromatography-Mass Spectrometry (GC-MS).

$$\text{Yield} = \frac{\text{mass of extracted citronella oil}}{\text{mass of dry citronella leaves}} \times 100\% \quad (1)$$

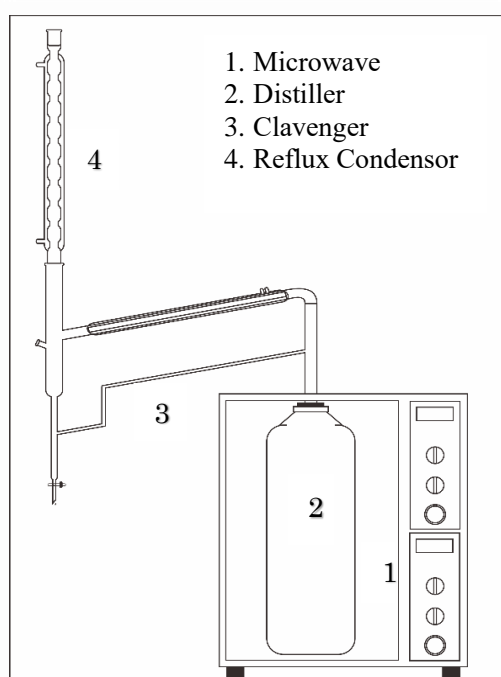


Fig. 1: Apparatus scheme of pilot-scale microwave-assisted hydro distillation

Extraction Kinetic Modelling

The kinetic model of MAHD was selected based on the mass transfer rate becoming first order and second order models. In contrast, the model could represent the rate parameters during extraction. The first order kinetic extraction equation was adopted from previous works (Kusuma and Mahfud, 2018; Ma'sum et al., 2021; Variyana and Mahfud, 2020) and shown as Equation (2) and

Equation (3). The constant k_1 is the extraction rate constant for the first order model, t is the extraction process time, C_t is the yield of extraction (%w/w) at time t , and C_s is the stationary extraction yield. Therefore, the boundary conditions are $C_t = 0$ at $t = 0$ and $C_t = C_s$ at $t = \infty$ equation (3) is obtained from the ODE solution of Equation (2).

The second-order mechanism model is based on the mass transfer rates and other effects related to the microwave heating mechanism, such as breaking the matrix material of a plant that contains essential oil, which could be expressed as a second-order model (Ho et al., 2005; Jokić et al., 2010; H. S. Kusuma and Mahfud, 2017; Ma'sum et al., 2021; Variyana and Mahfud, 2020). The extraction rate equation is described as Equations (3) and (4). Moreover, k_2 is the extraction rate constant for the second order model. C_s is the maximum extraction yield. Furthermore, the boundary conditions are $C_t = 0$ at $t = 0$ and $C_t = C_s$ at $t = \infty$. The integration of Equation (4) results in Equation (5). The model parameters k_1 and k_2 are obtained by fitting the parameters. The difference between the experimental data and that calculated from the model through Equation (2) or Equation (4) is minimized by utilizing the root-mean-square deviation (RMSD) using the solver application found in Microsoft Excel version 2010. The coefficient determination (R^2 adj) is also evaluated. The low RMSD value and the R^2 adj values, which is close to 1, indicate a good fitting between the experimental data and the model (Jokić et al., 2010; Ma'sum et al., 2021; Variyana and Mahfud, 2020). The RMSD and R^2 values are calculated by Equations (6) and Equations (7).

$$\frac{dC_t}{dt} = k_1(C_s - C_t) \quad (2)$$

$$C_t = C_s(1 - e^{-k_1 t}) \quad (3)$$

$$\frac{dC_t}{dt} = k_2(C_s - C_t)^2 \quad (4)$$

$$C_t = \frac{C_s^2 k_2 t}{t + C_s k_2 t} \quad (5)$$

$$RMSD = \sqrt{\frac{1}{n} \sum_{i=1}^n (C_{calc,i} - C_{exp,i})^2} \quad (6)$$

$$R^2 = 1 - \frac{(n-1) \sum_{i=1}^n (C_{calc,i} - C_{exp,i})^2}{(n-1-m) \sum_{i=1}^n (\bar{c}_{exp} - C_{exp,i})^2} \quad (7)$$

C_{exp} is the experimental yield of oil extracted, models calculated C_{calc} and C_{exp} is the experimental data average. Then n and m are successively the number of experimental data and the number of independent variables.

RESULTS AND DISCUSSION

The Extraction Process of Essential Oil from Lemongrass Leaves

This study of essential oil extraction from lemongrass leaves was conducted using the pilot-scale MAHD. In this method, the reflux process of the water contained in the material was carried out in a distiller flask called cohabitation using a Clevenger. The need for recycling the water arises since the amount of water in the distiller keeps decreasing owing to the evaporation of water with oil. This is also done to avoid the loss of oil that is still left over in the water distillate, allowing the maximum yield of the oil to be extracted as well as ensuring the continuous process (Heri Septya Kusuma and Mahfud, 2017; Kusuma and Mahfud, 2018).

The raw material in the form of fresh java lemongrass plants was cut into ± 4 cm in size. Then it was dried by storing them at room temperature and letting them completely dry for 4-5 days. Drying without direct sunrays was done to prevent the oil in the lemongrass

leaves from evaporating. In addition, this drying process aims to reduce the water content of the java lemongrass so that the raw materials have uniform water content, which helps shorten the extraction time (Mohamed Hanaa et al., 2012). Oil glands, vessels, oil pockets, or glandular hairs enclose the essential oil in the material. The extracted oil related to water vapor passes through the plant tissue and pushes it to the surface. Small material sizes could be improved rapidly to facilitate the release of essential oils after the material is penetrated by steam (Sastrohamidjojo, 2004).

This study uses the pilot-scale MAHD using a solvent as the essential oil extraction method. Samples of dried leaves were put in the distiller as much as 300, 500, and 700 g before water was added to 6000 ml. Subsequently, heating was conducted using a microwave power of 400, 600, and 800 W. The cooling process used a Liebig condenser with chilly water flowing. This extraction process was conducted for 240 min, starting from where the condensate first dripped into the separator funnel at the end of the Liebig condenser.

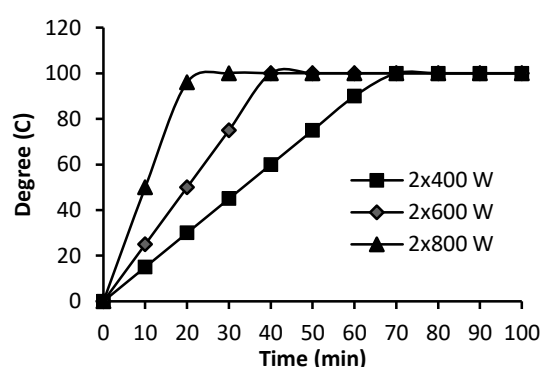


Fig. 2: Temperature profile during extraction for various microwave powers

The desired key components of the extraction of lemongrass are citral, lemongrass, methylheptane, n-decyl

aldehyde, linalool, and geraniol (M. et al., 2014; Mohamed Hanaa et al., 2012; Onawunmi et al., 1984; Piaru et al., 2012). To achieve these desired components, appropriate operating conditions are needed to produce high yields with high quality lemongrass essential oil under SNI. The citral content in lemongrass oil determines the quality and, consequently, the price of the oil. Figure 1 shows the temperature profile during extraction for three different microwave powers.

Increasing the microwave power accelerates the heating process of the extracted material. Higher heating temperatures on the extracted material will cause the oil glands in the lemongrass to overheat and the cell walls to lyse. Then, the oil will diffuse with the water solvent and the steam from the solvent. The extracted oil will pass through the Liebig condenser, where the condensation process takes place and flow to the separator funnel where the oil and the water solvent are separated (Heri Septya Kusuma and Mahfud, 2017; Masum et al., 2019; Variyana et al., 2019). Increased microwave power, however, only sometimes guarantees higher yields because each material has distinctive characteristics. Moreover, the best operating conditions are needed to produce high yields and superior-quality lemongrass oil.

The Effect of Extraction Time on the Yield of Lemongrass Oil

The increase in the yield of lemongrass oil due to the increase in extraction time using the MAHD method is common in the extraction process. The longer the time, the higher the amount of oil obtained. The oil release mechanism differs from conventional methods, especially for microwave-assisted methods, such as MAHD. In microwave

heating, microwave radiation can directly penetrate the walls of the distiller and be absorbed directly by the oil in the material matrix and solvent.

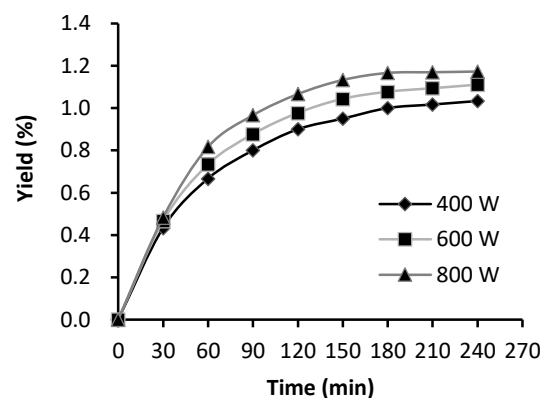


Fig. 3: The yield of oil function of time for various microwave powers (F/S=0.1)

Thus, the heating process can be evenly distributed and take place more quickly, so the increase in lemongrass oil yield is obtained faster when the extraction is conducted by MAHD method compared to the conventional extraction method, whose heating mechanism is based upon conduction and convection. The relationship between the effect of extraction time on the percent of yield is presented in Figure 3.

In the lemongrass oil extraction process using the MAHD method, the extraction time is crucial since the amount of oil obtained increases with the length of the extraction process, as shown in Figure 2. In general, the mechanism of this extraction process consists of two phases, i.e., the dissolving phase and the equilibrium phase (Raynie 2000, Kusuma et al., 2017). There is a transition phase between the dissolving phase and the equilibrium phase. In the dissolving phase, the oil is removed from the outer surface of the particles at a constant rate through diffusion and convection mechanisms. In this phase, the solute will overcome the interactions that bind it in the plant matrix

and diffuse into the extracting solvent. In the equilibrium phase, the extraction rate is relatively low because the diffusion rate decreases with increasing extraction time where the solute concentration is high in the liquid. Phases, have a transition phase, in which the mass transfer occurs by convection and diffusion. The yields of lemongrass oil as a function of time for various microwave power are shown in Figure 3. As can be seen from Figure 3, reaching the equilibrium phase takes about 200 min, and the diffusion phase starts showing after 220 min of extraction. The equilibrium phase also called the limiting phase, has very little oil that can be extracted, and is shown in the graph as a constant yield flat curve. The amount of time required to reach the equilibrium phase depends on material's characteristics and drying time. Even with the same drying time, the moisture content of each part of the material could be different because non-uniform drying rate of each material. Based on these results, the yield obtained from the extraction of lemongrass leaves for the ratio of material to solvent 0.1 is 1.17%. Several previous studies suggest that the laboratory scale MAHD method gives slightly higher yields, i.e., 1.2 - 1.46% (Ranitha et al., 2014). It is important to note that less material was used in the previous studies compared to this study, i.e., 40-60 g versus 300-700 g. As a concluding remark, with only an insignificant drop in the oil yield when being scaled up from the laboratory testing, the pilot scale MAHD method shows a promising future to be widely utilized on a larger scale.

The Effect of Microwave Power on Lemongrass Oil Yield

Figure 4 shows the effect of microwave power on the yield of oil produced from

lemongrass leaves. As can be seen from the figure, the yield increases with microwave power. This is because the energy received by the material will be converted into heat, facilitating the release of oil, so the higher the microwave power, the higher the yield of essential oils obtained. One important thing to note is that high microwave power does not guarantee high oil yields because each material has different characteristics.

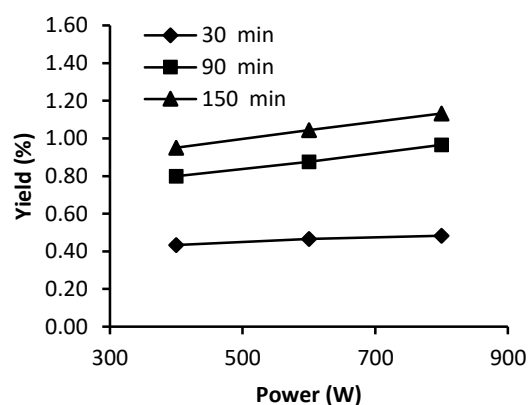


Fig. 4: Yield of oil as a function of microwave power (F/S=0.1)

The Effect of Feed to Solvent Ratio (F/S ratio) on the Yield of Lemongrass Oil

Figure 4 shows the yield of lemongrass oil produced as a function of feed to solvent (F/S) ratio. As can be seen from the figure, the yield of oil increases at the lowest F/S ratio range, i.e., from 0.06 to 0.08. However, the yield starts decreasing in the next range of F/S ratio, i.e., from 0.08 to 0.16. This can be explained as the material in the distiller being too dense, resulting in the distribution of steam being uneven, and it is difficult for the steam to penetrate the bed of materials to carry the volatile oil molecules that are diffused out of the material. Material density is closely related to the size of the space between materials. Material density that is too high and uneven can result in the

formation of uneven vapor paths or "channeling" which can reduce the yield and quality of essential oils (Guenther, 1990; Ma'sum et al., 2019). In addition, the higher the density of the material, the slower the rate of distillation or evaporation of the essential oil. This is due to the obstruction of the vapor chamber to be able to evaporate into the condenser, which in turn causes a decrease in the yield of basil oil obtained and reduces the distillation efficiency. In addition, if the solvent volume is small, the solvent will quickly evaporate, and the material will be burned by strong microwave radiation (Gao et al., 2006; Masum et al., 2019). Therefore, it is necessary to have an appropriate ratio of the mass of the material to the volume of the solvent to produce an optimal yield. Figure 5 shows that the highest yield was achieved at a 0.08 g/ml ratio.

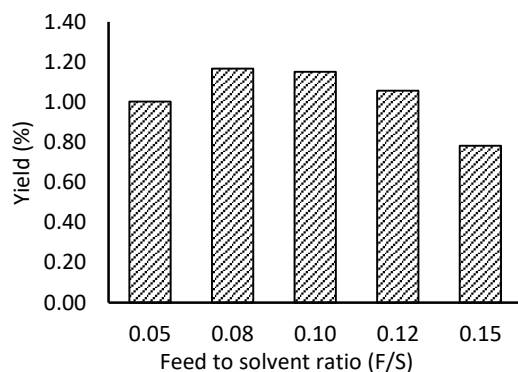


Fig. 5: The yield of oil as a function of Feed to solvent ratio (800W, 240 min)

The Extraction Kinetic of Microwave-Assisted Hydro Distillation (MAHD)

In general, the yield of lemongrass oil increases rapidly with the extraction time at the beginning before remaining relatively constant at the later extraction time. There are two mechanisms for releasing oil from the plant matrix (leaves). The first mechanism is like the conventional distillation process, in

which water as a solvent absorbs electromagnetic waves so that it becomes hot, then heats the leaves, which causes the oil to come out by diffusion and be carried away by the water. The second mechanism is that the oil in the leaf matrix absorbs electromagnetic waves so that the oil becomes hot and expands dramatically, followed by the tissue rupture so that the oil will come out in the direction of heat transfer from the inside to the outside. In this case, the microwave power interacts with water molecules present in the vascular matrix system as well as with water molecules as solvent. This phenomenon is generally found in the literature for the MAHD method (Kusuma and Mahfud, 2018; Ma'sum et al., 2021; Moradi et al., 2018; Nitthiyah et al., 2017).

The authors have developed several extraction models for the microwave-assisted extraction process, including a first-order mass transfer model, a modified second-order mass transfer model, an empirical kinetic model, a power law model, a hyperbolic model, the Weibull exponential equation and the Elovich logarithm equation. (Haqqyana et al., 2020). However, based on the data on the yield trend as a function of time in Figure 2 and the complexity of the microwave-assisted extraction phenomenon, most authors use a simple model called a first-order mass transfer model (Covelo et al., 2004; Koul et al., 2004; Kusuma and Mahfud, 2018; Milojević et al., 2013) and modified second-order mass transfer model (H. S. Kusuma and Mahfud, 2017; Ma'sum et al., 2021; Variyana and Mahfud, 2020). This study utilized the first order and second-order models based on Equation (2) and Equation (4). To determine the parameters for both the first order and the second-order model from the yield data of lemongrass oil

extraction using microwave-assisted hydro distillation, it is possible to use the parameter fitting method in the real (time) domain. This is done by comparing the experimental data with the results of calculations using Equation 2 and Equation 4, then the R^2 and RMSD values of each kinetic model used are calculated accordingly. The kinetic model represents the experimental results well if it has an R^2 value close to 1.0 and a small RMSD value. The comparison between the kinetic model and the experimental results using MAHD is shown in Figures 6, 7, and 8 for 400 W, 600 W, and 800 W microwave power, respectively.

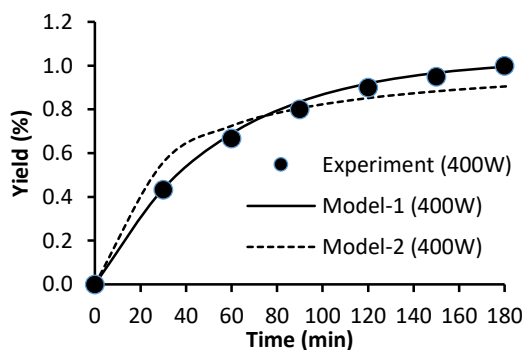


Fig. 6: The comparison of two kinetic models with experimental MAHD (400 W)

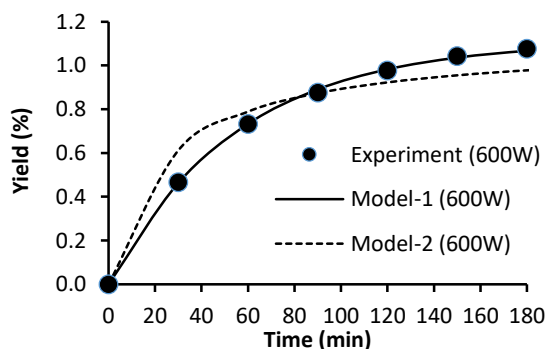


Fig. 7: The comparison of two kinetic models with experimental MAHD (600W)

Figure 6 shows the comparison between the extraction data of lemongrass oil

obtained by MAHD at 400 W, material size 2 cm, F/S ratio of 0.1g/mL versus the data calculated using a first-order kinetic model (equation 3) and, second-order kinetic model (equation 5). The comparison for the 600 W and 800 W is presented in Figure 7 and Figure 8, respectively.

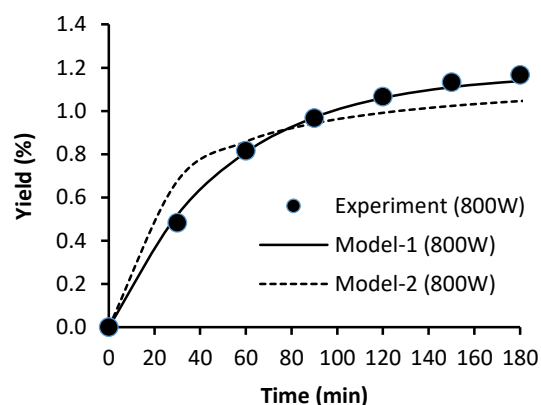


Fig. 8: The comparison of two kinetic models with experimental MAHD (800W).

Table 1 presents a set of parameter values for two different, i.e., first and second order kinetic models, respectively. The RSMD and R^2 values are calculated using Equation 6 and 7, respectively. As can be seen from the table, the RSMD values of model 1 are smaller than those of model 2 and, the R^2 values of model 1 is greater than those of model 2 for all three different microwave powers used. This indicates that kinetic model 1 (first order kinetic) represents the experimental data better than kinetic model 2 for the lemongrass oil extraction process using the MAHD.

By the previous investigations suggesting that the extraction of lemongrass (*Cymbopogon* sp.) can be best represented by the first order kinetic model (Koul et al., 2004; Milojević et al., 2013).

Table 1. Parameter values obtained for kinetic models.

| | k_1 or k_2 | RMSD | R^2 |
|-------------------------------|----------------|---------|---------|
| 1 st Order (400W) | 0.0183 | 0.04101 | 0.07731 |
| 2 nd Order (400W) | 0.0378 | 0.07731 | 0.80586 |
| 1 st Order (600W) | 0.0180 | 0.00873 | 0.99783 |
| 2 nd Order (800W) | 0.0369 | 0.08510 | 0.79396 |
| 1 st Order (8600W) | 0.0195 | 0.01870 | 0.99293 |
| 2 nd Order (800W) | 0.0386 | 0.10197 | 0.78978 |

Analysis of Physical and Chemical Properties of Lemongrass Oil

It is paramount into keep track of the physical and chemical properties of the extracted lemongrass oil as these properties determine the quality of the essential oil.

In addition, the extracted oil's physical and chemical properties can inform whether or not the essential oils undergo the adulteration process (Guenther, 1990). In terms of the physical properties of the extracted lemongrass oil, an average oil density value of 0.9065 was obtained from the experiment, which is well within the range of the Indonesian National Standard (SNI), i.e., 0.8731 - 0.910. Regarding the chemical properties, the components of the extracted lemongrass oil were analysed using gas chromatography-mass spectroscopy (GC-MS), with the resulting chromatogram presented in Table 2.

From Table 1, the main components of Java lemongrass oil are geranial (30.06%), z-citral (25.88%), eugenol (12.88%), and beta-myrcene (12.84%). These components are the key components responsible for the oil's anti-bacterial characteristics (Jafari et al., 2012; Mukarram et al., 2021; Onawunmi et al., 1984).

Table 2. List of components of the extracted oil from GC-MS analysis

| No | Compounds name | % |
|----|--|---------------|
| 1 | Geranial | 30.06 |
| 2 | Z-Citral | 25.88 |
| 3 | Eugenol | 12.88 |
| 4 | Beta-Myrcene | 12.84 |
| 5 | Cyclooctasiloxane | 4.30 |
| | 3-Methyl-2-methylene-4-hexenal | 4.19 |
| | Spiro [2.5] octane | 2.03 |
| | 2,6-Octadien-1-ol | 1.91 |
| 6 | Trans-Caryophyllene | 1.22 |
| 7 | Cinerone | 0.86 |
| | 5-Ocen-2-yn-4-ol | 0.84 |
| 8 | Cis-Ocimene | 0.82 |
| 9 | E-Citral | 0.51 |
| 10 | (+)-Beta-Gurjunene (Calaren) | 0.37 |
| 11 | Alpha-Bergamotene | 0.30 |
| 12 | Beta-Ocimene | 0.21 |
| 13 | Beta-Selinene | 0.20 |
| | Deterpene | 0.20 |
| 14 | [1aR-(1a.alpha.,4a.alpha., etc.)]-decahydro-1,1,7-trimethyl-4-methylene-1H-Cyclopropeazulene | 0,16 |
| 15 | (Z, E)-alpha-Farnesene | 0.12 |
| | 2-Methoxy-4-vinylphenol | 0.10 |
| | TOTAL | 100.00 |

CONCLUSION

The extraction of Java lemongrass oil (*Cymbopogon citratus*) was conducted on a pilot scale in this study using Microwave-Assisted Hydro distillation (MAHD) under various operating conditions, including extraction times, microwave powers, and feed-to-solvent (F/S) ratios. In general, the

yield of the extracted oil increases with time and the microwave power used. However, decreases after reaching a maximum value at one of the feed-to-solvent (F/S) ratios. Despite a slight decrease in oil yield compared to the previous study with a similar laboratory-scale experiment, this pilot-scale study shows promising results. A kinetic study on the extraction process was also conducted by evaluating various kinetic models. The most suitable model was determined based on its ability to represent the experimental data effectively. Consequently, the first-order kinetic model was found to be the best in representing the experimental data of this study. Analysis of the physical and chemical properties confirms that the extracted oil falls within the SNI national standard range and aligns with the findings of previous studies. Regarding the composition of the extracted oil, several main components were observed, including Geranial (30.06%), Z-Citral (25.88%), Eugenol (12.88%), and Beta-Myrcene (12.84%).

NOMENCLATURE

| | |
|----------------------|--|
| c_t | : yield of extraction at time [-] |
| c_s | : yield of extraction at maximum conditions [-] |
| c_{exp} | : experimental yield [mol l ⁻¹] |
| c_{cal} | : calculated yield by model equation [-] |
| $\overline{c_{exp}}$ | : experimental yield average [-] |
| k_1 | : extraction rate constant for the 1 st order model. [s ⁻¹] |
| k_2 | : extraction rate constant for the 2 nd order model [s ⁻¹] |
| $RSMD$ | : root-mean-square dev. [-] |
| R^2 | : coefficient determination [-] |
| R_{adj}^2 | : coefficient determination adjusted [-] |

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