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Performance and Emission Characteristics of Waste Transformer Oil and its diesel blends

Gaurav V. Bhawde[1]
gauravbhawde@rediffmail.com

Devanand R. Tayade[2]
devanand.tayade@raisoni.net

Mukund A. Patil[3]
mech8383@gmail.com

Department of Mechanical Engineering,
[1,2]G. H. Raisoni Institute of Engineering and Management, Jalgaon, Maharashtra, India

[3]Marathwada Institute of Technology, Aurangabad, Maharashtra, India

***Abstract*—Waste oils pose a very serious environment challenge because of their disposal problems all over the world. Currently, there is renewed interest in obtaining energy from wastes hitherto meant for disposal. These wastes are sources of energy and among the several sources of generating this energy are the waste-to-energy categories with potentials for useable fuel production. The biofuel is produced from the used transformer oil (WTO) by transesterification process using KOH, methanol. Single cylinder computerized research diesel engine made is used for experimental purpose. Experiments were conducted to evaluate the combustion, performance and emission parameters of a single cylinder, four strokes, air cooled, direct injection diesel engine, fueled with used transformer oil (WTO) and three of its diesel blends on varying the WTO concentration operation. There is an increase in thermal efficiency with significant improvement in reduction of smoke for WTO and its diesel blends compared to diesel. NO emission is higher for WTO and its diesel blends than that of diesel.**

Index Terms— Waste Transformer Oil, Alternative Fuel, Diesel Engine, Transesterification

I. INTRODUCTION

Exhaustible fossil fuel reserves and steep rise in fuel price has resulted in a continuous search for possible alternative fuels for internal combustion engines. The search is very particular to find suitable alternative fuels for compression ignition engine (CI) as they are widely used in many applications. Among the waste oils, the WTO is the most appropriate, because annually significant amount of UTO is disposed off. Day by day, more numbers of transformers are installed and hence it is expected that the disposal of the WTO will be significant in the current years.

In order to improve the performance and reduce the smoke emission by 13.7%, a dual fuel (Acetylene and UTO) operation [4], and increase in thermal efficiency [5] has been investigated with used transformer oil. Brake thermal efficiency and peak heat release rate have been improved with CCWTO and diesel blends fuel. An emission such as smoke, HC (hydrocarbon) and CO (carbon monoxide) has been reduced at the expense of increased NOX (nitrogen oxides) emission [24].

A chemically treat WTO (preheated with concentrated sulphuric acid and alkaline transesterification) has been used so as to bring down its viscosity and make it conducive for diesel engine application [25]. Derived Hydrocarbon fuel has been utilized in a diesel engine by optimizing the combustion bowl geometry (shallow depth, toroidal and hemispherical combustion chamber). Hydrocarbon fuel (HCF) has been derived from waste transformer oil through a traditional base-catalyzed transesterification process [26].

This paper reviews the performance of biodiesel fuels obtained from used domestic oils and to demonstrate the suitability of applying these fuels as substitutes to mineral diesel in various industries. Benefits of used transformer oil as a biodiesel feedstock are as well highlighted. New hydrocarbon fuel is derived from transesterification process. Experimental test have been carried out for performance and emission characteristics like brake power, brake specific fuel consumption, HC, NO and CO_2. Literature review reveals that there are only a very few researchers who have attempted to use waste transformer oil as a fuel for the CI engine. Papers related to the application of waste lubrication oil, waste plastic, oil and tire pyrolysis oil have been found and have been mentioned in the article.

II. USED TRANSFORMER OIL

A. *Used Transformer Oil*

The electrical transformer is an essential piece of equipment used in the transmission and distribution of the electrical energy that is installed in small, medium and large electrical distributing stations. It is also used in arc welding equipment and the electromotive units in trains. The performance and the life of an electrical transformer depend on the effective insulation and cooling. 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 transformer oil 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.

It is well known that the transformer oil is used mainly in the electrical transformer for insulation purpose. Moreover, cooling is another purpose of using transformer oil in the electrical transformer while the transformer is running. Among various properties, one of the main properties of transformer oil is to sustain high temperature during operation. When an electrical transformer is in operation, the transformer oil is subject to mechanical and electrical resistance. For a certain period of time, it is recommended to check the electrical and chemical properties of the transformer oil. At present 100 per cent transformer oil is not used in place of diesel fuel (DF) to run the engine rather blends of WTO and DF are used to run the engine. Transformer oils are an important class of insulating oils. They act a heat transfer medium in the transformer. Transformer oil have negligible amount of contamination which have adverse effect on the electrical properties. In general, transformer oil is produced from wax-free naphthenic oils. After certain period of time of operation in the transformer, the oil is thrown out in the form of waste. But after testing the transformer oil blends (transformer oil and diesel fuel) it has been seen that the property of transformer oil is comparable to that of diesel. A comparison of the chemical composition between of WTO and diesel is shown in Table 2.

Table I
PROPERTIES OF OIL

Properties	WTO	RWTO	DF
Density (kg/m^3)	895	874	860
Kinematic viscosity (cSt)	10.1	6.2	3.08
Flash Point (^{0}C)	140	125	90
Fire Point (^{0}C)	145	132	95
Gross calorific value (kJ/kg)	41775	43813	44500
Cetane Number	42	50	48

TABLE II
CHEMICAL COMPOSITION OF WTO AND DIESEL

Description	WTO	Diesel
C (%)	89.85	86.5
H (%)	9.19	13.2
N (%)	0.03	0.18
S (%)	0.35	0.3
C/H ratio	19.302	5.437
Carbon residue (%)	0.02	0.02

B. Alternative fuel from waste substance

Biomass sources, particularly vegetable oils (VOs), have attracted much attention as an alternative energy source since they are renewable, available locally, and have proved to be a cleaner fuel. Several VOs have been evaluated as diesel fuel substitutes, including soybean oil, sunflower oil, cotton-seed oil, and rape oil. The waste palm oil has been converted to ethyl ester by transesterification [2]. The study of potential of ethyl ester used as vegetable oil (VO; biodiesel) to substitute oil-based diesel fuel has been initiated [3]. The 100% ester fuel and the blend of 75:25 ester/diesel has given the best performance while the 50:50 blend consistently resulted in the lowest amounts of emissions over the whole speed range tested. They found that, blends burned more efficiently with less specific fuel consumption, resulted in higher engine thermal efficiency. The technical suitability of an alternative fuel oil (AFO) for use in marine applications has been presented [9]. This AFO used is a mineral origin fuel, produced from recycled and post-processed automotive lubricating oil. The combustion results show that the alternative fuel has worse combustion performance than distillate fuel but better than that of residual heavy fuel oils; however, it emits more smoke and particles than DFO. Advanced injection timing is advised to drastically reduce CO emissions but increase NOx emissions. The exhaust emissions of a Diesel direct injection Perkins engine fueled with waste olive oil methyl ester has been studied at several steady state operating conditions [6]. Wasted cooking oil from restaurants has been used to produce neat (pure) biodiesel through transesterification, and this converted biodiesel has been used to prepare biodiesel/diesel blends [11]. They studied trace formation from exhaust tail gas of a diesel engine when operate with neat biodiesel, biodiesel/diesel blends, and normal diesel fuels.

Waste lubricating oil (WLO/ULO), waste plastic oil (WPO) and tire pyrolysis oil (TPO) obtained from waste automobile tires, and waste plastics oil derived from plastics by pyrolysis (WPOP) have already been investigated for their effective utilization as alternative fuels in CI engines. The properties of WPOP have been analyzed; compared with the petroleum products and found that it is similar to that of diesel [13]. The fuel propertied comparison has been given in Table 3. After the analysis of oil, WPOP was used as an alternate fuel in a DI diesel engine without any engine modification. The performance, emission and combustion characteristics of a single cylinder, four-stroke, air cooled DI diesel engine run with waste plastic oil were obtained and compared with diesel operation. The experimental results have showed a stable operation and comparable brake thermal efficiency for WPOP with that of diesel. The unburnt hydrocarbon emission from WPOP fueled engine was found to be higher by about 15% compared to that of diesel operation. The CO emission for WPOP was higher by about 5% than that of diesel at full load. Smoke reduced by about 40% for WPOP compared to that of at all loads.

Used WPO has been utilized as alternative fuel to powered diesel engine [12]. At a four different injection timings like 23°, 20°, 17° and 14° BTDC, the influence of injection timings on performance, emission and combustion characteristics have been studied. The brake thermal efficiency has been increased by 4% for WPO as compared to that of diesel fuel. The smoke emission also increased by 35% for WPO than diesel fuel.

The evaluation for performance and emission characteristics of a single cylinder diesel engine have been carried out with 10, 30 and 50% blends of tire pyrolysis oil (TPO) with diesel [18]. The brake thermal efficiency of the engine fueled by TPO-diesel blends has been increased with increase in blend concentration and higher than diesel at full load. An emission from the engine has been increased due to aromatic content and longer ignition delay. Waste transformer oil (WTO) has been used as an alternative fuel for compression ignition (CI) engine. For this purpose different properties of the WTO were determined [19]. The thermal efficiencies with the WTO20 and RWTO20 were compared those of DF. Compared to DF, WTO20 blend showed higher thermal efficiencies. The fuel consumption for UTO10 for UTO 15 for UTO 20 was higher as compared to diesel fuel due to the lower heating value. The exhaust gas temperature of UTO10, UTO15, UTO20 were 1000C, 1000C, 1010C respectively which were higher than baseline diesel (980C) due to the more residence time and higher viscosity.

First time catalytic cracking process has been subjected to waste transformer oil in specifically designed reactor, in order to reduce its viscosity and used in a diesel engine as an alternative fuel [24]. The exhaust emissions such as Smoke, HC and CO have been reduced by 7.7%, 4.9% and 14.8% at full load condition, while NOX emission was increased by 9.4%, respectively. There has been effort taken to chemically treat WTO so as to bring down its viscosity. WTO is pretreated with concentrated sulfuric acid and subjected to alkaline transesterification with an alcohol and alkali catalyst [25]. Also, HCF has been utilized in a diesel engine by optimizing the combustion bowl geometry, considering that an engine modification is imperative to effectively operate high viscous fuel like derived HCF in a diesel engine. Different shapes for combustion piston bowl geometry viz Piston 1 (shallow depth combustion chamber), Piston 2 (toroidal combustion chamber) and Piston 3 (hemispherical combustion chamber) have been preferred.

Experiments has been conducted to evaluate the combustion, performance and emission parameters of a single cylinder, four stroke, air cooled, direct injection diesel engine, fueled with used transformer oil (UTO) and six of its diesel blends on varying the UTO concentration from 10% to 60%, at a regular interval of 10% by volume basis [5]. They observed that, increase in thermal efficiency with significant improvement in reduction of smoke was observed for UTO and its diesel blends compared to diesel. NO emissions were higher for UTO and its diesel blends than that of diesel. Ignition delay was marginally shorter for UTO and its diesel blends than diesel.

C. Biodiesel processing from Used Transformer Oil

Biodiesel can be produced by Used Transformer oil of esterification Technologies. The oils and fats are filtered and pre-processed to remove water and contaminants. If, free fatty acids are present they can be removed or transformed into biodiesel using special pre-treatment technologies. The pre-treated oils and fats are then mixed with an alcohol Butane and a catalyst KOH. The oil molecules are broken apart and reformed into esters and glycerol, which are then separated from purified. The Used Transformer oil having acid values nearly 1.0 were esterifies followed by transesterification. The butyl esters produced by these methods were analyzed to ascertain their suitability as diesel fuels. The process of biofuel production is given in Figure 1.

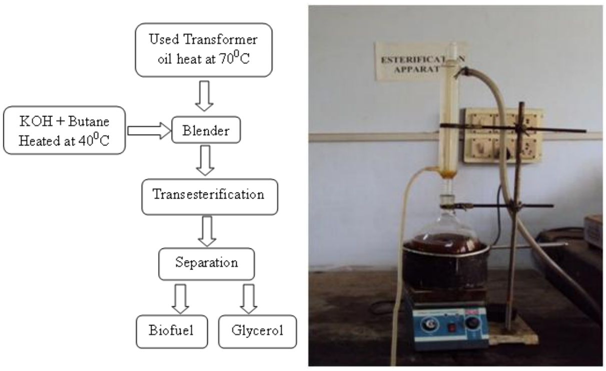

Figure 1: Biofuel production and Transesterification process

D. Experimental set up

Refined WTO is treated with sulfuric acid to break the higher molecules and make the oil favorable for alkaline transesterification process. By this measure, when alkaline transesterification is performed subsequently with methanol and alkali catalyst, KOH (potassium hydroxide), soap formation is prevented and the yield of derived hydrocarbon fuel is improved. Illustratively, a titration is performed to ascertain the quantity of KOH and methanol needed for transesterification process and by the end of this, it is understood that for transesterifying 1 L of pretreated WTO, 12 g of KOH and 210 ml of methanol are required. After adding the catalyst and methanol with pretreated WTO, the mixture is stirred and heated to 65^0C for around 30 min and when the reaction ceases, methyl ester of WTO is formed along with the residual glycerol in separate layers. Followed by the transesterification process, the derived HCF (hydrocarbon fuel) is washed with water and the mixture is agitated gently for 20 min so as to allow the water to settle down. Finally, the water and residual glycerol are removed and the produced HCF is heated upto 100^0C to remove the last traces of water particles.

Figure 2: Computerized research diesel engine set up

The compression ignition engine used for the current study is computerized research diesel engine, single cylinder, four strokes, and constant speed, vertical, water cooled. The engine is coupled with an eddy current dynamometer to apply different engine loads and the experimental setup and arrangements have been shown in Figure 2. The Chromel Alumel (k-type) thermocouples are installed at inlet and outlet ducts to measure the respective gas temperatures. The engine speed is measured by in-house designed magnetic pickup sensor connected to frequency meter. The experimental investigations are carried out for three different blend fuels: standard diesel, WTO 10 (10% of WTO + 90% of diesel by volume), WTO 15 (15% of WTO + 85% of diesel by volume) and WTO 20 (20% of WTO + 80% of diesel by volume) at various loading conditions. The fuel consumption, exhaust gas temperature and exhaust emissions such as NO, CO, HC are measured and recorded for different engine loading conditions.

E. Results and Discussions

Figure 3 shows the variation between brake specific energy consumption and brake power. As the fact, the

BSFC decreases with increase in brake power and engine load. Compare to diesel engine at standard situation, WTO shows lower consumption of brake specific fuel for particular brake power.

Figure 5 shows the variation of the BTE with brake power for the WTO and standard diesel. The values of the BTE for diesel and the WTO are found to be about 30.7% and 30.4% at standard compression ratio (18.5) and maximum brake power. The brake thermal efficiency of WTO is 16.98%, 19.88%, 21.7% and 23.5% at blends of DF, WT10, WT15, and WT20.

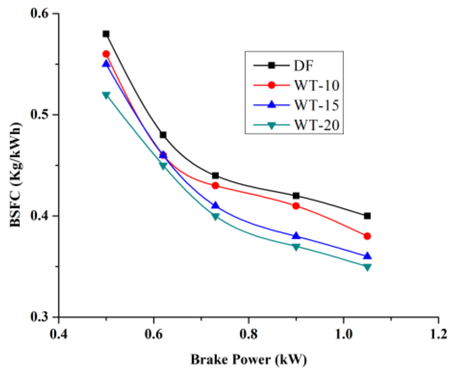

Figure 3: Variation of brake power with BSFC

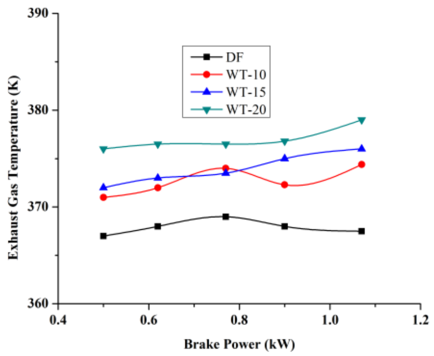

Figure 4: Variation of brake power with Exhaust gas temperature

The variation of exhaust gas temperature with brake power is shown in Figure 4. The exhaust gas temperature of WT10, WT15, and WT20 are 3680C, 3720C, 3770C respectively whereas diesel is 3660C. The reason is may be due to high auto ignition temperature for increase in exhaust gas temperature.

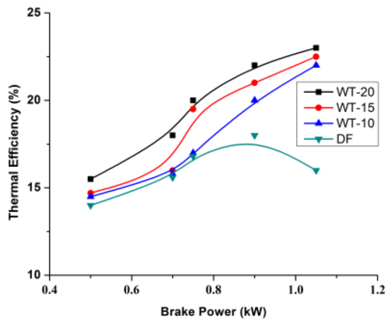

Figure 5: Variation of thermal efficiency with brake power

It can be observed from Figure 6, that HC emission is higher by about 12.7 % for WT-20 as compared to diesel fuel and 13.6 % lower at maximum brake power due to delays in ignition, which results to insufficient heat of compression so HC emissions decreases. Also, CO2 emission is always less in the WTO fuel compared with diesel as shown in Figure 8.

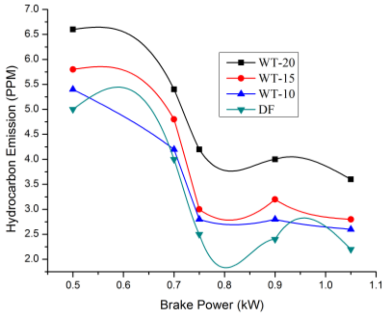

Figure 6: Variation of hydrocarbon emission with brake power

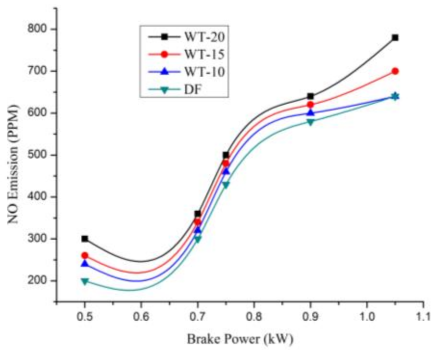

Figure 7: Variation of NO emission with brake power

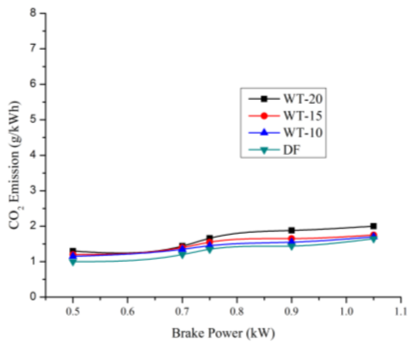

Figure 8: Variation of carbon dioxide emission with brake power

III. Conclusions

This paper gives a brief review on the waste transformer oils that can be used in diesel Engine as an alternative fuel. Performance and emission characteristics of a single cylinder, four strokes, water cooled, direct injection diesel engine having a power output of 5.2 kW at a constant speed of 1500 rpm, fueled with UTO, diesel blends and diesel have been analyzed and compared with those of diesel. The HC and CO emissions for the all compression ratio are higher than those of diesel operation at full load. The NO emission is higher at optimum CR 18.5 for used transformer oil fuel than diesel at full load.

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