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Comparative Assessment of Sal Methyl Ester and Kusum Methyl Ester with Diesel in CI Engine

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Abstract: *The present world scenario faces a serious threat from increasing dependence on fossil fuels. This has triggered the awareness to discover alternative energy as their sustainable energy sources. Biodiesel as a cleaner renewable fuel may be considered as a good substitution for diesel fuel due to it being used in any compression ignition engine without any modification. The main advantages of using biodiesel are its renewability and better quality of exhaust gas emissions. There has been increasing concerns that biodiesel feedstock may compete with food supply in the long term. The recent paper focuses on use of two non-edible oils Kusum oil and sal oil which abundantly available in India. The acid number of sal oil was found to be lower than kusum oil. Hence, the base catalyzed transesterification process was employed for production of sal oil methyl ester. On the other hand, kusum oil due to its higher free fatty acid content was esterified first and then, transesterified. B20 blend of biodiesels were used since it balances the property differences with conventional diesel e.g. performance, emission benefits and cost. Further, B20 blend can be used in automotive engines without modification. The present study focuses on the comparison of performance and emission characteristics of kusum oil biodiesel blends and sal oil biodiesel blends with diesel. Results showed better performance of sal methyl ester than kusum methyl ester. Emissions of CO, UHC and smoke are lower than neat diesel in both cases. Both B20 biodiesel blends were suitable for engine application.*

Keywords: *Diesel engine, emission, kusum oil, sal oil, performance*

1. INTRODUCTION

Energy is a crucial factor for humanity to continue the economic growth and maintain high standard of living. It is anticipated that the world will need 50% more energy in 2030 than today, of which 45% will be accounted for by China and India [1, 2, and 3]. Declining reserves of fossil fuels beside recognition that climate change is stemmed by growing carbon dioxide emissions has generated the interest in promoting biofuels as one of the leading renewable energy sources. The sustainable production of biofuels is a valuable tool in stemming climate change, boosting local economies, particularly in lesser-developed parts of the world, and enhancing energy security for all [4]. Biodiesel seems very interesting for several reasons; it is highly biodegradable and has minimal toxicity, can replace diesel fuel in many different applications such as boilers and internal combustion engines without major modifications. Furthermore, a small decrease in performances is reported, and it almost emits zero emissions of sulphates, aromatic compounds and other chemical substances that are destructive to the environment.The carbon dioxide (CO_2) emissions are relatively low when the whole life-cycle is considered (including cultivation, production of oil and conversion to biodiesel) and it appears to cause significant improvement of rural economic potential [5]. Biodiesel has been in use in many countries such as United States of America, Malaysia, Indonesia, Brazil, Germany, France, Italy and other European countries. Therefore, there is a good potential for its production and application. Globally, annual biodiesel production increased from 15 thousand barrels per day in 2000 to 289 thousand barrels per day in 2008 [6].

To support the aforementioned line of discussion, vegetable oils have been long considered and evaluated as a potential alternative for mineral diesel. The major problem with vegetable oils, however, has been their higher viscosity than that of diesel. The increased viscosity in vegetable oils is primarily due to presence of unsaturated free fatty acids and also the higher molar mass of the oils. When the engine temperature is high, unsaturated fatty acid polymerizes, thereby leading to creation of large agglomerations and subsequent gumming. It has been observed that the fuel injectors get choked after few hours of operation on vegetable oils in a direct injection diesel engine. Serious engine fouling is observed in the diesel engine as a result of incomplete fuel combustion and carbon deposition on the injector and valve seat which is attributed to the poor fuel atomization caused by higher viscosity of the vegetable oil. As a result of incomplete combustion, dilution and thickening of the lubricating oil occurs [6]. Therefore, vegetable oils are not recommended for direct diesel engine application. However, there are several methods like dilution, pyrolysis, transesterification and engine hardware modification through which vegetable oil can be used in diesel engines. Amongst these methods, transesterification has been established as the most documented and universally accepted method to use vegetable oils for diesel engine application. Transesterification is a chemical process in which the triglycerides of the vegetable oil are converted in to mono-alkyl esters and glycerol in the presence of a catalyst [7]. The vegetable oil alkyl esters are popularly known as biodiesel and have properties very similar to mineral diesel. The biodiesel can be derived from a wide range of vegetable oils, animal fats etc.

However, production of biodiesel from non-edible oil crops is of paramount significance in India on account of lack of self reliability of the country in edible oil production. In the light of the above discussion, it may be concluded that biodiesel derived from non-edible vegetable oils are a promising option to provide energy security in Indian context.

In the present research work focuses on biodiesel production from tree borne non-edible oilseeds known as “Sal and Kusum” to evaluate its potential as alternatives fuel in diesel engines. Sal (Shorea robusta) is grown over 10 million hectares of natural forests across the country [8].

1.1 SAL (SHOREA ROBUSTA)

Sal (Shorea robusta) is a large, deciduous tree up to 50 m in height. Under normal conditions the tree attains a height of 18-32 m and girth of 1.5-2 m. Bole is clean, straight and cylindrical but often bears epicormic branches. Crown is spreading and spherical. Bark is dark brown and thick, with longitudinal fissures deep in poles, becoming shallow in mature trees; provides effective protection against fire. The tree develops a long taproot at a very young age [9,10]. Fig.1 shows flowers and seeds of sal.

Fig. 1. Sal tree and Sal seeds.

1.2 KUSUM (SCHLEICHERA OLEOSA)

Kusum (Schleichera oleosa) is a medium to large sized, evergreen, dense tree with 35 to 45 feet height (Fig. 2). It mainly occurs in sub-Himalayan tracts in the north and central parts of eastern India. The flowers come from February to April and yields fruit in June and July of the year. The source of oil is the seeds. Seeds are mostly globular with 1.5 cm in diameter and weighing between 0.5 and 1.0 g. The weight of 1000 seeds is around 500-700 g. The fruits are berry type, ovoid and hard skinned with a pointed tip and dimension is roughly (1.25-2.5) X (1.1-1.8) cm; one cell contains 1 or 2 irregularly ellipsoidal and slightly compressed seeds with a thick brown seed coat or succulent aril. The brown seed coat is brittle and breaks at a slight pressure to expose a ‘U’ shape kernel as shown figure 2. The leaflets are 2 to 4 pairs, elliptic or elliptic-oblong, coriaceous, margins entire and apex rounded. The flowers are minute, yellowish green; male or bisexual, fascicled in spike like auxiliary racemes 7.5 to 12.5 cm long. The wood is suitable for firewood and charcoal. It is host tree for best grade lac insects. [11]. The annual production is around 66,000 tonnes in India, out of which 4000 to 5000 tonnes are actually collected [12].

2. MATERIALS AND METHODS

2.1 PRODUCTION OF THE SAL BIODIESEL AND KUSUM BIODIESEL

Sal seed is a forest product, the direct access to the procurement was difficult. Therefore, the extracted sal seed oil which was in butter form was procured from some of the outlets of Odisha Forest Development Corporation in Bhubaneswar. At room temperature the oil remains in butter form. The FFA of the sal oil was 2%. So single stage transesterification was used to produce sal methyl ester (SME) or sal biodiesel [13].

Kusum oil was extracted from good quality seeds using a screw press. The oil so obtained was pressure filtered and heated at 120°C for 20 minutes to remove moisture. The oil was then preserved in an airtight can. The FFA of the oil was found to be 11.0% leading to a two stage transesterification process necessary for the production of Kusum methyl ester (KME) or Kusum biodiesel [14].

As discussed earlier, the production of SME was carried out in a single stage transesterification process whereas the production of KME was carried out in a two stage esterification cum transesterification process. As two stages transesterification processes are energy intensive and time consuming, therefore process parameters corresponding to the reaction time in order to attain less than 2% FFA and maximum ester yield in percentage need to be found out. In this context, a series of initial transesterification processes are carried out and a suitable range for individual process parameters like reaction time, temperature, catalyst concentration etc. were determined corresponding to the optimum conditions.

Fig. 2. Kusum tree and Kusum seeds

After the production of biodiesel, four test fuel samples were prepared SME (neat sal biodiesel), SME20 (20% sal biodiesel + 80% diesel), KME (neat kusum biodiesel) and KME20 (20% kusum biodiesl + 80% diesel). The neat diesel was named as D100 and all the test fuel samples were subjected to rigorous physico-chemical tests. SME and KME were designated as B100 whereas SME20 and KME20 were treated B20 in present work.

A single cylinder, four stroke, water cooled diesel engine was used in this research. Similar engines are also used in low capacity agricultural and automotive applications. The block diagram of the experimental setup is presented in Fig. 2. The engine is operated at a constant speed of 1500 rpm. The fuel injection pressure is in the range of 200–205 bars. Fresh lubricating oil was poured in oil sump before beginning the experiment. The loading was provided by an eddy current dynamometer coupled with the engine shaft. In addition, a rpm encoder was attached at the end of the dynamometer for rpm measure.

2.2. EXPERIMENTAL SETUP

A single cylinder, four stroke, water cooled diesel engine was used in this work. The block diagram of the experimental setup is presented in Fig. 3. The engine is operated at a constant speed of 1500 rpm. The fuel injection pressure is in the range of 200–205 bars. Fresh lubricating oil was poured in oil sump before beginning the experiment. Engine specifications exhibit in table 1. The loading was provided by an eddy current dynamometer coupled with the engine shaft. In addition, a rpm encoder was attached at the end of the dynamometer for rpm measure. Air flow rate was measured using a mass airflow sensor. Fuel consumption rate was measured by burette and stop watch with level sensors. Fuel flow rate, air flow rate, load, rpm, pressure crank angle history and temperature data were fed to a centralized data acquisition system NI USB-6210, 16-bit. A personal computer with a software package “Enginesoft” was connected to the data acquisition system for online and subsequent offline analysis.

Besides, the air and fuel consumption data of the sensor was verified from the manual measurements. The data acquisition system inside the control panel received the signals and transmitted them to the computer. AVL Smoke meter and exhaust gas analyzer was employed to measure smoke and pollutants like NOx, CO and HC.

TABLE 1: Test Engine Specification

Make	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 arm length	185mm
Inlet Valve Opening	4.5°BTDC
Inlet Valve Closing	35.5°ABDC
Exhaust Valve Opening	35.5°BBDC
Exhaust Valve Closing	4.5°ATDC
Fuel injection timing	23^0BTDC
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

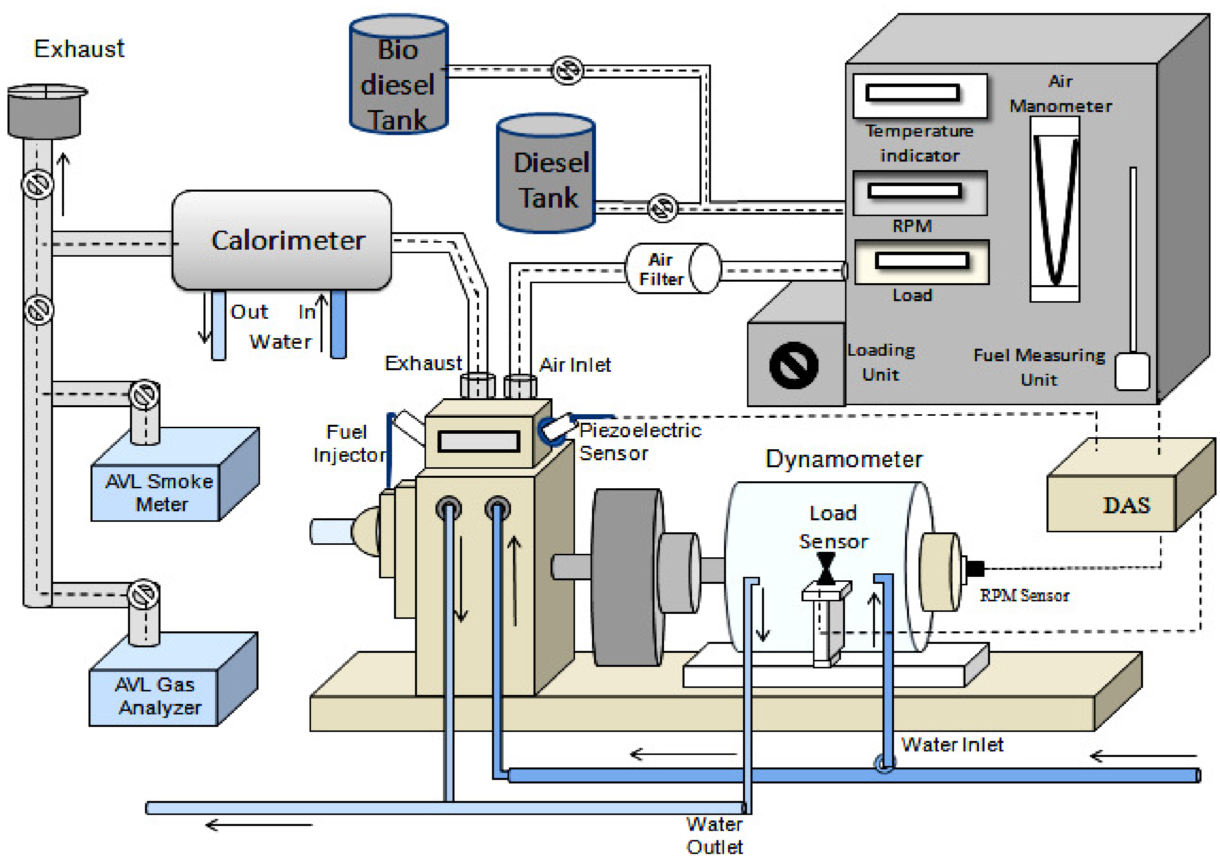

Fig. 3. Schematic diagram of the Engine setup

3. RESULTS AND DISCUSSION

3.1 PHYSICO – CHEMICAL CHARACTERIZATION

Various physico-chemical and fuel properties like density, viscosity, calorific value, cold flow properties, oxidations stability, fatty acid profiles etc. of the sample were determined in the laboratory. The respective equipments used for the tests were of standard quality with errors and repeatability within the permissible limits. Although, test fuels (biodiesel and its blends) showed marginal higher density than mineral diesel, but it was still well within the ISO 12185 standard limit of 0.86-0.89 g/cc. The viscosity of the test fuel samples was still higher than diesel, but it suitably conformed to ASTMD6751 standard. The heating value shown by the test fuels was very much comparable to mineral diesel. However, the CFPP of test fuels was higher as compared to the diesel baseline. Despite of inferior CFPP of test fuels, it may be well suitable for most of part of India on account of warmer climate. However, for cold climates, some additives may be added to improve the CFPP of sal and kusum biodiesel. The oxidation stability of the test fuels was commendable and conformed to both D675 and EN14112 standards. Table 2 presents the average values of the physico-chemical properties of the test fuels.

TABLE 2: Comparative assessment of physicochemical properties of the test fuels.

S. No	Properties	SME	KME	SME20	KME20	Diesel
1	Density at 15°C (g/cc)	0.876	0.878	0.833	0.844	0.8239
2	Viscosity at 40°C (cSt)	5.89	5.9	3.36	3.36	2.956
3	Calorific value (MJ/Kg)	39.65	41.6	43.73	44.52	45.49
4	Cold flow plugging point (°C)	10	-1	4	-6	-9
5	Oxidation stability (hours)	>6	> 6	--	--	--

3.2. ENGINE PERFORMANCE

Brake Thermal Efficiency

The variation of brake thermal efficiency (BTE) of the engine with test fuels and diesel are represented in Fig. 4. It was observed that at part load condition, the BTE in respect of test fuels and diesel were comparable. However, as the load was increased there was significant variation in the BTE. The BTE for SME20 and KME20 was higher 25% and 21% at full load respectively whereas BTE of B100 was lower throughout the load conditions.

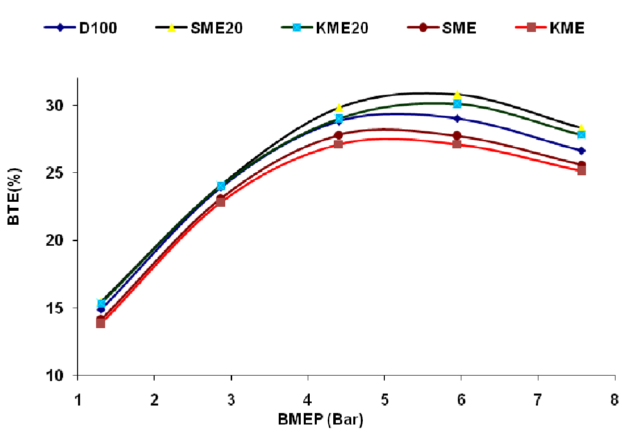

Fig. 4. Effect of the BMEP on BTE

Brake Specific Energy Consumption

The brake specific energy consumptions (BSEC) were found to be comparative for all test fuels throughout than baseline diesel fuel which is presented in fig. 5. At full load condition B20 shows lower BSEC compare to the diesel.

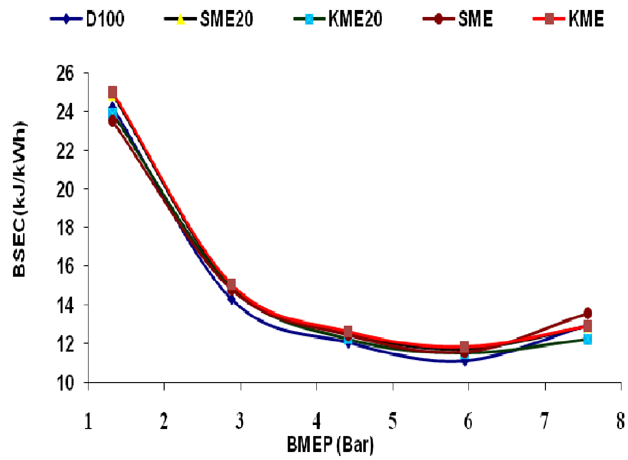

Fig. 5. Effect of the BMEP on BSEC

3.3. ENGINE EMISSION

Emissions from diesel engines contribute to environmental pollution considerably, particularly on fossil fuels. One of the advantages of renewable fuels such as biodiesel over its fossil fuel counterpart is its lower emissions. The subsequent section describes the emission characteristics of SME and its blends with diesel.

Carbon Monoxide

Carbon monoxide emissions for various test fuels are shown in Fig. 6. Formation of CO during in-cylinder combustion in diesel engines is primarily attributed to lower air–fuel equivalence ratios of the combustible mixtures.

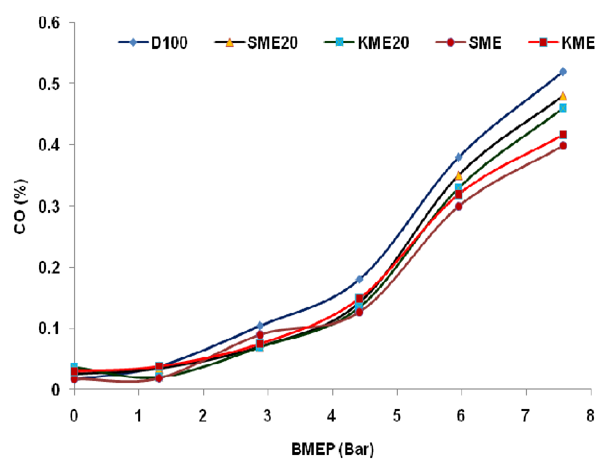

Fig. 6. Effect of the BMEP on CO

As load was increased, there was an increase in CO emission level at higher load due to rich mixture which results in incomplete combustion of fuel. It is worth relevant to mention that air–fuel mixing process is affected by the difficulty in atomization of biodiesel due to its higher viscosity resulting in locally rich mixtures of biodiesel and consequent higher CO emission particularly at lower engine loads. CO emissions were found to be lower for all test fuels throughout than baseline diesel fuel.

Unburnt Hydrocarbons

The emission of unburnt hydrocarbons in the engine exhaust at varying engine loads is shown in Fig. 7. Hydrocarbon emissions are primarily a result of engine configuration, fuel structure, combustion temperature, and oxygen availability and residence time. It was observed in the present study that UHC emissions were lower at partial load condition and increased at higher loads conditions due to relatively less oxygen available for the reaction when more fuel injected into the engine. It was also found that SME blended fuels exhibited lower UHC emissions as compared to baseline data of diesel. UHC emissions were found to be higher for all test fuels throughout than baseline diesel fuel. This reduction in emissions of in the test fuel may be attributed to the combined effects of higher in-cylinder temperature, higher cetane rating and reduced ignition delay.

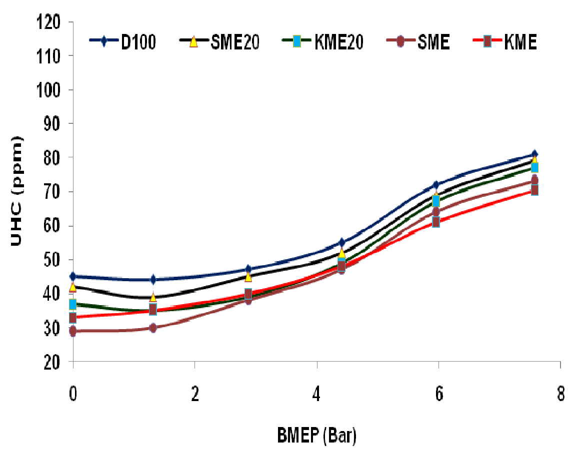

Fig. 7. Effect of the BMEP on UHC

Oxides of Nitrogen

Oxides of nitrogen popularly referred as NOx, are the critical diesel engine emissions of major concern owing to their toxicity. It mostly comprises of nitric oxide (NO) and nitrogen dioxide (NO_2), formed by ''Zeldovic Mechanism''. Combustion flame temperature, availability of oxygen and time for oxygen–nitrogen reaction are the major factors controlling NOx formation in diesel engines. [15]. Fig. 8 shows the emissions of NOx for various test fuels at different loads. It may be observed that the emissions of NOx were found to increase in the test fuels for the entire range of engine operation.

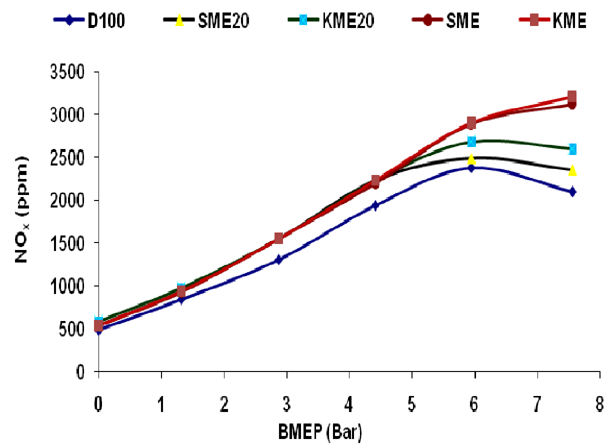

Fig. 8. Effect of the BMEP on UHC

Smoke Opacity

Fig. 9 shows the variation of smoke opacity for different test fuels at various loads. It may be observed that smoke level increased sharply with the increase in load for all the fuels. It was mainly due to the decreased air–fuel ratio at higher loads when larger volume of fuel is injected into the combustion chamber, much of which goes unburnt into the exhaust [16]. The reduction in smoke may be attributed to a number of factors such as higher oxygen content in biodiesel that contributes towards complete fuel oxidation even at locally rich zones [17], lower C/H ratio and absence of aromatic compounds. Higher number of carbon atoms in a fuel molecule leads towards higher smoke and soot formations whereas higher oxygen and hydrogen atoms lead to lower smoke and soot [18]. Smoke opacity was found to be lower for all test fuels throughout than baseline diesel fuel.

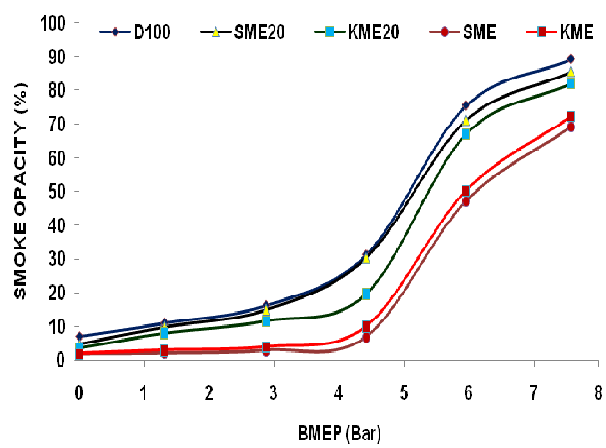

Fig. 9. Effect of the BMEP on Smoke Opacity

4. CONCLUSIONS

In the present work, an exhaustive engine trial was carried to evaluate the production, performance and emission characteristics of different SME, KME and its diesel blends. Production of SME was economical compared to the KME. The results suggest that BTE for B20 (SME20 and KME20) was higher whereas BTE of B100 (SME and KME) was lower throughout the load conditions. BSEC was found to be comparative for all test fuels throughout than baseline diesel fuel. CO, UHC emissions and Smoke opacity were found to be lower for all test fuels throughout than baseline diesel fuel whereas emissions of NOx were found to higher. B20 biodiesel blends were showed better results than neat diesel for all application without engine modification.

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