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Investigation of Optimum Fuel Injection Timing of Direct Injection CI Engine Operated on Preheated Karanj-Diesel Blend

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Abstract

The conventional petroleum fuels are depleting rapidly and the prices are going up day by day. Moreover, these petroleum fuels are responsible for green house emissions and other forms of pollution in the environment. Among various options available, the fuels derived from vegetable oils have emerged as promising alternate fuels for IC engines. The use of unmodified or straight vegetable oils in diesel engine creates operational problems due to their high viscosity and poor volatility. In the present work, an experimental setup has been designed to reduce the viscosity of the fuel by blending Karanj oil with Petro-Diesel and preheating the Karanj-Diesel blend. Experiments are also conducted to determine the optimal injection pump timing for the selected blend, with respect to the engine performance parameters. Experiments are performed using Petro-Diesel and preheated Karanj-Diesel blend (in ratio 40:60 by volume) on constant speed direct injection C.I. engine. The effect of injection timing on the preheated Karanj-Diesel blend is investigated and the results are analyzed. On the basis of results obtained, the optimal injection timing is determined for Karanj-Diesel blend, which is found to be 19º BTDC.

Keywords: Brake specific fuel consumption; Brake thermal efficiency; Emissions; Biodiesel; Transesterification; Diesel engine.

Nomenclature

BIS	Bureau of Indian standards
BSFC	Brake specific fuel consumption
BTDC	Before top dead center
BTE	Brake thermal efficiency
C.I.	Compression ignition
CO	Carbon monoxide
HC	Unburned hydrocarbons
HSU	Hartridge smoke unit
K40	Preheated blend of 40% Karanj and 60% Petro-diesel by volume
KO	Karanj oil
NOx	Oxides of nitrogen
SVO	Straight vegetable oil

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1. Introduction

Depleting oil reserves, increasing oil prices, lack of availability of the mineral oil and the problem of environmental pollutions have prompted research worldwide into alternate fuels for internal combustion engines. Vegetable oil based fuels have been proved as potential alternative greener energy substitute for fossil fuels. The vegetable oils are renewable in nature and have comparable properties with Petro-Diesel. These are biodegradable, non-toxic, and have potential to reduce the harmful emissions [1,2,3,4]. However, use of unmodified or straight vegetable oil (SVO) directly in the engine creates several operational and durability problems such as severe engine deposits, injector coking, piston ring sticking, gum formation and lubricating oil thickening. These problems relate to the high viscosity, poor volatility and cold flow characteristics of the vegetable oils due to large molecular weight and bulky molecular structure [5,6]. Researchers have suggested different techniques for reducing the viscosity of the vegetable oils, which are dilution/blending, heating/pyrolysis, micro-emulsification and transesterification [1,7,8]. The transesterification process has been proved as the most effective method and widely utilized. However, this method adds extra cost due to the chemical processing. Hence utilization of blended or heated vegetable oil as an alternate fuel is an attractive option in rural and remote areas of developing countries [5].

The vegetable oils can be blended in small proportion with the Petro-Diesel successfully [8,9,10]. But if greater blend ratio of the oil is to be used, then preheating of vegetable oil or its blend with petro-diesel is the viable solution of the problem. Several researchers have reported that the vegetable oils in small blending ratios with Petro-Diesel can be used safely and advantageously in the Diesel engine with the exception of the slight concern for the little increase of smoke level. The most of the emission like CO, CO_2, HC, NO_x and smoke are reduced when the vegetable oils are preheated compared to the unheated row vegetable oil although the level of emissions is slightly higher compared to the Petro-diesel [5,6,10,11].

Considering these facts, a set of engine experiments were conducted using preheated blend of Karanj oil with Petro-Diesel on a engine which is widely used for agriculture, irrigation and decentralized electricity generation. Further experimentations were carried out to determine the optimal injection timing for the given Karanj-Diesel blend.

Fuel modification method adopted in the present study or any other, can reduce the viscosity but other problems due to the differences in the properties like cetane number still exist. Hence, property changes associated with the differences in chemical structure between vegetable oil and petroleum-based diesel fuel may ask for change in the engine operating parameters such as injection timing, injection pressure etc. These operating parameters changes can cause different performance and exhaust emission than the optimized settings chosen by the engine manufacturer. Hence it is necessary to determine the changed optimum values of these parameters. In the present study, the attention is focused on finding the optimal injection pump timing for the Karanj-Diesel blend with respect to the performance parameters.

It is established that injection timing influences all engine characteristics significantly. The reason is that injection timing influences the mixing quality of the air fuel mixture and hence the whole combustion process. Several researchers have indicated that there is an advance in the fuel injection timing when the vegetable oil based fuel is used in place of Petro-Diesel in diesel engines. This is because of higher bulk modulus of vegetable oils than the mineral diesel. Due to higher bulk modulus and therefore higher sound velocity, the pressure waves from the fuel pump to the fuel injector travel faster and thus advances the fuel injection timing [12-14]. In addition to the advance injection timing, the vegetable oils have been noted to exhibit longer ignition delay periods especially at low load operating conditions. Longer delays between injection and ignition lead to unacceptable rates of pressure rise with the result of diesel knock, because too much fuel is ready to take part in premixed combustion. Hence the retardation of the injection timing will decrease the maximum pressure in the cylinder and leads to a lower peak rate of heat transfer and hence to lower combustion noise. The retarded injection leads to lower temperature, the NO_x emissions may also reduced. On the other hand the retarded injection timing may lead to increase in smoke emissions, but the trends vary significantly with the types and designs of the engines. HC emissions are already low for a direct injection diesel engine and vary only modestly with injection timing [13,14,15]. In the present research work, the effect of retarding the injection timing is investigated to find out the optimal injection timing of preheated Karanj- Diesel blend.

1.1. Selection of oil for study: Karanj oil

As per the information available about the inedible oils in the literature, Mahua, Neem, Karanj and Jatropha are the front runners in India in terms of the production and availability. Mahua is most abundantly available oil but the calorific value of Mahua is very low (30349 KJ/kg) [8]. Jatropha has also emerged as a major oil source but it is carcinogenic in nature. Neem oil can be a very good substitute but it should be spared for its well established use and practices in herbal and medical field. So by analyzing and comparing the properties of these oils, Karanj is chosen as SVO for the research.

The botanical name of Karanj tree is Pongamia Pinnata. It is chiefly found along the banks of streams and rivers or near the seacoast. It resists drought well, is moderately frost hardy and is highly tolerant of salinity. The tree starts bearing at the age of 4 - 7 years. The pods come to harvest at different periods of time in different parts of the country, but the harvest season extends in general from November - December to May - June. The yield of the seed is said to range from 9-90 kg per tree, indicating a yield potential of 900 to 9000 kg seed/ha (assuming 100 trees/ha). 25% of this yield might be safely considered as oil because the yield of oil from seeds is around 24 to 27.5%. The total yield in India is estimated to be about 135000 tons. But only 8000 tons of oil is presently being utilized which is only 6% of the total estimated produce. Thus there is an ample scope for utilizing the energy source (Karanj oil) as fuel [8,16,17]. Important physico-chemical properties of Karanj oil and Petro-Diesel have been shown in table 1.

2. Experimental Set-Up and Procedures

A naturally aspirated direct injection diesel engine is more sensitive to fuel quality. The main problem of using Karanj oil in unmodified form in diesel engine is its high viscosity. Therefore, it is necessary to reduce the fuel viscosity before injecting it in the engine. High viscosity of Karanj oil can be reduced by heating the oil using waste heat of exhaust gases from the engine and also blending the Karanj oil with diesel. Viscosity of Karanj oil and diesel was measured at different temperatures to find the effect of temperature on viscosity. A typical engine system widely used in the agricultural sector has been selected for present experimental investigations. A single cylinder, four stroke, constant speed, water cooled, direct injection diesel engine was procured for the experiments. The technical specifications of the engines are given in Table 2.

Power-star make electric dynamometer was used to measure torque or brake power. It consisted of an alternator to which electric bulbs were connected to apply load. The schematic layout of the experimental setup for the present investigation is shown in Fig.1.

Table 1 Comparison of physical and chemical properties of Karanj oil and diesel

S. No.	Parameters	Karanj oil	Diesel
1	Saponification Value	185 - 195	-
2	Iodine value	80 - 90	38.30
3	Acid Value (Max.)	20	0.06
4	Moisture (% max.)	0.25	24.66
5	Color in 1/4 inch cell (Y+5R)	40	102.5
6	Refractive Index (40 °C)	1.473 - 1.479	1.472
7	Specific Gravity (30 °C)	0.90	0.82
8	Cloud Point (°C)	-1	-11
9	Pour Point (°C)	-2 to -5	-12
10	Calorific Value (MJ/kg)	37	44
11	Viscosity (St at 30^0 C)	74.14	8.54
12	Cetane number	51.0	47.8
13	Flash Point (°C)	230	66
14	Carbon residue (%)	0.71	0.1
15	Ash content (%)	0.04	0.01
16	Sulphur content (%)	-	0.05

Table 2 Specifications of the Engine

S.No.	Component	Unit	Description
1.	Name of the engine	-	Kirloskar Oil Engine Model AV1
2.	Type of engine	-	Vertical, four stroke cycle, single acting, totally enclosed, high speed, C.I. engine
3.	No. of cylinders	-	1
4.	Direction of rotation		Counter clockwise (When looking at flywheel)
5.	IS Rating at 1500 rpm	kW(bhp)	3.7 (5.0)
6.	Bore	mm	80
7.	Stroke	mm	110
8.	Cubic Capacity	liters	0.553
9.	Compression Ratio	-	16.5 : 1
10.	No. of Injection Pumps and Type	-	1 number, Single cylinder, flange mounted without camshaft
11.	Governor type	-	Mechanical centrifugal type
12.	Class of governing	-	B1
13.	Injection timing	Degree crank angle	23º BTDC
14.	Fuel injection pressure	bar	200

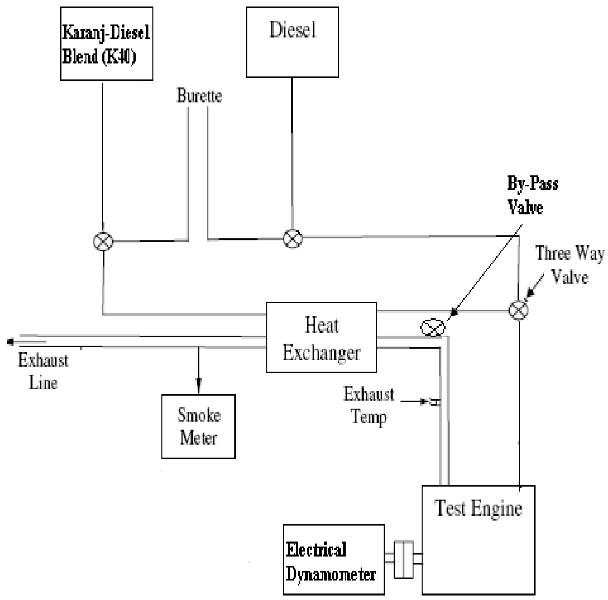

Fig.1 Schematic Diagram of Experimental Setup.

The main components of the experimental setup are two fuel tanks (Diesel and Karanj-Diesel blend), heat exchanger, exhaust gas line, and performance and emissions measurement equipment. The engine is started with diesel and once the engine warms up, it is switched over to Karanj-Diesel blend (K40). After concluding the tests with K40, the engine is again switched back to diesel before stopping the engine until the Karanj-Diesel blend (K40) is purged from the fuel line, injection pump and injector in order to prevent deposits and cold starting problems. A heat exchanger was designed to preheat the blend using waste heat of the exhaust gases. The temperature of the blend was maintained within the required range by providing a by-pass valve in exhaust gas line before the heat exchanger. A thermocouple was provided in the exhaust line to measure the temperature of the exhaust gases. Exhaust smoke was measured with the help of 'Envirotech APM 700 Smoke meter'.

3. Results and discussion

After finalizing Karanj oil as an alternate fuel, attempts were made to reduce its viscosity by preheating it, using the exhaust gases coming out from the engine. It was found that temperature obtained in the heat exchanger was not adequate to bring down the viscosity of pure Karanj oil equivalent to diesel. It is also known that the pure vegetable oils create more problems in engines than blended oils. So it was then decided to use Karanj oil as blending fuel in Diesel to obtain Karanj-Diesel blend. In the present study, viscosity was reduced by both preheating and blending. Before carrying out detailed experimentation, finalization of the optimum Karanj-Diesel blend was done. It was observed experimentally that the blend could be preheated up to 55-60 ºC at no load with heat exchanger developed. From the Fig. 2, it is observed that at this temperature range substitution of Diesel by Karanj oil to the extent of 40% makes a blend having viscosity equal to that of pure Diesel at room temperature. (BIS limits of viscosity: For Grade A diesel - 2.0 to 7.5 cSt at 38 °C, For Grade B diesel - 2.5 to 15.7 cSt at 38 °C) Thus the results in this research work pertain to preheated Karanj-Diesel blend having 40% Karanj oil and 60% Diesel oil (K40). Engine performance and smoke emissions at constant speed and variable load are covered in experimental investigations. Experiments were conducted for optimizing the fuel injection timing for K40. The fuel injection pressure was maintained at optimum injection pressure of 200 bar and tests were carried out at different injection timings starting from 23^0 BTDC to 15^0 BTDC, retarding the timing by the interval of 2^0 crank angle. The fuel injection timing was retarded through controlling the start of injection pump delivery, by inserting shims of different thickness between the fuel injection pump body and engine body. To perform all the experiments, the engine was run for sufficient time duration. During this period, the engine performed normally, with no undesirable combustion phenomena. The engine components were found to be in normal condition after the tests. The noise level during the operation was also within the limit.

3.1. Optimization of Performance parameters

Optimum fuel injection timing is that fuel injection timing, at which engine delivers maximum thermal efficiency, minimum BSFC. Engine was run at different fuel injection timings (23^0, 21^0, 19^0, 17^0, and 15^0 BTDC). BSFC, thermal efficiency, and smoke density were measured at different fuel injection timings for preheated Karanj-Diesel blend (K40). Injection pressure was maintained at optimum value of 200 bar for each injection timing. The base line data at standard injection timing of 23^0 BTDC for Diesel were also generated.

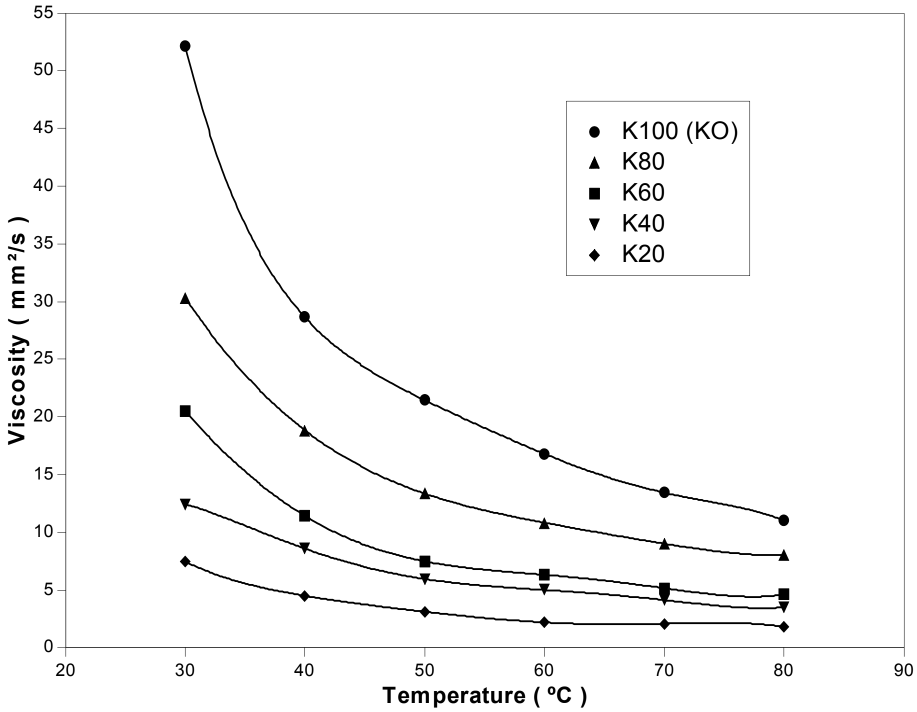

Fig.2 Effect of temperature on viscosity of KO and its blends with Diesel

3.1.1. Effect of injection timing on brake specific fuel consumption

Injection timing is a very important parameter that significantly influences all engine characteristics. This is mainly due to the fact that injection timing influences the mixing quality of the air–fuel mixture and, consequently, the combustion process, including harmful emission. Brake specific fuel consumption is a comparative parameter that shows how efficiently an engine is converting fuel into work. Brake Specific Fuel Consumption (BSFC) has been plotted against load for standard injection pressure at constant speed of 1500 rpm for different injection timing from 23º to 15º BTDC. Fig. 3 shows some typical curves for variation of BSFC with load. As seen from plots BSFC decreases with increase in of power output and then starts increasing after a point for the given injection pressures under study. The point at which it becomes minimum, is referred to as the "best economical load" point, which occurs at around 80-85% load for Karanj-Diesel blend. When we retard the injection timing, at first the BSFC decreases and then it increases. Lowest BSFC is observed at an injection timing 19 º BTDC. The value of lowest BSFC is 0.2691 Kg/KWh. Slight increase in the specific fuel consumption was observed at retarded injection timing from 19º to 15º BTDC.

3.1.2. Effect of injection timing on brake thermal efficiency

Brake Thermal Efficiency (BTE) is an important parameter, as it provides a measure of net power developed by the engine, which is readily available for use at the engine output shaft. In this Brake thermal efficiency curves are plotted at different injection timing at standard injection pressure. Typical variation of Brake Thermal Efficiency (BTE at standard conditions) with load at standard injection pressures of 200 bar is shown in Fig. 4. It has been observed from these plots that the brake thermal efficiency slightly increases with retarding the injection timing from 23º to 19º BTDC after that decrease in BTE are observed from 19º to 15º BTDC. From these plots it was also observed that maximum value of BTE lay between 80-85 % of full load for the given injection pressure under study. The maximum value of thermal efficiency was observed as 28.89 % at injection timing 19 º BTDC.

3.1.3. Effect of injection timing on Smoke Emission

Smoke is produced during acceleration, overloading or even during full load operation of the engine. Under these conditions more fuel is burned and the prevailing temperatures inside the combustion chamber become very high. Because of this high temperature there is thermal cracking of molecules rather than normal oxidation. This thermal cracking is in the form of soot/carbon. This soot is a graphite structure, jet black in colour and is called smoke. Smoke density is measured experimentally for different injection timing. The variation of smoke density with load is shown in Fig. 5, which shows minimum smoke during idling which increases with load. It is observed from these plots that the smoke density decreases with retarding the injection timing from 23º to 19º BTDC. However, it increases with further retarding the timing from 19º to 15º BTDC. From these plots it was observed that the minimum value of smoke density was observed at injection timing 19 º BTDC for complete range of load.

Based on these results obtained for BSFC, BTE and smoke density, 19 º BTDC was found the optimum injection timing for the K40.

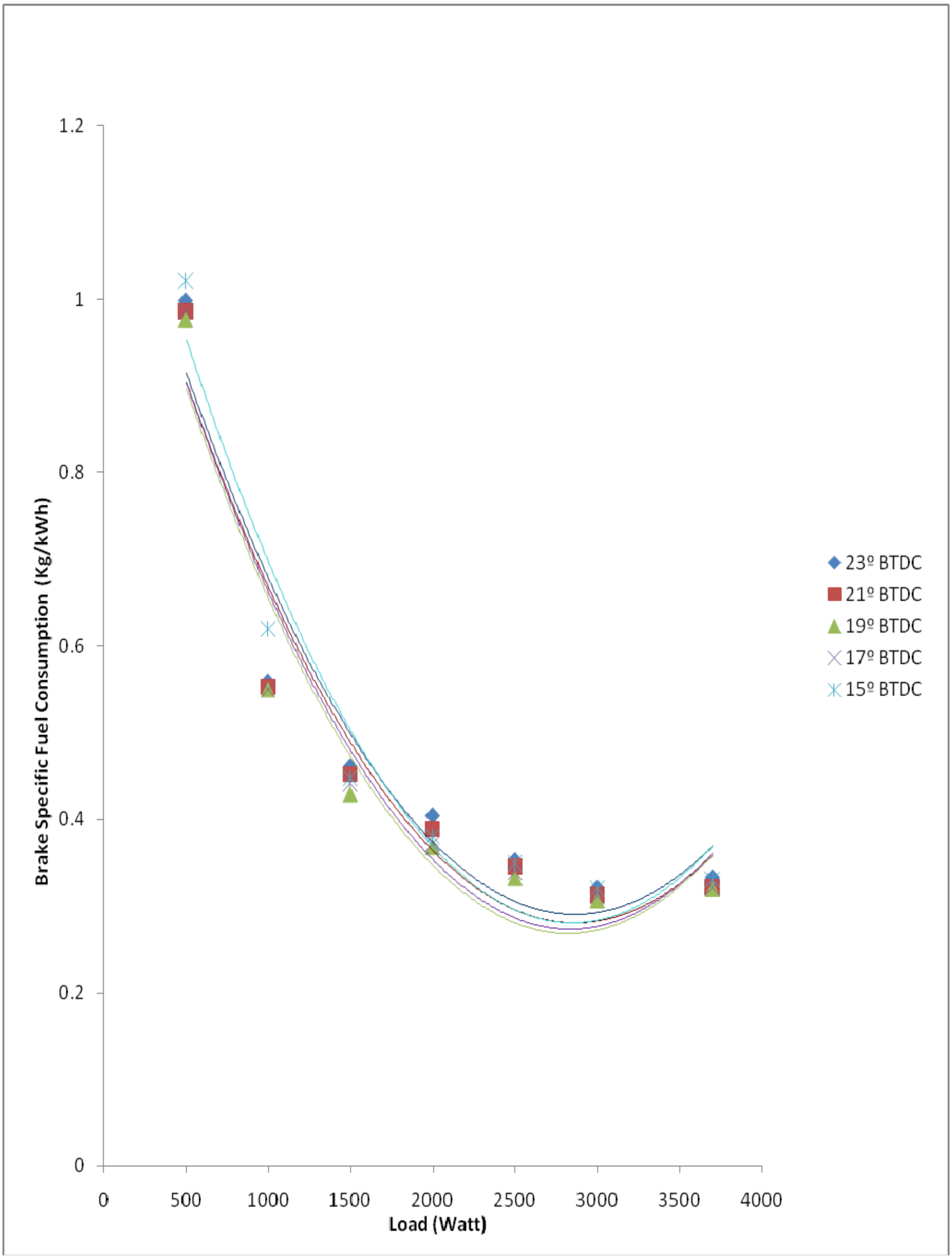

Fig.3 Variation of BSFC as a function of load for K40 at different injection timings

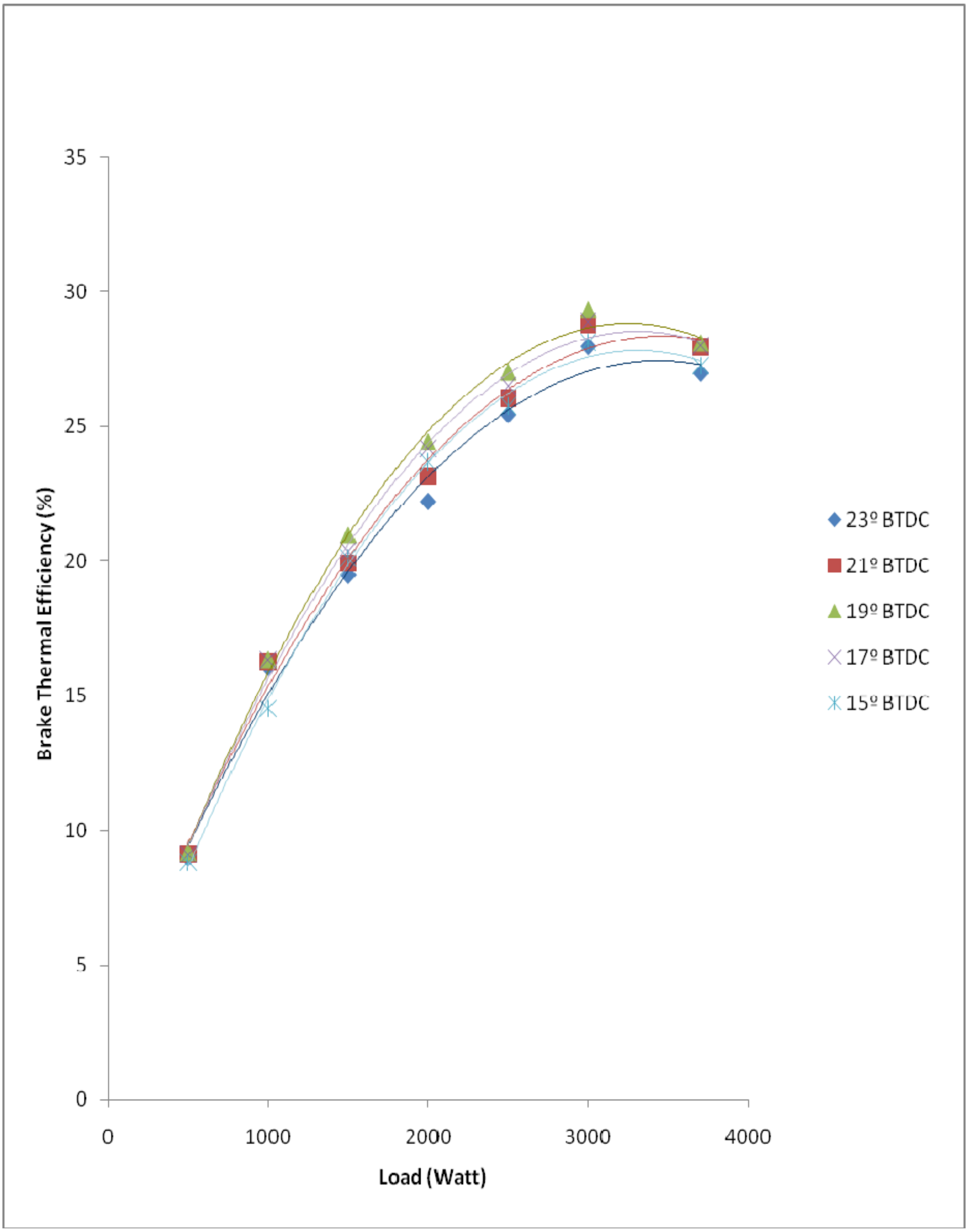

Fig.4 Variation of BTE as a function of load for K40 at different injection timings

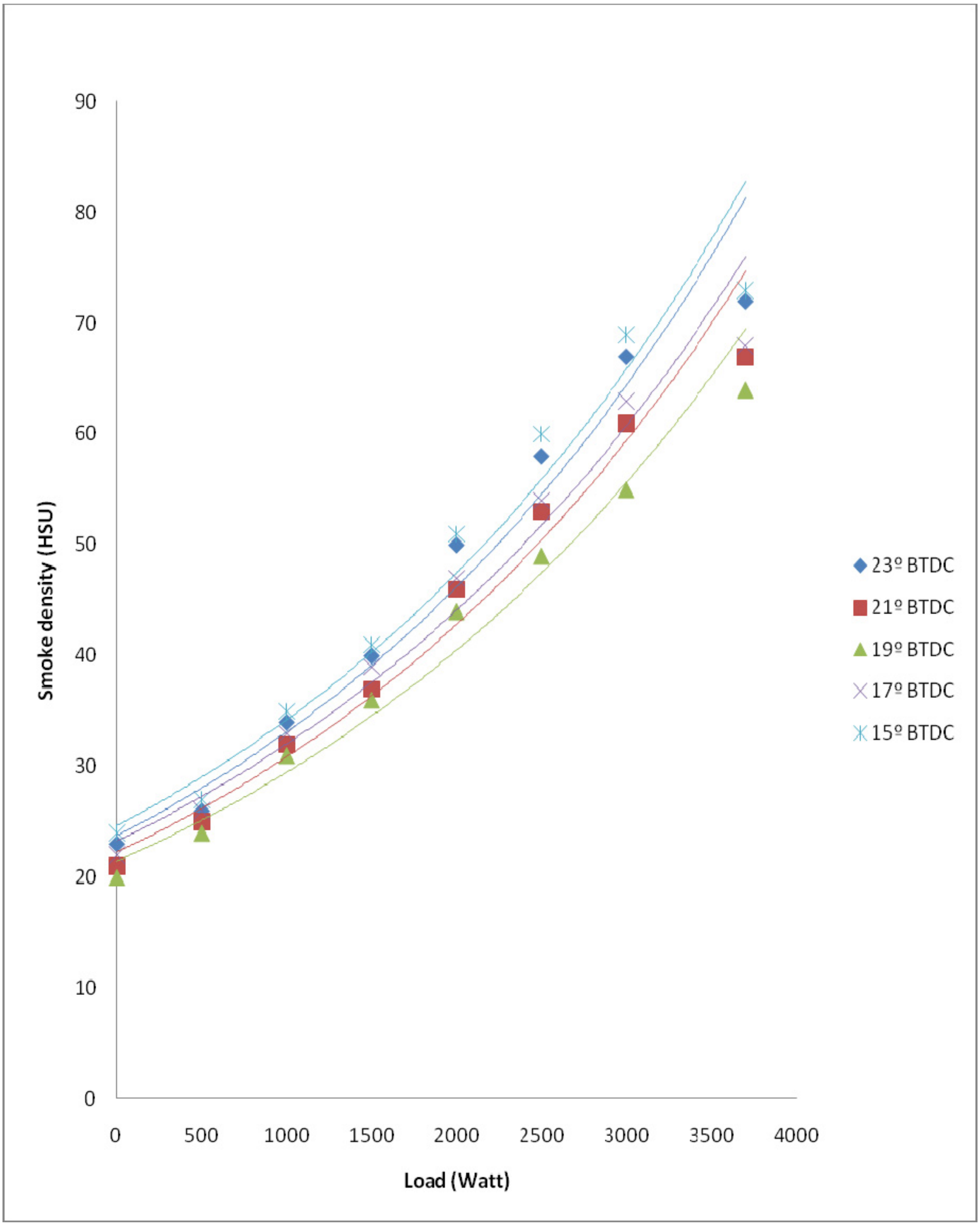

Fig.5 Variation of Smoke density as a function of load for K40 at different injection timings

3.2. Comparison of performance and smoke emission for different fuels

Variation of BSFC, BTE and smoke density as a function of load for Diesel, preheated K40 at standard injection timing and preheated K40 at optimum injection timing of 19º BTDC are shown in Fig.6, Fig.7 and Fig.8 respectively. It was observed that BSFC was lowest at all loads for pure Diesel (at standard timing of 23º BTDC) as shown in Fig.6. The minimum value of BSFC for pure Diesel was 0.2398 Kg/kWh. Highest value of BSFC was observed when running the engine with K40 at standard timing. The value of minimum BSFC for K40 at standard timing was 0.2901Kg/kWh. Lower calorific value of K40 leads to increased volumetric fuel consumption in order to maintain similar energy input to the engine. The value of

BSFC for K40 at optimum timing was lower as compared to the K40 at standard timing but higher than the value for Diesel. The value of minimum BSFC for K40 at optimum timing is 0.2691 Kg/KWh. This improvement may be due to the better mixing quality of air-fuel mixture because of retardation of injection timing. Despite the K40 at optimum timing, having higher brake specific fuel consumption than the Diesel, the brake thermal efficiency is practically the same as compared to the Diesel because of higher calorific value of Diesel. However the BTE for the K40 at optimum timing (28.89 %) is greater than the K40 at standard timing (27.52%) due to better mixing and hence better combustion efficiency. (Fig.7) Smoke density for Karanj-Diesel blend was greater than that of diesel. This is possibly a result of poor spray atomization and non –uniform mixture formation with Karanj oil. Smoke density increases with the increase in load in all the cases of fuels. The smoke density for the K40 at the optimum timing is lower than the smoke density for K40 at standard timing but it is greater than the Diesel. (Fig.8)

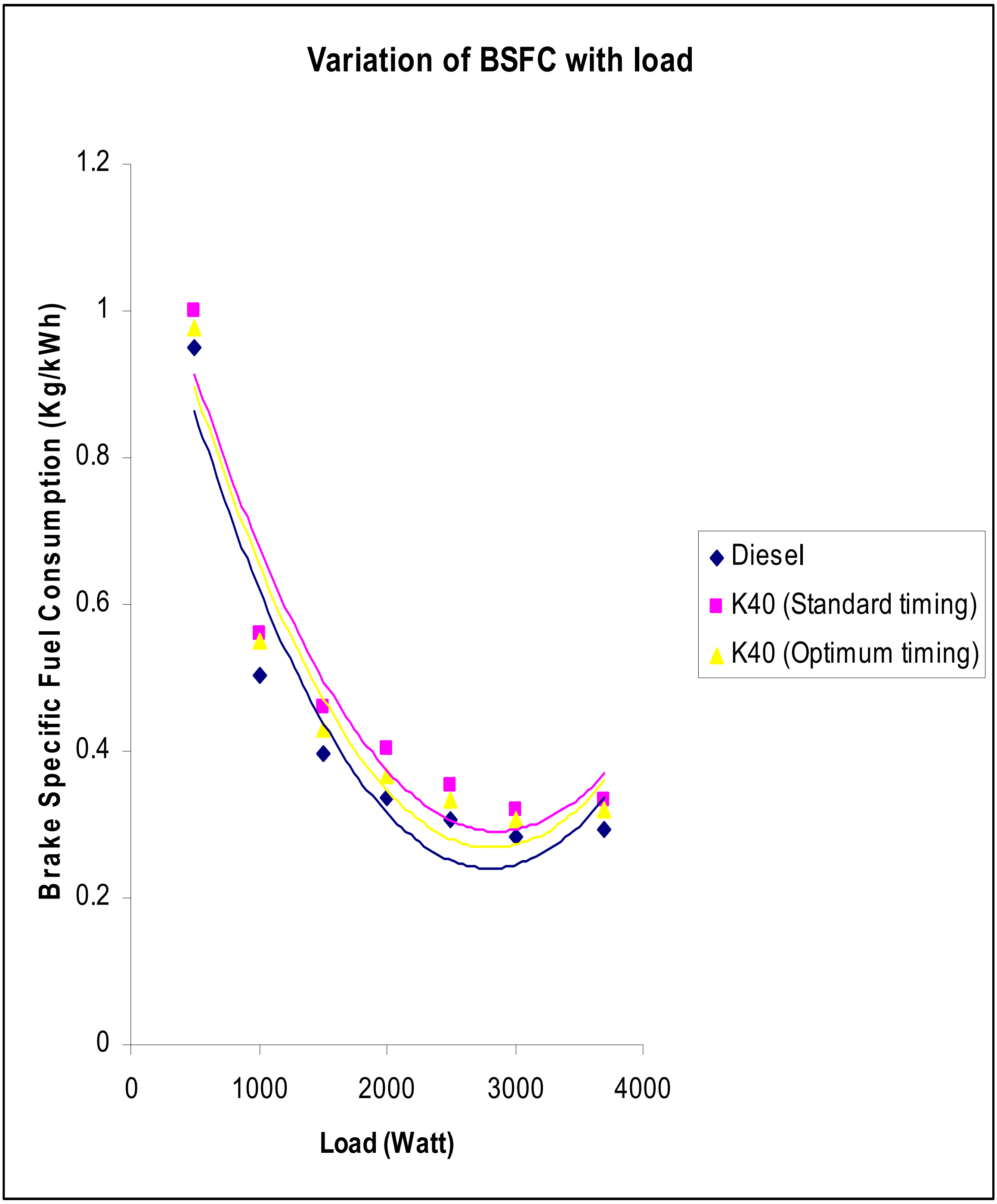

Fig. 6 Comparison of BSFC as a function of load for different fuels

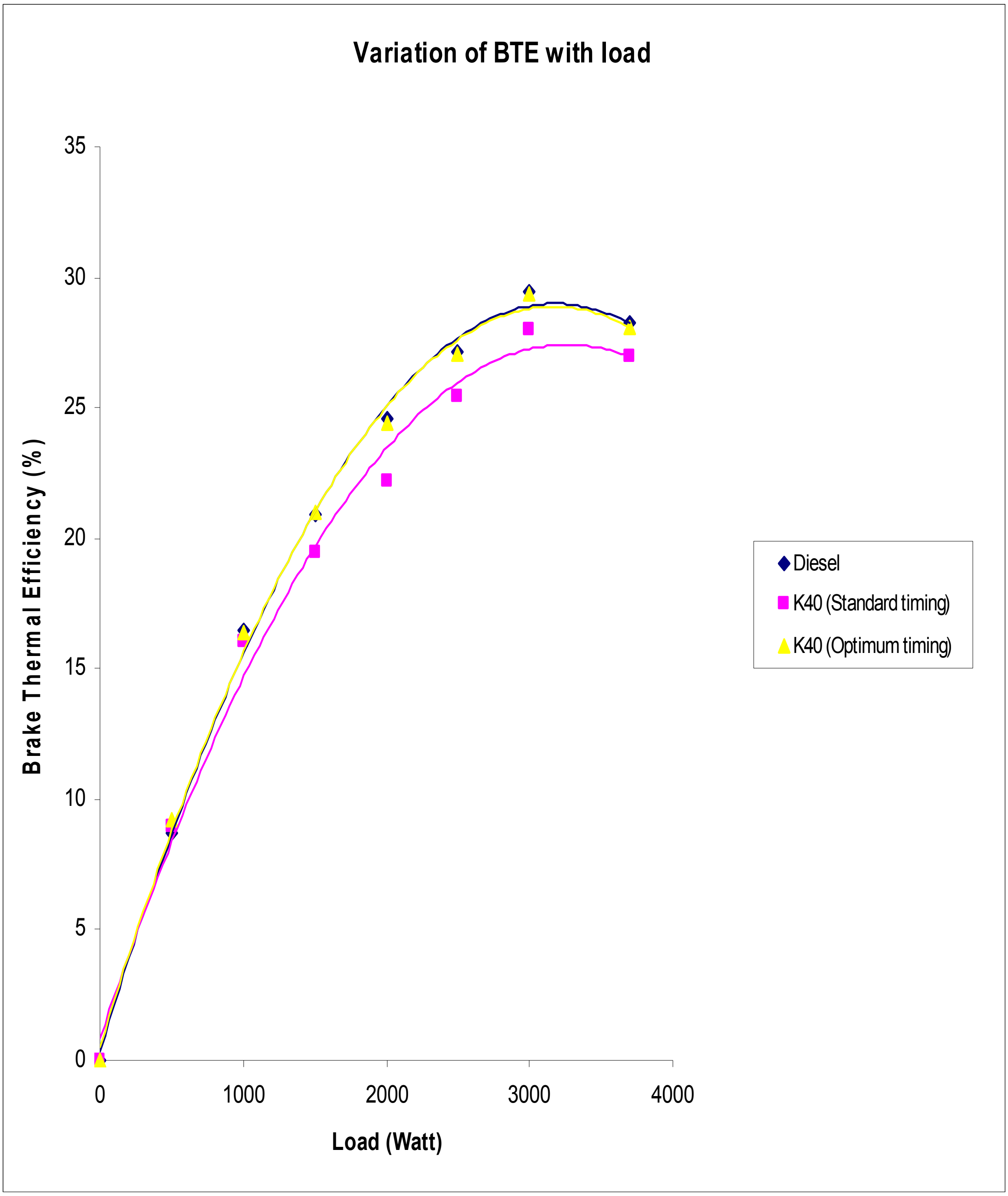

Fig. 7 Comparison of BTE as a function of load for different fuels

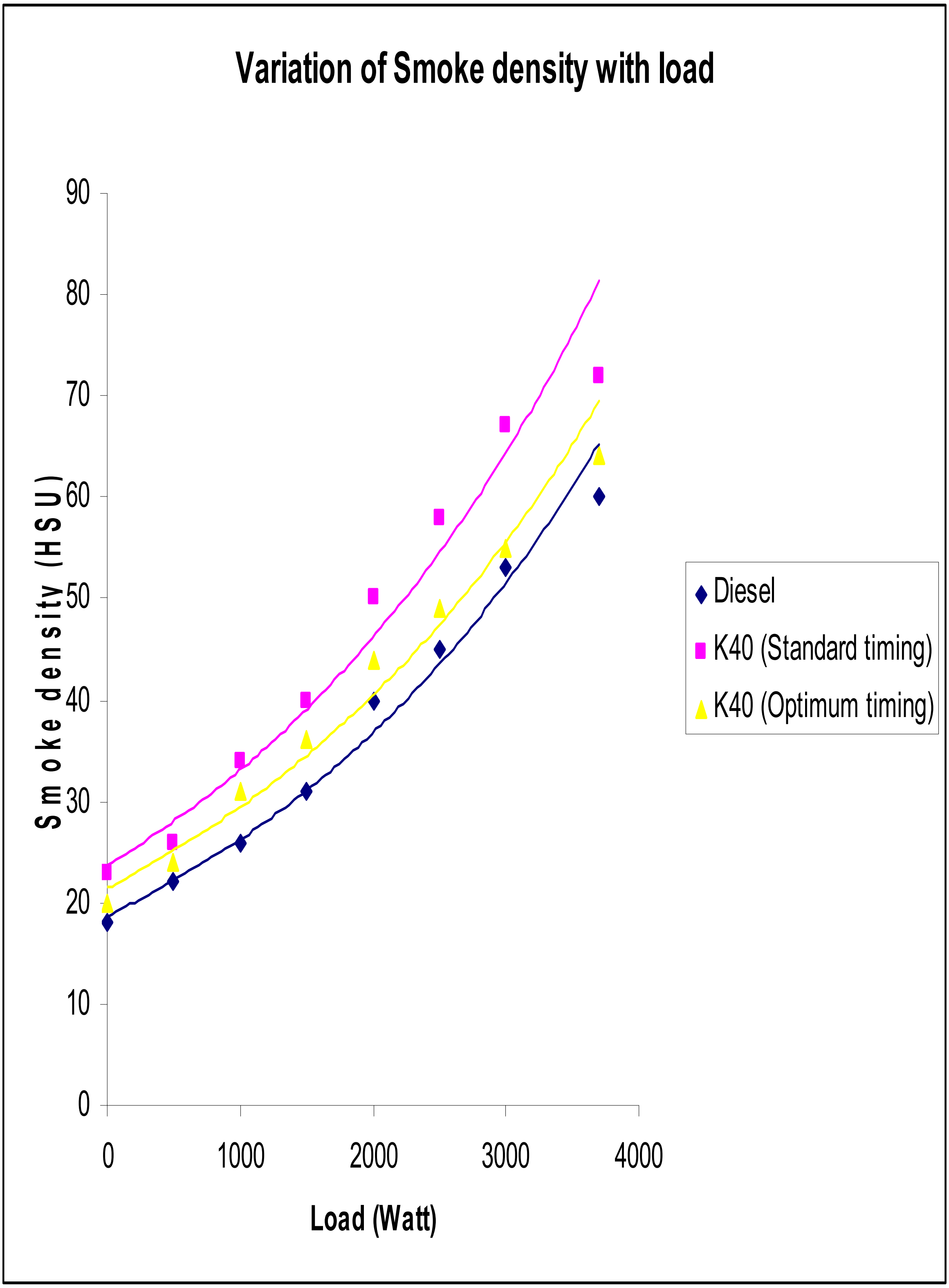

Fig.8 Comparison of Smoke density as a function of load for different fuels.

4. Conclusions

On the basis of the observations and the results of the experimental investigations on a single cylinder, four strokes, constant RPM, stationary, water cooled, compression ignition engine, run on Karanj-Diesel blend and Diesel oil at different injection timings, the following conclusions may be drawn from the present study.

The properties of Karanj -Diesel blend used for the study, are comparable with those of pure Diesel. The viscosity of Karanj oil is reduced by first preheating the Karanj oil and then by blending the Karanj oil with diesel. A suitable experimental setup developed, is able to reduce the viscosity of Karanj oil close to that of conventional diesel in order to make it suitable for use in a C.I. engine. Heating of the Karanj- Diesel blend is done through a heat exchanger, by utilizing the waste heat of the exhaust gases coming out from the engine. By the help of the heat exchanger developed, the temperature of the Karanj-Diesel blend can be raised to 55-60 ºC at no load. It is found that substitution of Diesel oil by Karanj oil to the extent of 40% is best possible in the temperature range of 55-60 ºC as the viscosity of blend becomes equal to that of pure Diesel. A successful operation of a compression ignition engine, fuelled with Karanj-Diesel blend over a wide range of load and injection timing without causing any undesirable combustion phenomena is observed. There is significant effect of injection timing on engine performance. For the above Karanj-Diesel blend (K40) injection timing of 19º BTDC is found to be the optimum injection timing, as highest brake thermal efficiency, lowest brake specific fuel consumption and lowest smoke density are observed over the entire load range at this injection timing. Similar values of brake thermal efficiency and higher values of brake specific fuel consumption in case of Karanj-Diesel blend can be attributed to low calorific value of Karanj oil as compared to that of Diesel oil. Slightly more smoke emissions are observed with Karanj-Diesel blend compared to the Diesel over the entire load range mainly due to poor atomization of Karanj oil. However the smoke level for K40 at optimum timing is less than the smoke level of K40 at standard timing.

Therefore, it may be concluded that preheating and blending of the vegetable oils with diesel, together can reduce the problems of straight vegetable oils drastically making it useful substitute for diesel fuel. The preheated Karanj-Diesel blend with optimized fuel injection timing can be used in CI engines more efficiently than the blend at standard injection timing.

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