Experimental Investigation of Diesel Engine by using Paper Cup Waste as the Producer Gas with help of Down-Draft Gasifier

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Abstract. For the past few years, the generation of the solid waste was increasing which makes the environment pollution. In such solid waste products are reused by waste management process like gasifier. The solid waste products majorly dump into the municipal wastages, the paper cup waste was regular waste from the municipalities in such waste was regular in practice. Recycling of paper cups is not easy because it has a paraffin or polyethylene plastic and also need 150 years to degrade. So far focus on the recycling of paper cup waste, which was treated to the downdraft gasifier when the producer gas formed by means of supplying compressed air to the gasifier, After that the producer gas pass with inlet air into to the combustion chamber. In this project deals the analysis of paper cup waste which characterized by using TGA, CHN analysis and also evaluated the performance of CI engine.

1. Introduction
Urbanization leads to upper levels of increases in wastage. The dumping of solid wastages happens a huge trouble for the reason that they not easy and costly to manage. Therefore, the effective use of wastes to generate electric power with helps of gasifier system and ICE. The gasifier system can be classified based on the density factor.

- Updraft
- Downdraft
- Fluidized-bed
- Cross draft

The downdraft gasifier has low tar content and best option for use in engines. Municipal corporations are to build up domestic capability towards separately manage the waste, the corporations carry a critical role by making policies and programmes and that economic support for infrastructure growth mutually with management of wastages in municipal areas. Even though waste management is a necessary facility with an obligatory purpose of corporation, that manage in an inadvertent method, that ascend to ecological degradation and cause severe illnesses of health mainly for children and women. So we go for recycling of municipal wastages with help of downdraft gasifier.
2. Materials and Methods

2.1. Paper Cup Waste

Paper cups are use of tea, coffee cold drinks cups or coffee which accumulated as unusable on the lands by a quick rate. In India, 11.5 million dispose paper cups are used for consume cold drinks and coffee every year. The positioned one after the other, waste cups should cover Earth 52 times. The paper cup wastages are intended meant for a distinct employ after that disposed. The paper cups are formed by polyethylene and petrol or paraffin and wood pulp, it develop the wet resist also confrontation to warm. It requires coating of 8–18 g/m² on a one surface. Cold drinks cups have 6–15 g/m² on the other surface and 8–18 g/m² on the overturn surface. A hot drink cups are usually made of 95% of paper and 5% of polyethylene for exterior cover. Cold drink cup has a fiber is 90% and polythene used is 10%. It has low-density polyethylene layered. The cups are undersized square pieces about 1 cm surface. The CHNS analyzer and ASTM D3173-75 device are used to analyze the ultimate analysis and proximate analysis of paper cups waste.

2.2. Downdraft Gasifier

In downdraft gasifier, the air is send to the top branch of the compartment level and the producer is detached from the bottom part of the compartment. Heat is additional from the top of the compartment, and the gas temperature increases in as it moves downward. The gas leaves the compartment at very high temperatures. The out of the chamber the gas must go through the ash, which decreases the amount of tars in the syngas. In this gasifier, the feed stocks and the air (or oxygen) are introduced high in the compartment so the oxidant and the feedstock mix together as they move downward. Gasifier of this range manage at high temperatures and are capable for easy to the conversion of waste supplies too low-tar product.

3. Setup and Analysis

3.1. Gasifier Setup

The following figure shows the assembled view of downdraft gasifier.

![Figure 1. General sketch of gasifier.](image)

3.2. Experimental Procedure

Biomass is sent into the first zone of the gasifier and roughly diesel 20 ml is making the early on fire. The combustion begins appropriately then reaches over the zone of oxidation which normally occurs about 6-7 minutes, further 5 kg of biomass is sent into the gasifier. The compressed airs send to the
oxidation zone the samples of producer gas are left which is purified and pass to the combustion chamber with inlet air mixture. Every investigational operation has 30 minutes. Towards the finish of the testing; ash charcoal is detached from the bottom of the gasifier. The present investigation, flow rate of air is ranging starting 2.4 to 4.7 m$^3$/h and then humidity ranging from 5% - 15%. Consumption rate of biomass is varying starting 1.6 - 4.4 kg/h.

3.3. Proximate analysis of paper cup waste

The proximate analysis of paper cup waste is shown in Table 1. It contains 51.5% and 45.8% fixed carbon. Ash content it is only about 2% and has a potential to produce larger volume of producer gas. Moisture content is also very low, that results in lesser energy outflow for remaining the moisture.

| Proximate analysis | (wt%) |
|--------------------|-------|
| Ash content        | 1.9   |
| Volatile matter    | 51.5  |
| Fixed carbon       | 45.8  |
| Moisture content   | 0.7   |

3.4. Ultimate analysis of paper cup waste

Ultimate analysis of paper cup is exposed in table 2. Carbon content of paper cup is 46.8% and which shows the higher potential for fuel production. It also contains more oxygen the results in oxidation of CO and C into CO2 and CO.

| Ultimate analysis | (wt%) |
|-------------------|-------|
| C/H molar Ratio   | 0.56  |
| C/O molar Ratio   | 1.39  |
| Gross calorific value (MJ/kg) | 20.2 |
| C                 | 46.8  |
| O                 | 44.37 |
| N                 | 2.13  |
| S                 | 0     |
| H                 | 6.6   |

3.5. TGA analysis of paper cup waste

TGA is a technique of valuable thermal analysis to examine the thermal constancy of a matter, or else to inspect its activities in different mode. TGA is used to find the thermal degradation paper cup waste behavior at different temperature. TGA-Thermo-gravimetric analysis plot of waste paper cups on a rate of heating of 26°C/min in atmosphere nitrogen is exposed in Figure. In pyrolytic zone was in involving the temperature varying of 270–510°C. Weight loss in three-step is noticed. In initial otherwise first step break down into constituent parts, 7.38% loss of weight was obtained that eliminate of humidity. In zone of active pyrolytic or second step disintegration, 70.41% loss of weight was noticed, and in the third stage decomposition, 22.21% weight loss was noticed. Because of large disintegration value per unit time, the quick disintegration zone or second step of decomposition is provided as zone of pyrolysis.
3.6. **Biomass Fuel Consumption**
When the gasifier was operating on paper cup waste, it consumed about 4490 gm of fuel to give a stable flame for 92 minutes (approximately 4.5 kg/hr).

3.7. **Physical and Combustion**
The physical and combustion properties of producer gas are shown in Table 3.

![TGA plot of waste paper cup](image)

**Figure 2.** TGA plot of waste paper cup.

### Table 3. Physical and Combustion Properties of Producer gas.

| Properties                      | Producer gas |
|---------------------------------|--------------|
| Stoichiometric air fuel ratio, (kg/kg) | 1.13:1       |
| Density, kg/m$^3$ (At 1 atm & 20°C) | 1.29         |
| Lower Calorific Value (kJ/kg)    | 5500         |
| Flammability Limits              | N/A          |

3.8. **Producer gas composition**
The composition of producer gas is analyzed through GCMS analyser and its results are exposing in table. The carbon dioxide, methane, and hydrogen content of the producer gas are 1.5 mol%, 27 mol% and 7.5 mol% respectively. Energy content of the producer gas would be higher.

### Table 4. Producer gas composition.

| Gases | Composition (mol %) |
|-------|---------------------|
| CH$_4$ | 1.5                 |
| CO$_2$ | 27                  |
| CO     | 8.5                 |
| N$_2$  | 44.6                |
| H$_2$  | 7.5                 |
4. Results and Discussion

4.1. Engine Performance Result

A single cylinder air-cooled 4 stroke and CI diesel engine planned to improve a power of 4.4kW at 1500 rpm was used for the investigational study. A characteristic and specification of engine is shown in Table 5.

**Table 5. Engine Specification.**

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

4.2. Brake Thermal Efficiency (%)

The graph gives the result of brake power at thermal efficiency at different load. A significant decrease in brake thermal efficiency is noted in dual fuel mode at every load. The maximum efficiency attained by diesel was 23.7% while in maximum efficiency of dual fuel mode was 22%. The decrease in thermal efficiency is owing to the producer gas has low calorific value, that has additional combusted blended that sends into the CI engine. Producer gas develop gradually starting the engine at high temperature after that producer gas density is decreased, that is decreases the rate of mass flow of producer gas and then air needed for combustion, finally reduction the level of oxygen needed for combustion. This inadequate absence of oxygen to the combustion chamber is makes the incomplete combustion.

![Figure 3. Engine setup with gasifier.](image-url)
4.3. Break specific fuel consumption (BSFC)

The next graph gives the difference among the specific fuel consumption and brake power. Brake specific fuel use is not a consistent factor to evaluate the dual fuels having various density and calorific values; therefore brake specific energy consumption has to relate the characteristic of CI engine.

![BP VS BTE](image)

**Figure 4.** Thermal efficiency Vs Brake power.

In dual fuel mode the specific energy consumption is evaluated from the calorific value of diesel and fuel consumption and producer gas. In dual fuel mode the specific energy consumption was recognized to be greater than of diesel fuel mode at every load settings. BSFC is reversing proportional to BTE therefore the brake thermal efficiency is decreasing by means of producer gas among by air, the BSFC is reduce with consequent rate of flow of producer gas.

![BP VS BSFC](image)

**Figure 5.** BSFC Vs Break power.

5. Emission Characteristics of Diesel Engine in Dual Fuel Mode

The quality of combustion takes place inside the engine from the emission characteristics. The emission parameters discover during diesel and dual fuel D+PG-1(Producer gas) mode are found as follows.

5.1. Carbon monoxide (CO) emission

Due to insufficient amount of oxygen has makes the incomplete combustion. The difference of CO emission of the engine with DF and dual fuel mode is shown in Fig.6. By raise in load, a development of CO emission is obtained with Diesel and Diesel with producer gas in dual fuel mode. A large
amount of CO emissions are found in dual fuel mode while compared with Diesel mode. The high concentration of CO emission in the dual fuel mode makes the incomplete combustion. The blend of higher temperature air flow and producer gas to the CI engine decrease the oxygen amount that needed for combustion completely. This makes incomplete combustion and CO emission also increases.

![BP vs CO](image)

**Figure 6.** Brake power Vs CO emission at various loads.

5.2. Hydro carbon emission
Unburned hydrocarbon emissions are the express effect of incomplete combustion. As shown in Fig.7, here is everlastingly a raise in HC emission while present in addition in loads. The unburned hydrocarbons and their properties that eagerly create vapour are named as volatile organic compounds. The VOCs act with nitrogen oxides in the occurrence of sunrays to produce photochemical smog and oxidants. The emission arises while a division of the fuel is inducing into the engine neglects combustion. At some stage in period of ignition delay, air fuel forms too rich mixtures to ignite and contribution of combustion makes the HC emissions.

![BP vs HC](image)

**Figure 7.** Brake power Vs HC emission at various loads.

5.3. Nitric oxide (NO) emission
The major reasons for the increase of oxides of nitrogen (NO\textsubscript{x}) are higher temperature and oxygen availability in CI engines. At low temperature when nitrogen is inert, however temperature greater than 1100\textdegree{}C by means of form oxides., it shows the NO emission increases by means of addition of load for each and every mode i.e. Diesel and D+PG fuel that is shown in Fig.8. Due to this temperature is high in combustion chamber formed at addition of load. NO emission is observed at low loads, insignificant difference in as working the engine taking place dual fuel mode and diesel. NO emission increases relating Diesel and D+PG fuel at increase the difference in load. In diesel operation NO
emission is create to be higher than that of dual fuel mode. Airs cause NO\textsubscript{x} formation due to organic nitrogen. Producer gas has not to contain organic nitrogen; it has only inorganic nitrogen from atmospheric nitrogen.

![BP vs NO\textsubscript{x}](image)

**Figure 8.** Brake power Vs NO emission at various loads.

5.4. **Smoke density**

Brake power increases as the smoke opacity become high. The reason of smoke is combustion deals incomplete to inaccurate ratio of fuel and air or inappropriate mixing of fuel by air. The smoke density of various fuels at no load and full load condition of significant difference is observed by following Fig. 19; however the modify was extremely inconsequential while starting load was set to CI engine. At first load oxygen available makes the lake of oxygen at no load. In dual fuel mode when function makes the density of smoke gives a maximum value 22\% wherever at the same time as 30\% in dual fuel mode engine for D+PG at full load condition. In this operation, the smoke density is obtained to be higher than DF + PG.

![BP vs Smoke](image)

**Figure 9.** Brake power Vs smoke density at various loads.

5.5. **Exhaust gas temperature (EGT)**

The EGT with brake power for Diesel and producer gas in dual fuel operation is showed in Fig. 20. The outlet temperature of gas for diesel on full load condition is makes to 330°C whereas the exhaust gas temperature at full load for D+PG1 are found 390°C and 450°C. The excess energy supplied to the engine that found the temperature of exhaust gas in dual fuel mode is forever high at Diesel. The exhaust gas temperature can be decreased by increasing the fuel mixture density for combustion.
6. Conclusion

The producer gas composition from the gasifier is Methane (1.5%), Carbon dioxide (27%), Hydrogen (7.5%) has obtained. The ultimate analysis and proximate analysis of waste paper cups are alone and the following conclusions are arrived. It contains only about 2% of ash.

In a single cylinder, 4-stroke, air cooled DI diesel engine operating with gasifier and the performance and characteristics of exhaust emission are experimentally investigated on a dual fuel mode and following results are arrived.

- By replacing of diesel with producer gas which makes saving of diesel. While conduct experiment 5.45% drop in brake thermal efficiency for the optimal condition in dual fuel operation by D+PG at full load condition which is compared with diesel, which cause the producer gas has lower heating value.
- In dual fuel operation of D+PG at full load condition makes NO emission is decreased by 18.60% is compared with diesel, which is a huge benefit of dual fuel mode more than diesel alone.

Carbon properties were higher and have a potential for the making of more volume of producer gas which shows that the producer gas is suitable for use in IC engines.

7. References

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