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Experimental Investigation of Waste Animal Fat Methyl Ester Blends in Diesel Engine

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Abstract : *The energy crisis is the concern that the world's demands on the limited natural resources that are used to power industrial society are diminishing as the demand rises. So alternative source is required to meet this requirement. This research work reports the preparation of Waste animal fat methyl ester (WAFME) and exhaustive trials of its blends on single cylinder-four stroke diesel engine for evaluation of performance and emission characteristics. The assessed performance parameters include Brake Thermal Efficiency (BTE) and Brake Specific Energy Consumption (BSEC). In addition, engine emissions like CO, HC, and smoke were found to be significantly reduced except NOx. Conclusions specified that WAFME- diesel blends up to 20% (v/v) could be used in the engine without modification.*

Keywords: Diesel engine, Emission, Performance, Waste animal fat methyl ester

I. INTRODUCTION

Energy is essential and plays a pivotal role for growth and development of global economy. Use of fossil fuels as energy sources has become a serious matter of concern primarily because of their limited reserves and environmental problems associated with their use as fuels. The modern world has been confronted with an energy crisis to depletion of finite resources of fossil fuel. The rapidly growing demand for transport fuel and industrialization has caused serious threats to the environment and energy security of the world. Global fossil fuel consumption increased by around 40% in 2011 compared with 2010. Moreover, only half of the usual energy demand can be supplied until 2023 with the current liquid fuel reserve. The consumption of fossil fuel at this fast rate is affecting environment and is leading to ruthless effects. These environmental degradation effects include global warming, air quality deterioration, ozone depletion, eutrophication, photochemical smog, oil spills, and acid rain.

Biofuels have that capacity to replace the markets of conventional fuels to a larger extent. Due to their non-polluting and easily degrading properties, enormous research works are being carried on in this field. Continuous efforts are being made to improve quality of biodiesel. Several blends of the biodiesel along with the diesel are being used. Biodiesel, the non-toxic fuel, is biodegradable and environmentally non-threatening fuel used in diesel engines. Sulphur or aromatic compounds are negligibly present in these fuels so their combustion results in lower emission of carbon monoxides, hydrocarbons and particulates. Biodiesel is produced from biological sources such as vegetable oils, animal fats and microalgae using a biochemical process known as 'transesterification' involving reaction of the reaction of an alkoxy group of an ester (i.e., monoglyceride, diglyceride, or triglyceride) with that of a lower alcohol and a catalyst (potassium hydroxide). Biodiesel is produced through process of transesterification and methanol is the most widely used alcohol owing to its simple geometry, excellent catalyst dissolution and relatively low cost. Various alcohols such as methanol and ethanol are commonly used for trans-esterification, due to their low price, chemical and physical advantages such as polarity of short-chain alcohols. The solubility of catalyst in methanol is faster as compared to other alcohols and it can easily react with triglycerides leading to faster reaction rates. Methanol is non-renewable but ethanol being renewable in nature is now investigated for transesterification. By comparison, the formation of ethyl esters is more difficult than of methyl esters due to the differing reactivity's of alcohols with catalysts in order to produce alkoxide ion (the active moiety in transesterification).

II. MATERIALS AND METHODS

A. Biodiesel Production

Mutton Fat is taken in a beaker and heated to above 120^0 C with the help of a hot plate for 30 minutes. Solid form fat transform into liquid form. Heating of the fat above 120^0 C will reduces moisture level in the fat otherwise, presence of water in the oil will affect the biodiesel preparation as there will be more probability of the formation of soap. After heating the fat, fat is melted and the oil is then cooled to 60^0C.

Methanol is used as an alcohol and KOH is used as a homogenous base catalyst in the trans-esterification reaction. Methanol is added to the sample in the molar ratio of 1:6. KOH (0.25 % wt.) is added to the mixture and the resulting mixture is heated on the Hot plate with the help of magnetic stirrer at below 65^0 C. After the trans-esterification reaction, the whole mixture is transferred into a separating funnel.

After 24 hours, both biodiesel and glycerol (trans-esterification by-product) separates out. Biodiesel occupies the top layer and glycerol settles down at the bottom of the separating funnel. Glycerol is separated out and Biodiesel is left in the separating Funnel.

Warm water at 50^0 C is taken in the volumetric ratio of 1:1 in the separating funnel and gently mixed with the biodiesel and the mixture is left out in the separating funnel to separate out. Washing removes the un-used KOH from the biodiesel. This process is repeated for 5-6 times. Finally, clear water is visible at the end of washing process in the separating funnel which marks the end of washing process.

Finally, Mutton Fat Methyl Ester is heated over 120^{0}C in the hot plate for removing the moisture content from it. After following the above processes, pure biodiesel is produced.

B. *Experimental Setup and Procedure*

A single cylinder, four-stroke, water cooled diesel engine was used in this research. The engine was operated at a constant speed of 1500 rpm. The fuel injection pressure was in the range of 200–205 bars. The loading was provided by an eddy current dynamometer coupled with the engine shaft. Also, an rpm encoder was attached at the end of the dynamometer for rpm measure. Fig. 1 presents the block diagram of the experimental setup.

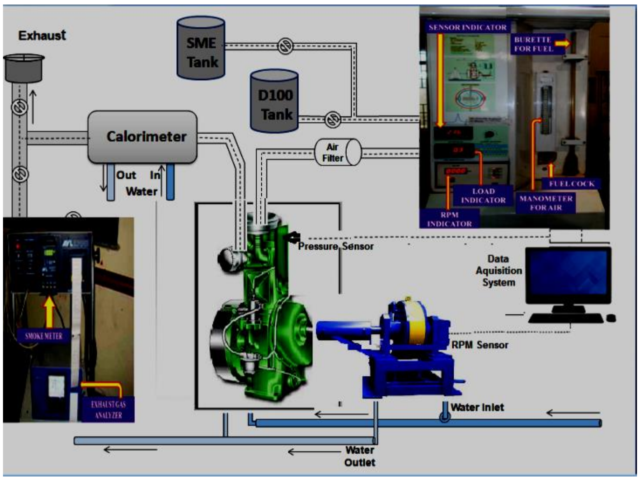

Fig. 1 Schematic diagram of the test setup used for this study

The cyclic variation of combustion pressure and the corresponding crank angle were recorded using a piezoelectric transducer. For exhaust gas temperature measurement; thermocouples (K-Type) were employed. The air flow rate was measured using a mass airflow sensor. A fuel pump measured fuel consumption rate. The fuel and air flow rates, load, rpm, pressure crank angle and temperature data were fed to the centralized data acquisition system. Engine-soft (computer software), was connected to the data acquisition system for automated and manual analyses. Test engine specifications as shown Table 1.

TABLE I
Test Engine specification

Make of the engine	Kirloskar
No. of cylinder	1
Strokes	4
Rated Power	3.5 kW@1500rpm
Cylinder diameter	87.5mm
Stroke length	110mm
Connecting rod length	234mm
Compression ratio	17.5:1
Orifice diameter	20mm
Dynamometer type	Eddy current
Rated power (dynamometer)	7.5 kW@1500rpm
Dynamometer arm length	185mm
Fuel injection timing	23^{0}BTDC
No. of injector holes	3
Nozzle diameter	0.148 mm
Spray orientation angle	55°CA
Injection duration	18°CA
Full load diesel injection per cycle	32.8 mg

III. RESULTS AND DISCUSSION

A. *Physico-chemical characterization of WAFME*

The study determines the physico-chemical properties according to standard methods. Table 2 presents the average values of triplicate analyses. The major constituents are: saturated fatty acid methyl esters and unsaturated fatty acid methyl ester (Octadecadienioc acid methyl ester).

TABLE III
PHYSICO CHEMICAL PROPERTIES OF WAFME AND ITS BLENDS

S. No	Property (units)	ASTM D6751	WAFME 100	WAFME 10	WAFME 20	D100
1	Kinematic viscosity (cSt)	D445	5.9	3.23	3.36	3.2
3	Oxidative stability (hours)	D675	<6	<6	<6	--
4	Density (g/cc)	D1298	0.8765	0.8281	0.8333	0.8227
5	Flash Point (°C)	D93	127	67.3	71.5	61
6	CFPP (°C)	D6371	12	0	4	-12
7	Calorific value (MJ/kg)	D4239	39.65	45.16	45.07	45.49

Table 2 presents the physico-chemical properties of WAFME100, diesel, and their corresponding blends. Although, WAFME40 shows 2.1 % higher density than mineral diesel, it was within the standard limit of 0.86-0.89 g/cc according to ASTM standard. The viscosity of the

WAFME100 was higher than diesel but conforms to ASTM D6751 standard. The calorific value of WAFME was comparable to baseline (D100). However, the Cold Filter Plugging Point (CFPP) of WAFME sample is 12°C as compared to -9°C exhibited by the diesel. Despite the inferior CFPP of WAFME it could be suitable to warm climatic conditions like India.

B. Engine Performance

1) Brake Thermal Efficiency (BTE)

The BTE is a vital engine performance parameter that needs to be investigated. It defines the ratio between useful mechanical work obtained at the engine shaft and the energy of the supplied fuel Fig. 2 shows the variation in BTE of various test fuels compared to the baseline data, at all loading conditions. It is significant to note that at 80% load, the BTE exhibited by WAFME10 and WAFME20 were 5.3% and 5.7% respectively, much higher than the baseline diesel operation. This could be attributed to the higher A/F ratio at higher load, coupled with the oxygenated nature of WAFME leads towards improved combustion; even at higher volume fractions. WAFME10 and WAFME20 illustrated similar BTE at all loads compared to the baseline data.

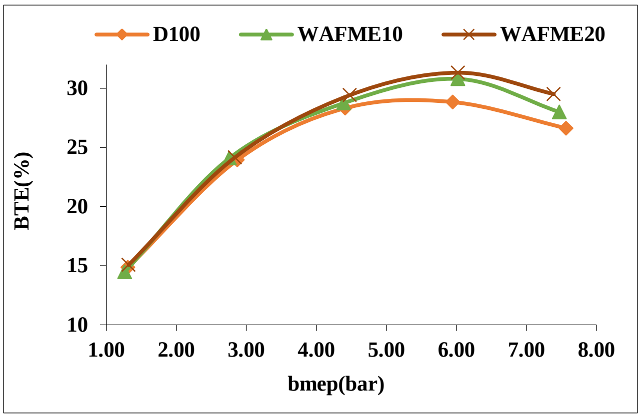

Fig. 1 Effect of brake thermal efficiency of the test fuels

It is concluded that the engine performance in terms of BTE was improved with biodiesel blends up to 20% substitution. Higher volume fraction of WAFME in the fuel, it resulted in a reduction of BTE as compared to the diesel baseline.

2) Brake Specific Energy Consumption (BSEC)

The comparative asses WAFME of volumetric consumption of fuel is an important parameter in explaining the engine performance exhibited by various test fuels. Fig. 3 shows BSEC with increasing load for the test fuels. It is pragmatic that BSEC was reduced with increasing WAFME volume fraction at 20% load. The reductions shown by the test fuels compared to the baseline data are 1.84%, 2.09%, for WAFME10 and WAFME20 respectively at 80% load condition. It was evident that WAFME10 and WAFME20 exhibited reduced BSEC compared to the baseline data. On the contrary, WAFME30 and WAFME40 illustrated higher BSEC than neat diesel data after 80% load.

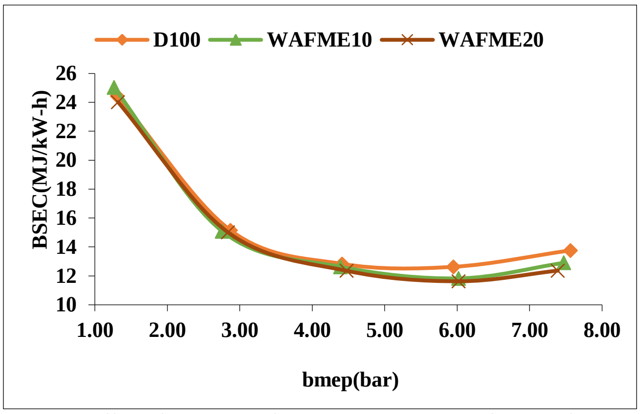

Fig.3- Effect of Brake specific energy consumption of the test fuels

3) - Exhaust temperature (EGT)

Fig. 4 shows the disparity of exhaust gas temperature with the load. It demonstrated that the temperature of the engine exhaust gasses varied linearly with load test fuels. It was evident that WAFME blends revealed reduced exhaust temperature compared to the baseline diesel at higher loads.

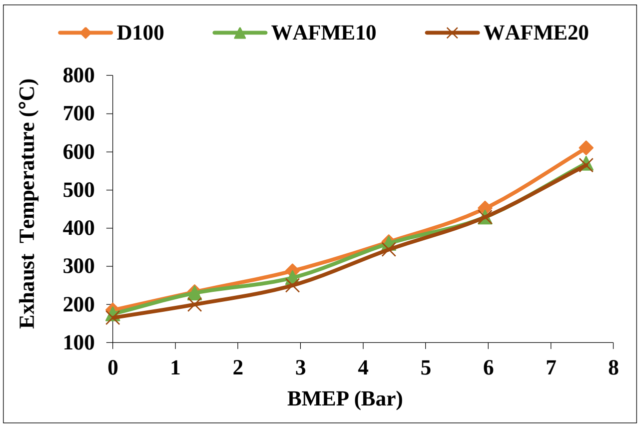

Fig.4- Effect of Exhaust temperature of the test fuels

C. Engine Emission

1) Carbon monoxide (CO)

Initially, the CO emission lower with varying load. Afterward, it records 60% load high CO emission, irrespective of test fuels. Under no-load condition, in-cylinder temperatures were fairly lower leading towards incomplete combustion. However, with increasing load, the temperature increased due to fuel injected in the cylinder. At higher temperature, improved fuel burning reduced the CO emissions. Interestingly, beyond 60% loading, higher fuel injection into the engine led to an incomplete combustion and increased CO emissions. At higher loads, WAFME and its blends revealed lower CO emissions as compared to the baseline data. Fig. 5 compares analysis of CO emissions from different WAFME blends to the baseline data. Theoretically, the air–fuel mixing process handles atomization difficulty of biodiesel, due to its higher viscosity, ensuring locally rich mixtures of biodiesel and higher CO emissions. This explains the premixed lean combustion in the excess air in the loads, thereby reducing CO emission to almost tangible. The reduced CO emission for WAFME and its blends at higher loads was associated with biodiesel oxygenation than diesel resulting in enhanced combustion.

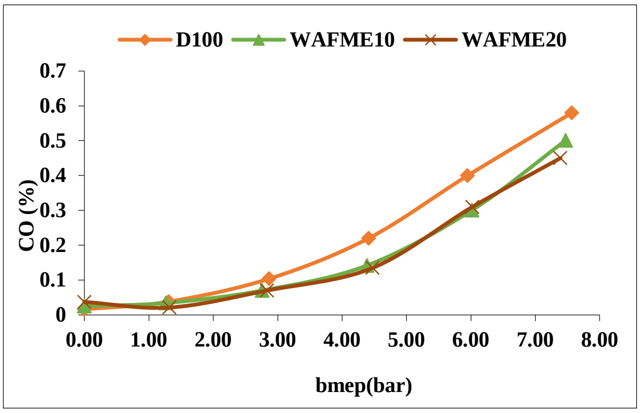

Fig.5- Effect of Carbon monoxide of the test fuels

2) Hydrocarbons (HC)

Fig. 6 presents the total hydrocarbons emission with the load. Test fuels for all loading conditions demonstrated HC reduction as compared to the baseline data. However, two basic explanations proved the description. Firstly, the HC reduction with increased fractions of WAFME in the test fuel was evident. In comparison to the neat diesel operation, it recorded up to 30% blend of WAFME in diesel, higher in-cylinder pressure and the bulk gas temperature. Secondly, WAFME has higher cetane rating and lower ignition delay than diesel.

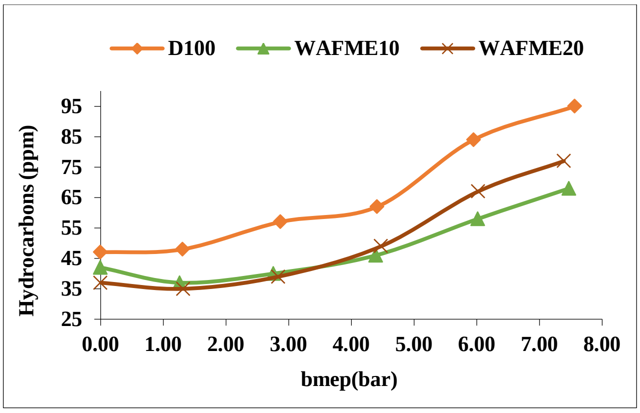

Fig. 6- Effect of the Hydrocarbons of the test fuels

Therefore, the combined effects of higher in-cylinder temperature, cetane rating and reduced ignition delay resulted in reduced emissions of HC for both WAFME and its blends compared to the baseline data of diesel.

3) Oxides of nitrogen (NO_x)

Oxides of nitrogen comprising nitrogen oxide (NO) and nitrogen dioxide (NO_2) are the critical diesel engine emissions of key concern. The “Zeldovich Mechanism” forms NO. Factors including combustion flame temperature, availability of oxygen and time for oxygen-nitrogen reaction, significantly influence NO_x formation in diesel engines [21]. Fig. 7 shows the bar chart of NO_x produced with respect to load. Lower NO_x emission is observable in all samples for WAFME and its blends, specifically at lower loading, compared to the baseline data. However, WAFME and its blends demonstrate higher NO_x emission as compared to the baseline data. The oxygenated fuel and the adiabatic flame temperature are responsible for this improvement. So, higher combustion temperatures are the predominant factor for increased NOx emissions for WAFME blends, whereas excess availability of oxygen is the predominant factor for increased NOx emissions.

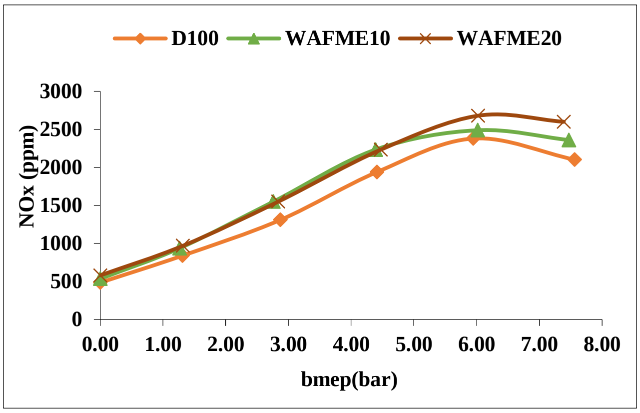

Fig. 7- Effect of the Oxides of the Nitrogen of the test fuels

4) Smoke opacity

Smoke is one of the most objectionable discharges in CI engines. The study observes that at part loads WAFME and its blends exhibit higher smoke opacities than from the baseline. Fig. 8 shows smoke opacities as exhibited by WAFME and its blends with the baseline data of diesel at various loads.

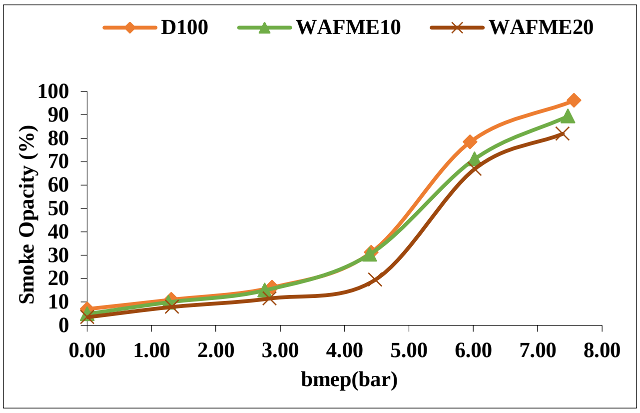

Fig. 8- Effect of the Smoke Opacity of the test fuels

This attributes to higher viscosities of biodiesel and lower in-cylinder temperatures at lower and medium engine loads, leading to poor atomization, locally rich mixtures and higher emissions of smoke [25-26]. However, like previously reported emissions, the smoke opacities at lower and medium loads are less than 50% hence, significantly lower than the 90% engine loading [27]. The researchers also record similar results.

IV. CONCLUSION

The present work evaluated the performance and emission characteristics of different WAFME-diesel blends. Physico-chemical properties of WAFME showed the dominance of saturated and oxygenated compounds, which improves its fuel properties such as its calorific value. During engine operations, lower WAFME blends demonstrated higher BTE at full load, in contrast to lower BSEC was analogous to the baseline diesel. Lower CO, HC and smoke opacity emissions were recorded as well, in contrast to the observed increasing NOx. Therefore, it is concluded that WAFME diesel blend is a potential greener fuel for CI engines.

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