RJC

RASĀYAN J. Chem.
Vol. 18 | No. 1 |52-60| January - March | 2025
ISSN: 0974-1496 | e-ISSN: 0976-0083 | CODEN: RJCABP
http://www.rasayanjournal.com
http://www.rasayanjournal.co.in

DEVELOPING A KINETIC MODEL FOR MICROWAVE HYDRO DIFFUSION AND GRAVITY WITH STEAM FLOW ON EXTRACTION OF ESSENTIAL OILS FROM *Amomum compactum* SEEDS

M. Mahfud[1,✉], A. R. Nabila[2] and Y. Variyana[2]

[1]Department of Chemical Engineering, Institut Teknologi Sepuluh Nopember, Jl. Arif Rahman Hakim, Surabaya, 60111, Indonesia

[2]Department of Industrial Chemical Engineering, Politeknik Negeri Lampung, Jl. Soekarno Hatta No.10, Bandar Lampung, 35144, Indonesia

✉Corresponding author: mahfud@its.ac.id

ABSTRACT

Lampung cardamom (*Amomum compactum*) has the potential to produce essential oils used for aromatherapy, cosmetics, and pharmaceutical purposes. This research aims to study the kinetics model that can represent the extraction process using the MHG method with the addition of steam flow. The operating variables considered include microwave power (300-600 W), extraction time (20-180 minutes), and the feed-to-distiller volume (F/D) ratio (0.15-0.2 g/ml). To determine the best model for describing the essential oil extraction process from local cardamom seeds using the MHG method, six kinetic models were analyzed: first-order, second-order, power law, hyperbolic, Weibull, and Elovich's. The results show that the Weibull model is the most accurate for representing the extraction process. This conclusion is based on its superior statistical performance, with the highest coefficient of determination (R^2) among the models, averaging 0.9933, and the lowest sum of squared errors (SSE), averaging 0.0072. Furthermore, the Weibull D parameter reveals that extraction efficiency increases as the F/D ratio rises, enabling the process to reach its maximum efficiency more rapidly. These findings underscore the suitability of the Weibull model for effectively capturing the dynamics of essential oil extraction from Lampung cardamom seeds.

Keywords: Essential Oil, Kinetics, Extraction, Cardamom, Microwave Hydrodiffusion and Gravity.

RASĀYAN *J. Chem.*, Vol. 18, No.1, 2025

INTRODUCTION

Indonesia recognized as one of the most biodiverse countries globally, plays an important role in the production of essential oils, which are integral to various industries such as aromatherapy, pharmaceuticals, and cosmetics. The country is home to over 40 varieties of essential oils that contribute significantly to the global market, with its diverse flora offering both economic and ecological values[1]. Among the plants utilized for essential oil production, cardamom (*Amomum compactum*), a species native to Indonesia, stands out due to its wide availability and potential for sustainable cultivation. Grown in over 20 provinces, cardamom seeds are rich in essential oils, yielding approximately 3% by weight[2]. The essential oil extracted from *Amomum compactum* is particularly prized for its bioactive compounds, with 1,8-cineole accounting for 60–80% of the oil. This compound is renowned for its potent antibacterial, antioxidant, and anti-inflammatory properties. Other notable compounds, including β-pinene, α-terpineol, and limonene, further augment its medicinal and functional applications[3]. Research has highlighted that 1,8-cineole can reduce mucus production and inflammation by inhibiting pro-inflammatory pathways like NF-κB, while enhancing antiviral responses, making it valuable for respiratory therapies[4,5]. Essential oils can be extracted from plants using various techniques. However, traditional methods for extracting essential oils—such as steam distillation, hydro distillation, and Soxhlet extraction—have limitations. These techniques are often time-consuming, energy-intensive, and involve hazardous solvents, raising concerns about both environmental impact and product safety. Moreover, prolonged exposure to high temperatures during extraction can degrade thermally sensitive bioactive compounds, resulting in lower yields and compromised quality. For example, traditional hydrodistillation can take up to 150 minutes, making it less efficient than modern alternatives[6,7]. In contrast, microwave-assisted extraction (MAE) could be a faster alternative. MAE utilized microwave radiation to reduce oil extraction time to mere minutes or hours[8,9]. This highlights the need for more innovative, efficient, and sustainable extraction technologies. Microwave-assisted extraction (MAE) has emerged as a promising alternative, offering the advantage of reduced extraction time and energy consumption while preserving the quality of essential oils. The Microwave Hydrodiffusion and Gravity (MHG) method is an innovative, solvent-free technique that uses microwave energy to heat plant material, causing cell membranes to rupture and release essential oils and water, which are then separated by gravity.[10,11] This method significantly reduces extraction time (to as little as 15–20 minutes compared to 90–150 minutes using hydrodistillation[12] and offers advantages in terms of lower energy consumption and the elimination of hazardous solvents.[13] The MHG method represents a significant advancement in essential oil extraction, aligning with global trends toward greener, more sustainable industrial practices[14] Given its efficiency and ability to preserve bioactive compounds, MHG is particularly suitable for extracting oils from thermally sensitive materials like cardamom seeds. This study aims to evaluate the kinetics of essential oil extraction from *Amomum compactum* (Lampung cardamom) seeds using the MHG method, with the addition of steam flow. Understanding the kinetics of the extraction process is crucial for improving the efficiency of the process. The research will identify the most suitable kinetic model to describe the extraction data, ensuring high yields and superior quality. Six kinetic models—first-order, second-order, power law, hyperbolic, Weibull, and Elovich's—will be evaluated based on their ability to fit experimental data. Key statistical indicators such as the coefficient of determination (R^2) and the sum of squared errors (SSE) will be used to assess model performance. The findings are expected to identify the best model for describing the extraction process, offering insights into the mechanisms of essential oil release and guiding future optimization efforts.

EXPERIMENTAL

Material and Methods

The cardamom (*Amomum compactum*) seeds obtained from farmer's plantations in Lampung, Indonesia which were still covered by a light brown seed coat. The coat needs to be peeled first so that the dark brown cardamom seeds with a distinctive cardamom smell can be used. Other chemicals used are obtained from local store in Surabaya.

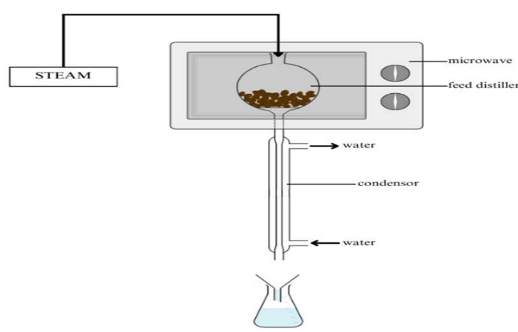

Fig.-1: Experimental apparatus for Oil Extraction Cardamom Seed (*Amomum compactum*) by Microwave Hydrodiffusion and Gravity Method with Steam Flow Addition

Experimental Set-Up and Procedure

The microwave hydro diffusion and gravity (MHG) extraction equipment that has been used has the same main part as the previous equipment[15], only with the addition of a steam generator shown in Fig.-1. This figure shows a schematic of the experimental equipment for cardamom seed oil extraction (*Amomum compactum*) using the microwave hydrodiffusion and gravity method with the addition of steam flow. The main equipment is a 1000 ml distiller placed in a domestic microwave (EMM 2308 X) with 800 W output power maximum, 2450 MHz frequency. The condenser is mounted on the lower side of the microwave and connected to a modified 1000 ml single-neck flask. The steam source is made from boiled distilled water using a heating mantle and the steam flows towards the distiller from the top of the distiller. Steam flow is needed so that the cardamom material does not burn and functions to push the oil that comes out of the material through the Liebig condenser, falling to be collected. The raw material used in this experiment is Lampung cardamom seeds, which will be placed into a 1000 mL boiling flask in predetermined quantities.

Once the seeds are added, the Liebig condenser is supplied with water to start the cooling process, and the microwave is turned on at a fixed power setting. Simultaneously, the flask containing distilled water is heated using an electrical mantle to generate steam, which is then directed into the distillation system. The moment the distillate begins to drip is defined as t = 0. Every 20 minutes, the distillate collected in the beaker is separated into water and oil phases using a separatory funnel. The amount of extracted cardamom oil is then weighed and recorded. The operating parameters for this experiment include microwave power (300-600 W), extraction time (20-150 minutes), and the feed-to-distiller (F/D) ratio (0.15–0.2 g/mL).

Kinetics of Extraction

Six kinetics models used are 1st-order, 2nd-order, power-law, hyperbolic, Weibull equation, and Elovich's equation for oil extraction cardamom seed (*Amomum compactum*) by microwave hydrodiffusion and gravity method with steam flow addition. The 1st-order kinetic equation is denoted as follows[12,16]:

$$q = q_0(1 - e^{-k_1 t}) \quad (1)$$

Meanwhile, the 2nd-order kinetic equation can be written as follows:

$$q = \frac{q_0^2 k_2 t}{1+q_0 k_2 t} \quad (2)$$

Where k_1 and k_2 (min^{-1}) are the rate coefficient of each model, t is the oil extraction time, q is the extraction yield at the time, and so is the maximum capacity extraction yield.

According to the previous work by Haqyana et al., 2020[17], the equation power-law (Eq.-3), hyperbolic (Eq.-4), Weibull exponential equation (Eq.-5), and Elovich's logarithmic equation (Eq.-6) kinetics model can be stated as follows:

$$\frac{q}{q_0} = Bn^t \quad (3)$$

$$\frac{q}{q_0} = \frac{C_1 t}{1+C_2 t} \quad (4)$$

$$\frac{q}{q_0} = 1 - exp\left(-\frac{t^m}{D}\right) \quad (5)$$

$$\frac{q}{q_0} = E_0 + E_1 \times \ln t \quad (6)$$

Where $\frac{q}{q_0}$Is the ratio of the cardamom oil yield at time t to the maximum yield, B and n are the rate coefficients of the power-law model, C_1 and C_2 are the rate coefficients of the hyperbolic model, m and D is the rate coefficient of Weibull exponential equation model, E_0 and E_1 is the rate coefficient of Elovich's logarithmic equation model. To determine the fit of the model with the experimental results, R-squared (R^2) and the sum of squared errors (SSE) were used. R^2 calculates the value of the dependent variable's variance (predicted yield) that can be explained by the independent variables and larger values suggest a better fit[18] SSE quantifies the discrepancy between the observed data and the predicted values, with lower values signifying a more accurate model. The equation determining the R^2 and SSE values is shown in equations (7) and (8)[12,19].

$$R^2 = 1 - \frac{(n-1)\sum_{i=1}^{n}(\frac{q}{q_0}_{cal,i} - \frac{q}{q_0}_{exp,i})^2}{(n-1-m)\sum_{i=1}^{n}(\frac{q}{q_0}_{exp} - \overline{\frac{q}{q_0}}_{exp,i})^2} \quad (7)$$

$$SSE = \sum_{i=1}^{N}(\frac{q}{q_0}_{cal} - \frac{q}{q_0}_{exp})^2 \quad (8)$$

RESULTS AND DISCUSSION

Modeling Kinetics

In the *Amomum compactum* oil extraction process using the MHG method with the addition of steam flow, two main mechanisms work synergistically. The first mechanism involves heating the material using a microwave. In the MHG extraction method, no chemical solvents are used. Therefore, only the water and oil in the cardamom seeds absorb microwaves, preventing energy loss to solvents outside the substance. This unique feature makes the extraction process more energy-efficient compared to other conventional methods that use solvents.[19] The heat produced by microwaves causes the water in the cardamom seeds to turn into steam. This approach is crucial because, during the extraction process, the water vapor formed within the seeds acts as a vital transport agent. The vapor opens plant cells and releases essential oils. Inside the cardamom seeds, the water vapor moves the essential oil out of the plant cells through hydrodiffusion, the second mechanism. The hydrodiffusion method ensures faster and more efficient extraction of essential oils. Additionally, because the water vapor is formed under higher pressure conditions, cardamom oils can be extracted without requiring excessively high extraction temperatures, thus better maintaining the quality of the essential oil produced. The release of essential oils from plant cells in the MHG method depends significantly on the rate at which the oil components absorb energy from microwaves and the presence of water in the cardamom seed matrix. The high energy efficiency of this method not only makes the extraction process more environmentally friendly but also preserves the integrity and quality of the essential oil produced.

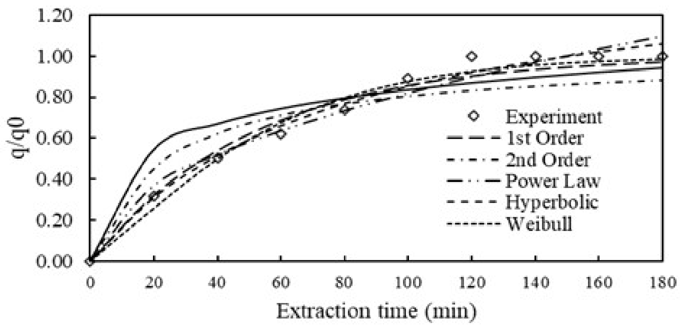

Fig.-2: Comparison Experiment Data with that Calculated from Six Models for 300 W Microwave Power

Thus, the MHG method offers an efficient and effective extraction solution for producing high-quality cardamom oil. Fig.-2, Fig.-3 and Fig.-4. present a curve that provides an overview of changes in the behavior of q/q0 over time. Based on this figure, the curve produced by the experimental results has a sigmoid or S shape that curves upwards. In the initial minutes, the resulting graph follows a pattern close to a linear line, indicating a steady and consistent increase. Following this, there is a significant spike in the number of results produced, reflecting the rapid extraction phase in the process. After these spike periods, the yields tend to remain constant, indicating stabilization and little variation in the amounts produced. This pattern shows that after a rapid ramp-up phase, the system is approaching its maximum capacity, as indicated by the increasingly sloping curve, suggesting that the output is reaching a minimum.

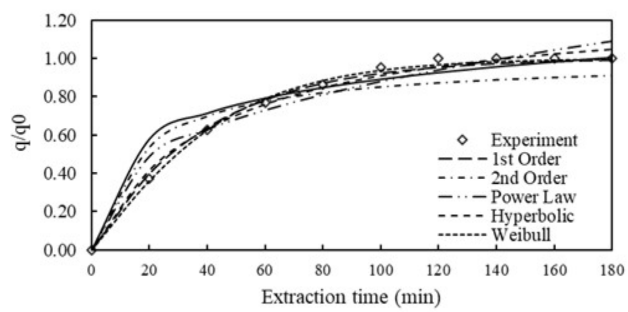

Fig.-3: Comparison of Experiment Data with that Calculated from Six Models for 450 W Microwave Power.

Overall, this sigmoid curve depicts three main phases in the process: the initial linear phase, the spike or exponential phase, and the constant or plateau phase, each with different characteristics and dynamics.[20] In general, the evaluation results in Table-1 highlight high R^2 values for nearly all kinetic models, close to 1 (R^2>0.9). This indicates their strong capability to explain variance in cardamom seed extraction data. Particularly noteworthy is the Weibull model, which boasts a slightly higher R^2 value compared to other models, totaling 2.9799 with an average of 0.9933. These figures underscore the Weibull model's exceptional fit for the cardamom seed extraction process using the Microwave Hydrodiffusion and Gravity (MHG) method supplemented with steam flow, demonstrating a close alignment between experimental data and model predictions.

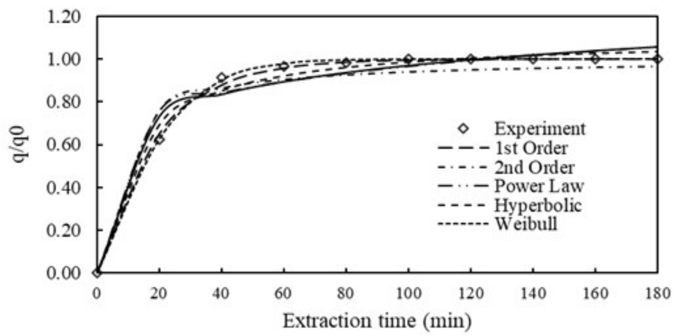

Fig.-4: Comparison Experiment Data with that Calculated from Six Models for 600 W Microwave Power

Moreover, across all variations in microwave power, the Weibull model exhibits the lowest SSE values among the kinetic models evaluated, further affirming its accuracy in predicting extraction outcomes. Conversely, the 2nd-order model presents the weakest performance in the dataset. It shows the lowest R^2 value and highest SSE, indicating its inadequacy in accurately describing the extraction process. A low R^2 suggests the 2nd-order model explains only a small fraction of data variance, while a high SSE signifies significant discrepancies between model predictions and actual results. Therefore, based on the findings in Table-1, it is evident that the 2nd-order model is ill-suited for modeling the cardamom oil extraction process using the MHG method enhanced with steam flow. Examining the parameters, it is observed that parameter m in the Weibull model evaluation results has a value above 1. The Weibull model demonstrates a characteristic behavior where, when $m>1$, the curve is S-shaped (sigmoid), featuring an upward curvature followed by a turning point[20]. This behavior is consistent with the shape of the experimental results curve, as seen in Fig.-2, Fig.-3, and Fig.-4. The high degree of fit and the distinctive curve shape further validate the Weibull model's suitability for describing the kinetic processes observed in the experiments. This alignment between the predicted yield by model and the experimental data suggests that the Weibull model is highly effective in capturing the dynamics of the cardamom seed extraction process, offering a reliable framework for predicting outcomes under similar conditions.

Table-1: Parameter and Statistical Value of Model

F/D ratio	Kinetics Model	Parameter	R^2	SSE
0.15	Orde 1	$k_1 = 0.0193$	0.9752	0.0269
	Orde 2	$k_2 = 0.0289$	0.8778	0.1323
	Power-law	B = 0.0835; n = 0.4960	0.9712	0.0312
	Hyperbolic	$C_1 = 0.0194$; $C_2 = 0.0128$	0.9858	0.0153
	Weibull	D = 126.7315; m = 1.2122	0.9831	0.0183
	Elovich's	$E_0 = 0$; $E_1 = 0.1817$	0.8707	0.1400
0.175	Orde 1	$k_1 = 0.0254$	0.9948	0.0053
	Orde 2	$k_2 = 0.0350$	0.9139	0.0880
	Power-law	B = 0.1641; n = 0.3644	0.9643	0.0365
	Hyperbolic	$C_1 = 0.0309$; $C_2 = 0.0239$	0.9915	0.0086
	Weibull	D = 65.7046; m = 1.1305	0.9974	0.0027
	Elovich's	$E_0 = 0$; $E_1 = 0.1932$	0.9394	0.0619
0.2	Orde 1	$k_1 = 0.0526$	0.9978	0.0020
	Orde 2	$k_2 = 0.0515$	0.9587	0.0380
	Power-law	B = 0.4797; n = 0.1519	0.9608	0.0361
	Hyperbolic	$C_1 = 0.0391$; $C_2 = 0.0845$	0.9856	0.0133
	Weibull	D = 41.0276; m = 1.2348	0.9995	0.0005
	Elovich's	$E_0 = 0.2902$; $E_1 = 0.1477$	0.9666	0.0308

Table-1 signifies that the D parameter decreases as the F/D ratio increases. This reduction in the D value suggests that as the F/D ratio rises, the time needed to reach the maximum extraction point accelerates.[16] The implication of this finding is significant for optimizing the extraction process, as it highlights the importance of adjusting the F/D ratio to achieve quicker stabilization times, thereby enhancing overall efficiency. Overall, the influence of the F/D ratio on the kinetic model parameters is presented in Table-1. shows that as the F/D ratio increases, the parameters k_1, k_2, B, C_1, and C_2 also increase. This trend indicates an overall enhancement in the extraction process's effectiveness, as higher values of these parameters generally correlate with improved extraction rates. Conversely, the parameters n and D decrease with an increasing F/D ratio. Parameter n is a diffusional exponent that explains the separation of cardamom oil from the plant and has a value of less than 1. Meanwhile, the parameters, E_0, and E_1 exhibit irregular patterns as the F/D ratio increases, indicating that their relationship with the F/D ratio is more complex and may be influenced by additional factors. These findings underscore the nuanced interplay between different kinetic parameters and the F/D ratio, offering valuable insights for refining and optimizing the cardamom seed extraction process using the Weibull model. Understanding these relationships allows for more precise control over the extraction conditions, potentially leading to improved yield and quality of the extracted product. Furthermore, the Weibull D parameter reveals that extraction efficiency increases as the F/D ratio rises, enabling the process to reach its maximum efficiency more rapidly.

GC-MS Analysis

The data from the GC-MS analysis (Fig.-5) showed that of the 90 peaks detected, five compounds had the most dominant area percentage, which is shown in Table-2 and Table-3. This analysis provides a more detailed picture of the chemical profile of cardamom oil, which is important for applications in the perfume, pharmaceutical, and food industries. Knowledge of this chemical composition is not only useful for determining the quality of cardamom oil but also for the most efficient sourcing and extraction techniques.

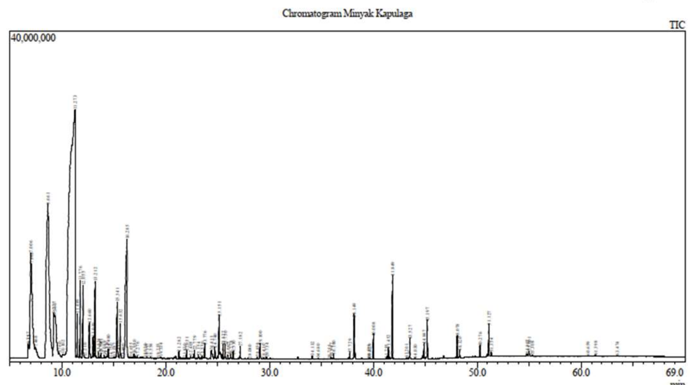

Fig.-5: GC-MS Analysis of Cardamon Oil Obtained from MHG method

Oxygenated monoterpenes are a derivative group of terpene compounds that have oxygen atoms in their structure. The components in this group exert a significant influence on the aroma of essential oils, which makes them invaluable in the perfume and aromatherapy industry. In general, *eucalyptol*, which belongs to the group of *oxygenated monoterpenes*, gives a distinctive aroma, that is spicy and soothing and produces a strong camphor-like aroma in essential oils.

Table-2: Compounds Category of Cardamom oil GC-MS Analyze Results

Terpene Group	Total Oil Content (%)
Monoterpenes	28.89
Oxygenated Monoterpenes	59.28
Sesquiterpenes	3.26
Oxygenated Sesquiterpenes	0.91
Diterpenes	2.61
Triterpenes	0.2
Oxygenated Triterpenes	0.23
Other compounds	4.62

Cardamom oil that has been extracted using the MHG method with the addition of steam flow also shows the presence of *eucalyptol* as its main component. This is in line with the characteristics of essential oils that have a soothing and fresh aroma. *Eucalyptol*, in addition to contributing to the aroma, also has a variety of health benefits. These compounds can significantly reduce the number of mucus-producing cells and the expression of mucus genes (MUC2 and MUC19) in sinusitis models, as well as reduce the activity of the inflammatory factor NF-κB. Furthermore, *eucalyptol* also increased the activity of the antiviral protein IRF3 while inhibiting the pro-inflammatory signal NF-κB. These benefits demonstrate the potential of *eucalyptol* as a therapeutic agent in the treatment of various inflammatory conditions and viral infections.

Table-1: List of Five Cardamom Oil Compounds from GC-MS Analyse Results

Peak	Compound	Chemical Formula	*Retention Time*	MW	%Area
11	*Eucalyptol*	$C_{10}H_{18}O$	11.273	154	45.45
6	*β- pinene*	$C_{10}H_{16}$	8661	136	14.27
3-4	*α-pinene*	$C_{10}H_{16}$	7.005-7.070	136	7.34
31	*α-terpineol*	$C_{10}H_{18}O$	16.285	154	6.54
7-8	*β-myrcene*	$C_{10}H_{16}$	9.225-9.301	136	4.18

In addition to its anti-inflammatory properties, *eucalyptol* is also known to have other benefits that are no less important. As an analgesic, *eucalyptol* can help relieve pain. Meanwhile, its antimicrobial properties make it effective in inhibiting the growth of various pathogenic microorganisms. Recent research by Hoch et al. (2023)[5] Shows that *eucalyptol* also has potential in the management of complex diseases such as Alzheimer's, neuropathic pain, and cancer. In Alzheimer's conditions, *eucalyptol* can help in reducing nerve inflammation and improving cognitive function. In neuropathic pain, this compound plays a role in reducing pain sensations caused by nerve damage. Meanwhile, in the context of cancer, *eucalyptol* shows antitumor activity that can inhibit the growth of cancer cells Thus, *eucalyptol* not only imparts a distinctive and soothing aroma to the essential oil, but it also offers a wide range of health benefits. This makes it a very valuable component in essential oils, both in terms of aroma and therapeutic properties.

CONCLUSION

Microwave hydrodiffusion and gravity present a fast, robust, and environmentally friendly approach for the extraction of essential oils from Lampung Cardamom (*Amomum Compactum*). The study demonstrates that critical parameters like material size and extraction time significantly influence the oil yield. Specifically, longer extraction times result in higher yields, while larger material sizes reduce the yield. Six kinetic models -1st-order, 2nd-order, power-law, hyperbolic, Weibull, and Elovich's - were employed to evaluate the kinetics of the extraction process. Among these, the Weibull model provided the best representation of the extraction process, as indicated by the highest criteria of determination (R^2) with an average value of 0.9933 and the lowest sum of squared errors (SSE), averaging 0.0072. The Weibull model's D parameter further highlights that the efficiency of the extraction process improves with an increased feed-to-diffusion ratio (F/D), allowing the system to reach its maximum efficiency faster. This conclusion emphasizes the efficacy of the MHG method in optimizing essential oil extraction from cardamom by fine-tuning parameters such as material size, extraction time, and F/D ratio. Moreover, the findings suggest that the adoption of MHG for industrial applications can enhance productivity and sustainability, aligning with the need for greener and more efficient extraction techniques in essential oil production.

ACKNOWLEDGMENTS

The authors would like to express my appreciation to S.P. Romadhan and R.A Ramadhani for their participation in collecting the data during this research.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

M. Mahfud https://orcid.org/0000-0001-7740-9670
A.R. Nabila http://orchid.org/ 0009-0007-8768-8088
Y. Variyana https://orcid.org/0009-0000-2854-3873

REFERENCES

1. Y. Mustamin, *Paper Knowledge Toward a Media History Document,* **May**, 1(2015), https://doi.org/10.13140/RG.2.1.2604.6883
2. L. R. Tambunan, Jurnal Kimia Riset, **2 (1)**, 57(2017), https://doi.org/10.20473/jkr.v2i1.402
3. Y. M. Alkandahri, A. Rusdin, and A. H. Kusumawati, Plant Cell Biotechnology Molecule and Biology, **22 (33&34)**, 61-69 (2021), https://doi.org/10.36805/jbf.v2i3.546
4. L. J. Juergens, H. Worth, and U. R. Juergens, *Advance Thererapy*, **37 (5)**, 1737(2020), https://doi.org/10.1007/s12325-020-01279-0
5. C. C. Hoch, J. Petry, L. Griesbaum, et al., *Biomedical Pharmacotherapy*, **167**, 115467(2023), https://doi.org/10.1016/j.biopha.2023.115467
6. F. Sari, R. A. Nugrahani, Anisa Nurtri Lestari, and D. Noviyanti, *Prosiding Seminar Nasional Sains dan Teknologi*, **16**, 1(2019).
7. M. Sarah, I. M. Hasibuan, E. Misran, and S. Maulina, *Molecules*, **27(19)**, 6544(2022), https://doi.org/10.3390/molecules27196544
8. S. Gala, S. Sumarno, and M. Mahfud, *Jurnal of Applied and Engineering Science,* **18 (4)**, 618(2020), https://doi.org/10.5937/jaes0-23695
9. H. S. Kusuma and M. Mahfud, *Journal of Applied Research on Medicinal and Aromatic Plants*, **4**, 55(2016), https://doi.org/10.1016/j.jarmap.2016.08.002
10. F. Chemat, M. Abert-Vian, A.S.Fabiano-Tixier, et al., *TrAC Trends in Analytical Chemistry*, **118**, 248(2019), https://doi.org/10.1016/j.trac.2019.05.037
11. Y. Variyana, M. Fitria, R. S. C. Muchammad, and M. Mahfud, *Results in Engineering*, **24**, Dec. 103294 (2024), https://doi.org/10.1016/j.rineng.2024.103294
12. S. W. Murni, T. M. Setyoningrum, F. X. D. D. Cahyaningrum, S. Alodia, and H. S. Kusuma, *Moroccan Journal of Chemistry*, **9(4)**, 671(2021), https://doi.org/10.48317/IMIST.PRSM/morjchem-v9i4.27799
13. H. Benmoussa, W. Elfalleh, S. He, M. Romdhane, A. Benhamou, and R. Chawech, *Industrial Crops and Proucts*, **124**, 633(2018), https://doi.org/10.1016/j.indcrop.2018.08.036
14. S. Moradi, A. Fazlali, and H. Hamedi, *Avicenna Journal of Medical Biotechnology,* **10(1)**, 22(2018), https://doi.org/10.1007/s13197-011-0610-y
15. Y. Variyana and M. Mahfud, *IPTEK Journal of Technoogy and Science,* **30(3)**,116(2019), https://doi.org/10.12962/j20882033.v30i3.5474
16. H. S. Kusuma, T. I. Rohadi, E. F. Daniswara, A. Altway, and M. Mahfud, *Korean Chemical Engineering and Research*, **55 (4)**, 574(2017), https://doi.org/10.9713/kcer.2017.55.4.574
17. H. Haqqyana, V. F. W. Tania, A. M. Suyadi, H. S. Kusuma, A. Altway, and M. Mahfud, *Moroccan Journal of Chemistry*, **8(S1)**, 64(2020), https://doi.org/10.48317/IMIST.PRSM/morjchem-v8i1.19126
18. D. Chicco, M. J. Warrens, and G. Jurman, *PeerJ Computer Science*,**7**,1(2021), https://doi.org/10.7717/PEERJ-CS.623
19. H. Haqqyana, A. Altway, and M. Mahfud, *International Journal of Applied Science and Engineering*, **9 (4)**, 1(2022), https://doi.org/10.6703/IJASE.202212_19(4).007
20. X. Yin, J. Goudriaan, E. A. Lantinga, J. Vos, and H. J. Spiertz, *Annalytical Botany*, **91(3)**, 361(2003), https://doi.org/10.1093/aob/mcg029

[RJC-9024/2024]