PERFORMANCE AND EMISSION CHARACTERISTICS OF STRAIGHT VEGETABLE OIL-ETHANOL EMULSION IN A COMPRESSION IGNITION ENGINE

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ABSTRACT

This paper investigates the performance and emissions of single cylinder, naturally aspirated, compression engine using Straight vegetable oil, its micro emulsions with ethanol and diesel fuel separately. During investigation, performance and emission parameters are measured with straight vegetable oil, micro emulsions of vegetable oil and ethanol and compared with petro diesel. The Micro emulsions are prepared to reduce the viscosity of vegetable oil. Basic properties like viscosity, calorific value, specific gravity are evaluated for all test fuels. The Straight vegetable oil (SVO) shows lower thermal efficiency, higher un-burnt hydrocarbon emissions etc. due to high viscosity and poor volatility. In long term, SVO show injector choking, fuel pump damage, fuel filter clogging etc. The emulsions of SVO with alcohol show lower viscosity, improved volatility, better combustion and less carbon deposits. The engine performance with the micro-emulsion ESVO-70 is very close to diesel fuel. Reduction in nitric oxide, carbon monoxide, and smoke emission are observed with increase in amount of ethanol in emulsion. It could be concluded that micro emulsion ESVO-70 can substitute diesel.

Keywords: compression ignition engine, vegetable oils, micro-emulsions, performance, emissions, blending, esterification.

1. 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 with regard to their energy needs.

There are many vegetable oils which can be used as fuel for diesel engines. But the edible oils like sunflower oil, peanut oils, soya oil, are costly and are for human consumption. The non edible oils obtained from plant species such as *Jatropha curcas* (Ratanjyot), *Pongamiapinnata* (Karanj), *honge, honne alophylluminophyllum* (Nagchampa), *Hevca brasiliensis, and rubber etc.* can be used as fuel for diesel engine. These non edible vegetable oil plant species can be grown on the land which is not suitable for agricultural purpose. The oil seeds upon crushing and extraction; oil can be obtained, which can be used as fuel for diesel engine. The vegetable oils offer many benefits including sustainability, regional development, reduction in green house gases and reduction on dependency on mineral diesel. Straight vegetable oils have very high viscosity which results into inferior engine performance.

One approach to utilization of vegetable oil as fuel has been to mix it with conventional diesel oil. These blends fall short of meeting the farmer's goal of energy self -sufficiency. Cracking and refining are effective in upgrading vegetable oils, but add considerably to the expenses and negate direct on farm utilization of the harvested product. Likewise, trans-estrification with a lower alcohol yields a fuel with lower viscosity and acceptable performance properties, but reduces the feasibility of direct use. Moreover, the trans esters have a solidification temperature about 4^oC, requiring the use of fuel pre heaters in cold winters.

The concept of diluting vegetable oil with ethanol, another agricultural based energy source is being investigated 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 disperse the water and alcohol in vegetable oil to form a micro-emulsion.

Many researchers tried to use vegetable oils with and without heating for diesel engine but it was found that the vegetable oils have very high viscosity and low volatility causing poor atomization, slow burning, high smoke emissions and erratic combustion.

Tadashi *et al*., [1] evaluated feasibility of rapeseed oil and palm oil for diesel engine. With palm oil, engine gave acceptable performance and emission levels for short term operations. However, they caused carbon deposits and sticking of piston rings with long run operations. Vellguth [2] analyzed the performance of diesel engine with vegetable oil; it was observed that the vegetable oils can replace diesel oil but unmodified engine coke up. Wang YD *et al*., [3] suggested that cotton seed oil can be directly used for diesel engine without any change in engine structure. In order to obtain highest power and thermal efficiency, engine parameters needs to be readjusted. Barsic *et al*., [4] tried to reduce the viscosity of vegetable oil by heating it before injection and found that the preheated vegetable oil solves the problem of filter clogging. Murayama *et al*., [5] concluded that heating vegetable oil up to 200^{0}C improved the engine performance, reduced the carbon deposits and sticking of piston rings. With preheating of vegetable oil, the brake thermal efficiency of diesel engine can be very close to that of diesel fuel.

There are many methods for reducing viscosity of oils by modifying its composition, namely; transestrification, blending of vegetable oils with suitable solvent, micro emulsification, pyrolysis and thermal cracking.

The trans-esterification is defined as the process of removal of all glycerol and fatty acids from the vegetable oil in presence of catalysts to obtain Biodiesel. It converts the triple chain triglyceride vegetable oil molecule to three single chain methyl (or ethyle) ester molecules, but the chain lengths of the fatty acids themselves remain the same. Biodiesel has lower viscosity than raw vegetable oil because of removal of all glycerol and the fatty acids from the vegetable oil.

Can Hasimonglu *et al*., [6] observed that, there was deterioration of engine power and engine torque with biodiesel due to higher viscosity. Higher specific fuel consumption was observed due to lower heating values. The in-cylinder combustion temperature was lowered due to lower heating values of biodiesel, and less heat lost to engine parts. D. Agrawal *et al*., [7] investigated performance of low heat rejection diesel engine operating with biodiesel of rice bran oil, it was observed that No_x emissions with bio diesel was higher due to presence of molecular oxygen. An exhaust gas recirculation was used for controlling the No_x emissions. However, application of EGR resulted in higher BSFC, increased HC, CO and particulate emissions.

D. Agrawal *et al*., [8] compared performance of linseed oil, rice bran oil and mahua oil with diesel. With 50% linseed oil blend with diesel, brake specific energy consumption was lower. However, the smoke density was higher. 30% mahua oil blend indicated higher thermal efficiency and lower smoke density as compared to diesel.

A micro emulsion is defined as the colloidal equilibrium dispersion of an optically isotropic fluid microstructures with dimensions generally in the range of 1-150nm formed spontaneously form two normally immiscible liquids and one or more ionic or non-ionic amphiphiles. Micro emulsions are transparent and thermodynamically stable colloidal dispersions. T.K. Bhattacharya *et al*., [9] 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 upto 44.4 percent 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*., [10] 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 was observed as compared to diesel. Lower unburnt hydrocarbon, carbon monoxide, Nitrogen oxide emissions were also observed with micro emulsions.

In this work, a constant speed diesel engine mostly used by farmers to run pumpset and other agricultural implements is operated with diesel, straight vegetable oil (SVO) and its micro emulsions (Honge oil with different proportions of ethanol and butanol). Experiments are conducted rated speed (at 1500 rpm) under variable loading conditions. The performance parameters like specific energy consumption, brake thermal efficiency, exhaust gas temperature and emission parameters like smoke density, nitrogen oxides, carbon monoxide and unburned hydrocarbon emissions are measured.

2. MATERIALS AND EXPERIMENTAL SETUP

2.1 Materials

The non edible oil (Honge oil) is filtered through 2 micron oil filter supplied by AOF filters, Hyderabad. Micro emulsions ESVO-80 (80%, 15%, and 05% of vegetable oil, ethanol and butanol v/v respectively) and ESVO-70 (70%, 20%, and 10% of vegetable oil, ethanol and butanol v/v respectively) are prepared for investigation. While preparing emulsion butanol is added to vegetable oil and then ethanol is added. The emulsion is stirred using magnetic stirrer. Various physical and chemical properties of diesel, ethanol, butanol, vegetable oil and emulsions are determined using standard testing procedures and the results are tabulated in Table-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-1. Properties of diesel, ethanol, butanol, Honge oil and micro- emulsions.

Properties	Diesel	Ethanol	Butanol	Neat Honge oil	ESVO-80	ESVO-70
Viscosity in Cst	4.25	1.2	3.67	40.25	25.78	10.12
Flash point (°C)	79	21	29	190	42	38
Fire point (°C)	85	25	32	210	50	45
Calorific value(kj/kg)	42700	27569	33254	37258	34633	34049
Specific gravity (at 25°C)	0.833	0.78	0.81	0.925	0.90	0.885

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2.2 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 temperature at inlet and outlet of calorimeter. Two piezoelectric sensors are used to measure cylinder pressure and a fuel pressure at the time of injection. 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-2.

Table-2. Specifications of Engine.

Parameter	Specification
Type	Four stroke direct injection single cylinder diesel engine
Software used	Engine soft
Nozzle opening pressure	200 bar
Rated power	3.5KW @1500 rpm
Cylinder diameter	87.5 mm
Stroke	110 mm
Compression ratio	12 to 18

The fuel flow rate is measured on volumetric basis using burette. Figure-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 are listed in Table-3.

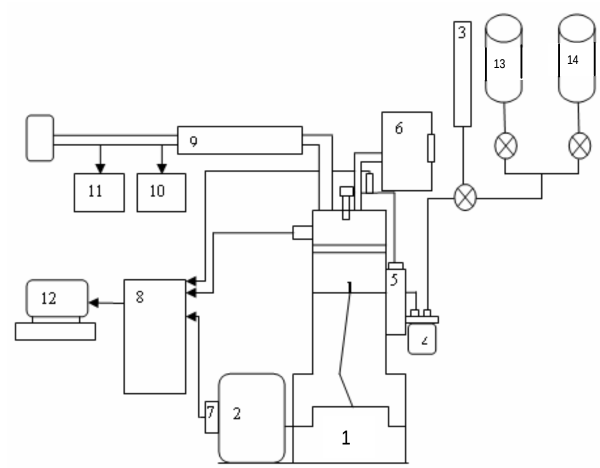

Figure-1. Schematic diagram of experimental setup.

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 analyzer, **12-**Computer, **13** and **14-** Fuel tanks,

Table-3. Specification of gas analyzer and smoke meter.

Machine	Measurement parameter	Range	Resolution
Gas analyzer	CO (Carbon Monoxide)	0-15 %	0.01 %
	CO_2 (Carbon Dioxide)	0-19.9 %	0.1 %
	NO_x (Oxides of Nitrogen)	0-5000 ppm	1 ppm
	HC (Hydrocarbon)	0-20000 ppm	1 ppm
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 micro-emulsions ESVO-80 and ESVO-70. 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 and after 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.

3. RESULTS AND DISCUSSIONS

3.1 Performance parameters

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

3.1.1 Brake thermal efficiency

The Variation of brake thermal efficiency (BTE) with load with different fuels is presented in Figure-2. In all cases the brake thermal efficiency increases with increase in brake power. This may be due to lower heat losses at higher loads. It is noticed that at full load, the brake thermal efficiency, with SVO, ESVO-80, ESVO-70 and diesel is about 21.12%, 23.33%, 24.49% and 31.85% respectively. The reason for lower thermal efficiency with SVO is higher viscosity, lower calorific value and poor volatility of vegetable oil results in poor atomization and poor spray characteristics. The poor spray pattern results in non homogenous fuel distribution in combustion chamber, which in turn results in poor combustion and lower thermal efficiency. The addition of ethanol to vegetable oil reduces the viscosity of the fuel and increases volatility. This results in improved combustion phenomenon with higher thermal efficiency. Further, it can be stated that inherent oxygen in ethanol improves the combustion phenomenon. As the percentage of alcohol in emulsion increases the brake thermal efficiency increases due to lower viscosity, better atomization and improved volatility.

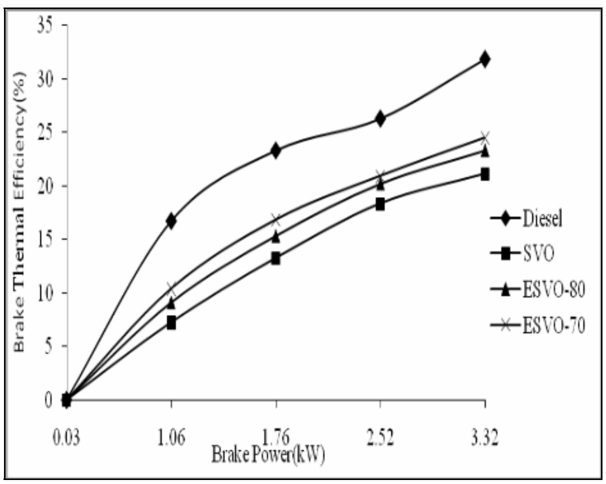

Figure-2. Variation of brake thermal efficiency with neat Vegetable oil and its emulsion.

3.1.2 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 same power. Better the combustion, lower will be the BSEC. The BSEC decreased with increase in load due to better combustion and lower heat losses. Variation in BSEC with the brake power 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. With micro emulsions, it is observed that, the BSEC is improved as compared to raw vegetable oil due to better atomization because of lower viscosity and increased volatility. Also micro-explosion of ethanol in emulsion leads to secondary atomization and reduces the mean diameter of injected fuel. BSEC improves with increase in percentage of ethanol due to improved atomization, better combustion (Figure-3).

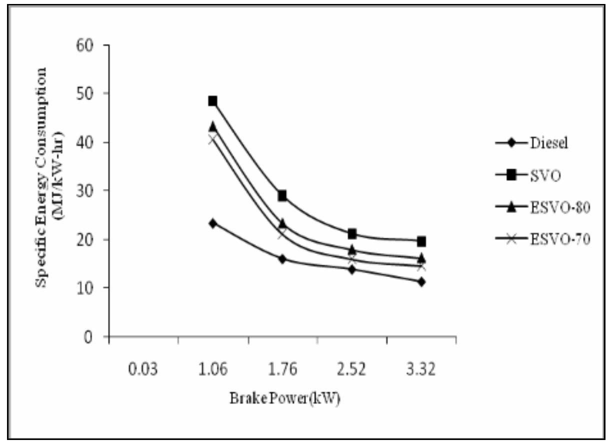

Figure-3. Variation of brake specific energy consumption with neat vegetable oil and its emulsion.

3.1.3 Exhaust gas temperature

Figure-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 and emulsions. The reason for higher exhaust gas temperature was poor atomization of vegetable oil due to higher viscosity which causes slow combustion and part of the oil supplied may burn late in cycle. Lower exhaust gas temperature with emulsions is due to the reduction in charge temperature as a result of vaporization of ethanol and better combustion. It is also observed that with increase in ethanol percentage in emulsion exhaust gas temperature decreases due to improvement in combustion process.

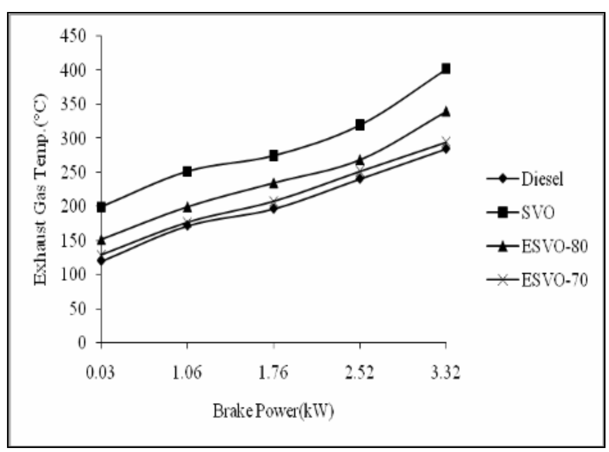

Figure-4. Variation of exhaust gas temperature with neat Vegetable oil and its emulsion.

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3.2 Emission parameters

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

3.2.1 Carbon monoxide and hydrocarbon emissions

Figures 5 and 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, poor distribution of fuel in combustion chamber. Addition of ethanol to vegetable oil lowers the CO emissions due to better spray characteristics, micro explosions of ethanol and water (As the ethanol added contains 1% water) and less carbon content in ethanol. Some of the CO produced during combustion of emulsions may be converted into CO_2 by using extra oxygen molecule present in the emulsion. The vegetable oil emulsions show higher carbon monoxide emission at low power output as compared to medium loads. The increase in the carbon monoxide levels with ethanol emulsion at low loads is the result of incomplete combustion of ethanol-air mixture. ESVO-70 shows lower carbon monoxide emissions as compared to other test fuel especially at high loads. At low loads ESVO-70 shows slightly higher CO emission as compared to ESVO-80.

Unburnt hydrocarbon emission from vegetable oil fuelled engine is higher as compared to diesel fuel. This may be due poor vaporization and improper atomization of the vegetable oil and poor mixing of vegetable oil with air which results in incomplete combustion .The UBHC emissions are low with micro-emulsions. This is due to overall reduction in the amount of carbon admitted into the engine and better combustion. However, emulsions show slightly higher HC emissions at light loads as compared to partial load conditions. This may be due to the fact that large amount of ethanol present in emulsions causes lower combustion temperatures and leads to partial combustion of fuel. With increase in ethanol in emulsions, UBHC emissions lowered at high loads but hydrocarbon increased at low loads.

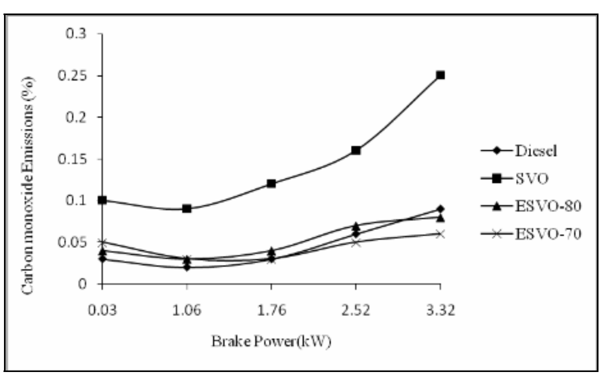

Figure-5. Variation of carbon monoxide with neat Vegetable oil and its emulsion.

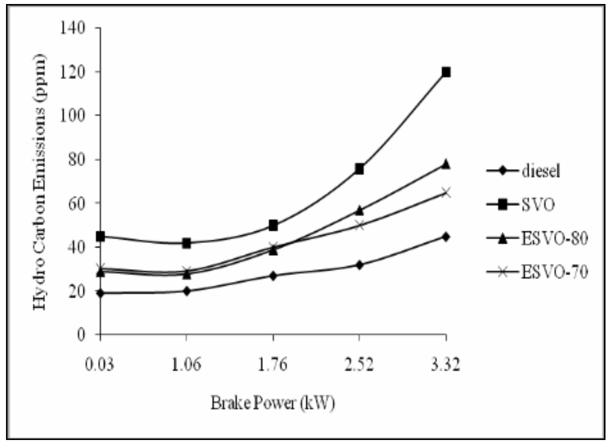

Figure-6. Variation of unburnt hydrocarbons with neat vegetable oil and its emulsion.

3.2.2 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.

Figure-7 shows variation of NO_x emissions with brake power. 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. Further NO_x emission with ESVO-70 is drastically reduced due high latent heat of evaporation of ethanol and butanol and lower combustion temperatures along with shortened combustion duration.

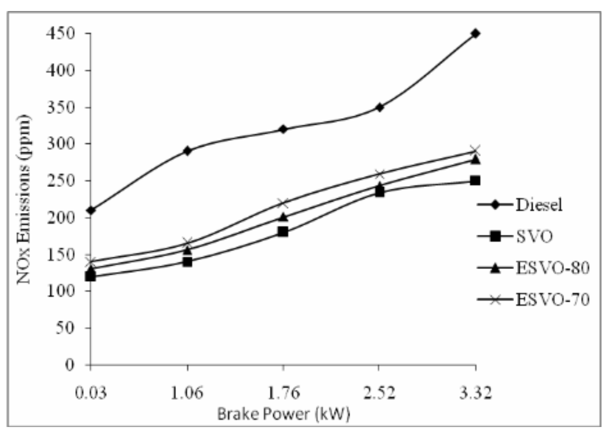

Figure-7. Variation of oxides of nitrogen with neat Vegetable oil and its emulsion.

3.2.3 Smoke Opacity

The smoke opacity is high at higher loads due to more fuel being injected into the combustion chamber resulting to incomplete combustion. Smoke opacity with vegetable oil is higher and with emulsions is lower as compared to mineral diesel. The heavier molecular structure and higher viscosity of SVO lead to poor atomization result in higher smoke opacity in spite of lower carbon content in vegetable oil than diesel. The lower smoke opacity with micro-emulsions may be due to more complete combustion and presence of oxygen in these fuels (Figure- 8).

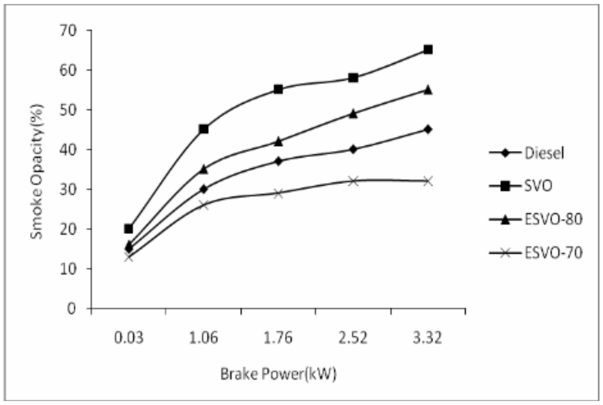

Figure-8. Variation of smoke density with neat Vegetable oil and its emulsion.

4. CONCLUSIONS

Following conclusions are drawn from the above investigations:

a) The brake thermal efficiency with ESVO-70 is close to the mineral diesel;
b) The brake specific energy consumption with ESVO-70 is lower on account of better atomization and improved combustion;
c) Exhaust gas temperature is lower with micro emulsions;
d) Carbon monoxide emission is lower with emulsions as compared to diesel. The CO emission lowers with increase in percentage of ethanol in emulsions;
e) At full load, Unburnt hydrocarbon emissions are higher with vegetable oil and its emulsions as compared to diesel;
f) Nitrogen oxide emission is lower with vegetable oil and micro-emulsions as compared to diesel on account of lower combustion temperature;
g) Smoke opacity is lower with emulsions as compared to straight vegetable oil; and
h) With increase in percentage of ethanol in emulsion, the engine performance and emission characteristic are improved.

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