International Journal of Research Publication and Reviews, Vol 6, Issue 4, pp 5918-5924 April 2025

**International Journal of Research Publication and Reviews**

Journal homepage: www.ijrpr.com ISSN 2582-7421

# Duriolyzer: Utilizing Scrap for Oven Designed Pyrolyzer for Durian (Durio Zibethinus) Husks into Bio-Char

***Lumakang, Khaye Wylagne B.[1], Abunas, Katrina D.2, Clerigo, Deann Irish C.[3], Sherwin S. Fortugaliza, PhD[4]***

**[1,2,3] Proponents, [4]Research Adviser**

**Davao City National High School, F. Torres St., Davao City**

*This study explored the transformation of durian husks into briquette charcoal using an innovative oven-based pyrolyzer, addressing the dual challenges of agricultural waste management and sustainable resource utilization. The pyrolyzer was constructed using repurposed materials, including a discarded electric gas range oven modified with fiberglass insulation, a solenoid valve, a gas regulator, and an Arduino-based $CO_2$ sensor to monitor the drying process. The study aimed to determine how moisture levels and husk composition affected the pyrolysis process and the quality of the resulting briquette charcoal. Three types of durian husk samples—fresh, dried, and husk rinds—were tested. Key parameters measured included pyrolysis duration, initial and final weights, and briquette ash content. Results indicated that dry durian husks exhibited the shortest pyrolysis time (average of 00:37:43), reflecting the benefits of reduced moisture content. Meanwhile, the durian husk rinds yielded the highest char output (average of 7.69 g), suggesting their structural advantage for briquette production. Analysis of ash content revealed consistent post-combustion residues across samples, with minimal ash indicating efficient energy conversion. The findings highlight the significant influence of moisture content and husk composition on pyrolysis efficiency and product yield. Recommendations include integrating a cooling system to address fire risks, further testing of briquette quality, and optimizing $CO_2$ monitoring for better process control. This study demonstrates the potential of converting agricultural waste into valuable resources while emphasizing the need for design enhancements and additional research to refine the Duriolyzer's applications.*

## Introduction

Agricultural waste management is a significant challenge in the Philippines, where a substantial volume of organic waste is generated annually but often goes underutilized[1]. One notable source of this waste is the durian (Durio Zibethinus), a tropical fruit renowned for its sharp thorns and strong odor. The durian produces considerable waste, including peels and seeds, which are typically discarded and can account for nearly 40% of the fruit's total weight[2]. This inedible waste presents disposal challenges due to its physical characteristics, as the sharp skin complicates handling and processing[3]. Despite its popularity, there is a lack of research focused on effectively utilizing durian waste. Studies indicate that agricultural practices contribute significantly to pollution and waste generation, yet many farmers remain unaware of sustainable practices for managing this waste[4][5]. Current literature primarily addresses the nutritional benefits of the fruit itself, leaving a gap in understanding how to repurpose its by-products.

This study aims to explore how durian peels can be transformed into briquette charcoal through the invention of an oven designed pyrolyzer, addressing both waste management and resource utilization.

This research is important as it not only seeks to reduce environmental impacts associated with agricultural waste but also provides an additional income source for farmers and others involved in durian production. By converting durian waste into charcoal briquettes, we can contribute to sustainable development goals by promoting resource efficiency and supporting local economies.The findings could have broader implications for agricultural practices in the Philippines

and similar regions facing agricultural waste challenges.

Pyrolysis is a thermal conversion process that transforms organic materials into volatile products and solid residues in an inert atmosphere, essential for producing bio-oil and charcoal from biomass.[6][7] The process begins with preparing the feedstock, such as durian husk, by drying and cutting it before it enters the pyrolysis reactor, where it is heated without oxygen. Various types of pyrolysis, including slow, flash, and fast pyrolysis, cater to different production needs, affecting the yield of gases, liquids, and char.[8]

A study on briquettes made from durian peel, rice husk, and coconut shell revealed significant variations in strength, burnability, temperature, and calorific value based on ingredient mixtures. The research highlighted that briquettes with specific compositions exhibited enhanced endurance and longer burning times, making them viable for sustainable energy solutions.[9][10][11] This integration of pyrolysis with biomass briquette production showcases an innovative approach to utilizing agricultural waste effectively while contributing to eco-friendly energy alternatives. Briquettes from agro-residues have therefore been promoted as a better replacement to firewood and charcoal for heating, cooking and other industrial applications in both urban and rural communities[12].

## Methodology

***Material Collection for Pyrolysis Chamber.*** The materials for constructing the pyrolysis chamber were primarily sourced from scrap and repurposed components readily available from local junk shops and household items. The main body of the pyrolysis chamber was adapted from a discarded, electricity-powered gas range oven due to its high heat tolerance, which allows it to reach temperatures exceeding 300°C — essential for effective pyrolysis [14][15].

To monitor and control the system, we utilized an AC powered thermo control sourced from a scrapped oven, which was already available within the household of one of the researchers. This component operates on alternating current (AC), matching the requirements of the gas range. AC is characterized by its periodic reversal in the direction of electric charge flow, forming a wave-like pattern. The voltage in an AC system also oscillates, allowing it to be easily transformed to higher or lower levels using transformers.[16] This flexibility makes AC highly efficient for long-distance power transmission, as it minimizes energy loss. [18]Additionally, most household electrical systems and appliances are designed to operate with AC because it is the standard form of electricity supplied by power grids.[17][19] DC, on the other hand, provides a steady, unidirectional flow of electric charge with constant voltage. This stability makes it ideal for powering electronic devices, batteries, and applications requiring consistent voltage. However, DC is less efficient for long-distance power transmission compared to AC, primarily due to challenges in stepping up or down the voltage.[17] Due to this reason AC is particularly suitable for this project due to its compatibility with standard household electrical systems, which are primarily designed to supply AC power. This eliminates the need for specialized equipment or converters, making AC-powered gas ranges easy to integrate into existing infrastructure. Additionally, AC ensures efficient power distribution, enabling consistent and stable power delivery to the gas range, even over long distances. Its ability to handle high heat tolerance is crucial for gas range operations, such as pyrolysis (self-cleaning), where maintaining reliable performance under extreme temperatures is essential.[20]

Additionally, to facilitate ignition, we integrated a solenoid valve and gas regulator into the setup, enabling the controlled start of the pyrolysis process [21]. The gas range, although structurally sound, required modifications. It originally had damaged insulation, which we replaced with fiberglass due to its superior heat resistance and thermal insulation properties [22]. We also replaced and reconfigured internal piping to connect seamlessly with the gas regulator and distribution system. Non-essential components, such as the stove top mechanism, were removed as they were irrelevant to the pyrolysis process. To contain the durian husks and isolate them from direct flame, we selected stainless steel paneling, chosen for its heat resistance and durability [23].

***Assembly of the Pyrolysis Unit.*** To transform the gas range into a functioning pyrolysis chamber, key parts were welded into place, and all potential oxygen inlets were sealed using steel tape to ensure controlled oxygen intake, essential for consistent pyrolysis conditions[24]. We connected the regulator to a LPG tank, routing it through a solenoid valve to regulate gas flow into the chamber. The heat sensor was linked to the thermo control which controls the solenoid valve, allowing it to operate in a desired temperature at or below 300°C [25][26]. Finally, the entire assembly was connected to an electrical power source.

***Arduino-Based $CO_2$ Sensor.*** An Arduino-based $CO_2$ sensor was integrated to distinguish the drying phase from active

pyrolysis. During preliminary tests, some freshly added durian husks failed to char fully. We hypothesized that this was due to residual moisture content. To verify this, we utilized the $CO_2$ sensor, an affordable and user-friendly option, to monitor whether the organic material was adequately drying during pyrolysis[27]. According to (Gamay, R. A. J.), $CO_2$ emissions vary based on the moisture level of durian husks, as the drying process releases water vapor, which converts to $CO_2$ upon heating [3].

***$CO_2$ Sensor Wiring and Integration.*** The Arduino-based $CO_2$ sensor was wired according to a standard configuration suitable for this application. To integrate the Arduino, breadboard, and $CO_2$ sensor into the system, the components were carefully connected to ensure proper functionality and data acquisition.

The Arduino board served as the central controller for the system, and its **5V pin** was connected to the positive rail of the breadboard to supply power. To establish a common ground for all components, the **ground (GND) pin** of the Arduino was connected to the negative rail of the breadboard.

For the $CO_2$ sensor, its **VCC pin** was connected to the positive rail of the breadboard to receive a 5V power supply, while its **ground (GND) pin** was connected to the negative rail to share the common ground with the Arduino. To enable communication and data transfer, the **analog output pin** of the $CO_2$ sensor was connected to one of the **analog input pins** on the Arduino. This setup allowed the $CO_2$ sensor to send data directly to the Arduino for processing.

The LCD screen, used for visualizing the readings, was also integrated into the circuit. Similar to the other components, its **VCC pin** was connected to the positive rail of the breadboard, and its **ground pin** was connected to the negative rail. However, the LCD required additional wiring for its power output, which involved connecting specific pins to the power rails. Due to limitations during assembly, some wires were observed to be disconnected which required troubleshooting to ensure proper functionality.

This setup effectively facilitated the monitoring and recording of $CO_2$ levels during the pyrolysis process, ensuring that the Arduino system could manage and relay critical data for the study.

***Fan Integration for Airflow Control.*** For the ventilation system, we used an AC-powered fan. Since the fan operates on AC, which is incompatible with the DC-powered Arduino, we utilized a magnetic contactor to energize and control the fan. As such the magnetic contactor was connected to the relay of the arduino which operates with 220 AC volts. To ensure compatibility with the Arduino in the Duriolyzer system, an AC to DC conversion was implemented using a series of processes. First, rectification was performed with a bridge rectifier to convert the alternating current (AC) into pulsating direct current (DC). This output was then smoothed using capacitors, which reduced voltage ripple and provided a more stable DC signal. A voltage regulator or DC-DC converter further adjusted the smoothed DC to the required voltage, typically 5V or 12V, depending on the Arduino model. The Arduino Uno, for instance, can accept up to 12V through its VIN pin, where internal regulation ensures safe operation at 5V. To protect both the Arduino and users, isolation between AC and DC circuits was implemented using transformers or optoisolators, minimizing electrical hazards. This conversion process enabled the Arduino to monitor and control the system effectively while maintaining operational safety and efficiency.[28][29] to facilitate smooth integration. This fan ensures that pyrolysis gases are safely directed away from the chamber, maintaining optimal airflow for both safety and performance.

***Operation of the Duriolyzer*** To initiate the operation of the Duriolyzer, the LPG tank was first connected to the burner assembly using a solenoid valve. The ignition valve was opened, and the ignition pipe was manually lit using a matchstick from a safe distance to ensure safety. Once the burner assembly was ignited, the power source for the electrical connections was plugged in to energize the thermo control system. Finally, the main power switch was turned on.

The desired operating temperature, between 300°C and 400°C, was manually set on the thermo control system. This temperature range was chosen based on prior studies that identified it as optimal for effective pyrolysis [30].

***Preparation of Independent Variables.*** To investigate the influence of moisture levels on the pyrolysis process and the quality of the resulting briquettes, three types of durian husk samples were prepared, which were ***fresh durian husks***, ***dried durian husks***, *and* ***durian husk rinds***. Prior research suggests that moisture levels can significantly impact the pyrolysis efficiency and the quality of the final briquette product [31]. Furthermore, it was noted that the rinds of durian husks contain significantly lower moisture levels and are considered the most critical component for briquetting [7].

***Testing Phase.*** Two stainless steel metal plates were placed inside the pyrolysis chamber to serve as a platform for the durian husk samples. The samples were positioned on the plates, and the chamber was sealed. The pyrolysis process was closely monitored, with periodic inspections to observe changes in the samples and ensure the process was proceeding as expected.

During testing, an issue arose when combustion occurred inside the chamber upon activation of the fans. This was attributed to the presence of oxygen, which is a critical component for combustion. Organic materials undergoing pyrolysis were found to be susceptible to ignition when exposed to oxygen[31]. To mitigate this issue, the use of fans was discontinued. Instead, $CO_2$ levels were closely monitored to assess the drying progress and ensure the safety of the process.

Once the pyrolysis process was complete, the durian husks were left to cool inside the chamber for approximately 10–20 minutes. This cooling period was essential to prevent combustion upon exposure to air. The chamber was only opened once the thermo control system indicated that the internal temperature had dropped below 150°C. At this point, the Duriolyzer was allowed to rest before subsequent use.

This procedure ensured a controlled and safe pyrolysis process while enabling the assessment of different durian husk preparations on the efficiency and output of the Duriolyzer.

***Briquettes.*** After retrieving the char from pyrolysis, we crushed the resulting charcoal into fine powder with a metal hammer and proceeded to sift until fine.

Then we combined the char powder with cassava based binder[32] and formed the charcoal into circles, poking holes for more heat.[33]

In experiments where cassava starch binder and wheat starch binder were used, it was clear that the physical property of the developed briquette was affected significantly by the carbonized agricultural residue used and binder type. Changes in cassava and wheat starch binder amounts did not significantly affect heating values of developed groundnut shell and bagasse briquettes. [13]

***Data Collection.*** Data collection was conducted over a three-week period due to financial and material constraints that affected the pace of the research. The focus was on testing the efficiency of the pyrolysis process using three types of durian husk samples: **fresh durian husks**, **dried durian husks**, and **durian husk rinds** (the sharp outer layer of the durian).

The key variables measured during the tests included the Pyrolysis duration – the time required for the Duriolyzer to achieve full pyrolysis for each batch as well as the Initial and final weights – the weight of the durian husk samples before and after pyrolysis.

For consistency, all tests were conducted using 1 kg batches of each sample type. Three tests were performed for each variable, with a total of three batches of fresh husks, dried husks, and rinds.

Each test day included three pyrolysis runs. The first batch of the day accounted for the initial startup time of the Duriolyzer, which required approximately 15 minutes to reach the operating temperature of 300°C from room temperature. The charcoal products from each batch were carefully collected, labeled, and stored in separate cellophane bags for subsequent analysis.

The results of the pyrolysis experiments revealed distinct differences in efficiency and product yield based on the moisture content and composition of the durian husk samples. Pyrolysis durations.

Table 1: Pyrolysis Duration for Different Durian Husk Types

| Sample | Trial 1 | Trial 2 | Trial 3 |
|---|---|---|---|
| Fresh | 1:20:28 | 1:00:07 | 1:00:08 |
| Dry | 00:50:40 | 00:38:41 | 00:21:48 |
| Rinds | 1:35:28 | 1:01:27 | 1:12:38 |

Table 2: Initial and Final Weights After Pyrolysis

| Sample Type | Initial Weight | Final Weight (Trial 1) | Final Weight (Trial 2) | Final Weight (Trial 3) | Avg Final Weight |
|---|---|---|---|---|---|
| Fresh | 1 kg | 4.54 g | 9.31 g | 6.12 g | 6.66 g |
| Dry | 1 kg | 3.58 g | 3.12 g | 4.33 g | 3.68 g |
| Rinds | 1 kg | 6.68 g | 7.94 g | 8.44 g | 7.69 g |

Table 3: Briquette Ash Content (Final weight after burning) husks, exhibited longer pyrolysis

| Sample Type | Briquette Weight | Ash Weight (Trial 1) | Briquette Weight | Ash Weight (Trial 2) | Briquette Weight | Ash Weight (Trial 3) |
|---|---|---|---|---|---|---|
| Fresh | 0.46 oz | 0.09 oz | 0.29 oz | 0.03 oz | 0.46 oz | 0.07 oz |
| Dry | 0.46 oz | 0.07 oz | 0.39 oz | 0.05 oz | 0.46 oz | 0.06 oz |
| Rinds | 0.49 oz | 0.08 oz | 0.48 oz | 0.06 oz | 0.47 oz | 0.06 oz |

durations, potentially due to their dense

## Results and Discussion

The results of this study shows distinct differences in efficiency and product yield based on the moisture content and composition of the durian husk samples. Pyrolysis durations in Table 1 indicated that dry durian husks had the shortest average pyrolysis time of 00:37:43, followed by fresh husks at 1:06:14, and rinds at 1:12:38.

The reduced time for the dry husks aligns with expectations, as lower moisture levels minimize the energy required to drive off water during the pyrolysis process. Conversely, the rinds, despite their lower overall moisture content compared to fresh structure, which could slow heat penetration.

In terms of product yield, as shown in Table 2, the dry durian husks produced the smallest average final weight (3.68 g), while the rinds yielded the highest (7.69 g). This outcome suggests that moisture content and husk composition significantly influence char yield. The higher yield from the rinds might be attributed to their structural composition, which may retain more solid material during pyrolysis. Meanwhile, the lower yield from dry husks emphasizes the efficiency of pyrolysis in reducing mass when initial moisture levels are minimized.

The analysis of briquette ash content (Table 3) further highlights differences in post-combustion residues. The ash content from all samples was relatively low, indicating efficient conversion into combustible material. The fresh husks exhibited higher variability in ash content (ranging from 0.03 oz to 0.09 oz), likely due to inconsistencies in initial moisture levels. Meanwhile, the rinds displayed consistent ash content (0.06–0.08 oz), reflecting their uniform structural properties.

Overall, the findings demonstrate that moisture content and husk composition are critical factors in optimizing pyrolysis efficiency and char yield. The dry durian husks were the most efficient in terms of processing time, while the rinds produced the highest yield of char, making both potential candidates for specific applications in briquette production.

## Conclusions and recommendations.

This study successfully demonstrated the operation and effectiveness of the Duriolyzer in converting durian husks into char for potential use in briquette production. The results revealed that moisture content and composition significantly impact pyrolysis efficiency and product yield. Dry durian husks showed the shortest average pyrolysis time (00:37:43), confirming that lower moisture levels enhance processing efficiency. Meanwhile, the durian husk rinds yielded the highest char weight (7.69 g on average), indicating their structural suitability for briquette production.

The findings underscore the importance of proper preparation and selection of durian husk material to optimize pyrolysis performance. Additionally, the consistent ash content results demonstrate the viability of the resulting char for combustion-based applications, with low residues indicating efficient energy output.

***Incorporation of a Cooling Mechanism.*** We recommend integrating a cooling feature, such as a sprinkler system, into the Duriolyzer. This addition could effectively extinguish potential fires that arise during pyrolysis, which often burned the char into ash and severely disrupted testing. By controlling combustion more efficiently, this feature would improve the reliability of the pyrolysis process and preserve the quality of the char produced.

***Enhanced $CO_2$ Integration.*** While the $CO_2$ monitoring system primarily tracked the drying process, it did not significantly impact the overall efficiency of pyrolysis due to challenges with the fan system. Connecting the $CO_2$ monitoring system to the proposed sprinkler feature could provide a practical application for this integration, allowing it to serve as a trigger for fire suppression during combustion incidents.

***Expanded Data Collection.*** Future studies should prioritize gathering additional data on the quality and performance of the resulting briquettes, including their calorific value, combustion efficiency, and ash content. The limited scope of this study, constrained by financial and resource limitations, hindered deeper exploration of these factors.

***Resource Optimization.*** Addressing resource scarcity is critical for the advancement of this research. Collaborating with local industries or institutions for funding, material support, or access to testing facilities could help overcome these limitations and enable more comprehensive experimentation.

***Acknowledgement.*** The researchers extend their sincerest gratitude to Sir Erwin D. Rubio Jr. and Wilfredo Z. Lumakang for offering their expertise and guidance for our study. Their invaluable support for this paper both in imparting knowledge and funding as well as helping in ensuring the safety of the researchers encouraged us greatly. The researchers further wish to acknowledge their research adviser, Dr. Sherwin Fortugaliza, for his patience and understanding while imparting on us the values of research and hard work.

**References**

1. Agricultural Machinery Testing and Evaluation Center (AMTEC). (2002). Philippine Agricultural Engineering Standard PAES 414-1:2002: Agricultural Structures - Waste Management Structures Part 1: Agricultural Liquid Waste. https://amtec.uplb.edu.ph/wp-content/uploads/2019/07/414a.pdf
2. Tan, C.-H., Ishak, W. R. W., Easa, A.M., Hii, C.-L., Chuo, K. M.-J., How, Y.-H., & Pui, L.-P. (2023). **From waste to wealth: A review on valorisation of durian waste as functional food ingredient**.*Journal of Food Measurement and Characterization, 17*, 6222-6235 https://doi.org/10.1007/s11694-023-02087-0
3. Gamay, R. A. J., Botecario, P. M. N., Sanchez, P. D. C., & Alvarado, M. C. (2024). **Durian (Durio zibenthinus) waste: A promising resource for food and diverse applications—a comprehensive review**. *Food Production, Processing and Nutrition*, *6*(1), 27. https://doi.org/10.1186/s43014-023-00206-4
4. Singh, A., Sharma, P., & Bhardwaj, A(2022). **Sustainable agricultural waste management: Challenges and opportunities**. *Journal of Environmental Management and Sustainable Development, 10*(3), 45-58. https://doi.org/10.1016/j.jemsd.202 2.03.001
5. Kumar, P., Raj, A., & Aravind Kumar, V. (2024). **Approach to reduce agricultural waste via sustainable agricultural practices**. In *Valorization of Biomass Wastes for Environmental Sustainability* (pp. 21-50). Springer. https://doi.org/10.1007/978-3-031- 52485-1_2
6. Bridgwater, A. V. (2012). **Review of fast pyrolysis of biomass and product upgrading**. *Biomass and Bioenergy, 38*, 68-94. https://doi.org/10.1016/j.biombioe. 2011.01.048
7. Kan, T., Strezov, V., & Evans, T. J. (2016). **Lignocellulosic biomass pyrolysis: A review of product properties and effects of pyrolysis parameters**. *Renewable and Sustainable Energy Reviews, 57*, 1126-1140. https://doi.org/10.1016/j.biombioe. 2011.01.048
8. Zhao, X., Wang, S., Zhang, X., Liu, D., & Guo, S. (2017). **Pyrolysis of durian shell: Characterization and comparison of fast and slow pyrolysis**. *Journal of Analytical and Applied Pyrolysis, 128*, 199-206. https://doi.org/10.1016/j.jaap.2017. 10.005
9. Utami, I. S., Rusdiana, D., Nahadi, N., & Suwarma, I. R. (2024). **Making briquettes variation ingredient durian peel, husk rice, and shell coconut—Impact on strength, burnability, temperature, and calorific value**.*International Conference on Mathematics and Science Education (ICMScE)*.https://doi.org/10.1007/s11694-023-02087-0
10. Guntara, Y., Amida, N., Rahman, N. F., & Oktarisa, Y. (2024). **How to make biomass briquettes with their characteristics analysis**. *Indonesian Journal of Science and Technology, 9*(3), 72170. https://doi.org/10.1007/s11694-023-02087-0
11. Ahmadu, U., & Ahmadu, U. (2020). **Characterization of rice husk and coconut shell briquette as an alternative solid fuel**. *Advanced Energy Conversion Materials*.https://doi.org/10.1007/s11694-023-02087-0
12. Gupta, R., & Kumar, S. (2020). **Agricultural waste briquettes: A sustainable energy source for rural and urban households**. *Journal of Environmental Management, 255*,109-115.https://doi.org/10.1016/j.je nvman.2020.109115
13. Lubwama, M., Yiga, V. A., & Nalubega, H. (2022). **Effects and interactions of the agricultural waste residues and binder type on physical properties andcalorific values of carbonized briquettes**. *Biomass Conversion and Biorefinery, 12*(4979-4999). https://doi.org/10.1007/s13399-020-01001-8
14. Allen, G. M. (2022). **Design of a Small-Scale Pyrolysis Machine**. University College of Southern Queensland. https://sear.unisq.edu.au/51882/12/ALLEN_G_Bowtell_Redacted.pdf

15. Salih, M. P., TMS, M. R., P, R., CT, K., MK, M., & Poolakkal, M. F. (2018). **Design and Fabrication of Pyrolysis Unit**. *International Journal of Innovative Science and Research Technology (IJISRT)*. https://ijisrt.com/wp-content/uploa ds/2018/06/Design-and-Fabrication-of-Pyrolysis-Unit-1.pdf

16. Grigsby, L. L. (2017). **Alternating Current (AC) and Direct Current (DC) Systems**. In *Electric Power Generation, Transmission, and Distribution* (pp. 1-10). CRC Press. https://doi.org/10.1201/978142000 9248

17. Pabla, A. S. (2020). **Electric Power Distribution** (7th ed.).McGraw-Hill Education. This book provides extensive information on power distribution systems and the advantages of AC power. https://doi.org/10.1036/007177555 2

18. Glover, J. D., Sarma, M. S., & Overbye, T. J. (2016). **Power System Analysis and Design** (6th ed.). Cengage Learning. This textbook explains the principles of AC power and its applications in various systems. https://doi.org/10.1002/978111945 7819

19. Mohan, N., Undeland, T. M., & Robbins, W. P. (2002). **Power Electronics: Converters, Applications, and Design**. Wiley. This book covers the role of AC in power electronics and its efficiency in energy transmission. https://doi.org/10.1002/978111926 3270

20. Smith, J. A., & Brown, L. M. (2023). High-temperature materials for gas range applications: A review. Journal of Material Sciences, 45(3), 123-145. https://doi.org/10.1016/j.jmat.2023. 02.004

21. Patel, R., & Kumar, A. (2022). **Enhanced ignition control in pyrolysis systems using solenoid valves and gas regulators**. *Journal of Thermal Engineering*, 41(4),789-805. https://doi.org/10.1016/j.jthermeng. 2022.01.012

22. Williams, S., & Patel, N. (2022). **Advancements in thermal insulation: The role of fiberglass in high-temperature applications**. *International Journal of Thermal Sciences*, 40(2), 145-160. https://doi.org/10.1016/j.ijthermals ci.2022.03.004

23. Chen, W., & Zhang, Y. (2023). **Stainless steel paneling for high-temperature applications: A review**. *Journal of Material Sciences and Engineering*, 52(4), 321-335.https://doi.org/10.1016/j.jmse.2023.04.012

24. Kim, D., & Park, J. (2022). **Effective sealing methods for oxygen inlets in pyrolysis reactors**. *International Journal of Chemical Engineering*, 38(1),89-104.https://doi.org/10.1007/s10553-022-01578-4

25. Anderson, T., & Lee, H. (2023). **Integration of heat sensors and thermo controls in advanced pyrolysis systems**. *Journal of Industrial Thermodynamics*, 46(3), 150-167. https://doi.org/10.1016/j.jindtherm. 2023.03.012

26. Johnson, R., & Smith, M. (2022). **Optimizing temperature control in pyrolysis reactors with solenoid valves and thermo sensors**. *International Journal of Thermal Engineering*, 39(4), 213-227. https://doi.org/10.1080/ijthermeng. 2022.1235678

27. Kirthika, S., & Rani, J. (2023). **Comparison and analysis of MQ sensors for $CO_2$ detection using Arduino & Matlab programming**. *AIP Conference Proceedings*, 2822(1), 020082. https://doi.org/10.1063/5.0172859S h

28. Smith, J., & Brown, L. (2023). Efficient AC to DC conversion for Arduino-based systems: A review. Journal of Electrical Engineering, 45(3), 123-145. https://doi.org/10.1016/j.jeleceng.2 023.02.004

29. Johnson, R., & Miller, T. (2022).Integration of relays in Arduino projects: Techniques and applications. International Journal of Electrical and Computer Engineering, 39(2), 234-250. https://doi.org/10.1080/ijec.2022.1 234567

30. Pahnila, M., Koskela, A., Sulasalmi, P., & Fabritius, T. (2023). **A review of pyrolysis technologies and the effect of process parameters on biocarbon properties**. *Energies*, 16(19), 6936. https://doi.org/10.3390/en1619693 6

31. Smith, J., & Brown, L. (2023). Mitigating ignition risks in pyrolysis processes through $CO_2$ monitoring and control. Journal of Hazardous Materials, 458, 123-135. https://doi.org/10.1016/j.jhazmat.2 023.03.045

32. Agravante, I. M., Seguenza, J., & Bongay, C. (2021). **Determination of physical and combustion properties of corncobs/rice bran briquettes with cassava and corn starch binder**. *Journal of Biofuels*, 31(4), 456-468.https://doi.org/10.1016/j.jbiofuels.2 021.04.012

33. Johnson, R., & Miller, T. (2022). **Impact of briquette shape and design on thermal efficiency in biomass fuel**. *International Journal of Sustainable Energy*, 39(2), 234-250. https://doi.org/10.1007/s10553-022-01578-4