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Study of Different Methods of Using Vegetable Oil as a Fuel for Compression Ignition Engine

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Abstract - This paper present a comparative study of performance and emission characteristics of compression ignition engine with different method of using straight vegetable oil. Single cylinder water cooled, constant speed diesel engine which is generally used for water pump or generator sets is used for investigations. During tests, engine is operated with petrodiesel, vegetable oil (at normal room temperature and at 90°C) and vegetable oil-ethanol emulsions at room temperature. The engine performance parameters and emissions are measured with different test fuels from no load to full load conditions.

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STUDY OF USE OF DIFFERENT METHODS OF USING VEGETABLE OIL AS FUEL FOR COMPRESSION IGNITION ENGINE

Strictly as per the compliance and regulations of:

Study of Different Methods of Using Vegetable Oil as a Fuel for Compression Ignition Engine

Nandkishore D.Rao [α], Dr.B. Sudheer Premkumar [σ] & Dr. M.Yohan [ρ]

Abstract - This paper present a comparative study of performance and emission characteristics of compression ignition engine with different method of using straight vegetable oil. Single cylinder water cooled, constant speed diesel engine which is generally used for water pump or generator sets is used for investigations. During tests, engine is operated with petrodiesel, vegetable oil (at normal room temperature and at 90°C) and vegetable oil - ethanol emulsion at room temperature. The engine performance parameters and emissions measured with different test fuels from no load full load conditions.

At normal temperature, the Straight vegetable oil (SVO) shows lower thermal efficiency, higher specific energy consumption with higher exhaust gas temperature as compared to diesel at all loading conditions. Preheating and emulsion of vegetable oil show improvement in engine performance. The smoke opacity is higher with neat vegetable oil and it reduces with preheating and emulsification. However, NO_x emissions are lower with unheated vegetable oil as compared to preheated oil due to lower in-cylinder temperature due poor combustion. With micro-emulsion, NO_x emissions are lowered as compared to pre-heated oil due to high latent heat of ethanol and water traces present in ethanol. Overall it is observed that oxides of nitrogen emissions with vegetable oil(at room temperature/preheated/emulsified) are lower as compared to mineral diesel. Higher unburned hydrocarbon and carbon monoxide emissions are observed with unheated SVO as compared to diesel. However, these emissions are considerably reduced with pre-heated and emulsified vegetable oil.

It could be concluded that with micro- emulsion of vegetable oil, the engine performance and emissions improved significantly.

Keywords : Compression Ignition engine, Vegetable oils, Micro-emulsions, Performance, Emissions, Blending, Esterification, pre-heating.

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I. Introduction

In country like India, majority of population lives in rural areas and they depend on agriculture. The diesel engines are popular in rural areas where it is not possible to have uninterrupted electric supply to run electric motor for water pump sets. If fuel for these diesel engines is prepared locally, it makes the farmers self-sufficient in regard to their energy needs.

There are many vegetable oils which can be used as fuel for diesel engines. The edible oils like sunflower oil, pea nut oil, soya oil etc are costly and are for human consumption. The non edible oils obtained from plant species such as *Jatropha curcas* (Ratanjyot),*Pongamiapinnata*(Karanj),*Calophylluminoph-yllum* (Nagchampa), *Hevca brasiliensis, honge, honne and rubber etc.* can be used as fuel for diesel engine. The land which is not suitable for agricultural purpose may be used for growing these trees to produce oil seeds, upon extraction, oil can be used as fuel for diesel engine with minor modifications. The vegetable oils offer many benefits including sustainability, regional development, reduction in green house gases, reduction on dependency on mineral diesel which is imported from foreign countries. Straight vegetable oils have very high viscosity which results into inferior engine performance

The viscosity of the vegetable oil can be reduced by converting it to biodiesel, mixing it with mineral diesel, preheating and diluting the vegetable oil with solvent. The trans-estrification(conversion of vegetable oil to its esters) with a lower alcohol yields a fuel with lower viscosity but reduces the feasibility of Direct use of vegetable oil. Also the esters have a solidification temperature about 4 degree C., requiring the use of fuel preheaters in cold winters.

Blending of vegetable oil with diesel fuel fall short of meeting the farmer's goal of energy self – sufficiency. Cracking and refining are effective in upgrading vegetable oils, but it increases the cost of fuel and negate direct on farm utilization of the harvested vegetable oil. The concept of diluting vegetable oil with ethanol, another agricultural based energy source may be possible for on the farm preparation of fuel. This mixing of vegetable oil and ethanol is confronted with the difficulty of phase separation. Hence, a 1-butanol is used as a non-ionic surfactant to dispersethe water and alcohol in vegetable oil to form a micro-emulsion. Pre-heating of vegetable oil reduces its viscosity thereby improving the engine performance. The Past investigation show that the preheated vegetable oil in diesel engine resulted in improved engine performance and combustion characteristics with lower hydrocarbon, particulate and higher NO_x emissions as compared toun-heated vegetable oil. **M. Pugazhvadivu and K. Jeyachandran [1]** conducted experimental investigation on diesel engine to study effect of pre-heated waste fried oil (WFO) on engine performance and emission characteristics. The engine performance improved significantly with maximum reduction in CO and smoke emissions with WFO at 135°C as compared to unheated WFO. They concluded that pre-heated WFO at 135°C can be a substitute for diesel. **M. Pugazhvadivu and G. Sankaranarayanan [2]** used preheated mahua oil s fuel for dieselengine and concluded that pre-heating the mahua oil to 130°C gave higher thermal efficiency with lower HC,CO, smoke and higher NO_x as compared to unheated mahua oil. **Sagarpramodraokadu and Rajandra H. Sarda [3]**conducted experiments on single cylinder COMET engine at different speeds with karanja oil heated from 30° C – 100°C .It was reported that at all speeds, pre-heated fuel showed marginal increasein brake thermal efficiency and significant increase in NO_x as compared to unheated oil. **Avinash Kumar agrawal and K. rajamohan [4]** used karanja oil and its blends with diesel with and without preheating. They reported that, with pre-heated fuel engine efficiency slightly improved with lower brake specific energy consumption. It is also reported that pre-heated oil showed lower carbonmonoxide, Hydrocarbon emissions with increased NOx emissions. **Dhinagar et.al. [5]** conducted experiments with neem oil, rice bran oil and karnji oil with and without pre-heating. With pre-heated oils engine efficiency is improved. **T. K. Bhattacharya et al [6]** used diesel alcohol micro emulsions for diesel engine. They reported that with increase in percentage of alcohol and ethyle acetate in emulsion, the specific fuel consumption of engine increased due to their lower gross heat of combustion. The carbon monoxide emissions were reduced up to 44.4percent with different emulsions as compared to diesel. The hydrocarbon emission was marginally higher for all loads. Nitrogen Dioxide emissions were lower. **Kerihuel. M et. al. [7]** investigated performance of diesel engine with micro-emulsions of Animal fat with water and methanol. Lower exhaust gas temperature, higher volumetric efficiency with micro-emulsions were observed as compared to diesel. Lower unburnt hydrocarbon, carbon monoxide, Nitrogen oxide emissions were also observed with micro emulsions.

In this work, engine performance, emissions with unheated vegetable oil, preheated vegetable oil and emulsion of vegetable oil with ethanol are investigated.

II. Material and Experimental Setup

a) Materials

The non edible oil (Honge oil) is filtered through 2 micron oil filter supplied by AOF filters, Hyderabad. The vegetable oil is preheated to a temperature of 90°C(PSVO) to reduce its viscosity. The micro-emulsion, ESVO (emulsion of vegetable oil, ethanol and butanol) is prepared for investigation While preparing emulsion butanol is added to vegetable oil and then ethanol is added. The emulsion is stirred for three hours using magnetic stirrer. Various physical and chemical properties of diesel, vegetable oil and emulsion are determined using standard testing procedures and results are tabulated in table No. 1.Viscosity is measured by using redwood viscometer, calorific value was estimated using bomb calorimeter (supplied by Datacone industries Pvt. Ltd),flash and fire points are determined by using Marten-penesky closed cup apparatus. It can be seen that with increase in percentage of ethanol in emulsion its viscosity reduces.

Table No 1 : Properties of diesel, Honge oil and Micro-emulsions

Properties	Diesel	Neat Honge oil	ESVO
Viscosity in Cst	4.25	40.25	25.78
Flash point (°C)	79	190	42
Fire point (°C)	85	210	50
Calorific value(kJ/kg)	42700	37258	34633
Specific gravity (at25°C)	0.833	0.925	0.90

b) Experimental setup

A TV-1, Single cylinder, constant speed, direct injection, diesel engine manufactured by kirloskar oil engine limited is used for experimental investigations. This engine is generally used for running water pumps for irrigation and generator sets. It is coupled to a water cooled eddy current dynamometer for loading. Engine is equipped with thermocouples to measure temperature of coolant, exhaust gas and water at inlet and outlet of calorimeter. A rotameter is used to measure amount of water flow, a manometer with air box is used to measure air flow rate and burette is used to measure fuel flow. Detailed engine specifications are given in table no 2.

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Table No 2 : Specifications of Engine

Sl.No	Parameter	Specification
1	Type	Four stroke direct injection single cylinder diesel engine
2	Software used	Engine soft
3	Nozzle opening pressure	200 bar
4	Rated power	3.5KW @1500 rpm
5	Cylinder diameter	87.5 mm
6	Stroke	110 mm
7	Compression ratio	17.5

The fuel flow rate is measured on volumetric basis using burette. Fig 1 shows the schematic diagram of experimental setup. Two fuel tanks (one for diesel and other for test fuels) are connected to burette. The engine is first started with mineral diesel and switched on to test fuels. A four gas analyzer was used to measure concentration of NO_x, CO and Unburnt hydrocarbon in the exhaust. The smoke concentration is measured using smoke meter. Details of emission measuring instruments is tabled in Table No 3

Table No 3 : Specification of Gas analyser and smoke meter

Machine	Measurement Parameter	Range	Resolution
Gas Analyser	CO(Carbon Monoxide)	0-15%	0.01%
	CO_2 (Carbon Dioxide)	0-19.9%	0.1%
	NO_x (Oxides of Nitrogen)	0-5000ppm	1ppm
	HC(Hydrocarbon)	0-20000ppm	1ppm
DIESEL SMOKE METER	Opacity	0-99.9%	0.1%

Initially experiment is carried out with injection pressure and injection timing set by manufacturer (200 bar and 23deg btdc) and diesel fuel at different loads. With same settings, experiment is repeated with unheated vegetable oil (SVO), pre-heated vegetable oil (PSVO) and micro-emulsion (ESVO) of filtered vegetable oil and ethanol with butanol as emulsifier. Variation in humidity and ambient temperature is neglected because all tests are performed for short duration. During all experiments, engine loading is done using an eddy current dynamometer. Fuel consumption is measured using burette .Thermocouples are used to measure exhaust gas temperature before it enters to the exhaust gas calorimeter.

After completing tests on every test fuel, fuel lines, fuel filters are drained and sufficient new test fuel is allowed to flow so that no trace of previous test fuel remains in injection system. After this again engine is allowed to run for 10 min on new fuel so it can be ensured that engine is operating with required emulsion.

III. Results and Discussion

a) *Performance Parameters*

The significant performance parameters like Brake thermal efficiency, Specific energy consumption and Exhaust gas temperature are calculated and are discussed.

i. *Brake thermal efficiency*

The Variation of brake thermal efficiency (BTE) with load with different fuels is presented in Fig.2. In all cases the brake thermal efficiency increases with increase in brake power. This may be due to lower heat losses. It is noticed that the brake thermal efficiency is about 21.12%, 22.56% 23.33% and 31.85%, with SVO, PSVO, ESVO and diesel respectively. The reason for lower thermal efficiency with SVO is lower heat content, higher viscosity and poor volatility. With pre-heating and emulsions thermal efficiency increases due to reduction in viscosity, better atomization of fuel and better combustion. The increase in thermal efficiency is more with ethanol emulsion due to presence of inherent oxygen in ethanol improves the combustion process by supplying additional oxygen .

ii. *Brake Specific Energy Consumption*

The Brake Specific energy consumption (BSEC) is an ideal variable to compare fuels with different densities. Because it gives an idea of amount of heat energy supplied to develop the power. Better the combustion lower will be the BSEC. The BSEC decreased with increase in load due to better combustion. Variation in BSEC with load is presented in fig 3. The brake specific energy consumption (BSEC) with raw vegetable oil is highest among all test fuels this may be due to lower calorific value and poor atomization because of higher viscosity. The BSEC with preheated vegetable oil and micro emulsions is lower as compared to SVO due to improved combustion because of better atomization. The BSEC is lower with emulsion as compared to PSVO due to better atomization and micro-explosions of ethanol leading to a secondary atomization, enhancing the fuel atomization (Refer Fig.3.)

iii. *Exhaust Gas Temperature*

Fig 4 indicates the exhaust gas temperature for various fuels. The exhaust gas temperature increases with increase in load for all tested fuels. This increase in EGT is due the fact that at higher load, extra amount of fuel is injected to develop more power. The neat vegetable oil shows highest exhaust temperature (402°C) as compared to diesel due to slow combustion. This may be attributed to poor atomization due to high viscosity. Also poor volatility of SVO results in poor distribution of air fuel mixture in combustion chamber and poor or slow combustion. By preheating the vegetable oil viscosity of the fuel decreases and volatility of the fuel increase which results in better atomization and quick evaporation and mixing of fuel vapours with air. This results in faster combustion and low exhaust gas temperature. and emulsions. Lower exhaust gas temperature with emulsions is due to better atomization and reduction in charge temperature as a result of vapourization of ethanol and better combustion.

b) *Emission Parameters*

The main emissions from compression ignition engine are hydrocarbon, carbon monoxides, oxide of nitrogen, smoke and particulates.

i. *Carbon monoxide and hydrocarbon emissions*

Fig. 5 and Fig. 6 shows the CO and HC emissions with various fuels. The maximum CO emissions are found at rated power. The carbon monoxide emissions with vegetable oils are higher as compared to diesel fuel. This trend may be due higher viscosity and poor atomization. Micro emulsion and preheated vegetable oil show lower CO emissions as Compared to un-heated SVO. With preheated oil the CO emissions are reduced due to better spray characteristics which leads to more complete combustion. The ESVO show drastic reduction in carbon monoxide emissions as compared to straight vegetable oil due to lower viscosity and water admitted with ethanol replaces a portion of fuel containing carbon. In addition, the presence of ethanol increases the availability of oxygen during combustion resulting in more complete combustion. Some of the CO produced during combustion of emulsions may be converted into CO_2 by using extra oxygen molecule present in the emulsion.

Unburnt hydrocarbon emission from unheated vegetable oil fuelled engine higher as compared to diesel fuel. This may be due poor vaporization and improper atomization of the vegetable oil which results in incomplete combustion. The UBHC emissions are low with pre-heated oil because of impoved vapourization and better mixing of fuel vapours with air, more complete combustion. with micro-emulsion, the hydrocarbon emissions are lower than SVO and pre-heated oil at full load. But at part load HC emissions with ESVO are slightly higher than pre-heated oil this may be attributed presence of ethanol leads to lower combustion temperature which leads to partial combustion.

ii. *Nitrogen Oxide emissions (NO_x)*

The nitrogen oxide emissions increase with increase in load as the load increases, the overall fuel-air ratio increases resulting in increased average gas temperature in the combustion chamber.

Fig.7 shows variation of NO_x emissions with load. The NO_x emissions are lower with vegetable oils as poor volatility and lower heating value of vegetable oil gives lower premixed combustion resulting to lower combustion temperatures as compared to diesel fuel. Pre-heating of oil reduces the viscosity which results in improvement in combustion leads to higher NO_x emissions as compared to un-heated oil. Further NO_x emission with ESVO is drastically reduced due high latent heat of evaporation of ethanol and butanol and lower combustion temperatures along with shortened combustion duration.

iii. *Smoke emissions*

The smoke density is high at higher loads due to more fuel being injected into the combustion chamber resulting to incomplete combustion. Smoke emissions with vegetable oil are higher due to poor atomization, injection of larger droplets causing more over rich zones in combustion chamber. With Pre – heated oil and emulsion smoke emission is lower as Compared to SVO. The lower smoke emissions with micro-emulsions may be due to more complete combustion and presence of additional oxygen. (Fig. 8)

IV. Conclusions

Following conclusions are drawn from above investigation:

1. The brake thermal efficiency improved with pre-heated and emulsified vegetable oil as compared to unheated vegetable oil. The BTE with emulsions are very close to diesel.
2. Exhaust gas temperature is lower with micro emulsions and pre-heated oils due to better combusiton.
3. Carbon monoxide emission is lower with ESVO emulsion as compared to diesel, unheated and preheated vegetable oil.
4. Unburnt hydrocarbon emissions are higher with unheated vegetable oil and lower with pre-heated oil

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and ESVO at full load as compared to diesel due to lower combustion temperature. However lowest UBHC emissions are observed with ESVO.

5. Nitrogen oxide emission is lower with vegetable oil and micro-emulsions on account of lower combustion temperature. Whereas NO_x emissions are higher with pre-heated oil.
6. Smoke opacity is lower with pre-heated oil and ESVO.

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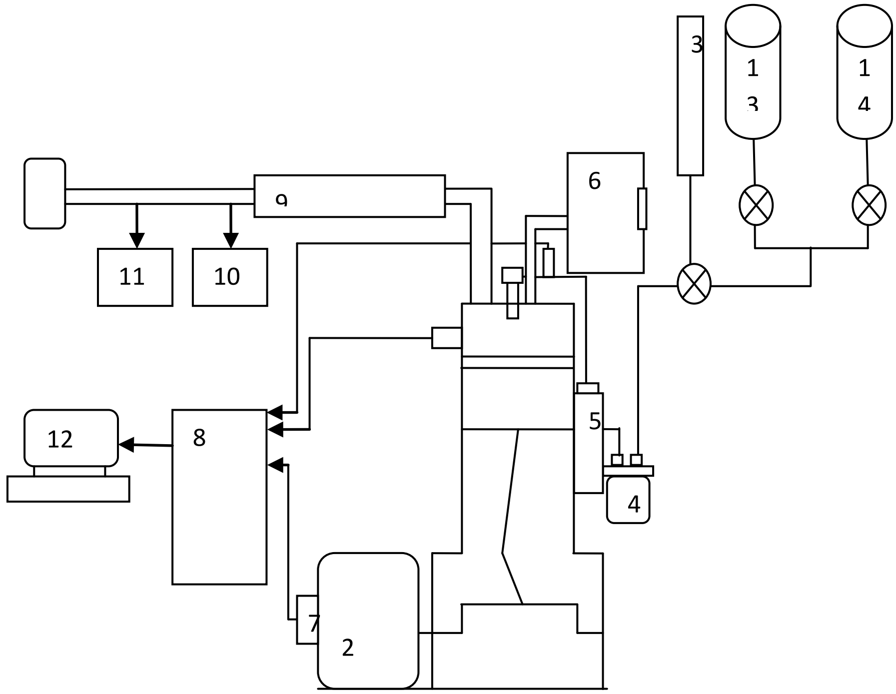

Figure 1: Schematic diagram of experimental setup.

1-Test engine, 2-Eddy current dynamometer, 3-fuel burette, 4-Fuel filter, 5-Fuel injection pump, 6- air box with U tube water Manometer, 7-TDC marker and speed sensor, 8- Data acquisition system and loading device , 9- Exhaust gas calorimeter, 10-Smoke meter,11-four gas analyser, 12-computer ,13 and 14- Fuel tanks.

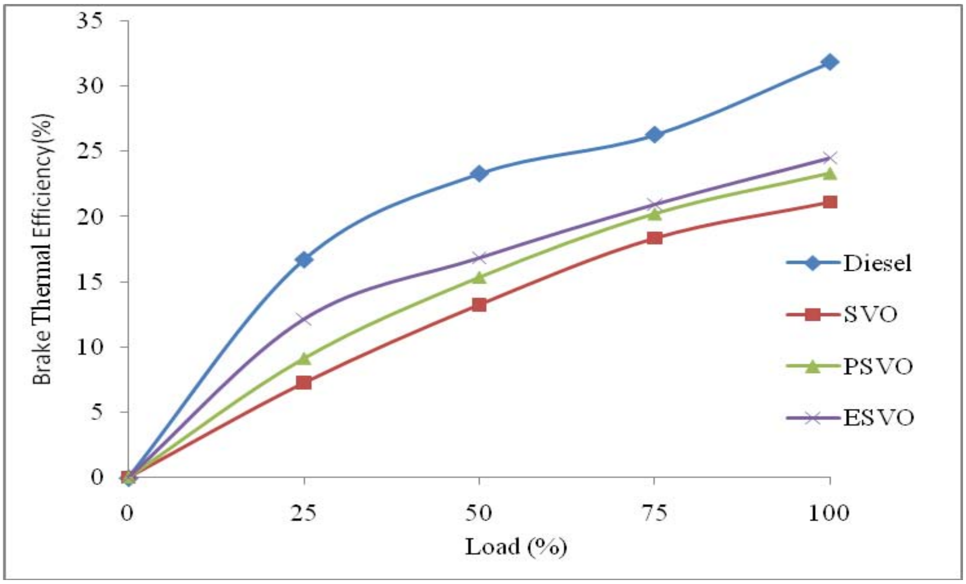

Figure 2 : Variation of Brake Thermal Efficiency with Un-heated & pre-heated Neat Vegetable oil and Emulsion

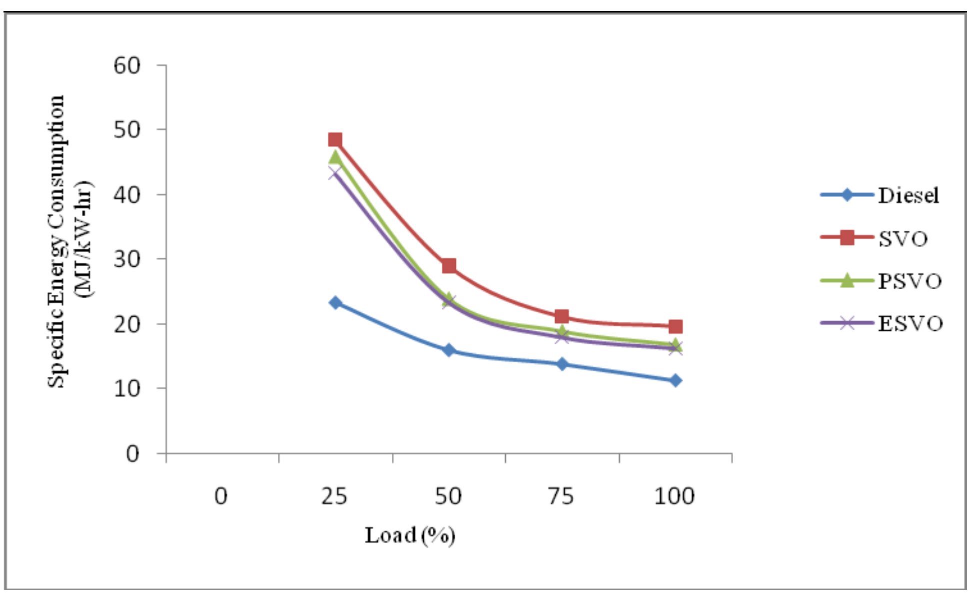

Figure 3 : Variation of Brake Specific Energy Consumption with Un-heated & preheated Neat Vegetable oil and Emulsion

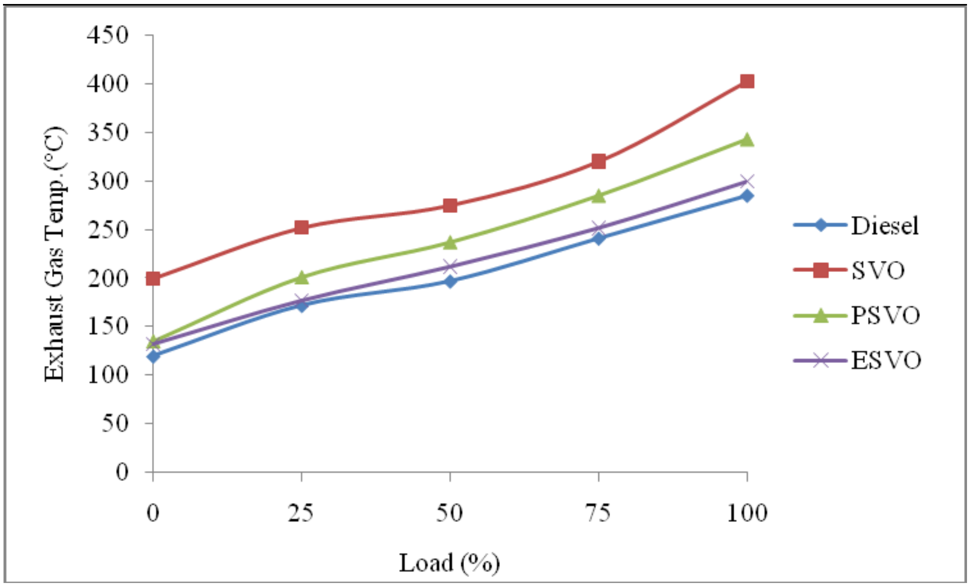

Figure 4 : Variation of Exhaust Gas Temperature with Un-heated & pre-heated Neat Vegetable oil and Emulsion

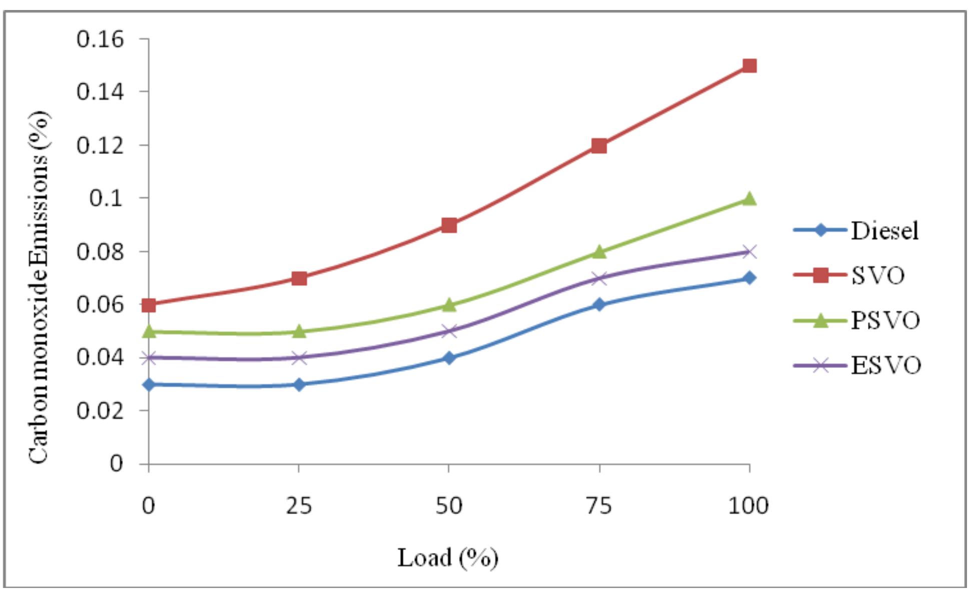

Figure 5 : Variation of Carbon Monoxide with Un-heated &pre-heated Neat Vegetable oil and Emulsion

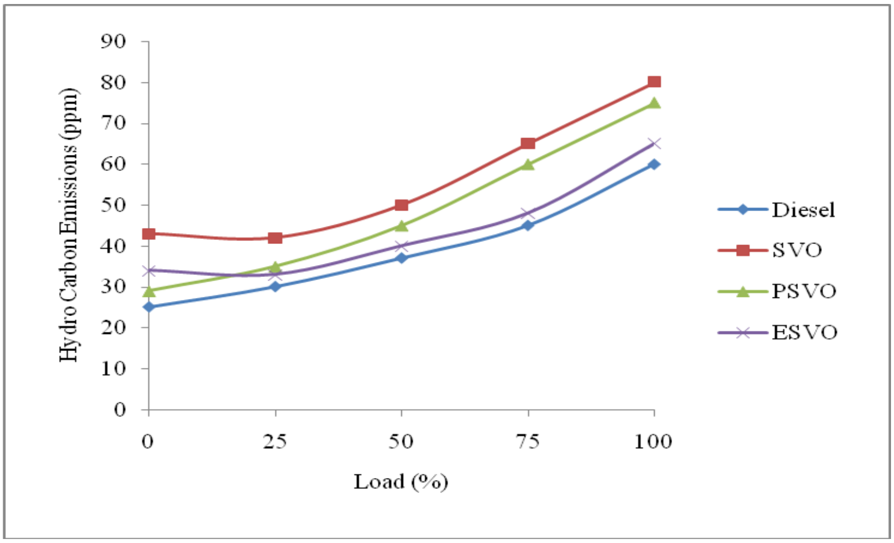

Figure 6 : Variation of Unburnt Hydrocarbons Un-heated &pre-heated Neat Vegetable oil and Emulsion

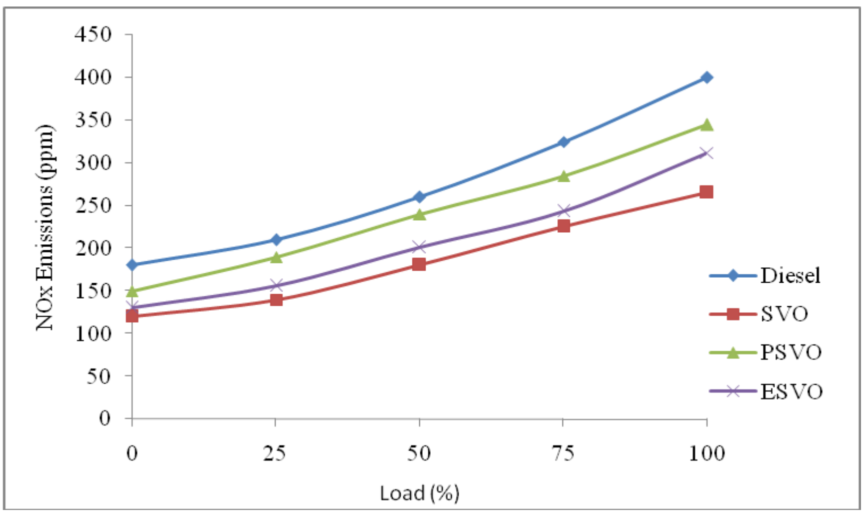

Figure 7 : Variation of Oxides of Nitrogen with Un-heated &pre-heated Neat Vegetable oil and Emulsion

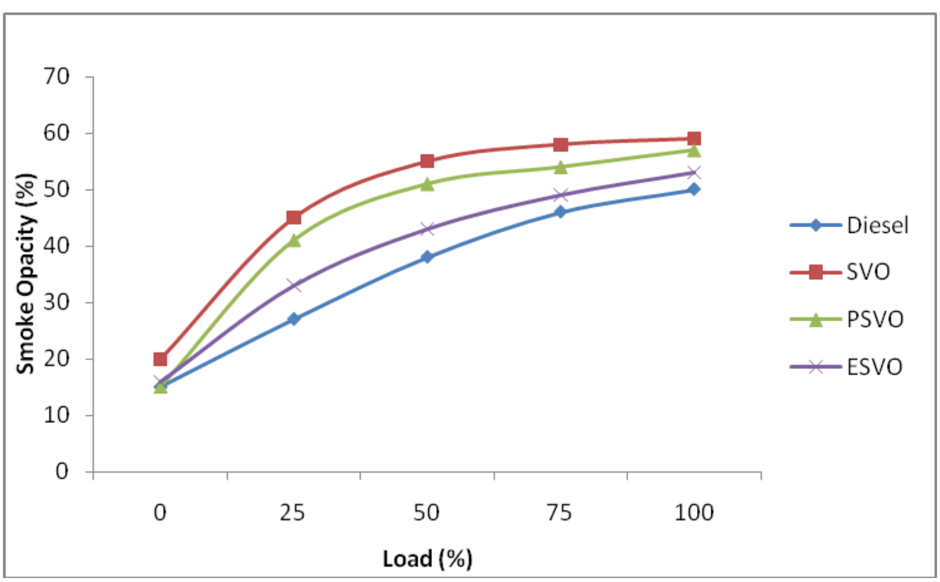

Figure 8 : Variation of Smoke Opacity with Un-heated &pre-heated Neat Vegetable oil and Emulsion