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Experimental investigation of Waste Transformer Oil as alternative Fuel in a DI Diesel Engine

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Abstract— *This paper reports on the Waste transformer oil fuel is blended with diesel fuel in different percentage and the effects of their operational characteristics and performance and emission characteristics of the DI diesel engine. In this study, the tested fuels were obtained through catalytic cracking process. Experimental results showed that the flash points and cetane number of the WTO blended diesel have increased with higher concentration of WTO. Based on the experimental results, HC, CO and NOx emissions noticeably decrease, while smoke emissions dramatically increase with increasing the dosing level of WTO. At the full load, the magnitude of HC, CO and NOx emissions for the neat diesel was 120 ppm, 0.36 (%by volume) and 1130ppm, whereas it was 68 ppm, 0.17 (%by volume) and 410ppm for the WTO20 fuel, respectively. The results also showed a significant enhancement in brake thermal efficiency and heat release rate due to the influence of the WTO20 in diesel blend.*

Keywords— Waste transformer oil (WTO), catalytic cracking, Performance, Emissions.

I. INTRODUCTION

The energy available in waste products can be used in a better way, which are being discharged. By doing so, not only the fuel costs 80% of waste products depending upon feedstock costs, considering the fact, can be disposed effectively but also can be used to reduce the overall fuel costs. In this regard, many researchers, have focused on raw materials for alternative fuels such waste lubricating oil, plastic oil, tire pyrolysis oil, waste cooking oil, waste cashew nut shell liquid, linseed oil, municipal waste and olive mill As waste is focused on the use of various waste sources, production and use in a diesel engine. In addition, it recently by some researchers as a source of fuel in a diesel engine in the WTO (used transformer oil) is also noteworthy to point out the effective use [1]. Mainly additional functions in addition to cooling the transformer, for insulating purposes, filled power transformers - during a period of time, petroleum-based mineral oil has been used in liquid. Several transformers are located in populated areas and shopping centers, and long-term use of transformer oil in an electric transformer for insulating purposes makes it ineligible, its Physio-chemical characteristics which are due some changes. Serious spills occur; it can contaminate the soil and waterways, because so, after being used up, power stations and transformers located throughout the country with a large number of fast disposals of WTO are becoming increasingly complex. Therefore, government regulatory agents are already looking into this problem and are imposing penalties for spills. Interestingly, the electrical insulating oil used in transformers is complex blends of hydrocarbons over 3000 and essentially highly aliphatic, Naphthenic Paraffinic crude or are branched. WTO and effectively, researchers have a viable alternative fuel for diesel engine applications have begun to see it as an attempt to dispose of the waste product in view of the fuel characteristics [2-4]. The extent of fossil fuel reserves and the huge rise in fuel prices possible alternative fuels for internal combustion engines has resulted in a continuous search. They are widely used for many applications as the compression ignition engine (CI) to find suitable alternative fuels is very special. For over 100 years, the petroleum-based mineral oil has been used in liquid-filled electric transformers. Power or electrical transformer small, medium and large power transformers of power stations and distribution stations have been established that are important tools used in the transmission and distribution of electrical energy. Physio-chemical stress induced by the operating condition of the transformer oil is flexible to the extent of component materials, depending on the saturation or stability. High stability over time is minimal sludge formation. Cooling function and the heat transfer efficiency are high oil,

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compositional purity higher [5]. Transformer oil because of the loading and climatic conditions continued to decline and fall of the power and suffers from cyclic thermal stress. The electrical transformer life may be affected & its performance can be decreased. The actual service life of the widely manufacturer, design, assembly, quality, materials used, maintenance, and depending on the operating conditions, expected life of a transformer is about 40 years. Is disposed of annually in the WTO sent data volume is quite difficult to estimate, but are installed transformers and transformer oils old days more than the number of days to be scrapped. Therefore, a continuous monitoring of transformer oil characteristics and hazards of oil is necessary to avoid deterioration. Depending on the use of transformer oil, preventive maintenance is carried out. For this purpose, various chemical, physical and electrical properties of transformer oil by the oil sample test are determined. Furthermore, biodegradable transformer oil is bad. Serious spills occur, it could contaminate our soil and waterways. Government regulatory agents are already looking into this problem and are imposing penalties for spills. Many transformers are located in populated areas and shopping centers. Effective use of open land in the WTO, but dispose of it can reduce environmental problems. After a proper treatment, the WTO can be used as an alternative fuel in CI engine.

II. DEGRADATION OF WTO

The transformer oil will deteriorate rapidly at high temperatures and moisture acts as a catalyst for its aging. There are also other substances and metals present in a transformer that are responsible for oil degradation. These include copper, paint, varnish and oxygen. The principal mechanism of transformer oil aging is oxidation, which results in acids and other polar compounds being formed. When a transformer is subjected to thermal and electrical stresses in an oxidizing atmosphere, it gradually loses its stability and becomes decomposed and oxidized, its acidity increases, and finally, it begins to produce mud. This is the degradation mechanism of the oil [6-9]. By looking at the color of Transformer oil can be discarded. There is no direct interrelationship between a change in the colour of the oil and a specific problem within the equipment, it happens to normally occur over long periods of time. A visual test should be performed, following ASTM D 1524-84.

A. Filtering of waster transformer oil

Figure 1 shows the schematic of the steps involved in the disposal of the WTO from transformer oil. Once the life of the oil was determined, the transformer oil was removed from the transformers and sent for settling.

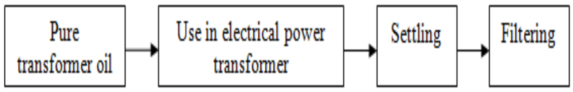

Fig. 1 Dispose of the waste transformer oil

Now the disposed transformer oil has been classified as WTO, afterwards two processes are involved in processing the oil (1) settling and (2) filtering.

(1) SETTLING: Unfamiliar particles and sediments of the WTO settle at the bottom of the oil tank. The settling works happens better in warm conditions and over a number of days or weeks. The settled WTO was dragged from the oil tank.

(2) FILTERING: Fine filters may be required depending on the application. For this study, the WTO was filtered with the help of a fabric filter of size 30 microns.

B. Waste transformer fuel produced by catalytic cracking process

This method is able to crack complex hydrocarbons to a less complex structure. With the help of a catalyst, the reaction is conducted at low temperature and pressure, so that in the quality and quantity of the product is very near to that of diesel, which is far more superior to the oil produced by transesterification process. In Catalytic cracking process, a batch reactor is filled waste transformer oil, which has a highly bonded chemical structure along with 50gms of Zeolite catalyst per liter of oil. When heat is applied a fast response chemical process occurs, in the process complex structure is broken down in the reactor to a simple structure producing low density and low viscosity biodiesel. Biodiesel yield begins at a temperature of 280° C and continues up to 315° C with some ten percent of the remaining residue in the reactor [10-12]. Catalytic cracking fuel plant consists of a batch reactor with oil inlet to pour waste transformer oil mixed with Zeolite catalyst, a pressure gauge to indicate pressure in the reactor, drain hole to remove residue and safety valve to safeguard reactor. At the bottom of the reactor heat is supplied by using gas burners. The temperature indicator is to display the temperature inside the reactor. Smoke, passes through the piping condenser and finally smoke produced is collected in the beaker is condensed into liquid fuel, called waste transformer oil (WTO) fuel.

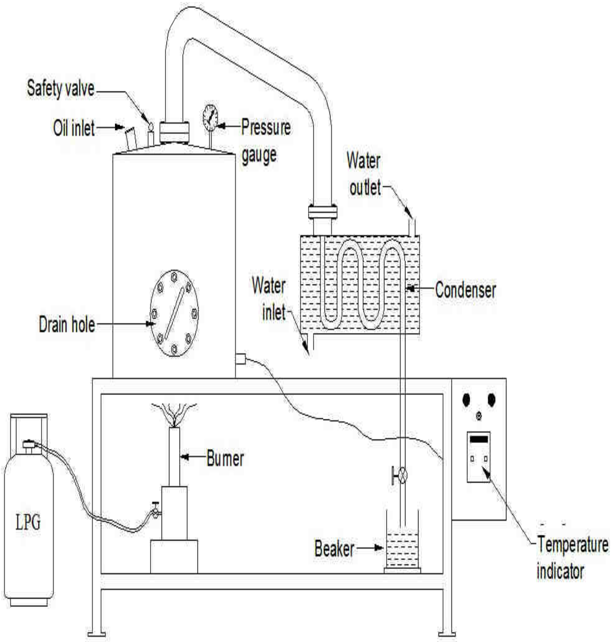

Fig. 2 Schematic diagram of catalytic cracking biodiesel plant

Table 1 Chemical composition of the WTF and diesel

Description	Diesel	WTF
C (%)	86.2	89.96
H (%)	13.2	9.19
N (%)	0.18	0.03

C. Properties of WTO fuel

In testing any alternate fuel in a diesel engine, detailed analysis of its physical and thermal properties is compulsory, and therefore, in this study, WTO fuel was investigated for its fuel properties. In this series, the physical and thermal properties of WTO fuel, such as specific gravity, density, flash point, gross calorific value and cetane number were estimated by ASTM standard methods and compared to that of diesel, as shown in Table 2.

Table 2 Properties of WTO fuel and diesel

Properties	Diesel	WTO fuel
Specific gravity@ 15/15°C (gm/cc)	0.835	0.8473
Kinematic Viscosity @ 40°C (cst)	2.57	11.06
Flash Point (°C)	75	144
Fire Point (°C)	48	70
Pour Point (°C)	-14	-15
Gross calorific value (kJ/kg)	44,633	42,782
Cetane index	50	52.7
Density @ 15°C (gm/cc)	0.834	0.8465

III. EXPERIMENTAL SETUP AND PROCEDURE

The experiment was conducted on Kirloskar TV-1 single cylinder direct injection (DI) diesel engine. Table 3 tabulates the specification of the engine while shows the schematic of the overall arrangement of the test engine.

Table 3 Specifications of test engine

Type	Single cylinder, vertical, water Cooled, 4-stroke diesel engine
Bore	87.5 mm
Stroke	110 mm
Compression Ratio	17.5:1
Orifice Diameter	20 mm
Dynamometer arm length	195 mm
Maximum Power	5.2 kW (7hp)
Speed	1500 rpm
Loading Device	Eddy current dynamometer
Mode of starting	Manually cranking
Injection Pressure	220 kgf/cm^2
Injection timing	23°C before TDC

The engine was coupled to an eddy current dynamometer for load measurement and the smoke density was measured using AVL smoke meter. NO_x emission was measured using AVL Di-gas analyzer. An AVL combustion analyzer was used to measure the combustion characteristics of the engine. The experiments were carried out in different phases.

Fuel flow rate is obtained on the gravimetric basis and the airflow rate is obtained on the volumetric basis. NO_x is obtained using an exhaust gas analyzer. AVL smoke meter is used to measure the smoke density. AVL Di gas analyzer is used to measure the rest of the pollutants. AVL combustion analyzer is used to measure the combustion characteristics of the engine. A burette is used to measure the fuel consumption for a specified time interval and the time is measured with the help of a stopwatch for a specified time interval and the time is measured with the help of a stop watch. The experimental setup is indicated in figure 4. Specification of the AVL Di gas analyzer is shown in Table 5. Specification of AVL smoke meter is shown in Table 6.

Table 4 Specifications of AVL Di gas analyzer

Make	AVL
Type	AVL Di Gas 444
Power Supply	11...22 volage ≈ 25 W
Warm up time	≈ 7 min
Connector gas in	≈ 180 I/h, max.overpressure 450

	hPa
Response time	$T_{95} \leq 15s$
Operating temperature	5...45 °C
Storage temperature	0...50 °C
Relative humidity	≤ 95%, non-condensing
Inclination	0...90°∠
Dimension (w x d x h)	270 x 320 x 85 mm^3
Weight	4.5 kg net weight without accessories
Interfaces	RS 232 C, Pick up, oil temperature probe

Table 5 Specifications of the AVL smoke meter

Make	AVL 437 Smoke meter
Type	IP 52
Accuracy and reproducibility	± 1 % full scale reading
Measuring range	0 to 100 opacity in % 0 to 99.99 absorption m^{-1}
Measurement chamber	Effective length 0.430 m ± 0.005m
Heating time	220 V approximately 20 min.
Light source	Halogen bulb 12 V/5W
Maximum smoke temperature	250 °C
Power supply	190 – 240 V AC, 50 Hz, 2.5 A
Dimensions	570mm ✕ 500mm ✕ 1250mm

IV. RESULTS AND DISCUSSION

The results of the experimental investigation carried out have been furnished hereunder.

4.1 Brake Thermal Efficiency

Fig. 4 shows the variations of BTE with brake power for diesel fuel with WTF blends. The brake thermal efficiency of WTO 20% with Zeolite catalyst is increased when compared to that of conventional fuel. The reason may be the lower viscosity of the blend that leads to better atomization in the injector. WTO 20% (20% of WTF with 80% of diesel fuel) has shown better results than other blends since it has lower viscosity when compared to others. The BTE of blend WTO 20% with Zeolite catalyst shows an increase of 1.31% when compared to that of conventional fuel at full load.

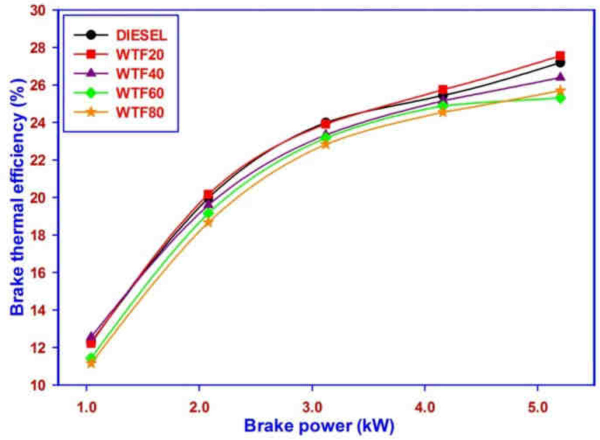

Fig. 4 Brake thermal efficiency against brake power

5.2 Specific fuel consumption

Fig. 5 shows the variations of specific fuel consumption with brake power for diesel fuel with WTO blends. As brake power increases, specific fuel consumption decreases. The SFC of the WTO 20% with Zeolite catalyst has shown lesser fuel consumption when compared to that of standard diesel fuel and other blends. This is due to, in maximum load the cylinder wall temperature increases, which results to reduce the ignition delay period and improves combustion and decreases the fuel consumption.

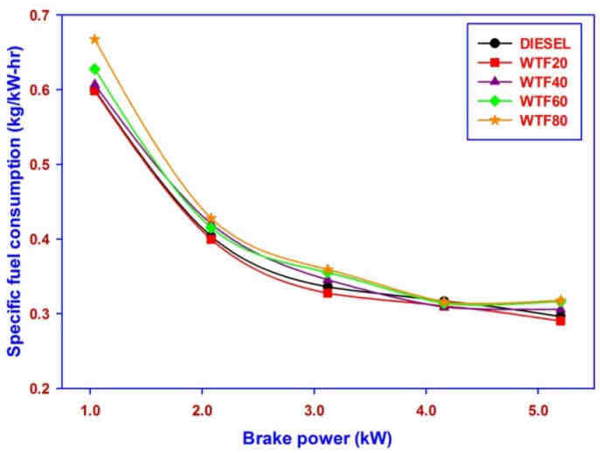

Fig. 5 Specific fuel consumption against brake power

5.3 Oxides of Nitrogen

Fig. 6 shows the variations of Oxides of Nitrogen with brake power for diesel fuel with WTO blends. From the graph it is clear that the NO_x emission of the WTF 20% with Zeolite catalyst is decreased when compared to that conventional fuel. The reason is the reduced combustion temperature that prevails inside the combustion chamber due to the higher heating value of the WTF blends. The blend WTF 20% with Zeolite has shows an decrease of

NO_x emission 59.57% when compared to that of conventional fuel at full load.

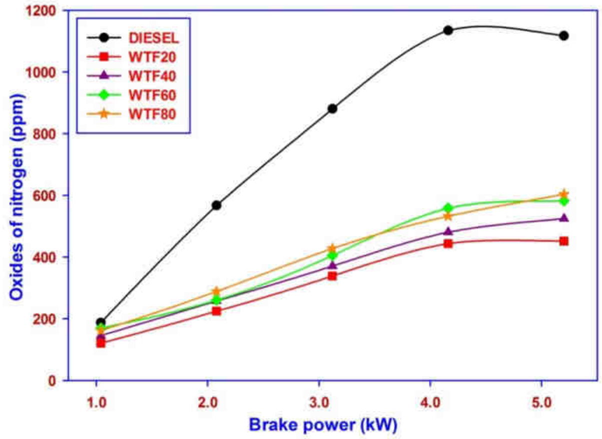

Fig. 6 Oxides of nitrogen against brake power

5.4 Smoke density

Fig. 7 shows the variations of smoke density with brake power for diesel fuel with WTF blends. From the graph it is clear that the smoke density of WTO 20% with Zeolite is increased when compared to that of diesel fuel. The reason for this trend may be the higher viscosity of WTF 20% which leads to poor combustion. The blend WTF 20% with Zeolite shows increase in smoke density when compared to that of conventional fuel. It has shown increase of 7.55% when compared to that of conventional fuel.

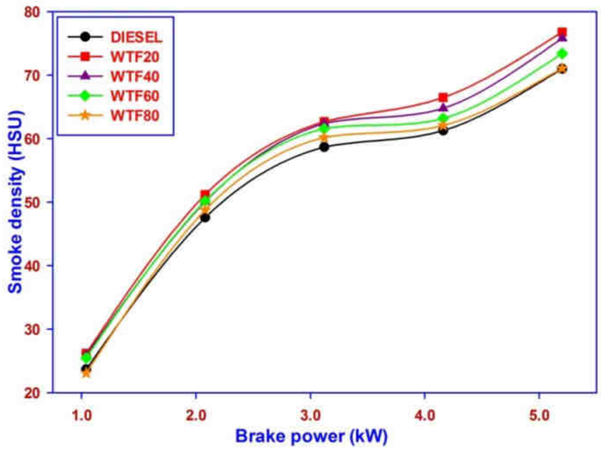

Fig. 7 Smoke density against brake power

5.5 Carbon monoxide

Fig. 8 shows the variations of Carbon monoxide with brake power for diesel fuel with WTF blends. From the graph it is clear that the CO emission is decrease for the blend WTF 20% with Zeolite catalyst when compared to all other blends. It has shown a decrease of 50.02%. At lower WTO concentration, the oxygen present in WTO blend aids for complete combustion. Hence the reason is that the addition oxygen content available in the WTO facilitates the conversion of CO to CO_2.

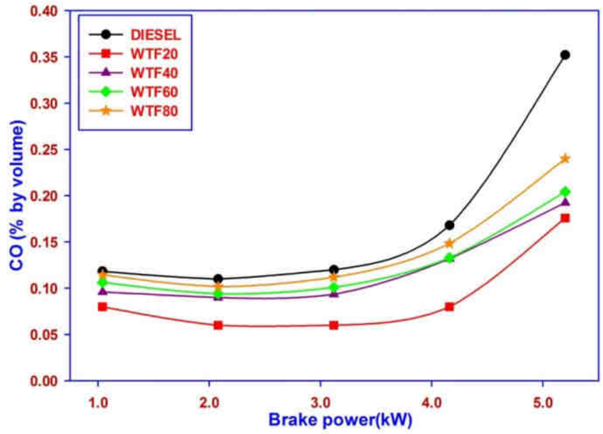

Fig. 8 Carbon monoxide against brake power

5.6 Hydrocarbon

Fig. 9 shows the variations of Hydrocarbon with brake power for diesel fuel with WTF blends. As the load increases there is appreciable increase in HC emissions of diesel fuel. From the graph it is clear that the HC emission of the blend WTO20 with Zeolite catalyst is decreased when compare to all WTF blends. It has shown decrease of 39.49%. This is due to, WTO20 has the required amount of oxygen which results good combustion condition.

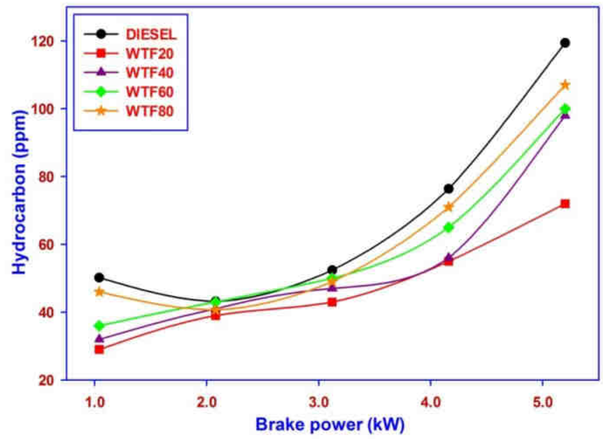

Fig. 9 Hydrocarbon against brake power

V. CONCLUSION

The main conclusions of this study are;

1. The physical properties of WTO fuel, such as viscosity, density, specific gravity, calorific value, flash point, fire point are similar to that of diesel fuel.
2. Using of WTF fuel in diesel engine causes improvement in engine emission characteristics as well as engine's performance.
3. 20% WTO fuel blend shows significant reduction in CO, HC and NO_x emission when compared to that of diesel fuel.

The smoke emission for 20% WTF with Zeolite catalyst is increased when compared to that of diesel fuel. In future in order to reduce the smoke emission, additives can be employed to attain the desired result.

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