

DESIGN AND PERFORMANCE EVALUATION OF AN UPDRAFT GASIFIER

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ABSTRACT

The escalating global energy demand and finite fossil fuel resources necessitate the exploration of renewable, sustainable energy alternatives. This study addresses the urgent need for environmentally friendly energy solutions by designing and evaluating an updraft gasifier using agricultural waste biomass, specifically rice husk and sawdust. The aim was to develop a cost-effective gasification system capable of converting locally available biomass into combustible syngas, with potential applications in rural electrification and decentralized energy production. The research methodology involved constructing a 10 kg capacity updraft gasifier using mild steel, galvanized iron, and stainless-steel components. The experimental approach employed a water boiling test to assess thermal performance, measuring key parameters such as start-up time, operating time, fuel consumption rate, and specific gasification rate. Performance evaluation focused on two biomass feedstocks: rice husk and sawdust. Results revealed significant variations between rice husk and sawdust performance. Rice husk demonstrated a longer start time (450 seconds), extended exhaust time (4600 seconds), and higher gasification temperature (1500°C) compared to sawdust. Moisture content analysis showed both feedstocks stabilized their moisture loss after nine days, with sawdust drying marginally faster. Combustible gas production tests indicated 60 minutes of gas generation for rice husk and 45 minutes for sawdust. The study concludes that the designed updraft gasifier offers a promising solution for converting agricultural waste into energy, with potential applications in rural and decentralized settings. It is recommended to optimize the gasifier design for higher efficiency, broaden the range of biomass feedstocks tested, and integrate the system into community-based renewable energy initiatives to enhance its scalability, sustainability, and impact.

Keywords: Updraft gasifier, Biomass, Renewable energy, Gasification, Agricultural waste

1 INTRODUCTION

In today's world, the demand for energy has escalated significantly, with a strong push for renewable sources to support sustainable development. This demand surge is largely due to the expanding industrial sectors, which have intensified energy consumption. However, this increased demand faces the limitation of finite fossil fuel resources, which have been extensively depleted over time due to industrialization and population growth [1, 2]. The overuse of these fossil fuels has led to environmental degradation and an increasing energy deficit, posing a considerable challenge to sustainable human progress. Consequently, the development of environmentally friendly, cost-effective, and sustainable energy sources has become an urgent priority. Biomass emerges as a promising renewable energy source derived from organic matter. Biomass-based bioenergy offers a sustainable alternative to conventional fossil fuels, largely due to its renewable origin [3]. Biomass can be converted into energy through various methods, primarily biological and thermal processes. Among thermal techniques, pyrolysis, gasification, and combustion are widely used. Pyrolysis and gasification, in particular, are significant thermochemical processes that transform biomass into valuable energy carriers. Pyrolysis involves heating biomass without oxygen to produce bio-oil, a liquid fuel, while

gasification is a low-oxygen process that generates syngas, a mixture of gases including carbon monoxide, hydrogen, methane, and other hydrocarbons. Gasification, due to its higher efficiency, has garnered significant attention compared to other thermal methods [4]. Thermochemical conversion methods, particularly gasification, yield a gas mixture that can be utilized in electricity generation, liquid fuel synthesis, and chemical production. Different types of gasifiers, typically categorized by the type of bed used for biomass reactions, include fixed and fluidized beds. Fluidized bed and entrained flow gasifiers, characterized by high gasification intensity, are more suitable for continuous, large-scale operations. However, they require significant investment and high-quality feedstock, particularly in terms of uniformity [5]. In 2018, a study by the Competitive Africa Rice Initiative (CARI) highlighted the significance of rice cultivation in Africa, especially in West Africa, which accounted for 66% of the 27 million metric tons produced that year. Nigeria, as the continent’s largest rice producer, generates approximately 1.1 million metric tons of agricultural waste annually, including rice husks and corn straw [6]. While this production growth is promising, it also results in substantial waste, which poses challenges for efficient utilization. Notably, agricultural waste like rice husks and corn straw has high lignocellulose content, potentially hindering biogas production. Addressing this challenge requires strategies such as co-substrate integration in biogas production and pre-treatment techniques for biomass [7]. Biomass gasification, a thermochemical process, transforms feedstock into producer gas, a combustible fuel. This technology is especially relevant in decentralized areas, such as remote villages without conventional electrical grids, as it uses locally available biomass and atmospheric air as a gasification agent. With capacities ranging from a few kilowatts to multiple megawatts, biomass gasifiers offer a practical solution for providing energy in rural areas. The implementation of gasification technology can reduce operational costs, generate employment, stimulate economic activities, and supply electricity to underserved communities. Economically, gasifiers are often cheaper to produce than coal-based centralized power plants, which require substantial investments. Additionally, gasifiers generate less pollution compared to centralized power plants, making them a beneficial option for rural electrification. The resulting gas can be used in thermal applications, internal combustion engines, or power generation, with a composition typically consisting of carbon dioxide (CO₂), methane (CH₄), carbon monoxide (CO), nitrogen (N₂), and hydrogen (H₂). Gasifiers vary by the direction of fuel, air, and gas flow. In downdraft gasifiers, both the fuel and air enter from the top, with gas exiting at the bottom. In updraft gasifiers, the fuel moves downward while air and gas move upward [8]. Updraft gasifiers, one of the oldest and simplest types, involve air entering from the bottom and moving upward while biomass feeds from the top and descends. As biomass moves through various stages—drying, devolatilization, gasification, and combustion—it produces syngas with a high tar content due to the absence of high-temperature reactions [9]. This study aims to design and evaluate the performance of an updraft gasifier.

2 MATERIALS AND METHODS

2.1 Materials

Table 1 presents the materials utilized in the fabrication of the fabrication of the updraft gasifier.

Table 1. Materials used for the fabrication and their functions.

Materials	Functions
Mild Steel	Used for the body, frame, hopper, and ash collector due to its strength, affordability, and ease of fabrication
Galvanized Iron:	Selected for external parts for its corrosion resistance, enhancing durability in moist environments.
Stainless Steel Grates:	Chosen for heat resistance to support biomass in the combustion chamber and withstand high temperatures (650–900 °C).
Mild Steel Rods:	Reinforce the structure to withstand operational stress and high temperatures.
Flat Mild Steel Sheets	Used in the fuel hopper, reduction zone, and ash collector for stable and easy fabrication.
Biomass Feedstock	Designed to process rice husk and sawdust for their availability, cost-effectiveness, and clean syngas production
Dry Cell Battery	Powers the blower system, maintaining airflow for efficient combustion.
Blower System	Ensures controlled oxygen supply for optimal gasification conditions.
Measuring Instruments	Workshop tools like scales, digital calipers, and tape measures were used for precise fabrication.

2.2 Methods

2.2.1 Construction Process of the Updraft Gasifier

The construction of the gasifier was carried out in multiple stages, beginning with the fabrication of the reactor. The reactor was made using two steel cylinders, each with a height of 800 mm. The inner cylinder had a diameter of 270 mm, while the outer cylinder had a diameter of 340 mm, both with a wall thickness of 10 mm. To align the two cylinders and accommodate the difference in height, a flange plate was used. This flange plate was 6 mm thick and had a diameter of 400 mm, with a central opening of 220 mm. The inner cylinder was inserted into this opening and welded in place at a distance of 600 mm from one end. Following this, the inner cylinder was positioned inside the outer cylinder, ensuring equal spacing between the two, and then welded securely in place. Once the reactor was constructed, a blower was installed to provide the necessary air supply for the gasification process. This blower operated on alternating current (AC) and was rated at 150 mm, 1.6 amperes, 110 volts, and 2500 revolutions per minute (rpm). The air inlet pipe, which was positioned 400 mm above the reactor bed, directed the airflow into a 19 mm diameter pipe made from galvanized iron (GI). To distribute air evenly across the reactor, a grate made from 10 mm iron rods was placed at the bottom. This grate also served as a mechanism for ash management; during and after combustion, ash from the fuel would fall through the grate and collect in an ash collector. After a cooling period, the ash could be easily removed through an ash outlet. The gasifier system's gas transport network consisted of several interconnected components. A pipe measuring 19 mm in diameter was mounted at the gasifier's upper section to facilitate gas evacuation. To manage pressure and slow down gas velocity, the system incorporated a conical gas delivery section with a 170 mm diameter. The gas transport system utilized elbows and universal joints to maintain proper pipe alignment and ensure efficient gas flow to the intended destination. This is in accordance to [4]. The final component was a cylindrical structure with specific dimensions: 280 mm in diameter, extending 300 mm vertically, and narrowing to 250 mm at a 90-degree bend. This section included a valve mechanism for precise gas flow regulation. The complete design configuration is shown in detail in Figure 1.

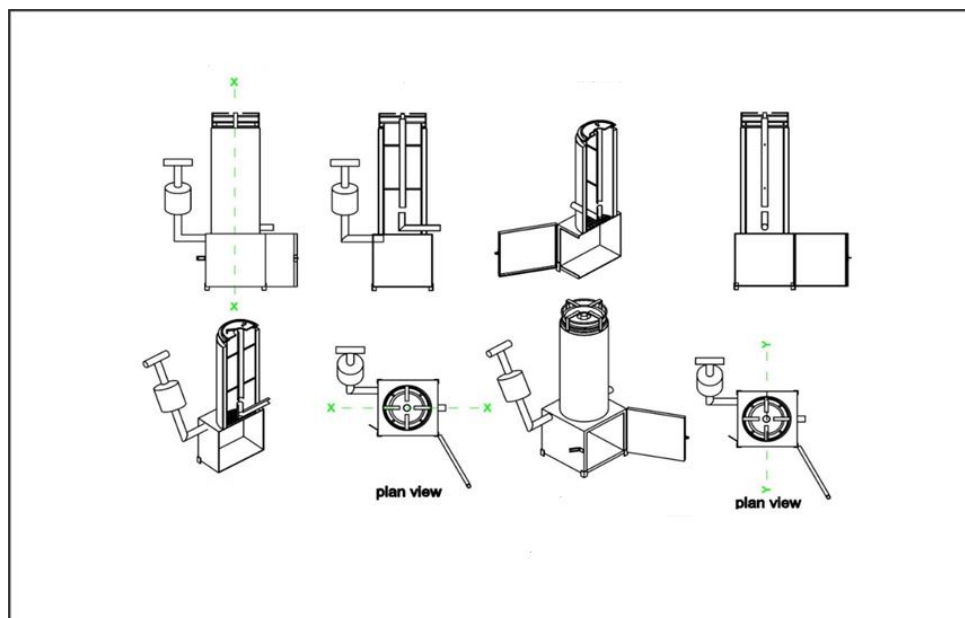


Figure 1. Section view of the gasifier

2.2.2 Design Parameters for the Operation of the Gasifier

The performance of the updraft-gasifier was assessed through several key metrics:

Start-up Time (ST): This measures the interval between initial fuel ignition and the first production of usable gas at the burner. The timing begins when burning feedstock was introduced into the reactor and ends when combustible gas emerges.

Operating Time (OT): This represents the active phase of gas generation, spanning from initial combustible gas production until the feedstock was depleted and gas production ceases.

Total Operating Time (TOT): This encompasses the entire process from initial fuel ignition to the termination of gas production. It combines both the ignition duration and gas production period.

Fuel consumption Rate (FCR): This metric quantifies the rate of wood consumption by dividing the total fuel mass used by the gas production period, calculated according to Equation 1 [10].

$$FCR = \frac{\text{weight of feedstock used (kg)}}{\text{Operating time (hr)}} \quad (1)$$

Specific Gasification Rate (SGR): This measures feedstock utilization by calculating consumption per time unit per reactor surface area, as defined in Equation 2 [11].

$$SGR = \frac{\text{weight of feedstock used (kg)}}{\text{Reactor Area} \times \text{Operating time (hr)}} \quad (2)$$

Combustion Zone Rate (CZR): This indicates how quickly the burning zone progresses downward through the reactor, calculated using Equation 3 [11].

$$CZR = \frac{\text{length of reactor (m)}}{\text{Operating time (hr)}} \quad (3)$$

Moisture Content of the fuel: The energy content of produced gas is significantly influenced by the feedstock's water content. The wood's moisture levels are evaluated on both wet and dry bases using Equations 4 and 5 [12].

$$MC_{wet} = \frac{\text{Wet weight} - \text{dry weight}}{\text{Wet weight}} \quad (4)$$

$$MC_{dry} = \frac{MC_{wet} \times 100}{100 + MC_{wet}} \quad (5)$$

2.2.3 Experimental Procedure for Performance Analysis

Water boiling test was used in evaluating the performance of the gasifier. This process involves bringing a pan of water to a boil and maintaining a rolling boil for 30 minutes, followed by a simmering phase of 60 minutes. First, the ambient air temperature (°C) was measured, and the biomass to be used was weighed (g). Each empty pot was also weighed separately, and these values were recorded. Then, the pots were partially filled with water, weighed again, and the initial water temperature was noted. Next, the biomass gasifier was ignited, allowing the water in the pot to reach a boil and evaporate. After the complete combustion of the fuel, the pot was weighed again to measure the amount of water evaporated. The thermal efficiency for different boiling rates was then calculated using Equation 6 as noted by [12].

$$PHU = \frac{M_n C_p (T_b - T_0) + M_e L}{M_f H_v} \times 100\% \quad (6)$$

Where PHU – percentage heat unutilized or thermal efficiency.

3 RESULTS AND DISCUSSION

3.1 Machine Assembly

The constructed updraft biomass gasifier features a durable mild steel body and frame, providing robust support for the hopper, combustion chamber, and ash collector. The hopper, made from flat mild steel sheets, enables efficient feeding of biomass such as rice husk and sawdust, while stainless steel grates in the combustion chamber ensure heat resistance and proper air distribution during gasification. A galvanized iron exterior enhances corrosion resistance, particularly in humid environments, and the ash collector ensures easy residue removal, completing the efficient and cost-effective design, which demonstrates compatibility with locally available biomass feedstock for clean energy generation. The assembly is shown in Figures 2 and 3.



Figure 2. CAD Isometric view of the updraft gasifier

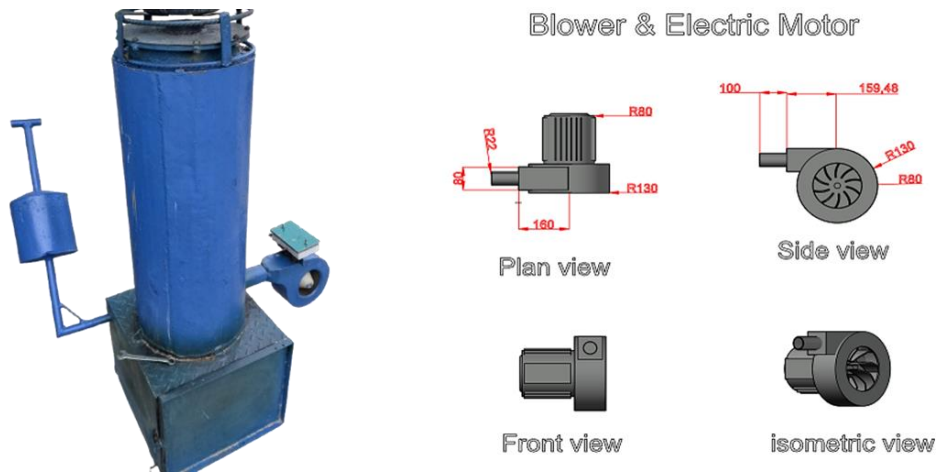


Figure 3. Up-draft Gasifier

3.3 Measurement of Performance

The result in Figure 4 shows that rice husk has higher start time as compared with sawdust. The maximum start time of 10 kg of rice husk recorded was 450 seconds, while the start time of 10 kg of sawdust was 380 sec. According to [13] rice husk usually has higher start as compared to woody biomass, this was because of high silica contain of rice husk.

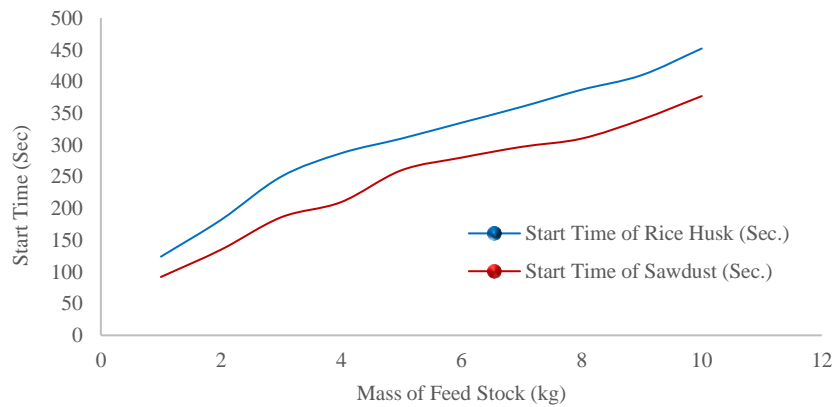


Figure 4. Mass of Feed Stock with respect to Start Time

Figure 5 shows the result of mass of feed stock with respect to exhaust time. The maximum exhaust time recorded of 10 kg of rice husk recorded was 4600 sec, while the maximum exhaust time recorded of 10 kg of sawdust was 3400 sec. This result shows that rice husk generates more gas compared to sawdust.

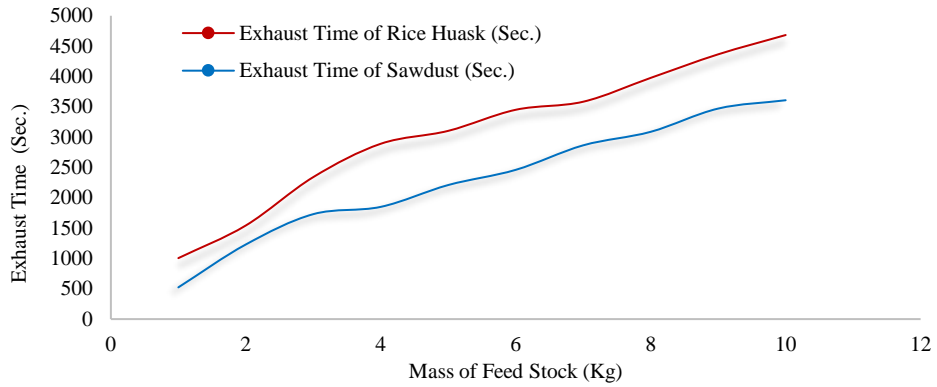


Figure 5. Mass of Feed Stock with respect to Exhaust Time

Maximum gasification temperature 1500°C was recorded for 10kg of rice husk, while 1100°C was recorded for 10kg of sawdust as shown in Figure 6. This shows that rice husk has higher gasification temperature as compared to saw dust.

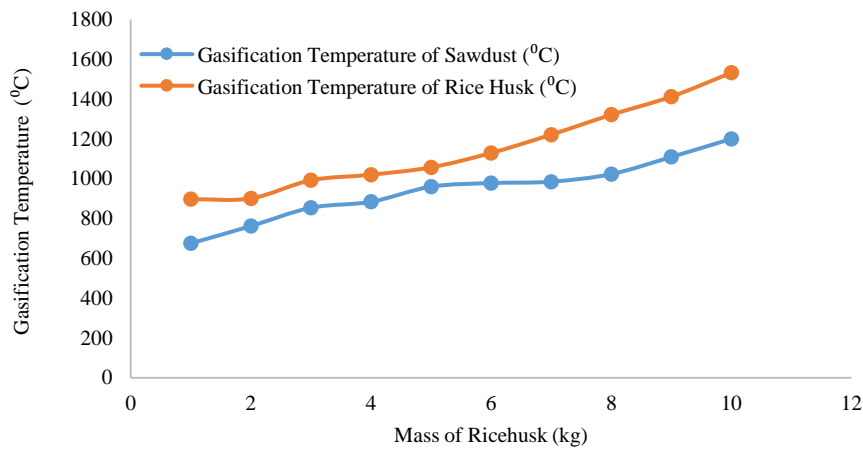


Figure 6. Mass of Feed Stock with respect to Gasification Temperature

Figure 7 shows rice husk has 5% maximum percentage moisture loss after 9days. The percentage loss was proportional to the number days from 0 to the 9th day and remain constant up to the 10th day. This shows that the feedstock has dried and will loss no more moisture under such environmental conditions.

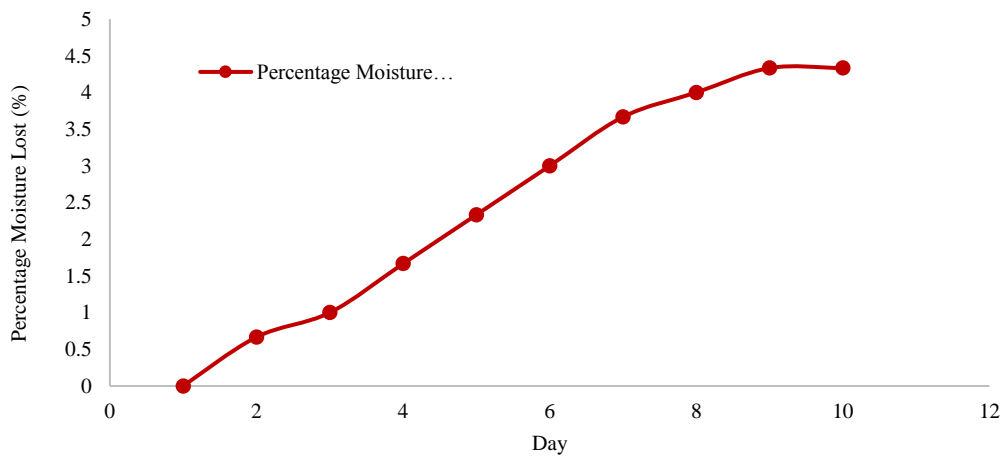


Figure 7. Percentage Moisture loss of rice husk

The result in Figure 8 shows the percentage moisture loss of sawdust with a maximum value of 6% after 9 days. The percentage loss remains constant after the 9th day and this shows that the feedstock has dried and will loss no more moisture under such environmental conditions after the 9th day. The study carried out by [14] shows that biomass such as sawdust will loss 5 to 7% of its moisture content under arid environmental condition between 8 to 10 days depending on the season and location within the region.

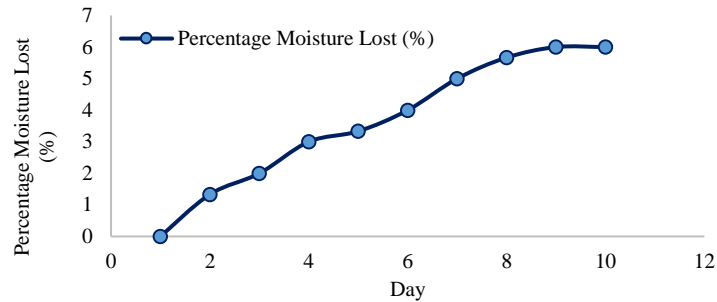


Figure 8. Percentage Moisture loss of sawdust

The result in Figure 9 shows the percentage moisture loss of rice husk and sawdust with a maximum value of 5% and 6% respectively after 9 days. The result shows that sawdust dries faster than rice husk under the same environmental condition, Thus the gas yield and tar generation of rice husk will be higher than that of sawdust. Researchers [15, 16, 17] have all indicated in their respective works that optimal gasification of biomass depend on the gasifier design, environmental conditions and properties the biomass feedstock. However, [16] further shows that optimal gas yield of rice husk is possible in updraft gasifiers and downdraft gasifiers.

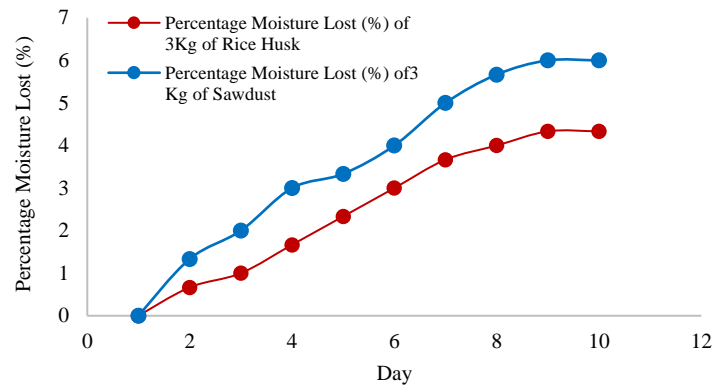


Figure 9. Percentage sawdust and Rice husk with respect to days

4 CONCLUSIONS

It can conclude that; An updraft gasifier with a 10 kg capacity, paired with a stove, was designed, built, and evaluated. The gasifier's volume was designed to hold enough biomass with a density of 400 kg/m³ to operate for at least 2 hours without refueling. The fuel hopper is located 0.8 meters above the grate. After ignition, the production of synthetic gases was observed, indicated by a yellow flame. Testing with 2 kg of rice husk and 2 kg of sawdust showed that combustible gas production lasted for 60 minutes and 45 minutes, respectively.

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