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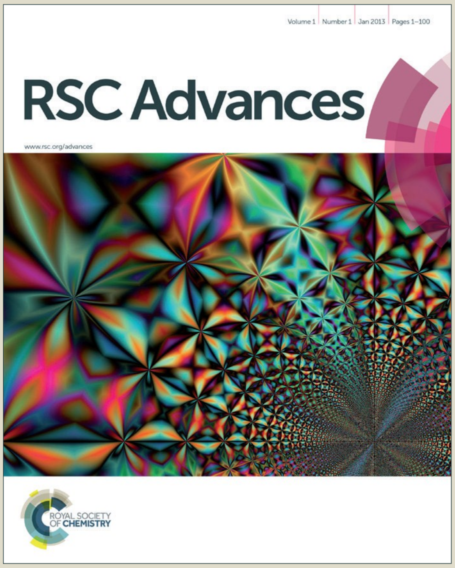

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Performance and emission characteristics of an indirect injection (IDI) multi-cylinder compression ignition (CI) engine using diesel/argemone maxicana biodiesel blends

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In this study, the performance and emission characteristics of diesel engine fueled with diesel/argemone biodiesel blends have been evaluated. An experiment was conducted on an indirect injection (IDI) compression ignition (CI) engine using diesel and diesel/argemone biodiesel blends. The result shows that with an increase in Argemone biodiesel blend ratio (up to B30) the performance characteristics such as brake thermal efficiency, brake specific fuel consumption get improved and result in significant reductions in CO and HC emissions. However, an increase in CO_2 and NOx emissions was observed for all biodiesel blends. The blends showed deterioration in brake thermal efficiency and brake specific fuel consumption at partial loads and high rpm conditions. The maximum value of brake thermal efficiency of 33.57% was obtained for B30 at full load @2500 rpm.

Keywords: Argemone biodiesel, Performance, Emission, Indirect injection

1.Introduction

Energy is an essential element for the economic and social development of a country. The demand for energy around the world is continuously increasing. Most of the world's energy is derived from fossil fuels which includes coal, petroleum fuels and natural gas. The transport sector is the main consumer of petroleum fuels. As per an estimate[1]; with the discovery of new oil fields, the total world proved oil resources reached 1687 billion barrels by the end of 2013 that is sufficient to meet only 53.3 years of global production of oil. Besides the fast depletion of petroleum fuels, another problem of concern is the gradual environmental degradation due to fossil fuel combustion. In the transport sector, the CI engines have an added advantage of being more efficient as compared to gasoline engine. However, the higher NOx and smoke emissions from CI engines remain a problem which hinders its increasing applications due to stringent emission norms. Thus it is imperative to develop low emission clean alternative fuel for use in diesel engines and biodiesel is a promising biodegradable fuel that has the potential to replace petroleum diesel.

Extant literature is available expressing advantages resulting by use of biodiesel: renewable nature, safe to handle, practically no sulphur content, no aromatic compounds, oxygen in fuel molecules leading to reduction in emissions of carbon monoxide (CO), unburned hydrocarbon (HC) and particulate matter (PM).[2,3,4] Further, production of biodiesel can enhance employment and economic development in rural areas, can develop long term replacement of fossil fuels and can reduce the national dependency on petroleum products.[5]

Vegetable oils are the main resources for world biodiesel production.[6] However, there are many reasons for not using edible oils as a source of biodiesel production because it may lead to a global imbalance in food prices and cause a reduction in their availability. Thus, the focus of the world has shifted towards non-edible oils which can grow on non-arable land which cannot be used for human nutrition. As listed by Azam *et al.*[7], 75 non-edible plant oils have more than 30% oil in their seeds or kernels. A number of studies have been conducted on non-edible oils viz. jatropha[8], karanja[9], tobacco[10], neem[11], sea mango[12] etc. But a serious drawback with most of non-edible oils is a high content of free fatty acids (FFAs), which increase the biodiesel production cost.[13] However, crude argemone oil (CAO) though being a non-edible oil, has a low free fatty acid value of 1.83 (i.e. less than 2%), implying argemone oil methyl ester (AOME) can be easily produced with single step transesterification process.

Most of the previous investigations show that biodiesel blending (up to a certain extent) improves the combustion process resulting in higher brake thermal efficiency and reduced brake specific fuel consumption.[14] It also results in a reduction of emissions such as CO, HC, PM and SO_2.[15] However, the increase in CO_2 and NOx emissions were observed by Lin(2007)[16] due to a 10-11% increase in oxygen

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content that leads to complete combustion and conversion of CO to CO_2 thereby increasing the cylinder temperature, resulting in higher NOx emissions. However, it is believed that fuels having higher viscosity than diesel (such as biodiesels) show good result in IDI engines as compared to DI engines. This is due to the cumulative effect of two factors. First, mixing of oil and air is better due to turbulence in the pre-combustion chamber. Second, NOx formation is reduced as less air is available in the secondary combustion chamber and the temperature of the main cylinder is also less as compared to a DI engine.[17]

Biodiesel has different physical and chemical properties as compared to mineral diesel such as lower heating value and higher stoichiometric fuel/air ratio, which affect the performance and emissions of a CI engine. Also, the performance and emission characteristics are different for the same biodiesel used in different types of CI engines. Many researchers have found that engine performance and emissions characteristics significantly depends upon the engine running conditions and type of biodiesel used.[18,19] K. Hossain *et al*.[17] reported 3% decrease in BSFC at full load conditions in IDI engine. MA Kalam *et al*.[20] and Ahmet Necati Ozsezen *et al*.[21] found that biodiesel blends showed lesser brake torques, powers and higher BSFC (16.1%) as compared to petroleum diesel (PD) at full load in IDI engine. The reason cited was lower energy content of the biodiesel. H. An *et al.*[22] carried out their tests on DI engine and reported 9.6 % increase in BSFC with the use of waste cooking oil in multi-cylinder engine at 100% load. These inconsistencies in the results are attributed to different fuel injection techniques, type of engine and different feedstock selected for biodiesel production.

Argemone Maxicana oil (toxic and adulterer to mustard oil) is a non-edible oil having low free fatty acid content and is easily available in India. But there has been no comprehensive study on the performance and emission characteristics of Argemone oil methyl ester (AOME) in any multicylinder IDI engine. In the previous studies, limited experimentation has been carried out with AOME. The results show significant improvement in performance and emission characteristics.[23] In this study, biodiesel was produced from crude argemone maxicana oil by transesterification. This study aims to investigate the properties of biodiesel/diesel and performance and emission characteristics of a multicylinder IDI engine operating on biodiesel–diesel blends and comparing these results with diesel.

2. Experimental setup

The experiment was performed on a four cylinder, four stroke, variable speed indirect injection (IDI) compression ignition (CI) engine. A schematic diagram of engine test bed is shown in figure 1 and the detailed engine specifications are listed in table 1. The engine was loaded with SAJ make AG80 eddy current type of dynamometer.

The setup has a stand-alone panel box consisting of air box, fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements. The air flow rate was measured with orifice meter and manometer, pressure transmitter and the fuel consumption rate was measured with glass fuel metering column and DP transmitter (Range 0-500 mm water column). Type K-Chromel (Nickel-Chromium / Nickel-Alumel) were used to measure gas temperature at engine exhaust, calorimeter exhaust, water inlet of calorimeter, water outlet of calorimeter and ambient temperature. The signals were interfaced with a computer through data acquisition system (DAQ). Exhaust emissions like CO, CO_2, HC and NOx were measured with the AVL 4000 Di-gas analyzer. The detailed specifications of gas analyzer are shown in the table 3. The basic properties of tested fuels such as Kinematic viscosity, density and calorific value were measured with Ostwald viscometer, automatic density meter and bomb calorimeter respectively.

2.1 Experimental methodology

In the present study, argemone/diesel blends (diesel, B10, B20, B30 and B40) were studied at different engine speeds ranging from 2500-4000 rpm with an interval of 500 rpm under the conditions of 25%, 50% and 75% load. For the systematic conduct of the experiment, engine range was studied and has been shown in figure 2. The range of 2500-4000 rpm was selected for the study as the engine can take a variety of loads in this range. For every blend of argemone biodiesel/diesel, the engine was operated for at least 20 minutes to eliminate the previous sample from fuel line completely. The engine operation showed more stability at 75% load condition than 100% load. Therefore, for safety reasons maximum load on engine was limited to 75%. All the measuring instruments were checked completely and dust particles, carbon deposits, etc. were removed. The cooling water circulation for eddy current dynamometer, engine and calorimeter was ensured to prevent any kind of damage to the system. To begin with the experiment, engine was gradually throttled up to the desired rpm and the engine was simultaneously loaded through dynamometer maintaining the same engine speed. While taking the readings, appropriate time was given to stabilize the temperatures. The data was logged in the “Engine soft”. Each reading was taken thrice for all fuel samples and average of these readings was taken for analysis in this study.

3. Results and discussion

The results concerning the comparison of fuel properties, engine performance and emission characteristics are presented in this section.

3.1 Fuel properties

From the physico-chemical analysis calorific value, viscosity and density of B100 were obtained as 37.7 MJ/kg, 7.12 cSt and 865 kg/m^3 respectively. The properties of other blends of biodiesel and their comparison with ASTM biodiesel standards, conventional diesel fuel have been shown in the table 2. The physic-chemical properties show that biodiesel blends have slightly lower heating value as compared to diesel. This is predictable as biodiesel has higher oxygen content which results in decrease in heating value. The viscosity of biodiesel blends is higher. Higher viscosity results in poor atomization. The density of biodiesel is more than diesel which means more energy content for same volume. This property will tend to compensate the lower heating value to some extent.

3.2 Performance and emission characteristics

In this section, the influence of diesel/argemone biodiesel blends on the performance of engine and emission characteristics are discussed at different load and rpm conditions. Based on engine speed, engine load and fuel consumption rate, brake thermal efficiency and brake specific fuel consumption were calculated. In addition to this, emission characteristics such as NOx, HC, CO, CO_2 and exhaust gas temperature were also studied.

3.2.1 Impact on brake thermal efficiency

It can be observed from the figure 3 (a-c) that brake thermal efficiency (BTE) increases with increase in load. It is a common viewpoint that with increase in load the percentage increase in brake power is more as compared to fuel consumption.[24,25,26] In the present work, maximum BTE was found at 75% load @ 2500 rpm for all fuel blends as compared to other speeds and loads. Moreover, it has been observed that with the increase in rpm, BTE decreased at lower load conditions, but at higher load conditions the effect on BTE with rpm enhancement is less significant. Many researchers have stated decrease in BTE with increase in biodiesel blend ratio[22,27]; however in this exertion, BTE increases with the increase in biodiesel blend ratio up to B30. This is attributed to high turbulence in the pre-combustion chamber of IDI engine that helps in better vaporisation of biodiesel/diesel blends. Due to this, higher viscosity of biodiesel/diesel blends have no negative effect on engine performance, but higher oxygen content results in improved brake thermal efficiency. It was also found that brake thermal efficiency decreases at lower loads and high speed as shown in figure 3 (a-b). This is because at low load and high speed; the fuel consumption and friction power losses are more when compared with high load and high speed condition. It can also be observed that the BTE values of B40 are consistently lower than that of B30 for all loading conditions as higher blends of biodiesel have less calorific value.

3.2.2 Brake specific fuel consumption

Figure 4 (a-c) shows the variation of brake specific fuel consumption (BSFC) with respect to engine speed for various loads. The brake specific fuel consumption decreased with increase in load for all tested fuels. This is again due to higher percentage increase in brake power as compared to fuel consumption at higher loads. Similar trends have also been observed by Xue *et al.*[24] In the present work minimum BSFC was observed at 75% load @2500 rpm for all tested fuels as compared to other rpm and load conditions. An *et al.*[22] observed increase in BSFC with the use of waste cooking oil blends in direct injection engine and the reason cited was the lower calorific value of the biodiesel. In the present work, it was found that with an increase in biodiesel blend ratio up to B30, BSFC decreases. This is again because of higher oxygen content in biodiesel blends that leads to better combustion of fuel and is responsible for reduction in BSFC. This work also showed increase in BSFC at lower loads and high speed as friction power losses increase at a rapid rate, resulting in slower increase in brake power than in fuel consumption. Higher values of BSFC are obtained for B40 when compared to B30 for all conditions as shown in figure 4. The lower heating value of higher biodiesel blends (B40) is responsible for this increase in BSFC.[28] In other words, the loss of heating value of B40 is compensated with higher fuel consumption.

3.2.3 Exhaust gas temperature

The Exhaust gas temperature (EGT) gives qualitative information about the combustion in an engine. EGT increases with increase in load as more heat is generated due to burning of more fuel. The EGT also increases with increase in rpm as less time is available for the combustion to complete at higher speeds. As can be seen from figure 5 (a-c), the maximum value of EGT has been found to be 512.7^{0}C for B20 at 75% load @4000 rpm. Some researchers observed that exhaust gas temperature decreases with increase in biodiesel blend ratio (Muralidharan and Vasudevan[27]; Canakci *et al.*[29]). However, Pramanik[30] and Ramadhas *et al.*[31], observed increase in EGT with increasing biodiesel/diesel blend ratio. Somewhat similar results were obtained in the present study. With an increase in biodiesel blends, EGT was found to be more than that of diesel up to B30 (after that decrease is seen) as more oxygen content in biodiesel is beneficial for combustion up to a certain extent. Thereafter due to reduced calorific value of higher blends, total energy release is reduced, and hence lowering the peak cylinder temperature and exhaust gas temperature. The increase in EGT for B10 and B20 especially at 25% and 50% load indicates slow combustion. The EGT of B30 has been almost similar to diesel for all loads. The EGT for B40 decreases, the prime reason for this seems to be reduced calorific value of higher blends which results in reduced total energy release.[32]

3.2.4 Impact on NOx emissions

The NOx emissions are very sensitive to engine combustion temperature which increases with increase in speed and load. The NOx emissions also depend upon excess oxygen and residence time. Figure 6 (a-c) shows the variation of NOx with respect to load. The maximum value of NOx was observed for B30 at 75% load @2500 rpm. Some correlation between NOx emissions and exhaust gas temperature was also observed. As can be seen from figure 5 (a-c), a decrease in exhaust gas temperature was observed for higher blends of biodiesel (above B30); similar such trends were followed by NOx for B40. Al-Shemmeri and Oberweis[33] too found that NOx emissions were directly proportional to engine exhaust emissions.

Moreover, it has been observed that NOx in higher blends of biodiesel was less at lower loads and high rpm conditions because of less time available for combustion and higher viscosity of biodiesel blends that leads to poor combustion which reduces the peak cylinder temperature and hence lowers the NOx. Qi *et al.*[34] observed decrease in NOx emissions for biodiesel blends as compared to diesel. The reason cited was difference in engine geometry, compression ratio, less reaction time and temperature for biodiesel. In the present study, on an average, NOx was more for biodiesel blends as compared to diesel. Apart from the higher oxygen content in biodiesel, another reason for higher NOx can be higher viscosity and density of biodiesel/diesel blends which leads to advancement in fuel injection and that results in advanced combustion. In addition to this, higher viscosity of biodiesel reduces leakages in a pump leading to an increase in injection pressure. As a result, in-cylinder temperature increases which results in an increase in NOx. As stated by Graboski *et al.*[35], higher ignition delay may also be the reason for the increased NOx.

3.2.5 Impact on hydrocarbon emissions

Unburnt hydrocarbon emission (HC) is the result of incomplete combustion in the engine. In this study, it can be observed from the figure 7 (a-c) that with increase in load, HC emissions decrease. HC emissions first decrease and then increase with the increase in rpm for all loads. Its maximum value was obtained as 12 ppm at 4000 rpm and high load condition. HC emissions first decrease with rpm due to increase in cylinder temperature; the increase thereafter with increase in rpm is due to less time available for combustion at higher speeds. Further, it can also be observed that with an increase in biodiesel blend ratio, HC emissions reduced up to B30 and after that increase in HC emissions was found as higher blends have higher viscosity that cause poor atomization of fuel and result in locally rich mixtures in chamber.

3.2.6 Impact on CO emissions

CO is a toxic gas resulting from incomplete combustion. The amount of CO depends largely on the air-fuel ratio. As diesel engines work in the lean combustion zone, the amount of CO emissions found is less as compared to gasoline engines. It can be easily observed from figure 8 (a-c) that the amount of CO is higher at the higher rpm condition for all loads because of less time available for combustion and rich mixture. Further, it can also be observed that with the increase in biodiesel blend up to B30, there is decrease in CO emissions. However, B40 shows higher CO emission as compared to B30 because of its higher viscosity which results in poor atomization and thus incomplete combustion. The findings and trends are in line with the literature.[34]

3.2.7 Impact on CO_2 emission

CO_2 indicates the combustion performance of a particular fuel. Increase in CO_2 emission means better combustion of a fuel. While some researchers have reported increased CO_2 emissions for biodiesel blends and the reason cited is the higher density of biodiesel which increased the overall fuel mass under complete combustion,[36] there are researchers who observed decrease in CO_2 emissions for biodiesel blends.[22] They contended that this occurred because biodiesel is a low carbon fuel due to the presence of oxygen atoms. Figure 9 (a-c) shows that CO_2 emissions increase with increase in load, as at higher load, air-fuel mixture gets richer and overall fuel mass consumption increases. It has also been observed that for higher blends of biodiesel (up to B30), CO_2 emissions first go up, and decline thereafter as compared to B30. The probable reason could be the presence of higher O_2 content in biodiesel that converts CO to CO_2, but this increased O_2 content also lowers the carbon to hydrogen ratio which may reduce CO_2 emissions for B40. Another factor could be the rise in CO emissions for B40. Thus, in contrast to CO_2, a higher quantity of CO is generated because of higher viscosity.

4. Conclusions

In this study a four cylinder indirect injection (IDI) compression ignition (CI) variable speed diesel engine with rated power of 52kW@4000 rpm and compression ratio of 18.5:1 has been tested with AOME/diesel blends. The blending of AOME with diesel reduces the viscosity and density of the blends and contributes to the presence of oxygen in the tested fuels. Tested fuels (diesel, B10, B20, B30 and B40) show small but significant variations in performance and emission characteristics of engine.

The biodiesel blends show improved brake thermal efficiency and brake specific fuel consumption due to higher oxygen content in AOME/diesel blends. However, this improvement is seen up to 30% blending of AOME only and after that deterioration is seen as inspite of higher oxygen, higher blends of biodiesel have less calorific value, high density and viscosity. The maximum brake thermal efficiency was noticed for B30 as 33.75% which is 11.9% higher than that of mineral diesel fuel.

Emission characteristics of engine such as CO and HC also improved with the use of AOME blends. This improvement is also seen up to 30% blending of biodiesel. Higher blends of biodiesel B40 shows slight increase in these two emission parameters. However, an opposite trend was observed for CO_2 and NOx, which shows better combustion up to 30% blending and poor combustion for higher blends.

It has also been observed that engine load has significant effect on the performance and emission characteristics of engine using different blends of diesel/biodiesel. At higher loads, biodiesel blends show better performance and emission characteristics as compared to lower loads.

It can be concluded that engine does not require any modifications in its configuration for utilization upto 30% AOME in engine and considerable improvements were observed in engine performance and emission characteristics with its use. The non-edible argemone maxicana oil may serve as raw material for the partial fulfilment of increasing demand for diesel.

Nomenclature

B10	10% biodiesel blended with 90% diesel
B20	20% biodiesel blended with 80% diesel
B30	30% biodiesel blended with 70% diesel
B40	40% biodiesel blended with 60% diesel
BTE	Brake thermal efficiency
BSFC	Brake specific fuel consumption

IDI	Indirect Injection
CI	Compression ignition
AOME	Argemone oil methyl ester.
DI	Direct injection
HC	Hydrocarbon
CO	Carbon monoxide
CO_2	Carbon dioxide
NOx	Oxides of Nitrogen
ppm	Parts per million
rpm	Revolution per minute
FFA	Free fatty acid

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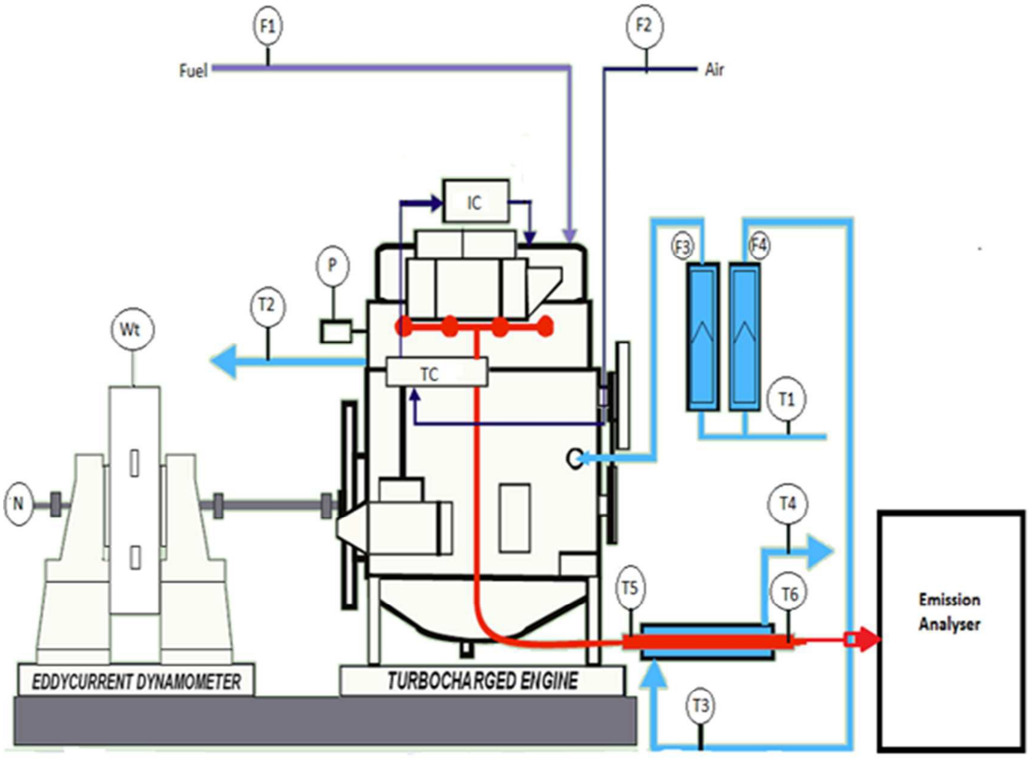


T1	Cooling water inlet temp to engine	F2	Air Consumption
T2	Cooling water outlet temp to engine	F3	Engine water flow
T3	Calorimeter Inlet water temp	F4	Calorimeter water flow
T4	Calorimeter Outlet water temp	Wt	Load Sensor
T5	Exhaust gas Temperature before Calorimeter	IC	Intercooler, TC turbocharger
T6	Exhaust gas Temperature after Calorimeter	P	Cylinder pressure and injection pressure sensor
F1	Fuel consumption	N	Speed Sensor

Figure 1 Schematic diagram of engine

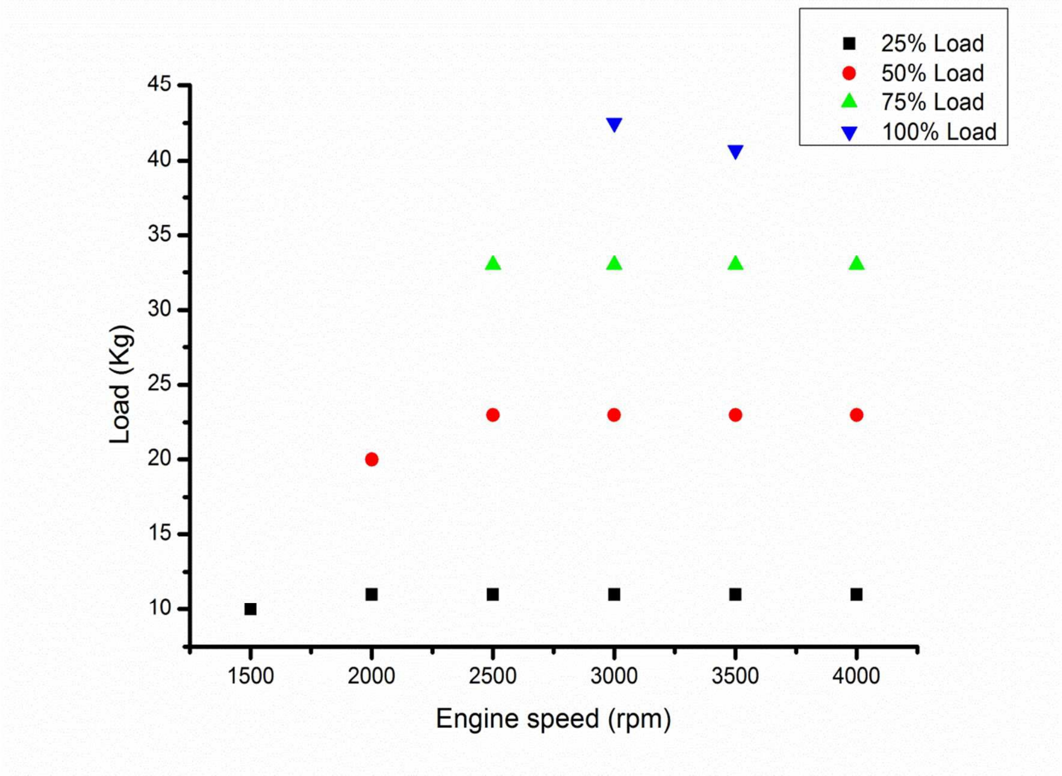
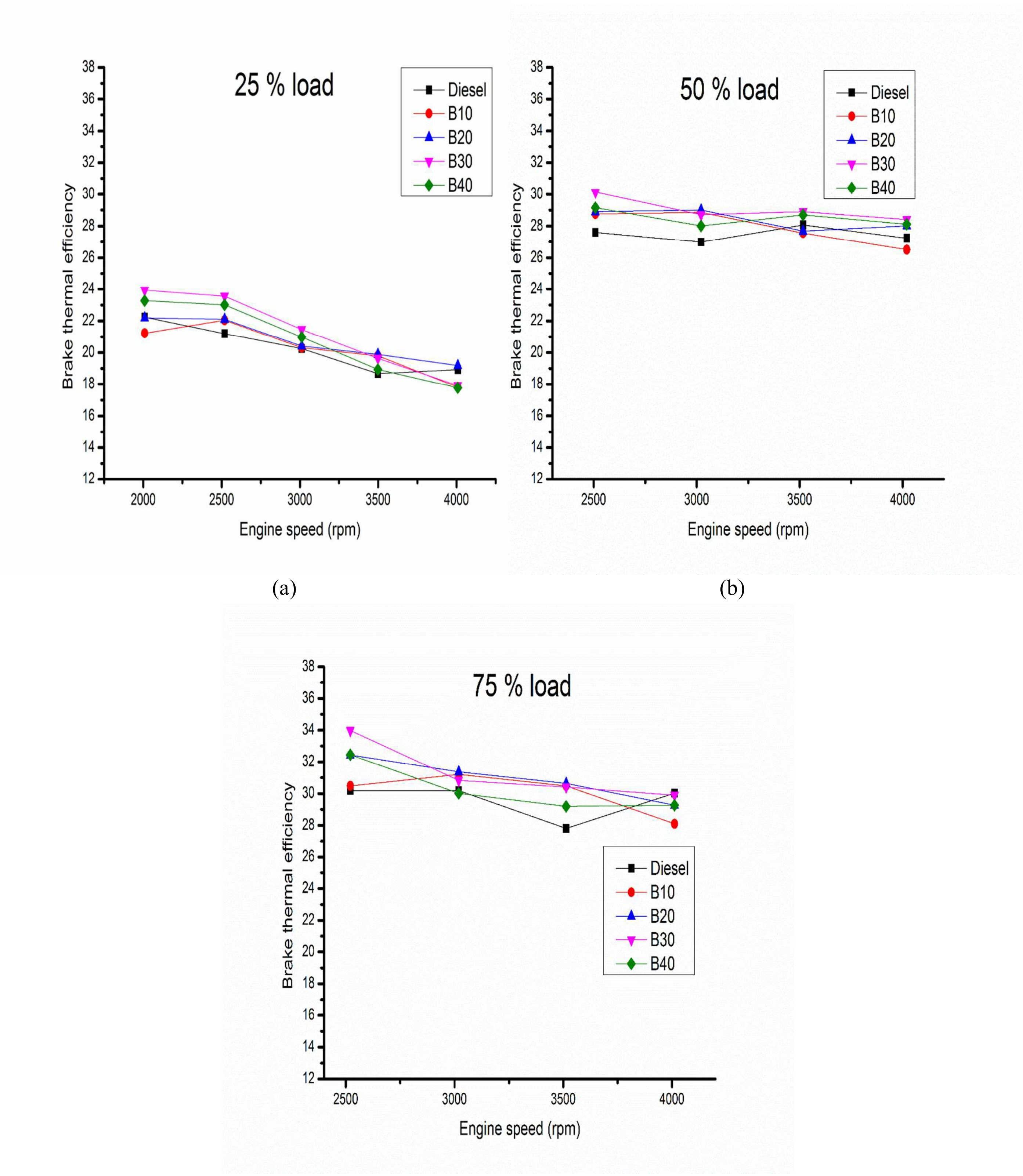


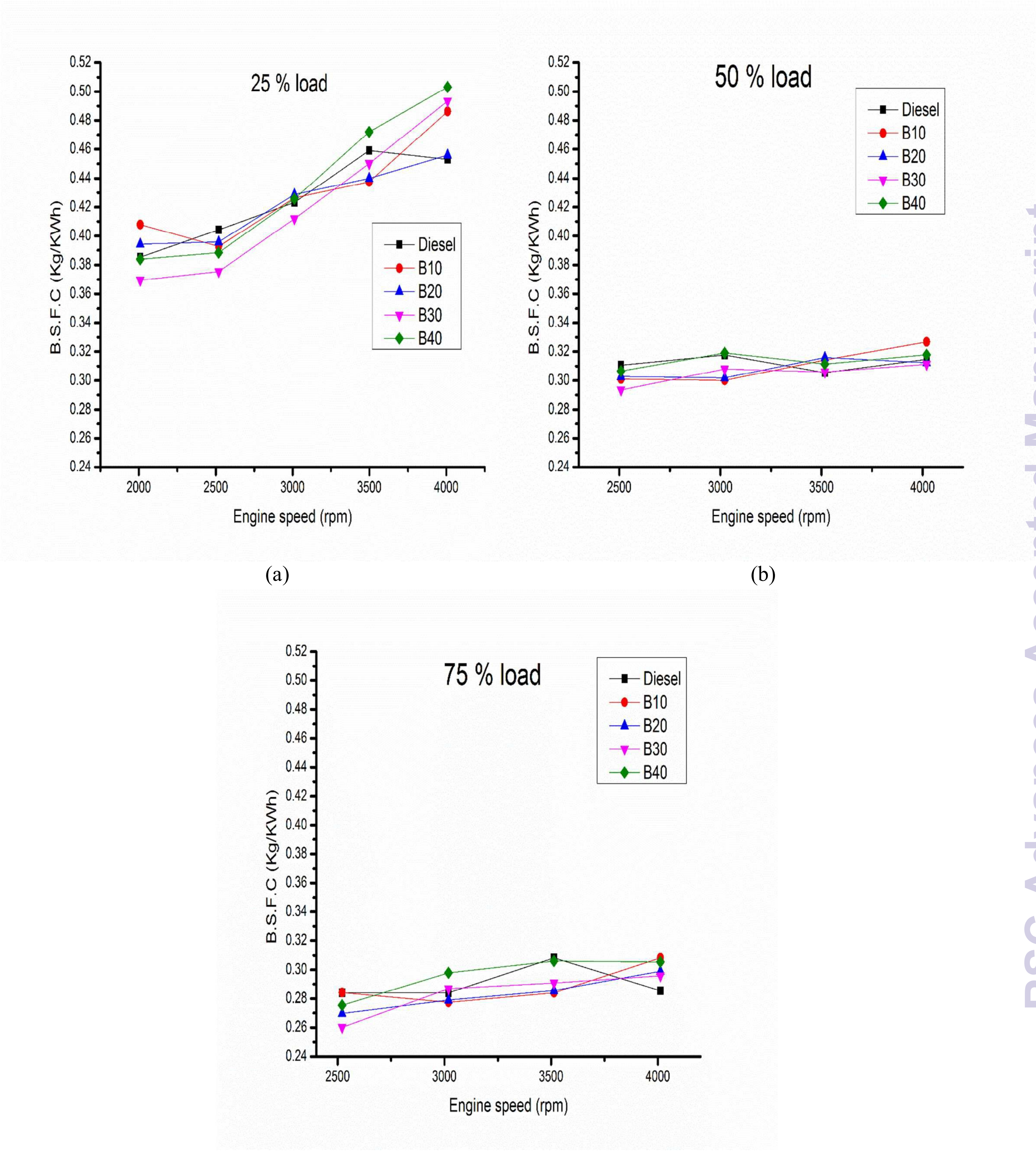
Figure 2 Engine range calculation



(a) (b)

(c)

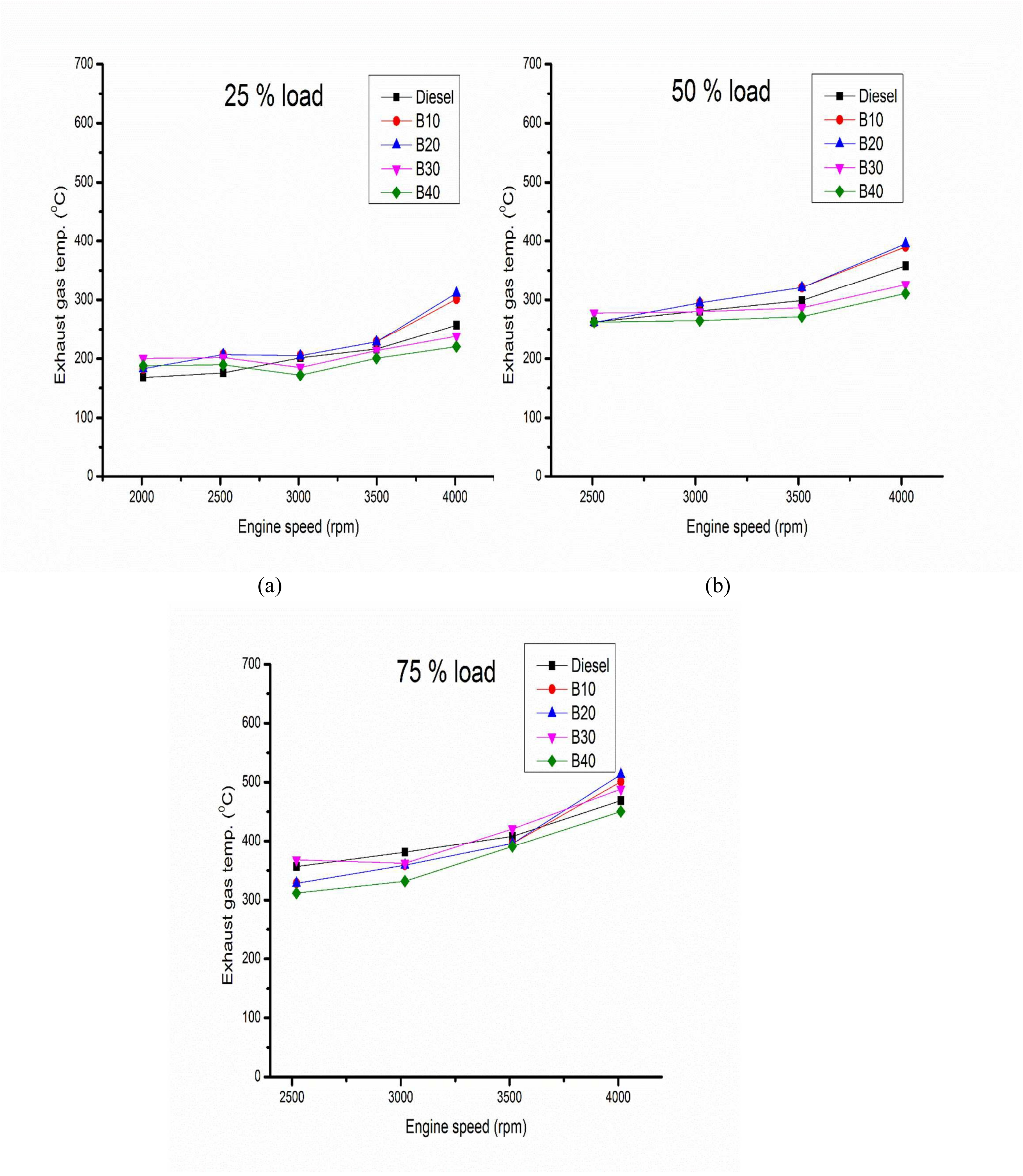
Figure 3 Variation of brake thermal efficiency with different load and engine speed (rpm)



(a) (b)

(c)

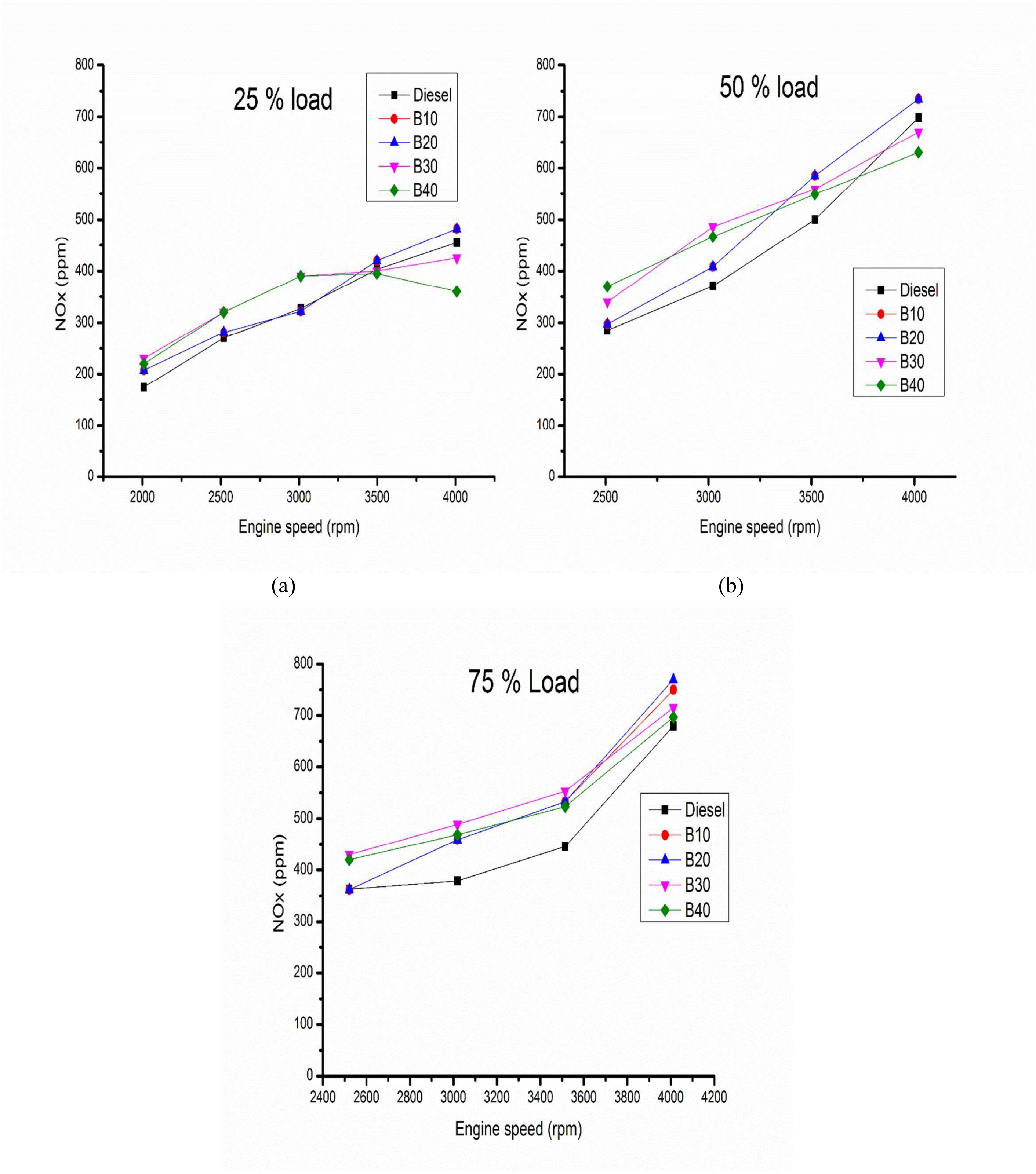
Figure 4 Variation of brake specific fuel consumption with different load and engine speed (rpm)



(a) (b)

(c)

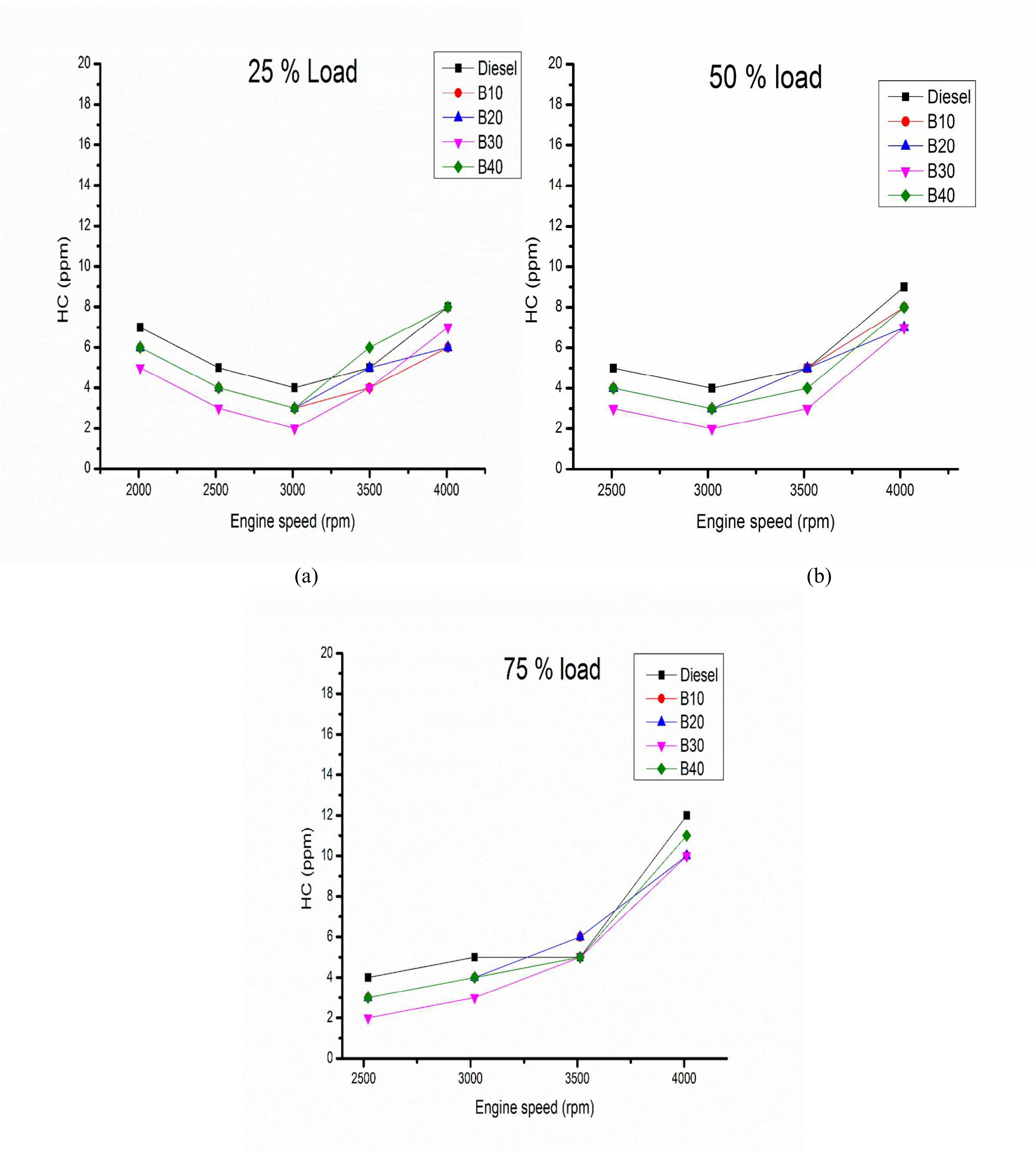
Figure 5 Variation of exhaust gas temperature with different load and engine speed (rpm)



(a) (b)

(c)

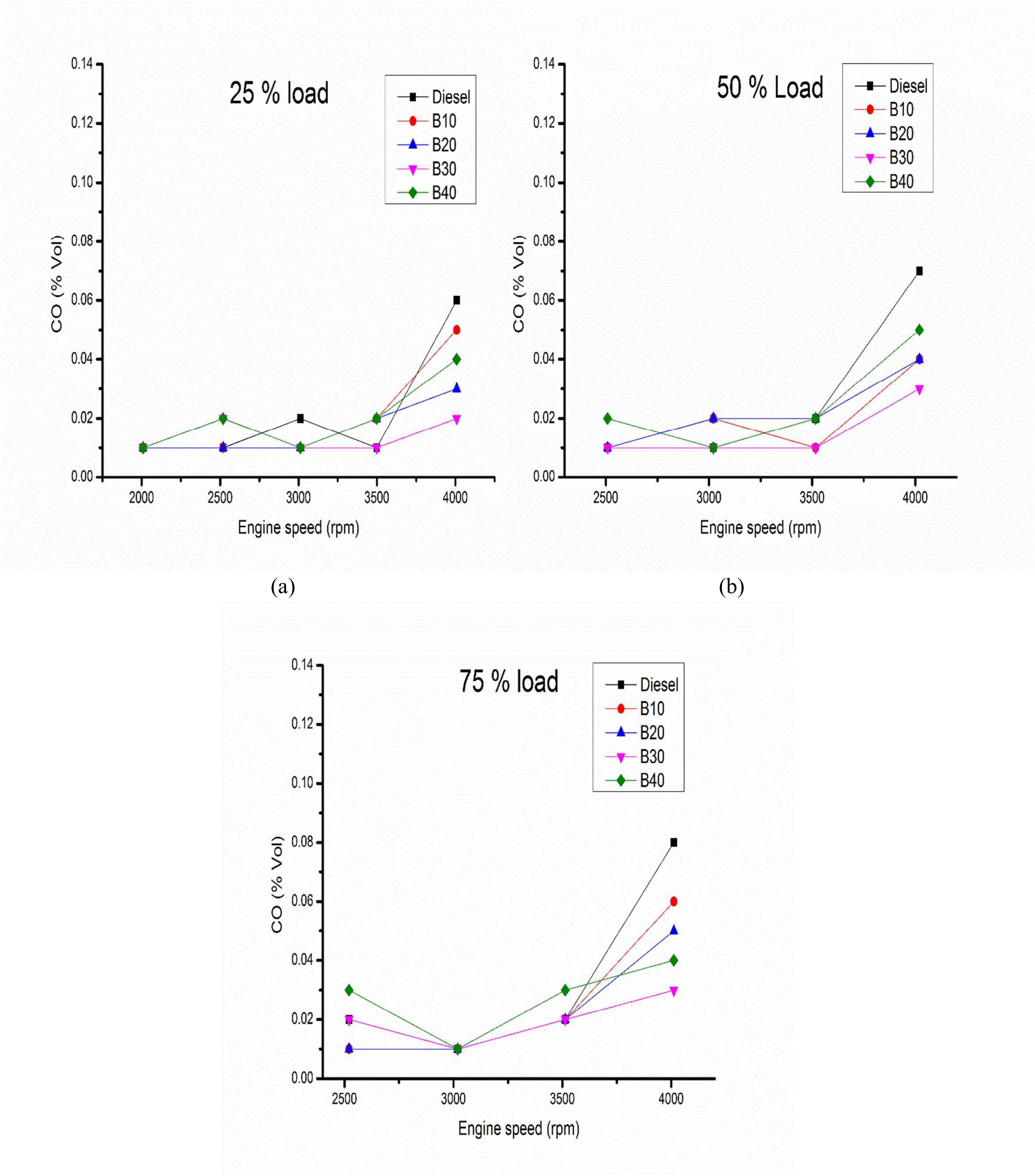
Figure 6 Variation of NOx with different load and engine speed (rpm)



(a) (b)

(c)

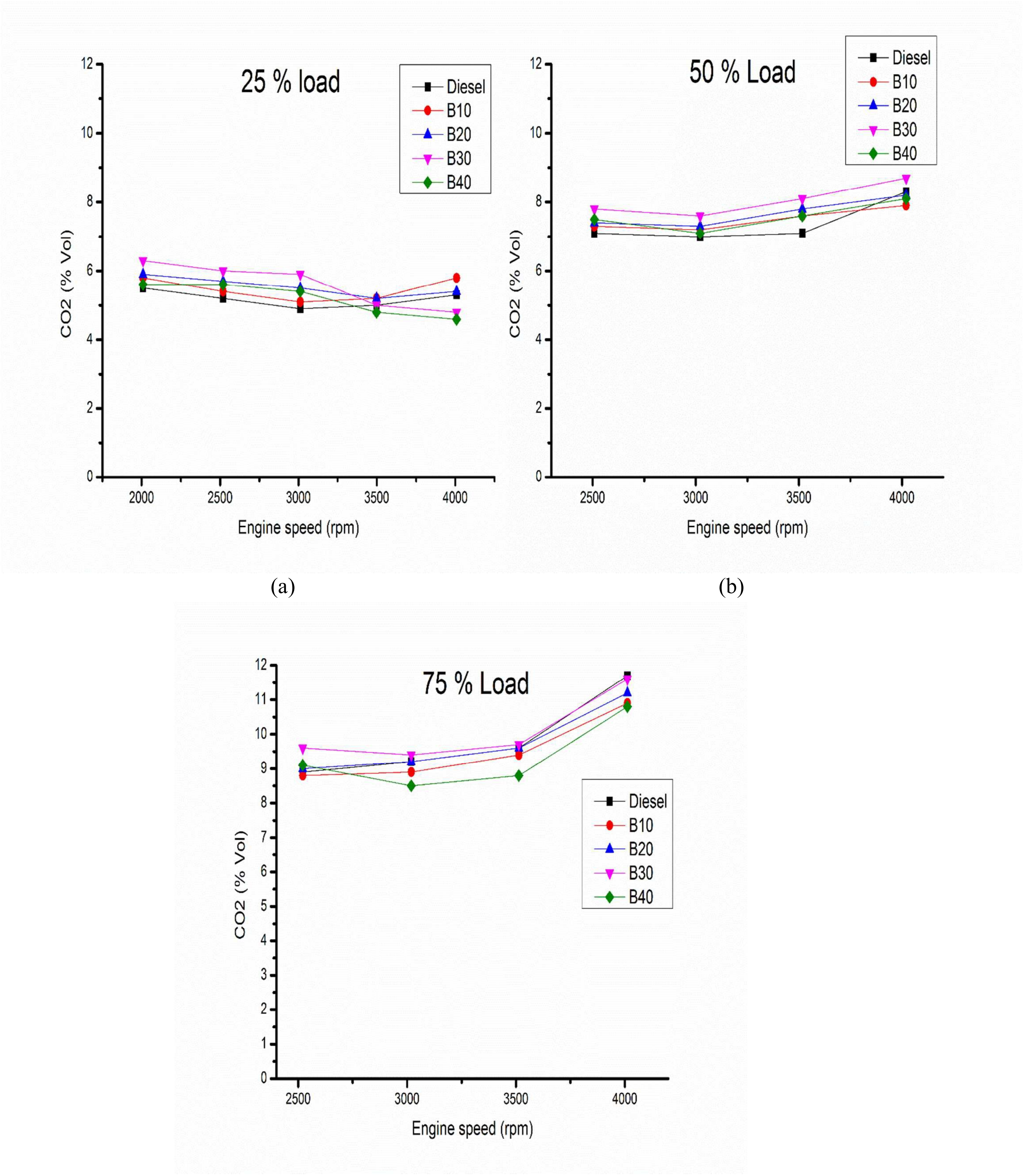
Figure 7 Variation of HC with different load and engine speed (rpm)



(a) (b)

(c)

Figure 8 Variation of CO with different load and engine speed (rpm)



(a) (b)

(c)

Figure 9 Variation of CO_2 with different load and engine speed (rpm)

Table 1Engine specifications

Maker	Tata Engineering Ltd.
Model	Tata Indica
Details	Four Cylinder, IDI, Four stroke
Bore and Stroke	75 mm × 79.5 mm
Compression ratio	18.5:1
Cubic capacity	1405
Rated power	52 KW @ 4000 rpm
Max torque	122.5 Nm @ 2500 rpm
Orifice diameter	48 mm
Cooling	Water

Table 2 Properties of diesel/Argemone biodiesel blends

Property	**Diesel**	**B10**	**B20**	**B30**	**B40**	**B100**	**ASTM Std**
Density 15 ˚ C (Kg/m^3)	820	824.5	829	833.5	838	865	-
Calorific value (MJ/Kg)	42	41.57	41.14	40.71	40.2	37.5	-
Viscosity 40 ˚C (c St)	3.55	3.907	4.264	4.621	4.978	6.54	1.9-6
Flash point	56	69.7	83.4	97.1	110.8	193	130 min
Copper strip corrosion test	-	Passed	Passed	Passed	Passed	Passed	-

Table 3 Specifications of emission analyzer

AVL DiGas 4000	**Measurement range**	**Resolution**
CO	0-10% Vol	0.01% Vol
CO_2	0-20% Vol	0.1% Vol
HC	0-20,000 ppm	1 ppm
NOX	0-5,000 ppm	1 ppm
O_2	0-25% Vol	0.01% Vol