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Thermal Performance and Conversion Efficiency of Biomass Gasification Stove: A Comparative Study of Sawdust and Wood Shavings

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ABSTRACT

The performance of a forced-draft biomass gasifier stove using sawdust and wood shavings was evaluated through the Water Boiling Test (WBT) at air velocities of 0.7, 0.9, and 1.05 m/s. Increasing airflow improved reactor temperature and gas yield for both fuels, with wood shavings achieving higher temperatures (465.9°C) and gas yield (46.62 wt.%) than sawdust. Wood shavings also produced greater water evaporation and higher thermal efficiency (15.07–19.59%) compared to sawdust (11.83–12.99%). Although fuel consumption increased with airflow, wood shavings demonstrated more stable combustion and better heat transfer due to its higher porosity and improved airflow distribution. These findings show that fuel structure and airflow significantly influence gasifier stove performance.

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INTRODUCTION

Access to clean and efficient cooking energy remains a major global challenge, particularly in developing countries where biomass fuels dominate household energy use (Thoharudin et al., 2018). It is estimated that more than 2.3–3 billion people worldwide still rely on solid biomass fuels such as firewood, agricultural residues, and charcoal for cooking purposes, primarily due to their affordability and accessibility (Cansee et al., 2025; Champion & Grieshop, 2019; Getahun et al., 2019). However, the widespread use of traditional biomass stoves is associated with low thermal efficiency and incomplete combustion, leading to significant emissions of harmful pollutants, including carbon monoxide (CO), particulate matter ($PM_{2.5}$), volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs) (Chen et al., 2016; Rebryk et al., 2024). These emissions contribute to severe household air pollution (HAP), which is responsible for millions of premature deaths annually and poses serious health risks, particularly for women and children who are most exposed during cooking activities (Himanshu et al., 2022; Rebryk et al., 2024).

Traditional cooking systems such as the three-stone fire are characterized by extremely low efficiencies, typically ranging between 5% and 15%, and high fuel consumption rates (Cansee et al., 2025; Ebissa & Getahun, 2024). These systems not only exacerbate deforestation due to excessive fuelwood demand but also contribute significantly to climate change through greenhouse gas emissions and black carbon release (Champion & Grieshop, 2019; Getahun et al., 2019). Despite efforts to introduce improved cookstoves (ICS), many interventions have not achieved the expected performance improvements under real-world conditions due to variations in fuel properties, user practices, and stove operation (Champion & Grieshop, 2019). Consequently, there is a pressing need to develop alternative cooking technologies that are both efficient and environmentally sustainable.

Among the various improved cooking technologies, biomass gasifier stoves have gained considerable attention due to their higher efficiency and lower emission characteristics. Gasification is a thermochemical process in which biomass is partially combusted under limited oxygen conditions to produce a combustible gas mixture known as syngas, primarily consisting of carbon monoxide (CO), hydrogen (H_2), methane (CH_4), and carbon dioxide (CO_2) (Getahun et al., 2019; Nwakaire & Ugwuishiwu, 2015). This process involves four main stages: drying, pyrolysis, oxidation, and reduction, which collectively convert solid biomass into gaseous fuel that can be burned more efficiently (Rabby et al., 2023). Compared to direct combustion stoves, gasifier stoves utilize both primary and secondary air supply mechanisms to enhance combustion completeness, resulting in cleaner flames, reduced smoke, and improved thermal performance (Hailu, 2022).

The performance of gasifier stoves is influenced by several factors, including fuel characteristics, stove design, and operating conditions. Key fuel properties such as moisture content, particle size, and energy content significantly affect the gasification process. For instance, fuels with low moisture content and appropriate particle size promote efficient combustion and reduce energy losses associated with drying and incomplete reactions (Bantelay, 2014). Similarly, the design of the combustion chamber, air flow configuration, and equivalence ratio play critical roles in determining the efficiency and emission profile of the stove (Himanshu et al., 2022). Studies have also highlighted the importance of optimizing air supply, as excess air can improve combustion efficiency but may simultaneously increase heat losses due to convection, thereby reducing overall thermal efficiency (Akolgo et al., 2024).

Another crucial aspect in evaluating cookstove performance is the selection of appropriate testing methods. The Water Boiling Test (WBT) is one of the most widely used laboratory-based protocols for assessing the thermal efficiency and fuel consumption of cookstoves. This method simulates real cooking conditions by measuring the amount of fuel required to heat and boil a known quantity of water, as well as the heat transferred to the cooking vessel (Chen et al., 2016; Getahun et al., 2019). The WBT provides a standardized approach for comparing different stove–fuel combinations, allowing researchers to identify performance differences and optimize design parameters. Despite variations in testing protocols across regions, the WBT remains a reliable and widely accepted method for evaluating cookstove performance (Chen et al., 2016).

In addition to stove design, the type of biomass fuel used plays a significant role in determining overall performance. Biomass fuels are highly heterogeneous, varying in composition, density, moisture content, and calorific value (Thoharudin et al., 2022). Common forms of biomass include wood chips, agricultural residues, sawdust, and wood shavings, each exhibiting different combustion and gasification characteristics (Osei et al., 2020). Sawdust, for example, is a fine particulate biomass with high surface area, which can enhance combustion but may also lead to airflow resistance and pressure drop in the reactor. On the other hand, wood shavings, which consists of larger and denser pieces, may provide better airflow but could result in slower combustion rates and incomplete gasification if not properly managed (Bantelay, 2014).

Previous studies have emphasized the importance of fuel uniformity in improving stove performance. Homogeneous fuels such as pellets have been shown to reduce variability in combustion behavior and emissions, thereby enhancing overall efficiency (Champion & Grieshop, 2019). However, in many developing regions, processed fuels like pellets are not readily available or affordable, making locally available biomass residues such as sawdust and wood shavings more practical alternatives. Despite their widespread availability, there is limited comparative research on the performance of these two fuel types in gasifier stoves, particularly under controlled experimental conditions.

Furthermore, the utilization of biomass residues such as sawdust and wood shavings offers significant environmental and economic benefits. These materials are often considered waste products from wood processing industries and are either underutilized or disposed of through open burning, contributing to environmental pollution (Osei et al., 2020). Converting these residues into useful energy through gasification not only reduces waste but also provides a sustainable and cost-effective energy source for household cooking. This aligns with global efforts to promote renewable energy utilization and reduce dependence on fossil fuels (Getahun et al., 2019).

Given the growing interest in clean cooking technologies and the need to optimize fuel–stove combinations, this study aims to evaluate and compare the performance of a gasifier stove using two different biomass fuels: sawdust and wood shavings. The Water Boiling Test (WBT) is employed as the primary evaluation method to assess key performance indicators such as thermal efficiency, fuel consumption rate, and boiling time. By systematically comparing these fuel types, the study seeks to identify the most suitable biomass fuel for gasifier stove applications, considering both efficiency and practicality.

Ultimately, this research contributes to the ongoing development of improved biomass cooking technologies by providing insights into the influence of fuel characteristics on stove performance. The findings are expected to support the design and optimization of gasifier stoves that are efficient, environmentally friendly, and suitable for widespread adoption in resource-limited settings.

THEORETICAL REVIEW

Biomass gasification is a thermochemical conversion process that transforms solid biomass into combustible gas (syngas) under limited oxygen conditions at high temperatures. The process produces syngas, biochar, ash, and tar compounds. Syngas mainly contains carbon monoxide (CO), hydrogen (H_2), and methane (CH_4), along with carbon dioxide (CO_2) and nitrogen (N_2). Compared with direct combustion, gasification provides higher energy recovery and better efficiency because biomass is first converted into gas before combustion occurs (Isgiyarta et al., 2022; Tezer et al., 2022)

The gasification process consists of four main stages: drying, pyrolysis, oxidation, and reduction. During drying, moisture evaporates from the biomass. Pyrolysis then decomposes biomass into volatile gases, tar, and char under oxygen-limited conditions (Thoharudin et al., 2020). Oxidation generates heat through partial combustion, while the reduction stage converts char into combustible gases that form syngas (Tezer et al., 2022).

Gasifier stoves are small-scale devices that convert biomass into syngas for cooking applications. Unlike traditional stoves that directly burn fuel, gasifier stoves separate gasification and combustion processes, resulting in cleaner flames, reduced smoke, and improved thermal efficiency (Jetter et al., 2012). These stoves generally consist of an inner combustion chamber and an outer cylinder. Primary air supports gasification inside the fuel bed, while secondary air burns the volatile gases above the fuel, producing a cleaner combustion process (Shahi et al., 2014).

Several types of gasifier stoves have been developed, including updraft, downdraft, natural draft, and forced draft systems. Among these, top-lit updraft (TLUD) stoves are widely used because of their simple design, low operating cost, and suitability for household cooking (Quist et al., 2020). TLUD stoves improve combustion efficiency by allowing volatile gases and tar compounds to pass through a hot char layer before combustion occurs (Rabby et al., 2023).

Thermal performance is an important parameter for evaluating gasifier stoves. Thermal efficiency refers to the ratio of useful heat transferred to the cooking vessel compared with the total energy contained in the fuel. Previous studies reported that gasifier stoves can achieve thermal efficiencies of approximately 20–30%, while traditional biomass stoves generally achieve only 10–15% (Rabby et al., 2023). Thermal performance is affected by factors such as fuel properties, airflow rate, moisture content, and stove design.

Sawdust and wood shavings are common biomass residues from wood-processing industries. Sawdust consists of fine wood particles, while wood shavings refers to the outer sections removed during lumber production. Both materials have good energy potential because of their high carbon content and wide availability.

Fuel characteristics strongly influence gasification performance. Sawdust has smaller particle size and larger surface area, which can improve heat transfer and accelerate pyrolysis. However, dense packing may reduce airflow inside the reactor. In contrast, wood shavings generally provides better airflow because of its larger particle size but may gasify more slowly. Differences in moisture content, ash content, and calorific value between sawdust and wood shavings can significantly affect combustion behavior, thermal efficiency, and conversion efficiency.

METHODOLOGY

This study adopted an experimental approach to evaluate the performance of a biomass gasifier stove using two different biomass fuels, namely sawdust and wood shavings. The comparison focused on key performance indicators including thermal efficiency, fuel consumption rate, and boiling time. All experiments were conducted under controlled laboratory conditions to ensure consistency and reliability of the results. The Water Boiling Test (WBT) was employed as the primary evaluation method, as it is widely recognized for assessing the thermal performance of cookstoves and enabling comparison between different fuel–stove combinations. Each test was repeated two times for both fuel types, and the average values were used in the analysis.

The fuels used in this study were sawdust and wood shavings, both obtained from local Sengon-processing residues. Sawdust represents a fine particulate biomass with a relatively high surface area, while wood shavings consists of larger, denser pieces. Prior to testing, both fuels were air-dried to reduce moisture content, as moisture significantly affects combustion and gasification efficiency by consuming heat during the drying phase. Sawdust was sieved to remove excessively fine particles that could hinder airflow, whereas wood shavings was cut into uniform sizes to ensure stable combustion and prevent bridging within the reactor. The illustration of the sawdust and wood shavings are depicted in Figure 1. The proximate and ultimate characteristic of Sengon wood is listed in Table 1.

The experimental setup consisted of a forced draft biomass gasifier stove equipped with primary air inlet with air velocity controlled into 0.7, 0.9, and 1.05 m/s to facilitate partial combustion and syngas generation (Figure 2). Additional equipment included a digital weighing scale (±0.01 kg accuracy), a thermocouple for temperature measurement, a stopwatch for recording time, and a cooking pot with known mass and capacity.

(a) (b)

Figure 1. Sengon tree in forms of (a) sawdust and (b) wood shavings

Table 1. Thermophysic properties of Sengon wood (Setyawan, 2024)

Proximate analysis	As received	Dry basis
Moisture content (wt.%)	10.71	-
Volatile matter (wt.%)	74.67	83.63
Fixed carbon (wt.%)	13.41	15.02
Ash (wt.%)	1.21	1.35
Sulfur (wt.%)	0.08	0.09
Ultimate analysis		
Carbon (wt.%)	44.06	49.35
Hydrogen (wt.%)	5.44	6.09
Oxygen (wt.%)	38.25	42.84
Nitrogen (wt.%)	0.25	0.28
Heating value (MJ/kg)	18.00	20.16

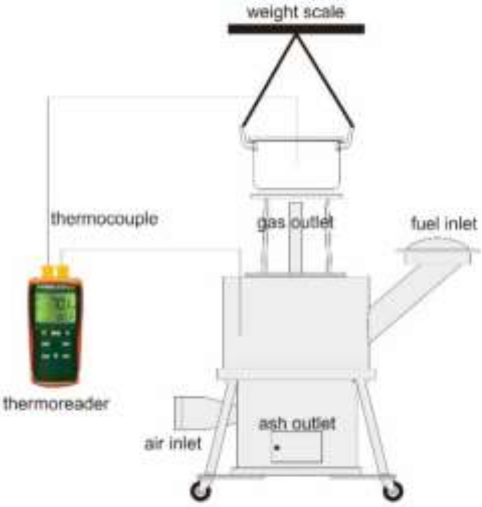

Figure 2. Schematic of the gasification stove test

The Water Boiling Test (WBT) was conducted to evaluate the stove's ability to convert fuel energy into useful heat for cooking. The procedure began by weighing the empty cooking pot, followed by filling it with a fixed volume of water (1 liter). The total mass of the pot and water was recorded, and the initial temperature of the water was measured.

A known mass of biomass fuel was then loaded into the gasifier stove and ignited using a small amount of starter material. Once stable combustion was achieved, the cooking pot was placed on the stove. The temperature of the water was monitored continuously until it reached the boiling point (approximately 100°C), and the time required to reach boiling was recorded.

After boiling, the remaining water was weighed to determine the amount of evaporated water. The residual fuel and ash were also collected and weighed to determine the mass of fuel consumed. This procedure was repeated for both fuel types under identical conditions to ensure comparability.

The performance of the gasifier stove was evaluated using several key parameters derived from the WBT data. Thermal efficiency was calculated as the ratio of useful heat transferred to the water to the total energy input from the fuel consumed. It is expressed in Equation 1 (Cansee et al., 2025).

$$\eta_{th} = \frac{M_w C_{pw}(T_b - T_o) + M_{ev} L_v}{M_f CV_f} \times 100\% \qquad (1)$$

where M_w is the mass of water (kg), C_{pw} is the specific heat capacity of water (kJ/kg·°C), Tb and To are the boiling and initial water temperatures (°C), M_{ev} is the mass of evaporated water (kg), L_v is the latent heat of vaporization (kJ/kg), Mf is the mass of fuel consumed (kg), and CV_f is the calorific value of the fuel (kJ/kg).

The fuel consumption rate (FCR) was used to evaluate how quickly fuel is consumed during operation and was calculated using Equation 2.

$$FCR = \frac{M_f}{t} \qquad (2)$$

where M_f is the mass of fuel consumed (kg) and t is the total time required to complete the boiling process (h).

The experimental data obtained from repeated tests were averaged to reduce random measurement errors. Comparative analysis was conducted to evaluate differences in performance between sawdust and wood shavings fuels. To ensure the validity of the comparison, all experiments were conducted using the same gasifier stove, cooking pot, and measurement instruments. The initial water volume and temperature were kept constant, and fuel preparation procedures were standardized. Ambient conditions were assumed to remain relatively stable throughout the experiments. Under these controlled conditions, any observed differences in performance were attributed primarily to the characteristics of the fuel used.

RESULTS AND DISCUSSION

Reactor Temperature

The temperature profiles of the gasifier increased steadily over time for all operating conditions, rising from approximately 98–137°C at the initial stage to 372–466°C at the final stage (Figure 3). This trend indicated the sequential progression of drying, pyrolysis, and gasification processes. At higher air velocities, the temperature rise became more pronounced. For sawdust, the final temperatures increased from 372.4°C at 0.7 m/s to 418.1°C at 1.05 m/s (≈12%

increase), while for wood shavings, the increase was from 372.2°C to 465.9°C (≈25% increase). The higher sensitivity of wood shavings to airflow suggested more effective oxygen utilization and stronger exothermic reactions. The average heating rate for wood shavings at 1.05 m/s was also higher (≈32.8°C per time interval) compared to sawdust (≈29.6°C per interval), indicating enhanced thermal reactivity.

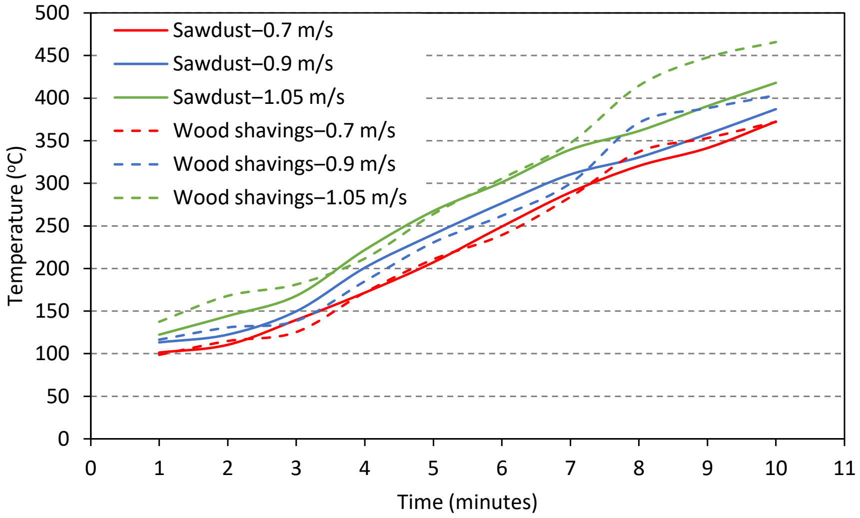

Figure 3. Gasifier Temperature Evolution

A clear distinction between the two fuels emerged, particularly at higher airflow conditions. At 1.05 m/s, wood shavings consistently produced temperatures 20–50°C higher than sawdust across most time intervals, with the largest difference observed at the final stage (≈47.8°C). This behavior was attributed to the structural properties of the fuels. Wood shavings, with higher porosity and larger particle size, facilitated better airflow distribution and reduced flow resistance, allowing more uniform oxidation and gasification reactions. In contrast, the fine and dense structure of sawdust limited oxygen penetration, resulting in less efficient heat generation. The relatively small temperature difference at 0.7 m/s (<10°C) further indicated that under oxygen-limited conditions, the influence of fuel structure was less significant.

The results demonstrated a strong interaction between air velocity and fuel characteristics. Increasing airflow enhanced temperature for both fuels, but the effect was significantly greater for wood shavings due to its superior permeability. The optimal condition was observed at 1.05 m/s using wood shavings, which achieved the highest temperature (465.9°C) and the fastest heating rate, indicating more efficient gasification. These findings suggested that while sawdust may require densification or reactor modification to improve performance, wood shavings was inherently more suitable for fixed-bed gasification systems due to its favorable physical and thermal properties.

Gasification Product Yield

The product distribution of the gasification process demonstrated a strong dependence on both airflow velocity and fuel type, with clear differences in gas yield, char formation, ash content, and unburned residues, as shown in Figure 4.

For sawdust, increasing the air velocity from 0.7 m/s to 1.05 m/s significantly enhanced gas production from 25.50 wt.% to 36.96 wt.% (≈45% increase), while char content decreased slightly from 50.96 wt.% to 48.50 wt.%. At the same time, ash and unburned fractions were reduced from 14.04 wt.% to 8.46 wt.% and from 9.50 wt.% to 6.08 wt.%, respectively. This trend indicates that higher airflow improved oxidation and conversion efficiency, promoting the breakdown of solid carbon into gaseous products while minimizing incomplete conversion. However, the relatively high char fraction (>48 wt.%) suggests that the gasification of sawdust remained limited by internal diffusion constraints, likely due to its dense packing structure, which restricted oxygen penetration and reduced reaction uniformity.

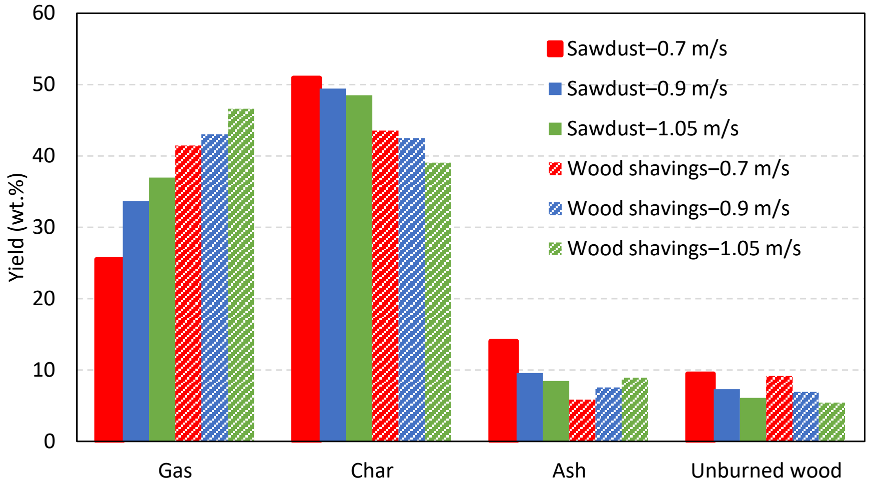

Figure 4. Gasification product yield

In contrast, wood shavings exhibited significantly higher gas yields across all airflow conditions, increasing from 41.46 wt.% at 0.7 m/s to 46.62 wt.% at 1.05 m/s, which was consistently 10–16 wt.% higher than sawdust. Concurrently, char content decreased more substantially from 43.54 wt.% to 39.04 wt.%, indicating more effective carbon conversion. Although ash content showed a slight increase with airflow (5.85 wt.% to 8.92 wt.%), the unburned fraction decreased to as low as 5.42 wt.%, reflecting improved combustion completeness. The superior performance of wood shavings can be attributed to its higher porosity and larger particle size, which facilitated better airflow distribution and enhanced mass transfer within the fuel bed. This allowed more efficient interaction between oxygen and carbonaceous material, resulting in higher gasification efficiency and reduced residual solids.

A deeper analysis reveals that airflow influenced not only the extent of conversion but also the distribution of products. For both fuels, increasing air velocity promoted gas production at the expense of char and unburned material, confirming that oxygen availability was a key controlling factor in the gasification process. However, the marginal increase in gas yield for wood shavings at higher airflow (≈12% from 0.7 to 1.05 m/s) compared to sawdust (≈45%) suggests that wood shavings already operated near optimal conversion even at lower airflow conditions. Furthermore, the relatively stable ash fraction for wood shavings indicates that mineral residue formation was primarily governed by inherent fuel composition rather than operating conditions.

Water Boiling Test

The water-heating performance of the gasifier stove under different airflow velocities and fuel types exhibited a consistent increase in temperature over time, as shown in Figure 5. The initial water temperatures ranged between 26.8°C and 30.15°C and increased to final values between 89.6°C and 96.9°C after 600 seconds. In general, higher air velocities resulted in faster and higher temperature increases. For sawdust, the final temperature increased from 89.6°C at 0.7 m/s to 95.75°C at 1.05 m/s (≈6.9% increase), whereas for wood shavings, it increased from 95.2°C to 96.9°C (≈1.8% increase). Although both fuels showed improved heating performance with increasing airflow, the effect was more pronounced in sawdust during the heating rate phase, while wood shavings maintained higher overall temperatures, especially in the later stages.

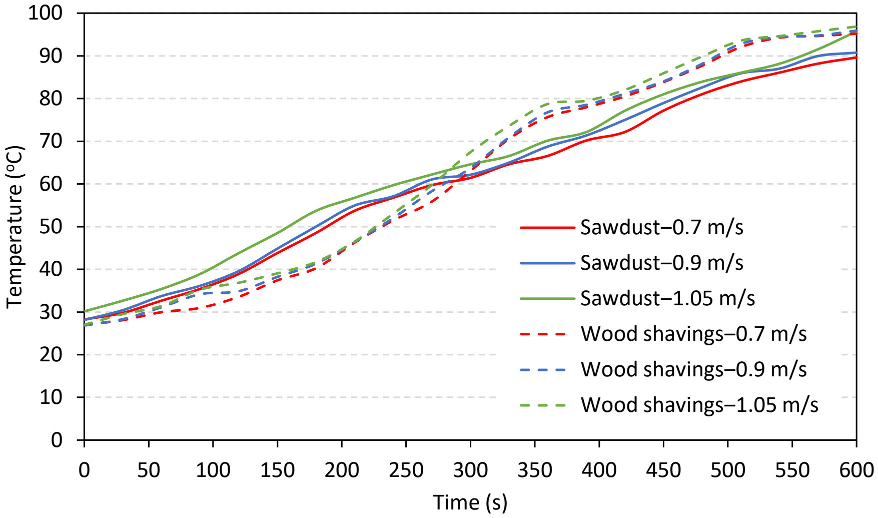

Figure 5. Water Temperature Evolution

A distinct difference in thermal behavior between the two fuels was observed throughout the heating process. During the initial and mid-heating periods (0–300 s), sawdust exhibited a slightly faster temperature rise, particularly at higher air velocities, reaching 64.6°C at 300 s for 1.05 m/s compared to 67.45°C for wood shavings. However, beyond 300 s, wood shavings demonstrated superior performance, achieving consistently higher temperatures across all airflow conditions. At 600 s, wood shavings exceeded sawdust by approximately 5.6°C at 0.7 m/s and 1.15°C at 1.05 m/s. This indicates that wood shavings provided more sustained heat release, likely due to its slower combustion rate and better structural integrity, which prolonged the gasification and combustion processes.

The heating rates further highlighted the interaction between airflow and fuel characteristics. Sawdust at 1.05 m/s showed a rapid increase from 30.15°C to 64.6°C within the first 300 s (≈0.115°C/s), whereas wood shavings under the same condition increased from 27°C to 67.45°C (≈0.135°C/s), indicating a slightly higher effective heat transfer rate for wood shavings. The improved performance of wood shavings can be attributed to its higher porosity and larger particle size, which enhanced airflow distribution and combustion stability. In contrast, the dense packing of sawdust may have restricted airflow, limiting sustained heat generation despite its initially faster response. The results suggested that while increasing air velocity improved water-heating efficiency for both fuels, wood shavings at 1.05 m/s provided the most effective and stable heating performance, achieving the highest final temperature and demonstrating better suitability for prolonged thermal applications.

The relative water mass during heating exhibited a clear decreasing trend over time for all operating conditions, confirming progressive evaporation as heat was supplied by the gasifier stove (Figure 6). In the early stage (0–150 s), the relative mass remained constant at 1.0 for all cases, indicating that the supplied heat was primarily used to raise the sensible temperature of the water rather than inducing phase change. The onset of evaporation began around 180 s, where a slight mass reduction was first observed, particularly for sawdust (e.g., 0.989 at 0.7 m/s and 0.987 at 1.05 m/s), while wood shavings still maintained nearly constant mass. This delay in mass loss suggests that wood shavings required a longer time to reach effective boiling conditions, despite its higher thermal stability observed in temperature profiles.

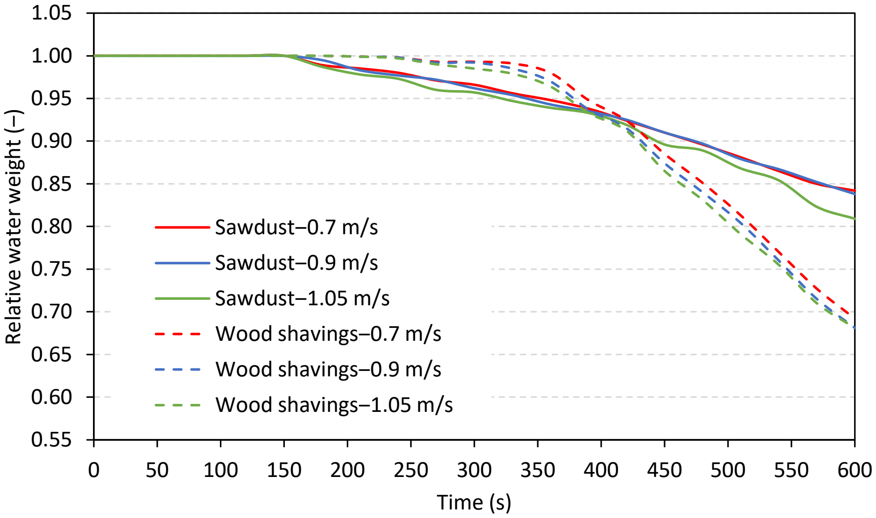

Figure 6. Relative water weight

As heating progressed, the rate of mass reduction increased significantly, especially beyond 300 s, indicating intensified evaporation due to higher water temperatures approaching boiling conditions. By the end of the experiment (600 s), the relative water mass for sawdust decreased to 0.842, 0.838, and 0.809 at airflow velocities of 0.7, 0.9, and 1.05 m/s, respectively, corresponding to total mass losses of approximately 15.8%, 16.2%, and 19.1%. In contrast, wood shavings exhibited substantially greater evaporation, with final relative masses of 0.692, 0.681, and 0.681, equivalent to mass losses of approximately 30.8–31.9%. This indicates that wood shavings produced nearly double the evaporation rate compared to sawdust under similar airflow conditions. The higher evaporation performance of wood shavings is consistent with its ability to sustain higher and more stable heat release over time, leading to prolonged boiling and increased latent heat transfer.

The influence of airflow velocity on evaporation behavior was also evident. For sawdust, increasing airflow from 0.7 m/s to 1.05 m/s resulted in a noticeable increase in total mass loss (≈3.3% difference), indicating improved heat transfer due to enhanced combustion intensity. However, for wood shavings, the effect of airflow on final mass loss was relatively small, as all airflow conditions converged to similar values (~0.68–0.69). This suggests that wood shavings reached a thermal regime where evaporation was no longer limited by heat supply but rather by the latent heat requirement and heat transfer efficiency to the water. Additionally, the sharper decline in mass for wood shavings after 420 s (e.g., from 0.924 to 0.692 at 0.7 m/s) indicates a transition to vigorous boiling, where evaporation rates were significantly accelerated.

The results demonstrated that evaporation behavior was strongly governed by both fuel characteristics and airflow conditions. While sawdust showed a gradual and airflow-dependent evaporation trend, wood shavings exhibited delayed onset but significantly higher overall evaporation, reflecting its superior ability to sustain high-temperature combustion.

The reduction in relative water mass showed a clear and physically consistent correlation with the water temperature profiles during heating. In the initial stage (0–150 s), water temperature increased from approximately 27–48°C while the relative mass remained constant at 1.0, indicating that all supplied energy was absorbed as sensible heat without evaporation. The onset of mass loss around 180 s coincided with temperatures reaching ~50–54°C, marking the transition to evaporation. Beyond 300 s, when temperatures approached 60–70°C, evaporation became significant, as reflected by a steady decline in relative mass. This demonstrates that once the water approached near-boiling conditions, additional heat input was increasingly converted into latent heat, accelerating mass loss rather than further raising temperature.

A comparison revealed that although both fuels reached similar final temperatures (~90–97°C), wood shavings produced substantially greater evaporation than sawdust. At 600 s, wood shavings achieved ~31–32% mass loss compared to ~16–19% for sawdust, despite only marginal temperature differences (<2°C at high airflow). This indicates that wood shavings delivered more effective and sustained heat transfer, particularly in the phase-change regime. The higher evaporation efficiency can be attributed to its porous structure, which enabled stable combustion and continuous heat release, ensuring that energy was consistently supplied for vaporization. In contrast, sawdust, with its dense packing, likely experienced restricted airflow and less stable heat generation, limiting its ability to sustain evaporation. Thus, the combined analysis of temperature and mass loss confirms that wood shavings exhibited superior thermal utilization, where heat was more effectively converted into latent energy rather than merely increasing temperature.

Water Boiling Gasification Stove Performance

The overall gasification performance reflected a strong interaction between airflow velocity and fuel characteristics, where wood shavings consistently demonstrated superior energy utilization compared to sawdust (Figure 7). While sawdust exhibited relatively low efficiency in the range of 11.83–12.99%, wood shavings achieved significantly higher values between 15.07% and 19.59%. This indicates that wood shavings was more effective in converting the chemical energy of the fuel into useful thermal energy, likely due to its higher porosity and better airflow distribution, which promoted more uniform combustion and stable heat release. In contrast, the dense structure of sawdust limited oxygen penetration, resulting in less efficient conversion despite increasing airflow. Additionally, the decrease in efficiency of wood shavings at higher air velocities suggests that excessive airflow may have shifted the process toward heat losses through convection and over-oxidation, thereby reducing the fraction of energy transferred to the heating load.

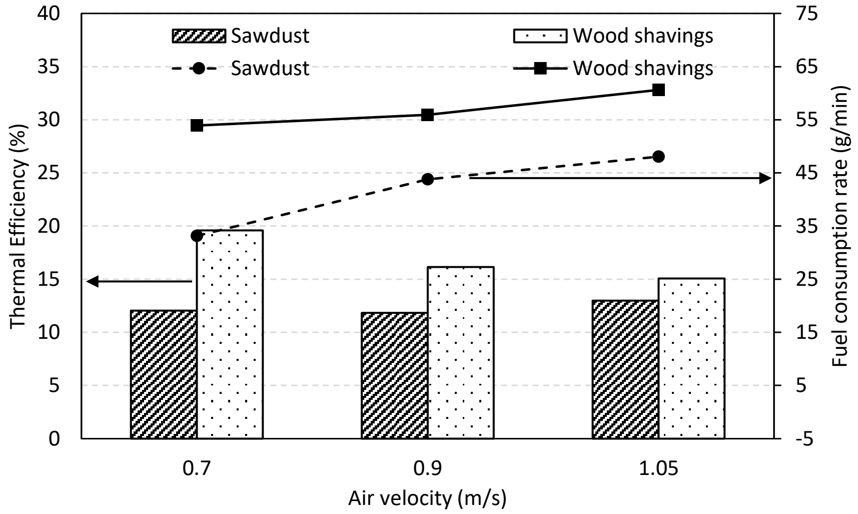

Figure 7. Gasification stove efficiency and fuel consuption rate

In addition, Figure 7 also shows the fuel consumption rate. It demontrated a clear increasing trend with airflow for both fuels, but with markedly higher values for wood shavings. Sawdust consumption increased from 33.15 g/min at 0.7 m/s to 48.05 g/min at 1.05 m/s, while wood shavings increased from 53.9 g/min to 60.6 g/min over the same range. This indicates that higher airflow intensified the combustion process, requiring more fuel to sustain the reaction. However, the relationship between fuel consumption and efficiency differed between the two fuels. For sawdust, the substantial increase in fuel consumption did not translate into a proportional improvement in efficiency, suggesting poor energy utilization and higher heat losses. Conversely, wood shavings maintained relatively high efficiency despite higher consumption rates, particularly at lower airflow, indicating a more effective conversion of fuel into useful heat. This highlights that optimal performance is not solely determined by fuel consumption but by the balance between combustion intensity and heat transfer efficiency, with wood shavings at moderate airflow conditions representing the most favorable operating regime.

CONCLUSIONS AND RECOMMENDATIONS

This study showed that airflow velocity and fuel type strongly affected gasifier stove performance. Increasing airflow from 0.7 m/s to 1.05 m/s increased reactor temperature and gas production for both fuels. Wood shavings performed better, reaching a higher temperature (465.9°C) and gas yield (46.62 wt.%) than sawdust. Sawdust also produced more remaining char, indicating incomplete combustion. Both fuels heated water to similar temperatures (~90–97°C), but wood shavings caused much higher evaporation, showing better heat transfer. Thermal efficiency of wood shavings (15.07–19.59%) was consistently higher than sawdust (11.83–12.99%). Although fuel consumption increased with airflow, wood shavings converted fuel into heat more effectively. Overall, wood shavings was more suitable for gasifier stoves because it produced higher gas yield, lower char residue, better evaporation, and higher thermal efficiency. Moderate airflow (0.7–0.9 m/s) gave the best performance.

FURTHER STUDY

Further studies are recommended to improve the performance of biomass gasifier stoves, particularly when using sawdust as fuel. Future research should investigate fuel densification methods such as pelletizing or briquetting to improve airflow distribution and combustion stability. In addition, optimization of reactor design, air inlet configuration, and insulation systems may help increase thermal efficiency and reduce heat losses. Further investigation on emission characteristics, syngas composition, and long-term stove durability is also important to evaluate environmental and operational performance. Moreover, comparative studies using other biomass residues and different operating conditions are needed to develop more efficient and sustainable gasifier stove technologies for household cooking applications.

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