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RESEARCH ARTICLE

Utilization of argemone oil biodiesel in commercial IDI-CI engine

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ABSTRACT

In this study the performance and emission characteristics of diesel engine fueled with diesel/Argemone biodiesel blends has 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, indicated thermal efficiency, indicated mean effective pressure improved and resulted in significant reductions in CO and HC emissions. However, an increase in CO_2 and NO_x emissions was observed for all biodiesel blends. The maximum value of brake thermal efficiency of 33.57 per cent was obtained for B30 at full load @2500 rpm. The blends showed deterioration in brake thermal efficiency and brake specific fuel consumption at partial loads and high rpm conditions. The comprehensive analysis of experimental results shows substantial improvement in engine emissions and performance characteristics by the utilization of 30 per cent AOME and without carrying out any engine modification.

KEY WORDS : Argemone biodiesel, Performance, Emission, Indirect injection, Low load, Full load

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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 (Statistical review of world energy and resources, 2014); with the discovery of new oil fields, the total world proved oil resources reached 1687 billion barrels at the end of 2013 that are 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 the petroleum diesel.

Sufficient literature is available with advantages derived using biodiesel: renewable nature, safe to handle, practically no sulfur content, no aromatic compounds, oxygen in fuel molecules which result in reduction in emissions of carbon monoxide (CO), unburned hydrocarbon (HC) and particulate matter (PM) (Demirbas, 2007). Also production of biodiesel can enhance employment and economic development in rural areas, to develop long term replacement of fossil fuels and to reduce the national dependency on petroleum products (Moser, 2009)

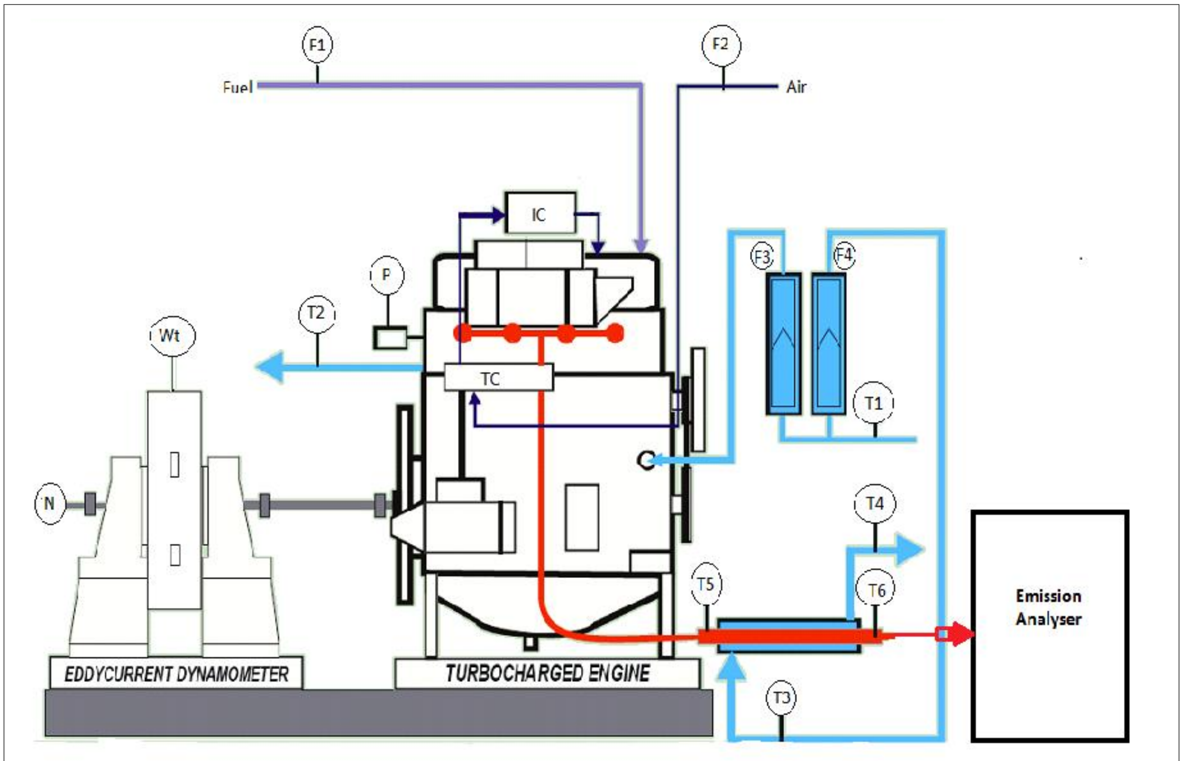
Vegetable oils are the main resources for world biodiesel production (Halek, 2009). However, there are many reasons for not using edible oils as a source of biodiesel production because it may lead to global imbalance as it can increase the food prices and cause reduction in their availability. Thus, the focus of the world has been shifted towards the non-edible oils which can grow on the wasteland and cannot be used for human nutrition. As listed by Azam (2005), 75 non-edible plant oils have more than 30 per cent oil in their seeds or kernels. A number of studies have been done on non-edible oils *viz.*, jatropha (Patil, 2009), Karanja (Naik M., 2008), tobacco (Velikovic, 2006), neem (Nabi, 2008), sea mango (Kansedo, 2009) etc. But a serious drawback which most non-edible oils have is a high content of free fatty acids (FFAs), which increase the biodiesel production cost (Leung, 2010). However, crude argemone oil (CAO) though being a non-edible oil, has low free fatty acid value of 1.83 (*i.e.* less than 2 %), which means AOME can be easily produced with single step transesterification process (Sithta, 2012)Most of the previous investigations show that biodiesel blending (up to a certain extent) improves the combustion process which results in higher brake thermal efficiency and reduced brake specific fuel consumption (Reference). Further, it also results in reduction of emissions such as CO, HC, PM and SO_2 (Ozsezen *et al.*, 2009). However, the increase in CO_2 and NO_x emissions were observed by Lin (2007) due to 10-11 per cent more oxygen content that leads to complete combustion and is responsible for conversion of CO to CO_2 thereby increasing the cylinder temperature, resulting in higher NO_x emissions. However, it is believed that fuels having higher viscosity than diesel (such as biodiesels) shows good result in IDI engines as compared to DI engines. This is due to cumulative effect of two factors. Firstly, mixing of oil and air is better due to turbulence in the pre-combustion chamber. Secondly, NO_x formation is less as less air is available in the secondary combustion chamber and the temperature of main cylinder is also less as compared to DI engine. (Hossain and Davied, 2012) As the biodiesel has different physical and chemical properties from mineral diesel including lower heating value and higher stoichiometric fuel/air ratio, the biodiesel will affect the performance and emissions of a CI engine. Also, the performance and emission characteristics will be different for the same biodiesel used in different types of CI engine. Argemone Mexicana oil (toxic and adulterer to mustard oil) is a non-edible oil that has low free fatty acid content and easily availability in India. But there is no comprehensive study available 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 showed significant improvement in performance and emission characteristics (Kumar, 2014). In this study, biodiesel was produced from argemone maxecana crude oil by the method of 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.

EXPERIMENTAL PROCEDURE

Argemone mexicana, has been selected as a feedstock for biodiesel production. It has low free fatty acid value, non-edible and is easy available in India. This plant is an annual herb which is a common weed in both agricultural and waste lands. The plant originated in tropical America but now it thrives well in India, Pakistan and Bangladesh. Traditionally, it is reported to be used as diuretic, purgative, anti-inflammatory, analgesic and believed to destroy the worms, cure itching, various skin diseases and an antidote to various poisons (Dash, 2011). The plant reaches a height of 2-3 ft, flowers during the month of March-April and sets fruit in the month of May-June (Ahmed *et al.*, 2011). The fatty acids present in Argemone mexicana seed oil is Myristic acid, Palmitic acid, Stearic acid, Oleic acid; Linoleic acid and Arachidic acid (Rao, 2012). Since, the FFA of Argemone mexicana is less than 2 per cent therefore, single step transesterification has been used for the production of methyl esters of Argemone oil. To start with the process 15g of Na metal was added to 260 ml methanol and was allowed to stand for 10 minutes; they react to form sodium methoxide (strong base). This mixture was then added to 1000 ml of crude argemone oil (preheated at 80°C) and the mixture was kept under constant agitation with the help of a motor at 250 rpm for two hours at a temperature between 65-70°C, to maintain the uniform heat transfer rate in the system. The mixture at the end of the reaction was allowed to settle. The lower glycerol layer was drawn off while the upper methyl ester was washed to remove entertained glycerol. The excess methanol was removed by heating the methyl esters for 4-5 minutes at the temperature of 100°C.

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 Fig. A and the detailed engine specifications are listed in Table A.The engine was loaded with SAJ make AG80 eddy current type of dynamometer.



T_1	Cooling water inlet temp to engine	F_2	Air consumption
T_2	Cooling water outlet temp to engine	F_3	Engine water flow
T_3	Calorimeter inlet water temp	F_4	Calorimeter water flow
T_4	Calorimeter outlet water temp	Wt	Load sensor
T_5	Exhaust gas temperature before calorimeter	IC	Intercooler, TC turbocharger
T_6	Exhaust gas temperature after calorimeter	P	Cylinder pressure and injection pressure sensor
F_1	Fuel consumption	N	Speed sensor

Fig. A : Schematic diagram of engine

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, Range (-) 250 mm WC and the fuel consumption rate was measured with glass fuel metering column, DP transmitter, Range 0-500 mm WC. Type K-Chromel (Nickel-Chromium / Nickel-Alumel) were used to measure gas temperature at engine exhaust, calorimeter exhaust, water inlet of calorimeter and water outlet of calorimeter, 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

Table A : Properties of diesel/Argemone biodiesel blends							
Property	Diesel	B10	B20	B30	B40	B100	ASTM Std
Density 15^0 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 40^0 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	93 max
Copper strip corrosion test	-	Passed	Passed	Passed	Passed	Passed	-

analyzer are shown in the Table 1.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.

In the present study, argemone/diesel blends (diesel, B10, B20, B30 and B40) were studied at different engine speeds from (2500-4000) with an interval of 500 rpm under the conditions of 25 per cent, 50 per cent and 75 per cent load.

For the systematic conduct of the experiment, engine range was studied and has been shown in Fig. 1. The range of 2500-4000 rpm was selected for the study as the engine can take a variety of loads between 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 good stability at 75 per cent load condition rather than 100 per cent load. Therefore, for safety reasons 75 per cent load condition was chosen. All the measuring instruments were checked completely and dust particles, carbon deposits, etc. were removed from them. The cooling water circulation for eddy current dynamometer, engine cooling and calorimeter was ensured to prevent any kind of damage to the system. To start 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 all the temperatures and data was logged in the "Engine soft". Each reading was taken three times for all fuel samples and then the average was taken out.

EXPERIMENTAL FINDINGS AND ANALYSIS

The results concerning the comparison of fuel properties, engine performance and emission characteristics are presented and discussed here.

Fuel properties:

From the physico-chemical analyses calorific value, viscosity and density of B100 were found as 37.7MJ/Kg, 7.12cSt and 865kg/m^3, respectively. The properties of other blends of biodiesel and their comparison with ASTM biodiesel standards, conventional diesel fuel has been shown in the Table 1. The physico-chemical properties show that biodiesel blends have slightly lower heating value as compared to diesel. This is expected 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 that more energy content for same volume. This property will tend to compensate the lower heating value to some extent.

Performance characteristics:

In this section, the impact of diesel/argemone blends on the engine performance at no load, partial load and high load conditions have been studied. Brake specific fuel consumption and brake thermal efficiency were calculated based on the engine speed, engine load and the fuel consumption rate which were averaged over 10 working cycles

Impact on brake thermal efficiency:

It can be easily observed from the Fig. 1 (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 (Xue, 2011). In the present work, maximum BTE was found at 75 per cent 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 reported decrease in BTE with increase in biodiesel blend ratio (H. An, 2012); however in the present work BTE generally increases with the increase in biodiesel blend ratio up to B30 except at lower loads and high r.p.m conditions as biodiesel contains 10-11 per cent more oxygen content as compared to diesel that leads to better combustion and is responsible for the increase in BTE but at lower loads and high rpm conditions, the fuel consumption and frictional power losses are more as compared to high load and high rpm condition. In addition to this, higher blends of biodiesel have less calorific value. As a result, at lower loads and high rpm conditions the BTE of higher blends of biodiesel is less. It can also be observed that the BTE values of B40 are consistently lower than that of B30 for all loading conditions.The maximum increase of 11.9 per cent in b.t.e has been observed at 75 per cent load @2500 rpm for B30 as compared to diesel fuel. However a decrease of 8.40 per cent is noted for B40 at 25 per cent load @4000 rpm B30 shows maximum values of BTE (33.57%) as compared to other biodiesel blends and diesel (29.9%).

Brake specific fuel consumption:

Fig. 2 (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 also due to higher percentage increase in brake power as compared to fuel consumption at higher loads. Similar trends have

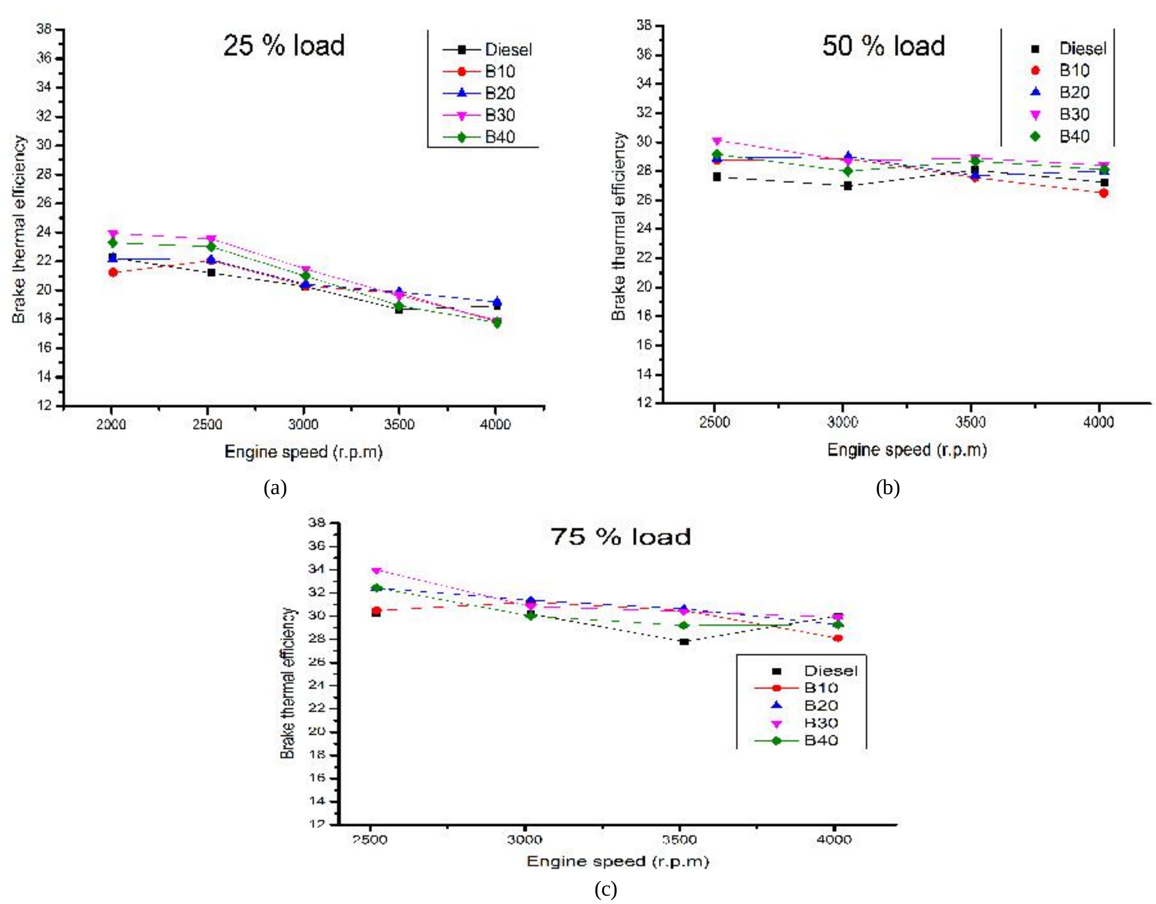


Fig. 1 : Variation of brake thermal efficiency with different load and engine speed (r.p.m.)

also been observed by Xue *et al.* (2011). In the present work minimum BSFC was observed at 75 per cent load @2500 rpm for all tested fuels as compared to other rpm and load conditions. An *et al.* (2012) observed increase in BSFC with the use of waste cooking oil blends in direct injection engine and reason mentioned was the lower calorific value of the biodiesel. However in the present research it was observed that with the increase in biodiesel blend ratio up to B30, BSFC decreases except at low loads and high rpm conditions. 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 but at lower loads and high rpm conditions, friction power losses increase at a rapid rate, resulting in slower increase in brake power than in fuel consumption. The lower heating value of biodiesel blends is another factor which results in increase in BSFC (Buyukkaya, 2010). It can also be observed from Fig. 3 that higher values of BSFC are obtained for B40 as compared to B30 for all conditions.

The maximum increase of 13.3 per cent in BSFC is observed at 25 per cent load @4000 rpm for B40 and decrease of 7.6 per cent is reported at 75 per cent load @2500 rpm for B30 as compared to diesel fuel. B30 shows the

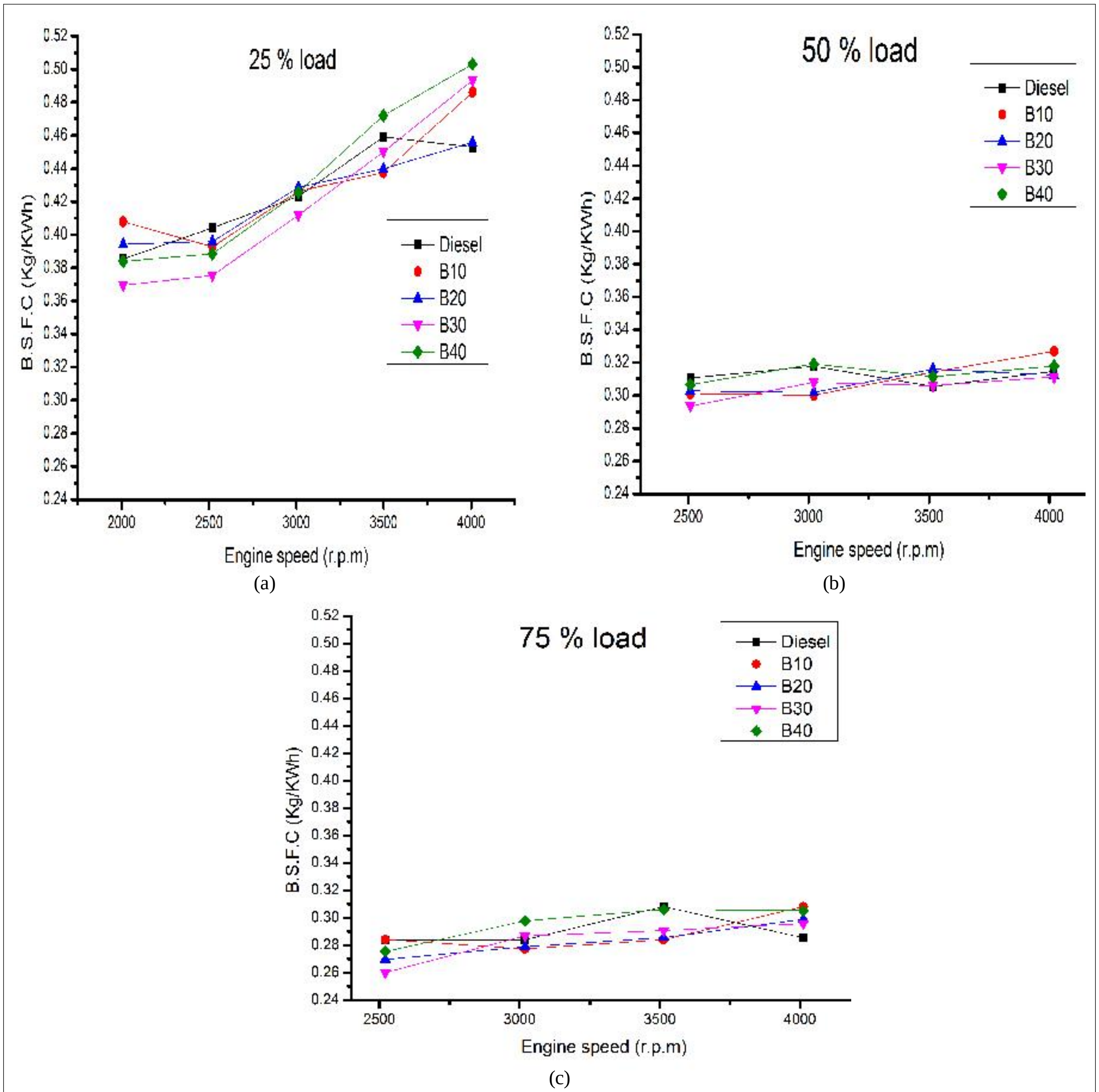


Fig. 2 : Variation of brake specific fuel consumption with different load and engine speed (r.p.m.)

lowest value of BSFC (0.26kg/KWh) as compared to other biodiesel blends and diesel (0.28 kg/kWh)

Impact on NOx emissions:

The NO_x emissions are very sensitive to engine combustion temperature which increases with increasing speed and load. The NOx emissions also depend upon excess oxygen and residence time. The maximum value of NO_x was observed as 680, 750, 770, 715 and 690 for diesel, B10, B20, B30 and B40 respectively (Fig. 3a-c). Some correlation between NO_x emissions and exhaust gas temperature was observed. As can be seen from Fig. 3(a-c), a decrease in exhaust gas temperature was observed for higher blends of biodiesel (above B30); similar such trends were followed by NO_x for B40. Al-Shemmeri and Oberweis (2011) too found that NO_x emissions were directly proportional to engine exhaust emissions. Moreover, it has been observed that NO_x in higher blends of biodiesel was less at lower loads and high rpm conditions because of less time availability for combustion and higher viscosity of biodiesel blends that leads to poor combustion which reduces the peak cylinder temperature and hence lowers the NOx. While on an average, NOx was more for biodiesel blends as compared to diesel. Qi *et al.* (2009) 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. Some researchers (Grabowsks McCormickRL, 1998) who reported higher

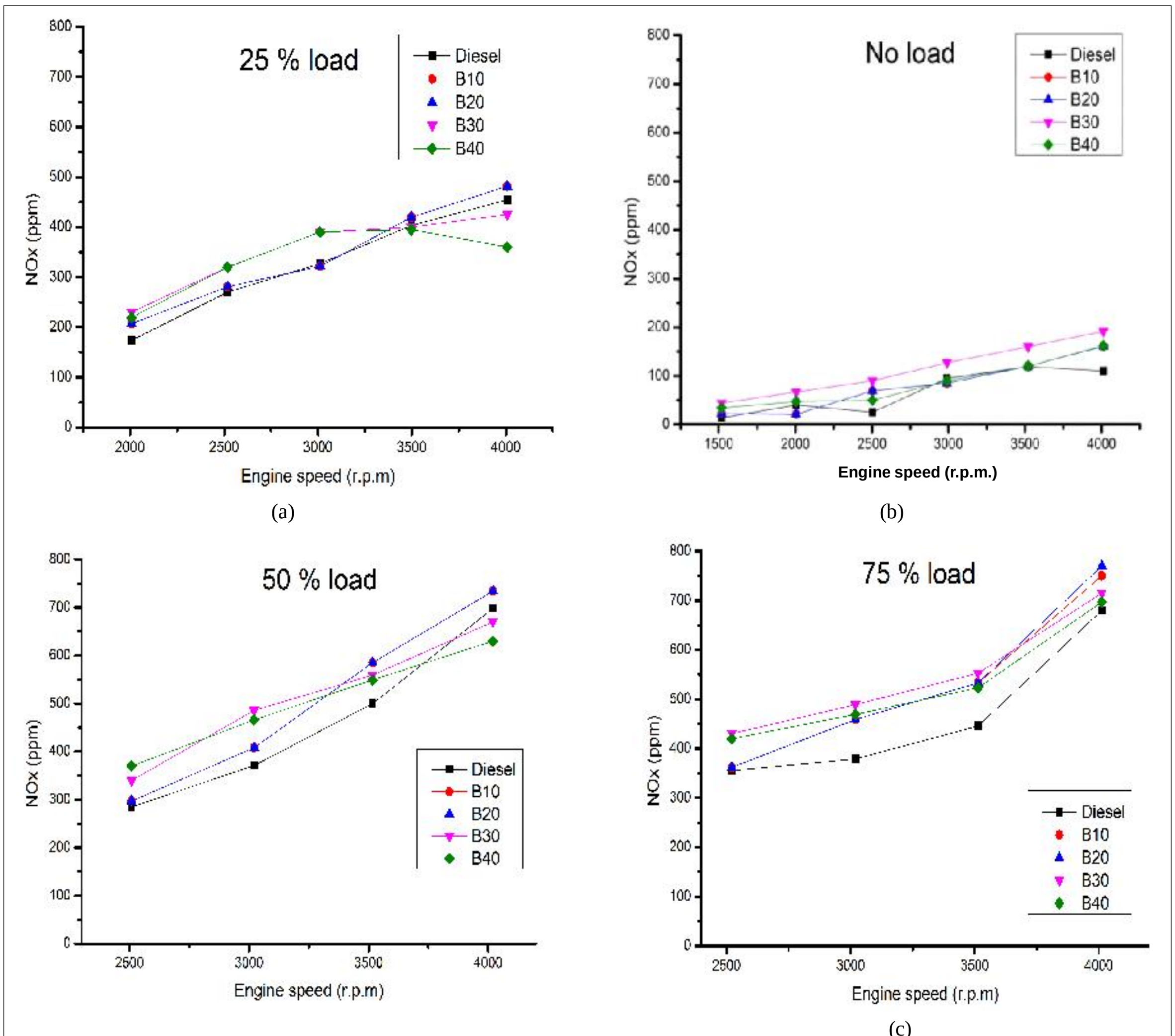


Fig. 3 : Variation of NOx with different load and engine speed (r.p.m.)

NOx for biodiesel than diesel stated higher ignition delay of biodiesel as a reason. The maximum increase of 18.30 per cent is observed for B30 at 75 per cent load @2500 rpm and maximum decrease of 20.8 per cent is found for B40 at 25 per cent load @ 4000 rpm as compared to diesel fuel.

Impact on hydrocarbon emissions:

Unburnt hydrocarbon emission (HC) is the result of incomplete combustion in the engine and it may also increase because of excessively rich air-fuel mixture. In this study it can be observed from the Fig. 4 (a-c) that with increase in load, HC emissions decreased. For medium and high load conditions, HC emissions first decreased and then increased with increase in rpm. HC emissions first decreased with rpm due to increase in cylinder temperature. HC emissions then increased with increase in rpm as less time is available for combustion at higher speeds. Further, it can also be observed that with an increase in biodiesel blend ratio, HC emission reduced up to B30 and after that increase in HC emissions is found as higher blends have higher viscosity that cause poor atomization of fuel and thus resulted in locally rich mixtures in chamber. The minimum value of HC was found as 4, 3, 3, 2 and 3 ppm for diesel, B10, B20, B30 and B40, respectively at 75 per cent load @2500 rpm and maximum value was measured as 12 ppm at 75 per cent load @4000 rpm for diesel fuel as compared to other diesel/Argemone biodiesel blends.

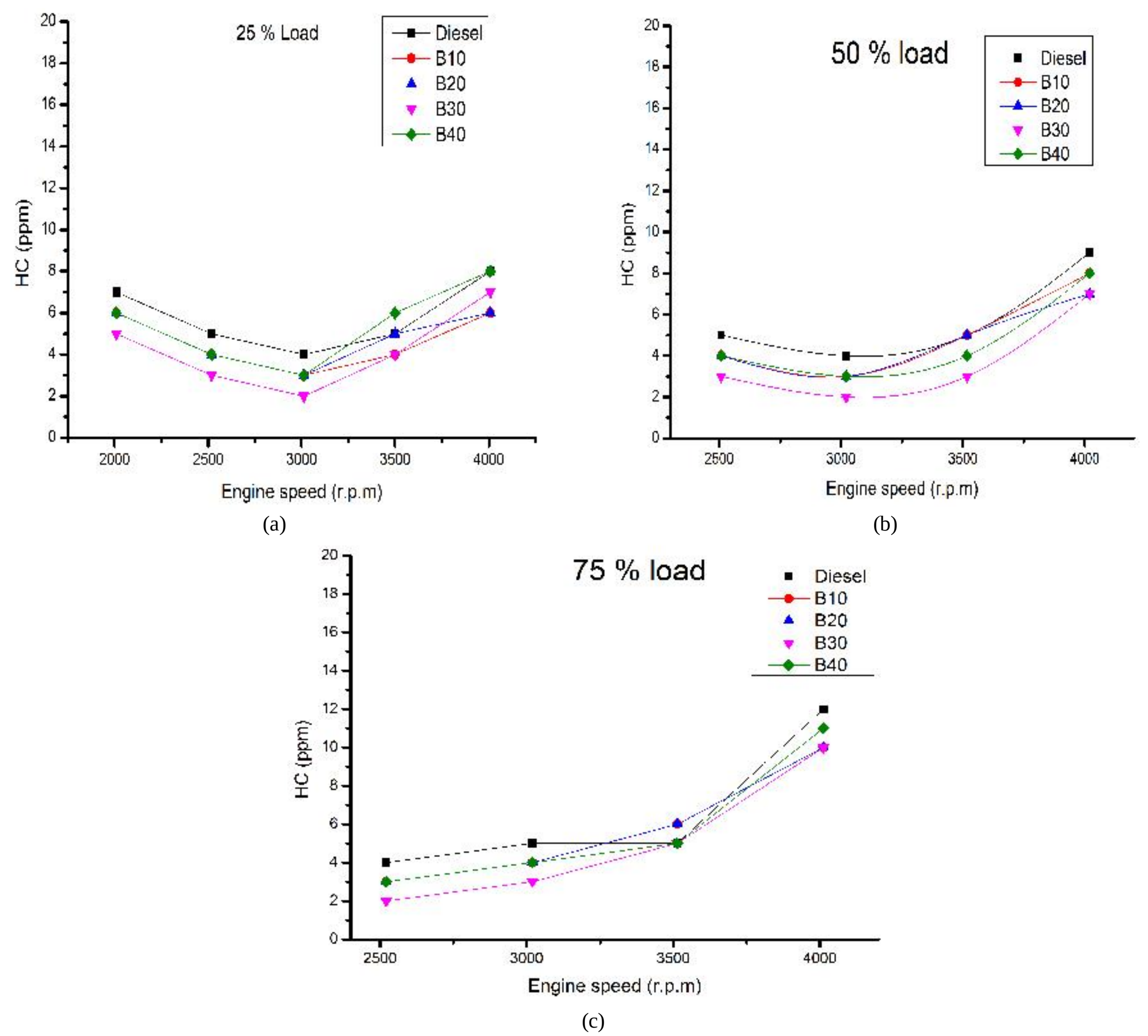


Fig. 4 : Variation of HC with different load and engine speed (r.p.m.)

Impact on CO emissions:

CO is a toxic gas resulting from incomplete combustion. The amount of CO depends greatly 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 Fig. 5 (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 decrease in CO emission is noticed. 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 maximum value of CO was found to be 0.08 per cent, 0.06 per cent, 0.05 per cent, 0.03 per cent and 0.04 per cent Vol for diesel, B10, B20, B30 and B40 at 75 per cent load @4000 r.p.m. The findings and trends were supported by literature available data (Qi *et al.*, 2009).

Impact on CO_2 emission:

CO indicates the combustion performance of a particular fuel. Increasing CO_2 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 (Ng, 2011), there are researchers who observed decrease in CO_2 emissions for biodiesel blends (An *et al.*, 2012). They concluded that this occurred because biodiesel is a low carbon fuel due to the presence of oxygen atoms. Fig. 6 (a-c) shows that CO_2 emission increased with increase in load as with an increase in load the air-fuel mixture becomes rich and overall fuel mass consumed is more. It has also been observed that with increase in biodiesel, CO_2 emission increases up to B30; after that decrease is observed as compared to B30.This increase in CO_2 could be due to more O_2 content in biodiesel that

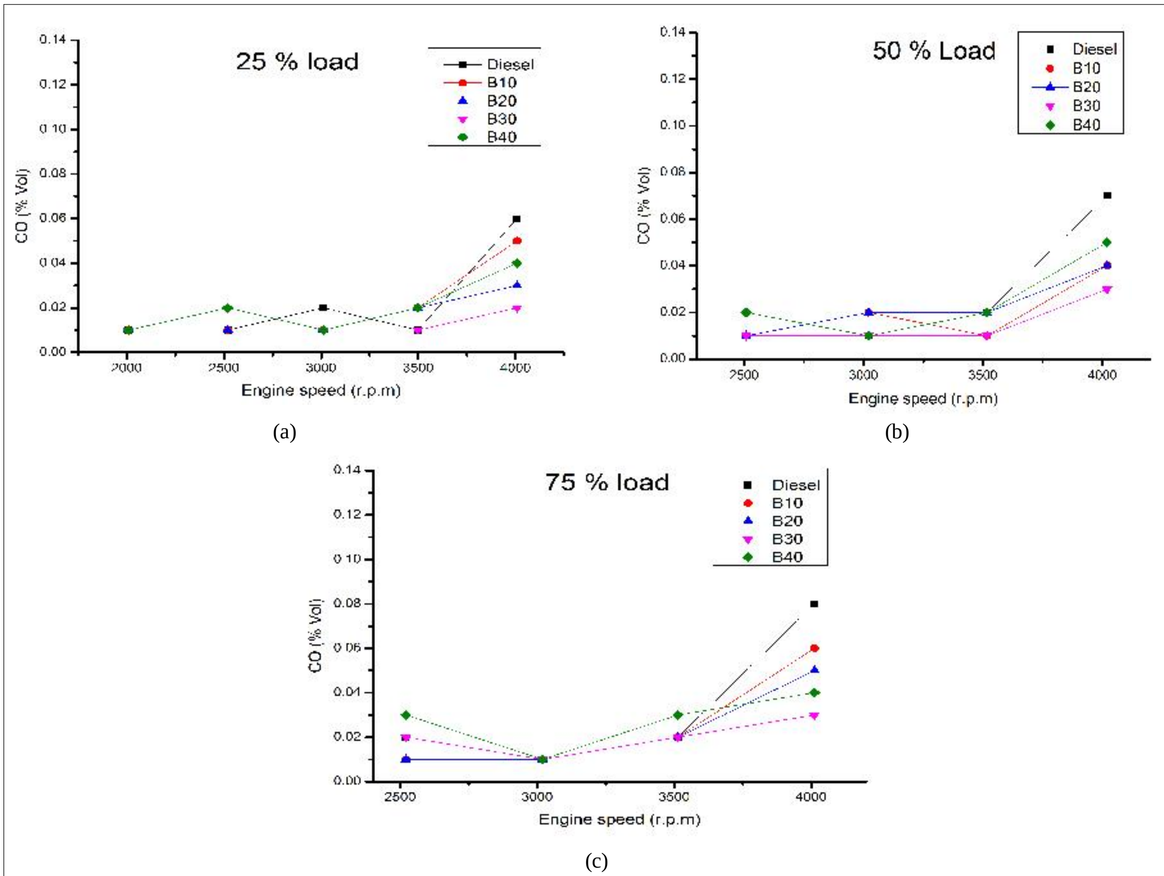


Fig. 5 : Variation of CO with different load and engine speed (r.p.m.)

leads to more conversion of CO to CO_2, but this increase in O_2 content also lowers the carbon to hydrogen ratio for higher blends of biodiesel which resulted in decreased CO_2 emissions for B40. Another probable reason for decrease in CO_2 emissions for B40 is the increase in CO emissions for B40. Thus instead of CO_2, more CO is generated because of higher viscosity. The maximum CO_2 was measured as 11.7 per cent, 10.9 per cent, 11.2 per cent, 11.6 per cent, and 10.8 per cent for diesel, B10, B20, B30 and B40 at 75 per cent load @4000 rpm. However, maximum increase of 11.2 per cent in CO_2 emission was observed for B30 at 75 per cent load @2500rpm and maximum decrease of 13 per cent was noticed at 25 per cent load @ 4000 rpm for B40 as compared to diesel fuel.

Conclusion :

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. Tested fuels (diesel, B10, B20, B30 and B40), shows small but significant variations in performance and emission characteristics of engine.

The biodiesel blends shows 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 per cent 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 per cent 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 perceived up to 30 per cent blending of biodiesel. Higher blends of

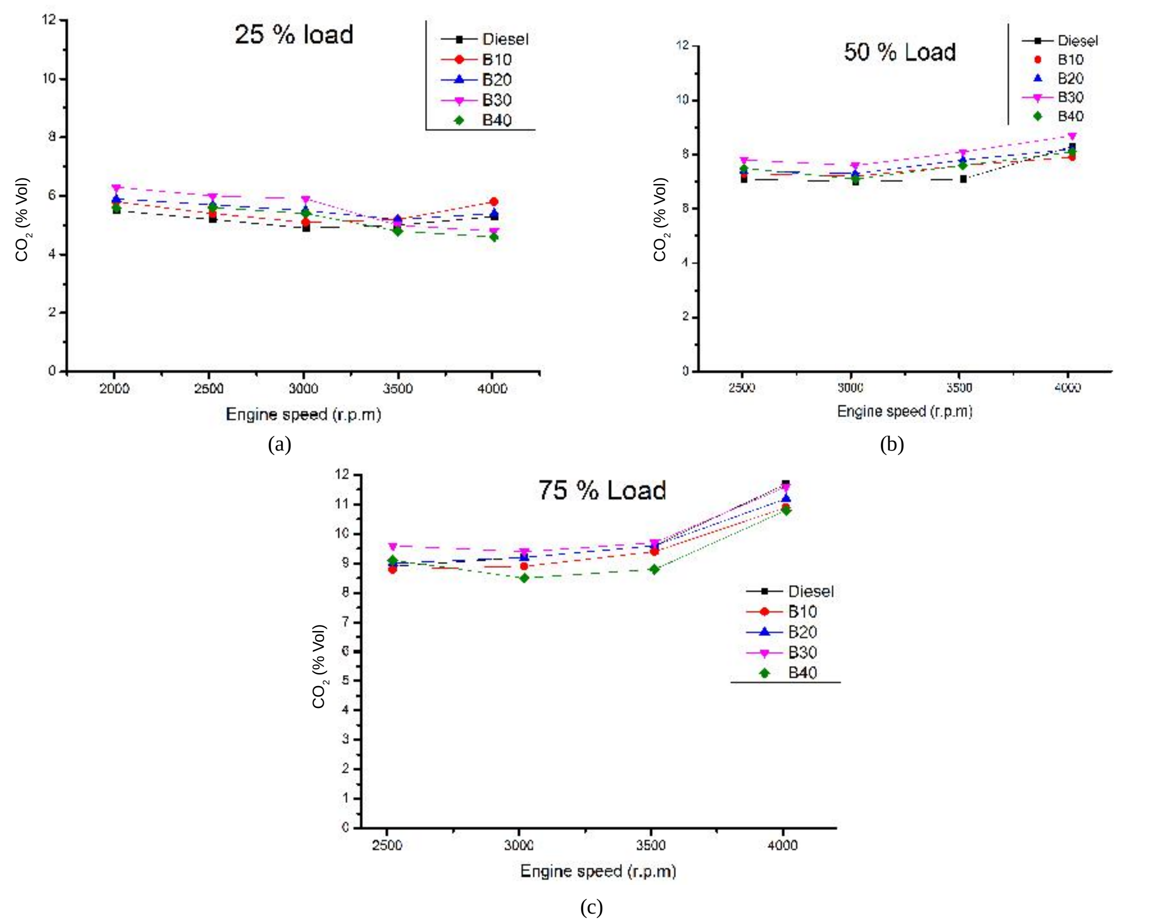


Fig. 6 : Variation of CO_2 with different load and engine speed (rpm)

biodiesel B40 shows slight increase in these two emission parameters. However an opposite trend was observed for CO_2 and NO_x, which shows better combustion up to 30 per cent blending and poor combustion for higher blends.It has been also observed that engine load has significant effect on the performance and emission characteristics. At higher loads, engine shows maximum brake thermal efficiency and minimum brake specific fuel consumption and maximum average increase of (59 %) in BTE has been found while moving from low load (25%) to full load (75 %) conditions. Moreover, engine speed affect BTE and BSFC at lower loads conditions only and no significant effect of engine speed is seen at higher loads. Further, it can also be concluded that engine does not require any modifications in its configuration for utilization of 30 per cent AOME in engine but considerable improvements were observed in engine performance and emission characteristics with its use.

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