Combined Effects of Thermal Barrier Coating and Blending With Diesel Fuel on Usability of Waste Plastic Oil in Diesel Engines

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Abstract - The possibility of using waste plastic pyrolysis oil blends in a thermally insulated diesel engine has been experimentally investigated. Initially, the standard diesel fuel was tested in the engine, as base experiment for comparison. Then the engine was thermally insulated by coating the piston crown exhaust surface with Yttrium - Stabilized Zirconium (YSZ). The main purpose of engine coating was to reduce heat rejection from the walls of combustion chamber and to increase thermal efficiency and thus to increase performance of the engine that using waste plastic pyrolysis oil blends. The experiments were performed using 10%, 20% and 30% waste plastic pyrolysis oil- diesel blends. Waste plastic pyrolysis oil is blended with diesel fuel. Blends and diesel fuel were then tested in the coated diesel engine. Experimental results proved that the main purpose of this study was achieved as the engine performance parameters such as brake thermal efficiency, mechanical efficiency, were increased with simultaneous decrease in fuel consumption. Carbon dioxide and unburned hydrocarbon were higher than that of the diesel baseline. The toxic gas carbon monoxide emission of waste plastic oil was higher than diesel. Smoke reduced by about 10% to 15% in waste plastic oil at all loads.

Keywords: Yttrium – Zriconia coating, Engine performance, Low Heat rejection, CI Engine, Emissions, AVL gas analyzer

I. INTRODUCTION

Waste plastics their disposal creates large problems for the environment. Waste plastics do not biodegrade in landfills, are not easily recycled, and degrade in quality during the recycling process. Instead of biodegradation, plastics waste goes through photo-degradation and turns into plastic dusts which can enter in the food chain and can cause complex health issues to earth habitants. 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% wt of the same is recycled, balance 60% wt is not possible to dispose off. . Plastics are produced from petroleum derivatives and are composed primarily of hydrocarbons but also contain additives such as antioxidants, colorants, and other stabilizers. However, when plastic products are used and discarded, these additives are undesirable from an environmental point of view [1, 2]. **Some fuels can be retrieved from Waste vegetable oil through transesterification process by using bio-diesel processor**. **R.Murali Manohar et al. [ ] investigated the performance and emission characteristics of diesel engine which is fueled with waste vegetable oil**

biodiesel and its blends. Waste management concept, waste management system, biomass and bio-waste resources, waste classification, and waste management methods were reviewed by Demirbas[3] Panda, et.al [4] described that production of liquid fuel from plastic waste would be a better alternative as the calorific value of the plastics is comparable to that of fuels, around 40MJ/kg. This option also reduces waste and conserves natural resources. It was also mentioned that mechanical recycling of plastic wastes is widely adopted method by different countries and the catalytic pyrolysis of plastic to fuel is gradually gaining momentum and being adopted in different countries recently due to its efficiency over other process in all respects.
.Walendziewski [5] carried out two series of waste plastic cracking. The first series of polymer cracking experiments was carried out in a glass reactor at atmospheric pressure and in a temperature range 350-420°C, the second one in autoclaves under hydrogen pressure (~3-5MPa) in temperature range 380-440°C.

They also concluded that the application of catalyst results in lowering of polymers cracking temperature, density of obtained liquid and increased the gas fuel yield.
Siddiqui et al. [6] explored the effects of various conditions such as catalyst type, amount of catalyst, reaction time, pressure and temperature on the product distribution of co processing of waste plastic. The rate of conversion in the coprocessing system depended upon the chemistry and composition of the particular plastic material. The effect of four different catalysts on coprocessing reactions showed that the coprocessing of plastics with residue is affected by catalyst type.
Ali et al. [7] reported that the high yields of liquid fuels in the boiling range 100–480°C and gases were obtained along with a small amount of heavy oils and insoluble material such as gums and coke. The results obtained on the coprocessing of polypropylene with coal and petroleum residues are very encouraging as this method appears to be quite feasible to convert plastic materials into liquefied coal products and to upgrade the petroleum residues and waste plastics.
Miskolczi, et.al [8] investigated the pyrolysis of real waste plastics (high-density polyethylene and polypropylene) in a pilot scale horizontal tube reactor at 520 °C temperature in the presence and absence of ZSM-5 catalyst. It was found that the yields of gases, gasoline and light oil could be increased in the presence of catalyst. They also concluded that the plastic wastes could be converted into gasoline and light oil with yields of 20–48% and 17–36% respectively depending on the used parameters.

Engine coating with a ceramic thermal barrier can be applied to improve reliability and durability of engine performance and efficiency in diesel engines. Because in-combustion chamber temperatures of coated engines are higher than those of uncoated engines, it may be possible to use a fuel with a large distillation range and lower quality fuels such as pure vegetable oils. It was reported that higher temperatures in the combustion
Chamber can also have positive effects on diesel engines due to the drop in self-ignition delay [9,10]. In a conventional diesel engine, about 30% of the total energy is rejected to the coolant and it was reported that the engine coating may be a good solution [11]. Main important advantages of the engine coating concept were reported by Taymaz et al. [12] such as improved fuel economy, reduced hydrocarbon, smoke and carbon monoxide emissions, reduced noise due to lower rate of pressure rise and high energy in the exhaust gases. Thermal barrier coatings are generally applied on the cylinder head, piston and valves by plasma spray method.
Coating these parts with ceramic also limits the negative effects of wear, friction, heating, corrosion and oxidation. It was also reported in a theoretical diesel cycle analysis, that the more the heat transfer decreases, the less energy will be lost, thus the work output and the thermal efficiency increase [13]. In another study, with engine coating an increase in engine power and decrease in specific fuel consumption, as well as significant improvements in exhaust gas emissions and smoke density have been addressed in comparison to the uncoated engine [14].
In the present work, Waste plastic pyrolysis oil is blended with diesel fuel by volumes of 10% Waste plastic pyrolysis oil to 90% diesel fuel (WPPO10),20% Waste plastic pyrolysis oil to 80% diesel fuel (WPPO20) and 30% Waste plastic pyrolysis oil to 70% diesel fuel (WPPO30).
The usability of Waste plastic pyrolysis oil as fuel in a thermally insulated diesel engine coated with Yttrium - Stabilized Zirconium (YSZ) were investigated. Comparisons were made between blends of Waste plastic pyrolysis oil and diesel fuel and in coated and uncoated diesel engines. Besides, the experimental results were fundamentally compared with normal uncoated diesel engine operation with diesel fuel.

II. Atmospheric Plasma Spray technique

The plasma generator consists of a circular anode, usually of copper, and a cathode of thoriated tungsten. The cathode is made of graphite in a water stabilized torch. A strong electric arc is generated between anode and cathode. This ionizes the flowing process gasses into the plasma state. Now, powdered feedstock material is injected into the plasma jet. Plasma jet will melt the material and propel it onto the work piece surface. Atmospheric plasma spraying is carried out using a Sulzer Metco F4 gun operating at power levels up to 50 kW. A gas mixture of hydrogen and argon is used as a plasma gas. The argon gas is also considered as a carrier gas for the feedstock material injection. Compressed air was used as the cooling gas during plasma spraying.

The Plasma spraying parameters and the Comparisons of properties of WPPO with the diesel fuel [15] used in the experiment are illustrated in table 1 and 2.

Table 1: Plasma spraying parameters

Sl. No	**Parameters**	**Value**
1.	Spray gun	3 MB
2.	Nozzle	GH
3.	Current (A)	490
4.	Voltage (V)	60 – 70
5.	Powder feed (g/min)	40-50
6.	Spray distance	76.2 - 127 ± 10 % mm
7.	Particle velocity (m/s)	Up to 450
8.	Arc Temperature (^{0}C)	16,000
9.	Particle size (µm)	14.5 – 45
10.	Inert gas flow rate	
	a.)Argon (l/min)	100– 200 ± 5%
	b.)Hydrogen (l/min)	100 ± 5%

Table 2: Comparisons of properties of WPPO,diesel

Property	WPPO	Diesel
Density @ 30˚C in (g/cc)	0.8355	0.840
Ash content (%)	0.00023	0.045
Gross calorific value (kJ/kg)	44,340	46,500
Kinematic viscosity, cst @ 40˚C	2.52	2.0
Cetane number	51	55
Flash point (˚C)	42	50
Fire point (˚C)	45	56
Carbon residue (%)	82.49	26
Sulphur content (%)	0.030	0.045
Distillation temperature (˚C) @ 85%	344	328
Distillation temperature (˚C) @ 95%	362	340

III. TEST ENGINE

Tests were carried out on a single cylinder, water cooled, direct injection, four stroke stationary diesel engine. Once the steady state condition was reached after loading, the readings such as time taken for 10cc fuel consumption, exhaust gas temperature, HC, CO and NO_x levels were taken. The pollutant emissions such as unburnt hydrocarbon, carbon monoxide, carbon dioxide and oxides of nitrogen concentrations were measured by AVL exhaust gas analyser. The analyser consists of an electrochemical sensor, which converts the concentration of different species in the exhaust gas into corresponding electrical signals. The exhaust gas temperature was measured by smoke meter.

The following Figure shows a photographic view of the Experimental set up. The Technical specifications of the engine used in the experiment are illustrated in table 3.

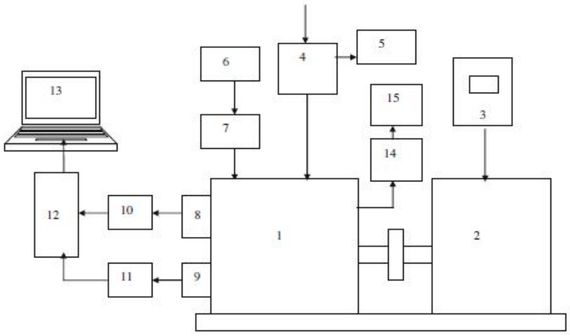

Figure 1: Schematic view of Experimental set-up.

1. Diesel engine
2. Alternator
3. Dynamometer controls
4. Air box
5. U –Tube manometer
6. Fuel tank
7. Fuel measurement flask
8. Pressure pickup
9. TDC position sensor
10. Charge amplifier
11. TDC amplifier circuit
12. A/D card
13. Personal computer
14. Exhaust gas analyzer
15. AVL smoke meter

Figure 2: Uncoated piston and Yttrium – Zirconium coated piston

Table 3: Technical specification of the engine used in the experiments

Engine Type	Vertical, Four stroke diesel engine
Bore Diameter	80 mm
Stroke Length	110 mm
Brake Power	3.728 kW
Compression ratio	16:1
Speed	1500 rpm
Injection Type	Direct Injection
Cooling	Water
Engine Power	5 bhp
No. of cylinder	1
Injection Pressure	210 bar

IV. RESULTS AND DISCUSSION

The performance and Emission characteristics of Yttrium – Zirconium coated piston diesel engine was investigated and compared with standard engine. The results obtained from the experiments conducted on the engine are presented in Figure 3 to Figure 7.

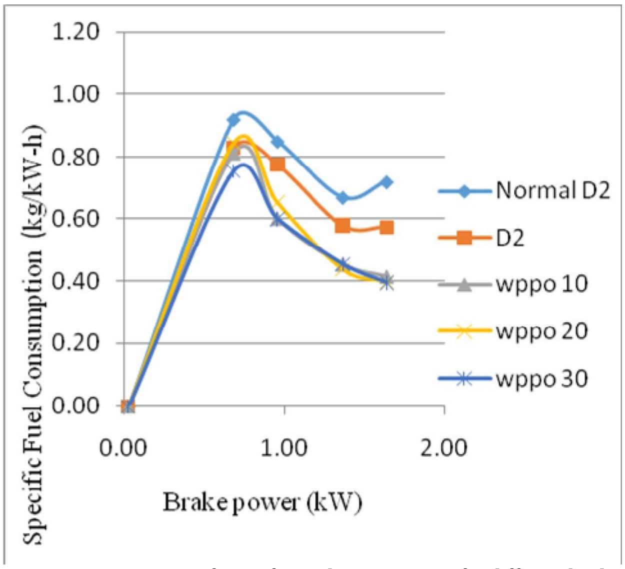

Figure 3: Comparison of Specific Fuel Consumption for different loads.

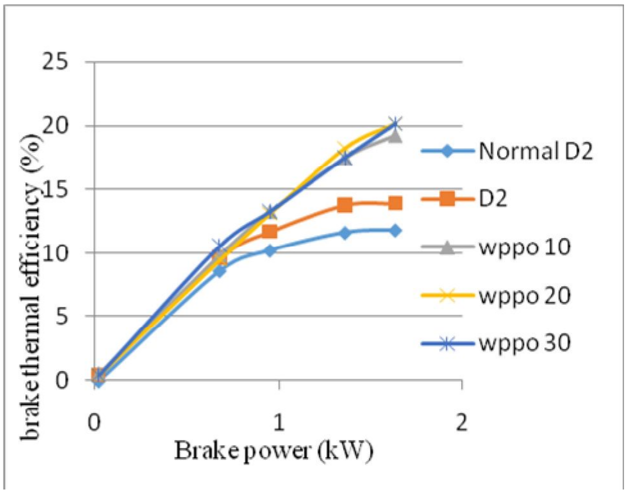

Figure 4: Comparison of Brake Thermal Efficiency for different loads.

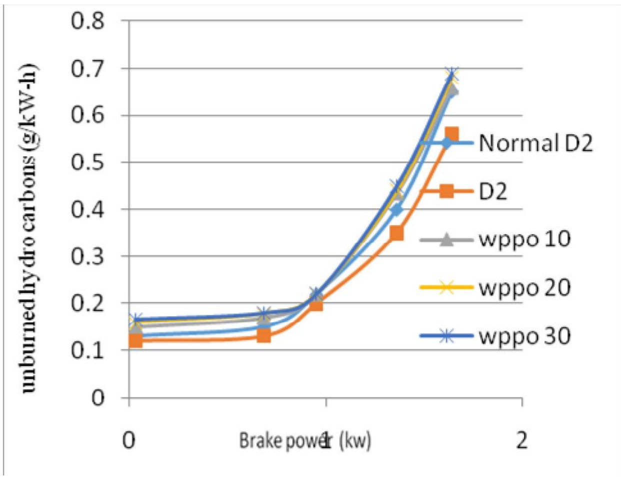

Figure 5: Comparison of Hydrocarbon emission for different loads.

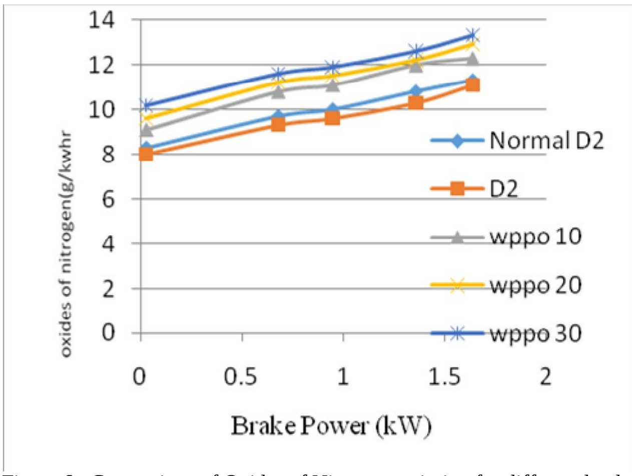

Figure 6: Comparison of Oxides of Nitrogen emission for different loads.

Figure 3 shows the variations of specific fuel consumption of standard engine and compared with Al-Ti and Ni-Cr coated piston crown and cylinder head. The specific fuel consumption is reduced by 16.6% for Al-Ti coating and 9.86% for nickel chromium coating compare to standard engine. Complete combustion of fuel inside the cylinder may reduce the amount of fuel consumed. T. Hejwowski and A. Weroński (2002) stated that specific fuel consumption for a coated engine decreases by 15–20% **[4]**.

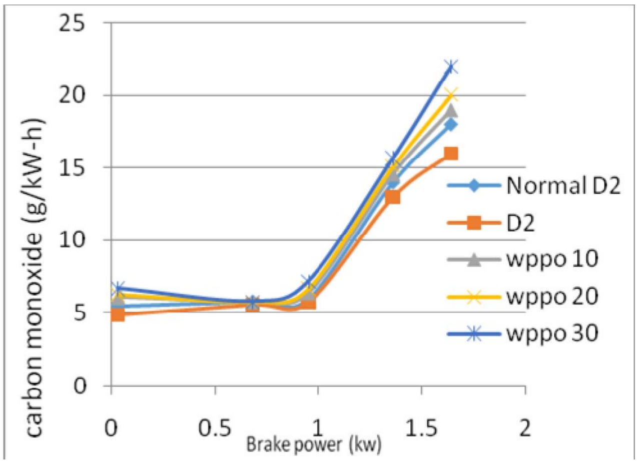

Figure 7: Comparison of carbon monoxide emission for different loads.

The variation of brake thermal efficiency with load for engine operating on Al-Ti and Ni-Cr coated engine and standard engine is shown in figure 4. It is significant that modified engine has higher efficiency than that of base line engine. Reduced thermal loss might be the reason for the improvement in brake thermal efficiency. The maximum brake thermal efficiency obtained for engine operating on Al-Ti coated and standard engine are 20% and 14.26 % respectively. Ilker Turgut Yilmaz (2010) also stated that break thermal efficiency for coated engine improved by 20-25% **[5]**.

Figure 5 shows the comparison of hydrocarbon emission for different loads. Combustion chamber temperature is inversely proportional to HC emission. So HC is slightly more than the conventional diesel engine at low and medium loads and lesser at high loads **[6]**. Modified engine HC emission is lower by around 10 % at full load condition.

Figure 6 indicated the variation of oxides of nitrogen with load for Al-Ti and Ni-Cr coated and standard engine. NO_x is generated mostly from nitrogen present in air and also from fuel. The inherent availability of nitrogen and oxygen in the fuel accelerates the formation of NO_x. NO_x formation is directly proportional to the combustion temperature. In Al-Ti and Ni-Cr coated engine, the NO_x level is reduced by 40 and 20 % respectively. Reduced combustion chamber temperature due to lower fuel consumption might be the reason for lower NO_x levels.

The measured CO emissions for Al-Ti and Ni-Cr coated engine and standard engine are shown in Figure 7. The reduction in CO emission is due to complete combustion and CO emission is slightly more than the conventional and nickel chromium diesel engines at low and medium loads and lesser at high loads.**[6]**

V. CONCLUSION

A conventional contemporary diesel engine is converted into Al-Ti and Ni-Cr coated diesel engine. SFC and emissions were measured for determining the performance and emission characteristics of the engine. The following conclusions can be drawn from the experimental results.

Al-Ti coated diesel engine shows better specific fuel consumption when compared to conventional and Ni-Cr coated diesel engine which is 16.6% lower than the standard engine. NO_x emission from Al- Ti coated engine is lower by 40 % than the standard engine. It is found to be that the value of in brake thermal efficiency is increased after the engine had been coated.

With the results obtained it is clear that the coated engines are optimum for low and medium load conditions and more suitable for high load conditions when compared to standard engine.

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