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A Review on Performance, Combustion and Emission Characteristics of CI Engine using Alternative Fuels and Its Blends with Nano Additive

Kartikkumar D. Chaudhari[1], Dr.Sanjay Patel[2]
[1]Research Scholar,
Charutar Vidya Mandal University,
kdchaudhari@gecrajkot.ac.in
[2]Assistant Professor
sanjay.patel@cvmu.edu.in

Abstract: IC engine have proved to be promising technological advancement in the field of the transportation. With the invention of automobiles there is continuous development and revolution was seen in the transportation sector. IC engine uses the hydrocarbon fuels for combustion and develops the required propulsion power for the automobiles. Along with the advantages of the IC engine there are also some of the effects which are observed on the environment due to the emissions generated by the combustion of the hydrocarbons. This effect was observed and came into light during the early nineties and it made the researchers in the field to find the ways to reduce the pollution generated due to combustion of the hydrocarbon fuels. Passenger vehicles are powered by the gasoline whereas heavy transportation vehicle are powered by the Diesel fuel due to space availability for the larger size engine accommodation and high power requirement. It is found that efficiency of the Diesel engine is less than the gasoline engine and it emits some of the more harmful pollutants due to dynamic driving cycle. So many different ways were implemented to reduce pollution and one of the methods in research is the use of the alternative fuels, fuels blend and most recent research is addition of the Nano-Additives in the fuels to improve the combustion efficiency and reduce the emissions. This paper summarizes the recent progress and research on performance, combustion and emission characteristics of CI engine by using the Plastic oils and other alternative fuels doped with nano additives.

Keywords: Fuel Blend; Plastic Oil; Nano Fuel Additives

1. Introduction

Internal combustion engines date back to 1876 when Otto first developed the spark-ignition engine and 1892 when Diesel invented the compression-ignition engine. Since that time these engines have continued to develop as our knowledge of engine processes has increased, as new technologies became available, as demand for new types of engines arose, and as environmental constraints on engine use changed. Internal combustion engines and the industries that develop and manufacture them and support their use, now play a dominant role in the fields of power, propulsion, and energy.

An enormous technical literature on engines now exists which has yet to be adequately organized and summarized. The purpose of internal combustion engines is the production of mechanical power from the chemical energy contained in the fuel. In internal combustion engines, as distinct from external combustion engines, this energy is released by burning or oxidizing the fuel inside the engine. The fuel-air mixture before combustion and the burned products after combustion are the actual working fluids. The work transfers which provide the desired power output occur directly between these working fluids and the mechanical components of the engine. Because of their simplicity, ruggedness and high power to weight

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ratio, Spark Ignition and Compression Ignition Engine have found wide application in transportation (land, sea, and air) and power generation (1). Spark Ignition (SI) engine starts the combustion process in each cycle by use of a spark plug. The spark plug gives a high-voltage electrical discharge between two electrodes which ignites the air-fuel mixture in the combustion chamber surrounding the plug. In early engine development, before the invention of the electric spark plug, many forms of torch holes were used to initiate combustion from an external flame. In Compression Ignition (CI) the combustion process starts when the air-fuel mixture self-ignites due to high temperature in the combustion chamber caused by high compression (2).

2. Automobiles: A Major Source of Pollution

In the 1950s through studies in Los Angeles, it became clear that emissions fromautomobiles were a major contributor to urban air pollution. This smog, formedin the atmosphere as a result of complex photochemistry between hydrocarbonsoftencalled volatile organic compounds (HC or VOC), and oxides of nitrogen(NOx)-on warm spring, summer, and fall days, results in high ambient levels ofozone and other oxidants. In addition, automobiles are the dominant source ofcarbon monoxide (CO) and of lead. It is not just cars: Light trucks, heavy trucks,and off-road vehicles also contribute significantly. So do stationary combustionsystems. Even natural (i.e., biogenic) hydrocarbon emissions are important.Starting in the late 1960s, vehicle emissions in the developed world havebeen regulated with increasing strictness. More recently, the fuels that the sparkignitionand diesel engines in these vehicles use (i.e., gasoline/petrol and diesel)have been or are about to be subject to more stringent constraints with the intentof further reducing emissions(3).

Four major emissions produced by internal combustion engines are hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NOx), and solid particulates. Hydrocarbons are fuel molecules which did not get burned and smaller equilibrium particles of partially burned fuel. Carbon monoxide occurs when not enough oxygen is present to fully react all carbon to CO2 or when incomplete air-fuel mixing occurs due to the very short engine cycle time. Oxides of nitrogen are created in an engine when high combustion temperatures cause some normally stable N 2 to dissociate into monatomic nitrogen N, which then combines with reacting oxygen. Solid particulates are formed in compression ignition engines and are seen as black smoke in the exhaust of these engines. Other emissions found in the exhaust of engines include aldehydes, sulfur, lead, and phosphorus. Two methods are being used to reduce harmful engine emissions. One is to improve the technology of engines and fuels so that better combustion Occurs and fewer emissions are generated. The second method is after treatment of the exhaust gases. This is done by using thermal converters or catalytic converters that promote chemical reactions in the exhaust flow. These chemical reactions convert the harmful emissions to acceptable CO2, H20, and N2(2).

3. Plastic Fuel: A Promising Alternative to Diesel Fuel

Economic development significantly contributes to improvements in life standards. Therefore, both economic development and environmental conservation are the immense

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important aspects and priorities of 21st century. Both require simultaneous indispensable support and adequate consideration, so that they are in fact not only being compatible but also remain mutually supportive. However, coupled with life standard improvement, economic prosperity also induces environmental degradation with long-term irreversible consequences for nature(4). India generates 15 million tons of plastic waste every year but only one fourth of this is recycled due to lack of a functioning solid waste management system. This leads to burden on the landfills and poor socio-economic conditions of the waste pickers, mostly women(5).

Solution to this problem, researchers have found the method to recycle the waste plastic and different methods has been devised for recycling the waste plastic.Recycling is the combination of several technologies that are carried out on waste plastics to produce secondary raw materials. Although recycling has a long-lasting history, it has only recently that environmental concerns and waste management issues are considered due to gradual increase in public awareness.Due to plastics chemical properties, the recycling of waste plastics possesses some technical complications but efficient collection and separation ofwaste plastics leads enhanced recycling efficiencies.

The various approaches that have been proposed for recycling of waste plastics mainly include:

- Primary recycling,
- Mechanical recycling, and
- Plastic recycling.

Primary recycling is the in-plant process of recycling of waste scraps materials. Mechanical recycling involves the separation of plastic polymer from its associated contaminants and further reprocessed through melting, shredding, and other related processes. During mechanical recycling of plastic compounds, the most important aspect is the separation of different types of plastic resins according to their chemical characteristics. Due to variation in melting points, at a definite temperature, a batch of plastic resins may fully transform and a different batch may exhibit partial transformations. Therefore, themechanical recycling ofwaste plastics is mostly carried out with a single-polymer waste stream and in order to achieve maximum efficiency and homogenous mechanical property of produced goods. Moreover, mechanical recycling mostly operated at a temperature of 200–300° C, which also results in the generation of various toxic gases. The third type of plastic recycling process is chemical recycling or feedstock recycling, which ultimately leads to complete or partial depolymerization of plastics. Chemical or feedstock recycling also includes pyrolysis, hydrogenation, and gasification. Depending upon the need of secondary materials and the availability of technology coupled with economic feasibility, any one method can be adopted for recycling of waste plastic streams. Chemical recycling is mostly the complete de-polymerization of the associated monomers or can be partial degradation of in order to produce secondary commercial products(4).

4. Production of Waste Plastic Oil from HDPE

Thermo-chemical conversion of plastic grocery bags (HDPE) to oils were conducted using a pyrolysis batch reactor in triplicate. Pyrolysis was performed in a Be-h desktop plastic to oil system (E-N-Ergy, LLC, Mercer Island, WA) containing a 2 L reactor and oil collection system using approximately 500 g of plastic grocery bags each time. The pyrolysis reactor has two heating zones (upper and lower); the upper andlower temperatures were set to 420 and 440 °C, respectively. Once the reactor reached the set temperatures, a reaction time of 2 h was employed from that point on. Vapors produced as a result of pyrolysis were condensed over water as plastic crude oil (PCO). The upper oil layer was separated and weighed. The reactor lid was opened oncethe temperature was below 50 °C to remove the remaining residual solid material and weighed separately(6).

Distillation of PCO was performed in a Be-h desktop plastic to oil system. A known amount of PCO (1 L) was added to the Be-h reactor vessel. The oil collection tank was cleaned by removing the water and dried before starting distillation. For collecting the gasoline equivalent fraction (b190 °C), the upper and lower temperatures were set to 175 and 190 °C, respectively. Once the liquid stopped dripping into the collection vessel, the gasoline equivalent fractionwas removed, filtered, and weighed to provide yield. The upper zone temperature was then raised to 275 °C and lower zone to 290 °C to collect a #1 diesel equivalent fraction (190–290 °C). The # 2 diesel equivalent fraction (290–340 °C)was then collected by setting the upper zone temperature to 330 °C and lower zone to 340 °C. The material remaining in the reactor vessel was an atmospheric residue equivalent fraction (N340 °C), whichwas removed using a siphon pump once the reactor temperature was below 50 °C. All fractions except the atmospheric residue equivalent (N340 °C) were filtered through Whatman filter paper #4 to remove residual solid particles(6).

Production of plasto-oils from municipal mixed plastic waste

A batch-scale production plant of 0.5 ton/batch was developed at Rudra Environmental Solution (India) Ltd., Pune, India for production of plasto-oils from municipal MPW.The MPW was collectedfrom local municipality/area of Pune, India for production of plasto-oils.The collected MPW was contained old plastic waste, bottles, smallmicron bags even the food pouches & food wrappers, multilayeredpackages, and cable covers. The MPW was cleaned i.e., removed dustwithout using water and shredded into small pieces prior to thermo-catalyticde-polymerization (TCD) process. Additional cleaning of the MPW was carried out to remove contaminants such as paper, oil, food particles and grease to enhance the quality of the output product and to attain higher conversion efficiency. Thermo-catalytic depolymerization is a process where long chains of polymer are cracked with the application of heat in a closed stainless-steel reactor to produce plasto-oils. The shredded MPW was loaded in to the reactor and heated at 380–430 °C in the absence of oxygen under catalytic environment. The catalyst helps in cracking the long chains of polymers to produce hydrocarbon vapors.

These vapors were condensedto produce liquid fuel product (plasto-oil), and the non-condensable gas (synthetic gas). The condensed liquid was passedthrough a filtering unit and

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cleaned prior to storage. The synthetic gas(byproduct of the TCD process) was also passed through a scrubber andcleaned for further use in the reactor to supply heat energy.

The plasto-oil obtained through initial TCD process is referred as plasto-oil 1(PO1). This oil was reprocessed in the same production line and the consequent oil obtained in second stage is referred as plasto-oil 2 (PO2) (**Error! Reference source not found.**). Physiochemical properties of the plasto-oils (PO1 and PO2) in comparison with conventional diesel fuel are given in (**Error! Reference source not found.**). The physicochemical properties of the fuels used in the study were determined as per ASTM methods i.e., heating value by ASTM D4868, and kinematic viscosity by ASTM D445(7).

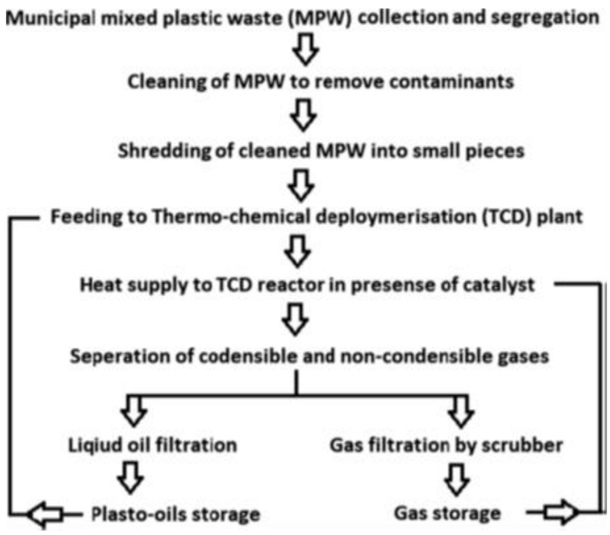

Fig. 1 Flow process indicating the production of pyro-oils from municipal waste (7)

PROPERTIES	EURO-IV DIESEL	PO1	PO2
Heating Value (MJ kg−1) (ASTM D4868)	43.41	42.04	42.97
Density (kg m−3) (ASTM D1298)	807	796	772
Cetane index	55.2	51.4	53.5
Viscosity at 40 °C (cSt)(ASTM D445)	2.64	2.61	2.53

Table 1: Physiochemical Properties of Fuels in Study (7)

Emulsion of Waste Plastic Oil

A W/O emulsion is an emulsion in which water droplets distributed in surrounding oil phase and an O/W/O emulsion is an emulsion in which oil droplets as inner phase contained in dispersed water droplets distributed in outer oil phase. To prepare the W/O two-phase emulsions, the emulsifier Span 80 is added into the oil phase and stirred homogeneously; next, distilled water is added into the oil and emulsifier mixtureby using a metering pump; the solution mixture of water, oiland emulsifier are then moved to the ultrasonic vibration tank;after 5 min of vibration, the W/O two-phase emulsionpreparation is complete. A mechanical agitator is used tocontinuously stir the W/O emulsions at a speed of 600 rpm tillthe engine performance testing is complete. The maximumprocess capacity of the ultrasonic vibration tank used in thisexperiment is 4.5l. To prepare the O/W/O threephaseemulsions, the emulsifier Tween 80 was used to prepare theO/W two-phase emulsions; a metering pump is then utilized toadd the O/W two-phase emulsions into the oil phase alreadymixed with Span 80; thereafter the solution mixture is vibratedfor 5 min to complete the three-phase emulsion preparation(8).There are different resin and different products obtained according to the process temperature and they are described in the (Table 1).

Resin	Mode of thermal decomposition	Low temperature products	High temperature products
Polyethylene	Random chain rupture (involves random fragmentation of polymeralong polymer length, results in both monomers and oligomers)	Waxes, paraffin oil, a-olefins	Gases and light oils
Polypropylene	Random chain rupture	Vaseline, olefins	Gases and light oils
Polyvinyl chloride	Chain-stripping (Side chain reactions involving substituents on thepolymer chain i.e. elimination of reactive substitutes or side groups(HCl) on the polymer chain, chain dehydrogenation and cyclization)	HCl (<300 8C), Benzene	Toluene (>300 8C)
Polystyrene	Combination of unzipping and chain rupture, forming oligomers	Styrene and its oligomers	Styrene and its oligomers
Polymethyl methacralate	Unzipping (Cracking is targeted at chain ends first, and thensuccessively proceeds down the polymeric length, results inmonomer formation)	Monomer Methyl methacralate	Less Methyl methacralate, More decomposition
Polytetrafluoro ethylene	Unzipping	Monomer tetrafluoro ethylene	-
Polyethylene terephthalate	b-Hydrogen transfer, rearrangement and decarboxylation	Benzoic acid and vinyl terephthalate	-
Polyamide 6	Unzipping	Caprolactum	-

Table 1: Mode of thermal decomposition of different thermoplastics and products (9)

4. Additives for CI Engine: Nano Materials a Promising Additive

Many different approaches are used to improve the Combustion characteristics, Performance characteristics and Emission characteristics of the CI Engine. Some attempts like changing the design of combustion chamber, using different fuel blends, changing the injection timing are experimented and some fruitful results are also obtained. Among this, use of Waste plastic oil as a fuel in CI engine has attracted the attention of the researchers and certain experiments has been carried out for the same to evaluate the various characteristics of the CI engine using it either as a neat plastic fuel or by blending it with other fuels. Addition of oxygenated additives like alcohols, esters, or ether can reduce the aromatic content of WPO. In specific, alcohols have greater tendency to improve spray characteristics which could be beneficial to reduce smoke**(10)**.

In the experiment conducted by **(11)**, waste plastic oil was extracted by heating the waste plastic in the absence of oxygen and the condensable gas was condensed, and the oil was extracted. The extracted oil is then processed by adding the different composition of titanium oxide, namely 100, 150, and 200 ppm. Using a probe type ultrasonicator, the nanoparticle is agitated with the plastic oil in order to achieve homogeneous mixture with higher stability of nanoparticle suspended in the fuel. The prepared fuel is tested in the diesel engine for performance and emission characteristics and the same is compared with neat diesel fuel. A regular testing procedure is used to assess the engine performance. After testing of different fuel blends and nano-additives in the engine, it was cleaned and tested with diesel fuel and the fuel tank is cleaned so as to remove the nanoparticle and plastic oil.

The Study conducted by **(12)**, which used the food packing plastic materials Polystyrene (PS) and polypropylene (PP) for producing the plastic fuels by pyrolysis of the waste plastic. This plastic oil was blended with the different concentration of the nano material Titanium Dioxide and its performance was evaluated by adjusting the fuel injection timings such as 23°BTDC,25°BTDC and 21°BTDC with a steady speed of 1500 rpm.Titanium dioxide with 50, 100 and 150 ppm were the three proportions to dope with raw plastic oil on a volume basis (For example, 100 percent WPO with 150 ppm TiO2 nanoparticle). Initially, the nanoparticles with 100 ppm are dispersed in neat WPO and evenly blended using a magnetic stirrer for one hour under atmospheric condition. Besides, the samples are sonicated for thirty minutes to achieve homogeneity using a probe style sonicator. The same procedure is repeated for the other two concentrations. The calorific value of neat WPO and the WPO with different proportions of TiO2 nanoparticle additive are tested and compared, as well as with the cetane number, viscosity and flash point**.** Error! Reference source not found.displays the properties of neat waste plastic oil and waste plastic oil with TiO2 nanoparticle nano additive fuel. The TiO2 nanoparticles are applied to the WPO in concentrations of 50, 100, and 150 ppm, resulting in specific gravity increases of 0.75, 1.52, and 3.79 %, respectively. Adding nanoparticles to WPO improved viscosity by 2.41, 3.64, and 6.71 percent for 50, 100, and 150 ppm TiO2 nanoparticle, respectively, when compared to neat WPO. For stability checking, TiO2 blended waste plastic oil was stored in a bottle under static conditions. The tested fuels remained stable for a week with no phase separation.

In few studies, biodiesel and its blends were tested using different Nano-Particles such as Graphene oxide, Cerium Oxide, Silica and Aluminum Oxide. The results of same are discussed in the next section.

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PROPERTIES	DIESEL	WPO	WPO + 50PPMTIO2	WPO + 100PPMTIO2	WPO + 150PPMTIO2	TEST STANDARD
Kinematic Viscosity (CST) @ 40 ◦C	2.14	2.62	2.71	2.79	2.83	ASTM D445
Calorific Value (kJ/kg)	42700	41900	42280	42620	42870	ASTM D240
Specific Gravity	0.83	0.815	0.82	0.829	0.845	ASTM D1298
Flash point (◦C)	45	62	58	52	48	ASTM D93
Cetane	52	48	50	52	54	ASTM D613

Table 3: Properties of neat WPO and WPO doped with different concentration of TiO2 (12)

5. Results and Discussion:

There are many experimental investigations done using Waste plastic Oil in the CI Engine with different combinations and results for combustion, performance and emission characteristics were studied. Results are summarized in the Table 4, Table 5, Table 6.

Combustion Characteristics:

Ref. No.	Engine Spec.	Test Cond.	Reference Fuel	Test fuel	Delay Period	Heat Release	Cyl. Peak Pressure	Remarks
(11)	1 Cylinder, 4T, Water Cooled, DI CI Engine	Peak Load	Diesel	PO with Nano Additive (TIO)	↑	-	↓	Performance of Plastic Oil with Nano-additives increases as compared to Plastic Oil
(11)	1 Cylinder, 4T, Water Cooled, DI CI Engine	Peak Load	Neat Plastic Oil (Without any additive)	PO with Nano Additive (TIO)	↓	-	↑	
(12)	1 Cylinder, 4T, Water Cooled, DI CI Engine	Full Load	Diesel	WPO	↑	↑	↓	WPO+TIO2 doped with 150ppm shows the Optimum combustion performance.
(12)	1 Cylinder, 4T, Water Cooled, DI CI Engine	Full Load	WPO	WPO+TIO2 (150 ppm of Titanium Dioxide)	↓	↑	↑	
(13)	1 Cylinder, 4T, Constant speed, DI CI Engine	Full Load	Diesel	WPO	↑	↑	↑	-
(14)	1 Cylinder, 4T, Constant speed, DI CI Engine	Full Load	Diesel	PO25 PO50 PO75 PO100	↑ ↑ ↑ ↑	↑ ↑ ↑ ↑	↑ ↑ ↑ ↑	PO100 has Highest DP, HR and Peak pressure.

Ref. No.	Engine Spec.	Test Cond.	Reference Fuel	Test fuel	Delay Period	Heat Release	Cyl. Peak Pressure	Remarks
(15)	1 Cylinder, 4T, Air Cooled, DI CI Engine	Full Load	Diesel	WPO PW10 PW20 PW30	↓ ↑ ↑ ↑	↑ ↑ ↑ ↑	↑ ↑ ↑ ↓	PW30 blend shows the favorable results in DI CI Engine without any modification
(16)	1 Cylinder, 4T, Constant speed, DI CI Engine	Full Load	Diesel	WPO WPO-20%EGR	↑ ↑	↑ ↓	↑ ↓	Peak pressure reduces with use of EGR.
(17)	1 Cylinder, 4T, Constant speed, DI CI Engine	Full Load and No Load	Diesel	PO15 NL PO30 NL PO15 FL PO30 FL	↑ ↑ ↑ ↑	↓ ↓ ↑ ↑	↑ ↑ ↑ ↑	Increased PO will result in higher DP (Chemical Delay due to more Kinematic Viscocity)
(18)	1 Cylinder, 4T, Water Cooled, DI CI Engine	Full Load	PO 10%EGR PO 20%EGR PO 30%EGR (25°CA bTDC)	PO (10%EGR) PO (20%EGR) PO (30%EGR) (21°CA bTDC)	↑ ↑ ↑	↓ ↓ ↓	↓ ↓ ↓	At early injection combustion was better due to better mixing of fuel-air.
(19)	4-Cyl., DI, Turbocharged, Water Cooled CI Engine	Full Load	Diesel	LDPE700 EVA900 EVA900 75%	≈ ↑ ↑	↓ ↓ ↓	≈ ↓ ↓	LDPE shows the better combustion characteristics and has identical performance with Diesel
(19)	4-Cyl., DI, Turbocharged, Water Cooled CI Engine	75% Load	Diesel	LDPE700 EVA900 EVA900 75%	≈ ↑ ↑	↓ ↑ ↑	↓ ↓ ↓	
(20)	4-Cyl., DI, Turbocharged, Water Cooled CI Engine	75% Load	Diesel	PPO25 PPO50 PPO75 PPO90 PPO100	↑ ↑ ↑ ↑ ↑	≈ ≈ ↑ ↑ ↑	≈ ↑ ↑ ↑ ↑	Higher PPO Blends will lead to increase the DP, PP and HRR
(21)	Naturally Aspirated, Single cylinder, Air Cooled CI engine	Full Load	Diesel	B20GO30 B20GO60 B20GO90	↓ ↓ ↓	↑ ↑ ↑	↑ ↑ ↑	Reduced delay period increases other two factors.
(22)	4T, Water Cooled CI Engine	Peak Load	Diesel	COB10 COB10+25 COB10+50 COB10+75	↓ ↓ ↓ ↓	↑ ↑ ↑ ↑	↑ ↑ ↑ ↑	50 ppm of CeO2 is optimum.

Table 2: Summary of Previous Investigation showing Combustion Characteristics

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Performance Characteristics:

Ref. No.	Engine Spec.	Test Cond.	Reference Fuel	Test fuel	Brake Thermal Efficiency	Brake Specific Fuel Consumption	Exhaust Gas Temp.	Remarks
(12)	1 Cylinder, 4T, Water Cooled, DI CI Engine	Full Load	Diesel	WPO	↓	↑	-	Advancing the IT at 25°CA bTDC will further reduce the BSFC and increase BTE.
(12)	1 Cylinder, 4T, Water Cooled, DI CI Engine	Full Load	WPO	WPO+TIO2 (150 ppm of Titanium Dioxide)	↑	↓	-	
(13)	1 Cylinder, 4T, Constant speed, DI CI Engine	75% Load	Diesel	WPO	≈	-	↑	Beyond 75% load, the BTE for Diesel is marginally higher.
(13)	1 Cylinder, 4T, Constant speed, DI CI Engine	Full Load	Diesel	WPO	↓	-	↑	
(14)	1 Cylinder, 4T, Constant speed, DI CI Engine	Full Load	Diesel	PO25 PO50 PO75 PO100	↓ ↓ ↓ ↓	-	-	BTE drops with increasing concentration of Plastic oil.
(15)	1 Cylinder, 4T, Air Cooled, DI CI Engine	Full Load	Diesel	WPO PW10 PW20 PW30	↓ ↓ ↓ ↑	↑ ↑ ↑ ↑	↑ ↓ ↓ ↓	Emulsion fuel has lower EGT because of presence of water Molecules.
(16)	1 Cylinder, 4T, Constant speed, DI CI Engine	Load Varying from 20% to 100%	Diesel	WPO	↓ ↓	-	↑ ↑	With increasing flow or EGR, BTE and EGT drops marginally.
(16)	1 Cylinder, 4T, Constant speed, DI CI Engine	Load Varying from 20% to 100%	WPO	WPO-20%EGR	↓ ↓	-	↓ ↓	
(17)	1 Cylinder, 4T, Constant speed, DI CI Engine	Full Load and No	Diesel	PO15 NL PO30 NL PO15 FL PO30 FL	↓ ↓ ↓ ↓	↑ ↑ ↑ ↑	-	With increasing load, BTE of all fuels were in increasing trend.

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Ref. No.	**Engine Spec.**	**Test Cond.**	**Reference Fuel**	**Test fuel**	**Brake Thermal Efficiency**	**Brake Specific Fuel Consumption**	**Exhaust Gas Temp.**	**Remarks**
		Load						
(18)	1 Cylinder, 4T, Water Cooled, DI CI Engine	Full Load (Retard Time)	PO 10%EGR PO 20%EGR PO 30%EGR (25°CA bTDC)	PO (10%EGR) PO (20%EGR) PO (30%EGR) (21°CA bTDC)	↓ ↓ ↓	↑ ↑ ↑	↓ ↓ ↓	Overall performance can be improved by advancing the IT to 25°CA bTDC
(19)	4-Cyl., DI, Turbocharged, Water Cooled CI Engine	Full Load	Diesel	LDPE700 EVA900 EVA900 75%	≈ ↓ ↓	-	-	LDPE700 shows the identical performance to Diesel Operation.
(20)	4-Cyl., DI, Turbocharged, Water Cooled CI Engine	75% Load	Diesel	PPO25 PPO50 PPO75 PPO90 PPO100	↓ ↓ ↓ ↓ ↓	↑ ↑ ↑ ↑ ↑	↑ ↑ ↑ ↑ ↑	This results are identical irrespective of load or blending ratio.
(21)	Naturally Aspirated, Single cylinder, Air Cooled CI engine	Full Load	Diesel	B20GO30 B20GO60 B20GO90	-	-	↑ ↑ ↑	Addition of GO Increases EGT.
(22)	4T, Water Cooled CI Engine	Peak Load	Diesel	COB10 COB10+25 COB10+50 COB10+75	↓ ≈ ↑ ↑	↑ ↓ ↓ ↓	-	50 ppm of CeO2 is optimum.
(23)	4T, Water Cooled, CI DI Single Cylinder Engine	25% Load	Diesel	10WPO 20WPO 30WPO	↑ ↑ ↑	↓ ↓ ↓	-	20% Blend Shows Optimum Performance at 75% load Condition
(23)	4T, Water Cooled, CI DI Single Cylinder Engine	100% Load	Diesel	10WPO 20WPO 30WPO	↑ ↑ ↑	↓ ↓ ↓	-	
(24)	4T Single Cylinder, VCR Engine with 5hp@1800 RPM	No Load	Diesel	SBME25 SBME25SiO225 SBME25SiO250 SBME25SiO275	↑ ≈ ≈ ≈	↑ ↑ ↑ ↑	-	At full Load Condition, BTE of Diesel is higher than all blends.`
(25)	4T, Single Cylinder CI	Full Load	Diesel	D+B20 D+B20+N50	↓ ↓	↑ ↑	-	DB20+N150 show the

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Ref. No.	Engine Spec.	Test Cond.	Reference Fuel	Test fuel	Brake Thermal Efficiency	Brake Specific Fuel Consumption	Exhaust Gas Temp.	Remarks
	Engine			D+B20+N100 D+B20+N150	↓ ↓	↑ ↑		optimum performance.
(25)	4T, Single Cylinder CI Engine	Full Load	D+B20	D+B20+N50 D+B20+N100 D+B20+N150	↑ ↑ ↑	↓ ↓ ↓	-	

Table 3: Summary of Previous Investigation showing Performance Characteristics

Emission Characteristics:

Ref. No.	Engine Spec.	Test Cond.	Ref. Fuel	Test fuel	NOx	CO	CO2	UHC	Smoke	Remarks
(11)	1 Cylinder, 4T, Water Cooled, DI CI Engine	Peak Load	Diesel	PO with Nano Additive (TIO)	-	↓	-	↓	-	Doping of Nano Additive will give favorable result for CO and HC Emission.
(11)	1 Cylinder, 4T, Water Cooled, DI CI Engine	Peak Load	Neat Plastic Oil (Without any additive)	PO with Nano Additive (TIO)	-	↓	-	↓	-	
(12)	1 Cylinder, 4T, Water Cooled, DI CI Engine	Full Load	Diesel	WPO	↓	↑	-	↑	↑	Adding TIO2 can improve emission characteristic
(12)	1 Cylinder, 4T, Water Cooled, DI CI Engine	Full Load	WPO	WPO+TIO2 (150 ppm of Titanium Dioxide)	↑	↓	-	↓	↓	
(13)	1 Cylinder, 4T, Constant speed, DI CI Engine	Full Load	Diesel	WPO	↑	↑	↓	↑	↓	-
(15)	1 Cylinder, 4T, Air Cooled, DI CI Engine	Full Load	Diesel	WPO PW10 PW20 PW30	↑ ↓ ↓ ↓	↑ ↑ ↑ ↑	-	↑ ↑ ↑ ↑	↑ ↓ ↓ ↓	PW30 emulsion shows better results compared to other emulsions.
(16)	1 Cylinder, 4T, Constant speed, DI CI Engine	Full Load	Diesel	WPO	↑	↑	-	↑	↑	Smoke emission reduces in Diesel with increasing EGR.
(16)	1 Cylinder, 4T, Constant speed, DI CI Engine	Full Load	WPO	WPO-20%EGR	↓	↓	↓	↑	↑	
(18)	1 Cylinder, 4T, Water Cooled, DI	Full	PO 10%EGR	PO (10%EGR)			-			Smoke emission increases as

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Ref. No.	Engine Spec.	Test Cond.	Ref. Fuel	Test fuel	NOx	CO	CO2	UHC	Smoke	Remarks
	CI Engine	Load	PO 20%EGR PO 30%EGR (25°CA bTDC)	PO (20%EGR) PO (30%EGR) (21°CA bTDC)	↓ ↓ ↓	↑ ↑ ↑		↑ ↑ ↑	↑ ↑ ↑	injection timing is retarded. All the emission worsened when injection timing was retarded.
(19)	4-Cyl., DI, Turbocharged, Water Cooled CI Engine	Full Load	Diesel	LDPE700 EVA900 EVA900 75%	↓ ↑ ↑	↓ ↓ ↓	↓ ↓ ↓	↑ ↑ ↑	-	CO reduces as engine load increases.
(19)	4-Cyl., DI, Turbocharged, Water Cooled CI Engine	75% Load	Diesel	LDPE700 EVA900 EVA900 75%	↓ ↑ ↑	↓ ↑ ↑	↓ ↓ ↓	↑ ↑ ↑	-	It is observed that medium blending ratio is suitable for use of PPO.
(20)	4-Cyl., DI, Turbocharged, Water Cooled CI Engine	75% Load	Diesel	PPO25 PPO50 PPO75 PPO90 PPO100	↑ ↑ ↑ ↑ ↑	↑ ↑ ↑ ↑ ↑	↑ ↑ ↑ ↑ ↑	↑ ↑ ↑ ↑ ↑	-	
(21)	Naturally Aspirated, Single cylinder, Air Cooled CI engine	Full Load	Diesel	B20GO30 B20GO60 B20GO90	↑ ↑ ↑	↓ ↓ ↓	↑ ↑ ↑	↓ ↓ ↓	-	Nox emission increases due to HHR
(22)	4T, Water Cooled CI Engine	Peak Load	Diesel	COB10 COB10+25 COB10+50 COB10+75	↑ ↑ ↑ ↑	↓ ↓ ↓ ↓	-	↓ ↓ ↓ ↓	-	50 ppm of CeO2 is optimum
(23)	4T, Water Cooled, CI DI Single Cylinder Engine	25% Load	Diesel	10WPO 20WPO 30WPO	↑ ↑ ↑	↑ ↑ ↑	↑ ↑ ↑	↑ ↑ ↑		20% Blend Shows Optimum Performance.
(23)	4T, Water Cooled, CI DI Single Cylinder Engine	100% Load	Diesel	10WPO 20WPO 30WPO	≈ ↑ ↑	↑ ↑ ↑	↑ ↑ ↑	↑ ≈ ↑	-	
(24)	4T Single Cylinder, VCR Engine with 5hp@1800 RPM	No Load	Diesel	SBME25 SBME25Si O225 SBME25Si O250 SBME25Si O275	↑ ↑ ↑ ↑	↑ ↑ ↑ ↑	-	↑ ↑ ↑ ↑	↑ ↑ ↑ ↑	At No Load and Full Load Results are same.
(25)	4T, Single Cylinder CI Engine	Full Load	Diesel	D+B20 D+B20+N5 0 D+B20+N1	↑ ↑ ↑ ↑	↓ ↓ ↓ ↓	-	↓ ↓ ↓ ↓	-	UHC and CO Emission reduces marginally with

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Ref. No.	Engine Spec.	Test Cond.	Ref. Fuel	Test fuel	NOx	CO	CO2	UHC	Smoke	Remarks
				00 D+B20+N150						use of DB20+N150
(25)	4T, Single Cylinder CI Engine	Full Load	D+B20	D+B20+N50 D+B20+N100 D+B20+N150	↑ ↑ ↑ ↑	↑ ↑ ↑ ↑	-	↑ ↑ ↑ ↑	-	

Table 4: Summary of Previous Investigation showing Emission Characteristics

Nomenclature

WPO	Waste Plastic Oil	NOx	Nitrogen oxides
PPO	Pyrolysis Plastic Oil	CO	Carbon Monoxide
LDPE700	Low Density Polyethylene Oil Produced At 700 ◦C	CO2	Carbon Dioxide
EVA900	Ethylene-Vinyl Acetate Oil Produced At 900 ◦C	UHC	Unburned Hydrocarbons
EVA900 75	75% EVA900 + 25% diesel fuel	BTE	Brake Thermal Efficiency
HRR	Heat Release Rate	↑	Increasing
NL	No Load Condition	≈	Equivalent
FL	Full Load Condition	↓	Decreasing
PW	Plastic Oil Emulsified with water	EGR	Exhaust Gas Recirculation
B20	Biodiesel-Diesel blend in 20% Ratio	GO	Graphene Oxide Nano particle
COB10	Corn oil 10% + Diesel oil 90% Blend	CeO2	Cerium Oxide Nano particle
SBME 25	Soya bean Methyl Ester 25% blend with diesel fuel	SiO2	Silicon Dioxide Nano Particle

6. Conclusion:

From the study of previous investigations done on using the neat waste plastic oil, blends of plastic oil and plastic oil doped with the nano particle in the CI engine and studying its effect on the performance, combustion and emission characteristics of the CI Engine, it can be concluded that;

1. Delay period increases with use of WPO, which is due to high kinematic viscosity and more chemical delay(17). Also, lower cetane number of WPO contributes to the longer ignition delay. Longer ignition delay also results in the High heat release rate and higher in cylinder peak pressure. Doping the Plastic fuel with nano particles will result in reduced ignition delay and lower the peak pressure in the cylinder(11). Using WPO with EGR can further increase the delay period but reduce the HRR and peak pressure in the cylinder because the EGR acts as a heat absorbing agent that reduces the cylinder charge temperature in the combustion chamber during the combustion process(16). Peak pressureand HRR for neat WPO reduced gradually with increasing EGR rates. The peak in-cylinder pressures and HRRs also dropped as the injection timing was delayed from 25°CA bTDC to 21°CA bTDC(18). Further when WPO

emulsion with water was used, peak pressure and heat release rate was reduced(15).

2. When Brake thermal efficiency was observed in general, WPO shows lower BTE as compared to diesel operation. Improvement in the BTE was seen when the plastic fuel was doped with nanoparticles. Also, water emulsion fuel when used shows higher BTE due to effect of micro-explosion of the water droplets contained in the emulsion fuel, which helps to break the larger size droplets oil into smaller one, accelerating fuel evaporation and mixing with air, thereby resulting in a faster combustion process and the higher BTE.BTE of WPO injectedat the early injection timing of 25°CA bTDC under 10% EGR was found to be better than diesel by 5.1%. However, BTE deteriorated at higher EGR rates at all injection timings(18). BSFC generally increases in WPO as compared to that of diesel. BSFC was improved by the addition of TiO2 nanoparticles into the WPO fuels, especially in case of the advanced fuel injection timing 25°BTDC(12). Exhaust gas temperature was higher in case of neat waste plastic oil whereas it lowered when WPO used with EGR or emulsion with water.
3. Emissions of Oxides of nitrogen were observed to be higher in majority studies when operated with WPO. It reduced when WPO was used with EGR or doped with nanoparticles. Reduction in NOx emissionsup to 30% was achieved when 30% emulsion fuel was used(15). NOx emissions were also lowered when EGR was used due to presence of higher heat capacity of gases which reduced the combustion temperature(16).
4. Emissions of carbon monoxide were higher in operation of engine with WPO, whereas it reduced with increase in EGR flow. CO emissions also reduced when nanoparticle was added to neat plastic fuel(11). Unburned hydrocarbonemissions were found to be increased for WPO operation. It was observed by (11), that UHC were lowered by adding nanoparticles to the WPO. Carbon dioxide emissions were found to be lower for almost all the operating conditions for WPO.
5. Smoke opacity for 30% emulsion fuel was 67% lower as compared to diesel in full load operation(15). Smoke opacity also reduced with adding the nanoparticle to WPO.
6. LDPE oil made by pyrolysis at temperature of 700°C show the similar combustion, emission characteristics to that of Diesel operation.
7. Using Biodiesel and Diesel blend showed quite improvement but further addition of Nano material, further the performance of engine was optimized in terms of BTE, and some Emission component as showed in results and discussion section.

It was observed from previous investigations that the diesel engine can run without any modification with WPO doped with nanoparticles and EGR amounting to 20%. Along with EGR, advancing fuel injection timing can further improve the overall performance of the diesel engine.

7. Future Scope:

Many experiments and study have been done and performance of CI engine has been tested with different plastic oil and its blends. Study was also done to use the plastic oil with

EGR flow to control emissions of nitrogen oxides. From the review done in this paper, it is observed that very few studies are conducted for testing the plastic oil doped with the nano particles. So, there is further scope of experimenting different nanoparticle doped plastic oil in the CI Engine. Emulsified Plastic oil with nano additives can also be tested, combination of EGR and plastic oil with nano additives can also be tested in the future experiments.

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