



Performance And Emission Analysis of Diesel Engine Using Co-Pyrolyzed Waste Plastic-Biomass Oil-Diesel Blends

¹ Rahul Biswal, ² Amitrakshya Baral, ³ Prasanta Bhuyan, ⁴ Manas Ranjan Mohanty

^{1,2,3,4} B.Tech Students

¹ Mechanical Department,

¹ Gandhi Institute For Technology (GIFT) Autonomous, Bhubaneswar, Odisha, Pin-752054

Guided by: Dr. Amar ku Das

Abstract. The unremitting population growth and industrialization caused augmented global energy requirements, resulting in challenges such as fossil fuel depletion, ecological pollution, and energy shortages. These confront have emphasized the need to harness rich renewable energy resources (biomass), by enhancing thermochemical conversion methods like co-pyrolysis. This paper explores biomass (Castor Seed powder) and polypropylene plastics co-pyrolysis for the high-valued production of biofuels, while also examining the blending of Aluminium oxide (Al_2O_3) Nano-particles into diesel for improved conductivity. It highlights co-pyrolysis advantages, product yields, mechanisms, synergistic effects among biomass and waste plastics, and the impact of key parameters, such as feed ratio, reactor temperature, and oil yields. In a tubular reactor, non-catalytic co-pyrolysis experiments were conducted, employing Castor Seed (CS) powder and varying proportions of polypropylene (PP). The pyrolysis temperature was systematically varied in $50^\circ C$ increments, spanning the range from $450^\circ C$ to $600^\circ C$. The study encompassed a spectrum of feed compositions, ranging from 0 wt. % to 50 wt. % of PP within the mixture. Leveraging machine learning techniques for the prediction of regression method, parameter optimization, and data analysis, this study validates experimental outcomes and highlights the feasibility of predicting non-catalytic co-pyrolysis yields of polypropylene (PP) and Castor Seed (CS) for fuel oil production. The model predicts the optimum oil yield of 71% at $550^\circ C$ with 50% of each feed composition and demonstrates promising enhancements in diesel blending efficiency using Al_2O_3 , offering a sustainable avenue for advancing co-pyrolysis and fuel technologies

Keywords: Castor Seed, medical waste plastics, Co-pyrolysis, Al_2O_3 , Diesel Engine.

1. Introduction

Energy is an essential component of contemporary sustainability, encompassing economic, technological, and societal aspects. It can be categorized into non-renewable and renewable sources [1]. Harnessing waste biomass sources has the potential to dramatically reduce India's dependency on fossil fuels while simultaneously strengthening the national economy [2]. Furthermore, this approach aids in mitigating CO₂ and other detrimental emissions, contributing to environmental carbon neutrality [3]. Among the array of energy extraction methods from biomass, pyrolysis emerges as the most capable option; characterized by its operational simplicity and robust technical feasibility [4]. Pyrolysis produces bio-oil, a clean alternative to fossil fuels after post-treatment, reducing environmental impact and pollution concerns [5]. Castor Seed was used for the production of liquid oil by pyrolysis at 600°C with a maximum bio-oil yield of 48 wt% [6]. Lower liquid oil yield rate accounts for a major limitation of the bio-oil extraction by lignocellulose biomass and can be significantly improved by co-feeding waste plastics [7]. The co-pyrolysis method has demonstrated superior reliability compared to the conventional practice of blending different oils to generate a homogeneous pyrolysis oil. The efficacy of co-pyrolysis arises from the interaction of radicals during the process, effectively preventing phase separation and resulting in the production of a stable pyrolysis fuel [8]. The objective of this research is quite imperative for better utilization of waste plastics (medical wastes) and waste biomass (Castor Seed) for the production of liquid fuel oil in the line of waste management policy. The quantitative and qualitative analysis of the oil produced by the co-pyrolysis was addressed by using the regression method of machine learning approach [9]. In this context, the present work focuses on the co-pyrolysis of medical plastic wastes (PP) and biomass (Castor Seed) in a batch reactor. The novelty of the work is to study the synergetic effects of temperature and biomass feed ratio on the thermal degradation of medical plastic wastes into qualitative alternate fuel. The experimental optimization of the process concerning temperature and feed ratio has been validated using regression analysis of the Machine learning approach.

2. Materials and Methods

2.1. Characterization of waste plastics and waste biomass

In this research, lignocellulosic biomass waste materials (Castor Seed) and medical waste plastics (polypropylene) are employed as co-feeds for the co-pyrolysis process to produce bio-oil. Castor Seed was collected from Local Market, while waste plastics (PP) were collected from local hospitals of Bhubaneswar. The waste plastics were cleaned and shredded into smaller pieces of around 1-2 mm size. The seeds of Castor seeds were rinsed with water, sun-dried for four to five days, and then chopped into powder form and stored in an airtight container to prevent moisture absorption.



Fig.1 Photographs of crushed biomass and medical waste plastics

2.2 Methods

A key factor in achieving the highest pyrolytic liquid production is the biomass to plastics proportions. Thus, in this study, the different weight percentages of waste plastics (PP) and Castor Seed (CS) were taken (0-50 %) by weight. The Co- pyrolysis was achieved at the different temperature ranges of 450-600 °C temperature in a batch reactor. The experimental setup utilized a stainless steel batch reactor, externally heated by an electric furnace, with temperature control via a PID system. The operating pyrolysis parameters were optimized for producing maximum liquid yield.

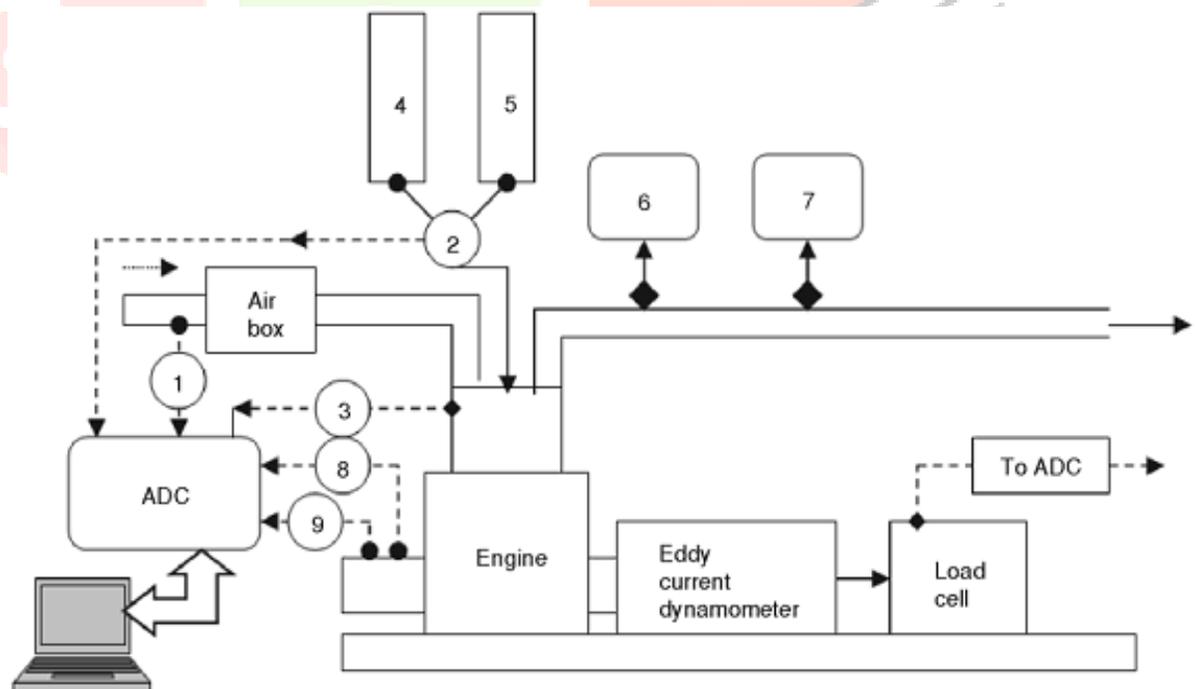
2.3 Diesel Engine Performance and Emissions Using Co-Pyrolyzed Bio-Oil Blends

This research explored the formulation and testing of fuel blends derived from co-pyrolysis of polypropylene (PP) and castor seeds, followed by their incorporation into diesel through blending with aluminium oxide (Al_2O_3). The study aimed to assess both performance metrics and emissions of a diesel engine using these bio-

derived blends. Experimental data concerning factors such as feed composition, co-pyrolysis conditions, and blending proportions were analyzed to optimize fuel properties. Engine performance was evaluated in terms of torque, efficiency, and combustion characteristics, while emission parameters like NO_x, CO₂, and particulate matter were carefully measured. Statistical methods, including regression models, were employed to correlate input variables with engine performance and emissions outcomes, ensuring prediction accuracy. Insights from this study support the feasibility of sustainable biofuel production with reduced environmental impact.

2.4 VCR Engine Working Principle

We are mostly using the small parts of the syringes, and polypropylene for the better results and quality. The quality of the oil is very good in syringes, oil is very thin and very fine and also the color is brilliant. The engine used for the experiment is started with DPO blends from diesel fuel and then its performance and emission readings are observed under various load conditions. Selecting suitable Blending DPO for single cylinder diesel engine and development of an experimental set-up with necessary instruments to study the performance and emission characteristics. The admission of Blending DPO along with diesel fuel makes the engine run under dual fuel Mode. Conducting the same trail for Blending DPO and diesel fuel from zero to full load condition for modified piston diesel engine. Compare the performance and emission parameters for diesel and DPO blends with diesel for both base engine and modified piston diesel engine.



1 – Air flow sensor, 2 – Fuel flow sensor, 3 – Pressure sensor, 4 – Diesel tank, 5 – Biodiesel tank, 6 – Five gas analyzer, 7 – Smoke meter, 8 – Speed sensor, 9 – Crank angle encoder

Fig.2 Working principle of VCR system

3. Results and Discussion

3.1 Characterization of Co-pyrolytic oil

The temperature-induced variation in the yield of different fractions, including liquid, solid, and gaseous components, was observed due to endothermic reactions occurring at elevated temperatures. Beyond 600°C, an increase in co-pyrolysis temperature activates secondary cracking or reforming reactions of heavy-molecular-weight compounds in co-pyrolysis vapors. Consequently, this results in a notable reduction in the bio-oil yield, accompanied by a significant increase in non-condensing gases such as H₂ and CO [6]. Table 1 represents the fuel properties of bio-oil obtained through co-pyrolysis in the current experiment under optimized temperature conditions.

Table 1. Properties of bio-oil from Co-pyrolysis

| Fuel properties | PP (Pyrolysis) | CS (Pyrolysis) | PP+CS (Co-pyrolysis) | Diesel |
|--------------------------------------|----------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Density @15 °C , (g/m ³) | 793 | 795 | 794 | 835 |
| Kinematic viscosity at 40°C (cSt) | 3.75 | 3.9 | 3.1 | 2.15 |
| Flash point (°C) | 55 | 75 | 50 | 52 |
| Fire point (°C) | 59 | 78 | 54 | 57 |
| GCV (MJ/kg) | 46 | 36 | 46.5 | 45 |
| Carbon numbers | C ₁₀ -C ₁₈ | C ₈ -C ₁₈ | C ₈ -C ₂₀ | C ₈ -C ₂₅ |
| Carbon (C) % | | | 73.12 | |
| Hydrogen (H)% | | | 10.15 | |
| Nitrogen (N)% | | | 1.35 | |
| Oxygen (O)% | 6.4 | 12 | 8.75 | 7.5 |

3.2 Performance and Emission Analysis of Fuel Blends

This analysis summarizes the performance and emission characteristics of diesel fuel and castor seed oil blends (90D10CB1, 80D20CB1, and 70D30CB1) across varying engine loads.

Performance (BTE & BSFC):

Diesel: Generally exhibited the best performance, with the highest Brake Thermal Efficiency (BTE) and lowest Brake Specific Fuel Consumption (BSFC), indicating superior fuel efficiency. Peak BTE was observed at 75% load.

Castor Seed Oil Blends: Showed lower BTE and higher BSFC compared to diesel, suggesting reduced thermal efficiency and increased fuel consumption. Higher castor seed oil proportions (70D30CB1) resulted in the poorest performance. The 80D20CB1 blend showed some improvement at higher loads.

Emissions (EGT, CO, HC, NO_x):

Diesel: Generally produced the lowest emissions of Carbon Monoxide (CO) and Hydrocarbons (HC). However, Nitrogen Oxides (NO_x) emissions increased significantly at higher loads.

Castor Seed Oil Blends: Tended to have lower Exhaust Gas Temperatures (EGT) compared to diesel. However, they generally exhibited higher CO and HC emissions, especially at lower loads. NO_x emissions were also generally higher than diesel, potentially due to the oxygen content in the castor seed oil.

Diesel fuel demonstrated the best overall performance in terms of thermal efficiency and fuel consumption. However, it also exhibited higher NO_x emissions at higher loads. Castor seed oil blends, while offering lower EGT, generally showed reduced performance and increased emissions of CO and HC. The 80D20CB1 blend appeared to offer a compromise between performance and emissions compared to the other blends with higher castor seed oil content. Further optimization of the blend composition and/or engine parameters would be necessary to improve the performance and reduce the emissions of castor seed oil-diesel blends.

3.3 Graphical Representations

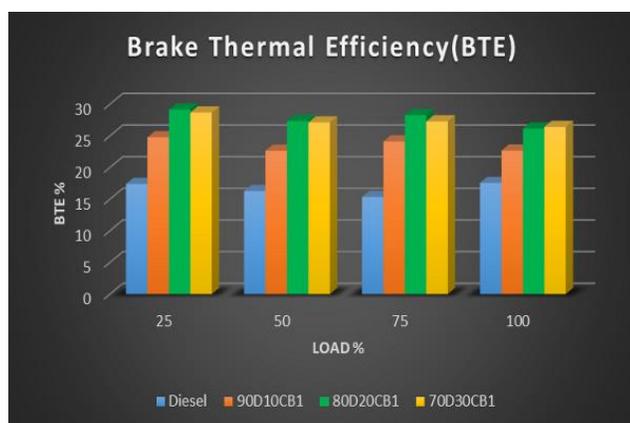


Fig.3 BTE (%) Performance Graph

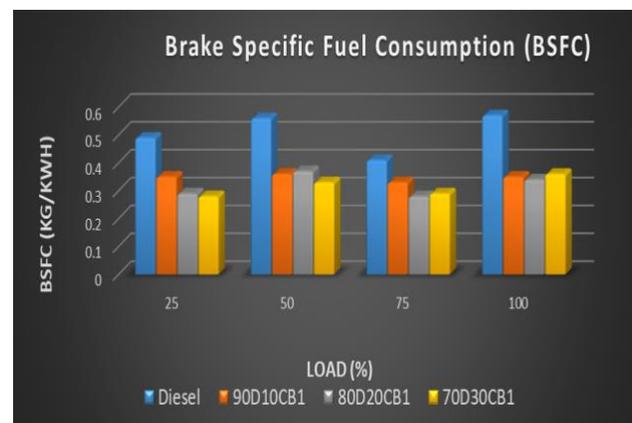


Fig.4 BSFC(kg/kwh) Performance Graph

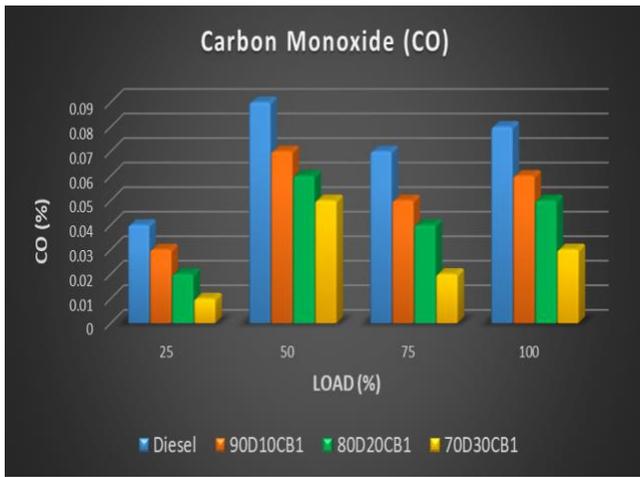


Fig.5 EGT(°C) Performance Graph

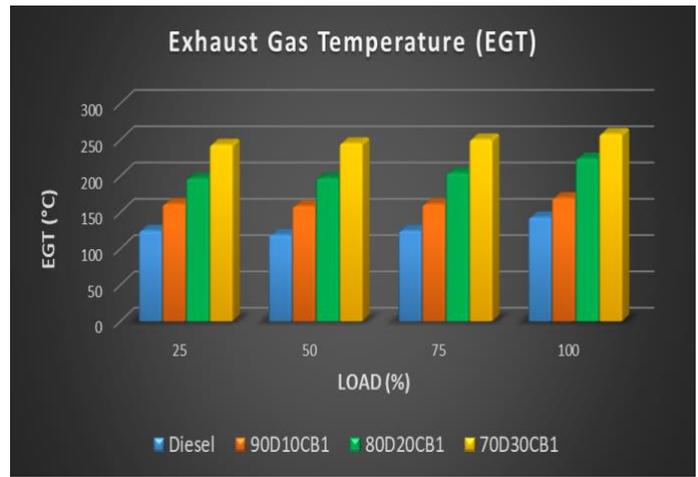


Fig.6 CO (%) Performance Graph

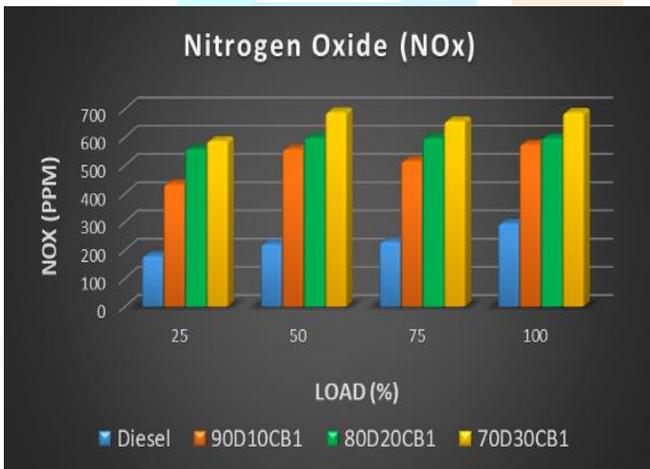
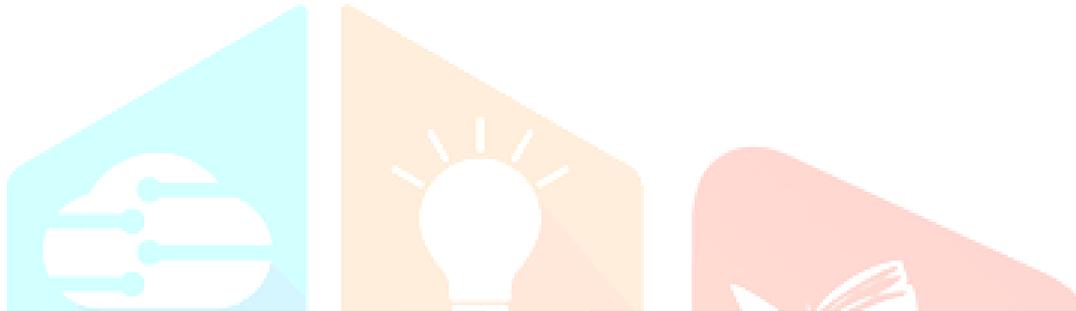


Fig.7 HC(ppm) Performance Graph

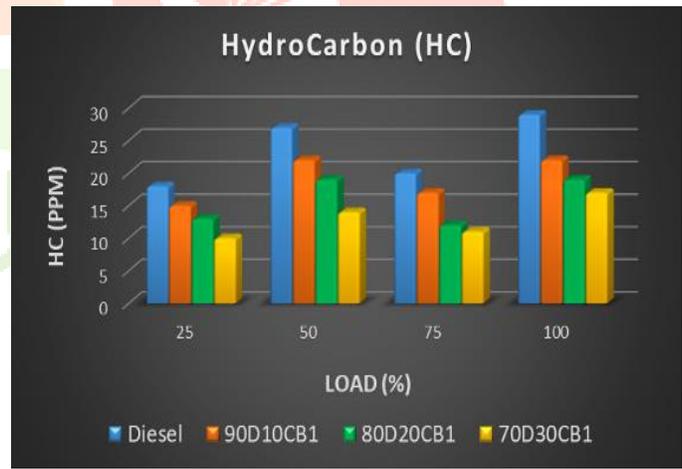


Fig.8 NOX(ppm) Performance Graph

4. Conclusion

The study comprehensively analyzed the performance and durability of a single-chamber diesel engine operating on fuel derived from waste plastic and biomass through copyrolysis. The experimental findings demonstrated that while the engine exhibited slightly lower torque and brake force with the copyrolysis-derived fuel compared to conventional diesel, the specific fuel consumption remained nearly equivalent. This suggests that copyrolysis-based fuel has the potential to serve as a viable alternative energy source, particularly with further refinement and optimization.

Brake thermal efficiency (BTE) tests revealed that a 20% blend of copyrolysis oil with diesel offered optimal performance at higher engine loads, with marginally improved efficiency over pure diesel. However, increasing the blend ratio beyond 20% led to reduced BTE due to variations in viscosity and calorific value, affecting combustion characteristics and overall fuel efficiency. Similarly, brake-specific fuel consumption (BSFC) decreased with higher loads, and a 20% copyrolysis blend demonstrated a significant reduction compared to diesel, highlighting its energy efficiency benefits. Exhaust gas temperature (EGT) measurements indicated an expected increase in temperature with increasing engine load for all fuel types, with the copyrolysis blends exhibiting slightly higher values at maximum load.

This underscores the need for thermal management strategies to ensure long-term durability of engine components. Emission analysis showed higher carbon monoxide (CO) and hydrocarbon (HC) levels at lower engine loads for copyrolysis blends, indicating incomplete combustion. However, nitrogen oxide (NO_x) emissions were notably higher with copyrolysis fuel, potentially due to its unique chemical composition and combustion dynamics.

The presence of metallic and non-metallic impurities in copyrolysis fuel led to increased wear on engine components, particularly affecting iron levels due to corrosion from elevated acidity. The study highlights the critical need for improved fuel purification processes and the incorporation of stabilizers or additives to enhance lubrication and mitigate long-term wear.

5. References

- [1] Shukla, P. R. (1997). Biomass energy in India: Transition from traditional to modern. *The social engineer*, 6(2), 1-21.
- [2] Manzano-Agugliaro, F., Alcayde, A., Montoya, F. G., Zapata-Sierra, A., & Gil, C. (2013). Scientific production of renewable energies worldwide: An overview. *Renewable and Sustainable Energy Reviews*, 18, 134-143.
- [3] Sheng, C., & Azevedo, J. L. T. (2005). Estimating the higher heating value of biomass fuels from basic analysis data. *Biomass and bioenergy*, 28(5), 499-507.
- [4] Czernik, S., & Bridgwater, A. V. (2004). Overview of applications of biomass fast pyrolysis oil. *Energy & fuels*, 18(2), 590-598.
- [5] Elliott, D. C., Beckman, D., Bridgwater, A. V., Diebold, J. P., Gevert, S. B., & Solantausta, Y. (1991). Developments in direct thermochemical liquefaction of biomass: 1983-1990. *Energy & Fuels*, 5(3), 399-410.
- [6] Pyrolysis of Waste Castor Seed Cake: A Thermo-Kinetics Study" by Abdullahi Muhammad Sokoto & Thallada Bhaskar, published in 2018
- [7] Co-pyrolysis of biomass and plastic waste into carbon materials with environmental applications: a critical review" – Jiaqi Deng, Baojun Yi, Ondřej Mašek, Xiangzhou Yuan, Sung Yeon Hwang, Hwai Chyuan Ong, Zewen Hua, Yong Sik Ok (2025)
- [8] Experimental Studies on Co-pyrolysis of Biomass and Plastic Waste" – Debalaxmi Pradhan (2017)
- [9] Copyrolysis of Woody Biomass and Plastic Waste in Both Analytical and Pilot Scale" – A.-C. Johansson, L. Sandstrom, O.G.W. Ohrman, H. Jilvero (2018)