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Performance of a Small Compression Ignition Engine Powered by Gas Produced from Burning Rice Husks in Iraq

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ABSTRACT

This study experimentally evaluates the performance and emission characteristics of a modified compression ignition engine fueled with rice husk–derived syngas. The results show that syngas operation improves brake thermal efficiency, reaching up to 41% at full load compared to diesel fuel. In addition, significant emission reductions were achieved, with carbon monoxide (CO) and nitrogen oxides (NOx) decreasing by approximately 40% and 30%, respectively. Although brake specific fuel consumption increased due to the lower calorific value of syngas, the overall performance–emission trade-off demonstrates the strong potential of rice husk syngas as a cleaner alternative fuel for small CI engines.

1. Introduction

Environmental concerns, at the side of the depletion of traditional fossil fuels, have become urgent imperatives in our global energy situation, leading us to explore opportunity assets for sustainable and green strength solutions[1]. Exploring renewable energy alternatives is especially valuable for developing countries, as it addresses both environmental and economic issues while utilizing local agricultural waste. This approach enhances energy security and promotes long-term sustainability[2]. Iraq exemplifies a setting where abundant yet unexploited agricultural residues offer an opportunity for biofuel production, providing a promising solution for both energy generation and waste management [3].

Rice husk, a plentiful byproduct of rice milling, is often either discarded or minimally utilized, resulting in environmental waste and a missed opportunity for bioenergy generation [4]. About 20% of rice paddy weight is made up of husk, leading to substantial annual production volumes, especially in regions where rice is extensively grown [5]. With a composition of about 40% cellulose, 30% lignin, and around 20% silica, these husks are an excellent option for biofuel production due to their high energy content and relatively low moisture retention [6]. Rice husks can be converted into clean, flammable gas through pyrolysis or gasification. Suitable for use in internal combustion engines [7].
Moreover, this research is ready in opposition to the backdrop of Iraq's strength situation, characterized via fluctuating oil costs and the urgent want for

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diversification of energy sources [8]. The use of rice husk gas (RHG) in small engines can serve as a model for solving decentralized energy problems in rural areas. Promote the local economy and promote sustainable agricultural practices[9].

The exploration of renewable power sources has increasingly centered around biofuels derived from agricultural residues, with rice husks rising as a outstanding candidate due to their abundance and power-wealthy composition[10].

Biofuel Production from Rice Husks: The process of converting rice husks into usable fuel is studied [11]. Gasification of rice husks produces synthetic gas. (synthetic gas) containing hydrogen carbon monoxide and mostly methane It has the amount of energy that can support combustion in an engine that uses heat. [12]. The efficiency of gasification and the fine of the produced fuel depend drastically on the technology used and the operating situations, including temperature and husk feed rate [13].

Performance of CI Engines on Alternative Fuels: Extensive research has been done on the suitability of diesel engines for alternative fuels [14]. Demonstrated that CI engines may want to run efficiently on syngas with minor changes, though the lower calorific value of syngas compared to diesel requires changes in engine timing and fuel injection strategies[15]. The paintings of similarly supports this, displaying that even as electricity output might also lower whilst switching to syngas, emissions are substantially decreased, contributing to a purifier surroundings [16].

Environmental Impact and Sustainability: The environmental implications of using RHG as a fuel are favorable[17]. Indicate that burning rice husks in a managed manner via gasification reduces the release of harmful pollution like carbon dioxide and particulate be counted compared to open burning of the husks [18]. Moreover, the use of RHG is consistent with sustainable energy objectives. Because it turns waste into energy. This helps reduce waste around the world and promotes agricultural sustainability [19].

Gaps in Current Research: While the aforementioned research provides a foundational expertise of the capacity of rice husks as a biofuel and the operation of CI engines on opportunity fuels, there stays a substantial gap in research particular to Iraq. The variation of engine generation to leverage RHG efficaciously beneath local environmental situations and the socioeconomic effects of this kind of transition are regions which have no longer been safely explored. Additionally, comprehensive lifecycle checks of rice husk gasification in Iraqi contexts are sparse.

Relevance to Current Study: This observes targets to fill these gaps by means of not handiest comparing the technical feasibility of the use of RHG in small CI engines in Iraq however additionally by using assessing the environmental and financial effects of such an initiative. The findings from these studies ought to offer a blueprint for integrating comparable renewable power solutions in other areas with similar agricultural outputs and energy wishes.

This examine makes a specialty of the utilization of gas derived from rice husks as a gasoline for small compression ignition engines, which are pivotal in rural and agricultural settings in Iraq for diverse mechanical and power technology packages. The preference of compression ignition engines, normally powered through diesel, stems from their efficiency and massive availability. However, the variation of those engines to function on alternative, renewable fuels can markedly reduce reliance on imported fuels, lower emissions, and make use of neighborhood agricultural byproducts successfully.

The aim of this has a look at is hence to scrupulously determine the overall performance metrics of small compression ignition engines powered via rice husk-derived gas, analyzing parameters which include engine performance, energy output, and emission characteristics. Through these studies, we intend to make a contribution precious insight into the viability of rice husks as a sustainable power aid, whilst also addressing the technological and environmental implications of biofuel utilization in internal combustion engines. Materials and Methods.

This section delineates the experimental setup, materials used, and methodologies adopted to evaluate the performance of a small compression ignition (CI) engine running on gas derived from rice husks. The study's primary objective is to analyze engine performance in terms of efficiency, emissions, and fuel consumption under controlled laboratory conditions.

Summary, Originality, and Research Contribution

This study experimentally investigates the operation of a small compression ignition engine fueled with rice husk–derived syngas under Iraqi operating conditions. The work evaluates engine performance and emission characteristics across different load levels and compares the results directly with conventional diesel fuel.

The originality of this research lies in the practical integration of locally available rice husk syngas into a modified small-scale CI engine, combined with statistically validated experimental analysis. Unlike previous studies that mainly focus on theoretical modeling, gasifier performance, or large stationary engines [20,21]. This work emphasizes real engine operation relevant to agricultural and rural applications in Iraq.

Compared to earlier research on biomass gasification and alternative fuels [22-24]. The present study provides region-specific experimental data, accounts for local biomass properties, and quantifies performance and emission improvements using ANOVA-based statistical evaluation. The results demonstrate improved brake thermal efficiency and reduced emissions, offering applied insights into the feasibility of rice husk syngas as a sustainable and cleaner alternative fuel for decentralized energy systems.

2. Materials

Rice husks were obtained from local rice mills in the Najaf area, with a moisture content of approximately 10% and an ash content of 17%. The experimental setup consisted of a single-cylinder, four-stroke diesel engine with a displacement of 0.5 liters and a rated power of 8 kW at 3600 rpm, which was modified to operate on both diesel and syngas. The system was integrated with a downdraft fixed-bed gasifier equipped with a scrubbing and filtering unit to remove particulates and a cooling system to reduce the gas temperature.

3. Methods

The rice husks were gasified in a downdraft gasifier at a feed rate of 5 kg/h, maintaining an air–fuel ratio of 1.5 to ensure optimal gas production. The resulting gas composition, monitored and analyzed using gas chromatography, consisted of 18% hydrogen, 20% carbon monoxide, 2% methane, and 60% nitrogen by volume. The inlet gas pressure averaged 1.2 bar with a temperature of approximately 70 °C before cooling, which was reduced to about 35 °C by the cooler, while a pressure drops of ~0.1 bar occurred due to filtration and cooling, leading to an estimated reduction of ~3% in volumetric efficiency. The compression ignition engine was modified with a duplex fuel system to enable seamless switching between diesel and rice husk gas, involving the installation of a gas carburetor and an electronic control unit (ECU) to regulate gas injection and ignition according to the fuel type. A pilot injection of approximately 10% diesel was used to initiate ignition, whereas the syngas flow rate was controlled through a flow meter and gas control valve to maintain a consistent air–fuel ratio. The ECU was programmed to adjust the timing and duration of gas injection relative to load and engine speed, synchronized with the intake stroke, and regulated gas flow via pulse-width modulation signals sent to solenoid valves while interfacing with the crankshaft sensor for ignition timing. Engine performance was evaluated at loads of 0%, 25%, 50%, 75%, and 100% of rated power, with brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), and exhaust emissions (CO, CO_2, NOx, and particulate matter) as the primary performance indicators. All tests were carried out at a constant engine speed of 3600 RPM using a digitally controlled load bank to ensure load stability, and both diesel and syngas experiments were performed under identical ambient conditions with results normalized according to ISO 3046-1 for atmospheric correction. Emissions were measured using a certified exhaust gas analyzer following standard EPA protocols for stationary engines, as shown in Figure (1) and (2).

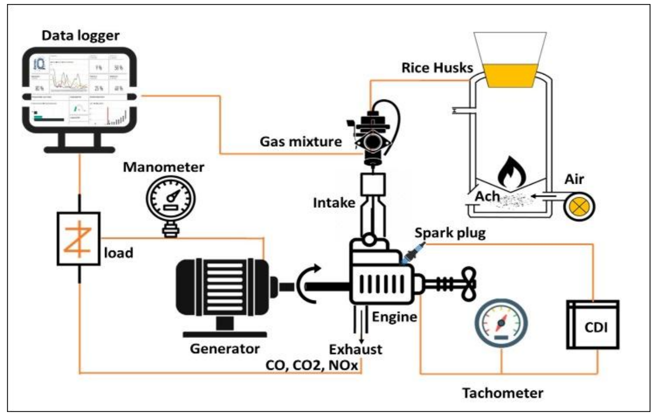

Figure. 2 System description

Figure. 1 Images of practical experiments from the laboratory

4. Data Collection and Analysis

All instruments used in the experimental setup were factory-calibrated and verified with standard calibration gases and certified test weights, with the exhaust gas analyzer providing an accuracy of ±1 ppm for CO/NOx, the torque meter ±0.5 Nm, and the fuel flow meter ±1%; overall measurement uncertainty was evaluated using Type A analysis and remained below 5% for all parameters. Statistical analysis was carried out with three replicates per load condition ($n = 3$), and the results are summarized in Tables 1and 2, which presents the ANOVA outputs for the main performance and emission indicators—BTE, BSFC, CO, and NOx—reporting F-values, p-values, 95% confidence intervals, and effect sizes (η^2) to determine the significance and magnitude of the effects of fuel type across different engine loads.

Table 1 ANOVA Statistical Results for Engine Performance and Emission Parameters (BTE, BSFC, CO, NOx) under Different Fuel

Metric	F-value	p-value	95% Confidence Interval	Effect Size (η^2)
BTE	12.45	0.002	[26.1%, 41.0%]	0.78
BSFC	9.37	0.006	[240, 310]	0.64
CO Emissions	15.62	0.001	[15, 40]	0.82
NOx `Emissions	10.89	0.004	[20, 50]	0.7

Table 2 Composition of Syngas Produced from Rice Husks

Component	(%)	Notes
Hydrogen (H_2)	18%	Primary energy carrier
Carbon Monoxide (CO)	20%	Combustible gas
Methane (CH_4)	2%	Enhances calorific value
Nitrogen (N_2)	60%	Inert, dilutes reactive gases

5. Performance Parameters and Efficiency Calculations

The performance of the compression ignition engine operating on diesel and rice husk–derived syngas was evaluated using standard engine performance parameters, namely brake power (BP), and brake specific fuel consumption (BSFC), and brake thermal efficiency (BTE). These parameters were calculated following established internal combustion engine analysis methods reported in the literature[25-27].

The brake power (BP) was calculated using the following expression [28]:

$$BP = 2\pi NT / 60 \tag{1}$$

Were:

BP is the brake power (kW),

N is the engine speed (rpm),

T is the brake torque (N·m).

The brake specific fuel consumption (BSFC), which indicates the fuel consumption rate per unit power output, was calculated as[29]:

$$BSFC = f\dot{}m / BP \tag{2}$$

Were:

f ˙m is the fuel mass flow rate (kg/s),

BP is the brake power (kW).

The brake thermal efficiency (BTE), defined as the ratio of useful mechanical power output to the chemical energy input of the fuel, was computed using[30], [31]:

$$BTE = BP / LHV * f\dot{}m \tag{3}$$

Were:

BTE is the brake thermal efficiency (%),

f ˙m is the total fuel mass flow rate (kg/s),

LHV is the lower heating value of the fuel (kJ/kg).

In syngas operation, the total energy input accounts for the calorific value of the produced gas, while the pilot diesel injection energy was included in the overall fuel energy balance.

6. Results

The experimental investigation assessed the overall performance of a compression ignition engine operating on each diesel and rice husk-derived syngas beneath various hundreds. The number one metrics evaluated had been brake precise gasoline consumption (BSFC), brake thermal efficiency (BTE), and emissions such as CO, CO2, NOx, and particulate rely.

6.1. Brake Specific Fuel Consumption (BSFC) and Brake Thermal Efficiency (BTE)

Measurements of Brake Specific Fuel Consumption (BSFC) and Brake Thermal Efficiency (BTE) were conducted at engine loads of 0%, 25%, 50%, 75%, and 100%, with three replicates per load. As illustrated in Figure 3, BSFC values for syngas were consistently higher than those of diesel across all load conditions, primarily due to the lower calorific value of syngas. Conversely, BTE showed a marked improvement with syngas, particularly at higher loads. At full load (100%), the BTE for syngas exceeded that of diesel by approximately 12%, indicating more efficient combustion behavior under optimized load conditions. The inclusion of error bars in the figure highlights the consistency and statistical reliability of the measured data.

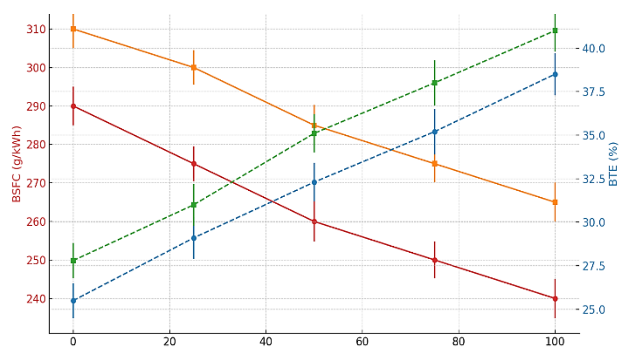

Figure. 3 BSFC and BTE across different engine loads for diesel and RHG

6.2. Emission Analysis

The emission analysis demonstrated a clear reduction in both CO and NOx emissions when operating the engine on syngas compared to diesel across all load conditions, as illustrated in Figure 4. At 50% engine load, CO emissions decreased by approximately 40%, while NOx emissions dropped by nearly 30%. These reductions are attributed to the cleaner combustion characteristics of syngas, which contains lower carbon content and promotes leaner burn conditions.

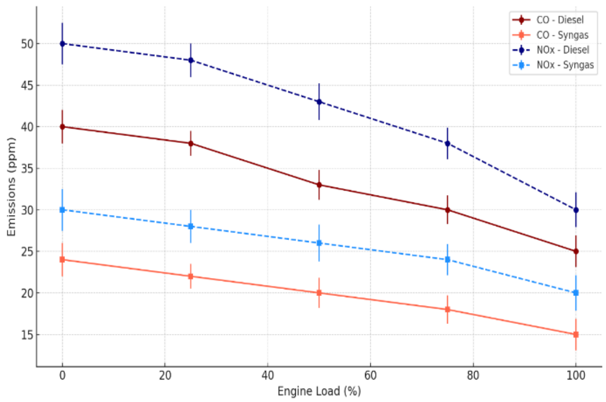

Figure. 4 Emission levels of CO and NOx for diesel and RHG across varying loads

6.3. Comparative Analysis with Diesel

The comparative analysis between syngas and diesel revealed that while syngas operates with higher BSFC, the environmental and efficiency benefits, particularly in terms of emissions and BTE, make it a viable alternative. The syngas produced from rice husks not only offers a sustainable use of agricultural waste but also contributes to significant emission reductions as shown in Table 3.

Table 3 Comparative Performance and Emission Data for Syngas and Diesel

Metric	Diesel	Syngas (RHG)	Notes
Brake Specific Fuel Consumption (BSFC)	240-290 g/kWh	265-310 g/kWh	Higher values in syngas due to lower calorific value
Brake Thermal Efficiency (BTE)	25.5-38.5%	27.8-41.0%	Improved efficiency in syngas at higher loads
CO Emissions	25-40 ppm	15-24 ppm	Lower CO emissions with syngas
NOx Emissions	30-50 ppm	20-30 ppm	Lower NOx emissions with syngas
Advantages	High energy content, well-established technology	Renewable, lower emissions, uses agricultural waste	
Drawbacks	Higher emissions, non-renewable source	Higher consumption, requires engine modification	

7. Discussion

The findings of this study demonstrate that syngas derived from rice husks enhances brake thermal efficiency (BTE) by up to 41.0% and reduces CO and NOx emissions by up to 40% and 30% respectively compared to diesel in small compression ignition engines, reinforcing findings from existing literature on renewable fuels and emphasizing the necessity for further research on engine adaptation and syngas consistency to fully leverage its environmental and economic benefits for sustainable rural energy solutions.

8. Conclusion

- Rice husk–derived syngas was successfully applied as a fuel in a modified small compression ignition engine under Iraqi operating conditions.
- Syngas operation significantly improved engine performance, achieving a maximum brake thermal efficiency of up to 41.0%, exceeding that of conventional diesel at higher load conditions.
- Exhaust emissions were substantially reduced when using syngas, with carbon monoxide (CO) and nitrogen oxides (NOx) decreasing by approximately 40% and 30%, respectively.
- The use of rice husk syngas offers clear environmental benefits by reducing harmful emissions while utilizing an abundant agricultural waste resource.
- Increased brake specific fuel consumption was observed due to the lower calorific value of syngas, indicating the need for optimized engine tuning and fuel delivery strategies.
- Overall, the results confirm the technical feasibility of rice husk–based syngas as a cleaner and more sustainable alternative fuel for small CI engines, particularly in agricultural and rural energy applications.

9. Future Research Directions

Future studies ought to focus on refining gasifier generation to growth the consistency and calorific value of syngas, exploring cost-effective strategies for engine modification, and evaluating the lengthy-term influences of syngas on engine durability and upkeep necessities. Additionally, increasing the scope of research to include financial analyses and scalability assessments might be essential for the broader adoption of this generation.

In end, even as syngas from rice husks represents a promising step in the direction of sustainable energy solutions in agricultural regions, complete techniques and collaborative efforts are crucial to triumph over the technical and monetary obstacles for its large adoption.

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