JURNAL PENELITIAN Saintek
Vol. 27, No. 1, pp. 1-11 p-ISSN:1412-3991 | e-ISSN: 2528-7036

Energy profile and improvement proposal of a sawdust charcoal briquette factory

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Abstract: This study aimed to analyze the profile of energy consumption and identify efforts to improve energy efficiency. In the present work, the evaluation was focused on the main production lines, including energy utilities sourced from electricity as well as an analysis of thermal energy-based equipment. A medium-scale charcoal plant in Yogyakarta was selected as the object of the present study to represent the characteristics of a sawdust charcoal briquette industry. Measurements of electrical current were made using a clamp meter to determine the utility of the electrical devices while an infrared thermal camera was used to determine the temperature distribution. Results of this study indicate that thermal energy has the largest proportion in the main production line. Some points of heat concentration were found which could potentially cause hazards and thermal discomfort. Ideas for improvement were also proposed qualitatively as a recommendation.

Keywords: *energy consumption, energy efficiency, thermal distribution, thermal comfort, energy conservation*

How to Cite (APA 7th Style): Majid, A. I., Maulana, S., & Prasidha, W. (2022). Energy profile and improvement proposal of a sawdust charcoal briquette factory. *Jurnal Penelitian Saintek*, *27*(1), 1-11. DOI: https://doi.org/10.21831/jps.v1i1.48513

INTRODUCTION

The energy demand always increases worldwide by year. The world is also entering the energy transition era where the usage of renewable energy sources is accelerated to reduce the dependency on fossil-based fuels. One of Indonesia's most potential renewable energy sources is biomass (Simangunsong *et al*., 2017; Primadita, Kumara, & Ariastina, 2020) which can be obtained from various sources, including sawdust charcoals briquette. To fabricate that, the wood powders, obtained from waste of sawn industry or furniture manufacturer, are then pelletized into the briquette form which is further processed to be charcoal (Adegoke & Mohammed, 2002). In practice, this type of solid fuel can be utilized from power generation to reduce dependency on coal, until household applications such as cooking.

There have been many studies related to sawdust charcoal briquette. Most of the studies concerning the mechanical (strength) properties, proximate-ultimate analyses, and calorific value (Antwi-Bosiako & Acheampong, 2016; Rajaseenivasan *et al*., 2016; Akogun *et al*., 2020). Some of the scholars also elaborated on the whole fabrication process (Rotich, 1998; Sanchez, Pasache, & Garcia, 2014). From those studies, it can be elucidated that (1) briquette from sawdust charcoal meets the recommended criteria as good solid fuel, (2) has market potential, especially in the developing countries (Akowuah, Kemausuor, & Mitchual, 2012), and (3) potentially used in wide applications. However, there is still a lack of studies that report the sawdust charcoal briquette on an industrial scale. Interestingly, this type of industry is classified as high-energy demand as it requires both thermal and electrical powers in the production process. Hence, the understanding of the energy profile is useful to control the energy and process efficiencies.

In order to get a comprehensive picture of process effectiveness, a full-scale production process should be studied. By obtaining this fact, we can also propose some improvements in process efficiency. As a case study, we investigated the energy consumption profiles of a large sawdust charcoal briquette plant in Yogyakarta, as an example of a high-energy consumption industry. Meanwhile, the high-temperature features of this factory also tend to affect the human's comfortability in response to the thermal environment, known as thermal comfort. For those reasons, the temperature distributions in "hot spots" should be identified.

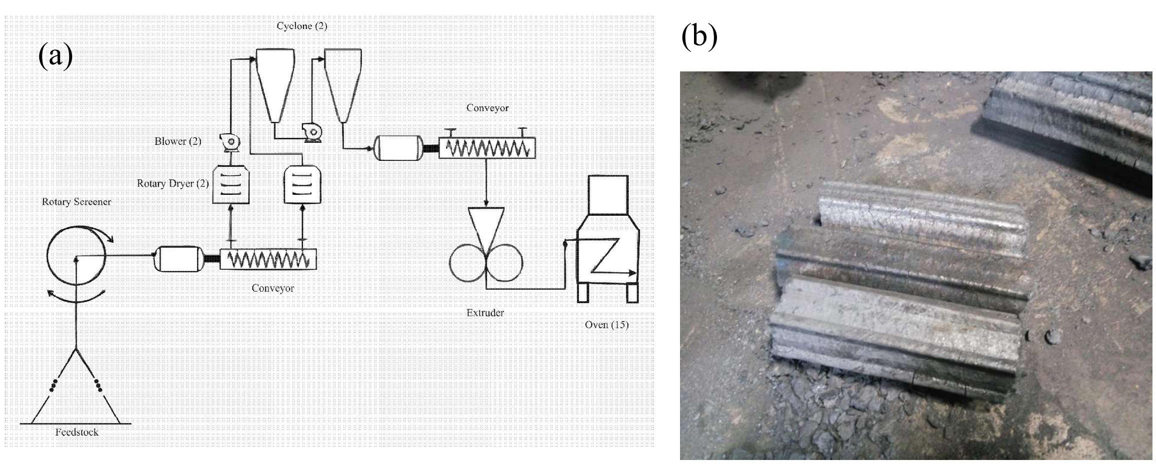
The present study is aimed to address the energy consumption profiles in the main production sector and propose some actions to improve energy efficiency. The contribution of this study is providing some insights on how the energy and temperature characteristics of a sawdust charcoal briquettes factory. Results of this study are expected to be a preliminary representation of a typical industry profile. Furthermore, these studies can also be an input to evaluate and design a thermally comfortable factory related to the workers.

METHOD

Process description and research objects. A medium-scale charcoal plant in Yogyakarta was selected as the object of the present study to represent the characteristics of a sawdust charcoal briquette industry. Figure 1a shows the main production line that becomes the focus in this present study while the results of the charcoal briquette are shown in Figure 1b.

The sawdust (wood powder) is first collected at the feedstock, then it is transported to a rotary screener by the conveyor 1. Those powders are divided into two ways and sent to be dried on the rotary dryers through conveyor 2. The heat generated to dry the powders inside the rotary

Figure 1. (a) Process flow diagram of sawdust charcoal briquettes fabrication; (b) The sample of sawdust charcoal briquettes product after carbonization process (in an oven)



dryers is sourced from the combustion process inside a furnace. To collect the dried particles (and separate them from the hot gas), 2 cyclone separators are used in the next step. The particles are then dispatched to the extruder through a conveyor. In the extruder, the particles are bonded to be a compact hexagonal briquette by mixing them with adhesive paste and molded-in high temperature, called as extrusion process. After that, all the pellets are carbonized to be charcoals by burning them inside an oven.

We focused our observation on the ten devices/spots which are considered as high-energy demand, both electrical and thermal energies. Figure 2 depicts the sketch of the factory and points considered in the present study. The properties of each device are described in Table 1. Here, the definition of an "electrical" energy source is limited to the energy required by the electrical motor of those devices whilst the "thermal" energy is defined as the energy gained by the combustion process to support the system.

Figure 2. Main production line as the focus point of this study (scale 1:500)

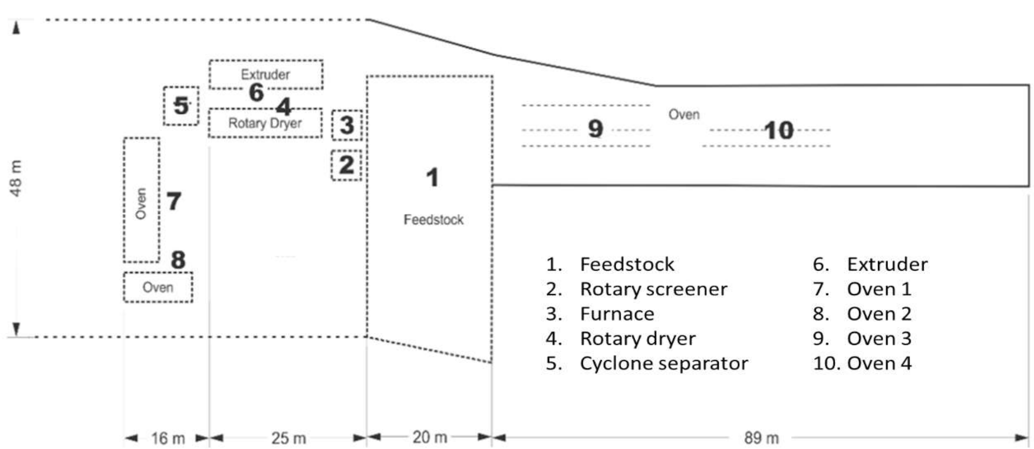


Table 1. Description of each device

Device	Number (unit)	Duration (hour/day)	Energy Source	Remark
Feedstock	1 unit	20	Not studied	Max. capacity: 2000 m^3
Rotary screener	1 unit	20	Electrical	Max. capacity: 768.5 gr/s
Conveyor stockpile	1 unit	20	Electrical	1-phase electrical motor
Rotary dryer	2 units	20	Electrical+ thermal	- 1-phase electrical motor - The combustion process inside the furnace generates heat.
Cyclone	2 units	20	Electrical	3-phase electrical motor.
Extruder	14 units	20	Electrical+ Thermal	- 3-phase electrical motor - Max. capacity: 3.3 kg/min per unit - Hot extrusion process.
Oven	161 units	as needed	Thermal	450 ton (maximum)
Packaging Area	1 unit	20	Not studied	Max. capacity: 4000 m^3

Measurement and analysis. To measure the temperature distribution, a FLIR® IR (infrared) thermal imaging camera was used. This device can detect and measure the thermal radiation of the objects and convert that IR data into an electronic image (Kylili *et al*., 2014). Before acquiring an IR image, the emissivity (e) of the measured object was adjusted in the device to obtain a proper measurement. Hence, the surface temperature of the measured object can be elucidated. This method was also commonly used by previous scholars (Kluczek & Olszewski, 2017; Lucchi, 2018).

In the present study, evaluation of the electrical energy was conducted by re-measurement activities of the effective current of the electrical motors that support main devices. By measuring that, we were then able to calculate the power factor ($\cos\theta$) and compare the actual/real power. A clamp meter was used to measure the current and power factor of the electrical devices, as it was also a suggested tool for energy auditing (Kluczek & Olszewski, 2017). Calculations for the energy required by 3-phase and 1-phase electrical motors (E_{mt}) are presented in the equation (1). For the devices that use a 1-phase electrical motor, we use the equation (2) where V is voltage (volt), I is measured current (Ampere), and t represents time/duration (hour). For 3-phase motor, we assume the $\cos\theta$ value as 0.85.

$$E_{mt} = V.I.t.\sqrt{3}\cos\theta\ (kWh) \quad (1)$$

$$E_{mt} = V.I.t \quad (2)$$

For thermal-related devices such as furnace, extruder, and oven, the energy (E_{th}) – in kWh, is calculated ideally based on the mass, m_{fuel} (kg/hour) and calorific value – CV (kJ/kg) of the feeding materials and neglecting all losses potential (example: radiation heat transfer to the wall, conduction, assuming good insulation, etc), such like the equation (3). The thermal energy calculation data as shown in Table 2.

$$E_{th} = \frac{m_{fuel}.CV}{3600}\ (kWh) \quad (3)$$

Table 2. Thermal energy calculation data (with an assumption of 20 hours usage)

Device	Fuel source	Calorific value (kJ/kg)	Mass required for 20 hours (kg)	Assumption
Furnace	Firewood	18514	400	• CV is taken from Günther *et al*. (2012) of maple wood and Rahmatullah (2014) of mahonia wood. • Using 1 truck of firewood/day (20 hours) = 400 kg.
Extruder	Charcoal briquette	23091	280	• CV is taken from testing result • Use of 20 kg/day (20 hours) for 14 extruders – 280 kg feed masses.
Oven	Wood pallet	25167	2800	• CV is taken from testing result • Use of 70 set x 10 kg per oven, which consists of 4 ovens (1 stack) in 20 hours process = 2800 kg.

In the final part, ideas for improvement are proposed, not only for energy efficiency but also general upgrading scheme for the main device of the observed production line. The proposed suggestions are limited only by qualitative approaches and best practices from the engineering perspective are used in that proposal. Yet, the quantitative impacts (such as economical and energy savings) are not the focus of this study.

FINDING AND DISCUSSION

First, the energy consumption profile is discussed here. These diagrams show the profile of energy consumption of each device corresponding to each energy source. For each calculation, we assume that all devices are used for 20 hours. Figure 3(a) presents the profile of energy required per single electrical device. Amongst the others, the cyclone units require most of the power (46.95%), followed by an extruder (28.34%), and feedstock unit (15.82%) - which consists of a rotary screener and conveyor, and finally the rotary dryer (8.89%). However, if we consider the cumulative units (real usage), as depicted in Figure 3(b), a different proportion is shown. Since there are 14 extruder units, the 3-phase electrical motors used in each extruder unit significantly consume energy (80.73%), followed by blowers used in 2 cyclones (10.76%), feedstock unit (4.43%), and rotary dryers (4.07%). Here, percentage shown in these diagrams are taken from the total energy consumption in each case.

Figure 3. Energy consumption profile: (a) per single device (electrical-based); (b) cumulative calculation of electrical-based devices for 20 hours

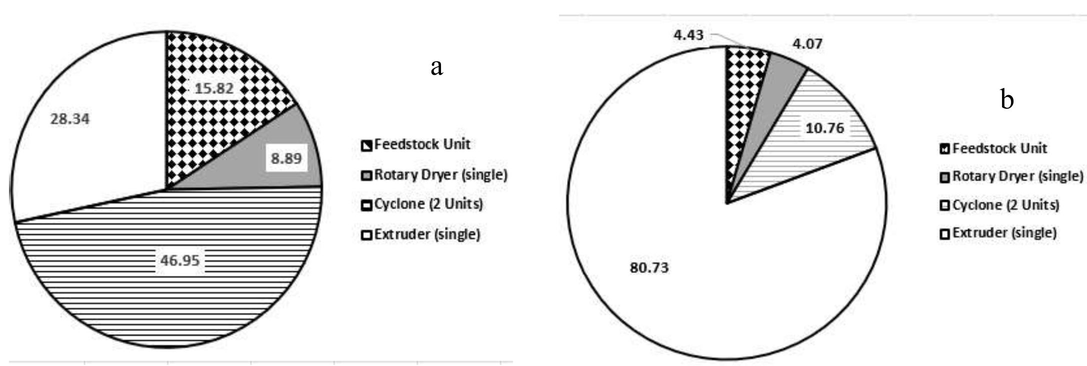


Table 3 addresses the utility report of the main electrical-supported devices used in the main process. The utility is calculated from the comparison of actual versus ideal measurement results (in percentage). In general, most of the devices still perform properly, represented by a well-performed power factor (above 90%). Particularly, the utility values of electrical motors used for fans of the 2 cyclones are not as high as the others (below 85%), especially for the fan cyclone 2 (only 66.38%). This fact can be understood since each fan should provide a large air supply to transport a mixture of air and dried sawdust. Moreover, the cyclone separator itself has a drawback that uses a quite large pressure drop which also potentially affects the energy loss.

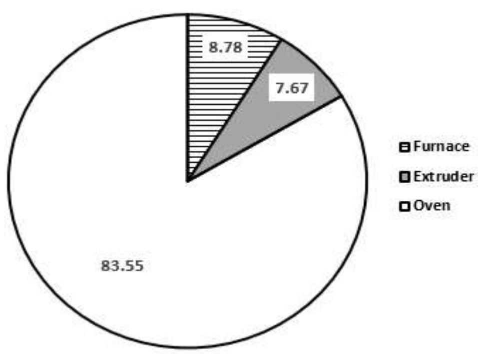
Figure 4 addresses the energy consumption profile of thermal-energy related devices both in percentage and kWh-unit for 20 hours process. Close observation of the figure indicates that the carbonization process in the oven consumes most of the energy (83.55%), followed by the furnace (8.78%), and 14 units of extruder (7.67%). The carbonization process (converting the pallet into charcoal briquette) involves a large amount of mass and using 4 ovens. Therefore, this process requires thermal energy the most.

Total electrical and thermal energies required by each device are presented in Figure 5(a). Energy used by the oven (78.30%) is still dominant, compared to that of the rotary dryer (9.55%), extruder (7.21%), cyclone (3.5%), and feedstock (1.44%). It is a reasonable fact as the

Table 3. Measurement of real power for electrical devices

Objects (Electrical Motor)	Ideal (as per Specifications)			Actual Measurement			Utility (%)
	Voltage (V)	Current (A)	Power (Watt)	Voltage (V)	Current (A)	Power (Watt)	
Conveyor Stockpile 1	220	15.20	3344	220	14.20	3124	93.42
Filter/screener	380	15.33	8566.25	380	14.90	8325.97	97.20
Conveyor Stockpile 2	220	15.20	3344	220	14.90	3278	98.03
Rotary Dryer	380	15.33	8566.25	380	14.80	8270.09	96.54
Fan Cyclone 1	380	42.40	23692.70	380	34.10	19054.74	80.42
Fan Cyclone 2	380	58.00	32409.82	380	38.50	21513.42	66.38
Conveyor 1 (Top)	220	15.20	3344	220	14.20	3124	93.42
Extruder	380	42.40	23692.70	380	41.50	23189.79	97.88
Conveyor 2 (Final)	220	15.20	3344	220	14.50	3190	95.39

Figure 4. Energy consumption profile for thermal devices



Device	Energy required for 20 hours (kWh)
Furnace	2057
Extruder	1796
Oven	19569

first 3 devices not only consume electrical energy to rotate the motor but also thermal energy. On contrary, in the feedstock unit, the most of energy is used to operate a 1-phase motor for the conveyor, so it only needs the smallest energy compared to the others.

Meanwhile, the proportion of electrical and thermal energies is shown in Figure 5(b). In general, the thermal process requires more energy than the electrical power required by the electrical motors (74.36% versus 25.74%). The general trend of this measurement, which shows a thermal energy dominant, is in good agreement with a study from Gentil and Vale (2015) that found that thermic energy dominates the total energy required of sawdust briquettes production.

In the second part, the surface temperature profile of heat-related devices are presented here. Table 4 presents the IR measurement results on the selected hot-spots area such as furnace, extruder, and oven. From those pictures, it is shown that the processes in those devices are heat transfer intensive and have the potential to release excess heat to the surrounding. Results of this measurement can be used as a consideration to further design the thermal discomfort protection and heat excess saving in that factory.

To closely observe, the area around the furnace experiences extremely high temperatures due to the combustion process inside the furnace. Similarly, some points nearby the extruder hot dies also indicate a higher temperature concentration. A good treatment of the locations near the heat cores should be considered by the company to reduce heat loss, increase safety, and the worker's thermal comfort. From these measurements, it can be referred that good heat management in this plant is essentially needed.

Figure 5. (a) Total recap of energies per device; (b) Comparison of energy required by electrical and thermal devices

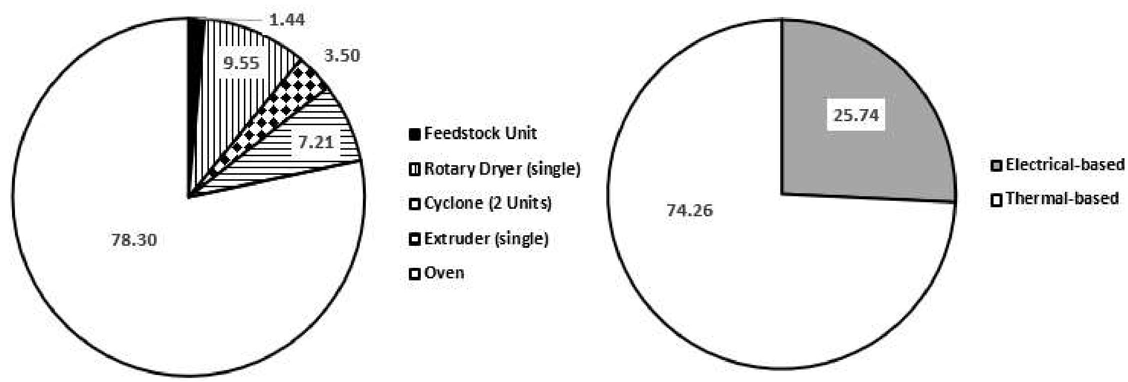
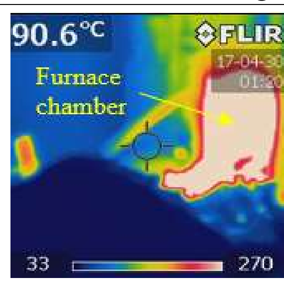
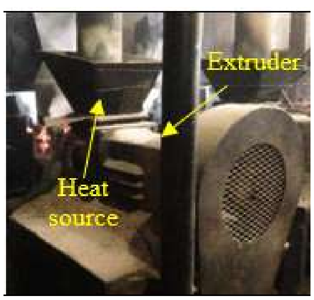
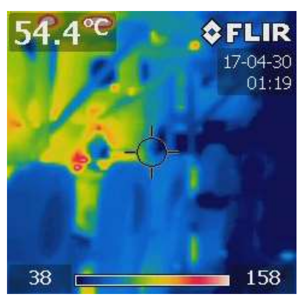
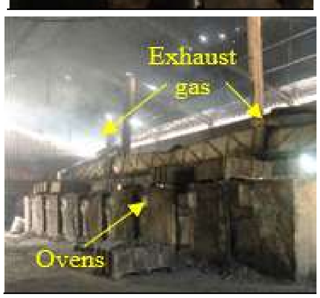
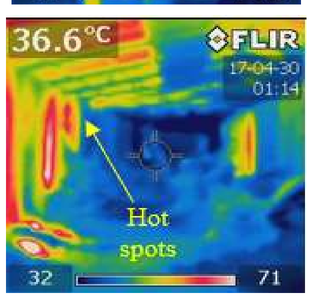


Table 4. Temperature distribution in selected "hot-spot" locations

	Real image	Thermal image	Interpretation
Furnace			• Temperature ranges from 33 to 270°C. • The hottest temperature is concentrated inside the furnace chamber. • The selected point indicates about 90.6°C which is higher than room temperature, located at a few meters beside the furnace. • Potential to affect thermal comfort of the workers in the surrounding.
Extruder			• Temperature ranges from 38 to 158°C. • Measurement was conducted when the pellet extrusion process is running. • The selected point around the extruder's screw is still around 54.4°C which is higher than the room temperature. • Potentially affecting thermal discomfort around the device due to high temperature.
Oven			• Temperature ranges from 32 to 71°C. • Some of the ovens still have a high-temperature region above the room temperature. • Exhaust gas from the burning process of charcoal pallets inside the oven has the potential to affect the thermal comfort of the workers in the surrounding.

Lastly, some ideas for factory improvement, mainly to increase energy efficiency, are also proposed. The feasible actions per unit section, divided as pre-processing (all processes before sawdust are dried), thermal processing step (mostly consists of drying and extrusion steps), and post-processing (carbonizing and packaging processes) are listed in the following tables.

Table 5 shows the proposal of improvement in all stages before powders are dried, known as the pre-processing step. Since the usage of the electrical motor in this stage is still relatively good (see Table 3 above), the improvement should be focused on the optimization of raw materials. The ineffective design or system of the current device contributes to material losses, as shown in Figure 6. Minimizing the material losses can potentially increase the production system to be more economical.

Table 5. Ideas for improvement in pre-processing steps

Section	Improvement Proposal	Expected Impact
Feedstock	• Centralized unloading point. • Feedstock cover and dust filter.	Minimize losses and fly dust from the sawdust powders.
	Pre-treatment of the sawdust raw material by source selection and preheating.	Improve calorific value by moisture reduction and ensuring uniformity of raw material.
Conveyor stockpile	• Put protector in the belt-side • Prohibit non-essential activities or people passing under the belt. • Regular inspection of electrical motor.	• Prevent material losses around the conveyor. • Transporting the material more safely and efficiently.
Rotary screener	Put cartridge around the machine as residual products found nearby.	More efficient use of raw materials.

Figure 6. Snapshots of inefficient usage of raw materials

Table 6 deals with the improvement of core briquetting processes which intensively consume thermal energy. Among the critical points are related to the action to control the temperature and combustion process, exhaust gas management, and fuel diversification. If the factory can resolve those abovementioned problems, it would significantly reduce energy consumption. Figure 7 depicts some heat loss due to an inefficient thermal management system. The presence of flames outside the oven (around the stack) indicates an uncontrolled burning process inside the oven. These phenomena should be controlled so that all heat sources can be converted optimally.

Table 7 lists the improvement proposals for the post-processing steps, for instance, the packaging process. The focus of the improvement proposal is for the forklift and product arrangement, as shown in Figure 8. The proposed ideas are expected to reduce fuel consumption and perform better plant management.

Table 6. Ideas for improvement in thermal-processing steps

Section	Improvement Proposal	Expected Impact
Rotary dryer	Use gas or coal instead of only using wood chips or residual products. • Put measuring device for the blower and fuel supply such as thermocouple and flowmeter. • Exact calculation when supplying fuel instead of current random supply • VSD to control blower when supplying air (not at max. speed). • Semi-automation fuel input and closed system of the furnace. • Signs for the hot or dangerous area. • Heat-resistant cloth for the workers around this spot.	Fuel diversification and lower energy cost of the furnace. • Provide good monitoring and instrumentation system. • Control combustion process efficiently to generate heat for drying process by managing air and/or fuel supply. • Improve Health, Safety, Environment (HSE) system for the workers.
Cyclone separator	• Modification of cyclone geometry by reducing gas inlet and/or enhancing gas outlet. • Installing filter or particle trap near the stack	• Reduce dust content in cyclone exhaust gas (to the surrounding).
Extruder	• Modification of screw geometry • Reduce axle speed of extruder screw • Exhaust fan to absorb extra smoke • Widening of smoke outlet and install dust/ powder catcher around	• Reduce screw wear and increase compaction pressure of the pallets. • Provide better smoke and air circulation around the device.
Oven	• Better arrangement of pallet supply to minimize broken pallets. • Exhaust fan to absorb extra smoke after the carbonization process. • Waste heat utilization for other processes such as preheating of raw materials.	• Minimize material losses. • Reduce smoke pollution generated by the device. • More sustainable fuel usage.

Figure 7. Snapshots of heat losses that cause inefficient energy usage

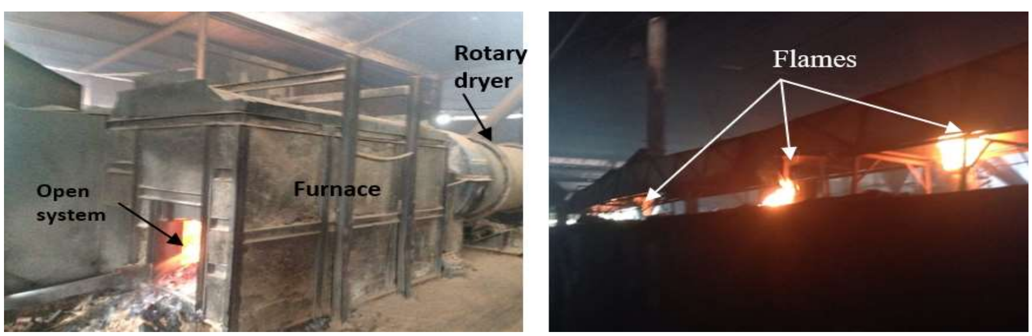


Table 7. Ideas for improvement in post-processing steps

Section	Improvement proposal	Expected impact
Packaging Stockpile	• Migration for electrical forklift or mechanical bikes/cart instead of using diesel engine forklift. • Stop the engine when loading and unloading processes occur. • Labeling and better arrangement of resulting products.	• More optimum usage of fuel in transporting device (forklift). • More effective warehouse management system.

Figure 8. Snapshots of transporting process and warehouse of the final product

Additionally, safety awareness should be also improved. Since the environment is hot and dusty, the workers should wear protective equipment such as heat-resistant clothes and mask. From the observation, not all workers implement that protection. The creation of special signs for production pathways and hazard indicators can improve understanding of hazard levels for any stakeholders in that company. Since a lot of flying sawdust, the factory cleanliness also needs to be improved. Goodwill from the company would accelerate the implementation of the proposed suggestions.

CONCLUSION

A study to evaluate the energy consumption and temperature distribution of a sawdust charcoal briquettes industry in Yogyakarta has been conducted. The present work indicates that the fabrication of sawdust charcoal briquette requires high energy consumption. It is also performed in a high-temperature environment. The average utility of the electrical energy is 84.9 % meaning that most of the electrical motors supporting the devices work sufficiently. In total, this is a thermal-energy dominant process since thermal energy usage is 74.26% of the total energy used (compared to electrical energy).

The sweltering environment in some core devices of the main production line indicates that this factory leads to a potential of heat losses from the main process, even, thermal discomfort for the workers, and the worse, unhealthy work environment. A better heat management system is strongly recommended to improve the plant. From our observation, this factory is still far from the energy-efficient plant. By implementing the proposed improvement steps, it is expected to reach a more efficient energy usage and more optimum production process.

Acknowledgements

The authors would like to express sincere thanks to the late Muhammad Reza Pradecta, David Fernando Sinurat, and the team for the technical supports. We appreciate Nur Wakhid, Denny, and Adi for fruitful discussions and the opportunity to use the data. Priceless support from the Innovation Center for Automotive (ICA) and Heat Transfer Laboratory of Mechanical and Industrial Engineering Department of Universitas Gadjah Mada for measurement devices is greatly acknowledged.

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