Indonesian Journal of Electrical Engineering and Computer Science
Vol. 37, No. 3, March 2025, pp. 1497~1505
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v37.i3.pp1497-1505

Implementation and analysis of temperature and gas sensor datalogger in multi-stage condenser pyrolysis

Muhammad Fathuddin Noor[1], Sumardi Hadi Sumarlan[2], Yusuf Hendrawan[2], Bambang Dwi Argo[2], Hartawan Abdillah[3]
[1]Department of Agro-Industrial Technology, Faculty of Agricultural Technology, Brawijaya University, Malang, Indonesia
[2]Department of Biosystem Engineering, Faculty of Agricultural Technology, Brawijaya Univesity, Malang, Indonesia
[3]Department of Electrical Engineering, Panca Marga University, Probolinggo, Indonesia

Article Info

Article history:

Received Jan 3, 2024
Revised Oct 1, 2024
Accepted Oct 7, 2024

Keywords:

Arduino mega
Condenser
Datalogger
Gas sensor
Pyrolysis
Thermocouple

ABSTRACT

The development of alternative energy sources is crucial for addressing contemporary energy and environmental challenges. This study presents the implementation and analysis of a temperature and gas sensor datalogger within a multi-stage condenser pyrolysis system, designed to assess the potential of pyrolytic liquid smoke derived from *Cerbera odollam* (bintaro) fruit waste. The datalogger system was developed to continuously capture and retain data on temperature, air humidity, and non-condensable gases throughout the pyrolysis process. The experimental research focused on evaluating the impact of varying reactor temperatures (250 °C, 300 °C, and 350 °C) and cooling fluid flow rates on the performance of the condenser and the production of bio-oil. Results indicated that reactor temperature significantly affects bio-oil yield, with the highest output of 190 mL obtained at 350 °C. Additionally, the temperature of the smoke entering each condenser and the cooling water's temperature were found to influence the composition of the condensates produced by each stage. This study highlights the importance of integrating sensor technologies to optimize pyrolysis conditions, thereby enhancing the efficiency of energy production from bintaro fruit waste.

Corresponding Author:

Muhammad Fathuddin Noor
Department of Agro-Industrial Technology, Faculty of Agriculture Technology, Brawijaya University
Veteran St, Malang, East Java, ZIP 65145, Indonesia
Email: fathuddin@student.ub.ac.id

1. INTRODUCTION

The use of biomass as an alternative energy source [1] is increasingly receiving significant attention in an effort to reduce dependence on fossil fuels [2] and reduce negative impacts on the environment [3]. The biomass pyrolysis process is a promising technology for converting biomass into value-added products such as biochar [4], bio-oil and bio gas [5]. However, monitoring and in-depth understanding of the pyrolysis process is the key to increasing the efficiency and quality of the products produced.

Biomass pyrolysis is a thermochemical process in which biomass materials [6], such as wood, straw, agricultural waste [3], or other organic waste such as bintaro fruit (*Cerbera odollam*) [7] as seen in Figure 1, are heated in the absence of oxygen or with very limited amounts of oxygen. This process produces gas, liquid and solid products [8]. The gas produced consists of a mixture of hydrogen [9], carbon monoxide, methane and other hydrocarbons, while the liquid produced usually consists of a mixture of bio-oil and bio-tar, as well as solids such as charcoal or biomass coke.

Figure 1. Cerbera odollam gaertn

Recent experimental investigations have focused on the separation of groups of target compounds as bio-oil fractions [10]. The condensation temperature range is determined based on the dew point of certain organic groups, thereby allowing for selective and physical separation between each fraction [11]. Controlling the nitrogen flow and narrowing the cooling temperature are key features to maximize liquid recovery.

Although there has been a lot of research carried out in the field of biomass pyrolysis, most of it focuses on the kinetics of the reaction and analysis of the final product, without paying attention in detail to the heat transfer process and the appearance of gas or smoke during the process. Limited direct supervision of the pyrolysis process causes gaps in a comprehensive understanding of the mechanism of pyrolysis. Previous research tends to rely on mathematical models that require complete and accurate experimental data. Therefore, this research aims to fill this gap by utilizing an integrated datalogger system and sensors in an effective manner.

Using a datalogger system with appropriate sensors is an important step in monitoring and recording key parameters during the pyrolysis process. This research has very important relevance because it can provide a deeper understanding of the biomass pyrolysis process, especially in terms of heat transfer and gas or smoke formation. By monitoring the process directly using a datalogger system and appropriate sensors, it is hoped that accurate and comprehensive data will be created to validate existing mathematical models and identify factors that influence the efficiency and quality of pyrolysis products. A better understanding of this process could pave the way for the development of more efficient, environmentally friendly and sustainable biomass pyrolysis technologies in the future.

2. METHOD

The method used in this study is an experimental method based on analyzing heat transfer energy in a pirolysis system with multistage condensor and temperature data taken by implementing and analyzing dataloggers. In this study, the condensor was designed using a cooper coil tube (∅12.5 mm × 1,000 mm) with a PVC material shell (∅90 mm × 500 mm) for 4 units. To heat the reactor chamber, a high-pressure stove burner with LPG fuel was used.

A fixed bed reactor is a type of reactor in which the basic material is placed in a fixed bed and then heated. This reactor energy can be modeled using (1) [12].

$$\frac{dT}{dt} = \frac{Q}{m \cdot C_p} \quad (1)$$

Where:

T : temperature in the reactor (°C),
t : time (seconds),
Q : heat rate applied to the reactor (Watt/m^{2}K),
m : mass rate of raw materials in the fixed bed (kg/hour), and
Cp : material heat capacity (Joule/kgK).

The water-cooled spiral condenser cools the bio-oil vapor produced during pyrolysis so that it condenses and becomes liquid. The cooling capacity and heat transfer can be calculated using (2) [13].

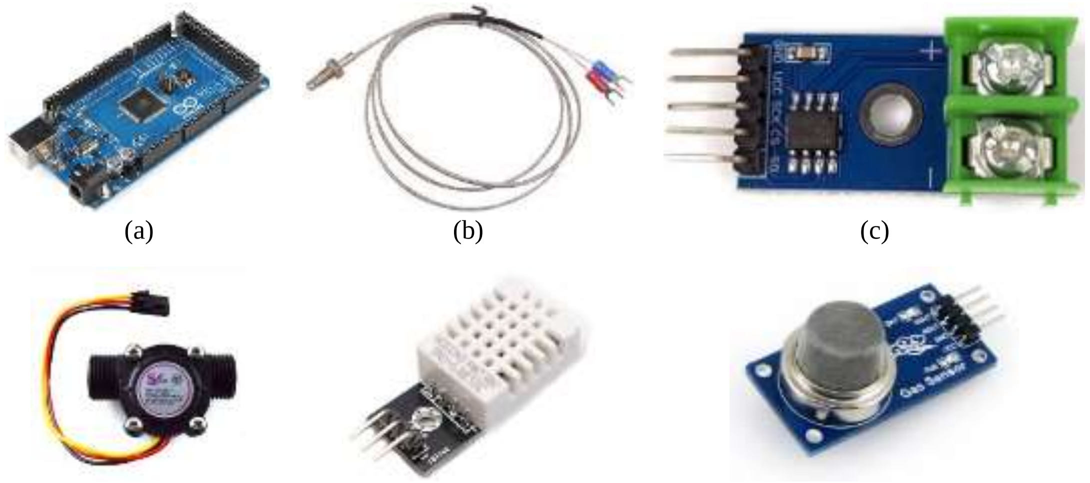
$$Q = U \cdot A \cdot \Delta T \tag{2}$$

Where:
Q : heat transferred (Watt/m^{2}K),
U : heat transfer coefficient (Watt/m.K),
A : heat exchange surface area (m^2), and
ΔT : temperature difference between steam and cooling medium (^{o}C).

The calculation of heat transfer rates will utilize data obtained from measurements taken throughout the specified experimental timeframe. To achieve accurate and reliable results, it is essential to gather a substantial amount of data, encompassing continuous recordings throughout the entire pyrolysis process. This extensive dataset ensures that the calculations reflect real-time conditions and variations in the reactor, enabling precise modeling of the heat transfer dynamics. By relying on comprehensive experimental data, the analysis will provide a more accurate representation of the thermal behavior within the system, thereby enhancing the validity of the calculated heat transfer rates.

2.1. Temperature datalogger design

In Figure 2 the equipment used in designing the datalogger consists of an Arduino Mega 2560 R3 microcontroller as in Figure 2(a), a temperature sensor used 8 type K thermocouples with working voltage specifications of 3-5 V, temperature measurement range 0-800 °C, accuracy 0.25 °C as in Figure 2(b), and the MAX6675 module as in Figure 2(c). The cooling fluid flow rate is measured using the YF-S201 sensor as in Figure 2(d). Air humidity is measured using a DHT22 sensor, as in Figure 2(e). The non-condensable gas that comes out is measured using the MQ-135 sensor as in Figure 2(f).



(a) (b) (c)

(d) (e) (f)

Figure 2. Components datalogger system: (a) Arduino mega 2560, (b) module thermocouple Max6675, (c) thermocouple type K, (d) flow sensor YF-S201, (e) humidity and temperature sensor DHT22, and (f) gas sensor MQ135

The system has been meticulously developed following the highly compact wiring diagram design, as illustrated in Figure 3, where each connection has been optimized to minimize cable length and enhance operational efficiency. Additionally, the design was created with careful consideration to avoid potential interference that could arise from overlapping cable paths. This ensures that the sensor measurements are highly precise and accurately reflect real-time conditions observed during the experiment.

Figure 4 displays the computer script specifically developed for the management and monitoring of instruments within the pyrolysis system. This script is tailored to precisely control and record temperature measurements, coolant flow rates, and gas production throughout the experimental process. By enabling real-time data acquisition, it ensures accurate tracking of these parameters, thereby enhancing the analysis and optimization of the multi-stage condenser's performance.

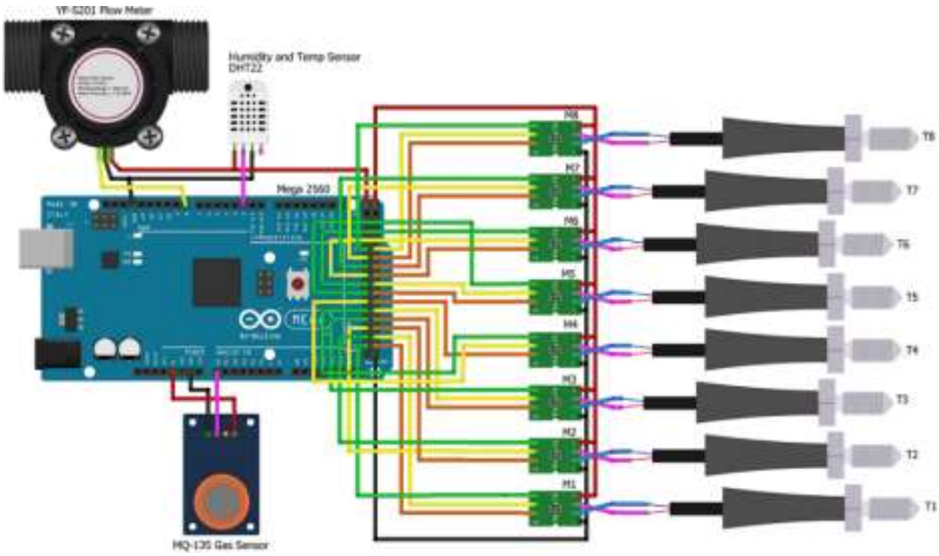


Figure 3. Wiring design

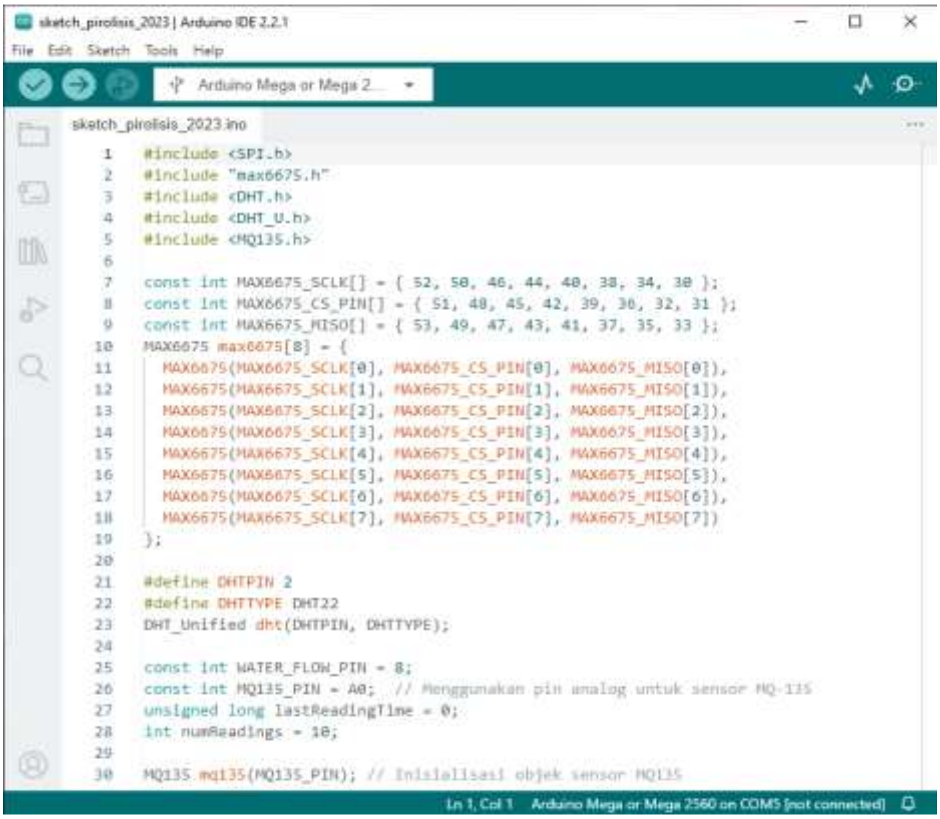


Figure 4. Software display

The arrangement of thermocouple sensors, labeled T1 through T8, was strategically configured at various critical points in the system to monitor temperature distribution with high precision [14]. The coolant flow rate was accurately measured at the outlet of the condenser (C-1) to assess cooling efficiency effectively. Additionally, humidity and ambient temperature were recorded using a DHT22 sensor, which was placed in a shaded area to avoid thermal interference from the reactor and gas duct system, ensuring reliable data collection. This setup is depicted in Figure 5.

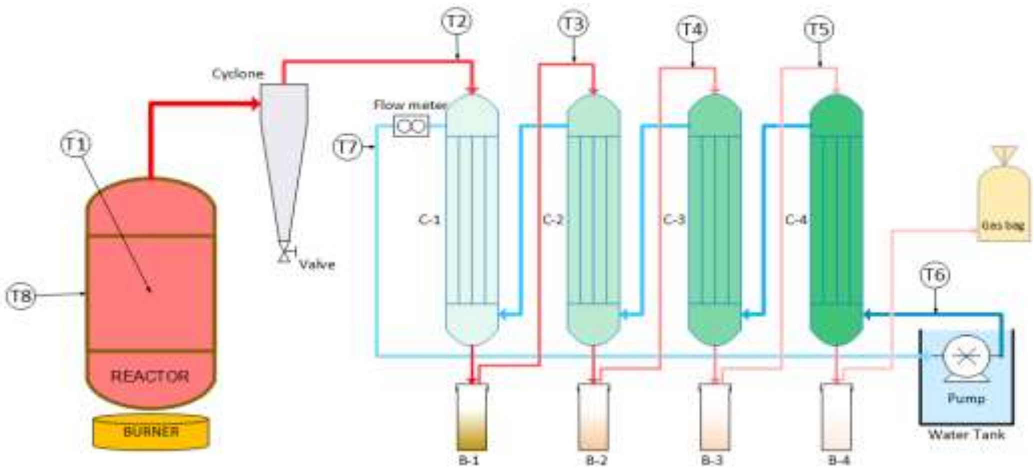


Figure 5. Position of the thermocouple on the system pyrolysis

2.2. Experimental procedure

The raw material, consisting of fallen *Odollam Cerbera* fruit, was sourced from the northern coastal region of Probolinggo district. The initial processing involved size reduction, followed by sun drying for three days. Subsequent drying was conducted in an oven at a temperature of 105±5 °C for three hours. Each process involved weighing 3 kg of the material for three different temperature variations. During the pyrolysis process, key parameters such as temperature, humidity, product gas composition, and coolant flow rate were meticulously recorded. The entire research procedure adhered to the sequence outlined in the flowchart presented in Figure 6.

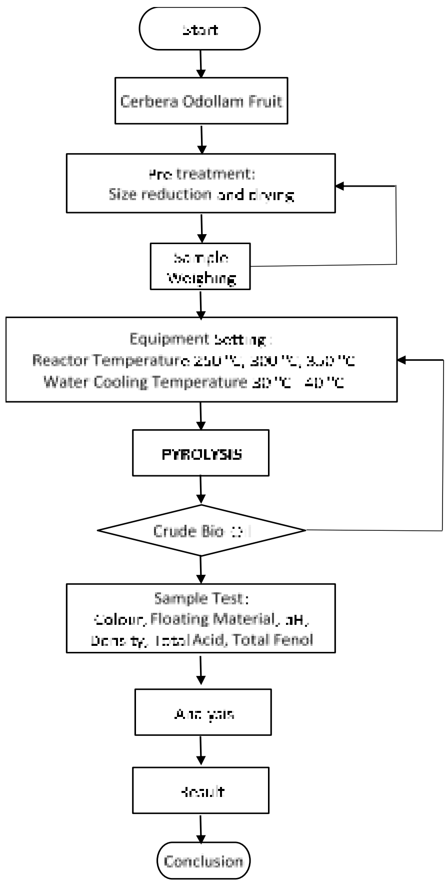


Figure 6. Experimental procedure

3. RESULTS AND DISCUSSION

3.1. Test results temperature data

The results of pyrolysis of *cerbera* fruit with variations in reactor temperature produce pyrolysis products in the form of solids in the form of charcoal and liquids in the form of bio-oil, and the remainder is gas, which cannot be condensed. From Figure 7, it can be seen that the temperature of the reactor experienced a significant increase after the 5th minute and then fluctuated between a temperature of 250 °C and 350 °C. The temperature of the T-in condenser ranges from 87.3 °C to 35.6 °C. Meanwhile, the T-out of the condenser ranges from the lowest value to 22.9 °C. This phenomenon occurs because the initial pyrolysis process requires time to reach the desired operational temperature [15], and after reaching that temperature, temperature fluctuations are caused by variations in raw material supply or complex pyrolysis reaction characteristics. The inlet temperature (T-in) at the first stage condenser also shows quite large fluctuations, although with a lower range.

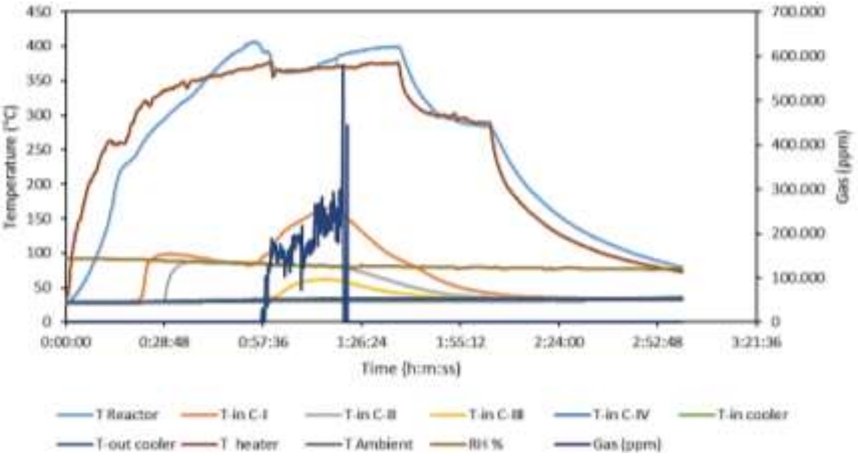


Figure 7. Temperature changes in reactor and multi-stage condenser

Temperature fluctuations in the reactor, cyclone, and condenser indicate challenges in maintaining stable operational conditions during the pyrolysis process. These temperature fluctuations can affect the efficiency of the pyrolysis process and the resulting product yield. Wide temperature variations can also indicate problems with temperature control and heat transfer in the system. In addition, temperature fluctuations in the condenser can also impact condensation and cooling conditions, which can affect the quality and quantity of the condensed product [16]. Therefore, temperature control and heat transfer in the pyrolysis system need to be considered more carefully to achieve more consistent and optimal results.

3.2. Heat transfer analysis

At high temperatures, as in the case of the highest char yielding temperatures, the dominant chemical reactions include dehydration, depolymerization, decarboxylation, and reduction of complex molecules to simpler compounds. High temperatures destroy chemical bonds in large molecules [17], such as cellulose and lignin [18], which are present in bintaro fruit. This process produces smaller molecules, including hydrocarbon compounds [19]. This reaction is the first step towards the formation of charcoal [20]. This is referred to as depolymerization [21]. Meanwhile, this reaction involves the removal of the carboxyl group (-COOH) from organic compounds as a decarboxylation process which can produce aromatic hydrocarbon compounds [21], which are the main components in charcoal.

The dehydration process also occurs at temperatures of 250-350 °C. The dehydration process removes water molecules from organic compounds, such as cellulose and lignin [22]. This reaction causes an increase in the carbon concentration in the molecular structure [23], which is the main characteristic of charcoal [24]. And finally, there is a molecular reduction process where at a high enough temperature, a reduction reaction occurs where oxygen is released from organic compounds [25]. This results in a higher carbon concentration in the molecular structure, which also contributes to char formation.

3.3. Product of bio-oil

The processes mentioned above, which occur during pyrolysis at temperatures that produce the highest bio-oil, cause changes in the structure and composition of bintaro fruit leading to the formation of charcoal and bio-oil [26]. Since this chemical reaction is strongly influenced by temperature [27], the proper operational temperature can influence the conversion rate and the final outcome of bio-oil formation in the pyrolysis process as shown in Figure 8.

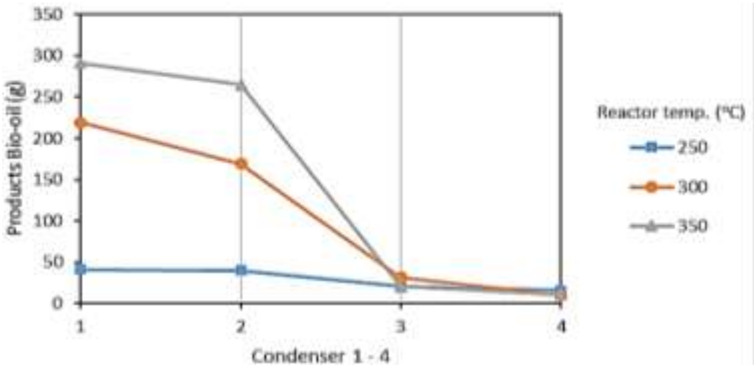


Figure 8. Product bio-oil in experiment

Based on graphical data, the study reveals that the majority of the bio-oil production was concentrated in condensers C-1 and C-2, with significantly lower yields observed in condensers C-3 and C-4. The substantial disparity in output between the first two condensers and the latter two suggests that the cooling and condensation processes are most efficient in the initial stages, where the temperature gradient and vapor concentration are likely at their peak. Consequently, the effectiveness of the third and fourth condensers is considerably diminished, indicating that future designs of the pyrolysis system may only require the implementation of two condensers to achieve optimal bio-oil recovery. This adjustment could streamline the system, reduce operational complexity [28], and lower costs without compromising the efficiency of bio-oil production.

4. CONCLUSION

To capture and analyze temperature, air humidity, and non-condensable gases throughout the pyrolysis process, a specialized temperature and gas sensor datalogger system was implemented. This system enabled a detailed evaluation of the performance parameters within the multi-stage condenser during the pyrolysis of bintaro fruit waste. The study investigated how variations in reactor temperature and cooling fluid flow rate affected the condenser’s efficiency and bio-oil production. The results demonstrated that reactor temperature plays a critical role in determining bio-oil yield, while the temperatures of the smoke entering each condenser and the cooling water significantly influence the composition of the condensates produced at each stage. Future research should focus on optimizing these parameters, potentially varying feedstock composition and condenser configurations, to enhance both yield and quality of bio-oil. The key takeaway is the significant role of advanced sensor technologies in optimizing pyrolysis systems for sustainable biofuel production from biomass waste like bintaro fruit.

REFERENCES

[1] M. N. Uddin, J. Taweekun, K. Techato, M. A. Rahman, M. Mofijur, and M. G. Rasul, “Sustainable biomass as an alternative energy source: Bangladesh perspective,” *Energy Procedia*, vol. 160, pp. 648–654, 2019, doi: 10.1016/j.egypro.2019.02.217.

[2] D. McCauley and K. Pettigrew, “Building a just transition in asia-pacific: Four strategies for reducing fossil fuel dependence and investing in clean energy,” *Energy Policy*, vol. 183, no. December 2022, p. 113808, 2023, doi: 10.1016/j.enpol.2023.113808.

[3] V. I. Ameh, O. O. Ayeleru, P. N. Nomngongo, and I. M. Ramatsa, “Bio-oil production from waste plant seeds biomass as pyrolytic lignocellulosic feedstock and its improvement for energy potential: a review,” *Waste Management Bulletin*, vol. 2, no. 2, pp. 32–48, 2024, doi: 10.1016/j.wmb.2024.03.002.

[4] X. Zou, P. Debiagi, M. A. Amjed, M. Zhai, and T. Faravelli, “Impact of high-temperature biomass pyrolysis on biochar formation and composition,” *Journal of Analytical and Applied Pyrolysis*, vol. 179, no. March, p. 106463, 2024, doi: 10.1016/j.jaap.2024.106463.

[5] A. Bhatnagar, A. Singhal, H. Tolvanen, K. Valtonen, T. Joronen, and J. Konttinen, “Effect of pretreatment and biomass blending on bio-oil and biochar quality from two-step slow pyrolysis of rice straw,” *Waste Management*, vol. 138, no. September 2021, pp. 298–307, 2022, doi: 10.1016/j.wasman.2021.12.013.

[6] Y. Wang and J. J. Wu, “Thermochemical conversion of biomass: potential future prospects,” *Renewable and Sustainable Energy Reviews*, vol. 187, no. January, p. 113754, 2023, doi: 10.1016/j.rser.2023.113754.

[7] H. C. Ong, A. S. Silitonga, T. M. I. Mahlia, H. H. Masjuki, and W. T. Chong, “Investigation of biodiesel production from Cerbera manghas biofuel sources,” *Energy Procedia*, vol. 61, pp. 436–439, 2014, doi: 10.1016/j.egypro.2014.11.1143.

[8] V. Piazza *et al.*, "Detailed speciation of biomass pyrolysis products with a novel TGA-based methodology: the case-study of cellulose," *Journal of Analytical and Applied Pyrolysis*, vol. 178, no. July 2023, p. 106413, 2024, doi: 10.1016/j.jaap.2024.106413.

[9] T. Matamba, A. Tahmasebi, J. Yu, A. Keshavarz, H. R. Abid, and S. Iglauer, "A review on biomass as a substitute energy source: Polygeneration influence and hydrogen rich gas formation via pyrolysis," *Journal of Analytical and Applied Pyrolysis*, vol. 175, no. June, p. 106221, 2023, doi: 10.1016/j.jaap.2023.106221.

[10] P. Dhakal, E. O. Månsson, and A. Achour, "Producing upgradeable bio-oil from food bio-waste via hybrid-assisted pretreatment coupled with catalytic hydrotreatment," *Bioresource Technology Reports*, vol. 24, no. September, 2023, doi: 10.1016/j.biteb.2023.101626.

[11] A. Mati *et al.*, "Fractional condensation of fast pyrolysis bio-oil to improve biocrude quality towards alternative fuels production," *Applied Sciences*, vol. 12, no. 10, 2022, doi: 10.3390/app12104822.

[12] L. Mastroianni, M. Di Serio, T. Salmi, and V. Russo, "Comprehensive reverse flow reactor model for fluid–solid systems," *Chemical Engineering Science*, vol. 280, no. March, p. 119019, 2023, doi: 10.1016/j.ces.2023.119019.

[13] X. W. Li, X. K. Su, L. Gu, X. Y. Wang, and D. J. Fan, "Numerical study on conjugate heat transfer in a liquid-metal-cooled pipe based on a four-equation turbulent heat transfer model," *Nuclear Engineering and Technology*, vol. 55, no. 5, pp. 1802–1813, 2023, doi: 10.1016/j.net.2023.02.011.

[14] H. Saputro *et al.*, "Modeling and experimental study condenser performance of fixed bed pyrolysis reactor: a case study of solid waste palm starch processing," *Cleaner Engineering and Technology*, vol. 16, no. September, p. 100677, 2023, doi: 10.1016/j.clet.2023.100677.

[15] S. Bhattacharjee and M. Delichatsios, "Predicting the pyrolysis temperature for thermally thin fuels in opposed-flow flame spread in the thermal regime," *Proceedings of the Combustion Institute*, vol. 39, no. 3, pp. 3871–3878, 2023, doi: 10.1016/j.proci.2022.07.246.

[16] P. Hatefirad and A. Tavasoli, "Effect of acid treatment and Na2CO3 as a catalyst on the quality and quantity of bio-products derived from the pyrolysis of granular bacteria biomass," *Fuel*, vol. 295, no. November 2020, p. 120585, 2021, doi: 10.1016/j.fuel.2021.120585.

[17] M. S. Abbas-Abadi *et al.*, "Challenges and opportunities of light olefin production via thermal and catalytic pyrolysis of end-of-life polyolefins: towards full recyclability," *Progress in Energy and Combustion Science*, vol. 96, no. October 2022, p. 101046, 2023, doi: 10.1016/j.pecs.2022.101046.

[18] Y. Shao *et al.*, "Sequential pyrolysis for understanding specific influence of cellulose- and lignin-derived volatiles on properties of counterpart char," *Green Chemical Engineering*, no. March, 2023, doi: 10.1016/j.gce.2023.04.004.

[19] H. Tian, R. Zhu, L. Chen, J. Wang, and Y. Cheng, "Aromatic hydrocarbons rich bio-oil production from Miscanthus pyrolysis by coupling torrefaction and MoO3/ZSM-5 dual catalysis process," *Industrial Crops and Products*, vol. 204, no. PA, p. 117314, 2023, doi: 10.1016/j.indcrop.2023.117314.

[20] D. Tamburini, C. R. Cartwright, P. Gasson, J. J. Łucejko, and C. L. D. Leme, "Using analytical pyrolysis and scanning electron microscopy to evaluate charcoal formation of four wood taxa from the caatinga of north-east Brazil," *Journal of Analytical and Applied Pyrolysis*, vol. 151, no. July, 2020, doi: 10.1016/j.jaap.2020.104909.

[21] X. Yue *et al.*, "Conversion of highly polymerized lignin into monophenolic products via pyrolysis: a comparative study of acidic and alkaline depolymerization pretreatments using deep eutectic solvents," *Chemical Engineering Journal*, vol. 478, no. November, p. 147368, 2023, doi: 10.1016/j.cej.2023.147368.

[22] C. Zhao, E. Jiang, and A. Chen, "Volatile production from pyrolysis of cellulose, hemicellulose and lignin," *Journal of Energy Institute*, vol. 90, no. 6, pp. 902–913, 2017, doi: 10.1016/j.joei.2016.08.004.

[23] Y. N. Tu, D. Zhou, H. Liu, W. Tang, W. Wu, and Y. Li, "Insight into enhanced photogeneration mechanism of reactive intermediates from dissolved black carbon by co-pyrolysis of plastics and biomass," *Environmental Technology and Innovation*, vol. 33, no. November 2023, 2024, doi: 10.1016/j.eti.2023.103482.

[24] A. O. Otieno, P. G. Home, J. M. Raude, S. I. Murunga, and A. Gachanja, "Heating and emission characteristics from combustion of charcoal and co-combustion of charcoal with faecal char-sawdust char briquettes in a ceramic cook stove," *Heliyon*, vol. 8, no. 8, p. e10272, 2022, doi: 10.1016/j.heliyon.2022.e10272.

[25] Y. Guo *et al.*, "Ecotoxicology and environmental safety release of biogenic volatile organic compounds and physiological responses of two sub-tropical tree species to smoke derived from forest fire," *Ecotoxicology and Environmental Safety*, vol. 275, no. July 2023, 2024, doi: 10.1016/j.ecoenv.2024.116250.

[26] M. Afraz *et al.*, "Production of value added products from biomass waste by pyrolysis: an updated review," *Waste Management Bulletin*, vol. 1, no. 4, pp. 30–40, 2024, doi: 10.1016/j.wmb.2023.08.004.

[27] A. P. da Luz Corrêa, P. M. M. da Silva, M. A. Gonçalves, R. R. C. Bastos, G. N. da Rocha Filho, and L. R. V. da Conceição, " Study of the activity and stability of sulfonated carbon catalyst from agroindustrial waste in biodiesel production: Influence of pyrolysis temperature on functionalization," *Arabian Journal of Chemistry*, vol. 16, no. 8, 2023, doi: 10.1016/j.arabjc.2023.104964.

[28] Akinpelu *et al.*, "Machine learning applications in biomass pyrolysis: From biorefinery to end-of-life product management," *Digital Chemical Engineering*, vol. 8, no. May, 2023, doi: 10.1016/j.dche.2023.100103.

BIOGRAPHIES OF AUTHORS

Muhammad Fathuddin Noor was born in Purwokerto, Indonesia, in 1976 received the B.S. degree obtained from Brawijaya University/Department of Mechanical Enginering, Malang, Indonesia in 2000 while M.T. degree obtained in 2006 in the same department. Currently continuing Doctoral Program (S3) in Agricultural Technology, Brawijaya University. His research interests include energy conversion machinery and renewable energy, with a particular focus on recent studies related to industrial agriculture. He can be contacted at email: fathuddin@student.ub.ac.id.

Sumardi Hadi Sumarlan professional experience in post-harvest handling techniques for cereal and horticultural products, designer and implementer of biogas installations, product handling systems for storage packaging and warehousing (as resource trainer). Research and publication experience: 1) analysis of the drying process for cereal products, 2) engineering of the drying process using solar collectors, 3) engineering of making bioplastics from various tuber products, 4) engineering of the preservation process using pulse electric field (PEF), 5) processing various kinds of fruit and sweet potato chips using vacuum frying. He can be contacted at email: smardihsb@ub.ac.id.

Yusuf Hendrawan is an expert in the fields of bio-instrumentation, control, and systems engineering. One implementation is the development of a plant factory or so-called also a fully controlled closed bioproduction system based on plant response-based sensing. Another area of expertise is the application of non-destructive sensing in agriculture for both pre-harvest and post-harvest products. Another skill related to the industrial revolution 4.0 in the agricultural sector is the application of the internet of things (IoT) and artificial intelligence (AI) for modeling and solving optimization problems in the field of agricultural engineering. He completed his Ph.D. in Applied Life Sciences at Osaka Prefecture University Japan. He can be contacted at email: yusuf_h@ub.ac.id.

Bambang Dwi Argo is currently an active teaching staff in the bioprocess technology study program, Department of Agricultural Engineering, Faculty of Agricultural Technology, Brawijaya University since 2014. Master's and Ph.D. education was completed at the National Institute of Science Applique Toulouse, France in the field of Engineering and Energy Systems from 1989 to 1994. His professional experience while leading TSSU resulted in many tool and machine designs, especially in the agro-industrial sector, which have been implemented throughout Indonesia. Apart from that, experience providing training in the design, implementation and maintenance of various tools and machines organized by either government or private institutions. He can be contacted at email: dwiargo@ub.ac.id.

Hartawan Abdillah is an expert in the fields of electronic-instrumentation, programming, control, and systems engineering. Completed an Associate Degree (D3) at the Faculty of Engineering, State University of Malang, Indonesia from 2013 to 2016. The title of his thesis is "Energy Conversion Controller in Solar Panels". Continuing Bachelor of Engineering Science (S.T) education at the Faculty of Engineering, State University of Malang, Indonesia from 2016 to 2019. Obtained a Master of Engineering (M.T) degree in the Electrical Engineering Study Program, State University of Malang, Indonesia in 2021. His thesis was entitled "Monitoring the influence of sunlight intensity on the power performance and efficiency of solar power plants using radio frequency in multi-storey buildings". He can be contacted at email: abdillahhartawan@upm.ac.id.