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Investigation on environmental factors of waste plastics into oil and its emulsion to control the emission in DI diesel engine

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ABSTRACT

Rapid depletion of conventional fossil fuel resources, their rising prices and environmental issues are the major concern of alternative fuels. On the other hand waste plastics cause a very serious environmental dispute because of their disposal problems. Waste plastics are one of the promising factors for fuel production because of their high heat of combustion and their increasing availability in local communities. In this study, waste plastic oil (WPO) is tested in DI diesel engine to evaluate its performance and emission characteristics. Results showed that oxides of nitrogen (NO_x) emission get increased with WPO when compared to diesel oil. Further, the three phase (O/W/O) plastic oil emulsion is prepared with an aid of ultrasonicater according to the %v (10, 20 & 30). Results expose that brake thermal efficiency (BTE) is found to be increased. NO_x and smoke emissions were reduced up to 247 ppm and 41% respectively, when compared to diesel at full load condition with use of 30% emulsified WPO.

1. Introduction

Alternate fuels provide a huge supporting channel for depleting conventional fossil fuel resources. The present technology depends on a sustainable product in replacing the fossil products such as coal, petrol, diesel, etc. Bender (2000). Plastic usage has become a crucial part in today's world, because of their light weight durability, faster rate of production and design flexibility. Discarding of the waste plastics create an enormous risk to the surroundings. It takes nearly 8 years for degrading the waste plastic resources. Increasing quantity of waste plastic adversely pollutes the environment. Plastics are filtered from petroleum derivatives containing hydrocarbons, anti-oxidants and other stabilizers. These materials affect the human beings and animals to a larger extent (Williams and Williams, 1990). Nearly 2.7 million tons of plastics are recycled every year. As in India, the usage of indispensable plastics has witnessed approximately 8 million tons in the year 2008 and it is expected to grow significantly by a factor of 6 within the year of 2030. The disposable plastic wastes are increasing relatively faster than the consumption of plastics because of their increase in usage for sustainable life and the lower recycling rates (Naik et al., 2010). Land filling is not a suitable option for disposing plastic wastes because of their slow degradation rates. The use of incinerator generates some pollutants to the air, which also cause environmental issues. Therefore, recycling and recovering methods have been used to minimize the environmental impacts and to reduce the damage of plastic wastes. Aguado et al., (2007) Because of the existing after effects of the waste plastics, these materials can be transformed into an alternate fuel with the aid of conversion processes like thermal cracking and catalytic pyrolysis cracking methods (Al-Salem et al., 2009; Walendziewski, 2002). Diesel engines are the most preferred power plants due to their excellent drive ability and higher thermal efficiency. From the last few decades strict emission norms are followed to cut back the environmental pollutions. The major pollutant of diesel engine is NO_x which affects human health and environment adversely. Investigation on alternate fuel is enhanced in recent years because of the depletion of available fuel resources and increase in production of automotive vehicles. Recent works have been conducted in diesel engine with use of WPO and the results shows that NO_x emission is found to be increased; with reduction in brake thermal efficiency when compared to diesel (Mani et al., 2009).

1.1. Emulsified oil as an alternate fuel for diesel engine

Water and oil are immiscible, but with the help of mechanical stirring, magnetic or ultrasonic vibrator, these two substances can be temporarily dissolved together. The use of a suitable surfactant

Abbreviations: PW10, Plastic oil+water10%+Surfactants; PW20, Plastic oil+water20%+Surfactants; PW30, Plastic oil+water30%+Surfactants

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can further reduce the surface tension between water and oil, leading to the formation of an emulsion (Lin and Wang, 2003). Ultrasonic homogenizing is the most commonly used technique for emulsion preparation in the industry sectors. The emission of NO_x, CO and PM are reduced using the emulsified fuels instead of neat diesel (Nadeem et al., 2006). This work aims the use of emulsified waste plastic oil as an alternate fuel for single cylinder DI diesel engine to analyze the performance and emission characteristics.

2. Methodology

2.1. Pyrolysis process

Pyrolysis is a thermal degradation process in the absence of oxygen, performed to obtain WPO by using silica alumina as a catalyst. Different sizes and shapes of waste plastics are collected and crushed with shredder for ease of handling the process. The fine crushed plastic particles are fed in a reactor chamber. The copper coil placed around the chamber is heated and maintained at a temperature range of 320 °C–500 °C for 3–4 h duration. At this high temperature, waste plastic gets vaporized and passes through the condenser devices. Because of the cold water present inside the condenser, latent heat transfer occurs by condensing the waste plastic vapour (Guntur et al., 2011; Hariharan et al., 2013).Condensed waste plastic vapour is then stored in the oil collector in the form of plastic oil. From the pyrolysis treatment the following output products were collected: Waste Plastic Oil – 75% to 90%, Gas – 5% to 20% and Residual coke – 5% to 10%.

2.2. Prepared the waste plastic oil emulsion

For the emulsification method of ultrasonic vibration, an ultrasonically vibrating tank with a capacity of 500 ml is used to prepare two-phase and three-phase emulsions. The vibrating frequency and the input power of the ultrasonic waves are set to be 25 kHz and 650 W, respectively. The proportion of Span 80 and Tween 80 emulsifier is selected based on the HLB value required for a three phase O/W/O emulsion. The two-stage emulsification technique is applied to produce the O/W/O emulsions. In the first stage, the two-phase O/W emulsion is produced with aid of Tween 80. In the second stage, the WPO is mixed with Span 80 and dispense into the ultrasonically vibrating tank. The O/W emulsion is then fed into the tank and ultrasonically vibrated together with the mixture of WPO and Span 80 (Lin and Chen, 2006). Three different emulsions are prepared to test a diesel engine.

1. Waste Plastic oil 88%, water 10% and surfactant 2% (span-1% and Tween-1%)
2. Waste Plastic oil 78%, water 20% and surfactant 2% (span-1% and Tween-1%)
3. Waste Plastic oil 68%, water 30% and surfactant 2% (span-1% and Tween-1%)

2.3. Properties of fuels

The properties of diesel, WPO and their emulsion are tested based on IS and ASTM standards. Density of pyrolysis plastic oil is 845 kg/m^3 and its density increases with water emulsification as follows: PW10, PW20, PW30 is 908 kg/m^3, 915 kg/m^3 and 926 kg/m^3 respectively. Viscosity of the WPO is 3.254cSt and its viscosity increases with emulsified water as follows: PW10, PW20, PW30 is 3.36cSt, 3.61cSt and 4.27cSt. Flash point decreases by 9 °C for WPO as compared to diesel and in case of emulsified plastic oil. It is found to be increased by 10–25 °C compared with WPO. Fire point of WPO decreases by 7 °C when compared to diesel while the fire point of emulsified plastic oil increases by 9–23 °C.

3. Experimental setup

An experimental setup of 4.4 kW single cylinder air cooled direct injection diesel engine. U-tube pressure gauge is fitted with anti-pulsating drum to observe the mass flow rate. A specification of the test engine is shown in Table 1. AVL software is used for combustion analysis and DAQ card placed in between the computer and the engine converts the analog signal into digital value. AVL365C angle encoder is attached to the engine measures the crank angles for different piston positions. AVL Pressure transducer GH14D is used to indicate the pressure level in the combustion chamber. K-2 type thermo couple is used to measure the exhaust gas temperature (EGT). Test engine coupled with electrical dynamometer to apply load on the engine. Electrical Dynamometer consists of electrical power bank which applies 0%, 25%, 50%, 75%, 100% loads on an engine and it is controlled with the aid of ammeter and voltmeter. Engine is connected with the computer to record and analyze the output data. The combustion parameters such as cylinder pressure, instant heat release rate and ignition delay are evaluated. AVL DiGas 444 exhaust gas analyzer is used to measure engine emissions such as NO_x, unburnt hydro carbon (UBHC), carbon monoxide (CO) and Carbon dioxide (CO_2). Smoke opacity of the exhaust gas is measured with the use of AVL 437C smoke meter.

4. Error analysis

Error analysis is performed to identify the accuracy of the measuring instruments. Errors can occur due to many factors which include environmental conditions, calibration, observation, instruments and test planning. The percentage uncertainties of NO_x, HC, CO, CO_2, O_2, EGT and smoke opacity.

Percentage of uncertainties present in experiments is

= square root of ((uncertainty of pressure transducer)^2+(uncertainty of angle encoder)^2+(uncertainty of NO_x)^2+(Uncertainty of HC)^2+(uncertainty of CO)^2+(uncertainty of CO_2)^2+(uncertainty of O_2)^2+(uncertainty of smoke opacity)^2+(uncertainty of K-2 thermocouple)^2+(uncertainty of stop watch)^2+(uncertainty of manometer)^2+(uncertainty of burette)^2)

=square root of $((0.01)^2+(0.2)^2+(0.2)^2+(0.2)^2+(0.3)^2+(0.2)^2+(0.3)^2+(1)^2+(0.2)^2+(0.2)^2+(2)^2+(1.5)^2)$=square root of $(7.6701)=\pm 2.769\%$.

Table 1
Single cylinder DI diesel engine specifications.

Particulars	Specifications
Name of the manufacturer	Kirloskar TAF-1
Bore and stroke	87.5 mm, 110 mm
Number of cylinder	1
Rated speed	1500 rpm
Rated Brake power	4.4 kW
Displacement volume	661.45 cc
Cooling system	Air-cooled
Compression ratio	17.5:1
Nozzle opening pressure	200 bar
Injection timing	23° bTDC