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# PERFORMANCE AND EMISSION CHARCTERISTICS OF C.I. ENGINE USING WASTE PLASTIC PYROLYSIS OIL–DIESEL BLENDS

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## ABSTRACT

Our country is facing the critical problem of fuel and energy deficiency. The fast depletion of petroleum reserves in the world and frequent rise in prices of crude oil led to search for alternative fuels. On the other hand, plastic waste has become a major element in garbage which does not decompose naturally and causes very serious environmental problems. In this context, pyrolysis of waste plastics is currently receiving renewed interest for getting the fuel. The properties of the oil derived from pyrolysis of waste plastics were analyzed and compared with the petroleum products and found that it has properties similar to that of diesel. In the present work, waste plastic Pyrolysis oil was used as an alternate fuel in a C.I. engine without any modification. The present investigation was to study the performance and emission characteristics of a single cylinder, four-stroke, air-cooled DI diesel engine run with waste plastic pyrolysis oil-diesel blends. Brake thermal efficiency of the engine is less than the diesel fuel operation at full load and higher at part loads. Unburned hydrocarbon and Carbon dioxides were marginally higher than that of the diesel baseline. The toxic gas carbon monoxide emission of waste plastic pyrolysis oil was higher than diesel.

**Keywords**: Diesel engine, Waste plastic pyrolysis oil, Performance, Emissions

## 1 INTRODUCTION

Waste plastics problem is an ever-increasing menace for global environment. Because of durability, flexibility, and economy, a phenomenal rise is observed in the plastic consumer base. Throughout the world, research on waste plastics management is being carried out on war-footing. According to a nationwide survey, conducted in the year 2003, more than 15342.46 T of plastic waste is generated daily in our country, and only 40% by wt of the same is recycled, balance 60% by wt is not possible to dispose off [1,2].

Plastic waste contributes to the solid waste streams by about 8% - 15% by weight and twice that by Volume (GOI 1997). It is projected that annual post-consumer plastic waste will reach 5.6 million tons by the year 2008-2009. At these alarming levels of waste plastics generation, India needs to prepare a lot in recycling and disposing the waste. Several processes and means have been attempted to fight against these alarming levels of waste plastics generation. However each process has its drawbacks and economical, operational & financial limitations for practical implementation.

A large proportion of sheeting materials and molded parts and stickers etc is left out by rag pickers. The small bags /molded parts are soiled and are difficult to identify. Also they have no value as feed stocks for recycle. These un-utilized waste plastics remains uncollected and spread everywhere, littered in open drains or in garbage dumps, often resulting in choking of municipal sewers and storm water drains. Thus the balance 40 wt% gradually goes on accumulating, thereby leading to:

- Serious environmental problems
- Disposal problems
- Wastage and non utilization of high energy material.

## 2 WASTE PLASTIC OIL IN MARINE DIESEL ENGINES

The diesel engine has the highest thermal efficiency of any regular internal or external combustion engine due to its high compression ratio. Diesel engines are most preferred power plants due to their higher thermal efficiency, excellent and driveability. Despite their advantages, they emit high levels of NOx and smoke which will have an effect on human health. Hence, strict emission norms and the depletion of petroleum fuels have necessitated the search for alternate fuels for diesel engines. Application of Waste Plastic Disposals reduces the experimental heavy fuel oil viscosity. The results showed that waste plastic disposal oil when mixed with heavy oils reduces the viscosity significantly and improves the engine performance [3]. Although Oxides of Nitrogen(NOx) emission slightly increases, the emission of particulate matters (PM), dry soot (DS) and soluble organic fraction (SOF) decreases by half at the mixing ratio of 30 % by vol. The kind of plastic materials are HDPE, LDPE, PE, PP, Nylon, Teflon, PS, ABS, and FRP.

## 3 PYROLYSIS

Pyrolysis is the chemical decomposition of organic substances by heating. The word is originally coined from the Greek-derived elements pyro "fire" and lysys "decomposition". Pyrolysis is usually the first chemical reaction that occurs in the burning of many solid organic fuels, cloth, wood, and paper, and also of some kinds of plastic. Anhydrous pyrolysis process can also be used to produce liquid fuel similar to diesel from plastic waste.

## 4 PROCESS TECHNOLOGY

This process, involves Pyrolysis technology is thermal degradation process in the absence of oxygen. Plastic waste is treated in a cylindrical reactor at a temperature of 370ºC - 420ºC. The polymer is gently cracked by adding Catalyst and the gases are condensed in a series of condensers to give a low sulphur content distillate. All this happens continuously to convert the waste plastics into Fuel that can be used in Generators or as Furnace oil.

The Catalyst used in this system will prevent formation of all the dioxins and Furans (Benzene ring) .All the gases are treated before it is let out in to atmosphere. The Flue Gas is treated through scrubbers and water/ chemical treatment is done for neutralization. The non- condensable gas goes through water before it is used for burning. Since the Plastics waste is processed about 370ºC - 420ºC and there is NO OXYGEN in the processing reactor, most of the Toxics are burnt. The flow chart of preparation of oil is shown in Figure 1

**Products Obtained**

The main products of pyrolysis are oil, Hydrocarbon gas and carbon black. When waste plastic is used as raw material for pyrolysis plants, general input output ratio is shown in table 1and the properties of oil obtained are listed in Table 2

| NOMENCLATURE | |
|---|---|
| **CI** | **Compression Ignition** |
| **WPPO** | **Waste plastic pyrolysis oil** |
| **WPPO 10** | **10% Waste plastic pyrolysis oil + 90% Diesel** |
| **WPPO 30** | **30% Waste plastic pyrolysis oil + 90% Diesel** |
| **BP** | **Brake Power** |
| **IP** | **Indicated Power** |
| **TFC** | **Total Fuel Consumption** |
| **BSFC** | **Brake Specific Fuel consumption** |
| **HC** | **Unburned Hydrocarbon** |
| **CO** | **Carbon monoxide** |
| **$CO_2$** | **Carbon dioxide** |
| **$O_2$** | **Oxygen** |
| **cSt** | **centistokes** |

## 5 ENGINE TESTS

### Engine Performance

Engine performance is an indication of the degree of success with which it is doing its assigned job, i.e., the conversion of the chemical energy contained in the fuel into the useful mechanical work. The degree of success is compared on the basis of the following

1. Specific fuel consumption
2. Break thermal efficiency
3. Exhaust emissions

Specific fuel consumption is widely used to compare the performance of different engines.

Brake thermal efficiency is the true indicator of the efficiency with which the thermodynamic input is converted into mechanical work. It also accounts for combustion efficiency.

Exhaust emissions such as unburnt hydrocarbons, carbon dioxide, carbon monoxide oxygen etc, are nuisance for the environment.

## 6 EXPERIMENTAL SETUP

The experimental setup of the test engine is shown in Figure 2. The specifications of the test engine are given in Table 3. Diesel engine is coupled to an alternator. The fuel consumption rate is measured on volumetric basis using a burette and a stopwatch. Chromel alumel thermocouple with a digital temperature indicator is used to measure the exhaust gas temperature.

A four Gas Analyzer is used to measure the level of HC, $CO_2$, CO, $O_2$.

## 7 RESULTS AND DISCUSSIONS

Three test fuels were used during experiments including neat 100 % diesel fuel and a blend of 10% and 30% with waste plastic pyrolysis oil by volume in the diesel. The tests were carried out for the above proportions of waste plastic pyrolysis oil and diesel. The engine was not modified in any way for use with waste plastic pyrolysis oil blends. The performance tests were conducted at 1500 rpm with loading of 0, 20,40,60,80 and 100 percent of rated power. The engine was operated for data collection with 5 minutes at each interval. The Performance was compared with pure diesel operation. The basic performance parameters such as specific fuel consumption, brake thermal efficiency and mechanical efficiency were calculated and presented against load for all cases as shown in Figure 3 to Figure 5.exhaust emissions such as unburned hydro carbons, carbon monoxide, carbon monoxide and oxygen were measured and plotted against load as shown in Figure 6 to Figure 10.

### 7.1Brake Specific Fuel Consumption

The rate of fuel consumption divided by the rate of power production is termed as Brake specific fuel consumption. Brake specific fuel consumptions descend from lower to higher load conditions. It is related with brake thermal efficiency. At higher load conditions the brake thermal efficiency is decreased and brake specific fuel consumption increased. Figure 3 shows the variation of brake specific fuel consumption (BSFC) with load for WPPO 10, WPPO 30 and diesel oil. As the load increases, BSFC decreases for all fuel blends up to part load i.e.80 %, higher consumption at full load. The engine will consume more fuel with diesel waste plastic pyrolysis blended fuels than with neat diesel fuel to gain the same power output due to the lower calorific value of blended fuel.

**7.2 Brake Thermal Efficiency**

The variation of brake thermal efficiency with load for WPPO-Diesel blends is shown in Figure 4. The brake thermal efficiency is lower for the WPPO-Diesel blends than diesel at full load. WPPO is a mixture of hydrocarbons varying from C10 to C30 having both low and heavy fractions with aromatics. Because of the changes in composition, viscosity, density and calorific value of WPPO-Diesel blends the brake thermal efficiencies of WPPO-Diesel blends are high at part loads.

**7.3 Mechanical efficiency**

From Figure 5, it is clear that the mechanical efficiency of the engine increases with an increase in load under all operating conditions. On pure diesel mode at full load, the mechanical efficiency is found to be 67.5%. When operated with WPPO 10 the corresponding value is 69.3%, a rise of about 2.6 % is observed. At full load, the mechanical efficiency is 70.34 % with WPPO 30 and there is a raise of about 4.21%, which indicates that the engine produces more power as blend of the waste plastic pyrolysis oil is increased.

**7.4 Exhaust Gas Temperature**

Figure 6 shows the variation of exhaust gas temperature with load for waste plastic pyrolysis oil and diesel blends. The results show that the exhaust gas temperature increased with load in all cases. Higher exhaust gas temperature in the case of WPPO compared to diesel is due to higher heat release rate. It may also be due to the oxygen content of the WPPO, which improves combustion. In the case of WPPO, the fuel spray becomes finer and effective combustion takes place.

**7.5 Hydrocarbon emission**

The variation of hydrocarbons with load for tested fuels is shown in Figure 7. Hydrocarbon ranges from 25 ppm at low load to 33 ppm at full load for diesel fuel operation. For WPPO 10, it varies from 27 ppm to 32 ppm at full load. It can be observed that HC varies from 28 ppm at low load to 32 ppm at full load for WPPO 30. From the results, it can be noticed that the concentration of hydrocarbon of WPPO- Diesel blends is marginally higher than Diesel. When the WPPO- Diesel blends is injected and mixes with air, because of non-homogeneity of fuel air mixture some local spot in the combustion chamber will have mixture that will be too lean for proper combustion. In a combustion chamber some fuel spots may be too rich with insufficient oxygen to burn all the fuel. Hence, some local spots with rich and lean mixture would be available in the combustion chamber [5]. In fuel rich zones some fuel droplets do not react due to lack of oxygen and the combustion may be incomplete [6,7]. This is the reason for higher HC emission in the case of WPPO-Diesel blends compared to Diesel. At lower loads due to lean mixture, the hydrocarbon ranges of WPPO and Diesel is less while at higher loads due to higher quantity of fuel admission hydrocarbon.

**7.6 Carbon monoxide**

The variation of carbon monoxide with brake power is depicted in Figure 8. Since, CI engines are operating with lean mixtures; the CO emission would be low when compared with SI engine. CO emission is toxic so it must be controlled. CO is an intermediate product in the combustion of a hydrocarbon fuel, so its emission results from incomplete combustion. Therefore, emission of CO is greatly dependent on the air fuel ratio relative to the stoichiometric proportions. Rich combustion invariably produces CO. The reason behind this increase of CO emission is incomplete combustion. The increase in CO emission at higher loads is due to higher fuel consumption.

**7.7 Carbon dioxide**

As shown in Figure 9, it can be observed that the variation of carbon dioxide emission with load for Diesel and WPPO-Diesel operation. From the results, it is observed that the amount of $CO_2$ produced while using WPO- Diesel blends is higher than Diesel at all load conditions. Carbon dioxide, or $CO_2$, is a desirable byproduct that is produced when the carbon from the fuel is fully oxidized during the combustion process. As a general rule, the higher the carbon dioxide reading, the more efficient the engine is operating.

**7.8 Oxygen**

The variation of brake thermal efficiency with load for WPPO- Diesel blends is shown in Figure 10. It is clear that oxygen present in the exhaust gas decreases as the load increases. It is Obvious that due to improved combustion, the temperature in the combustion chamber can be expected to be higher and higher amount of oxygen is also present, leading to formation of higher quantity of NOx, in WPPO-Diesel blends. Oxygen ($O_2$) readings provide a good indication of a lean running engine. Misfires typically cause high $O_2$ output from the engine.

## CONCLUSIONS

From the tests conducted with waste plastic oil and diesel on a diesel engine, the following conclusions are arrived:

- Part Load Thermal efficiency is higher than the diesel fuel operation
- CO emission increased with waste plastic pyrolysis oil compared to diesel operation.
- Unburnt hydrocarbon emission is higher than the diesel
- Oxidation of fuel is good at part loads which results higher $CO_2$
- Waste plastic pyrolysis oil can be used alternate fuel to the diesel


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## REFERENCES


1. Central Pollution Control Board (CPCB) `Information Related to Plastics Waste Management, 2003.
2. Vu Phong Hai, Osami Nishida, Hirotsugu Fujita, Wataru Harano, Norihiko Toyoshima, Masami Iteya. Reduction of NOx and PM from dieselengines by WPD emulsified fuel, http://www.sae.org/technical/ papers/2001-01-0152; 2001. SAE Technical Paper 2001-01-0152.
3. Paul T. Williams, Elizabeth A. Williams. Interaction of plastics in mixed plastics pyrolysis.Journal of Energy and Fuels 1999; 13 (1), pp 188–196.
4. Murugan S, Ramaswamy MC, Nagarajan G. Tyre pyrolysis oil as an alternate fuel for diesel engines. Journal of SAE 2005;01:2190.
5. Smet Cel, Kten. An experimental investigation of the effect of the injection pressure on engine

performance and exhaust emission in indirect injection diesel engines. Journal of Applied Thermal Engineering 2003;21:2051-2060.

6. Ren Y, Huang Z, Jiang D, Liu L. Combustion characteristics of a compressionignition engine fuelled with dieseledimethoxy methane blends under various fuel injection advance angles. Journal of Applied Thermal Engineering 2006;21:327e37.

7. Jerzy Walendziewski. Engine fuel derived from waste plastics by thermal treatment. Journal of Fuel 2002;81:473-481.

8. Soloiu A, Yoshinobu Y, Masakatsu H, Nishiwaki Kazuie, Mitsuhara Yasuhito,Nakanish Yasufumi. The investigation of a new diesel produced from waste plastics. ISME; 2000.

| Table 1 plastic pyrolysis : input – output ratios | | |
|---|---|---|
| Input Material | Input Quantity | Output quantity |
| Waste mixed plastic scrap | 1000kgs | - 650 to 900 lit of Pyrolysis Oil<br>- 50 to 100 Kg of Hydrocarbon Gas<br>- 50 to 70Kg of carbon Black |

**Table 2 Comparisons of Properties of WPPO, diesel**

| Sr. No. | Properties | WPPO | Diesel |
|---|---|---|---|
| 1 | Density @ 30 $^0$C in (g/cc) | 0.7930 | 0.84 to 0.88 |
| 2 | Ash content (%) | < 0.01% (wt) | 0.045 |
| 3 | calorific value (kJ/kg) | 41,858 | 42000 |
| 4 | Kinematic viscosity, cSt @ 40$^0$ C | 2.149 | 5 |
| 5 | Cetane number | 51 | 55 |
| 6 | Flash point ($^0$C) | 40 | 50 |
| 7 | Fire point ($^0$C) | 45 | 56 |
| 8 | Carbon residue (%) | 0.01 % (wt) | 0.20 |
| 9 | Sulphur content (%) | <0.002 | <0.035 |
| 10 | Acidity (mg KOH/gm) | 0.16 | 0.20 |
| 11 | Pour Point,$^0$C | -4 | 3 - 15 |

**Table 3 Specifications of the Test Engine**

| S.No | Parameter | Specification |
|---|---|---|
| 1 | Make of Model | Alamgir ATF-1 |
| 2 | Engine type | air-cooled vertical 4 stroke single cylinder diesel engine |
| 3 | Power | 6.6 kW/ 9 HP at 1500 rpm |
| 4 | Rated speed | 1500 rpm |
| 5 | Bore size | 102 mm diameter |
| 6 | Stroke length | 116 mm |
| 7 | Compression ratio | 16.5 |

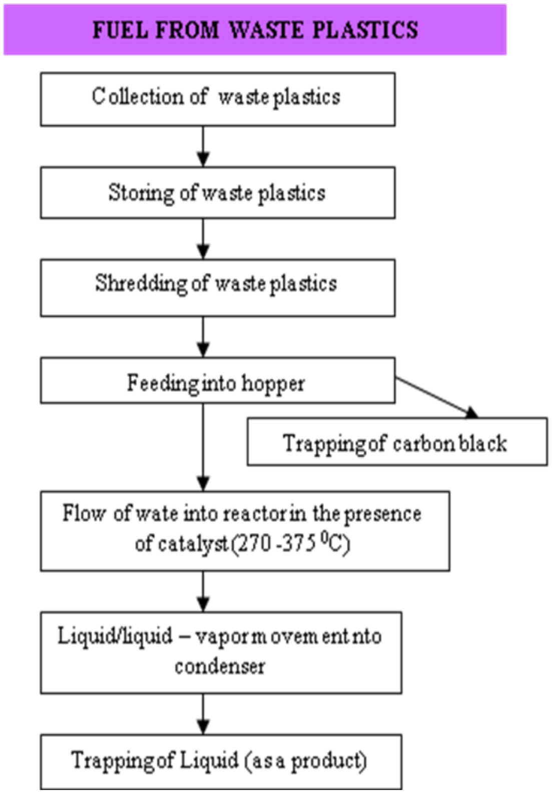
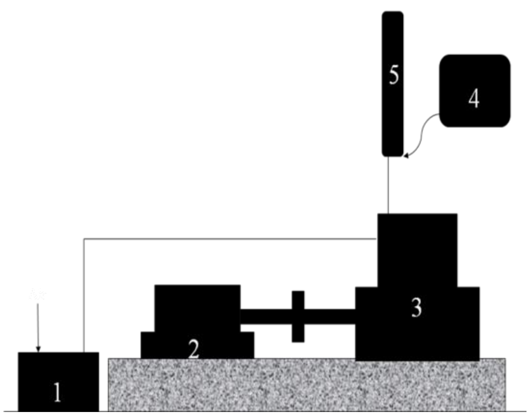



**Figure 1 Conversion of Plastics waste into Liquid Fuel**




1. Air box 2. Alternator 3. Engine 4.Fuel tank 5.Burette

**Figure 2 Experimental setup of the test engine**

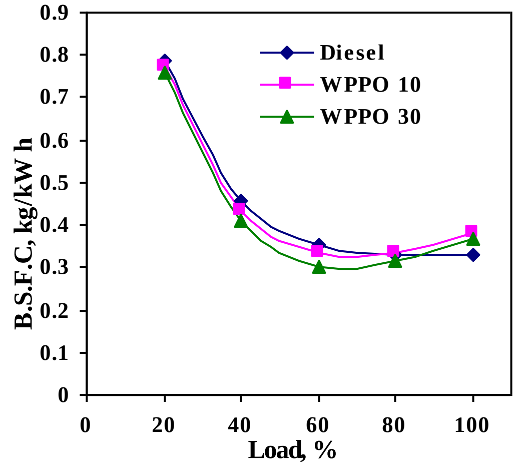



**Figure 3 Load against B.S.F.C.**

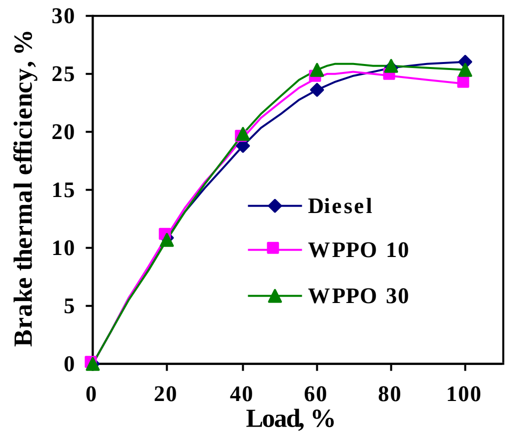



**Figure 4 Load against Brake Thermal efficiency**

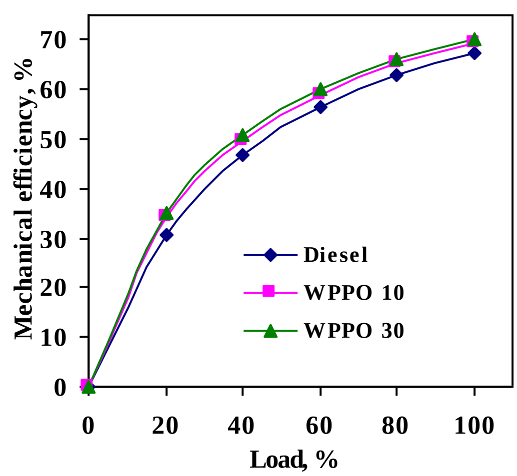



**Figure 5 Load against Mechanical efficiency**

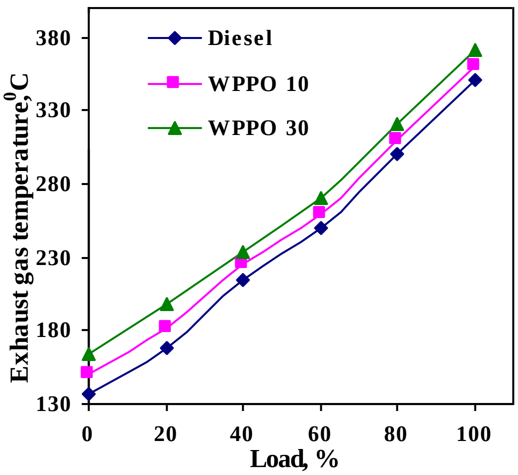



Figure 6 Load against Exhaust gas temperature

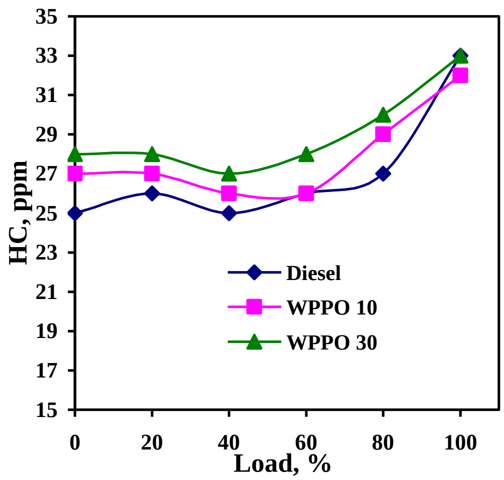



Figure 7 Load against HC

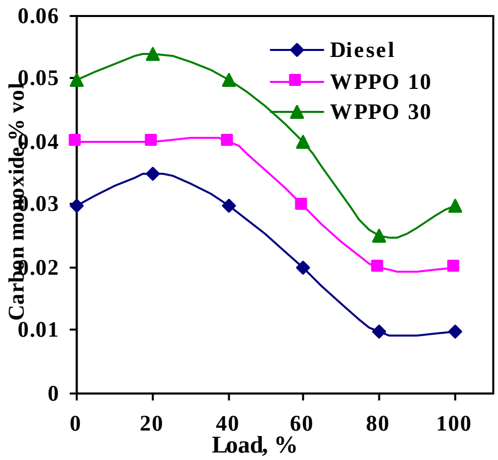



Figure 8 Load against Carbon monoxide

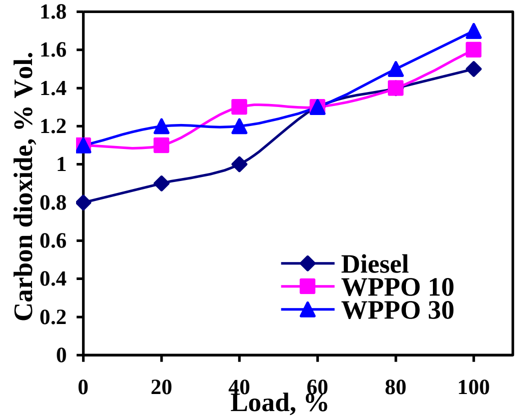



Figure 9 Load against Carbon dioxide

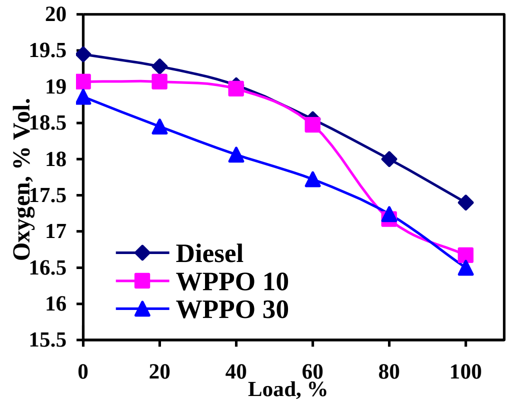



Figure 10 Load against oxygen