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Effect of Ethanol addition to Straight Vegetable oil on Performance and Emission Characteristics of Compression Ignition Engine

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Abstract— Experimental investigations have been carried out to evaluate the effect of addition of ethanol to vegetable oil on performance and emission characteristics of a compression ignition engine. Use of straight vegetable oil (SVO) for diesel engine is limited due to their higher viscosity and poor volatility. The SVO shows lower thermal efficiency and higher unburnt hydrocarbon emissions, etc. In long term, SVO exhibits injector coking, fuel pump damage and fuel filter clogging, etc. To reduce the viscosity and to increase the volatility of the fuel, an ethanol is added to the vegetable oil so that thermal efficiency and emissions can be improved.

During investigation, blends of vegetable oil with different proportions of ethanol are prepared. Blends BSVO-80 and BSVO -70 are prepared using 20% and 30% of ethanol with SVO respectively. Basic properties like viscosity, calorific value, specific gravity, etc. are evaluated for all test fuels.

The blends of SVO with alcohol show lower viscosity, improved volatility, better combustion and less carbon deposits as compared to SVO. Improvement in brake thermal efficiency, reduction in oxides of nitrogen, carbon monoxide and smoke emissions are observed with increase in amount of ethanol in blend. The engine performance with the blend BSVO-70 is in closer approximation with diesel fuel. It could be concluded that blend BSVO-70 can be a good substitute for diesel.

Index Terms— Compression Ignition engine, Vegetable oils, Blend, Performance, Emissions, Esterification.

1 Introduction

In country like India, majority of population lives in rural areas and they depend on agriculture. In the event of regular electricity failure, diesel engines are used to operate water pump sets and other agricultural implements. 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 available, which can be used as fuel for diesel engines. Use of edible oils like sunflower oil, peanut oils and soya oil, etc. for diesel engine may cause conflict between food and fuel. The non edible oils obtained from plant species such as Jatropha curcas (Ratanjyot), Pongamiapinnata (Karanj), Calophylluminophyllum (Nagchampa), Hevca brasiliensis, honge, honne 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 vegetable oils offer many benefits including sustainability, regional development, reduction in green house gases and reduction on dependency on mineral diesel, etc. Straight vegetable oils have very high viscosity which results in inferior engine performance and higher emissions.

One approach to utilization of vegetable oil as fuel is to blend it with conventional diesel oil. These blends fall short of meeting the farmer's goal of energy self –sufficiency. Cracking is 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 properties, but reduces the feasibility of direct use of vegetable oil. The concept of diluting vegetable oil with ethanol, another agricultural based energy source being investigated for on the farm preparation of fuel.

Many researchers have tried to use vegetable oils (with or without heating) for diesel engine but they found that the vegetable oils have very high viscosity and low volatility causing poor atomization, slow burning, poor engine performance, higher emissions and inconsistant combustion, etc.

Tadashi et al. [1] evaluated feasibility of rapeseed oil and palm oil for diesel engine. With vegetable oils, engine gave acceptable performance and emission levels for short term operations. However, it caused carbon deposits and sticking of piston rings in 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. Y.He 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

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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°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 was very close to that of diesel fuel.Can Hasimonglu et al. [6] observed that, there was deterioration of engine power and engine torque with biodiesel due to their higher viscosity. Higher specific fuel consumption was observed due to lower heating values. The in-cylinder combustion temperature was lower 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 Nox 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, the 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 a 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. Mustafa Canakci et al. [11] conducted experiments on single cylinder diesel engine with methanol- diesel blend to investigate effect of percentage of methanol on engine performance and emission characteristics.It was observed that with increase in percentage of methanol in blend, BSEC and BSFC decreased with reduction in smoke,CO and HC emissions and increased NO_x and CO_2 emissions. Prommes K. Wanchareon et al.[12] used diesel-biodiesel-ethanol blend for running diesel engine. They found that the calorific value, cetane number, flash point,etc. of blends were lower than diesel.The heating value of the blends contaning lower than 10% ethanol was not significantly different than diesel. Use of blends resulted in lower emissions as compared to diesel.

In this work, a constant speed diesel engine is operated with diesel, straight vegetable oil (SVO) and its blends (Honge oil with different proportions of ethanol). 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 opacity, oxides of nitrogen, carbon monoxide and unburned hydrocarbon emissions are calculated/measured and compared with diesel.

2. Material and Experimental setup:

2.1. Materials:

A straight vegetable oil (SVO) namely Honge oil and its blends BSVO-80 (80% of vegetable oil, 20% ethanol) and BSVO-70 (70% of vegetable oil and 30% ethanol) are prepared for investigation. Various physical and chemical properties of diesel, ethanol, vegetable oil and its blends are determined using standard testing procedure and results are tabulated in table No. 1. Viscosity is measured using redwood viscometer, calorific value was estimated using bomb calorimeter, flash and fire points are determined by using Marten-penesky closed cup apparatus. It is observed that viscosity of the blends decreased with increase in percentage of ethanol.

TABLE 1
Properties of Diesel, ethanol and vegetable oil - ethanol blends

Properties	Diesel	Ethanol	Neat Honge oil	BSVO-80	BSVO-70
Viscosity in cSt	4.25	1.2	40.25	24.20	10.08
Flash point(°C)	79	21	190	40	37
Fire point(°C)	85	25	210	47	42
Calorific value(kj/kg)	42700	27569	37258	34312	34105
Specific gravity	0.833	0.78	0.925	0.89	0.86

2.2. Experimental setup:

The experiments are conducted on a single cylinder, four stroke, direct injection, naturally aspirated compression ignition engine. The technical details of the engine are given in Table 2. This type of engine is primarily used for agricultural purpose in India. The computerized diesel engine test rig supplied by Apex Innovations is used for investigations. The test setup consists of electrical dynamometer for loading the engine. The load on the dynamometer is measured using strain gauge load sensor. An air cooled piezo-quartz pressure sensors supplied by piezotronics Ltd, USA are mounted in cylinder head and between injection pump and injector to measure cylinder pressure and fuel injection timings respectively. The pressure sensor signals are obtained at every 1°crank angle. These signals are passed to charge amplifier for amplification. The crank shaft position is measured by using Kublar -Germany encoder. The Coolant temperature, exhaust temperature and air temperature are measured using thermocouples. The fuel flow rate is measured on volumetric method using differential pressure transducer. Figure 1 shows the schematic diagram of experimental setup. Exhaust gas analyser is used for measuring carbon monoxide, unburnt hydrocarbon and oxides of nitrogen emissions. A smoke meter is used for measurement of smoke opacity. The details of exhaust gas analyser and smoke meter are given in table no.3.

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, experiments are repeated with blends BSVO-80 and BSVO-70. Variation in humidity and ambient temperature is neglected because all tests are performed for short duration. During all experiments, engine is allowed to run at rated speed of 1500 rpm and at 25%, 50%, 75% and 100% load conditions. 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 fuel.

TABLE 2
ENGINE SPECIFICATIONS

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

TABLE 3
SPECIFICATIONS 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%

3 RESULTS AND DISCUSSION:

3.1. PERFORMANCE PARAMETERS:

The performance parameters like Brake thermal efficiency, Specific energy consumption and Exhaust gas temperature are calculated/ measured for different fuels and discussed in following paragrphs.

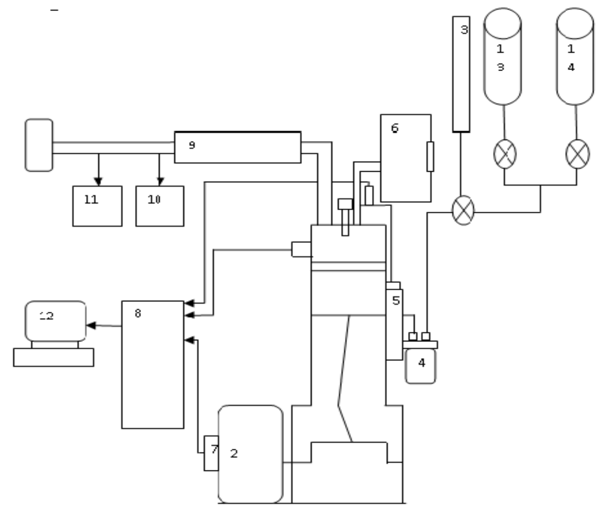

Fig. 1 Experimental Set up

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 & 14 Fuel tanks

3.1.1. BRAKE THERMAL EFFICIENCY (BTE):

The Variation of brake thermal efficiency (BTE) with different fuels is presented in Fig.2. In all cases, the brake thermal efficiency increases with increase in load. It is noticed that at full load, the brake thermal efficiency with SVO, BSVO-80, BSVO-70 and diesel is about 21.12%, 23.93%, 24.60% and 31.851 % respectively. The reason for lower thermal efficiency with SVO is its higher viscosity, lower calorific value and poor volatility which results in poor atomization and spray pattern. The poor spray pattern results in non homogenous fuel distribution in combustion chamber, resulting in poor combustion and lower thermal efficiency. The addition of ethanol to vegetable oil reduces the viscosity and increases volatility of the fuel. This results in improved combustion phenomenon and higher thermal efficiency. Further, presence of inherent oxygen in ethanol improves the combustion phenomenon. Increase in percentage of al-

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cohol in blend increases the brake thermal efficiency due to reduction in viscosity, better atomization and improvement in combustion phenomenon.

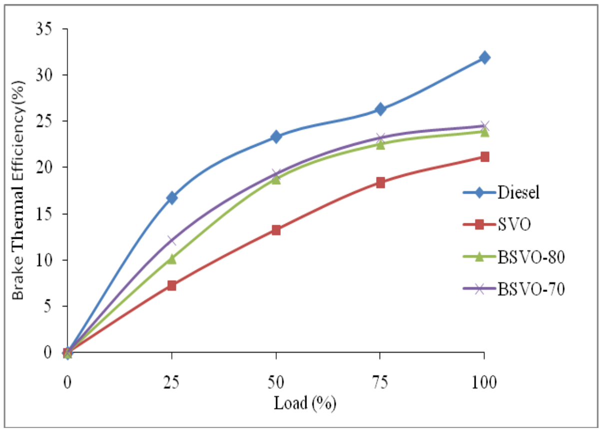

Fig. 2. Varitation in brake Thermal efficiency with different fuels

3.1.2 Brake Specific Energy Consumption (BSEC):

The Brake Specific energy consumption (BSEC) is an ideal parameter for comparing fuels with different densities. Because it gives an idea of amount of heat energy supplied to develop the same power irespecitive of fuel properties. The BSEC decreases with increase in load due to better combustion and lower heat losses. Variation in BSEC for various fuels is presented in fig 3. The brake specific energy consumption (BSEC) with straight vegetable oil (SVO) is highest among all test fuels due to its lower calorific value and poor atomization because of its higher viscosity. With blends, the BSEC is improved as compared to straight vegetable oil due to reduction in viscosity, improvement in volatility and better atomization. Also micro-explosion of ethanol and traces of water in blend leads to secondary atomization which reduces the mean diameter of injected fuel. It is observed that BSEC improves with increase in percentage of ethanol. BSVO-70 shows lower BSEC as compared to SVO and BSVO-80.

3.1.3. Exhaust Gas Temperature (EGT):

Fig 4 indicates variation in exhaust gas temperature for various fuels. The exhaust gas temperature increases with increase in load for all tested fuels. The straight vegetable oil shows highest exhaust temperature as compared to diesel and blends. The reason for higher exhaust gas temperature is 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 blends is due to reduction in charge temperature as a result of vaporization of ethanol and improvement in combustion process. It is also observed that with increase in ethanol percentage in blend, exhaust gas temperature decreases due to improvement in combustion process.

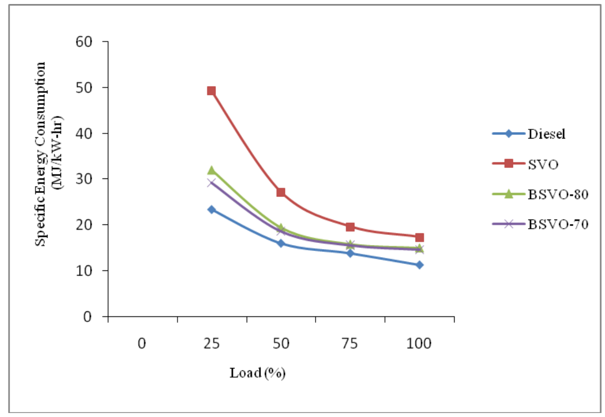

Fig. 3. Varitation in Brake Specific Energy Consumption with different fuels

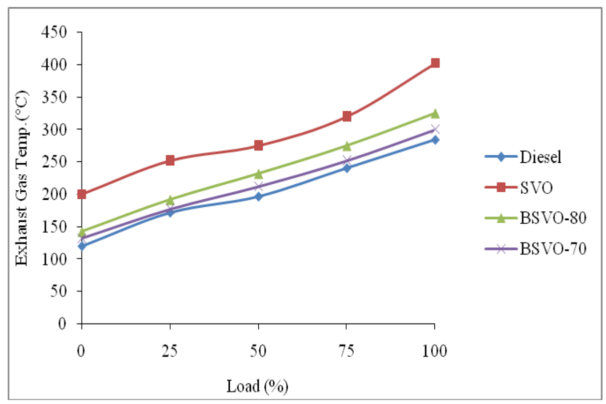

Fig. 4. Varitation in Exhaust Gas Temperature with different fuels

3.2. Emission Parameters:

3.2.1 Carbon monoxide emissions (CO):

Fig. 5 shows the CO emissions with various fuels. The maximum CO emissions are found at rated power. The straight vegetable oil exihibits highest carbon monoxide emissions as compared to other test fuels.

Addition of ethanol to vegetable oil resulted in lower CO emissions due to better spray characteristics, micro explosions of traces of water (0.1%) and less carbon content in ethanol. Some of the CO produced during combustion of blend may be converted into CO_2 by using extra oxygen molecule present in the blends. The vegetable oil blends show higher carbon monoxide emissions at lower loads as compared to medium loads. The increase in the carbon monoxide levels with blends at lower loads may be due to incomplete combustion of ethanol-air mixture. BSVO-70 shows lower carbon monoxide emissions as compared to other test fuel especially at high loads. At low loads, BSVO-70 shows slightly higher CO emission as compared to BSVO-

80 and diesel.

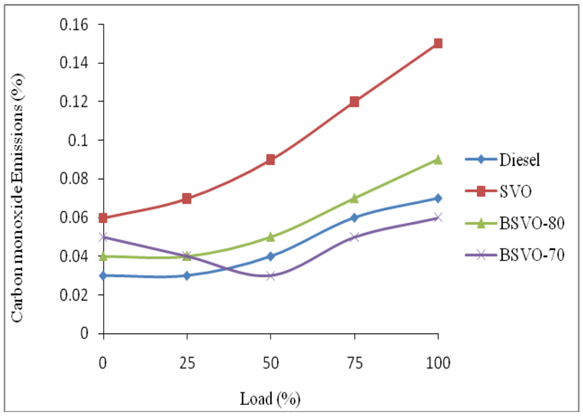

Fig. 5. Varitation in Carbon monoxide emissions with different fuels

3.2.2 Unburnt hydro-carbon emissions(UBHC):

Unburnt hydrocarbon emissions from vegetable oil fuelled engine are higher as compared to diesel fuel. This may be due poor vaporization, improper atomization of the vegetable oil and poor mixing of vegetable oil with air and incomplete combustion. The UBHC emissions are lower with blends as compared to neat vegetable oil. This may be attributed to improved combustion because of lower viscosity and higher volatility of blends. Also, overall reduction in the amount of carbon admitted into the engine due to addition of ethanol. However, blends show slightly higher HC emissions at lower loads as compared to partial load conditions. This may be due to the fact that large amount of ethanol present in blends causes lower combustion temperatures and leads to partial combustion of fuel. Increase in ethanol in blends results in lower UBHC emissions at high loads and marginal increase in hydrocarbon emissions at lower loads as compared medium loading conditons. BSVO-70 shows lowest UBHC emissions as compared to other test fuels. (Fig. 6).

3.2.3 Oxides of nitrogen emissions (NO_x):

The oxide of nitrogen emissions increases with increase in load due to increase in overall fuel-air ratio and increased average gas temperature in the combustion chamber.

Fig.7 shows variation of NO_x emissions with various test fuels. The NO_x emissions are lower with vegetable oil due its poor volatility and lower heating value; lower premixed combustion resulting to lower combustion temperature. NO_x emissions with blends are marginally higher as compared to straight vegetable oil. With increase in proportion of ethanol in blend, NO_x emission increased due to improvement in combustion phenomenon. The rate of rise in NO_x is lower due high latent heat of evaporation of ethanol which results in lower combustion temperatures. The BSVO-70 shows slightly higher NO_x emissions as compared to BSVO-80.

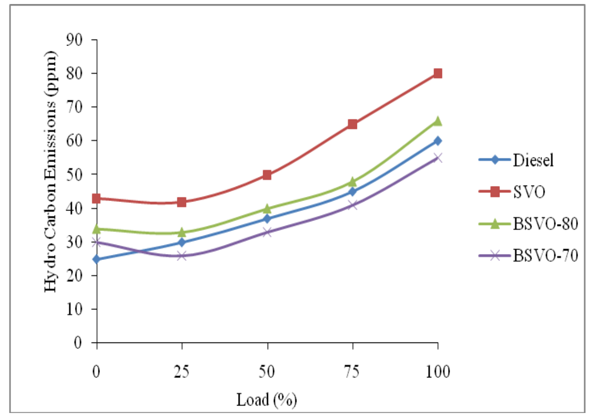

Fig. 6. Varitation in Unburnt Hydrocarbon emissions with different fuels

3.2.4 Smoke Opacity (SO):

The smoke opacity is high at higher loads due to more fuel being injected into the combustion chamber causing incomplete combustion. The Smoke opacity is higher with straight vegetable oil due to poor combustion. The heavier molecular structure and higher viscosity of SVO leads to poor atomization and poor combustion. The blends show lower smoke opacity due to improvement in combustion phenomenon.The smoke opacity decreased with increase in percentage of ethanol in blend due to increased volatility and more complete combustion. At full load, lowest smoke opacity is observed with BSVO-70 (Fig.8).

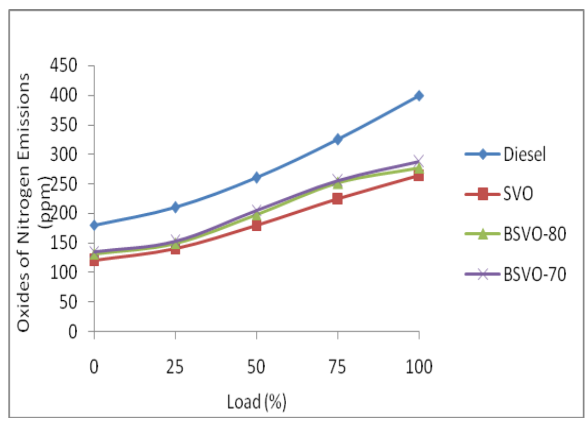

Fig. 7. Varitation in Oxides of Nitrogen emissions with different fuels

4. Conclusions

Following conclusions are drawn from above investigation:

1. The brake thermal efficiency with vegetable oil blends is higher than straight vegetable oil due to better combustion characteristics. BSVO-70 shows BTE closer to diesel.
2. The brake specific energy consumption with blends is lower as compared to SVO on account of better atomiza-

tion and improved combustion. Increase in ethanol in blends resulted in lower BSEC.

3. The exhaust gas temperature is lower with vegetable oil – ethanol blends as compared to SVO. This is due to lower combustion temperature.
4. Unburnt hydrocarbon emissions are highest with straight vegetable oil. Blends show lower hydrocarbon emissions as compared to SVO. BSVO-70 exihibits lower UBHC emissions as compared to other test fuels.

5. Carbon monoxide emissions are lower with blends compared to SVO. The CO emission lowers with increase in percentage of ethanol in blends. The CO emissions with BSVO-70 are lower than diesel.
6. NO_x emissions are lower with vegetable oil and blends as compared to diesel on account of lower combustion temperature. Increase in proportion of ethnol in blend shows marginal increase in NO_x emissions.
7. Overall, it can be said that increase in percentage of ethanol in blends results in improved engine performance and emission characteristics.

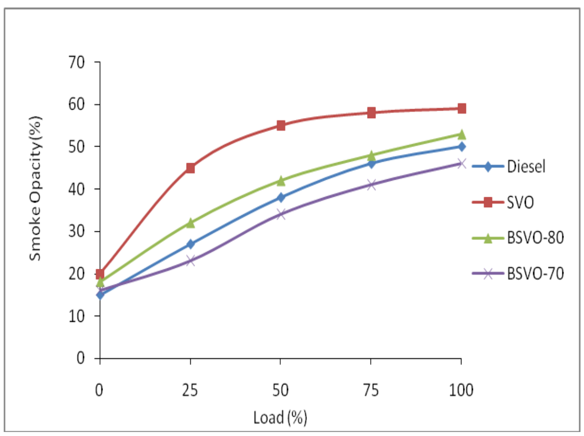

Fig. 8. Varitation in Smoke Opacity with different fuels

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Nandkishore D.Rao was born in Karnataka, India. He has received his B.E degree in Automobile Engineering from Gulbarga University, Gulbarga and M.E. degree in Mechanical Engineering from Veermata Jijabai Technological Institute, Mumbai in 2000. Currently he is working as an Associate professor and Head of Automobile Engineering, Guru Nanak Dev Engineering College, Bidar. He has 18years of teaching experience. He is presently a research scholar in JNTU, Hyderabad. He is working in the area of Biofuels.

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