

## Emission Analysis of Blended Pyrolysis Oil Derived from Waste HDPE and Coconut Shell in CI Engines

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### ABSTRACT:

*This research examines the emissions characteristics of Compression Ignition (CI) engines utilizing a blend of diesel fuel and pyrolysis oil derived from discarded high-density polyethylene (HDPE) and coconut shells. The emissions from the CI engine, encompassing hydrocarbons (HC), carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO) and nitrogen oxides (NO<sub>x</sub>), were systematically analysed utilising an RS232 exhaust gas analyser in conjunction with a smoke meter. The findings pertaining to the engine performance under loading conditions of 30%, 60% and 90% were derived from the utilization of a fuel mixture comprising pyrolysis oil blend in the ratios of HDPE oil, coconut shell oil and diesel, specifically 5:5:90, 5:10:85, 10:5:85 and 10:10:80. The emissions profile exhibited variability contingent upon the pyrolysis blending ratios employed. The CI engine operating with a fuel blend of 5:10:85 demonstrated a reduction in NO<sub>x</sub> and HC emissions. Concurrently, the emissions of CO and CO<sub>2</sub> were decreased with the 10:5:85 and 5:5:90 blends, respectively, when compared to 100% Diesel fuel. The optimal fuel blend comprising a ratio of 5:5:90, integrated with nano-additives, aims to mitigate emission behaviour associated with the automotive industry.*

### KEYWORDS:

*Pyrolysis oil; High-density polyethylene; Coconut shell; Emissions; Energy Efficiency;*

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## 1. Introduction

To combat the increasingly worsening global crisis of plastic pollution and the soon to be encountered challenges of dwindling fossil fuel reserves, there exists an imperative for innovations that are not only new but also immediate. Annually almost 350 million tonnes of plastic waste flood into terrestrial and marine ecosystems, resulting in severe disruptions to the previously finely tuned balance between the biotic and abiotic elements of the environment [1-2]. This material falls in the category of plastic waste. Fossil fuels have been accumulated over thousands of years and the supply is finite therefore their depletion is bound to occur in a short time if the consumption rate is not reduced. The threat has been identified since it was noticed that the consumption rates have not declined [3-4]. Considering the dangerous nature of the problem, it is crucial to hasten the shift to environmentally friendly alternatives. Pyrolysis presents itself as a significant contender in such a momentous task [5]. Pyrolysis is the thermo-chemical degradation of organic material that is brought about by heat application. This is because the process takes place in an anoxic

environment, meaning without oxygen. Breakdown of waste materials such as plastics and biomass comprising food waste and agricultural residues results into valuable products through controlled breakdown. The most evident product from the breaking of plastics and biomass is bio-oil. The bio-oil in question has tremendous potential as a feasible alternative fuel for CI engines, which form the backbone of the operation of the transportation sector. Realisation of this potential is, however dependent upon its blending with conventional diesel fuel in appropriate proportions. However, for the transformation mentioned above to take place it is necessary that the bio-oil be first mixed with diesel fuel [6-7].

High-density polyethylene (HDPE) is especially noted for its durability, cost-effectiveness and flexibility, making it a popular material of choice in most industries such as construction, packaging and consumer goods. However, the resistance to biodegradation indicates a threat of high intensity to the environment [8-9]. There is a need for environmentally benign recycling technologies to be developed as more waste consists of plastic. The liquefaction process undertaken by bio-oil by way of pyrolysis can transform this waste stream into a resource. It is one of the notable alternatives for converting this

waste stream. The process of bio-oil liquefaction has a great opportunity to surpass the available mechanical and chemical recycling methods, which are mostly partial solutions to the complex problem of waste management. Mechanical recycling and chemical recycling are two different approaches in the wide context of recycling technologies [10]. Coconut shells are an agricultural by-product that is readily available in substantial quantities. Hence, this can be a good opportunity for it as a reliable feedstock for the production of bio-oil [11]. Coconut shells are found to be easily available and renewable as well, giving the whole thing a very attractive option [12]. The integration of coconut shell biomass into the pyrolysis process would potentially enhance both the overall efficiency of the fuel production cycle and the environmental sustainability of the procedure [13]. Although there are promising routes of using waste plastics and biomass for the generation of bio-oil as a fuel for transportation, it is critical to be cognizant of the environment impact that surrounds the production and usage of bio-oil. Bio-oil is a form of biofuel which is generated by the treatment of waste plastics [15]. For instance, emission profiling for the production of blends that include bio-oil and diesel should, for example be entirely examined on an element-wise threat to the environmental integrity.

Investigations based on diesel mixes involving pyrolysis oil made from HDPE or coconut shells observed negative impacts attributed to high consumption of such feedstocks [16]. Hoang et al [17] reported that a B10 blend containing 10% biodiesel blends containing rubber seed oil diesel, has superior combustion performance compared to that of higher blends (B20, B30). Major contributing factors to increased emissions of HC and CO into the atmosphere upon combustion in reactivity-controlled compression ignition (CI) engines include the availability of oxygen and latent heat of evaporation from alcohol-based fuels. This might be due to complex interactions between various contributing factors. To ensure the proper commercialization of bio-oil as a fuel for transportation, mix ratios should be optimized along with pyrolysis processes. This is to reduce the volume of emission produced. At the same time, it has to be made sure that there is a decrease in the volume of emissions generated [18]. Research into bio-oils as viable and environmentally friendly alternative fuel needs to be ongoing, where technological innovations would be advanced in order to be realized by encouraging collaboration among the researchers, the policymakers and the industry. It is only through this process that the potential of bio-oils can be comprehensively actualised. Each of these elements constitutes a fundamental component that is requisite for the present investigation.

## 2. Materials and methods

Non-biodegradable waste plastics that comprise HDPE are used as feedstock for the extraction of bio-oil in the pyrolysis process. Before the bio-oil is extracted, the collected HDPE waste undergoes a washing process in running water, which facilitates the removal of sand and dust particles found in the waste material. The drying of washed plastics is done in an electric oven at 50°C for 10

minutes. Dried plastics are shredded into pieces that are 3-5 mm in size through the process of shearing. Fig. 1 shows the pyrolysis process. The pyrolysis equipment hopper introduced shredded waste plastics, which then proceeded to a sealed vessel reactor. The PID controller combined with the reactor controlled and monitored the temperature in the reactor system. For the most part, the temperature inside the reactor system was maintained at 300°C to initiate HDPE decomposition. Subsequently, under anaerobic conditions, the temperature of the reactor is elevated from 300 °C to 500 °C, a process that serves to restrict combustion while promoting thermal degradation.

In the course of heating, the pressure within the system is sustained at levels below atmospheric pressure, 1 bar, thereby mitigating the occurrence of superfluous thermal reactions. The temperature is raised to 550°C within the reactor to achieve thorough dehydration of HDPE for 3 hours. The temperature within the reactor system is measured using an R-type thermocouple placed at the reactor wall [19]. Coconut shell is also used as feedstock for bio-oil extraction, as it contains organic composition, biodegradability and rich availability in the natural environment. The harvested coconut shells are washed by running water to remove sand dust and husk from the shells, which are then sun-dried and ground. The ground shells are further crushed to have a particle size of 3 to 5 mm using a ball milling apparatus. The same pyrolysis apparatus is used for the extraction of bio-oil at a temperature range of 400°C to 500°C. Fig 2 shows the extracted bio-oils and diesel. The blending of HDPE and coconut shell bio-oil with diesel occurs in various percentages by volume as 5:5:90, 5:10:85, 10:5:85 and 10:10:80. Fig. 3 shows the test engine setup. The experimental investigation was conducted utilizing a Kirloskar 240 PE engine, characterized by an injection pressure of 250 bar and an injection timing set at 23 degrees before top dead centre TDC. Table 1 provides the specifications for the test engine. Fig. 4 shows a schematic of the experimental set up.



Fig. 1: Pyrolysis setup



Fig. 2: HDPE bio-oil, diesel and coconut shell bio-oil



Fig. 2: Test engine setup

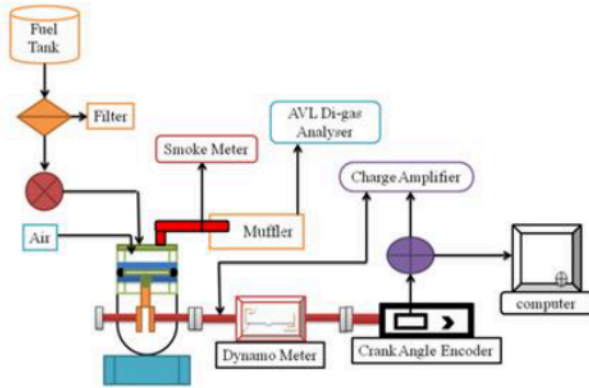


Fig. 4: Schematic of experimental set up

Table 1: Specifications of Kirloskar 240 PE test engine

Specification	Value
Number of cylinders	1
Engine weight (Dry)	108 kg
Number of strokes	4
Cooling system	Water cooled
Rated speed	1500 rpm
Compression ratio	17.5:1
Stroke length	110 mm
Bore diameter	87.5 mm
Pressure range	0-350 bar

### 3. Results and discussion

In order to assess the efficiency and effectiveness of a single-cylinder engine, its performance has to be judged. The important measures of performance include brake power (BP), brake thermal efficiency (BTE), brake specific fuel consumption (BSFC) and emissions. All these are very strongly dependent on operating parameters like fuel injection timing, air-fuel ratio (AFR) and engine speed. BTE quantifies the amount of work obtained from a combustion engine per unit of fuel consumed in its operation. Fig. 5 shows that the variation of BTE against BP. AFR alone accounts for 9.6% of the variability of BP. Results affirm that H5C5D90 has improved performance. More the proportion of diesel that is added, better the performance in terms of BTE. Higher proportions of coconut shell oil produce the worst performance, as in the case of H5C10D85. That is because coconut shell oil will increase the viscosity and decrease the volatility, which adversely affects the combustion. H10C5D85 experiences a slight loss in performance because of the lesser cetane number and combustion instability. From Fig. 6, it can be observed that BSFC is maximized for H5C10D85 in most

cases, which means that a higher the coconut shell oil percentage corresponds to higher energy consumption, which relates to its enhanced viscosity and lowered calorific content, hence burning efficiency. In contrast, higher diesel concentration blends have lower BSFC values and therefore improve the fuel economy.

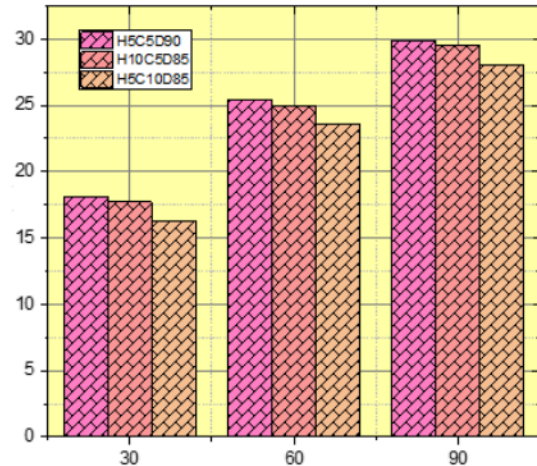


Fig. 5: BTE vs. Load

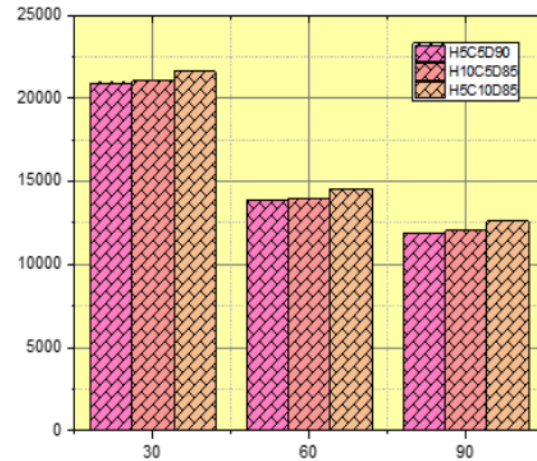


Fig. 6: BSFC vs. Load

Ethanol-gasoline blends reduce CO and UHC emissions but generally increase CO<sub>2</sub> levels. Improvements in BTE and BSFC can be realized through the optimization of blends. However, the challenge of increasing NOx emissions persists, highlighting the necessity for further research to achieve a balance between emission control and engine performance [20]. From Fig. 7, it can be observed that H10C5D85 has the lowest HC emissions at all tested load conditions [15]. This is because the energy content in the blend is relatively low, which results in controlled combustion and reduced unburnt HC. H5C10D85 blend has higher HC emission. This can be ascribed to incomplete combustion that is associated with high coconut shell oil content. H5C5D90 blend, characterized by high diesel content, exhibited moderate HC emissions. Fig. 8 shows the CO emissions for three different fuel blends at different engine loads of 30%, 60% and 90%. CO emission decreases with an increase in engine loading. Reasonable explanations of the observed effect are enhanced completeness of combustion with higher operating temperatures and pressures. Significantly, the H5C5D90

blend remains the least CO emitted under every load, giving an impression of this combination of derived pyrolysis elements plus coconut shell oil together with diesel helping to better exhaust. In contrast, the H10C5D85 blend shows the highest levels of CO emissions, indicating that an increase in the proportion of pyrolysis oil, without a associated increase in coconut shell oil, may adversely affect the combustion efficiency. The H5C10D85 blend shows CO emissions that are intermediate when compared to the other two blends.

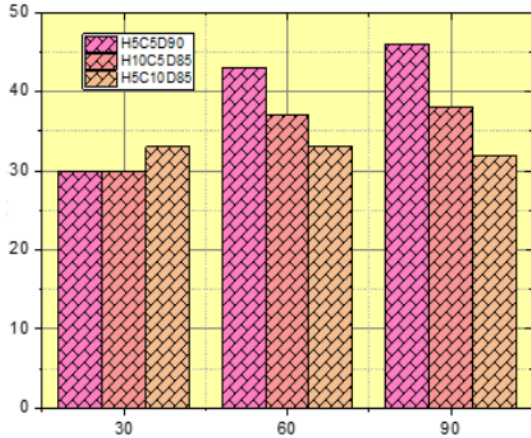


Fig. 7: HC emissions vs. Load

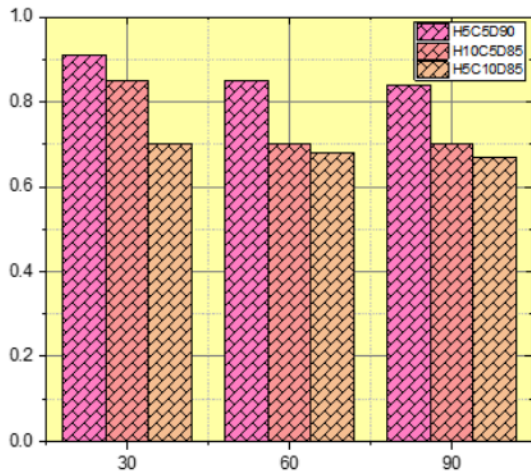


Fig. 8: CO emissions vs. Load

Fig. 9 shows the percentage of CO<sub>2</sub> emissions for three different engine loads, 30%, 60% and 90% of three fuel blends. There exists a trend that is easily identifiable with increased CO<sub>2</sub> emissions parallel to an increase in engine load in all the blends of fuel as expected in the operations of conventional combustion engines that consume more fuel when subjected to higher power production [21]. However, a comparison of the different blends revealed that H5C5D90 showed the least levels of CO<sub>2</sub> emissions at all states of loads, signifying better combustion. In contrast H10C5D85 exhibits the highest levels of CO<sub>2</sub> emissions which may suggest a reduction in combustion efficiency and as a result an increased fuel consumption for equivalent power output. H5C10D85 exhibits intermediate concentrations of CO<sub>2</sub>. The results reflect the possible fact that the ratio of the amount of pyrolysis oil to coconut shell oil in the fuel mixture has a direct impact on its effects on CO<sub>2</sub> emissions and it is already established that a mixture composed of 5%

quantities of pyrolysis oil and coconut shell oil produces the best improvement of combustion efficiency.

Fig. 10 shows the concentration of NO<sub>x</sub> emissions, quantified in parts per million (ppm), for three different fuel blends H5C5D90, H10C5D85 and H5C10D85, at three engine loads of 30%, 60% and 90%. The trend of increasing NO<sub>x</sub> with rising engine load can be clearly seen in all fuel blends. This is attributed to the increased combustion temperatures and pressures that occur with higher loads which facilitate the formation of NO<sub>x</sub> compounds. However, the relative emissions of NO<sub>x</sub> vary between the various fuel blends. It is particularly remarkable that under 60% and 90% load, H5C5D90 showed the most NO<sub>x</sub> though earlier considerations pointed to less bad news of CO and CO<sub>2</sub> emissions. The above is indicative of potential compromise, i.e., when it reduces CO and CO<sub>2</sub> emissions well while failing to make things worse somehow NO<sub>x</sub> get easier to come about. As expected, H10C5D85 and H5C10D85 result in lower emissions of NO<sub>x</sub> compared to the H5C5D90. This indicates that both changes in composition of the blends, either with an increase of coconut shell oil input or improvement in pyrolysis oil that does not reflect an increase of coconut shell oil should significantly impact production of NO<sub>x</sub>. An open cup apparatus is used to find flash and fire points of H5C10D85 blended fuel. The evaluation process followed by ASTM D93 standard. The findings reveal that the optimum flash and fire point temperatures were 40°C and 52°C, respectively. Similarly, H10C5D85 and H5C5D90 results showed 43°C & 54°C, 44°C & 56°C respectively.

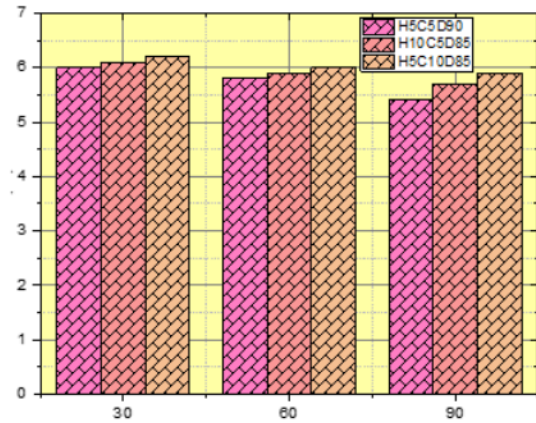


Fig. 9: CO<sub>2</sub> emissions vs. Load

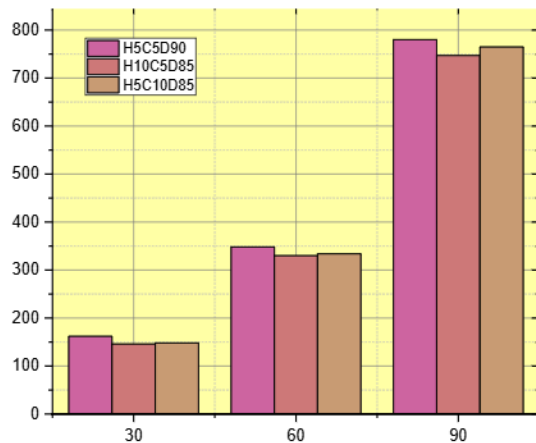


Fig. 10: NO<sub>x</sub> emissions vs. Load

Fig. 11 illustrates the effect of fuel blends on CI engine under varied loading conditions. The CI engine functioned with diesel fuel without oil blends showed 2.78 kW on a 30% load and progressively improved by 4.71% and 6.11% on increased loading conditions of 60% and 90%, respectively. Generally, the BP gradually increases with increasing load. The CI engine with 5% HDPE oil blended diesel fuel exposed better BP performance than the diesel operated engine. The enhancement of BP is due to the higher energy content with an enriched HDPE oil/diesel mixture. The blend with 5% HDPE oil found maximum BP compared to the other blends tested. Moreover the pyrolysis oil blends with diesel fuel offered better CI engine performance with an improved BP of 13%.

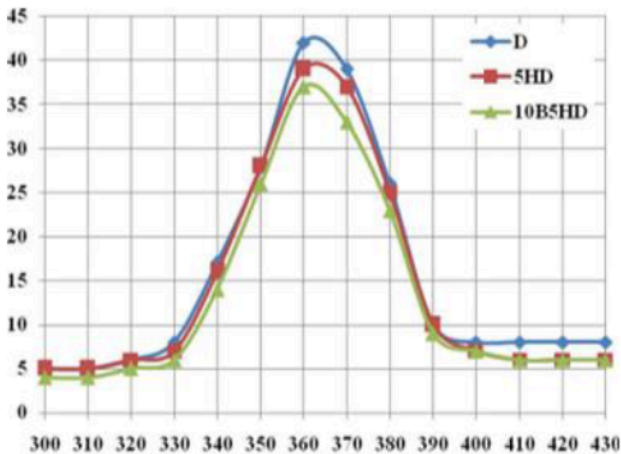


Fig. 11: BP under varying load conditions

#### 4. Conclusion

This paper examines the characteristics of emissions produced by a CI engine fuelled by blends of oil from pyrolysis that are derived from waste HDPE and coconut shells with diesel. Optimum blend as 10% HDPE oil, 5% coconut shell oil and 85% diesel (10:5:85) was reported to have a decreased NO<sub>x</sub> and HC emissions in all the tested loading conditions such as 30%, 60% and 90%. Blend of 5:10:85 emitted lower CO levels, while the 5:5:90 blend emitted lower CO<sub>2</sub> levels. This indicates that certain blending ratios can be used to optimize emissions profiles. Increased performance of CI engines with blends of higher fractions of diesel is noted; for higher diesel fractions the increase in BP and efficiency are observed clearly. Increase in coconut shell oil proportions resulted negatively affecting the combustion as its viscosity affects combustion adversely.

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