

## Performance and Emission Studies of Blended Plastic Oil Prepared using CuO/CaP Catalyst in Diesel Engine

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### Abstract

The thermal and catalytic cracking processes of turning waste plastics into fuels are the good productive techniques to minimize the destructive effects created to the environment by the plastics, and decrease the dependence on fossil fuels. This paper shows how to recycle plastic wastes into useful petrochemical materials using catalytic cracking process and also study the performance of variable compression ratio engines using the blends of obtained plastic oil with diesel. The appropriate selection of catalysts can improve the yield of fuel and lower the residue with lower hydrocarbon content. The catalytic decomposition of waste plastics is carried out in a self-designed reactor with the catalyst (CuOCaPB). The catalyst is coated on the beads to increase its surface area, so that rate of reaction increases. The temperature range was maintained in the range of 350–450°C. Along with liquid (fuel), solid residue (tar), gases (combustible) are formed in the reaction. Performance and emission characteristics of the plastic fuel were found by blending 10% of plastic fuel in diesel and tested in a variable compression four stroke engine.

**Keywords:** Plastic to fuel, Catalytic cracking, CuO-CaP catalyst, Combustion and Emission characteristics.

### I. INTRODUCTION

Postconsumer and municipality waste plastic has been increasing drastically over years. This causes a lot of damage to our soil because it does not let the rain water to percolate into the earth and ultimately it leads to the reduction of underground water. The plastic also forms a layer on the surface of the sea and ocean, it prevents the sunlight entering into the deep ocean, and hence, they damage the aquatic life. According to 2018 reports we are producing nearly 300 million tonnes of plastic per annum, with a guesstimate 50% of plastic used once and thrown away, 8 million tonnes of plastic is discarding into ocean per year and 7000 tonnes of plastic waste is thrown on earth every day [1]. The main problem is that plastic lavish cannot be disposed easily and it takes really a long time to decay and it also causes lot of environmental imbalances. Another main reason to the increase in need of alternate fuels is fast depletion of fossil fuels. So, recycling of plastic is the only way to reduce the damage caused to the environment. Catalytic cracking process is one of the most beneficial methods to breakdown plastics into fuel [2], in the privation of oxygen compared to normal pyrolysis. The fuel obtained with normal pyrolysis is

lower grade with dark colour and pervasive smell compared to the fuel obtained with catalytic cracking process [3]. The catalytic cracking of waste plastics was reported on desilicated beta and Al-MSU-F (AMF) and zeolite-Y catalysts [4,5]. In the present investigation, waste LDPE and polypropylene were converted into lighter hydrocarbons (fuel) in the presence of catalyst. In this process the gases and liquid products both are combustible. A small quantity of tar forms as the end product. CuO supported over calcium phosphate was used as the catalyst in this process. The main aim of this project was to check the performance and emission characteristics of a VCR (Variable Compression Ratio) engine using plastic oil prepared with the above catalyst.

### II. EXPERIMENTAL

#### Preparation of the Catalyst

From the literature survey, it was found that the acidity of the catalyst plays an important role in promoting catalytic cracking and the copper oxide is known for its oxidizing capacity. Hence, the catalyst was prepared by adopting the procedure reported by Induja *et al.*, [6] and the copper oxide deposited over the calcium phosphate support has been proved to have acidity of 0.34 mmol eq g<sup>-1</sup> of the catalyst with uniformly dispersed CuO particles. The catalyst was prepared by making slurry of calcium carbonate (99.96%) and phosphoric acid (85%) in the ratio of 1:1 and coating over ceramic beads substrate of 5 mm diameter by wash-coat technique. The contents were dried at 120°C for 4 h and sintered at 800°C for 2 h. Copper nitrate (98%) was dissolved in a minimum quantity of water and deposited over the coated ceramic beads. A minimum quantity ammonia solution was added to get deep-blue copper complex and cooked in hot water bath to evaporate the water. Finally, the cooked beads were dried at 120°C for 4 h and calcined at 400°C for 2h to get the catalyst CuOCaPB. The weight percent of calcium phosphate coated on the ceramic beads was around 10% and the weight of CuO deposited on the support was around 10%. This makes the composition of the catalyst as 90 g of ceramic beads (substrate), 9 grams of calcium phosphate (support) and 1 gram of CuO (catalyst). The idea of using ceramic beads as substrate was to increase the surface area of the catalyst, uniform distribution of heat, effective contact over the viscous molten plastic and easy separation after reaction. The purpose of using calcium phosphate as the support was to impart acidity for the catalyst.

**Catalyst Characterization**

The XRD pattern of the catalyst was recorded using GE Analytical XRD (XRD 3003 T/T) and SEM image was captured using Quanta Field Emission SEM (Quanta-200F) microscope.

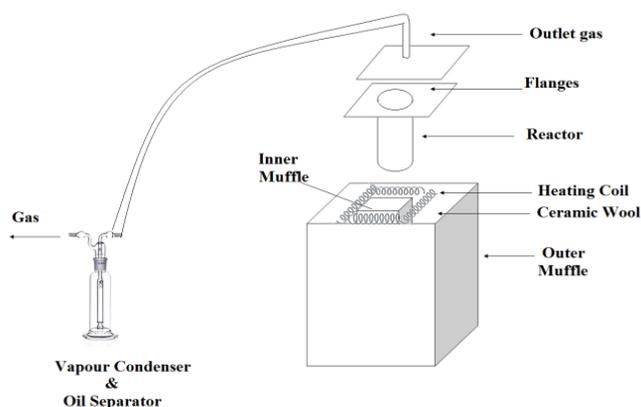
**Reactor set-up**

The reactor was made with stainless steel cylindrical batch reactor wound with a Kanthal heating coil for heating and controlled using RT-100 thermocouple and temperature controller. The 4A dimmerstat was used to control the current and 20A contactor was used to supply current to the coil from dimmerstat. The entire SS310 reactor-setup was cased in a muffle and cladded with ceramic wool to prevent heat loss and contained in another muffle. The top of the reactor was fitted SS310 flanges for loading the catalyst and plastic reactants. 100 grams of polypropylene and LDPE pieces of around 1 cm<sup>2</sup> size was added into the reactor. The catalyst was added in the ratio of 10:1, with respect to plastic and CuO. The flanges were sealed with bolt-nut and HTV silicone was used as sealant. The outlet gas from the reactor was collected using high temperature silicone tube and cooled by passing through water. The liquid fuel was collected using the glass-trap and non-condensable gases are collected by downward displacement of water. The volume of gas was measured for calculating the mass-balance during the reaction. After complete collection of liquid and gaseous products, the reactor was cooled and the solid ash (tar) was separated from the catalyst and weighed.

$$\text{weight of input plastic} = \text{weight of liquid} + \text{weight of solid} + \text{weight of gas}$$

The schematic representation of reactor set-up is shown in Fig.1.

The plastic oil was blended with diesel in the ratio of 90:10 (by volume) and sonicated for efficient blending. The blended fuel was found to be stable without separation of layers and labelled as ‘plastic oil blended diesel – POBD’.



**Fig.1:** Schematic representation of reactor set-up

**Engine Specifications:**

Make/ model	Kirloskar/240PE
Swept volume	661cc
Bore X stroke	87.5 X 110
No. Of cylinder	1
Compression ratio	17.5
Rated output	5hp
Injection timing	23° before TDC
Power	3.54 kw@1500 rpm
Load type	Eddy current
Cooling type	Water
Maximum torque	48 N-m @ 1500 rpm

**Smoke Meter Specifications:**

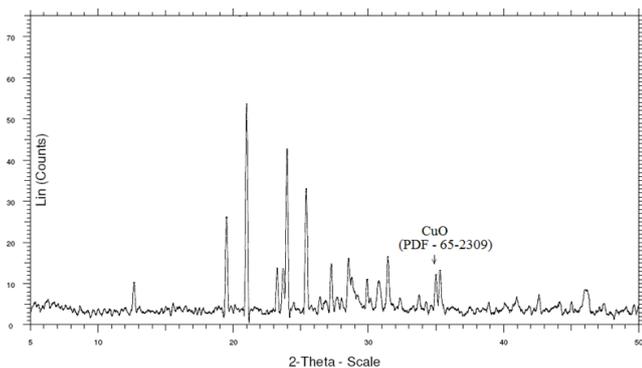
Make	AVL
Model	437C
Measurement Length	430.5 mm
Dimension	600 X 26 X 370 mm
Measurement Range	Absorption - 0.999m <sup>-1</sup> Opacity - 0 - 100%
Interface	RS 232
Resolution	Absorption - 0.01m <sup>-1</sup> Opacity - 0.1%



**Fig.2:** Experimental Setup (Kirloskar Engine)

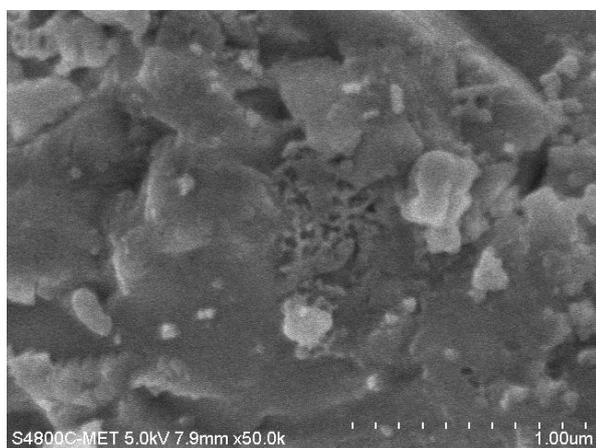
**III. RESULTS AND DISCUSSION**

The XRD pattern on the catalyst CuOCaPB is given in the Fig.3. The peaks matches well with β-Ca(PO<sub>3</sub>)<sub>2</sub> (PDF No.17-0500) and the additional peak at 2θ = 35.6 confirms the presence of CuO (PDF No.65-2309).



**Fig.3:** XRD pattern of CuOCaPB catalyst

The SEM image of the CuOCaPB is given in Fig.4, which shows dispersed CuO particles over the catalyst support.



**Fig.4:** The SEM image of CuOCaPB catalyst

The plastic oil obtained from the present investigation was analyzed for its characteristics and presented in the following Table 1.

**TABLE I: RESULTS OF FUELS CHARACTERISTICS**

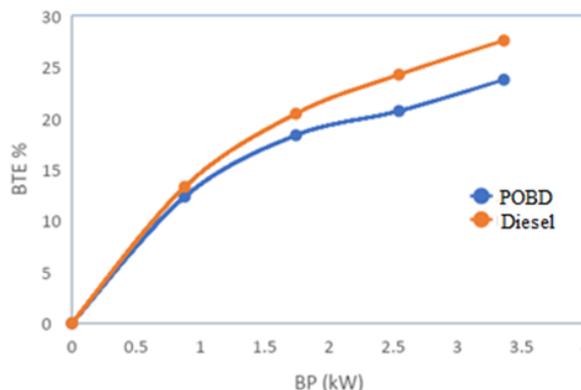
Parameters	Diesel	Plastic oil	POBD oil
Flash point (°C)	60	22	54
Fire point (°C)	65	28	59
Specific gravity	0.83	0.75	0.81
Calorific value (kJ/kg)	44,700	44,877	44,820
Kinetic viscosity (CST)	2.0	2.34	2.30

*Combustion characteristics studies*

The yield of the product using the present catalyst was 85% in which around 2.5% was solid (tar) and 5% was gaseous products.

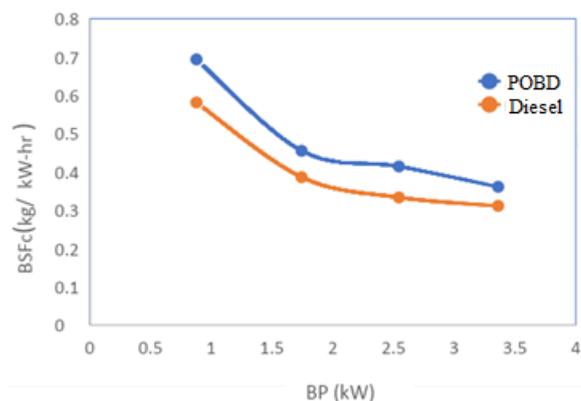
The brake thermal efficiency (BTE) of the POBD fuel and straight diesel under different load condition was studied and

the results are presented in the Fig.5. Under no load condition the BTE for blended fuel and straight diesel was found to be nearly same, but under load condition, the BTE for the blended fuel was observed to be low as compared to the straight diesel. The decrease in BTE can be attributed to poor atomization of the fuel under load condition [7].



**Fig.5:** Variation in Brake thermal efficiency from no load to full load operations using straight diesel and POBD.

The brake specific fuel consumption (BSFC) for the blended fuel and diesel was studied under different load condition and the results are presented in the Fig.6. The BSFC for blended fuel was found to be higher as compared to diesel under varied load condition. The BSFC depends on the physico-chemical properties of the fuel, namely, density, viscosity, calorific value, etc. The blended fuel exhibits high viscosity with lower specific gravity and flash point. This may result in high volatility of the fuel, which in turn affect the air-fuel mixing and hence, the BSFC was found be higher.



**Fig.6:** Variation in Break Specific Fuel Consumption from no load to full load operations using straight diesel and POBD.

*Emission Characteristics*

Fig.7(A) represents the hydrocarbon emission characteristics of POBD and compares with diesel. The higher hydrocarbon emissions observed in POBD may be due to improper combustion at low load condition. The hydrocarbon emissions

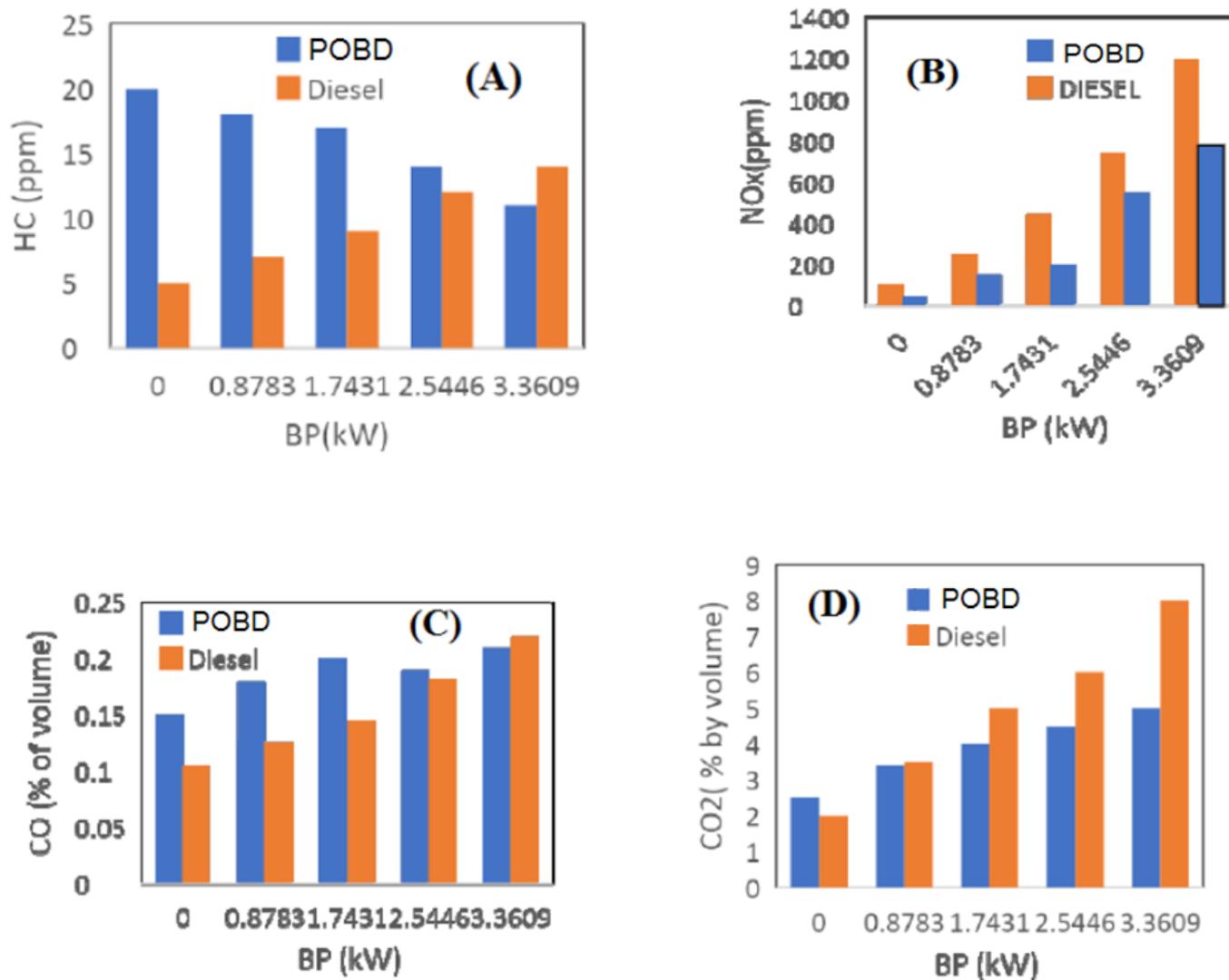
was found to decrease with the increase in the load and at high load condition the hydrocarbon emissions of blended fuel was less than that of straight diesel.

The NO<sub>x</sub> emissions of POBD and diesel are presented in Fig.7(B). The NO<sub>x</sub> emissions follows an increasing trend from low load condition to high load condition, however, the NO<sub>x</sub> emissions was found to be lesser in POBD as compared to straight diesel. The observed decrease in NO<sub>x</sub> can be attributed to the absorption of heat by plastic oil molecules in POBD, as NO<sub>x</sub> is generally formed at high temperatures. Increase in aromatic content also generally increases combustion temperature which in turn increases NO<sub>x</sub> in the exhaust [8]. Addition of plastic oil to diesel has been reported to reduce the NO<sub>x</sub> content in the exhaust by earlier workers [9].

Fig.7(C) shows the emission characteristics of carbon monoxide, it is evident that diesel engines are lean

combustion engines and produce less amount of CO. In general, with the increase in load condition, emission of CO increases due to rich air-fuel ratio [10]. Such an observation was observed in the present investigation. Albert *et. al.*, has reported that with the increase emission of hydrocarbons, the emission of CO should also increase, since, they are products of incomplete combustion reaction [11], but on the contrary at high load condition, the CO emission was found to decrease.

Higher CO<sub>2</sub> emission generally represents complete combustion, but, since, the POBD has higher auto ignition temperature, it leads to improper combustion, hence CO<sub>2</sub> emission was low (Fig.7(D)). However, the variation can only be seen at high loads because of the rich mixture. This may be because of the delay in the combustion of plastic fuel to that of the diesel.



**Fig.7:** Variation in emission characteristics no load to full load operations using straight diesel and POBD (A) hydrocarbon emission (B) NO<sub>x</sub> emission (C) CO emission and (D) CO<sub>2</sub> emission.

#### IV. CONCLUSION

The formation of plastic oil depends on the type of plastic used. Initially, when LDPE covers were used as a feedstock in the reactor, the liquid product was less and more gaseous products were formed with nearly nil solids over CuOCaPB catalyst. The polyethylene terephthalate (PET-water bottles) resulted in solid wax which choked the outlet tube. The present catalyst efficiently degraded the LDPE-polypropylene into plastic oil (85% yield) with low flash point and fire point with calorific value equivalent to that of diesel. The blended fuel performance and emission characteristics of the present POBD was found to be equivalent to that reported in literature.

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