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Comparative study of gasification and pyrolysis derived from coconut shell on the performance and emission of CI engine

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A B S T R A C T

The depletion of fossil fuel and environmental impacts due to emissions of IC engines forces the researchers to discover various alternate fuels. The project aims to develop the bio-fuel by various methods from a feedstock and analyzes the properties of the fuel. The locally accessible wastages were used to substitute fuel for diesel in the appropriate manner. Waste management is an important factor that has an impact on the development and the welfare of the population. In this project, an attempt has been made to evaluate the pyrolysis and gasification process. Pyrolysis oil has carboxylic acids, alkenes, aromatics, alkaline and little gaseous amount yield from the pyrolysis process. In the gasification process the producer gas was obtained. At these optimum process conditions, the obtained pyrolysis oil and producer gas were analyzed for physical and chemical properties to be used in the CI engine as an alternative fuel. The performance parameters like brake thermal efficiency (η_{BTE}), brake specific fuel consumption (BSFC) and emission parameter like carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbon (HC), oxides of nitrogen (NO_X) and smoke emission were examined.

1. Introduction

The global energy demand is rising rapidly in various resources. The availability of conservative energy sources can satisfy the ever-increasing demand for global energy. Conserved energy sources are cause acid rain, global warming and other forms of devastation. As a result of the growing crisis and environmental deprivation, which needs bio-fuel, is replacing conventional fuel. Pyrolysis and gasification are the most suitable and cost-effective methods of converting biomass to energy [1]. Pyrolysis generates gas, which is a liquid fuel, flammable vapour, which is subjected to a mild heat process and char. When the bio-oil is pyrolyzed and used as bio-fuel in a CI engine to generate power, it is a source of a few chemicals such as organic acids, phenol, aldehyde, alcohol, and so on. A few kinds of coal gasification literature are useful for design of biomass gasifiers [2]. The interiors of downdraft reactors' are coated with a stoneware material that can withstand both high and low temperatures. The blower suction delivers air through the gasifier top as well as the air tyres supply at each point circumferentially. Sync gas is used as fuel energy in an internal combustion engine, necessitating the use of a cooling mechanism and the washing of the gasifier, which emits dirt-free producer gas.

2. Materials and methods

2.1. Pyrolysis

The flash pyrolysis method is used to extract the pyrolysis oil produced by the coconut shell. At the time of the pyrolysis process, we put a feed of 1 kg chips of coconut shell in the pyrolysis reactors (Figs. 1 and 2).

2.2. Extraction of pyrolysis oil

The pyrolysis reactor is also outfitted with a temperature sensor, with the optimal temperature determined by a temperature systematized device. The pyrolysis reactor has one end of the condenser flask attached with a tube, with condensed liquid collecting at the other end through the tapering flask. The temperature in the reactor's interior is critical during the first phase, increasing at a rate of 8 °C per minute, and then decreasing to 3 °C at the end.

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Fig. 1. Coconut shell.

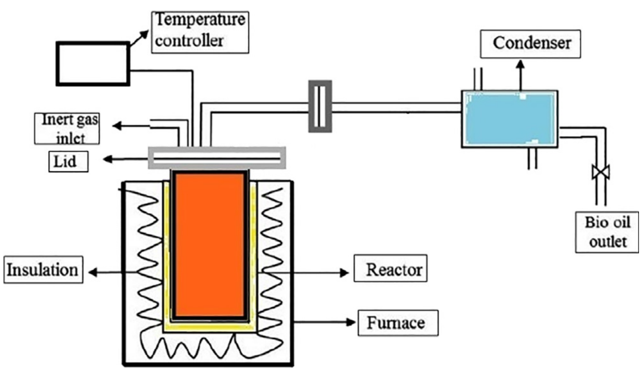

Fig. 2. Layout of pyrolysis setup.

As a result, the temperature manager device sets the temperature to 600 °C, and the average energy meter measures 4.9kWh.

The pyrolysis reactor generates condensable and non-condensable gases. At 320 °C, the coconut shell contains water, and this usually begins with the presence of moisture, followed by a colour change to dark brown in the liquid at 650 °C. Pyrolysis oil starts to become available at 350 °C and can be used up to 700 °C. The cylindrical reactor is used, and it is completely shielded by refractory lining and glass wool (Figs. 3 and 4).

2.3. Gasification

The producer gas generated by the downdraft gasifier, since it makes smaller amount of tar evaluate toward that of the updraft gasifier. Because diesel engine has combined with the gasifier for performance, combustion and emission analysis the producer gas

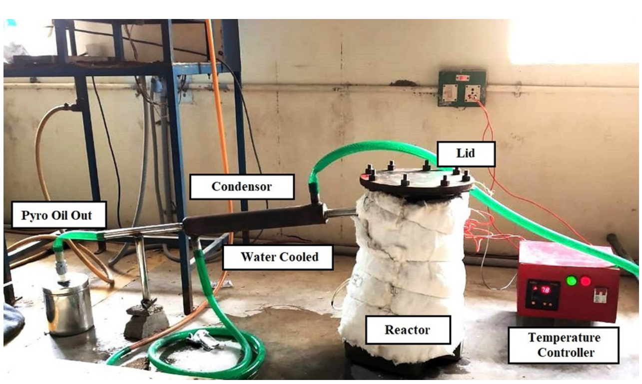

Fig. 3. Photographic view of pyrolysis setup.

Fig. 4. Pyrolysis oil.

has to free as of tar because higher tar content will have corrosive. In these cone zone gasification reactions like reduction, oxidation and preheating are found [3]. The vertical convergent and divergent nozzle in the cone region is shaped (from top to bottom) and made of mild steel with a thickness of 6 mm. The divergent section has an upper diameter of 350 mm and a height of 400 mm and a lower diameter of 200 mm. Gasification is a process of thermo-chemical in carbonaceous substance be petroleum, coke, coal, biomass is used to produce producer gas after that used as a liquid fuel. A blower is a motorized device to deliver air or gas at the required flow rate and velocity. These fans increase the velocity and air stream by the rotating impellers. Cheston CB-20 type blower is utilized in this work. The particulate from gas, air, or liquid removed by cyclonic separation, not including the employ of filters, during vortex partition. Hydro cyclone is used while removing particulate matter from liquids, a gas cyclone is used whereas from gas. A particulate filter is a tool collected of tough materials that removing solid particulates such as bacteria, mold, pollen, and dust from the air. Filters have a catalyst such as charcoal that can possible remove gaseous pollutants and odors. Air quality is important, notably in building ventilation systems and in IC engines.

The proximate analysis has expected to account for the moisture substance such as fixed carbon, ash and volatile matter. In the guide heat, the gasifier system, such as drying, devolatilization and gasification, the biomass is dried up to 120 °C, the volatile matter is volatalized up to 370°C and the char over 370°C is gasified. The solid char possibly will be there as a fuel. In hydrocarbons is high in the gaseous fuel among calorific value is high. While the solid char calorific values of pyrolytic oil and mass density are extremely huge that have high-power density evaluated for a novel mass (Figs. 5 and 6).

2.4. Procedure for producer gas generation

The downdraft gasifier is used to generate the producer gas by following a procedure that makes the cyclic operation of producer gas. The step involved the various zone involved to generate producer gas as follows,

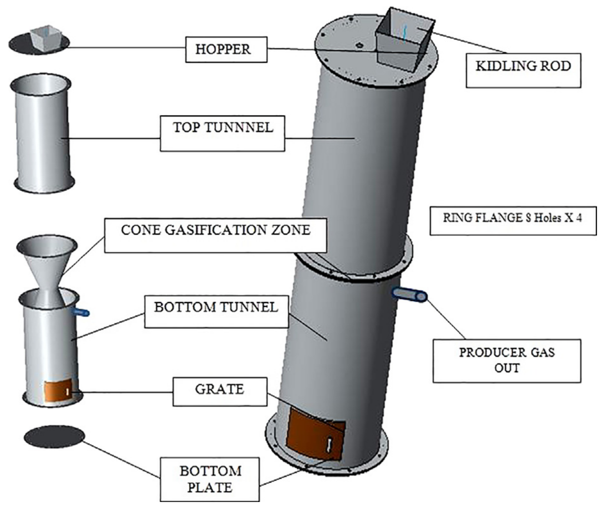

Fig. 5. Design of Gasifier.

Fig. 6. Fabrication of gasifier.

- The initial step has to be followed before the gasification.
- First, the red hot charcoal has to place in the cone of the gasifier, with the support equipment.
- The suction blower is used to direct air into the combustion zone through the value fitted at the cone of the gasifier.
- The coconut shell as the feedstock is feed into the cone of the gasifier through the hopper.
- By increasing the air supply over red hot charcoal, the temperature of the chamber increases and facilitates thermochemical reaction that happens inside in the gasifier and hence the producer gas.

When the gasifier was run on the ground nutshell, it occurred 4500 gm to provide a steady burn by 90 min (around 4.4 kg/hr).

3. Testing and analysis of coconut shell

3.1. TGA analysis of coconut shell

Thermo-gravimetric analysis (TGA) is an important thermal inspection technique to observe the material thermal permanence and to check its behavior in various modes. Thermal decrepitude behaviors of coconut shell at the different temperatures are studied by TGA shown in Fig. 7.

The TGA plot of coconut shell at a heating rate is 27°C/min in a nitrogen environment is shown in Figure. The TGA of coconut shell gives that the zone of pyrolytic was in about the varying of temperature is 280–560°C. The weight loss is found in three-stage. In the first stage smash down into small parts, 7.47% weight loss is obtained which has the elimination of moisture content. In the second stage decomposition, 71.32% weight loss was obtained, and in the 3rd stage decay, 21.12% weight losses were observed. Due to the elevated decomposition rate per unit point in time, as an active zone, a rapid decomposition zone is given. The GCMS analyzer was used to study the composition of producer gas and its result is shown here following Table 2.

3.2. Ultimate analysis of coconut shell

The Ultimate test scenario analysis of coconut shell is exposing in Table 1. C contented of coconut shell was 63.9% that shows the huge ability for fuel energy yield. Also, it involves the level of oxygen is high that resulting in C into CO_2 and CO done by CO oxidation.

3.3. Producer gas composition

The producer gas composition was tested by GCMS analysis and the values are shown in Fig. 8, Table 2. The methane, hydrogen and carbon dioxide involves in producer gas composition are 1.7 mol%, 7.6 mol% and 28 mol% correspondingly. The form of energy of the gas supplier must be greater.

3.4. Proximate analysis of coconut shell

The proximate analysis of the coconut shell is shown in Table 3. It has a fixed carbon content of 51.5% and 45.8%. The residue is about 2% and has the probability to generate a higher producer gas volume. The humidity is too low down to result in a small outflow of energy.

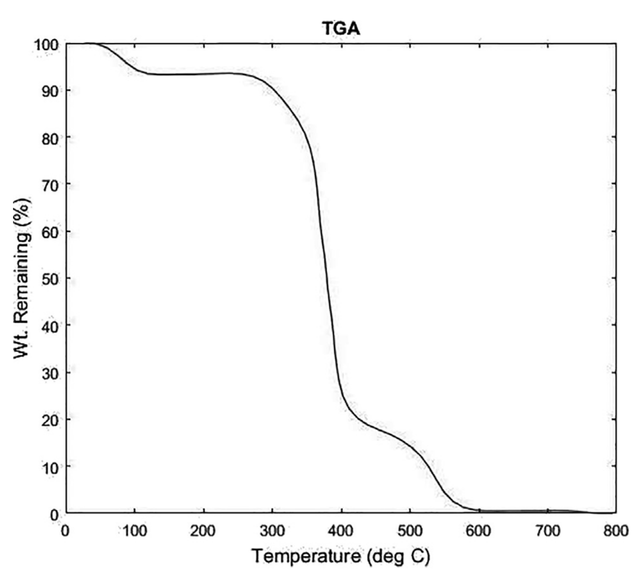

Fig. 7. TGA plot of coconut shell.

Table 1
Ultimate analysis.

Ultimate analysis	(wt%)
O	28.57
C	63.9
S	0.03
N	2.35
H	5.11
Gross calorific value (MJ/kg)	18

Table 2
Producer gas composition.

Gases	Composition (mol %)
CH_4	1.7
CO_2	28
CO	8.2
N_2	44.3
H_2	7.6

3.5. Ultimate analysis of coconut shell pyrolytic oil

The ultimate analysis of coconut shell oil is shown in following Table 4. The coconut shell carbon content is 46.8% and has a superior fuel output capacity. The results during oxidation of carbon monoxide and carbon into carbon dioxide and carbon monoxide are higher in oxygen.

Table 3
Proximate analysis.

Proximate analysis	(wt%)
Ash content	2
Fixed carbon	45.8
Volatile matter	51.5
Moisture content	0.7

4. Result and discussion

4.1. Performance result of engine

Diesel engine (CI- Compression Ignition) intended to build up a capacity of 4.4 kW at 1500 rpm (4 S, Air-cooled and single cylinder). The engine state component is shown in Table 5 (Fig. 9).

Table 4
Ultimate analysis of pyrolytic oil.

Ultimate analysis	(wt%)
Gross calorific value (MJ/kg)	20.3
C/H molar Ratio	0.55
C/O molar Ratio	1.39
C	46.8
O	44.37
S	0
N	2.14
H	6.5

4.2. Engine performance – Brake specific fuel consumption and thermal efficiency

As with gasifiers, the composition of producer gas is CH_4 (1.7%), CO_2 (28%), and H (7.6%). It contains only about 2% of ash. The decrease in thermal efficiency is caused by the lower CV (Calorific Value) of the PG (Producer gas) in the additional mix of combustion that is sent to the CI engine. PG is developing continuously from the engine which is next to high temperature and after that gas density is lowered, which in turn decrease the flow rate of mass of producer gas and the air necessary for on fire, ensuing in lower the point of oxygen necessary for firing. This lack of O_2 in the chamber of combustion results in incomplete combustion. Based on the consumption of fuel and the diesel calorific value, pyrolytic oil and producing gas, the Brake specific fuel consumption of fuel in dual-mode is assessed. It was recognized that brake-specific fuel consumption of the fuel in dual-mode was greater than that in the conventional mode at every load.

BSFC is reversing comparative to Brake thermal efficiency so the brake thermal efficiency (η_{BTE}) is reduced through gas next to through air, the BSFC (Brake Specific Fuel Consumption) is lessened employing consequent producer gas flow rate (Figs. 10 and 11).

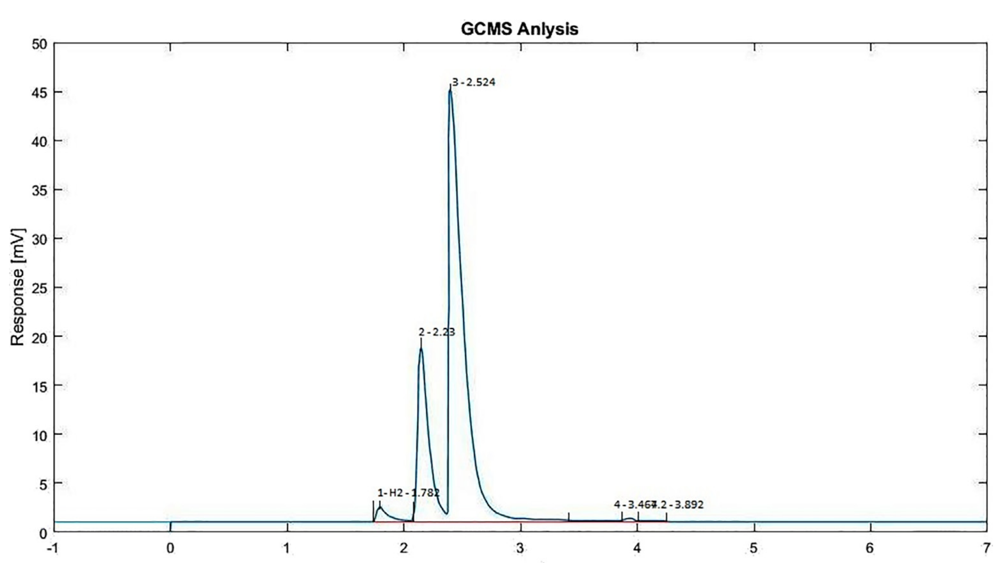

Fig. 8. GCMS Analysis.

Table 5
Engine Specification.

Specifications	Details
Model	Kirloskar TAF 1
Stroke (mm)	110
Compression ratio	17.5:1
Bore (mm)	87.5
Injection timing, (οCA)	23
Brake power (kW)	4.4
Rated speed (rpm)	1500
Cooling system	Air cooled
Nozzle opening pressure (bar)	200

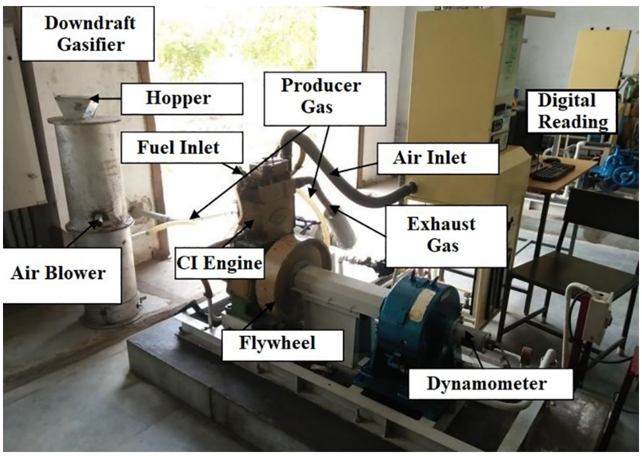

Fig. 9. Engine setup with gasifier.

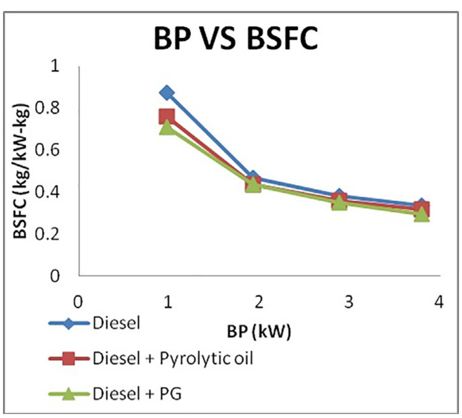

Fig. 10. BP vs. BSFC.

4.3. Emission characteristics of Diesel engine

The airflow mixture and the gas generated by the engine decrease the oxygen amount required for combustion. It also increases the emission of CO through incomplete combustion. The VOCs react with NO_X in the being there to found oxidants. Owing to the ignition delay time and combustion, the fuel–air mixtures become too rich to burn and add to HC emissions. The producer gas has atmospheric nitrogen, which has inorganic nitrogen, which does not have organic nitrogen. The difference of NO emissions between Diesel + Pyrolytic oil and D + PG fuel increases as the load increases. In diesel service, NO emissions are produced to be high rather than fuel in dual mode. As well as organic bio nitrogen, since the environment allows oxides of nitrogen (NO_X) to form.

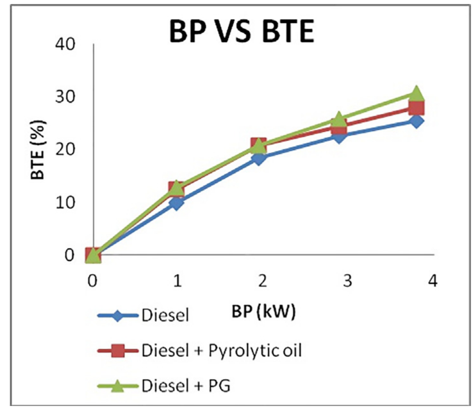

Fig. 11. BP vs. BTE.

The density of smoke has an utmost value of 23% when it is 32% follows the fuel in dual mode for D + PG (Diesel + Producer gas) at various conditions involved at full load in diesel + pyrolytic oil overhaul. The smoke density is obtained to be greater than the DF + PG value in the dual fuel mode of service. It is still higher in dual-fuel method than Diesel + pyrolytic oil, which can be obtained from the temperature of the exhaust gas amount. By increasing the fuel mixture density for engine run due to the additional energy source gives to the engine, the temperature of exhaust gas is decreased (Figs. 12–15).

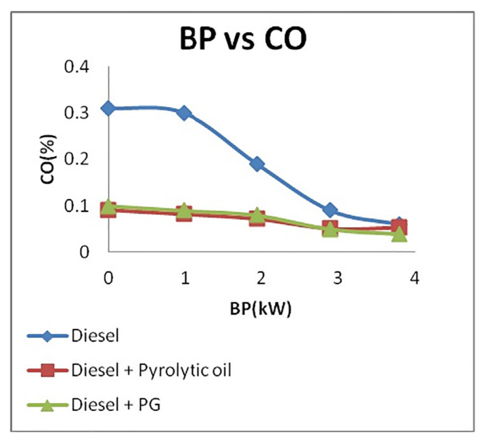

Fig. 12. BP vs. CO.

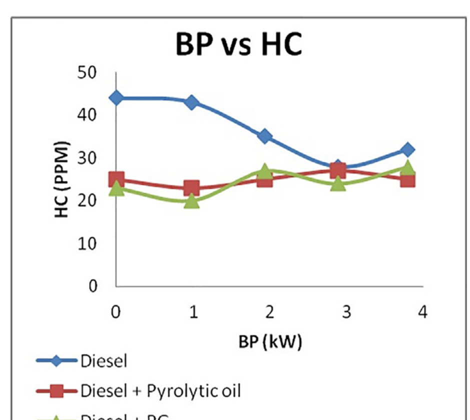

Fig. 13. BP vs. HC.

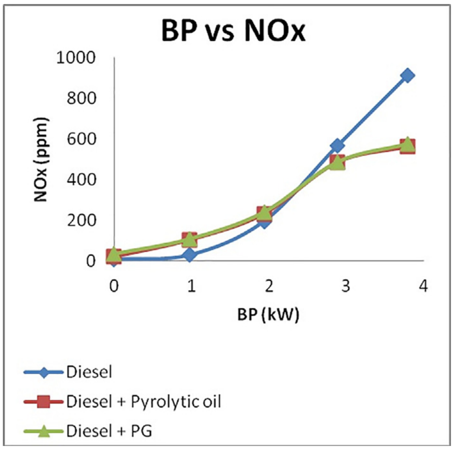

Fig. 14. BP vs. NO_X.

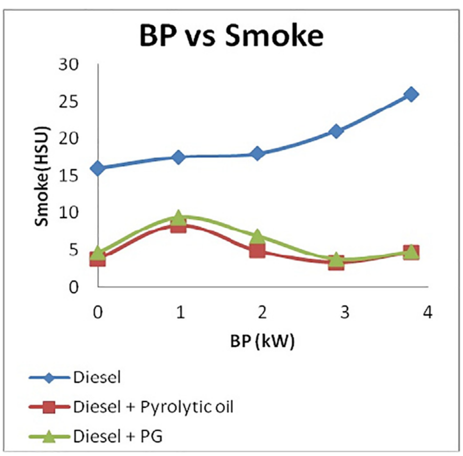

Fig. 15. BP vs. Smoke.

5. Conclusion

The following results were obtained from the performance and emission test on a 4-stroke, single-cylinder, CI engine (Air-cooled) working employing the gasifier and pyrolytic oil on fuel in dual mode.

- At full load conditions, 8.65% and 5.39% reduction in thermal efficiency (η_{BTE}) were noted for the Diesel + pyrolytic oil and Diesel + producer gas respectively. Hence the Diesel + Producer gas has a higher heating value than Diesel + pyrolytic oil.
- Reduction in NO emissions is by 25.70% with 19.21% in dual fuel mode of Diesel + Pyrolytic oil and Diesel + Producer gas at full load in compared to diesel, which is lead to the immense gain of dual-mode greater than alone of diesel fuel like a conventional engine running operation.

The combustible sources are more in producer gas and can power the IC engine effectively when compared to conventional diesel and diesel with pyrolytic oil.

CRediT authorship contribution statement

R. Thamizhvel: Conceptualization, Methodology, Writing - original draft. **K. Suryavarman:** Validation, Data curation. **V. Velmurugan:** Supervision. **N. Sethuraman:** Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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