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Control of Pollutants from Ceramic Coated Diesel Engine with Carbureted Butanol and Plastic Oil

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ABSTRACT

In the context depletion of fossil fuels, ever increases of fuel prices in International market causing economic burden on government of India and ever increases of pollution levels with fossil fuels, the search for alternative fuels has become pertinent. Alcohols and vegetables oils are important substitutes for diesel fuel as they renewable in nature. However, the drawbacks of vegetables oils (high viscosity and low volatility) and alcohols (low energy content and cetane number) call for semi-adiabatic diesel engine (SADE). The high energy content of plastic oil and high volatility of butanol can be taken together in order to have minimum pollution levels. Investigations were carried out to control pollutants of particulate matter measured by AVL Smoke meter, nitrogen oxide (NO_x) levels determined with Gas Analyzer and aldehydes by means of wet-method with single cylinder, four-stroke, water cooled, 3.68 kW, Kirlosker diesel engine with ceramic coated cylinder head with varied injection timing. Butanol was carbureted into the engine through variable jetcarburetor installed at the inlet manifold of the engine at different percentages of crude plastic oil at full load on mass basis. Crude plastic oil was injected through injector in conventional manner. The semi adiabatic diesel engine with carbureted butanol reduced exhaust emissions in comparison with diesel operation on conventional engine.

Key words : *Pollutants, Health Hazards, Concept of SADE, Ceramic coated diesel engine, Diesel, Plastic oil, Alcohol induction, Injection timing*

Introduction

Effect of pollutants on human beings

Particulate matter the major pollutant formed from diesel engine is due to incomplete combustion of fuel. Nitrogen levels are formed due to the availability of oxygen and high temperatures. Aldehydes are intermediate compounds. Inhaling of these pollutants causes asthma, bronchitis, emphysema, slowing down of reflexes, vomiting sensation, dizziness, drowsiness and severe headache. Such pollutants also cause detrimental effects on animal and plant life, besides environmental disorders (Fulekar, 2004). Driving methodology, road layout, traffic density, traffic condition, age and maintenance of the vehicle were some of the reasons for the formation of pollutants (Sharma, 2012).

Concept of Semi-Adiabatic Diesel Engine (SADE)

The concept of SADE is to reduce heat loss to the coolant by providing thermal insulation in the path of heat flow to the coolant. There are two types of SADEs. 1. Ceramic coated diesel engine and 2. Air gap insulated piston engine. The piston was divided into two portions such as the crown and the body of the piston. Crown was made of low thermal conductivity material like superni-90. It was assembled to the body of the piston by means of scuds, or welding or riveting or threading. Screwing or threading was found to be successful attempt to assemble crown and the body of the piston. The gas made of superni-90 material was placed in between the body and the crown, maintaining air gap in between these two components. The two low thermal conductivity of materials of air and superni-90 had resulted in SADE. Nitrogen oxide levels were found to be very high with air gap insulated engines. Partially stabilized zirconium (PSZ) of thickness 500 (optimum thickness as reported by previous researcher) was coated inside portion of cylinder head to form SADE. The degree of insulation is lower with SADE with ceramic coated cylinder head resulting lower NOx levels.

Investigations on SADE with ceramic coating with diesel as fuel

Investigations were conducted on SADE with ceramic coating on inside portion of cylinder head with diesel as fuel. They reported that performance marginally improved, PM marginally reduced and NO_x marginally increased with SADE with ceramic coating on inside potion of cylinder head in comparison with conventional engine (CE) with diesel as fuel (Parlak *et al.*, 2005; Ekrem *et al.*, 2006; Ciniviz *et al.*, 2008).

Investigations on conventional engine with plastic oil as fuel

Investigations were conducted on conventional diesel engine with plastic oil as fuel (Mani Mathuvel *et al.*, 2010). They reported that performance marginally improved, PM increased, and NO_xalso increased with in comparison with conventional engine (CE) with diesel as fuel.

The objective of this research was to study the effect of using waste plastic oil in a diesel engine without any engine modification (Jane Pratoomyod *et al.*, 2013). The engine used in this study is 6 cylinders naturally aspirated 4-stroke diesel engine (Compress Ignition) "Hino Wo6d". In present work , the engine fueled with blends of diesel fuel with plastic oil in the ratio of diesel to waste plastic oil 75:25 (blend25%), 50:50 (blend50%) and 25:75(blend75%) are experimentally measured and analyzed and compared with that of diesel fuel. The test results showed the specific fuel consumption of waste plastic oil blends were higher than diesel fuel. Amount of Carbon dioxide carbon monoxide hydrocarbon and nitrogen oxide from waste plastic oil were higher than diesel operation.

In the present work, plastic pyrolysis oil is manufactured via a fast pyrolysis process using a feedstock consisting of different types of plastic. (Ioannis Kalargaris *et al.*, 2017). The oil was analysed and it was found that its properties are similar to diesel fuel. The plastic pyrolysis oil was tested on a four-cylinder direct injection diesel engine running at various blends of plastic pyrolysis oil and diesel fuel from 0% to 100% at different engine loads from 25% to 100%. The engine combustion characteristics, performance and exhaust emissions were analyzed and compared with diesel fuel operation. The results showed that the engine is able to run on plastic pyrolysis oil at high loads presenting similar performance to diesel while at lower loads the longer ignition delay period causes stability issues. The brake thermal efficiency for plastic pyrolysis oil at full load was slightly lower than diesel, but NO_X emissions were considerably higher. The results suggested that the plastic pyrolysis oil is a promising alternative fuel for certain engine application at certain operation conditions.

With increase in energy expenditure, stringent emission norms, depletion of petroleum fuels and undulate cost of petroleum products in India, it has become vital to use alternative fuels for diesel engines (Sushma, 2018). The energy conversion from waste plastics has been an intelligent way to tackle the environmental pollution problem of waste plastic management in the landfills. Plastics being derived from petrochemical source has higher amount of hydrocarbon which yield oil with high calorific value. In this review, performance combustion and emission characteristics of diesel engine using neat plastic oil, blends of waste plastic oil and additives used with plastic oil as fuels are addressed. It is concluded that it is possible to use plastic oil derived from plastic wastes as an alternative fuel for diesel engines.

A trial has been attempted here to assess the change in properties of PPO (plastic pyrolysis oil) by blending with TiO_2 nanoparticles and also to assess the power output and emission behavior of a mono cylinder CI engine operating on PPO added with the above mentioned additive (Sachuthananthan Bharathi *et al.*, 2019). Initially, the PPO was produced from the discarded waste plastics through the pyrolysis process by thermal cracking. Later, the nanoparticles were dispersed on mass fraction into the PPO using a binding agent with a homogenizer and ultrasonicator. Measurements were done to bring out the change in physiochemical properties of TiO_2-added PPO. Tests were conducted on a diesel engine using diesel, PPO, PPO+25 ppm T_iO_2, PPO+50 ppm T_iO_2, PPO+75 ppm T_iO_2 and PPO+100 ppm T_iO_2 fuel samples. The output reveals that the brake thermal efficiency (BTE) of PPO with 50 ppm T_iO_2 sample combination increased by 2.1% when compared to neat PPO at maximum load situation. The CO, HC and smoke pollutants dropped considerably due to the blending of 50 ppm T_iO_2 to PPO when compared to the other fuel combinations.

Investigations on SADE with plastic oil as fuel

This experimental work analyzes the usage of 100% of Waste Plastic Oil (WPO) in low heat rejection (LHR) diesel engine without diesel (Sivakumar and Bridjesh, 2019). For this purpose, the hardware components of conventional diesel engine were coated with lanthana-doped partially stabilised zirconia, to a thickness about 300 μm by plasma spray coating technique. WPO was produced in a research facility scale setup by pyrolysis method. Coated and uncoated engines were tested with WPO and the outcomes were compared with diesel. Results authenticate the objective of this study and shows enhancement in performance and diminution in specific fuel utilization. The reduction in emission with exception of NO_x was noticed in lanthana-doped partially stabilised zirconia coated engine than that of uncoated diesel engine.

Investigations on conventional diesel engine with butanol blends

The use of alcohols in diesel engines is an alternative way of reducing dependence on diesel fuel. Specifically, higher alcohols such as n-butanol (nB) and 1-pentanol (Pn), which consist of high carbons and can be produced from mainly non-edible sources, can directly be mixed with diesel fuel which in return provides significant promise from economic and environmental stand points (Alpaslan Atmanlý and Nadir Yilmaz, 2018). For this reason, the examination of the use of such high-carbon alcohols in diesel engines has become significantly important in recent years. In this work, six different binary (D-nB and D-Pn) fuel mixtures were obtained by mixing the diesel fuel with n-butanol and 1-pentanol at low and high mixing ratios (5%, 25% and 35% alcohol by volume) and basic fuel properties were examined. The test fuels were tested at four different loads (0, 3, 6 and 9 kW) at a constant engine speed (1800 rpm) in a direct injection diesel engine with diesel as the reference fuel. Fuel properties of the binary fuels were in compliance with the European Norm (EN590) and all of thefuels exhibit a steady phase without any indication of phase separation. Compared to diesel fuel's engine characteristics, brake specific fuel consumption (BSFC) increased by 14.02% in binary blends, resulting in a 7.36% reduction in brake thermal efficiency (BTE). However, exhaust gas temperature (EGT) increased by an average of 47.55%. The addition of 1-pentanol to diesel had a significant impact on the decrease of oxides of nitrogen (NOx) emissions as an average decrease of 14.27% was observed. On the other hand, the higher latent heat of evaporation (LHE) of n-butanol and 1-pentanol had multiple disadvantageous outcomes such as a cooling effect in-cylinder, lower combustion efficiency and slightly higher carbon monoxide (CO) and hydrocarbon (HC) emissions as compared to diesel. The results indicated that the binary blends with 35% alcohol content happened to be a promising alternative for lower NOx emissions at the expense of increasing CO and HC emissions. Overall, it is concluded that n-butanol and 1-pentanol blends can be safely used in diesel engines without any engine modification or any additive.

Investigations on carbureted alcohol with ceramic coated diesel engine

Experiments were conducted to study particulate emissions and nitrogen oxide (NO_x) levels with varied brake mean effective pressure of the engine and aldehydes (formaldehyde and acetaldehyde) at full load operation of the engine with LHR combustion chamber consisting of ceramic coated combustion chamber with mixture of carbureted alcohol and injected crude vegetable oil, with varied injector opening pressure and injection timing (Muralikrishna *et al.,* 2015). Aldehydes were measured by 2,4, dinitrophenyl hydrazine (DNPH) method. Alcohol (ethanol/methanol) was inducted through a variable jet carburetor, installed at the inlet manifold of the engine at different percentage of jatropha oil at full load operation during suction stroke and crude jatropha oil was injected at near end of compression stroke. The maximum induction of alcohol was 50%

at recommended injection timing (27°bTDC, [before top dead centre]), while it was 45% at optimum injection timing (31°bTDC) with engine with LHR combustion chamber. Comparative studies were made with conventional engine (CE) and engine with LHR combustion chamber with pure jatropha oil operation and diesel operation at similar operating conditions.

Variation of injection timing

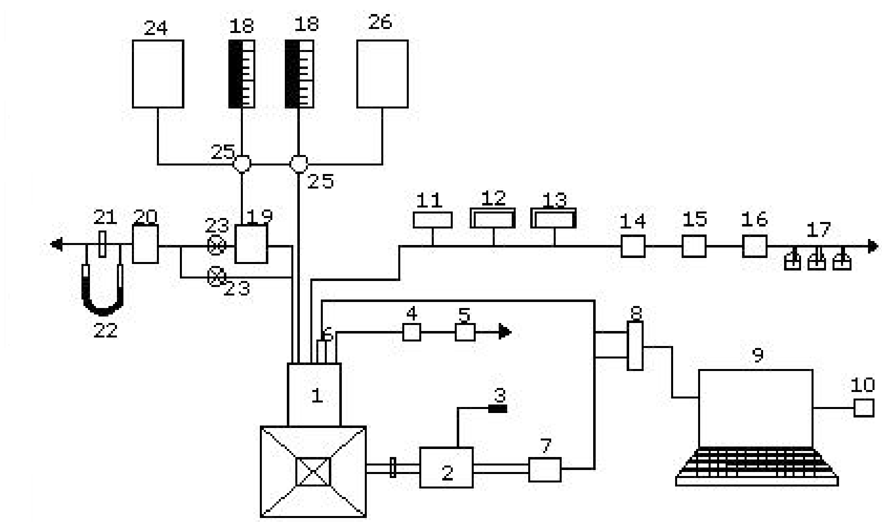
Performance of the conventional engine increased with advanced injection timing with test fuels. Particulate emissions decreased, while NO_x levels increased with advanced injection timing. (Chandrakasan Solaimuthu and Palani Swamy Govindaraju, 2012; Venkateswara Rao *et al.*, 2013.a; Venkateswara Rao *et al.*, 2013.b.)

Little reports are available on control of pollutants from semi adiabatic diesel engine with ceramic coated cylinder head with carbureted butanol with varied injection timing with injected plastic oil. Hence the authors have made an attempt to work in this direction.

Materials and Methods

Experimental Set up: The schematic diagram of the experimental setup used to study exhaust emissions from the engine with LHR combustion chamber with jatropha oil and carbureted alcohol is shown in Fig.1.

Engine with low grade LHR combustion chamber consisted of cylinder head coated with partially stabilized zirconium (PSZ) of thickness 500 microns with spray coating [11]. The experimental engine was single–cylinder, four–stroke, water–cooled compression ignition engine with brake power 3.68 k W at a speed of 1500 rpm. It had an aluminum alloy piston with a bore of 80 mm and a stroke of 110 mm. The compression ratio was 16:1 and manufacturer's recommended injection timing and injector opening pressure were 27°bTDC and 190 bar. The fuel injector had 3 holes of size 0.25 mm. The combustion chamber consisted of a direct injection type with no special arrangement for swirling motion of air. The engine was connected to an electric dynamometer for measuring its brake power. Dynamometer was loaded by a loading rheostat. Brake power at different percentages of load was calculated by knowing the values of the output signals (voltmeter reading and ammeter reading) of dynamometer and speed of the engine. The accuracy of engine load is ±0.2 kW. The speed of the engine was measured with digital tachometer with accuracy ±1%.Burette method was used for finding fuel consumption of the engine (Burette, stop watch, density of fuel).



1. Engine, 2. Electical Dynamometer, 3.Load Box, 4. Outlet jacket water temperature indicator, 5. Outlet-jacket water flow meter Orifice meter, 6. Piezo-electric pressure transducer, 7. TDC encoder 8.Console, 9. Pentium Personal Computer, 10. Printer, 11. Exhaust gas temperature indicator, 12. AVL Smoke meter, 13. Netel Chromatograph NOx Analyzer, 14. Filter, 15.Rotometer, 16. Hetaer, 17. Round bottom flask containing DNPH solution, 18.Burette, 19. Variable jet carburetor, 20.Air box, 21. Orifice meter, 22. U-tube water manometer, 23. Bypass valve, 24. Butanol tank, 25. Three-way valve, 26 Waste Plastic oil tank.

Fig. 1. Schematic diagram of experimental set–up

Density of fuel was found out using hydrometer. The accuracy of determination of brake thermal efficiency obtained is ±2%. Air consumption of the engine was measured by air-box method (Air–box, orifice meter, U–tube water manometer). Diaphragm was provided with air–box to reduce pressure pulsations of the engine. The naturally aspirated engine was provided with water–cooling system in which outlet temperature of water was maintained at 80°C by adjusting the water flow rate. Engine oil was provided with a pressure feed system. No temperature control was incorporated, for measuring the lube oil temperature. Injection timing is varied by means of electronic sensor and its effect on the performance of the engine was studied, along with the change of injector opening pressures from 190 bar to 270 bar (in steps of 40 bar) using nozzle testing device. The maximum injector opening pressure was restricted to 270 bar due to practical difficulties involved.

Butanol was inducted through a variable carburetor jet, located at the inlet manifold of the engine at different percentages of plastic oil at full load operation by mass basis and crude waste plastic oil (WPO) was injected in conventional manner. Two separate fuel tanks and burette arrangements were made for measuring crude plastic oil and butanol consumptions.

Measurement of Exhaust Emissions

Exhaust emissions of particulate matter and NO_x were recorded by AVL smoke meter and Netel Chromatograph NO_x analyzer at various values of brake mean effective pressure of the engine.

With carbureted alcohol–plastic oil operation, the major pollutant emitted from the engine is aldehydes. These aldehydes are carcinogenic in nature, which are harmful to human beings. The measure of the aldehydes is not sufficiently reported in the literature. DNPH method was employed for measuring aldehydes in the experimentation (Venkateswara Rao *et al.,* 2013b). The exhaust of engine was purified by means of filter and measured quantity (2 l/m) was sent through rotometer. The exhaust of the engine was heated up to 140°C by means of heater provided in the circuit. The exhaust of the engine was bubbled through dinitrophenyl hydrazine (2,4 DNPH) solution. The hydrazones formed were extracted into chloroform and were analyzed by employing high performance liquid chromatography (HPLC) to find the percentage concentration of formaldehyde and acetaldehyde in the exhaust of the engine. The advantage of this method was determination of both formaldehyde concentration and acetaldehyde concentration simultaneously in the exhaust of the engine.

Test Fuels

Plastic oil

The present work involves the synthesis of a petroleum-based fuel by the catalytic pyrolysis of waste plastics (Christine Cleetus *et al.,* 2013). Catalytic pyrolysis involves the degradation of the polymeric materials by heating them in the absence of oxygen and in the presence of a catalyst. In the present study different oil samples are produced using different catalysts under different reaction conditions from waste plastics. The synthesized oil samples are subjected to a parametric study based on the oil yield, selectivity of the oil, fuel properties, and reaction temperature. Depending on the results from the above study, an optimization of the catalyst and reaction conditions was done. Gas chromatography-mass spectrometry of the selected optimized sample was done to find out its chemical composition. Finally, performance analysis of the selected oil sample was carried out on a compression ignition (CI) engine. Polythene bags are selected as the source of waste plastics. The catalysts used for the study include silica, alumina, Y zeolite, barium carbonate, zeolite, and their combinations. The pyrolysis reaction was carried at polymer to catalyst ratio of 10:1. The reaction temperature ranges between 400 °C and 550 °C. The inert atmosphere for the pyrolysis was provided by using nitrogen as a carrier gas.

Preparation of Butanol

Alcohol can be produced from organic materials such as grains, fruit, wood and even municipal solid wastes and waste or specifically grown biomass. The municipal solid wastes can be converted to alcohol. The wastes are first shredded and then passed under a magnet to remove ferrous materials. The iron free wastes are then gasified with oxygen. The product synthesis gas is cleaned by water scrubbing and other means to remove any particulates, entrained oils, H_2S and CO_2. CO shift conversion for $H_2/CO/CO_2$ ratio adjustment, synthesis, and alcohol purification are accomplished. Alcohol (ethanol and methanol) is renewable in nature. It has oxygen in their molecular composition. It has a low C/H. It has low stoichiometric air–fuel ratio. Therefore, carbureted alcohol can be effectively used in compression ignition engine.

The properties of the diesel, plastic oil and butanol used in this work are presented in Table 1 and Table 2.

Results and Discussion

Fig. 2 shows the variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) of the engine with percentage variation of butanol in conventional engine (CE).

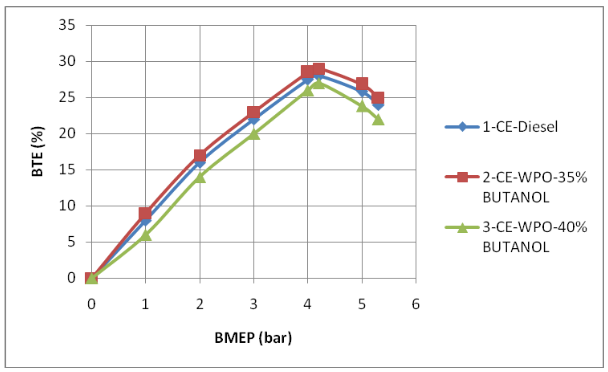


Fig. 2. Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in conventional engine (CE).

BTE increased up to 80% of the full load and beyond that it decreased in CE. Increase of fuel conversion efficiency, mechanical efficiency and air fuel ratio up to 80% the load increased BTE. Decrease of the same parameters beyond 80% of the full the performance of the engine deteriorated leading to reduce the BTE of the engine. BTE increased with increase of butanol induction in CE. Decrease of dissociation losses, increase of ratio of specific heats and homogeneity of mixture due to high volatility of the Butanol increased BTE of the engine. The maximum induction of butanol was found to be 35% of the total mass of waste plastic oil at full load. Beyond 35% of butanol induction, BTE reduced as there was drop of combustion temperatures due to high latent heat of butanol. Hence the maximum induction of butanol was found to be 35% at 27^{o}bTDC (before top dead centre).

The injection timing was varied with electronic sensors. Performance test or load test was conducted with CE. The optimum injection timing was found to be 32^{o}bTDC with CE. The optimum injection timing was the timing at which maximum BTE was obtained. At optimum injection timing, the maximum induction of butanol was also found to be 35%.

Fig. 3 shows the variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) of the engine with percentage variation of butanol in semi adiabatic diesel engine (SADE). The curve followed the similar trends with CE. However, the maximum induction of butanol was found to be 45%. Since there was hot environment in SADE, more amount of butanol was absorbed by the engine at recommended injection timing. BTE was found to be higher with SADE with butanol induction. High heat release rate, faster rate of combustion and reduction of coolant loss increased BTE of the SADE with butanol induction. The optimum injection timing with SADE with butanol induction was

Table 1. Properties of Waste Plastic oil (WPO)

Property	Test Method	Diesel	WPO
Density (kg/m^3) at 15 ^{o}C.	ASTM D1298	834	823
Kinematic viscosityat 40 ^{o}C. (cSt)	ASTM D 445	3.44	3.11
Flash Point (^{o}C))	ASTM D 93	66	54
Cetane Number	ASTM D976	56	46

Table 2. Properties of Waste Plastic oil (WPO)

Property	Test Method	Diesel	Butanol
Density (kg/m^3) at 15 ^{o}C.	ASTM D1298	834	800
Latent heat of evaporation (kJ/kg)		256	596
Cetane Number	ASTM D976	56	10
Gross Calorific value (MJ/kg)	ASTM D240	45.5	36.7

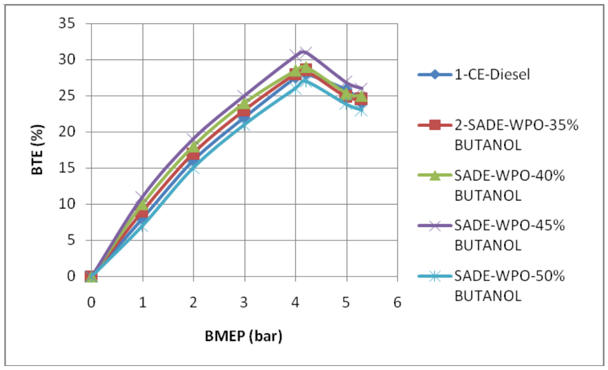


Fig. 3. Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in semi adiabatic diesel engine (SADE).

found to be 31°b TDC. Since the combustion chamber was hot, it permitted less injection timing advance with SADE with butanol induction.

Fig. 4 shows the variation of particulate matter (PM) with brake mean effective pressure (BMEP) of the different versions of the engine at recommended injection timing (RIT) and optimum injection timing (OIT) with test fuels. Particulate are more or less constant and low at no load or part load with different version of the engine at recommended injection timing (RIT) and optimum injection timing (OIT). Air fuel ratios are very high at no load or part load and hence particulate matter is less. However, beyond 80% of the full load, particulate emissions drastically increased with both versions of the engine at RIT and OIT. Deterioration of thermal efficiency, fuel conversion efficiency and volumetric efficiency beyond 80% of the full load increased particulate emissions. Particulate emissions decreased with butanol induction with both versions of the engine at different injection timings .Butanol has got oxygen in its molecular composition, which improved the combustion and reduced particulate matter. Particulate emissions decreased with increased injection advance with both version of the engine. Increased atomization of the fuel and more time available for the fuel to react with oxygen decreased particulate emissions.

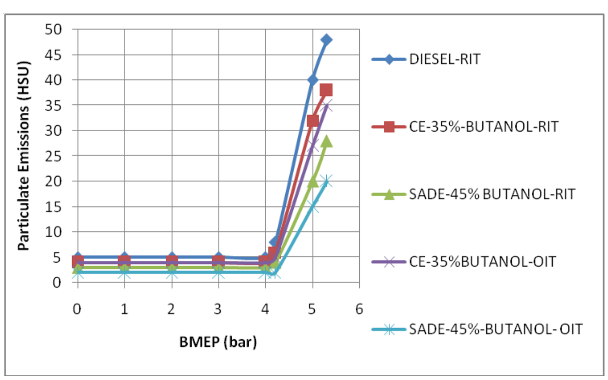


Fig. 4. Variation of particulate matter with brake mean effective pressure (BMEP)

SADE decreased particulate emissions than CE at different injection timings. Improved heat release rate and faster rate of combustion improved combustion and thus reduced particulate emissions.

Fig. 5 shows the variation of nitrogen oxide (NO_x) levels with brake mean effective pressure (BMEP) of the different versions of the engine at recommended injection timing (RIT) and optimum injection timing (OIT) with test fuels. NO_x emissions increased with an increase of BMEP of the engine with both versions of the engine at RIT and OIT. Increase of combustion temperatures due to increase of fuel consumption increased NO_x levels with both versions of the engine at RIT and OIT. SADE increased NO_x emissions in comparison with CE at RIT and OIT. Increased heat release rate and faster rate of combustion with SADE increased combustion temperatures and hence NO_x. Induction of butanol decreased NO_x levels with both versions of the engine with absorption of combustion temperatures due to high latent heat of butanol. Increased injection advance increased NO_x levels with CE, while it decreased the same with SADE. Increase of gas temperatures due to increased resident time with CE

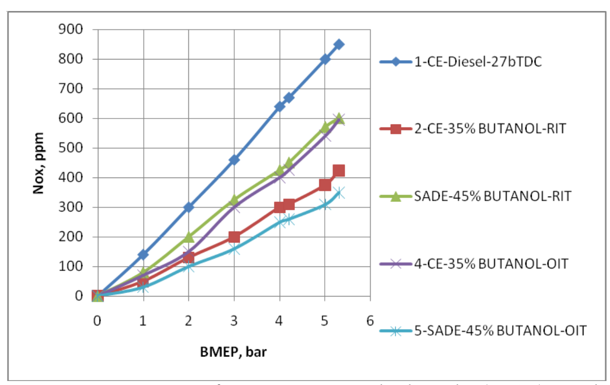


Fig. 5. Variation of nitrogen oxide levels (NO_x) with brake mean effective pressure (BMEP)

increased NO_x levels. Decrease of combustion temperatures with improved combustion with SADE decreased NO_x levels.

Fig. 6 presents bar chart showing the variation of formaldehyde levels at full load operation with both versions of the engine at recommended injection timing (RIT) and optimum injection timing (OIT).

Formaldehyde emissions increased with butanol induction with both versions of the engine at RIT and OIT. Low combustion temperatures with induction of butanol increased intermediate compounds causing to increase formaldehyde emissions. However, formaldehyde emissions were lower with SADE in comparison with CE at different injection timings. Increased heat release rate and faster rate of combustion reduced intermediate compounds, aldehydes with SADE. Increased injection timing advance with both versions of the engine reduced formaldehyde emissions due to increased atomization characteristics of the fuel.

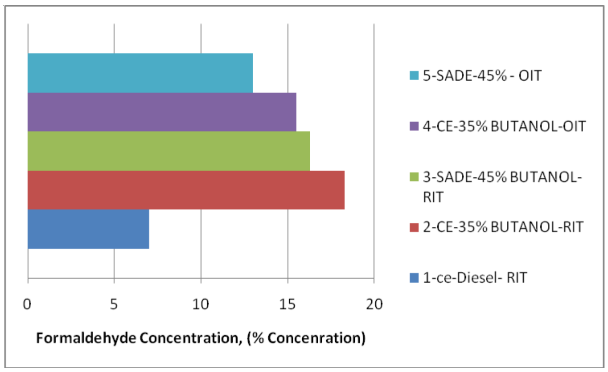


Fig. 6. Bar charts representing the variation of formaldehyde levels at full load operation.

Fig. 7 presents bar chart showing the variation of acetaldehyde levels at full load operation with both versions of the engine at recommended injection timing (RIT) and optimum injection timing (OIT). The advantage of wet method of measuring aldehyde levels is it can measure both formaldehyde and acetaldehyde levels. The Acetaldehyde levels followed similar trends with formaldehyde levels at RIT and OIT with both versions of the engine with test fuels. However, the values of acetaldehyde concentration were higher than formaldehyde concentration, as the number of carbon atoms present in butanol is more than one.

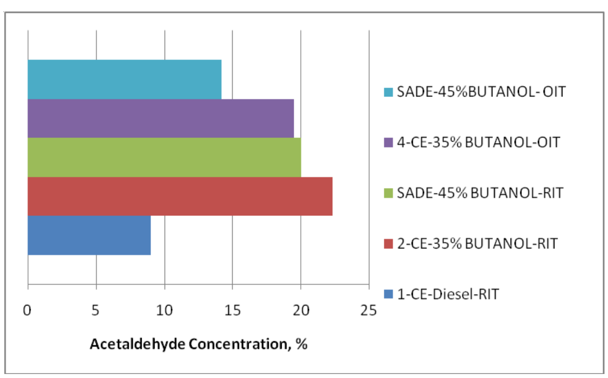


Fig. 7. Bar charts representing the variation of acetaldehyde levels at full load operation

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References

Alpaslan Atmanlý and Nadir Yilmaz, 2018. A comparative analysis of n-butanol/diesel and 1-pentanol/diesel blends in a compression ignition engine. *Fuel.* 234 : 161-169.

Chandrakasan Solaimuthu and Palani Swamy Govindaraju, 2012. Effect of injection timing on performance, combustion and emission characteristics of diesel engine using mahua oil methyl ester. *Journal of Scientific and Industrial Research.* 71 : 69-74.

Christine Cleetus, Shijo Thomas and Soney Varghese, 2013. Synthesis of Petroleum-Based Fuel from Waste Plastics and Performance Analysis in a CI Engine. *Journal of Energy*. 2013, Article ID 608797.

Ciniviz, M., Hasimoglu, C., Sahin, F. and Salman, M. S. 2008. Impact of thermal barrier coating application on the performance and emissions of a turbocharged diesel engine. *Proceedings of The Institution of Mechanical Engineers Part D-Journal of Automobile Engineering,* 222 (D12) : 2447–2455.

Ekrem, B., Tahsin, E. and Muhammet, C. 2006. Effects of thermal barrier coating on gas emissions and performance of a LHR engine with different injection timings and valve adjustments. *Journal of Energy Conversion and Management.* 47 : 1298-1310.

Fulekar, M.H. 2004. Chemical pollution – a threat to human life. *Indian J Environmental Protection.* 1: 353-359.

Ioannis Kalargaris, Guohong Tian and Sai Gu, 2017. Combustion, performance and emission analysis of a DI diesel engine using plastic pyrolysis oil. *Fuel Processing Technology.* 157 : 108-115.

Jane Pratoomyod, Ing Krongkaew and Laohalidanond, 2013. Performance and Emission Evaluation of Blends of Diesel fuel with Waste Plastic Oil in a Diesel Engine *International Journal of Engineering Science and Innovative Technology.* 2 (2).

Mani Mathuvel, Nagarajan Govindan and Shobana Sampath, 2010. An experimental investigation on a DI diesel engine using waste plastic oil with exhaust gas recirculation. *Fuel.* 89 (8) : 1826-1832.

Murali Krishna, M.V.S., Ohm Prakash, T., Usha Sri, P., Janardhan, N. and Krishna Murthy, P.V. 2015. Experimental *Investigations on direct injection diesel engine with ceramic coated combustion chamber with carbureted alcohols and crude jatropha oil, Renewable and Sustainable Energy Reviews.* 53 : 606–628.

Parlak, A., Yasar, H. and ldogan, O. 2005. The effect of thermal barrier coating on a turbocharged Diesel engine performance and exergy potential of the exhaust gas. *Energy Conversion and Management*. 8904, 46(3): 489–499.

Sushma, P. 2018. Waste plastic oil as an alternative fuel for diesel engine – A Review. *IOP Conference Series. Materials Science and Engine*erin. 455.

Sachuthananthan Bharathi, Balaji Gnanasikamani and Krupakaran Radhakrishnan Lawrence, 2019. Investigation on the use of plastic pyrolysis oil as alternate fuel in a direct injection diesel engine with titanium oxide nano-additive *Environmental Science and Pollution Research*. 26 : 10319-10332.

Sharma, B.K. 2012. *Engineering Chemistry*, Pragathi Prakashan (P) Ltd, Meerut. 150-160.

Sivakumar Ellappan and Bridjesh Pappula, 2019. Utilization of unattended waste plastic oil as fuel in low heat rejection diesel engine. *Sustainable Environmental Research.* 29.

Venkateswara Rao, N., Murali Krishna, M.V.S. and Murthy, P.V.K. 2013a. Effect of injector opening pressure and injection timing on performance parameters of high grade low heat rejection diesel engine with tobacco seed oil based biodiesel. *International Journal of Current Engineering & Technology.* 3(4) : 1401-1411.

Venkateswara Rao, N., Murali Krishna, M.V.S. and Murthy, P.V.K. 2013b. Effect of injector opening pressure and injection timing on exhaust emissions and combustion characteristics of high grade low heat rejection diesel engine with tobacco seed oil based biodiesel. *International Journal of Recent Technology and Engineering.* 2 (4) : 70-79.