Experimental Study on Producer Gas Generation from Acacia Wood Using a Cross-Draft Biomass Gasifier

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ABSTRACT

This study presented the development of a cross-draft biomass gasifier for electricity generation on a small scale using Acacia wood as fuel. The gasifier was constructed from two welded oil drums, with a fuel capacity of 20 kg and a combustion chamber volume of 0.444 m^3. The producer gas was utilized to power a HONDA GX160 gasoline engine attached to an alternator. The apparatus achieved a maximum electrical power output of 31.94 W at a speed of 2,780 rpm and average power output of 26.73 W at 1,393.56 rpm. Temperature was taken in the major areas of operation, including drying, pyrolysis, combustion, and reduction using thermocouples, while the major components of the producer gas were identified to be carbon monoxide (CO), hydrogen (H_2), and methane (CH_4). The experimental results revealed that the electric power output of the Acacia wood gasification system which ranged from 27.68 to 31.94 W was comparable to that of the conventional gasoline operation (29.48 W), which made it suitable for energy generation. Future work should focus on the enhancement of the gas quality and overall efficiency.

Keywords-biomass; gasification; producer gas; cross-draft biomass gasifier

I. INTRODUCTION

Biomass is an organic material derived from plant-based sources, such as wood, agricultural residues, and organic waste [1-3]. It constitutes a significant renewable energy source, as its decomposition and combustion processes release heat with no carbon dioxide emissions, compared to fossil fuels [4-6]. In Thailand, biomass plays an important role supporting sustainable energy production. The country possesses abundant agricultural resources, including rice husks, sugarcane bagasse, palm oil residues, and wood waste, which provide substantial potential for biomass utilization. The Thai government has actively promoted biomass energy within its broader renewable energy strategy to reduce the amount of Greenhouse Gases (GHGs) and enhance energy security. Specifically, various industries have developed biomass gasification and combustion technologies to produce heat and electricity. However, challenges, like feedstock supply chain management, technological efficiency, and consistent implementation of supportive policies, have grown through this implementation.

Gasification is a thermochemical process that converts solid biomass into a combustible gas mixture known as producer gas. Among different types of gasifiers, the cross-draft gasifier has been widely studied for its compact design, rapid response to load changes, and suitability for charcoal-based applications [7]. It operates by introducing air from the side, allowing the gas to exit through an outlet positioned opposite to the air inlet. This design can lead to a high-temperature reaction zone, enhancing the efficiency of gasification [8].

Acacia biomass has gained a lot of interest in Thailand, and it is already utilized in industrial applications and sustainable land management, mostly for power generation. It is usually converted into producer gas through the gasification process or directly burned for heat and electricity. The high calorific value of Acacia makes it a highly efficient fuel source.

The objective of this study is to experimentally investigate the performance of a cross-draft biomass gasifier fueled with Acacia wood under local operating conditions in Thailand. The research focuses on analyzing the gas composition, combustion characteristics, and overall efficiency to evaluate the potential of Acacia-based producer gas as a renewable energy source.

II. LITERATURE OVERVIEW

A. *Gasification Technologies*

Gasification, a key process for biomass conversion, has been extensively studied. For example, syngas production from Underground Coal Gasification (UCG) of lignite and fracture-type coal was investigated in [9]. Additionally, authors in [10] examined the production of syngas through a cross-draft gasifier, with a focus on varying temperature and rice straw mass as a filter. In [11], it was stated that cross-draft gasifiers could be effectively employed in agricultural applications, while authors in [12] found that they were highly sensitive to the feedstock quality and required well-dried, uniform-sized charcoal for optimal performance. Additionally, authors in [13] pointed out that cross-draft gasifiers may produce higher concentrations of carbon monoxide and particulate matter compared to downdraft gasifiers, posing environmental concerns.

B. *Producer Gas from Acacia Wood*

In Thailand, Acacia wood has gained a lot of attention due to its rapid growth, high heating value, and suitability for energy applications. Studies have shown that the gasification of Acacia wood produces producer gas with calorific values ranging from 4 to 6 MJ/Nm^3, comparable to other woody biomass sources. The composition of producer gas primarily includes CO, H_2, CH_4, CO_2, and N_2, with yields depending on factors, such as moisture content, particle size, gasifier design, and operating conditions. Authors in [14] investigated the combustion of low-calorific producer gas from small-scale biomass gasification, including Acacia mangium, within porous burners. The producer gas had lower heating values ranging from 3,800 to 4,232 kJ/kg. The use of tapered porous burners achieved nearly complete combustion with minimal CO and NO_x emissions. Additionally, in [15], the gasification process of Acacia trees under varying operating parameters was evaluated. The results demonstrated that increasing the gasification temperature could improve the overall efficiency, while higher pressure negatively affected the reaction efficiency. In [16], the prediction of the gasification process of Acacia wood was studied using a non-stoichiometric equilibrium model.

C. *Emerging Technologies and Applications*

Research has also covered biomass applications beyond the energy production, such as the use of nanosilica from rice husk as an iron metal adsorbent in textile wastewater treatment [16] and the application of power transistors as solar cell devices [17]. The design of induction heating for coal liquefaction has also been explored [18]. Authors in [19] studied the effect of the temperature on Zhudong coal gasification, highlighting that elevated temperatures improved the gasification efficiency and influenced the sodium behavior. In efforts to improve gas cleaning, authors in [20] tested straw as a filter medium in an updraft gasifier, showing its effectiveness in reducing the impurities in syngas. In [21], tar reduction was examined through an indirect water condenser using rice straw, demonstrating improved gas cleanliness. Complementing these studies, authors in [22] conducted an experimental evaluation comparing the diesel engine performance, using producer gas and conventional fuel. Their results indicated that while the producer gas could effectively supplement diesel in dual-fuel operation, the performance and efficiency were sensitive to the gas quality and engine load. Additionally, authors in [23] performed an experiment of a multi-flow biomass gasifier. Using locally sourced Acacia Nilotica and Eucalyptus wood chips, they found that the gasifier could produce a producer gas with a maximum lower heating value of 4.39 MJ/kg. The experiment also determined the optimal Equivalence Ratio (ER) of 0.309 for achieving a high cold gasification efficiency (72.2%), confirming that these local woods were suitable feedstocks. In [24], the modeling and optimization of a downdraft gasifier using Acacia nilotica wood was explored. A reliable model was developed to predict the gas composition, lower heating value, and cold gas efficiency based on operating parameters, like the reaction time and gas flow rate. Using Response Surface Methodology (RSM), they were able to optimize the system to achieve the best overall results with minimal error, paving the way for more efficient decentralized power systems.

III. MATERIALS AND METHODS

A. *Experimental Setup*

In this study, a biomass cross-draft gasifier was designed that features four district reaction zones: drying, pyrolysis, oxidation, and reduction. The construction involved welding together two oil drums each measuring 89.5 x 59.5 cm. Air was supplied using a 50.8 mm diameter pipe. The system had a fuel capacity of 20 kg with a combustion chamber volume of 0.444 m^3. Air entered the combustion zone through a horizontally aligned nozzle, while the biomass gas was evacuated around the surrounding vertical structure.

The gasifier was coupled to a Honda GX160 engine, which is a 163 cm^3 air-cooled, 4-stroke OHV engine that produces a net power output of 4.8 HP (3.6 kW) at 3,600 rpm and a net torque of 7.6 lb-ft (10.3 Nm) at 2,500 rpm. The engine contained also a compression ratio of 9.0:1, a 3.1-L fuel tank capacity, and a 0.58-L oil capacity. The power output was supplied to an alternator operating within a voltage range of 13.8 - 14.4 V and a current output of 50-70 A under standard conditions. Figure 1 presents the whole setup.

Fig. 1. Imbert-type cross draft gasifier experimental setup.

Compared to stratified gasifiers, this system featured a narrowed combustion zone and varying diameters between the pyrolysis and reduction sections. Biomass was introduced into the gasifier from the top, and air was introduced into the oxidation zone using nozzles to start the combustion process. The generated heat moved upwards, causing pyrolysis in the upper zones, where biomass was decomposed into volatiles and char. The resulting gases then moved downwards through the hot char bed in the reduction zone to undergo further reactions, while a water seal ensured the downward flow.

The gasifier height was 1.6 m. It had a pyrolysis diameter of 310 mm, a reduction diameter of 150 mm, and a reduction zone height of 100 mm. The movable grate at the bottom contributed to the ash removal while preventing biomass bridging. The temperature profiles across the gasifier were measured using six pairs of chromel-alumel thermocouples, which were located at different heights and radial locations within the reduction, oxidation, and pyrolysis zones. The thermal gradients within each reaction zone were captured and a data logger was used to record the temperature data.

B. Experimental Procedure

1) Pre-Processing

Before each run, the cross-draft biomass stove was cleaned, and all seals (water seals at top and bottom) were properly positioned to prevent gas leakage. A homogeneous batch of biomass was prepared and divided into sub-batches, with the moisture content of each adjusted to 4%, 8%, and 12%. A moisture meter was employed to verify the content. For each run, 500 g of charcoal was pre-weighted, ensuring its uniformity in size and type. Before starting the first run, the airflow rotameter, temperature sensors (thermocouples), and synthesis gas analyzer were calibrated.

2) Running the Experiment

To initiate the experiment, 500 g of charcoal were placed into the reduction zone. The prepared biomass was added to the oxidation zone, and the airflow was introduced at the predetermined rate using the rotameter. Then, 25 ml of diesel were applied to ignite the biomass. The system was allowed to stabilize for 3 - 4 min until stable combustion was reached. Once stable, additional 3 kg of biomass were inserted, the system was sealed, and the timer was started for a 25-min run.

3) Data Collection

Every 5 min, the following data were recorded:

- Temperature: At specified points (e.g., combustion zone, reduction zone)
- Gas Samples
- Visual Observations: Any changes in flame color or gas output

4) Post-Experiment Analysis

The synthesis gas analyzer was utilized to determine the composition of the collected gas samples. After the 25-min run, the remaining biomass and charcoal were carefully removed and weighed in order to calculate the biomass consumption rate.

Specifically, the biomass consumption rate was calculated as the difference between the initial and final biomass mass. The Higher Heating Value (HHV) of the producer gas was estimated using an empirical formula based on the gas composition. The ER was computed using the provided stoichiometric air-to-biomass ratio (5.22 m^3/kg), with the formula defined as:

$$ER = \frac{Actual\ Air-to-\ Fuel\ Ratio}{Stoichiometric\ Air-to-\ Fuel\ Ratio} \qquad (1)$$

Figure 2 illustrates the experimental procedure of the current study.

Fig. 2. Experimental procedure.

The electrical power output (*P*) of the engine-alternator system was determined from the measured voltage and current:

$$P = V \times I \qquad (2)$$

where *P* is the electrical power output (W), *V* is the voltage (V), and *I* is the current (A).

The energy content of the producer gas (E_{gas}) was estimated using:

$$E_{gas} = V_{gas} \times LHV_{gas} \qquad (3)$$

where E_{gas} represents the energy content of the producer gas (kW or MJ/hr), V_{gas} is the volumetric flow rate of gas (m^3/s or m^3/hr), and LHV_{gas} is the lower heating value of producer gas (MJ/ m^3). Depending on the gas composition, the LHV typically ranges between 4 and 6 MJ/ m^3 and the LHV of the main gas constituents were taken as: CO = 12.63 MJ / m^3, H_2 = 10.78 MJ/ m^3, and CH_4: 35.85 MJ/ m^3.

IV. RESULTS AND DISCUSSION

A. Cross-Draft Gasifier Testing Using Acacia Wood as Fuel

This experiment was conducted as a part of a project to design, construct, and evaluate a cross-draft biomass gasifier for electricity generation using dried Acacia wood. Each test run utilized 9 kg of Acacia wood. The gas produced from combustion was used to operate a HONDA GX160 gasoline engine coupled to an alternator to generate direct current electricity. Voltage (*V*) and current (*A*) were measured using a voltmeter and ammeter on a control panel, and the electrical power output (*P*) was calculated. Table I and Figure 3 present the results of each test.

The findings indicated that the gasifier-generated producer gas could effectively run the engine and generate stable electrical power. The highest power output was recorded in test No. 9, with a voltage of 13.2 V, current of 2.42 A, and power output of 31.94 W at 2,780 rpm. The lowest values were observed in test No. 2: 12.58 V, 2.20 A, and 27.68 W at 820 rpm.

TABLE I. RESULTS OF EACH TYPE OF BIOMASS TEST

No.	Engine speed (rpm)	Voltage (V)	Current (A)	Elec. P. (W)
1	0	0	0	0
2	820	12.58	2.2	27.68
3	999	12.59	2.22	27.95
4	1,183	13.1	2.25	29.48
5	1,270	13.2	2.32	30.62
6	1,415	13.2	2.32	30.62
7	1,820	13.2	2.32	30.62
8	2,255	13.2	2.4	31.68
9	2,780	13.2	2.42	31.94
Average	1,393.56	11.59	2.05	26.73

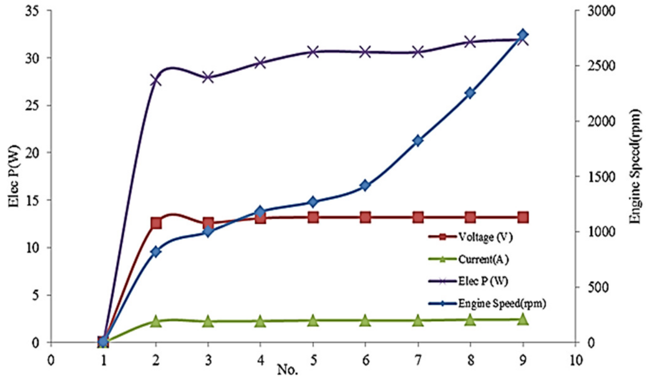

Fig. 3. Electrical power generated by the engine operating on producer gas.

The average engine speed was 1,393.56 rpm, with a voltage of 11.59 V, a current of 2.05 A, and a power output of 26.73 W.

B. Testing the Generation of Producer Gas from Acacia Wood

This part of the experiment evaluated whether the producer gas generated from the cross-draft gasification of Acacia wood was enough to start and operate a HONDA GX160 engine and produce usable electricity. For comparision, laboratory tests using gasoline fuel on a 5.5 HP engine produced a voltage of 13.1 V, current of 2.25 A, and a power output of 29.48 W.

C. Analysis of Internal Temperature Profiles in a Cross-Draft Gasifier with Acacia Wood Fuel

In the first experiment, the airflow into the combustion zone was controlled at 0.101 m^3/s, and 14 kg of Acacia wood was introduced into the gasifier. The system operated for 42 min, before being shut down.

The purpose of this test was to record the internal temperature across various zones of the gasifier. The following temperature readings were measured using Type-K thermocouples:

- T1: Temperature in the Drying Zone
- T2: Temperature in the Pyrolysis Zone
- T3: Temperature in the Combustion Zone
- T4: Temperature in the Reduction Zone.

These values were continuously monitored and recorded throughout the test to analyze the thermal behavior of the gasifier when operated with Acacia wood as the feedstock (Figure 4).

- In the Drying/Pyrolysis Zone (T1), the temperature started at 37.2 °C, gradually increased with a jump toward the end, from 190.1 °C to 248.7 °C, reaching a final value of 284.3 °C. This pattern suggested that T1 is a location that heats up slowly and then experiences a rapid temperature increase, possibly as the thermal front reaches it. The temperature profile in T2 was consistently higher than T1, stabilizing around 200 °C with a slight peak at the end. Additionally, the temperature in Combustion/Reduction Zone (T3) steadily climbed and reached over 300 °C. This high temperature range is characteristic of a combustion or reduction zone within a gasifier. Finally, T4 indicated a rapid temperature increase, but with a different pattern. It started at 39.3 °C and quickly rose, reaching its peak at 557.1 °C. This extremely high temperature revealed that T4 was located in the core reduction zone of the gasifier, where hot gases reacted with char to produce carbon monoxide and hydrogen.

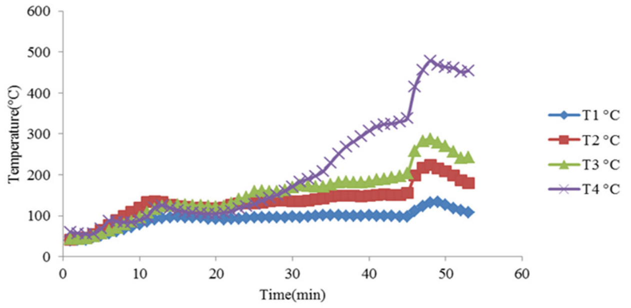

Fig. 4. The temperature distribution across different zones within the cross draft gasifier.

In the pyrolysis zone, the wood's organic components, such as cellulose, hemicellulose, and lignin, were thermally decomposed, releasing volatile gases, including CO, H_2, CH_4, and tars. For Acacia wood, the maximum devolatilization was observed between 250 °C and 380 °C. The gas composition profiles are depicted in Figure 5.

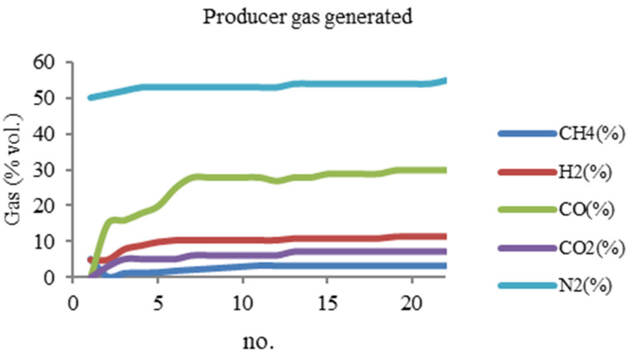

Fig. 5. Gas component measurement.

The trends indicated that both methane and hydrogen generally increased from the beginning of the dataset to the end. Specifically, methane started at 5% and stabilized at approximately 3.1%, while hydrogen initiated at 0% and reached 11.5% until the end. The carbon monoxide and carbon dioxide percentages also showed an overall increasing trend. CO began at 0% and reached 30% by the end, while CO_2 started at 0% and rose to 7%.

Overall, during a field test, the engine operated on producer gas derived from Acacia wood, generating an electrical power output of approximately 29.48 W. These results indicated that Acacia wood is a viable fuel for gasifier systems used in decentralized electricity generation.

D. Material Balance Calculation

Based on the previous explanation and the hypothetical values, a brief material balance calculation for 9 kg of Acadia wood is presented below. The calculation was based on the principle that the total mass of inputs must equal the total mass of outputs.

Inputs:

- Dry Acadia Wood: 9 kg
- Air: 22 kg
- Total Input Mass: 31 kg

Outputs (based on typical yields):

- Ash: 0.18 kg (2% of wood input)
- Char: 1.8 kg (20% of wood input)
- Tar/Water: 0.45 kg (5% of wood input)
- Syngas (by difference): 28.57 kg

Mass Closure:

$$Total\ Output\ Mass: 0.18\,kg + 1.8\,kg + 0.45\,kg + 28.57\,kg = 31\,kg$$

Thus, the mass closure is:

$$\frac{31\,kg}{31kg}\ x\,100 = 100\%$$

This calculation demonstrated that when all products were accounted for, including ash and char, the material balance was complete.

V. CONCLUSION AND FUTURE SCOPE

This research focused on the feasibility of integrating a cross-draft biomass gasifier with Acacia wood as feedstock for power generation. The gasifier produced steady syngas that could power a small internal combustion engine, achieving a peak electrical output of 31.94 W and an average power of 26.73 W. From the temperature analysis, it was clear that the cross-draft gasifier performed as expected: drying and pyrolysis took place in the lower zones, combustion maintained high heat in the middle, and the reduction zone reached high temperatures to produce gas. Additionally, this gasifier produced higher CO compared to the downdraft gasifiers, but generally less H_2, as a result of fast combustion and a shorter period for gas-phase reactions.

Despite the effectiveness of this design, its practical application is currently constrained by the modest setup, the resultant low power output, and the absence of long-term testing for real-world implementation. To enhance the applicability of this system, future work should focus on the optimization of the airflow and Equivalence Ratio (ER) to improve the gas quality and power output, preprocessing of Acacia wood for uniform size and moisture content, as well as the integration of gas-cleaning systems to extend the engine lifespan and reduce the environmental impact.

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