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Design and Implementation of a Fixed-Bed Biomass Gasifier for Syngas Production from Pine Leaf Pellets

1 1 1
***Abstract*— This study presents the design, construction, and performance evaluation of a fixed-bed biomass gasifier fueled by pine leaf pellets. Developed as a compact and low-cost prototype intended for educational use and potential rural deployment, the system integrates principles of thermochemical conversion, mechanical design, and energy efficiency. The reactor was built using stainless steel components and featured a manually controlled airflow system to regulate combustion. Operational tests included infrared temperature monitoring at key points and visual analysis of the flame to confirm syngas production. The gasifier successfully generated combustible gas under controlled conditions, demonstrating the viability of pine leaf pellets as a sustainable biofuel. Challenges such as airflow regulation, material fatigue, and limited instrumentation were addressed during iterative development. While gas composition analysis was not performed, qualitative indicators confirmed system functionality. The outcomes contribute to the advancement of accessible biomass gasification technologies and serve as a foundation for future improvements in small-scale decentralized energy systems.**

***Index Terms*— Biomass, gasification, fixed-bed reactor, pine leaf pellets, renewable energy, syngas, prototype design.**

I. INTRODUCTION

Growing concerns about environmental sustainability, coupled with rising global energy demand, have spurred interest in alternative decentralized energy sources. One promising technique for using thermochemical reactions to convert organic waste into useful energy is biomass gasification. Pine leaf pellets stand out among the different biomass options as an affordable and sustainable resource that is especially advantageous for communities with limited access to traditional fuels.

Syngas, a flammable mixture mainly made up of carbon monoxide, hydrogen, and methane, is produced by gasification from solid biomass and can be used for engine fuel, heating, or power generation. Because of their ease of use, low cost, and versatility in handling various biomass types, fixed-bed gasifiers are preferred in small-scale settings.

Despite advancements in industrial gasification, there is a notable lack of low-cost prototypes suitable for academic settings or remote regions. This work addresses that gap by
9 presenting the design, construction, and testing of a small-scale fixed-bed gasifier using pine leaf pellets.

This prototype was conceived and developed within the academic framework of the course Energía del Hidrógeno (Hydrogen Energy), offered by Universidad Tecnológica Centroamericana (UNITEC). As part of the course objectives, students were encouraged to explore practical applications of renewable energy technologies through experimental design and prototyping. Under the guidance and technical support of Engineer Irías, the development of the fixed-bed gasifier became a hands-on learning experience that bridged theory with real-world implementation. The project aimed not only to demonstrate the potential of pine leaf pellets for syngas production but also to promote engineering creativity and resourcefulness in contexts where budget constraints and material accessibility are common challenges. The academic environment fostered collaboration, innovation, and iterative problem-solving throughout the design and testing phases, making the project both a technical and educational achievement.

In addition, small-scale biomass gasifiers like the one presented in this study hold strong potential for practical implementation in rural and underserved areas. Beyond academic interest, such systems could be adapted to provide energy for domestic cooking, water heating, or even small electricity generators. Their modular nature, reliance on locally available biomass, and low production cost make them suitable for decentralized energy solutions, especially in regions where grid connectivity is limited or absent. This underscores the relevance of the present work as a steppingstone toward sustainable and accessible energy technologies tailored to real-world constraints.

II. RELATED WORK

Biomass gasification has been extensively studied as a sustainable alternative for energy production. Kumar et al. [1] provided a comprehensive review of thermochemical gasification technologies, outlining various reactor types and feedstocks. Their work highlights fixed-bed gasifiers as especially effective for decentralized applications due to mechanical simplicity and adaptability to diverse biomass materials.

Indeed, fixed-bed designs (particularly downdraft configurations) are widely favored in small-scale systems for their low cost and ease of operation, as well as their ability to yield relatively clean syngas with minimal tar after internal thermal cracking [2], [3]. However, downdraft gasifiers also have known drawbacks: they are generally limited to dry feedstocks (moisture <30%) and can suffer from grate blocking, channeling or fuel bridging when handling low bulk density fuels [2]. These issues underscore the importance of fuel preparation and gasifier design in achieving reliable operation at small scales.

Pine needle residues have attracted interest as a biomass fuel in gasification systems, especially in regions where pine leaf litter poses environmental hazards (e.g. forest fire risk) [4]. Recent studies have shown that pine needle pellets possess a favorable heating value (~18.6 MJ/kg) and relatively low ash content (~4%), comparable to conventional woody biomass fuels [5]. García et al. [6] evaluated pine leaf pellets as a gasifier feedstock and found their fuel properties (high volatiles, low ash) to be suitable for small fixed-bed gasifiers. Similarly, Reutter and Chahín [7] developed a low-cost gasifier prototype optimized for high thermal efficiency, which provides a useful reference for reactor design and materials selection in compact systems. These efforts confirm that densified pine biomass can be a viable fuel for decentralized gasification, offering an outlet for problematic forest waste while delivering useful energy.

A number of design innovations have been explored to improve the performance and tar handling of small fixed-bed gasifiers [2]. The choice of gasifier configuration significantly affects syngas quality. Updraft fixed-bed gasifiers are simple and fuel-flexible but typically produce gas with high tar and moisture content that requires downstream cleaning [8]. Downdraft (stratified) gasifiers, on the other hand, force product gases through a high-temperature combustion/reduction zone, resulting in partial tar cracking and a cleaner syngas with higher hydrogen content [8], [3]. Susastriawan et al. [2] note that design parameters such as throat geometry, air intake strategy, and insulation can greatly influence gasifier efficiency and tar production. For example, incorporating a restriction throat and pre-heated air jets has been shown to increase gas heating value and reduce tar in downdraft units [2]. Reutter and Chahín's prototype [7] emphasizes insulated combustion zones and proper grate design to maximize thermal efficiency, which aligns with observations from other researchers that careful engineering of the reaction zones leads to improved syngas quality [2].

Apart from design, operational parameters have a strong impact
10 on gasification outcomes. Equivalence ratio (ER) – the ratio of air supplied to the stoichiometric air demand – is a key control: moderate ER values around 0.2–0.3 are generally optimal for air-blown fixed-bed gasifiers, maximizing syngas yield and energy content [8]. Too low an ER can cause incomplete conversion (excess tar and char), while too high an ER drives complete combustion and a lean, low-energy gas. Gasification temperature is another critical factor; higher reactor temperatures tend to increase syngas production and improve the concentration of CO and H2 [8]. In small downdraft units,
17 maintaining bed temperatures above ~800 °C is often desirable to crack tar effectively. The choice of gasifying agent also
12 matters using oxygen or injecting steam can significantly enrich the hydrogen yield. Zhang et al. [9] report that adding steam to a fixed-bed gasifier markedly increases H2 content in the syngas (via water–gas shift reactions), at the cost of slightly lower throughput. In practice, many small-scale systems operate with air as the gasifying medium for simplicity, but there is growing research into air-steam or oxygen-enriched gasification to boost syngas quality [9].

Fuel characteristics likewise play a pivotal role in gasifier performance. Wei et al. [10] conducted pilot-scale tests on a downdraft gasifier using feedstocks ranging from wood chips and sawdust to agricultural residues and even biodiesel-derived glycerol. Interestingly, they found only minor differences in syngas composition, heating value, and tar levels among the various biomass types when using similar operating conditions. This suggests that downdraft gasifiers can handle a diverse array of fuels and still produce consistently combustible gas, provided the feedstocks are adequately sized and dried. Nonetheless, certain physical properties of the fuel can introduce challenges. Fine or powdery biomass with low particle size, low density, or high resin content tends to cause bridging, clumping, and channeling inside fixed-bed reactors. Such flow blockages disrupt the uniform descent of fuel, leading to poor gasification and even operational failure. To mitigate these issues, low-density residues like pine needles are often densified into pellets or briquettes. Densification increases the bulk density and creates a uniform particle size, improving feed handling and contact between fuel and gasifying agent. However, fuel densification can have trade-offs: Gautam et al. [11] observed that pelletized biomass sometimes yields higher tar concentrations than equivalent wood chips in the same downdraft gasifier. In their study, gasifying wood pellets resulted in tar levels of 340–680 mg/Nm^3, substantially more tar than a similar system running on chipped wood. This was attributed to the pellets' compact structure, which can limit tar cracking unless the reactor's design and conditions are adjusted for the different devolatilization behavior. Such findings highlight that while pine leaf pellets are a suitable and energy-rich fuel, the gasifier design and operating regime may need optimization to handle the fuel's specific characteristics.

Research on improving syngas quality and reducing tar in small gasifiers has yielded several strategies. One approach is the use of catalysts or reactive bed additives. Upadhyay et al. [12] demonstrated that mixing a dolomite catalyst ($CaMg(CO_3)_2$) with biomass can significantly upgrade syngas in a downdraft gasifier. In their 10 kW pilot system, adding just 5% dolomite (by weight) to the feed led to 6–9% higher concentrations of CO and H_2 in the product gas, a ~6% increase in lower heating value, and a similar improvement in cold-gas efficiency. More importantly, the dolomite acted as a tar-cracking medium: tar and particulate emissions were noticeably reduced compared to non-catalytic runs. Such in-situ catalytic gasification techniques are attractive for decentralized systems because they simplify downstream cleanup. Another tactic is to use staged or novel fixed-bed designs to enhance tar conversion. Kurkela et al. [13] developed a pressurized two-stage updraft gasifier in which a portion of the tar-rich gas from the primary updraft stage is routed through a high-temperature catalytic reformer before cooling. This configuration, tested on biomass residues, achieved tar contents of only 2–12 g/m³ in the raw gas – comparable to tar levels from industrial fluidized-bed gasifiers. After the secondary reformer, heavy tars were virtually eliminated. This result shows that even at small scales, combining an updraft gasifier with hot gas filtration or catalytic cracking can produce clean syngas suitable for engines or turbines. Thomson et al. [3] have similarly noted that most successful commercial small-scale gasifier systems incorporate measures for tar mitigation, and almost all employ downdraft fixed-bed designs to leverage their inherently cleaner producer gas. In fact, downdraft derivatives dominate the 70 kWe–3 MWe biomass gasifiers on the market, underscoring the balance these designs strike between simplicity and syngas quality.

16 Despite these advances, much of the literature focuses on either large-scale gasifiers or controlled lab-scale experiments. There are relatively few detailed reports on the design, construction, and field testing of truly small-scale (<50 kW) gasifiers built with locally sourced materials and fuels. Small commercial units do exist and have demonstrated economic viability in niche applications [3], but academic documentation of open-source or educational prototypes remains limited. This work addresses that gap by presenting a fully constructed and tested fixed-bed gasifier prototype using pine leaf pellets. By drawing on the related work above – fuel property characterization, design best-practices, and operational insights – the present study aims to contribute practical knowledge to the deployment of decentralized biomass gasifiers in resource-constrained settings.

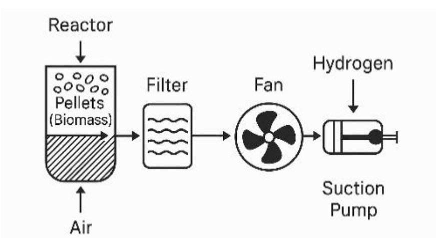

Fig.1.
Schematic diagram of the fixed-bed biomass gasifier prototype.

III. METHODOLOGY

This project was developed as part of the *Hydrogen Energy* course at UNITEC, taught by Engineer Cristian Irías. The objective was to build a functional biomass gasifier and demonstrate syngas production using pelletized pine leaves as fuel. The design followed a fixed-bed updraft configuration, adapted to the materials and tools we had available locally.
The gasifier body was a stainless-steel cylinder, approximately 50 cm tall and 30 cm in diameter. Stainless steel was chosen for its durability under high heat and resistance to corrosion. The reactor included an upper inlet for feeding biomass, a lower air intake, and a lateral gas outlet. This layout allowed gases to flow upward while collecting syngas more easily.

Inside the reactor, we placed a perforated metal grate to support the biomass and let ash fall through. For the air intake, we reused a small fan from an old CPU cooler, connected it to a PVC pipe, and added a manual switch. It was a very simple setup, but it provided enough airflow to keep the gasification going.

Figure 3 illustrates the component layout of the fixed-bed updraft gasifier, visually outlining how the main parts interact to convert biomass into usable fuel gas.

The drum serves as the main chamber where biomass is fed, and gasification takes place through the application of heat and limited oxygen. Inside this chamber, thermal decomposition of biomass generates a mixture of carbon monoxide (CO), hydrogen (H_2), and methane (CH_4).

The resulting gas then flows into the filter unit, which removes solid particles, tars, and ash. This step is crucial for ensuring that the final gas is clean and suitable for energy applications.
A fan, located at the base of the system, regulates the airflow. It ensures a steady supply of oxygen to support partial combustion and helps extract the syngas toward the filtration stage.

The clean combustible gas exits the system and can be used for electricity generation, heating, or cooking.

The diagram provides a clear overview of the flow from biomass input to clean gas output, emphasizing how each component contributes to the overall gasification process.

To start the system, we used a regular lighter. Since there was already a mix of charcoal and pine pellets inside the chamber, it lit up almost immediately. Once the flame caught, the heat kickstarted the drying process of the biomass and led to pyrolysis and partial oxidation steps that are key in syngas formation.

To measure temperature, we used an infrared laser thermometer and took readings near the air inlet and gas outlet. This helped us understand how heat behaved during operation and checked that things were running safely.

The fuel came from pine leaf pellets made at UNITEC's Energy Lab by students from the Biomass course, also taught by Engineer Irías. They collected, dried, and shredded the leaves, then compressed them using a pelletizer to form uniform cylinders. This gave the fuel better density and helped with consistent combustion.

After passing through a basic filter—shown in Figure 1—the gas exited and was lit for observation. The flame was bluish purple, a color that usually signals the presence of hydrogen and carbon monoxide. We didn't have instruments to analyze the gas precisely, but the flame looked stable, which told us the process was likely working as it should.

A. *Gasification and Syngas Generation Process*

A typical gasification system involves several stages, both for preparing the biomass and treating the resulting gas. However, the most critical and complex stage is the gasification itself. The process begins with the pre-treatment of the feedstock, which prepares the biomass to meet the operating requirements of the reactor. Depending on the type of biomass, this can include steps such as drying and compressing, mainly to reduce its moisture content.

Moisture in biomass can range from 15% to over 90%, depending on the source. In extreme cases—such as sewage sludge or animal waste—the water content may exceed 90%. Every kilogram of water requires at least 2,260 kJ of energy to evaporate, which is lost from the system unless it's captured as steam for external use. Therefore, removing excess moisture is key to maximizing the efficiency of the gasification reaction.
Once the biomass is properly conditioned, it enters the gasifier where four main stages occur inside the reactor:

Drying – As the material enters the hot zone of the reactor (above 100 °C), external moisture is removed. The biomass eventually reaches temperatures of around 200 °C, where internal compounds begin to volatilize.
Pyrolysis Also known as thermal decomposition or the "distillation zone." At this stage, long hydrocarbon chains break down into lighter gaseous compounds (condensable and non-condensable) in the absence of oxygen. One notable byproduct is tar, which can cause problems due to its viscous nature.
Combustion reactions as shown in Fig.2. Referred to as the oxidation zone or the "heart" of the reactor. Here, a limited amount of air or gasifying agent is introduced to partially burn some gases. This exothermic reaction releases heat and helps maintain the autothermal nature of the process. Temperatures can reach up to 1,200 °C.

Fig. 2. Internal view of the reactor during operation, showing the glowing metallic grate under active combustion conditions.

Gasification reactions, also called the reduction zone, this is where endothermic reactions take place, partially oxidizing the carbon-based compounds to produce combustible gases such as carbon monoxide (CO), hydrogen (H_2), and methane (CH_4). This stage occurs between 600 °C and 1,000 °C.
These steps collectively result in the transformation of solid biomass into a usable syngas, which can later be filtered and applied for combustion or energy production

Fig.3. Assembled prototype of the fixed-bed biomass gasifier.

IV. Results and Discussion

Once the gasifier was fully assembled and all components were secured, we moved into the testing phase to evaluate how well the system could convert our pine leaf pellets into syngas. This stage was both exciting and nerve-wracking, as it was the first time we would see if our design worked beyond theory.

Our initial tests weren't successful. The main issue was airflow. Even though we had a fan installed, it wasn't delivering enough oxygen to sustain combustion. The flame would start but then quickly die out. After several adjustments, including repositioning the fan, modifying the intake pipe, and sealing some small leaks. we finally reached a configuration that provided steady airflow. Once that was in place, we were able to ignite the biomass and maintain a visible flame, signaling the beginning of gasification.

The bluish-purple flame we observed at the gas outlet was especially promising. Although we didn't have gas sensors or chromatographic tools to confirm the exact composition, that flame color usually indicates the presence of hydrogen and carbon monoxide core components of syngas (see Fig.4.).

Fig. 4. Visible flame at the gas outlet of the fixed-bed biomass gasifier, indicating syngas ignition under peak operating conditions.

We also used an infrared thermometer to monitor the temperature at two key locations: the air intake and the gas outlet. The air inlet reached 637.7C as shown in Fig. 5, which confirmed that active combustion was taking place within the reactor. Meanwhile, the gas outlet maintained a temperature of around 104.6°C. These readings matched what we had found in technical references for small-scale, updraft gasifiers using dry biomass. This gave us confidence that the core thermochemical reactions like pyrolysis, partial oxidation, and reduction were indeed happening.

Fig. 5. Temperature reading at the air intake of the biomass gasifier using an infrared thermometer, showing a peak of 637.7 °C during combustion.

The gasifier stayed operational for several minutes during the longest tests, which showed good system stability. During those moments, the flame stayed constant, and we noticed a clear reduction in smoke after the gas passed through our homemade filter. This was a simple unit, made from accessible materials, but it managed to remove most visible impurities like ash and small particulates. Even though it's basic, it performed better than expected and was an important step in making the syngas cleaner and more usable.

Another key learning moment came when we tested the durability of the materials. Some of the components we originally used like plastic parts and thinner metal sheets, started to fail once exposed to high heat for extended periods. We had to replace them with stainless steel and add extra insulation in a few spots to keep the heat contained and avoid burns or structural damage. These upgrades significantly improved safety and gave the system more resistance to prolonged use.

Aside from the technical data, one of the most rewarding parts of this process was teamwork. Each person contributed their unique skills, some focused on mechanical assembly, others on airflow and combustion theory, and others on documenting every step. Sharing ideas, fixing mistakes together, and celebrating small wins really shaped the experience and kept us motivated, especially when we faced unexpected setbacks.

A. Limitations and Future Work

Even though the system worked well for the first version, we identified several areas for improvement:

No gas composition analysis: Since we lacked gas sensors, we couldn't measure exact CO, H_2, or CH_4 levels. This made it hard to calculate energy content or efficiency. In future versions, adding a basic gas analyzer or even using test tubes with water displacement methods could help quantify output.
Basic temperature control: The temperature data was useful, but we didn't have automated controls. Adding a variable-speed fan or a thermostat could improve consistency and optimize reaction zones inside the reactor.

Short runtime: The tests were brief, and we didn't evaluate the system under long-term operation. Future tests should explore how the gasifier performs over hours or days, checking for ash buildup, material fatigue, or clogging in the filter.

Fixed capacity: Our design worked with a small number of pellets, but scaling it up would require a stronger structure, better air control, and a more robust filtration system. It's an important step if the system is to be used for real-world energy production in homes or rural areas.

Despite these limitations, this first prototype proved that it's possible to build a low-cost, functional gasifier using local materials and basic tools. More importantly, it showed us that with the right teamwork, problem-solving mindset, and persistence, we could go from concept to a working solution that demonstrates real-world energy conversion.

Looking ahead, we see many possibilities. With better analysis tools, improved insulation, and longer testing periods, this design could evolve into a more advanced system for small-scale electricity generation or heat production. It could also be used as a learning tool in schools or community projects, helping others understand how clean energy can be produced from natural waste.

V. Conclusion

This project successfully demonstrated the design, construction, and operational testing of a small-scale fixed-bed biomass gasifier fueled by pine leaf pellets. The system proved capable of producing syngas consistently under controlled conditions, validating its potential as a low-cost, accessible solution for renewable energy generation in both educational environments and off-grid communities.

Beyond meeting its technical objectives, the project highlighted the value of using locally available materials and repurposed components to build a safe and functional reactor. The structure, including its chamber, filter system, and airflow control—functioned effectively, and observations of the syngas flame suggested good combustion quality. Although some limitations were encountered, such as the need for improved insulation and airflow regulation, the prototype worked reliably and safely.

Importantly, the experience also served as a powerful educational tool, promoting student engagement with renewable technologies and encouraging innovative thinking within budget constraints. Overall, this project illustrates the feasibility of small-scale gasifiers as a sustainable alternative for decentralized energy production—reducing organic waste, lowering reliance on fossil fuels, and supporting cleaner energy practices.

References

[1] Kumar, D. D. Jones, and M. A. Hanna, "Thermochemical biomass gasification: a review of the current status of the technology," Energies, vol. 2, no. 3, pp. 556–581, 2009.

[2] A. P. Susastriawan, H. Saptoadi, and Purnomo, "Small-scale downdraft gasifiers for biomass gasification: A review," Renew. Sustain. Energy Rev., vol. 76, pp. 989–1003, 2017.

[3] R. Thomson, P. C. W. Kwong, A. Ejaz, and K. D. P. Nigam, "Clean syngas from small commercial biomass gasifiers: a review of gasifier development, recent advances and performance evaluation," Int. J. Hydrogen Energy, vol. 45, no. 41, pp. 20693–20705, 2020.

[4] M. D. V. Reddy, B. M. Reddy, and T. G. Bhaskar, "Pine needle biomass: an underutilized resource for energy and bio-based products," Biomass Conv. Bioref., vol. 12, pp. 1123–1135, 2022.

[5] Y. Gao, S. Zhang, and H. Zhang, "Syngas production from biomass gasification: influences of feedstock properties, reactor type, and reaction parameters," ACS Omega, vol. 8, no. 35, pp. 31620–31631, 2023.

[6] J. D. García, S. M. Martínez, and R. A. Pérez, "Aprovechamiento de residuos forestales: Evaluación del pellet de hoja de pino como biocombustible," Revista de Energía Renovable, vol. 12, no. 3, pp. 45–52, 2020.

[7] J. B. Chahín and A. Reutter Alerta, "Diseño de un reactor de gasificación de biomasa con enfoque en eficiencia térmica y selección de materiales," Tesis de Ingeniería, Universidad de Chile, Santiago, Chile, 2014.

[8] Y. Gao et al., "Evaluation of updraft and downdraft gasifier configurations on syngas quality from agricultural waste," Renewable Energy, vol. 149, pp. 1057–1065, 2020.

[9] S. Zhang, Y. Li, and M. A. D. Cordero, "Steam-enhanced gasification of biomass in fixed-bed reactors: hydrogen production and energy analysis," Int. J. Hydrogen Energy, vol. 46, no. 12, pp. 8890–8901, 2021.

[10] L. Wei et al., "Effects of feedstock properties on the performance of a downdraft gasifier," in Proc. ASABE Annu. Int. Meeting, Reno, NV, USA, 2009, paper no. 096873.

[11] G. Gautam, S. Adhikari, S. Thangalazhy-Gopakumar, C. Brodbeck, S. Bhavnani, and S. Taylor, "Tar analysis in syngas derived from pelletized biomass in a commercial stratified downdraft gasifier," BioResources, vol. 6, no. 4, pp. 4652–4661, 2011.

[12] D. S. Upadhyay, A. Chaudhary, A. Trada, D. Patel, and R. N. Patel, "Improvement of syngas quality in fixed bed gasifier using CaMg(CO3)2 catalyst," in Proc. 10th Int. Conf. Fluid Flow, Heat Mass Transfer (FFHMT), Ottawa, Canada, 2023.

[13] E. Kurkela, M. Kurkela, and I. Hiltunen, "Pilot-scale development of pressurized fixed-bed gasification for synthesis gas production from biomass residues," Biomass Conv. Bioref., vol. 13, pp. 6553–6574, 2023.