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Review of types of biomass as a fuel-combustion feedstock and their characteristics

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KEYWORDS

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Renewable energy sources

Rice husks

Sawdust

Sustainable energy development

ABSTRACT

Biomass is organic matter produced through photosynthetic techniques, each within the form of products and waste. Biomass energy sources have several benefits; amongst others, renewable power to provide sustainable energy sources. Biomass resources are all organic materials that can be renewed, including plants and trees specifically for that energy, food crops, agricultural waste, forestry waste and waste, aquatic plants, animal waste, urban waste, and other waste materials. Improvements in agriculture will lead to increased biomass yields, reduced processing charges, and stepped forward environmental best. Biomass material handling systems constitute a considerable share of investment capital and operating costs in bioenergy conversion facilities. The future improvement of biomass utilization for electricity is collectively burning biomass in current coal boilers and introducing high-efficiency blended-cycle gasification systems, mobile gasoline systems, and modular systems. The use of biomass as gas is more environmentally friendly than fossil fuels. Some types of biomass can be used as a fuel with certain characteristics, such as rice husks and sawdust which will be reviewed in this review. Biomass, as a substitute for coal used as fuel for power plants, has almost similar specifications to coal. Where the value of HHV coal is 5217 kcal/kg (adb) while rice husk, teak sawdust, and Ironwood sawdust have HHV values respectively 3380 kcal/kg (adb), 4460 kcal/kg (adb), and 4465 kcal / kg (adb). Other tests conducted are volatile content, fixed carbon, moisture, and dust content.

Introduction

Biomass is organic count produced through photosynthetic processes, whether within the shape of products or waste. Examples of biomass include plants, bushes, grass, yams, agricultural waste, wooded area waste, feces, and farm animal manure. Further to getting used for the primary cause of fiber, foodstuffs, animal feed, vegetable oils, or constructing substances, biomass is likewise used as a supply of electricity (gas). In widespread, what is used as fuel is biomass that has a low monetary cost or is a waste after the primary product is taken (BPPT, 2009).

Initially, biomass was known as a source of energy when humans burned wood to prepare dinner food or heat the body in winter. Wooden is a biomass energy source that is nevertheless usually used. However, other biomass energy resources include food vegetations, grass, and other plants, agricultural or forest processing waste and residues, organic components of household and business waste, as well as methane fuel as a result of landfills.

Biomass energy sources have numerous benefits; among others, renewable energy resources offer sustainable energy sources (sustainable). In Indonesia, biomass is a vital natural resource with a variety of number-one products, including fiber, wood, oil, foodstuffs, and etc. These biomasses are further used to fulfill domestic needs or exported, hence becoming the spine of the country's foreign exchange earnings.

The capability of biomass in Indonesia that may be used as an electricity supply is very abundant. Waste from animals and vegetation is all capacity for development. Food vegetation and plantations produce a huge amount of waste, which can be used for other purposes, such as biofuels. The usage of waste as gasoline gives three direct advantages:

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1. First, an increase in general power performance due to the massive energy content of biomass and may be wasted if no longer applied.
2. Second, price financial savings because frequently casting off waste can be more expensive than utilizing it.
3. Third, reduce the need for landfills because the provision of landfills will become more complicated and steeply priced, in particular in urban regions.

Using waste biomass as the main product for power assets had additionally recently evolved hastily. Oil palm, castor, and soybean are a few plants whose predominant products are raw materials for biodiesel. While cassava, corn, sorghum, and sago are plants whose products are regularly meant as substances for bioethanol (Karras et al., 2022; Hongrapipat et al., 2020).

Biomass may be used as gasoline, so technology is needed to transform it. There are numerous technologies for biomass conversion. Biomass conversion generation requires differences inside the gear used to transform biomass and ensuing differences in the gas produced (Muller et al., 2011).

In general, biomass-to-fuel conversion technology may be divided into three, particularly direct combustion, thermochemical conversion, and biochemical conversion. Direct combustion is the best generation because widespread biomass may be burned simultaneously (Basu, 1991). A few biomass needs to be pre-dried and densified for practicality in use. Thermochemical conversion is a generation that requires thermal remedy to trigger chemical reactions to produce gasoline. While biochemical conversion is a conversion generation that uses microbial assistance to generate fuel (Basu, 2015).

To overcome the scarcity of fuel oil, it is time for the government and farming communities to develop food land and promote biomass as an alternative electricity supply that is environmentally pleasant. In addition, the involvement of researchers and large and private companies is also essential in developing this energy source which will be able to anticipate the scarcity of fuel, especially in Indonesia in the future. Therefore, this study aimed to determine whether or not the biomass (i.e., rice husk, teak sawdust, and Ironwood sawdust) when substituted for coal as a power plant fuel at a certain content.

Research Methods

A review of the methods of using biomass as a substitute for coal for fuel in power plants was carried out according to Table 1. The following discussions related to the use of biomass as a substitute for coal were performed.

Biomass resource management

Biomass resources are all renewable organic materials, including plants and trees specifically for energy, food crops, agricultural waste and crop residues, forestry waste and waste, aquatic plants, animal waste, urban waste, and other waste substances. Material handling, logistics, and collection infrastructure are crucial components of the biomass resource delivery chain (Martín-Gamboa et al., 2020; Brosowski et al., 2016). Biomass sources include:

a. Special energy plants

un the form of green plants harvested every year after waiting 2-3 years to achieve complete productivity. These are including grass plants such asshrubs, *Meschantus sp.* (elephant grass), bamboo, sugarcane, wheat plants, etc.

b. Special energy tree

Special energy tree is normally a hybrid tree. For example, short-cycle wood which is a quick-growing hardwood tree harvested in 5-8 years after planting.

c. Industrial plants

Industrial plants are developed to produce special materials or chemicals for industry, including kenaf and straw for optical fibers and castor bushes for ricinoleic acid. New transgenic plants are being developed to provide the favored chemical substances that only require the extraction and grounding of the product (Åkerman and Peltola, 2010).

d. Agricultural plants

This food reserve includes staple products along with cornmeal and corn oil, oils and foodstuffs from soybeans, wheat flour, other vegetable oils, and all other staple crops. Generally, these materials produce sugar, oil, and raw materials, but they can produce plastics and chemicals (Hongrapipat et al., 2020).

e. Aquatic plants

There are excellent aquatic biomass sources, including algae, seaweed, and marine microflora.

Table 1. Biomass research review for powerplant's fuel

Refs	Title	Journal
Ayub et al. (2022)	Prediction of process parameters for the integrated biomass gasification power plant using artificial neural network.	Frontiers in Energy Research
Boumanchar et al. (2019)	Investigation of (co)-combustion kinetics of biomass, coal and municipal solid wastes	Waste Manage
Chen et al. (2021)	Review on slagging evaluation methods of biomass fuel combustion.	J Anal Appl Pyrolysis
Dam-Johansen et al. (2013)	Co-firing of coal with biomass and waste in full-scale suspension-fired boilers	Cleaner Combustion and Sustainable World
Febrero et al. (2015)	Influence of combustion parameters on fouling composition after wood pellet burning in a lab-scale low-power boiler.	Energies
International Finance Corporation (2017)	Converting biomass to energy - a guide for developers and investors.	Energy & Water Advisory
Haygreen and Bowyer (1996)	Forest Product and Wood Sciences: An Introduction	IOWA State University Press
Heinzel et al. (1998)	Investigation of slagging in pulverized fuel co-combustion of biomass and coal at a pilot-scale test facility.	Fuel Process. Technol
Kalinci et al. (2009)	Biomass-based hydrogen production: a review and analysis.	Int J Hydrogen Energy
Kargbo et al. (2021)	"Drop-in" fuel production from biomass: Critical review on techno-economic feasibility and sustainability.	Renew Sustain Energy
Madanayake et al. (2017)	Biomass as an energy source in coal co-firing and its feasibility enhancement via pre-treatment techniques.	Fuel Process. Technol
McKendry(2002a)	Energy production from biomass (part 1): Overview of biomass.	Bioresour Technol
McKendry (2002b)	Energy production from biomass (part 2): conversion technologies.	Bioresour Technol
Medic et al. (2010)	Effect of torrefaction process parameters on biomass feedstock upgrading.	ASABE
Mehmood et al. (2012)	Energy analysis of a biomass co-firing based pulverized coal power generation system.	Sustainability
de Almeida Moreira et al. (2021)	Production of pellets for combustion and physisorption of CO_2 from hydrothermal carbonization of food waste – Part I: High-performance solid biofuels.	J Clean Prod
Narayanan and Natarajan (2007)	Experimental studies on cofiring of coal and biomass blends in India.	Renew. Energy
Pimchuai et al. (2010)	Torrefaction of agriculture residue to enhance combustible properties.	Energy Fuels
Ramos et al. (2022)	Biomass pre-treatment techniques for the production of biofuels using thermal conversion methods – A review.	Energy Conversion and Management
Rashidi et al. (2022)	Biomass energy in Malaysia: Current scenario, policies, and implementation challenges.	BioEnergy Research
Riaza et al. (2014)	Combustion of single biomass particles in air and in oxy-fuel conditions.	Biomass Bioenergy
Shahabuddin et al. (2020)	A review on the production of renewable aviation fuels from the gasification of biomass and residual wastes.	Bioresour Technol
Siwal et al. (2021)	Recovery processes of sustainable energy using different biomass and wastes.	Renew Sustain Energy
Tumuluru (2018)	Biomass preprocessing and pretreatments for production of biofuels.	CRC Press
Yadav et al. (2020)	The production of fuels and chemicals in the new world: critical analysis of the choice between crude oil and biomass vis-à-vis sustainability and the environment	Clean Technol Environ Policy

f. Remnants of forest products

Forest product residues are unused biomass or disposed of from timber processing sites either from commercial processing or from forestry management operations such as selective cutting and disposal of wood stumps.

g. Urban waste

Household waste, markets, etc., have content derived from organic materials, which are renewable power assets. Waste paper, cardboard, wood waste, and garbage in the backyard are examples of biomass assets in urban waste.

h. Waste biomass processing

All biomass processing produces byproducts and waste streams, referred to as wastes, that have energy potential. The stays are easy to apply because they have been selected, such as processing wood for products or pulp to produce sawn remains and piles of bark, branches, and leaves/grains.

i. Animal waste

Fields and animal processing operations dispose of waste that may be a complex supply of organic matter. This waste may be used to make various bioenergy products.

Improvements in agriculture will lead to accelerated biomass yields, reduced processing prices, and progressed environmental pleasant. Biomass material handling systems constitute a considerable share of the investment capital and operating costs in bioenergy conversion facilities. The needs rely on the sort of biomass to be processed in conversion technology in addition to the needs of food storage warehouses, which include biomass storage, handling, transportation, size discount, cleaning, and drying.

Use of biomass for electricity

The future development of biomass utilization for electricity is the combustion of biomass together in current coal boilers and the introduction of high-efficiency blended-cycle gasification systems, mobile gasoline systems, and modular systems. Biomass utilization technology for energy or energy reserves based on the system (Backreedy, 2005; ESDM, 2016):

a. Direct burning

Direct combustion entails burning biomass with copious air, producing hot flue gases that might generate steam inside the heat exchange section of the boiler. Steam is used to provide energy in a steam turbine generator.

b. joint burning

Co-combustion leads to biomass usage in high-efficiency coal-burning boilers as an extra supply of energy. Co-combustion has been evaluated for an expansion of boiler technology along with pulverized coal, cyclone, fluidized bed, and spreader stokers. For utility companies and coal-fired generation plants, co-combustion with biomass may also represent one of the low-fee renewable power alternatives.

c. Gasification

Gasification of biomass to provide energy entails heating biomass in low-oxygen surroundings to supply medium or low-calorie fuel. Biogas is then used as gasoline in a combined cycle electricity plant unit consisting of a gas turbine in the upper cycle and a steam turbine in the lower cycle (Pang, 2008).

Wood waste has low-calorie content, so an efficient furnace is needed because of the large mass of fuel that must be put into it. This is the reason why biomass power plants have lower efficiency than coal.

In this case, it is necessary to consider mixing (blending) biomass/materials with higher calorie content. The low-calorie conditions contained in biomass materials require special boilers with a larger volume of combustion than coal fuel, the calorie content of which is two times higher, causing the cost of building biomass power plants to be higher than coal power plants.

Although the construction of a biomass power plant is still considered less economical, several considerations support the feasibility of the realization of a biomass power plant, among others:

- The availability of fuel in nature can be unlimited since it is a renewable material.
- For special purposes such as social and environmental considerations. For instance, tackling garbage or waste problems which may remain as a big problem for society in the future.
- A smaller contribution to pollution and the greenhouse effect than coal.

Environmental aspects

The use of biomass as a fuel is more environmentally friendly than fossil fuels. Currently, fossil fuels contribute the most to environmental problems such as greenhouse gases, air pollution, and groundwater contamination. The following are the contributions of biomass utilization to improve environmental quality (Kemenperin, 2012):

a. Air quality and global climate change

Using bioenergy can reduce emissions of NOx, SOx, and greenhouse gases associated with the use of fossil fuels, which the greenhouse effect will result in global climate change or global warming.

b. Soil conservation

Soil conservation issues related to biomass production include soil erosion control, food storage, and Riverside stabilization.

c. Water conservation

The life cycle of biomass technology can impact watershed stability, groundwater quality, flow and surface quality, and neighborhood water use for agricultural irrigation, and/or treatment facility needs.

d. Biodiversity and habitat change

Biodiversity is the diversity of genetics and species of living things in a particular place or region. Changes in land use to support multiplied biomass manufacturing can lead to habitat and biodiversity stages adjustments.

Types of biomass as fuel and their characteristics

a. Rice husk

Indonesia has a tropical climate with reasonably even rainfall- most of the population work as farmers, especially rice farmers. Indonesia produces about 25 million tons of rice annually. Agriculture is run at an independent rural level. At a production level of 25 million tons, rice husks can be produced for around 7.55 million tons. The utilization of waste/rice husks as energy to produce electricity is an alternative to sustaining the electrical energy crisis. Suppose the energy from rice farming waste is utilized in rural areas are supported by the government and managed properly in the future. In that case, the village will be independent and has self-sufficient energy (Natarajan et al., 1998).

The husk is part of the grain of grains (cereals) in the form of a dry, scaly, and inedible sheet. Agricultural waste, such as rice husks, can be used as an environmentally friendly and economical energy source. However, until now, rice husks have not been optimally utilized as an energy source. The heat value of rice husk is quite high with the value of ~4,000 kcal/kg or equivalent to 4,652 kWh (Kwong et al., 2007; EBTKE ESDM, 2022).

Rice husk is a mixture of cellulose and silica as a byproduct of the rice milling process. The amount of silica content varies depending on the soil types. The moisture or water content of rice husks is about 8-10%, depending on heat transpiration, movement, and transportation by air. While the calorific value of rice husk is about 6200 Btu / lb. Rice husk is 14-28.5% of the weight of the grain variety of rice, but the average is 25%. The characteristics of rice husk can be seen in Table 2 and Table 3.

b. Sawdust

Wood is one of Indonesia's most abundant natural products. Any processing of wood into semi-finished materials (e.g., in the form of boards or beams) or finished goods (e.g.,furniture) always produces by-products in the form of waste sawdust (i.e., sawdust) sawing results (Passalacqua and Zaetta, 2004).

Wood sawdust waste causes many management issues and need to be used optimally. The waste is left to naturally degraded and is burned by sawmills or wooden artisans. Mixing sawdust with a low calorific value coal at a certain ratio can be an alternative to simultaneously increase the utilization of sawdust and low-calorie coal (Skodras et al., 2002).

The chemical content of wood is cellulose of ~60%, lignin of ~28%, and other substances (including sugar substances) of ~12%. The cell wall is composed mainly of cellulose ($C_6H_{10}O_5$). Lignin is a mixture of organic substances consisting of carbon (C), water (H_2O), and oxygen (O_2). Wood sawdust contains the main components of cellulose, hemicellulose, lignin, and wood extractive substances. The presence of resins in wood affects the calorific value produced. Wood containing resin has a better calorific value than wood that does not have resin. For example, oleoresin has a high calorific value (8,500 kcal/kg) (Haygreen et al., 2003). Therefore, wood needles (Pine) containing resin have a higher calorific value. The average chemical content of wood is presented in Table 4.

Table 2. Rice husk composition

No	Parameters	Unit	Lab Testing	Dry
1	Water	%	8.18	-
2	Ash	%	18.44	20.09
3	Fuel	%	59.93	66.27
4	Carbon	%	13.45	14.64
5	Calorific Value	Btu/lb	52.20	67.55
6	Specific Gravity	Lb/ft^3	17.26	-

Source: Sumartono (1989)

Tabel 3. Rice husk composition

No	Elements	Content (%)
1	Silicon oxide	92.0
2	Magnesium oxide	2.0
3	Manganese Oxide	0.2
4	Ferro oxide	0.1
5	Calcium oxide	0.1
6	Barium Oxide	0.04
7	Potassium oxide	0.02
8	Aluminum oxide	0.01
9	Sodium oxide	0.01
10	Copper oxide	-
11	Nickel oxide	< 0.01
12	Carbon	2.5
13	Water	< 3.0

Source: Sumartono (1989)

Tabel 4. Sawdust composition

Chemical Compositions	Dry Weight (%)
Carbon	45 - 50 (11 - 15% solids, 35% volatile)
Hydrogen	6.0 - 6.5
Oxygen	38 - 42
Nitrogen	0.1 - 0.5
Sulfur	Maks. 0.05

Source: Huhtinen (2005)

c. Biomass testing

Material characteristics have been tested, which was carried out in the Laboratory of PT Carsurin, to determine the content and properties related to the characteristics of the power plant fuel. Figure 1 shows the activity of testing the characteristics of materials, namely rice husk, Ironwood sawdust, teak sawdust, and coal.

Results and Discussion

Differences in the characteristics of biomass and coal

There are fundamental differences between biomass and coal, among others:

a. Elemental and proximate evaluations of coal are critical for biomass characterizations. Biomass has a high H/C and O/C ratio, while coal's H/C and O/C ratio is low.
b. The nature of biomass is tremendously variable and heterogeneous. Even one-of-a-kind elements of the tree can have one-of-a-kind compositions.
c. Unlike coal, biomass absorbs moisture and rot while stored for long periods.. In addition to destructive effects on thermal performance, moisture can also cause the improvement of dangerous fungi.
d. Biomass is much less brittle and more fibrous than coal, resulting in quite one-of-a-kind grinding traits.
e. Ash in biomass is much richer in compounds (i.e., K, Ca, and Si) than in comparison to coal. Biomass waste can also take chlorine, potassium, and heavy metals. All of those significantly improve the fouling, slagging, and corrosion ability in pipes of coal-fired boilers.

Critical components in co-firing at power plants

Here are some critical components during the application of co-firing in PLTU (Figure 2).

a. Furnace in CFB Boiler
b. Chain Grate in Stoker Boiler
c. Mill or Pulverizer in PC Boiler

Feed preparation

In a PC boiler, the Fed coal is first ground in a pulverizer to a size of about 75-μm and distributed using air pressure through a pipe into the burner. As for fluidized-bed boilers, the fuel is crushed to a size of 10 mm or less and fed into the furnace by utilizing gravity. Because it is more flexible to fuel, generally fluidized-bed boilers are relatively easier to co-Fire biomass than PC boilers.

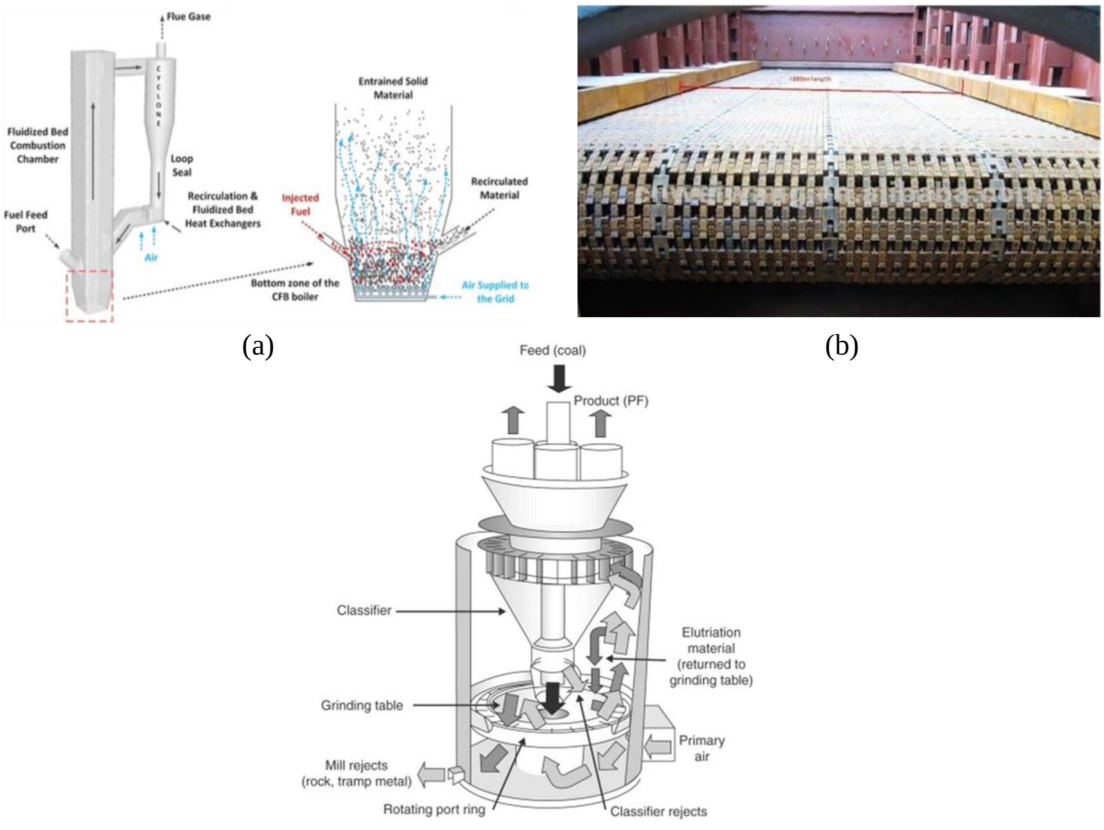
In order to be used in PC boilers, biomass of comparable size is required (75-75-μm) and then distributed using compressed air through pipes. Due to its clayier characteristics, higher energy is needed to grind the biomass until the abovementioned size is obtained. For example, grinding a ton of coal to a size of 50% under

500µm, it takes about 7-36 kWh of energy. As for grinding raw poplar and pine types, energy is needed, respectively, about 130 and one hundred seventy kWh. In addition to the large energy consumption, the output (ton/H) of the pulverizer is also reduced when grinding biomass collectively with coal for co-firing. The reduction in mill output will at once reduce the generations of Plant Power (Setya et al., 2019; Quaak et al. 1999).

In addition, there are problems related to the processing of raw materials for various types of biomass because they have different fiber surfaces. With the torrefraction technique, biomass is processed to be more brittle, finer, and reduce fiber content. It is thus easier to smooth, and the friction created by interlocking fibers during pneumatic transport handling can be reduced.

(a) (b) (c)

Figure 1. Characteristic Testing for Biomass and coal: (a). Samples are ready for analysis (being inserted by the analyst into the sample bottle; (b). Process oven for sample drying; (c). Weighing pan and sample



(c)

Figure 2. Critical Components for Co-Firing at Coal-Fired Power Plants: (a). Furnace in CFB Boiler; (b). Chain Grate in Stoker Boiler; (c) Mill/Pulverizer in PC Boiler (Basu,2015).

Co-firing combustion process
Biomass debris is typically more reactive due to its extra risky content and more porous shape as than coal. Consequently, whilst dried to an identical extent and crushed to the same length as coal particles, biomass particles can burn quicker than coal. Because of this, biomass does not need to be ground as finely as PC. However, its size must additionally no longer be too large so that after being fed, it will fall into the furnace before it burns out (Sasongko and Budiarto, 2022).

In addition, high moisture content in biomass materials can put off the ignition. If this put-off is significant, the flame can flow in addition and similarly away from the combustion chamber itself. Although, in decreasing moisture content, the ignition temperature of dry biomass is highly decrease than coal. Consequently, it is crucial to store biomass in dry dryness before used as co-firing gas feedstocks (Sasongko et al., 2017; Suzuki et al., 2017).

Coal testing
The results of coal testing using the ASTM method are shown in Table 5 below. The test results showed that the gross calorific value of coal (HHV) of 5217 kcal/kg (adb) with a moisture content of 11.43% (adb) and ash of 8.36% (adb). The relative density of coal is 1.412 g/mL.

Rice husk testing
The results of rice husk testing using the ASTM method are shown in Table 6. The test results showed that the HHV of rice husk is 3,380 kcal/kg (adb), is smaller than coal. While the moisture content of 6.84% (adb) is less than coal. The ash content of 21.4% (adb) is much greater than coal's. Particularly striking is the volatile matter (VM) content which reaches 59.05% (adb) about 10% higher than coal and fixed carbon (FC) of 12.71% (adb), much lower than coal. The relative density of rice husk is 1.5853 g/mL, higher than coal. While the bulk density of 0.111 g/mL is much smaller than coal.

Ironwood sawdust testing
The test results of sawdust Iron using the ASTM method are shown in Table 7. The test results showed that the HHV ironwood sawdust is 4,465 kcal/kg (adb), lower than coal but higher than rice husk. While the moisture content of 7.74% (adb) is less than coal but higher than rice husk. The ash content of 0.96% (adb) is much lower than that of coal and rice husk. While the VM content reached 71.3% (adb) is much higher than coal and rice husk. However, the FC content of 20.0% (adb), is higher than rice husk although lower than coal. The relative density of ironwood sawdust of 1.2973 g/mL, lower than rice husk and coal. However, the bulk density of 0.354 g/mL is higher than that of coal and rice husk.

Teak sawdust testing
The results of teak Sawdust testing using the ASTM method are shown in Table 8 below. The test results showed that the HHV of teak sawdust is 4,460 kcal/kg (adb), approximately the same as sawdust Ironwood, lower than coal but higher than rice husk. While the moisture content of 5.26% (adb) is less than coal, rice husk, and sawdust Ironwood. The ash content of 2.96% (adb) is lower than that of coal or rice husk, but slightly higher than the sawdust of Ironwood. Almost the same as Ironwood, the VM content of teak wood reaches 75.88% (adb) much higher than coal and rice husk, but slightly higher than Ironwood. However, the FC content of 15.93% (adb), is lower than coal and Ironwood, but higher than rice husk. The bulk density of teak wood (0.256 g/mL) is higher than rice husk but still smaller than Ironwood and coal.

Analysis of biomass feeding system
There are various aspects to be considered in the biomass feeding system into the boiler, especially for CFB-type boilers, include:

a. Density and particle size
The density, or density, together with the particle sizem largely determines the fluidization character of the biomass material to be mixed. Low-density materials tend to be more easily carried by air than coal. With the same air velocity, biomass particles, which have a density smaller than biomass, can be carried higher and burned at different locations than coal, and cause different temperature distributions in the combustion chamber. Therefore, one of the requirements that must be met in mixing biomass is minimal density. If the minimum density is not met, biomass particles should be process to achieve the minimum density requirements required, prior to beused into pellets (Demirbas, 2003).

It can be seen from Table 9 that although the relative density of rice husk is higher than coal, the bulk density is very low. In the condition of biomass supply, as it is, rice husk has a lighter density than coal or sawdust. For this reason, it is necessary to consider the feeding system of rice husks in the boiler, taking into account the flying characteristics of the rice husks. For mixing up to less than 5% by weight of fuel, it is estimated that there is no serious problem with mixing rice husks because all rice husks will burn out in the combustion chamber. For larger quantities, it is necessary to consider converting the biomass into pellets to increase the density close to that of coal. Thus, the biomass fuel characteristics may similar to the characteristics of coal and are more manageable to burn out in the combustion chamber.

For sawdust, with a higher density, it is easier to regulate the airflow and keep it burned out in the combustion chamber up to a higher biomass ratio.

Table 5. Coal testing results

Parameters	Standard	Results			
		adb	ar	db	daf
A. Total Moisture, Weight %	ASTM D3302/D3302M - 19	-	23.76	-	-
B. Proximate Analysis, Weight %					
Moisture content	ASTM D3173/D3173M - 17a	11.43	-	-	-
Ash Content	ASTM D3174 - 12 (2018)	8.36	7.20	9.44	-
Volatile Matter	ASTM D3175 - 20	42.55	36.63	48.04	53.05
Fixed Carbon	ASTM D3172 - 13	37.66	32.41	42.52	46.95
C. Total Sulfur, Weight %	ASTM D4239 - 18e1	0.79	0.68	0.89	0.98
D. Gross Calorific Value, Kcal/kg	ASTM D5865 - 19	5.217	4.491	5.890	6.504
E. Ultimate Analysis, Weight %					
Carbon	ASTM D5373 - 16	52.43	45.10	59.20	65.40
Hydrogen	ASTM D5373 - 16	4.34	3.74	4.90	5.41
Nitrogen	ASTM D5373 - 16	0.94	0.81	1.06	1.17
Oxygen	ASTM D3176 - 15	21.71	18.71	24.51	27.04
F. Ash Analysis, Weight %					
Silicon Dioxide, SiO_2	ASTM D3682 - 13	38.68			
Aluminium Oxide, Al_2O_3	ASTM D3682 - 13	19.03			
Ferric Oxide, Fe_2O_3	ASTM D3682 - 13	15.03			
Calcium Oxide, CaO	ASTM D3682 - 13	10.47			
Magnesium Oxide, MgO	ASTM D3682 - 13	4.83			
Sodium Oxide, Na_2O	ASTM D3682 - 13	0.39			
Potassium Oxide, K_2O	ASTM D3682 - 13	1.42			
Titanium Oxide, Ti_2O	ASTM D3682 - 13	0.71			
Phosphorus Oxide, P_2O_5	AS 1038.9.3-2000 (Reconfirmed 2013)	0.30			
Manganese, Mn_3O_4	ASTM D3683	0.16			
Sulfur Trioxide, SO_3	ASTM D5016	7.05			
G. Ash Fusion Temperature, °C		**Reducing**		**Oxidizing**	
Initial Deformation Temperature	ASTM D1857	1,115		1,210	
Softening Temperature	ASTM D1857	1,130		1,225	
Hemispherical Temperature	ASTM D1857	1,145		1,260	
Fluid Temperature	ASTM D1857	1,240		1,295	
H. IgnitionTemperature, °C	Fusion	443			
I. Chlorine, ppm	ASTM D4208	90	77	102	112
J. Bulk Density, g/mL	ASTM D291-07 (2012)				
K. Relative Density, g/mL	AS 1038.21.1.2 - 2002 (Reconfirmed 2013)	1,4120			

Table 6. Rice husk testing result

Parameters	Standard	Results			
		adb	ar	db	daf
A. Total Moisture, Weight %	ASTM D3302/D3302M - 19	-	11.38	-	-
B. Proximate Analysis, Weight %					
Moisture Content	ASTM D3173/D3173M - 17a	6.84	-	-	-
Ash Content	ASTM D3174 - 12 (2018)	21.40	20.36	22.97	-
Volatile Matter	ASTM D3175 - 20	59.05	56.17	63.39	82.29
Fixed Carbon	ASTM D3172 - 13	12.71	12.09	13.64	17.71
C. Total Sulfur, Weight %	ASTM D4239 - 18e1	0.05	0.05	0.05	0.07
D. Gross Calorific Value, Kcal/kg	ASTM D5865 - 19	3,380	3,215	3,628	4,710
E. Ultimate Analysis, Weight %					
Carbon	ASTM D5373 - 16	35.30	33.60	37.90	49.20
Hydrogen	ASTM D5373 - 16	4.45	4.23	4.78	6.20
Nitrogen	ASTM D5373 - 16	0.68	0.65	0.73	0.95
Oxygen	ASTM D3176 - 15	31.28	29.73	33.57	43.58
F. Ash Analysis, Weight %					
Silicon Dioxide, SiO_2	ASTM D3682 - 13	89.67			
Aluminium Oxide, Al_2O_3	ASTM D3682 - 13	0.01			
Ferric Oxide, Fe_2O_3	ASTM D3682 - 13	5.29			
Calcium Oxide, CaO	ASTM D3682 - 13	0.01			
Magnesium Oxide, MgO	ASTM D3682 - 13	0.05			
Sodium Oxide, Na_2O	ASTM D3682 - 13	0.,47			
Potassium Oxide, K_2O	ASTM D3682 - 13	1.99			
Titanium Oxide, Ti_2O	ASTM D3682 - 13	0.02			
Phosphorus Oxide, P_2O_5	AS 1038.9.3-2000 (Reconfirmed 2013)	0.42			
Manganese, Mn_3O_4	ASTM D3683 -	0.02			
Sulfur Trioxide, SO_3	ASTM D5016 -	0.06			
G. Ash Fusion Temperature, °C		**Reducing**		**Oxidizing**	
Initial Deformation Temperature	ASTM D1857 M	1,470		>1,500	
Softening Temperature	ASTM D1857 M	>1,500		>1,500	
Hemispherical Temperature	ASTM D1857 M - 18	>1,500		>1,500	
Fluid Temperature	ASTM D1857 M - 18	>1,500		>1,500	
H. IgnitionTemperature, °C	Fusion Tester	312			
I. Chlorine, ppm	ASTM D4208 - 19	591	562	634	824
J. Bulk Density, g/mL	ASTM D291-07 (2012)	0.110			
K. Relative Density, g/mL	AS 1038.21.1.2 - 2002 (Reconfirmed 2013)	1.5853			

Table 7. Test results ironwood sawdust

Parameters	**Standard**	**Results**			
		adb	ar	db	daf
A. Total Moisture, Weight %	**ASTM D3302/D3302M - 19**	**-**	17.79	**-**	**-**
B. Proximate Analysis, Weight %					
Moisture Content	ASTM D3173/D3173M - 17a	7.70	-	-	-
h Content	ASTM D3174 - 12 (2018)	0.96	0.86	1.04	-
Volatile Matter	ASTM D3175 - 20	71.30	63.51	77.25	78.06
Fixed Carbon	ASTM D3172 - 13	20.04	17.84	21.71	21.94
C. Total Sulfur, Weight %	ASTM D4239 - 18e1	0.06	0.05	0.07	0.06
D. Gross Calorific Value,	ASTM D5865 - 19	4,465	3,977	4,837	4,888
E. Ultimate Analysis, Weight %					
Carbon	ASTM D5373 - 16	48.99	43.60	53.10	53.60
Hydrogen	ASTM D5373 - 16	5.50	4.90	5.96	6.02
Nitrogen	ASTM D5373 - 16	0.49	0.44	0.53	0.54
Oxygen	ASTM D3176 - 15	36.30	32.36	39.30	39.77
F. Ash Analysis, Weight %					
Silicon Dioxide, SiO_2	ASTM D3682 - 13		27.71		
Aluminium Oxide, Al_2O_3	ASTM D3682 - 13		6.21		
Ferric Oxide, Fe_2O_3	ASTM D3682 - 13		9.35		
Calcium Oxide, CaO	ASTM D3682 - 13		39.89		
Magnesium Oxide, MgO	ASTM D3682 - 13		5.76		
Sodium Oxide, Na_2O	ASTM D3682 - 13		0.43		
Potassium Oxide, K_2O	ASTM D3682 - 13		3.93		
Titanium Oxide, Ti_2O	ASTM D3682 - 13		0.37		
Phosphorus Oxide, P_2O_5	AS 1038.9.3-2000 (Reconfirmed 2013)		1.65		
Manganese, Mn_3O_4	ASTM D3683 - 11		0.20		
Sulfur Trioxide, SO_3	ASTM D5016 - 16		2.58		
G. Ash Fusion Temperature, °C		**Reducing**		**Oxidizing**	
Initial Deformation	ASTM D1857 M - 18	1,185		1,210	
Softening Temperature	ASTM D1857 M - 18	1,220		1,225	
Hemispherical Temperature	ASTM D1857 M - 18	1,230		1,235	
Fluid Temperature	ASTM D1857 M - 18	1,255		1,275	
H. IgnitionTemperature, °C	Fusion Tester		324		
I. Chlorine, ppm	ASTM D4208 - 19	90	80	98	99
J. Bulk Density, g/mL	ASTM D291-07 (2012)		0.354		
K. Relative Density, g/mL	AS 1038.21.1.2 - 2002 (Reconfirmed 2013)		1.2973		

Table 8. Test results teak sawdust

Parameters	Standard	Results			
		adb	ar	db	daf
A. Total Moisture, Weight %	ASTM D3302/D3302M - 19	-	33.72	-	-
B. Proximate Analysis, Weight %					
Moisture content	ASTM D3173/D3173M - 17a	5.26	-	-	-
Ash Content	ASTM D3174 - 12 (2018)	2.93	2.05	3.09	-
Volatile Matter	ASTM D3175 - 20	75.88	53.09	80.09	82.65
Fixed Carbon	ASTM D3172 - 13	15.93	11.14	16.82	17.35
C. Total Sulfur, Weight %	ASTM D4239 - 18e1	0.04	0.03	0.04	0.04
D. Gross Calorific Value, Kcal/kg	ASTM D5865 - 19	4,460	3,120	4,708	4,858
E. Ultimate Analysis, Weight %					
Carbon	ASTM D5373 - 16	47.16	33.00	49.80	51.40
Hydrogen	ASTM D5373 - 16	5.52	3.86	5.83	6.01
Nitrogen	ASTM D5373 - 16	0.58	0.41	0.61	0.63
Oxygen	ASTM D3176 - 15	38.51	26.93	40.63	41.92
F. Ash Analysis, Weight %					
Silicon Dioxide, SiO_2	ASTM D3682 - 13	20.46			
Aluminium Oxide, Al_2O_3	ASTM D3682 - 13	58.70			
Ferric Oxide, Fe_2O_3	ASTM D3682 - 13	9.00			
Calcium Oxide, CaO	ASTM D3682 - 13	4.54			
Magnesium Oxide, MgO	ASTM D3682 - 13	3.27			
Sodium Oxide, Na_2O	ASTM D3682 - 13	0.40			
Potassium Oxide, K_2O	ASTM D3682 - 13	0.29			
Titanium Oxide, Ti_2O	ASTM D3682 - 13	0.71			
Phosphorus Oxide, P_2O_5	AS 1038.9.3-2000 (Reconfirmed 2013)	3.51			
Manganese, Mn_3O_4	ASTM D3683 - 11	0.07			
Sulfur Trioxide, SO_3	ASTM D5016 - 16	0.75			
G. Ash Fusion Temperature, °C		**Reducing**		**Oxidizing**	
Initial Deformation Temperature	ASTM D1857 M - 18	>1,500		>1,500	
Softening Temperature	ASTM D1857 M - 18	>1,500		>1,500	
Hemispherical Temperature	ASTM D1857 M - 18	>1,500		>1,500	
Fluid Temperature	ASTM D1857 M - 18	>1,500		>1,500	
H. IgnitionTemperature, °C	Fusion Tester	318			
I. Chlorine, ppm	ASTM D4208 - 19	304	213	321	331
J. Bulk Density, g/mL	AS 1038.21.1.2 - 2002 (Reconfirmed 2013)	0.256			
K. Relative Density, g/mL	AS 1038.21.1.2 - 2002 (Reconfirmed 2013)	…			

Table 9. Biomass fuel density

No	Biomass Fuel	Density[g/mL]	
		Relative Density	Bulk Density
1	Coal	1.4120	-
2	Rice Husk	1.5853	0.110
3	Ironwood Sawdust	1.2973	0.354
4	Teak Sawdust	-	0.256

b. Mixing methods

A suitable mixing method is needed, thus biomass and coal can be mixed evenly. Therefore, when fed into the boiler, the combustion occurs more evenly and there is no uneven temperature distribution in the combustion chamber (Sukadarrumidi, 2017). Ideally, the mixing is done before the fuel is fed into the fuel feeder silo so that it can be fed evenly into the combustion chamber (Sugiyanto and Sudiro, 2014).

Conclusion

The findings confirmed that coal has an HHV of 5,217 kcal/kg (adb) with VM content of 42.55% (adb), FC content of 37.66% (adb), moisture of 11.43% (adb), and ash 8.36% (adb). Rice husks have an HHV of 3380 kcal/kg (adb) with VM content of 59.05% (adb), FC content of12.71% (adb), moisture of 6.84% (adb), and ash 21.40% (adb). Teak wood powder has an HHV of 4,460 kcal/kg (adb) with VM content of 75.88% (adb), FC content of 15.98% (adb), moisture of 5.26% (adb), and ash 2.93% (adb). The ironwood powder has an HHV of 4,465 kcal/kg (adb) with VM content of 71.30% (adb), FC content of 20.04% (adb), moisture of 7.70% (adb), and ash 0.96% (adb). The study also confirmed that the bulk density of biomasses is lower than coal, especially rice husks with a value of 0.110 mg/L. Special attention is required when mixing rice husks with coal (if portion is higher than 5%) to ensure homogeneity. Thus, it can burn out in the combustion chamber under the same fluidization conditions as coal.

Declarations

Conflict of interests The authors declare no competing interests.

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