

6

RESULTS AND DISCUSSION

This chapter includes the analysis of results obtained from experimental work and numerical modeling. The experiments have been conducted on the VCR-CI engine to evaluate the comparative performance and emission of Castor, Linseed, Mahua, and Neem biodiesel blends (B10, B20, B30, and B50) with pure diesel. In addition, thermodynamic performance analyses have been conducted using the new empirical correlation for the burning duration. This chapter also includes the comparative energy and economic analysis of different vegetable oil plants for the production of biodiesel.

6.1 Experimental analysis of biodiesel

The biodiesel obtained from Castor, Linseed, Mahua, and Neem oil through the transesterification process. There after, performance and emission have been analysed by using variable compression ratio (VCR) CI-engine coupled with AVL gas analyser with biodiesel blended fuel (i.e. it mixed in a certain proportion; 10%, 20%, 30%, and 50% to diesel). The present work aims to determine the most favorable performance (BP and BSFC) and emission (CO and NO_x) levels among Castor, Linseed, Mahua, and Neem biodiesel blends (B10, B20, B30, and B50) with diesel.

6.1.1 Engine Performance

(a) Brake power (BP)

Brake power is the power output of the engine. Measurement of brake power involves the determination of the torque and angular speed of the engine output of the shaft (i.e., brake

$$\text{power} = \frac{2\pi \times N \times T}{60}, \text{ where, } N \text{ is the engine speed in rpm and } T \text{ is the engine torque in}$$

(Nm). Brake power mainly depends on fuel calorific value and engine operating variable. The figure 6.1 to 6.4 have shown the comparative brake power for Castor, Linseed, Mahua, and Neem biodiesel blends (B10, B20, B30, and B50) and diesel at varying compression ratio (15, 16, 17 and 18). Diesel shows the higher brake power in comparison to all biodiesel blends. It may be due to higher calorific value of diesel [268, 269]. Additionally, it could be due to improper combustion and affect of operation variable in an engine. The brake power increases with increasing the compression ratio, which might be due to the higher rate of conversion of chemical energy into mechanical energy [270].

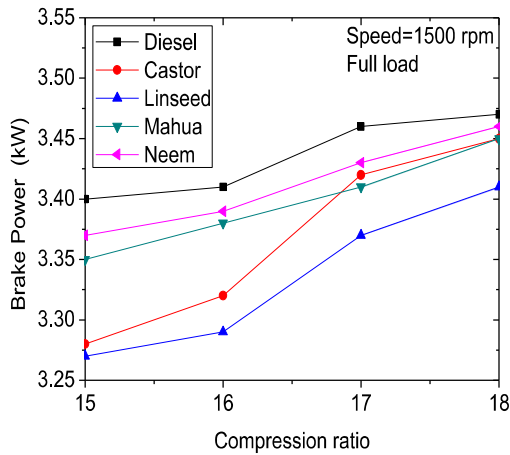


Figure 6.1: BP vs. CR at B10

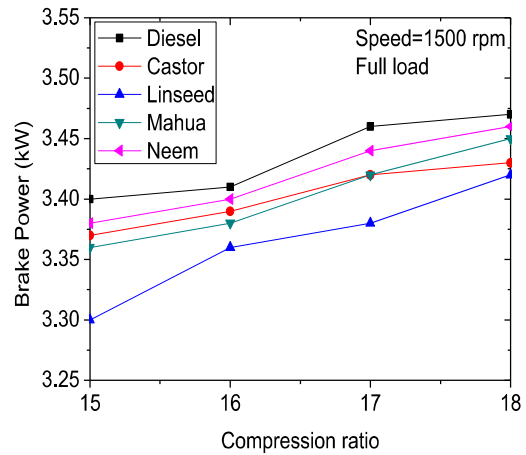


Figure 6.2: BP vs. CR at B20

The figure also shows that brake power is higher for Neem and Mahua in comparison to Castor and Linseed biodiesel blends. This is due to Neem and Mahua having the higher calorific value in comparison to Castor and Linseed biodiesel. The average brake power was increased by 0.68%, 1.07%, 1.20%, 1.01% and 0.86% for diesel fuel, Castor, Linseed, Mahua and Neem biodiesel blends while varying the compression ratio from 15 to 18. Maximum (3.47 kW) and minimum (3.27 kW) brake power are obtained for diesel

and Linseed biodiesel blend (B10) at compression ratio 18 and 15 respectively. Neem biodiesel blend B20 shows the comparable results with diesel.

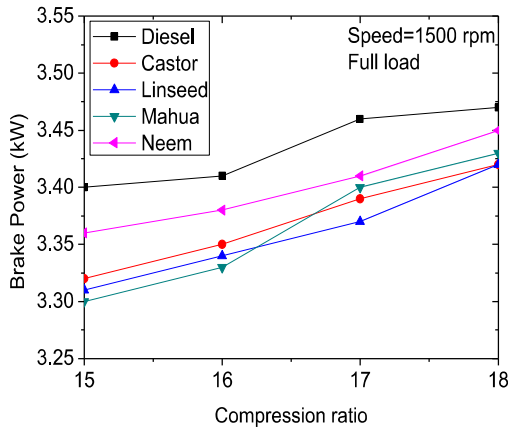


Figure 6.3: BP vs. CR at B30

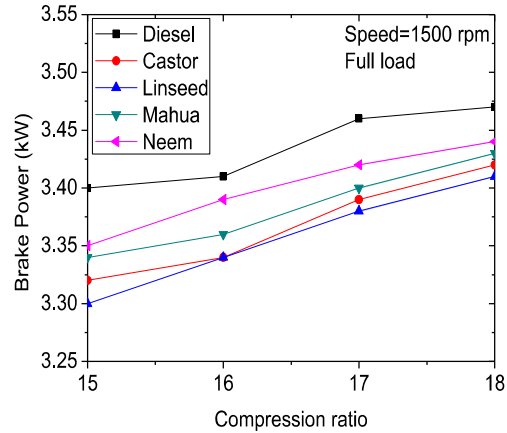


Figure 6.4: BP vs. CR at B50

(b) Brake specific fuel consumption (BSFC)

The brake specific fuel consumption (BSFC) is the mass of fuel required to develop 1 kW power for an engine in hour operation (i.e., kg/kWh). The BSFC shows the engine performance regarding fuel economy. The figure 6.5 to 6.8 shows the variation of BSFC for Castor, Linseed, Mahua, Neem biodiesel blends (B10, B20, B30, and B50) and diesel fuel at different compression ratios. The value of BSFC decreases with increasing the compression ratio of 15, 16, 17 and 18 for all the fuel. As compression ratio increases, the temperature inside cylinder also increases and hence proper combustion of fuel takes place [269, 271]. All the biodiesel blends have shown the higher BSFC in comparison to diesel fuel. Due to the lower calorific value, Castor and Linseed shows the higher BSFC as compared to Neem and Mahua biodiesel. The figure also depicts that the value of BSFC increases with increasing the proportion of biodiesel in blends. It could be due to biodiesel having lower heating value, higher viscosity and density than that of diesel. Therefore, it needed more mass of fuel for same output from the engine, due to which to

compensate the decrease the chemical energy increases the fuel consumption [268, 2267, and 272].

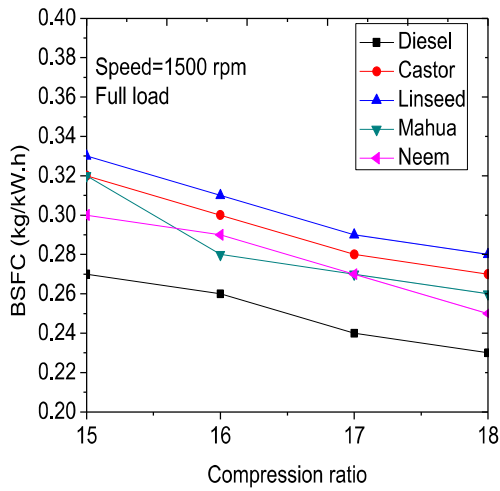


Figure 6.5: BSFC vs. CR at B10

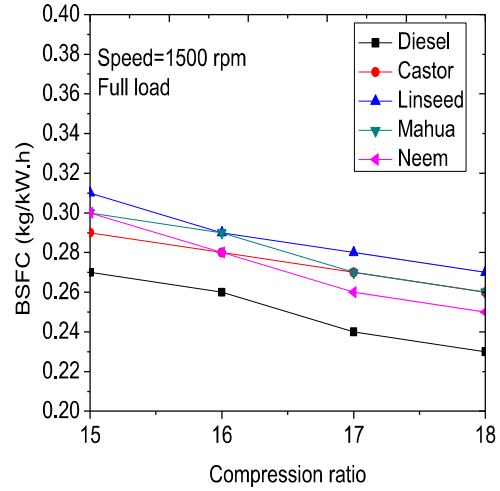


Figure 6.6: BSFC vs. CR at B20

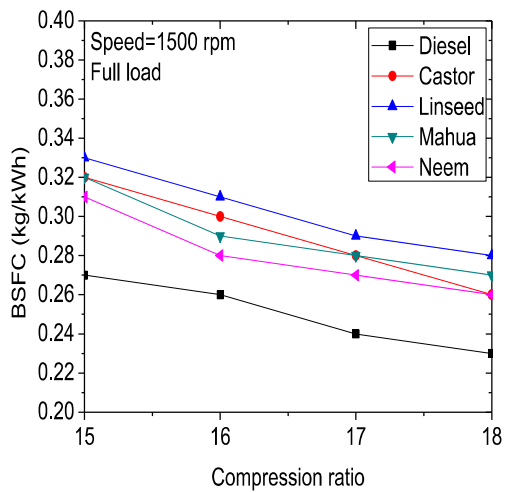


Figure 6.7: BSFC vs. CR at B30

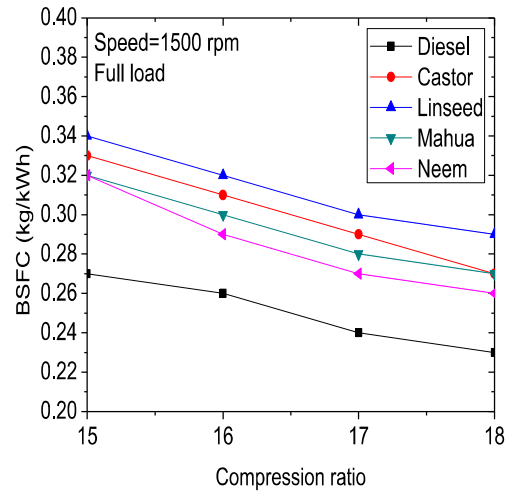


Figure 6.8: BSFC vs. CR at B50

Decreasing order of BSFC is Linseed, Castor, Mahua, Neem and diesel fuel. Mahua and Neem shows the comparable results with diesel fuel. While varying the compression ratio from 15 to 18, the average value of BSFC decreased by 6.58%, 5.84%, 5.07%, 5.46% and

6.02% for diesel, Castor, Linseed, Mahua and Neem biodiesel blends, respectively. BSFC decreases with increase in compression ratio (15 to 18), minimum BSFC (0.25 kg/kWh) was obtained for B20 Neem biodiesel which was comparable to the diesel fuel (0.22 kg/kWh) at CR 18.

6.1.2 Exhaust Emissions

The exhaust emissions, CO (vol %), and NO_x (ppm) at the engine tailpipe were measured with a portable AVL digas 444 gas analyzer. The details of the gas analyzer are given in table 3.9 and the experimental procedure in chapter 3. In this section, the emission analysis of the CO and NO_x formation with the variation of compression ratios for Castor, Linseed, Mahua, and Neem biodiesel blends in comparison to diesel fuel is presented.

(a) Carbon monoxide (CO)

The hemoglobin in the blood, which carries oxygen to the different parts of the body, has a higher affinity for carbon monoxide than for oxygen. Carbon monoxide is toxic and generated in an engine while the engine runs with a fuel-rich equivalence ratio because there is not sufficient oxygen to convert all carbon into carbon dioxides. The concentrations of carbon monoxide are measured by infrared absorption [292]. The formation of CO is mainly due to incomplete combustion, and it forms during the intermediate stage of combustion of fuel. This might be due to the absence of air or low-temperature and hence incomplete combustion, as a result of that the CO forms [268, 273]. The figure 6.9 to 6.12 shows the variation of CO formation for different biodiesel blends with compression ratio. The formation of CO emission decreases as increases the compression ratio for all fuels. This is because the temperature of combustion chamber increases while increasing the compression ratio and leads to complete combustion and hence lower formation of CO. Also, change in

properties of the fuel, decrease the availability of oxygen at high speed, shortage in combustion time, provides lower CO formation with rising combustion chamber temperature with increases in compression ratio [274, 275].

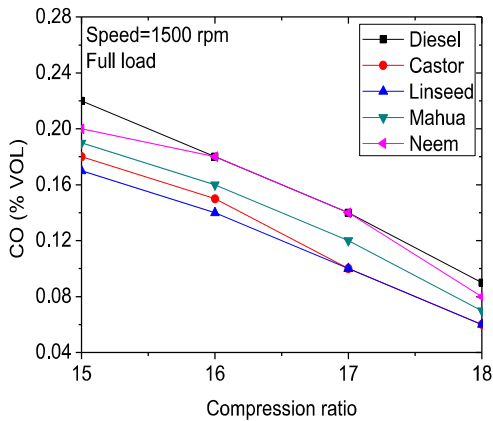


Figure 6.9: CO vs. CR at B10

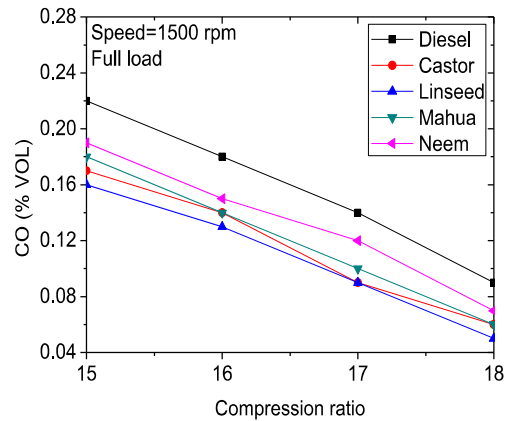


Figure 6.10: CO vs. CR at B20

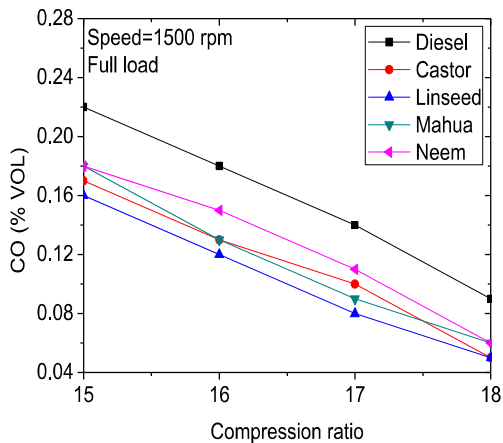


Figure 6.11: CO vs. CR at B30

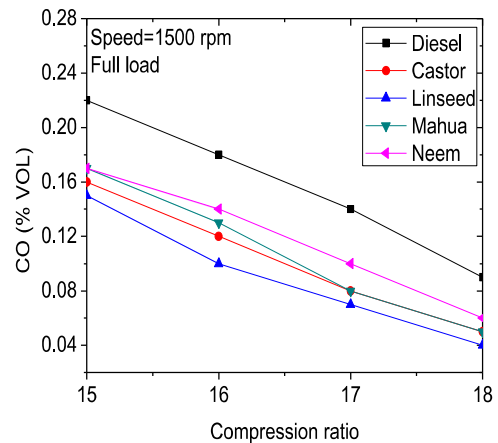


Figure 6.12: CO vs. CR at B50

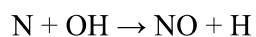
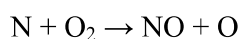
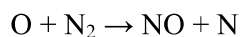
It also depicts that the diesel fuel produces higher CO in comparison to all biodiesel blends. On the other hand, higher CO formation for Neem as compared to other remains biodiesel and its blends. The CO formation is decreases with increasing the proportion of biodiesel in blends. This is because the present of oxygen in biodiesel. Additionally, it might be due to biodiesel has less C/H ratio as compared to diesel [273, 275-277]. The average value of CO

formation was decreased by 25.37%, 30.71%, 31.85%, 30.38% and 27.73% respectively for diesel fuel, Castor, Linseed, Mahua and Neem biodiesel blends with varying the compression ratio from 15 to 18. The maximum (0.22% vol.) and minimum (0.04% vol.) value of CO formation was obtained for linseed biodiesel blends (B50) and diesel fuel while engine operates at compression ratio 15. Lower CO emission observed for Linseed biodiesel blends in comparison to all biodiesel blends and diesel fuel at all compression ratios.

(b) Oxides of nitrogen (NO_x)

Nitrogen oxides settle on hemoglobin in the blood. The most unwanted toxic effect of nitrogen oxides is the tendency to form nitrate acid in association with moisture in the lungs. The photochemical smog (smoke + fog) is formed mainly due to the NO_x. These are following photochemical reactions that form the smog: NO₂ + energy from sunlight → NO + O + Smog. Monoatomic oxygen reacts with O₂ to form ozone (O₃) as follows: O + O₂ → O₃. Ozone is harmful to lungs, biological tissues, crops, trees. It reacts with rubber, plastics, and other materials causing damage.

The oxides of nitrogen (NO_x) generally contain the NO, a small quantity of NO₂, and traces of other nitrogen oxides, and most of the NO_x is formed from atmospheric nitrogen. The concentrations of NO_x are measured by chemiluminescence. The possible reactions that produced NO, such as flame front and post flame gases. There are following reactions that form the NO:



N, O and OH are formed at high temperatures by dissolution of N_2 , O_2 and H_2O vapour which are present in the combustion chamber (2500-3000 K). The combustion reaction temperature is higher; thus, the dissociation of diatomic nitrogen (N_2) to monoatomic nitrogen (N) will more, and consequently, the formation of NO_x will be increased. On the contrary, the minimum quantity of NO_x will be formed at low temperatures [292]. The higher combustion temperature and concentration of oxygen are highly affecting the NO_x formation. Reaction involved in combustion needs high activation energy, and is determined by concentration of oxygen at reaction, supplied equivalence ratio, and combustion temperature [225, 273, 277-279]. Figure 6.13 to 6.16 exhibit the NO_x formations with compression ratio for diesel fuel and biodiesel blends (B10, B20, B30, and B50). It is clear from figure that the NO_x formation increases with the increasing of compression ratio from 15 to 18 for the all fuel. This is due to the cylinder pressure and temperature increase when increasing the compression ratio [272]. The NO_x emission takes place at elevated temperature and presence of oxygen during combustion in the cylinder, which leads to form NO_x [273, 275].

The increasing order of the NO_x formation is Diesel, Linseed, Castor, Mahua and Neem respectively at all compression ratios. The figure also illustrates that the formation of NO_x is decreases with increasing the proportion of biodiesel in blends. The presence of oxygen in biodiesel is essential factors for the formation of NO_x , however, reduction on NO_x could be due to lower temperature, lower sensible heat production and calorific value. The NO_x formation increased by 14.06%, 27.39%, 23.15%, 23.23% and 21.11% respectively for diesel fuel, Castor, linseed, Mahua and Neem biodiesel blends when increasing the compression ratio from 15 to 18. While increasing the compression ratio causes to rise in temperature, and oxygen concentration in fuel ultimately promotes the NO_x emission [280-282]. The maximum (395 ppm) and minimum (145 ppm) NO_x are

obtained for castor biodiesel blends (B10) and diesel fuel respectively at compression ratio 18 and 15. Linseed biodiesel blends show lower NO_x emission at all compression ratio and comparable to diesel fuel.

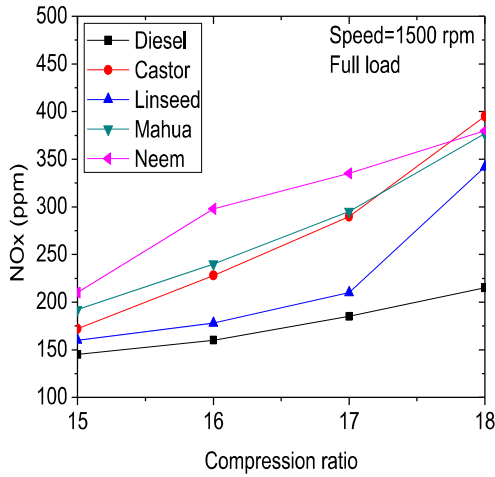


Figure 6.13: NO_x vs. CR at B10

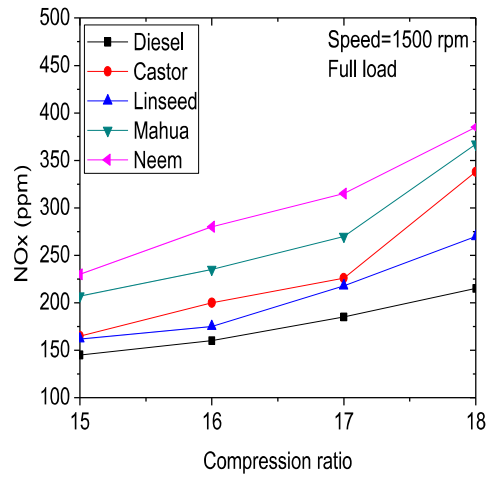


Figure 6.14: NO_x vs. CR at B20

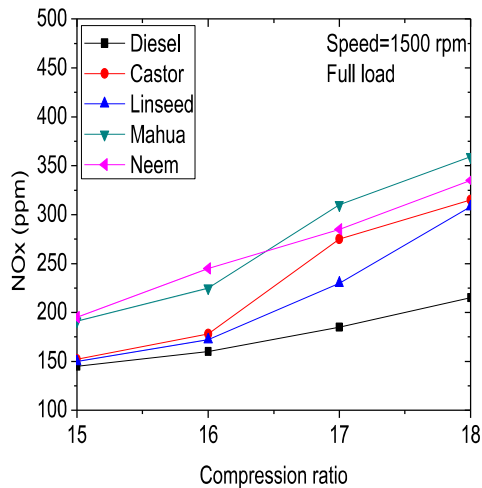


Figure 6.15: NO_x vs. CR at B30

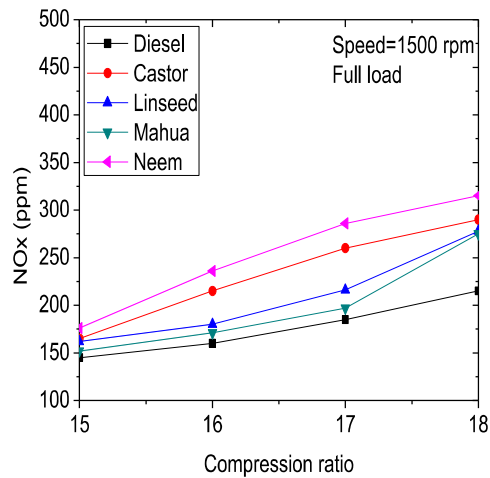


Figure 6.16: NO_x vs. CR at B50

6.2 Computational Analysis

In addition to variation in operating variables, engine design is also affects the performance of an engine such as cylinder dimension (bore, stroke, and length of connecting rod). Therefore, in this section computational results (P_{max}, BMEP, IMEP,

BP, IP, BSFC, ISFC, and NO emission) have obtained by the previous validated computational program (Chapter-5). In the simulation program, there are several input variables have been taken: engine speed (rpm), compression ratio, cylinder dimensions (bore, stroke, and length of connecting rod in meter), angle of fuel injection, fuel properties (carbon, hydrogen and oxygen atoms, calorific value and viscosity of fuel), and equivalence ratio (details of these variable parameters are listed in the appendix A). Among the different variables, results are predicted with the variation of biodiesel blends (calorific value of fuel), fuel injection timing, and stroke/bore ratios for B20 Neem biodiesel.

6.2.1 Effect of biodiesel blends

(a) Peak cylinder pressure (P_{max})

The peak cylinder pressure of the CI engine depends on the fraction of burn burned fuel during the phase of premixed burning, that is, the initial combustion stage. The cylinder pressure is characterized by the ability of the mixing of fuel with air properly and it's burning [276]. The figure 6.17 shows the variation of peak cylinder pressure with biodiesel blends at different compression ratio. It has been clear from figure that the peak cylinder pressures are slightly decreased with increasing the proportion of biodiesel in the blends. This may be due the lower volatility and higher viscosity of biodiesel [224]. The figure also depicts that the value of peak cylinder pressure are increased with compression ratio. Increase in CR increases pressure and temperature of air inside the combustion chamber. Higher CR increases the density of air hence improves the mixing of fuel-air. Increase in the vaporization improves the quality of uncontrolled combustion resulting in higher cylinder pressure [224]. With increasing the biodiesel blends from B00 to B50, the average value of peak cylinder pressure decreased by 2.86 %.

(b) BMEP and IMEP

In internal combustion engines, the mean effective pressure merely is average pressure acting on the piston during the complete thermodynamic cycle, and it measures the capacity of the engine to do the work. The indicated mean effective pressure (IMEP) is the uniform pressure that would be required throughout the power stroke of an engine to do the same amount of work as is done by the varying pressures that are in fact obtained during the stroke. The brake dynamometer is used to the measured work output of the engine, and the break mean effective pressure (BMEP) of the engine is estimated with using the following relation,

$$\text{BMEP} \left(\frac{\text{N}}{\text{m}^2} \right) = \frac{\text{Brake work output (Nm) per cylinder per mechanical cycle}}{\text{Swept volume per cylinder (m}^3\text{)}}$$

$$\text{or in term of brake power, BMEP} = \frac{\text{Brake power}}{(L \times A \times n \times N)} = \frac{\text{Brake power}}{(V_s \times N)}$$

Where, L = Stroke length of piston (m), A= area of piston (m²), n = number of cylinders, V_s = swept volume (m³), N = number of mechanical cycles of operation per second (for all pistons).

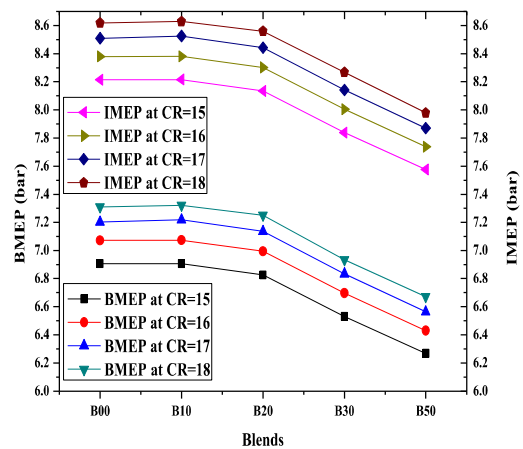
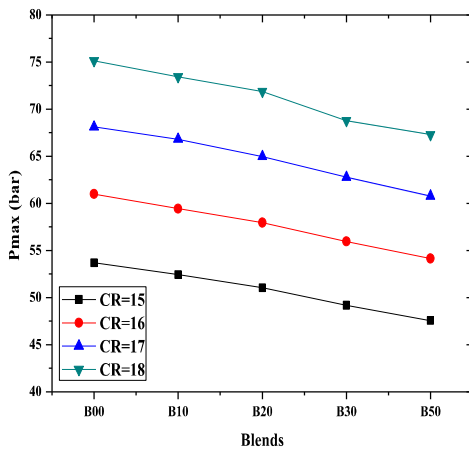


Figure 6.17: Peak cylinder pressure vs blends

Figure 6.18: BMEP and IMEP vs blends

The BMEP is a measure of work output from an engine, and not of pressures in the engine [222]. Figure 6.18 shows the variation of BMEP and IMEP with biodiesel blends at different compression ratio. Both BMEP and IMEP are decreased as increasing the proportion of biodiesel in blends. This may due the lower heating value of biodiesel [268, 269]. On the other hand the value of BMEP and IMEP are increases with increasing the compression ratio from 15 to 18. The rate of conversion of chemical energy into mechanical is higher when engine operate at higher compression ratio [270]. The average value of BMEP and IMEP are decreased by 2.31 and 1.94 % respectively with increasing the biodiesel blends from B00 to B50.

(c) Brake power and indicated power

The brake power (BP) is defined as the power developed by an engine at the output shaft. On the other hand, indicated power (IP) is idefined as the total power developed with the combustion of fuel in the combustion chamber. Theoretically, IP is the maximum output power of the engine. Indicated power measured the power developed on top of the pistons, while brake power measures the power developed at the output of the crankshaft [222]. Figure 6.19 shows the variation of brake power and indicated power with biodiesel blending (B00, B10, B20, B30 and B50) at different compression ratio (15, 16, 17 and 18). It has been clear from figure that the value of BP and IP are gradually decreases as increases the proportion of biodiesel in the blends. This may be due to the lower calorific value of biodiesel [268, 269]. The figure also indicates that the value of BP and IP are increases with increasing the compression ratio. This might be due the higher rate of conversion of chemical energy into mechanical energy [270]. The average value of BP and IP are decreased by 2.31 and 1.94 % with increasing the proportion of biodiesel from B00 to B50.

(d) BSFC and ISFC

The specific fuel consumption is a way to compare different engines of different sizes on its efficiency. It is the ratio of the rate of fuel consumption to the power developed by the engine. If an engine has a higher SFC, it indicates it needed more fuel in the production of one unit of power; therefore, the engine is less efficient. According to power developed by the engine, it categorized into brake specific fuel consumption (BSFC) and indicated specific fuel consumption (ISFC) [222]. The BSFC defined as the fuel consumption rate divided by the produced power at shaft. It measured the fuel efficiency of fuel of an engine that burned and produced the shaft power. Whereas, ISFC is the fuel consumption rate divided by total power developed by an engine (indicated power). The ISFC is an ideal condition of engine; thus, practically, while we talk about SFC, we ultimately intend it is the BSFC [292].

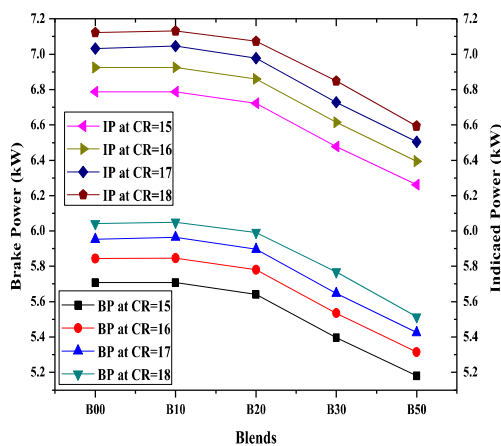


Figure 6.19: BP and IP vs blends

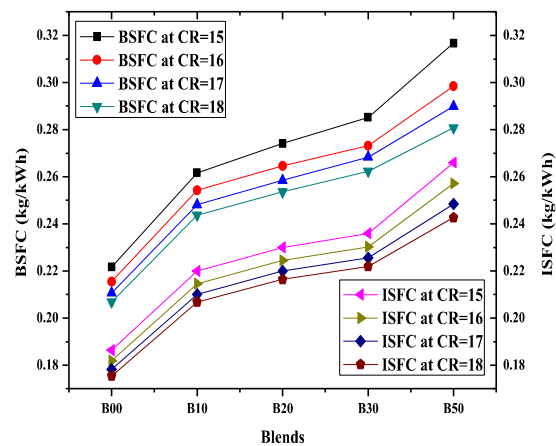


Figure 6.20: BSFC and ISFC vs blends

Figure 6.20 shows the variation of BSFC and ISFC with biodiesel blends at different compression ratio. The figure depicts that the value of BSFC and ISFC are increases with increasing the proportion of biodiesel in the blends. This is because the lower calorific value, higher viscosity and density of biodiesel as compared to diesel. Therefore, the

engine required more mass of fuel for the same output to maintain 1500 rpm, due to which fuel consumption is increased to compensate for the reduction in chemical energy [268, 269, and 272]. The figure also depicts that both BSFC and ISFC are decreases with increasing the compression ratio. While engine operate at higher compression ratio the temperature inside the cylinder become higher and consequently this leads to proper combustion of fuel [269, 271]. The average value of BSFC and ISFC are increased by 8.67% and 9.03 % with variation of biodiesel blends from B00 to B50.

(e) NO Formation

Figure 6.21 exhibit the variation of NO formations with biodiesel blends at different compression. The figure depicts that the NO formation decreases with increasing proportion of biodiesel in the blends. The presence of oxygen in biodiesel is promoting factor for the formation of NO, however, reduction on NO could be due to lower temperature, lower sensible heat production and calorific value. On the other hand, its value increases with compression ratio. This is due to the cylinder pressure and temperature increment when increasing the compression ratio [272].

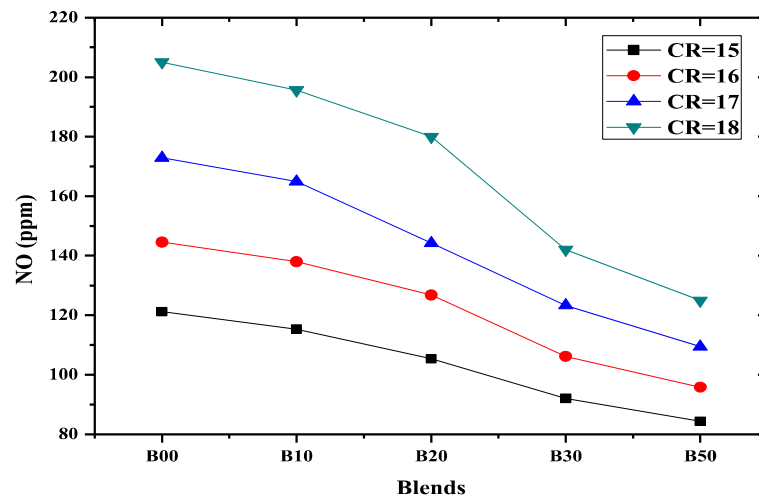


Figure 6.21: NO formation vs blends

The NO emission takes place at elevated temperature and presence of oxygen during combustion in the cylinder, due to this reason at high temperature N_2 converts into NO_x [273, 275]. While increasing the compression ratio causes rise in temperature and oxygen concentration in fuel ultimately promotes the NO_x emission [280-282]. The average value of NO_x formation is decreased by 10.1%, with increased biodiesel blends from B00 to B50.

6.2.2 Effect of injection timing

Combustion, performance and emission characteristics of compression ignition engine depend on several factors like fuel injection pressure, injection, injection rate, injection pattern, quantity of injected fuel, number of injections (post and pilot), design of combustion chamber and nozzle spray patterns. In which, fuel injection timing is one of the most important parameter which affects the performance, emissions, and combustion characteristics of engine. Thus in this section, engine performance and emissions are predicted with variation of fuel injection timing (43, 33, 23, 13, 3 °bTDC and 7 °aTDC) at different engine speed (1500, 2000, 2500, 3000 and 4000 rpm). There are several results (Performance; BP, IP, BSFC, ISFC, BMEP, IMEP, and Peak cylinder pressure, Emission; NO formation) are obtained at different engine speed, these are discussed below:-

(a) Peak cylinder pressure (P_{max})

The figure 6.22 shows the effect of injection timing on peak cylinder pressure (P_{max}) at different engine speed. Higher values of peak cylinder pressure are observed for all engine speed when engine operate at advanced injection condition (43° bTDC). Generally,

cylinder pressure increases with advanced injection timing. With advancing the fuel injection timing the ignition delay increases, due to this the preparation of better air-fuel mixture and hence good combustion and higher cylinder pressure [285, 286]. However, with retardation of injection timing shortens the ignition delay period; due to this reduced the cylinder pressure during the initial stage of combustion. On the other hand, its values are decreases with retarded the injection from 43° bTDC to 7° aTDC for all the engine speed. The maximum value of peak cylinder pressure (77.491 bar) is observed with advanced condition (43° bTDC) when engine operates at 4000 rpm. S. Gnanasekaran et al. [286] were reported the 77.6 and 73.6 bar peak cylinder pressure respectively for diesel and pure biodiesel with 27° bTDC injection timing. The figure 6.22 also shows the effect of engine speed on the peak cylinder pressure. It has been observed that the values of peak cylinder pressure are significantly decreases with increasing the engine speed from 1500 to 4000 rpm at a given injection timing. It may be due to the increase in the delay period and the combustion duration [126]. The average value of peak cylinder pressure is decreased by 5.26% with retarded the injection timing from 43° bTDC to 7° aTDC.

(b) BMEP and IMEP

Figure 6.23 shows the effect of injection timing on break mean effective pressure (BMEP) and indicated mean effective pressure (IMEP) with varying engine speed. The figure depicts that the values of BMEP and IMEP are decreases as the injection timing advanced from rated value (23° bTDC). On the conversely, opposite trends are followed for retarded condition up to 13° bTDC, then after its value decreases for all speed range. The maximum and minimum of BMEP and IMEP are obtained respectively at 13° bTDC and 7° aTDC. The average value of BMEP and IMEP are decreased by 1.18% and 0.92% with retarded the injection timing from 43° bTDC to 7° aTDC. The figure 6.23 also shows

the effect of engine speed on BMEP and IMEP. The values of BMEP are decreases with increasing the engine speed from 1500 to 4000 rpm. On the other hand reverse trends are follows for IMEP. This is primarily due to the increase in friction mean effective pressure (FMEP) with speed [225]. The result shows that the maximum BMEP can be obtained near to 13° bTDC.

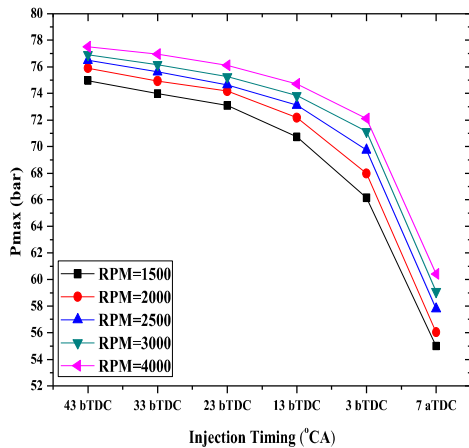


Figure 6.22 Pmax vs injection timing

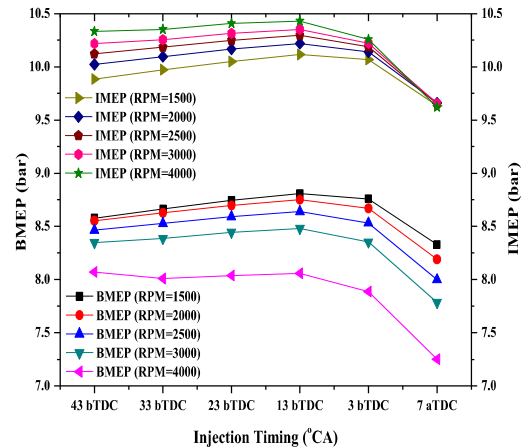


Figure 6.23: BMEP and IMEP vs injection timing

(c) Brake power and indicated power

The figure 6.24 shows the effect of injection timing (43, 33, 23, 13, 3 °bTDC and 7 °aTDC) on brake power (BP) and indicated power (IP) at different engine speed (1500, 2000, 2500, 3000 and 4000 rpm). Both brake power and indicated power increase as the injection timing is advanced or retarded from the rated value (23 °bTDC). The maximum and minimum values are obtained respectively at 13 °bTDC and 7 °aTDC for all engine speed. Its average values are decreased by 0.97% and 0.71% with retarded the injection timing from 43° bTDC to 7° aTDC. The figure 6.24 also shows the effect of engine speed on the brake power and indicated power. It has been clear from figure that the both brake power and indicated power are increases with increasing the engine speed from 1500 to

4000 rpm for all the injection timing. The optimum injection timing was found around 13° bTDC for achieving the maximum brake power for all engine speed.

(d) BSFC and ISFC

The figure 6.25 shows the variation of break specific fuel consumption (BSFC) and indicated specific fuel consumption (ISFC) with injection timing at varying engine speed. The figure depicts that the value of BSFC and ISFC are slight increased as the injection timing advanced from rated value, on the other hand its value decreased with retarded condition. Its minimum and maximum values are obtained respectively at 13° bTDC and 7° aTDC for all speed ranges. T. Ganapathy et al. [126] demonstrated that the value of BSFC are increased when the fuel injection timing advanced or retarded from the rated crank angle degree (15° bTDC) for different load and speed when engine run with diesel. As they claimed that fuel injection timing increased from 20° bTDC to 10° bTDC the value of BSFC continuously increased at given load and speed. It was also reported that the optimum injection timing is 20° bTDC for minimum BSFC when engine fuelled with Jatropha biodiesel. The figure 6.25 also shows the effect of engine speed on BSFC and ISFC. The figure shows that the values of BSFC are increases with increasing the engine speed from 1500 to 4000 rpm. On the contrary, reverse trends follows for ISFC. It may be due to increase in frictional power at a rapid rate when the engine operates at higher speed consequently, power increasing slower rate than fuel consumption and hence increase the BSFC [283, 284]. The maximum value of BSFC (0.259 kg/kWh) and ISFC (0.195 kg/kWh) are obtained with 7° aTDC injection timing when engine run at 4000 rpm. On the other hand its minimum values (0.21345 and 0.18026 kg/kWh) are obtained with 13° bTDC injection timing while engine operated at 1500 and 4000 rpm, respectively. The literature [283] also reported that the minimum value of BSFC obtained at advanced fuel injection timing. The average value of BSFC and ISFC are increased by 1.273% and

0.981% for the injection timing from 43° bTDC to 7° aTDC. The minimum BSFC was obtained near to 13° bTDC for all engine speed.

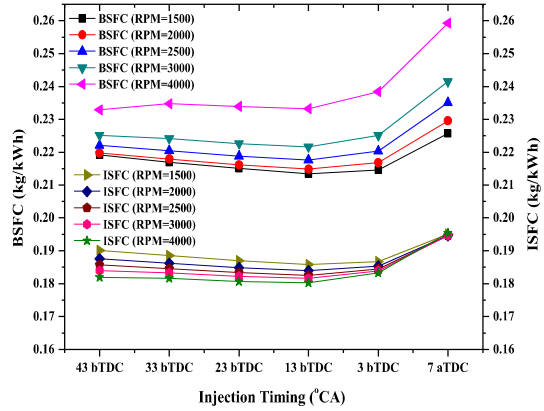
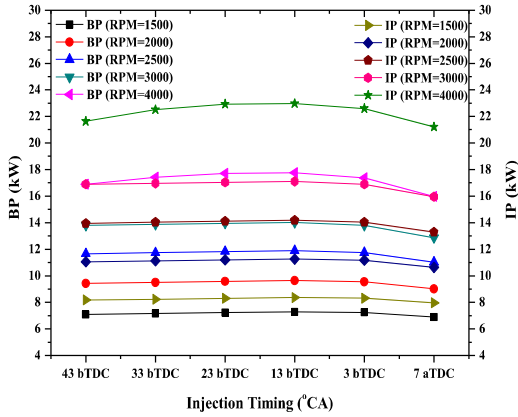


Figure 6.24: BP and IP vs injection timing Figure 6.25: BSFC and ISFC vs injection timing

(e) NO formation

The figure 6.26 shows the effect of injection timing on NO formation at various engines speed. It has been clear from figure that the NO formation decreases with retarded injection timing from 43° bTDC to 7° aTDC. The delay period increases with advancing the injection timing, due to this more burning of the fuel-air mixture in premixed combustion phase and hence higher combustion temperature. On the conversely, the NO formation decreases with retarded injection timing for all engine speed. S. Gnanasekaran et al. [286] and Sayin et al. [287] have also been reported the similar variations. The average value of NO formation is decreased by 13.67% while retarded the injection timing from 43° bTDC to 7° aTDC. The figure also shows the effect of engine speed on the NO formation at various injection timing. It has been observed that the values of NO emission are decreases with increasing the engine speeds from 1500 to 4000 rpm at a

given injection timing. The maximum (1942.4 ppm) and minimum (429.1 ppm) values of NO are obtained with 43° bTDC and 7° aTDC injection timing when engine run respectively at 1500 and 4000 rpm. In view of lower NO emission and without loss of brake power, injection timing can be taken between 3° bTDC to 13° bTDC.

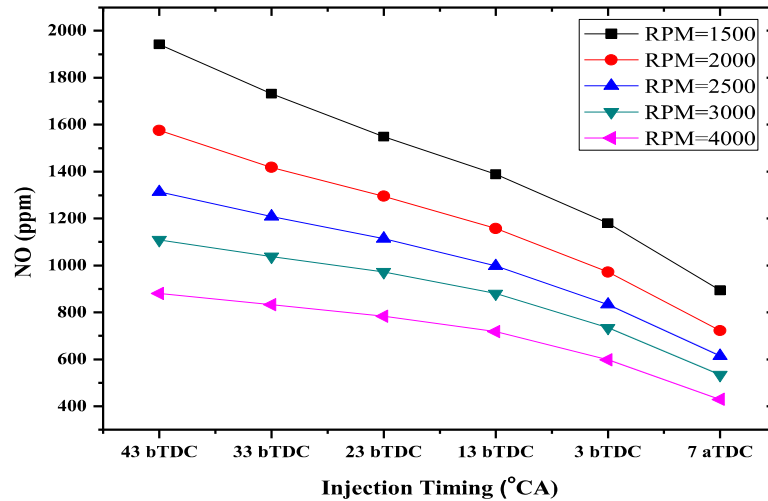


Figure 6.26: NO formation vs injection timing

6.2.3 Effect of stroke/bore ratio for B20 of Neem biodiesel

The geometry of the combustion chamber is one of the crucial factors that affect engine performance. The changes in these geometries of an engine, even small quantities, have produced tremendous variation in the performance and emission. The stroke/bore (S/B) ratio is one of the most prominent geometric parameters for advanced IC engines because it determines the overall engine dimensions for a given displacement [293, 294]. The researchers and automobile manufacturers have focused on variable-stroke engines due to its fuel-economy advantage. Siewart [295] has reported a fuel economy nearing 20% for variable-stroke engines over fixed-stroke engines. Thus in this section, engine performance and emissions are predicted with the change of engine geometry; variation in

stroke/bore ratio (stroke length varies, and the bore is fixed) at different engine speeds and compression ratio with Neem biodiesel blends B20 as fuel. There are several results (Performance; BP, IP, BSFC, ISFC, BMEP, IMEP, and Peak cylinder pressure, Emission; NO formation) are obtained at different engine speed, these are discussed below:-

(a) With varying engine speed at fixed CR

(i) Peak cylinder pressure (P_{max})

Figure 6.27 shows the effect of stroke/bore ratios on the peak cylinder pressure at different engine speed. The figure depicts that the values of peak cylinder pressure are decreases with increasing the stroke/bore ratios from 0.50 to 2.0 for engine all speed. Maximum pressure reduces the advantages of increased compression ratio on both efficiency and IMEP. Similar variation was obtained by [225]. It has been also obtained that the values of peak cylinder pressure are decreased by 0.13%, 0.18%, 0.22%, 0.24%, 0.25% and 0.10% respectively with step wise increment in the stroke/bore ratios from 0.5 to 2.0. The figure 6.27 also shows the variation of peak cylinder pressure with engine speed for a particular stroke/bore ratio. It has been clear from figure that the values of peak cylinder pressure are increases with increasing the engine speed from 1500 to 4000 rpm. The maximum values of peak cylinder pressure have been observed at 0.75 stroke/bore ratio for all engine speed. The average value of peak cylinder pressure is decreased by 0.16% when stroke/bore ratio increased from 0.5 to 2.0. The results show the maximum peak cylinder pressure was obtained at 0.75 stroke/bore ratios.

(ii) BMEP and IMEP

Figure 6.28 shows the effect of stroke/bore ratios on brake mean effective pressure (BMEP) and indicated mean effective pressure (IMEP) at different engine speed. It has been clear from figure the value of BMEP and IMEP are slightly increases with

increasing the stroke/bore ratios from 0.5 to 2.0 for all engine speed. The variations in initial pressure, inlet temperature, residual gas fraction, and atmospheric moisture fraction have only a modest effect on the fuel conversion efficiency. The effects of variations on IMEP are more substantial; however, it depends directly on the initial charge density that is depends on inhalation capacity [225]. It has been also founded during the observation of results that the percentage increase of BMEP are 1.38, 1.38, 0.83, 0.67, 0.57 and 0.51 respectively with step wise increment in the stroke/bore ratios from 0.5 to 2.0. Similarly, the values of IMEP are increased by 1.36%, 0.91%, 0.69%, 0.56%, 0.48% and 0.42% when step wise increment in the stroke/bore ratios from 0.5 to 2.0.

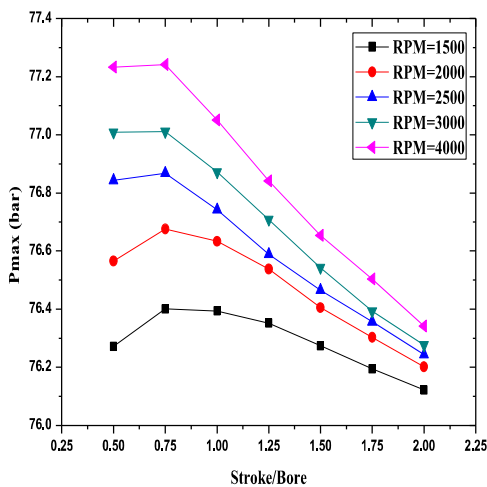


Figure 6.27 Pmax vs S/B ratios

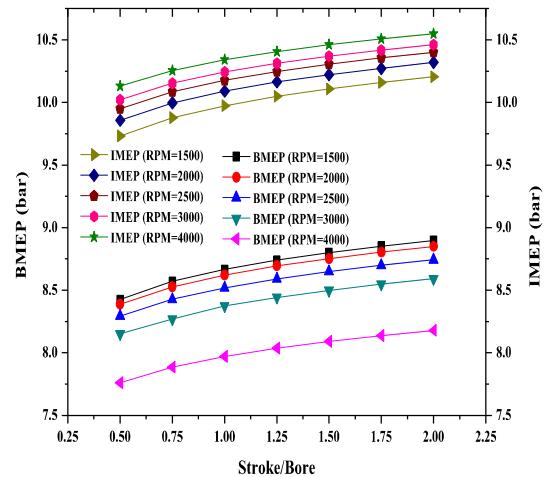


Figure 6.28: BMEP and IMEP vs S/B ratios

The figure also shows the variations of BMEP and IMEP with an engine speed for a particular stroke/bore ratio. It has been illustrated from the figure that the values of BMEP are increased with increasing the engine speed. On the other hand, reverse trends are followed for IMEP while enhancing the engine speed from 1500 to 4000 rpm. The average value of BMEP and IMEP are increased by 0.89% and 0.71% when stroke/bore ratio increased from 0.5 to 2.0.

(iii) Brake power and indicated power

Figure 6.29 shows the effect of stroke/bore ratios (0.5, 0.75, 1.0, 1.25, 1.50, 1.75 and 2.0) on the brake power and indicated power at different engine speeds (1500, 2000, 2500, 3000 and 4000 rpm). Both brake power and indicated power are increases continuously with increasing the stroke/bore ratios from 0.5 to 2.0 for all engine speed. While increasing the stroke/bore ratio increased swept volume (stroke length*cross section area of cylinder) as well as increasing inhalation capacity for air at various speed. Hence, the indicated work (IMEP*Swept volume) and available work (BMEP*Swept volume) get increased as well as indicated power and brake power also get increased [288, 289]. During the observations of results, it has been also founded that the percentage increases of brake power are 52.90, 34.42, 26.04, 20.80, 17.34 and 14.86 % respectively while step wise increase stroke/bore ratios from 0.5 to 2.0 (0.5-0.75,0.75-1.0,1.0-1.25,1.25-1.50, 1.50-1.75 and 1.75-2.0). Similarly, the values of indicated power are increased by 52.04%, 34.54%, 25.87%, 20.67%, 17.22% and 14.77% when step wise increase the stroke/bore ratios from 0.5 to 2.0. The figure 6.29 also shows variation of brake power and indicated power with engine speed. It has been clear from figure that the values of brake power and indicated power are increases with increasing the engine speed from 1500 to 4000 rpm. The average value of brake power and indicated power are increased by 27.52% and 27.43% with increase of stroke/bore ratios from 0.5 to 2.0.

(iv) BSFC and ISFC

Figure 6.30 shows the effect of stroke/bore ratios on the break specific fuel consumption (BSFC) and indicated specific fuel consumption (ISFC) at different engine speed. The figure depicts that the both BSFC and ISFC are decreases with enhancing the stroke/bore ratios from 0.50 to 2.0 for all engine speed. It may be due the increase in indicated power (IP) and brake power (BP) while increasing the stroke length (for given mass of fuel

injected) ultimately this leads to lowering the ISFC and BSFC [290, 291]. It has been also founded during the observation of results that the percentage decrease of BSFC are 1.22, 0.68, 0.43, 0.26, 0.17 and 0.10 respectively with step wise increment in the stroke/bore ratios from 0.5 to 2.0. Similarly, the values of are decreased by 0.94%, 0.50%, 0.29%, 0.15%, 0.07% and 0.01% with step wise increment in the stroke/bore ratios from 0.5 to 2.0.

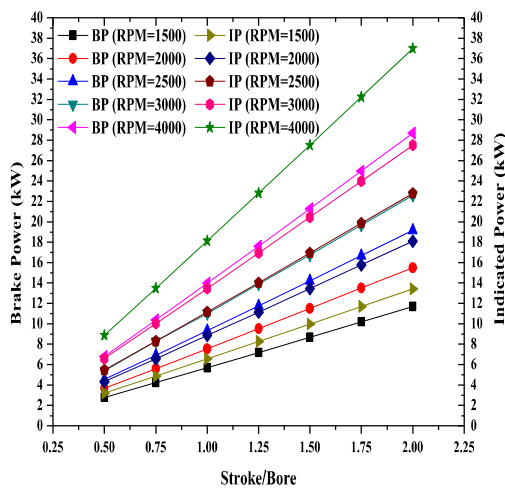


Figure 6.29: BP and IP vs S/B ratios

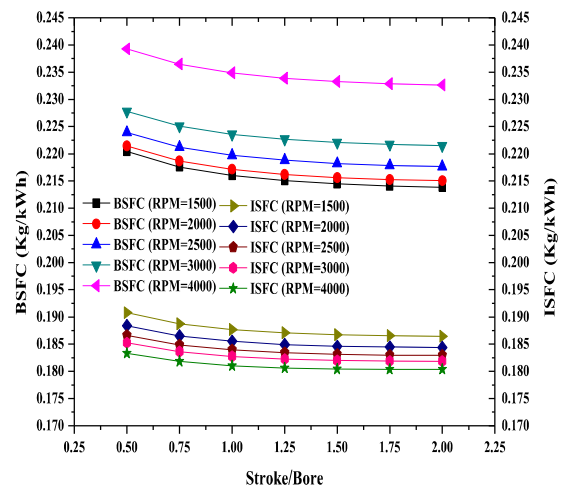


Figure 6.30: BSFC and ISFC vs S/B ratios

The figure 6.30 also shows the variation of BSFC and ISFC with engine speed for a particular stroke/bore ratio. It has been clear from figure that the values of BSFC are increases with increasing the engine speed from 1500 to 4000 rpm. On the other hand, the values of ISFC are decreases with increasing the engine speed from 1500 to 4000 rpm. The average value of BSFC and ISFC are decreased by 0.48% and 0.33% when stroke/bore ratio increased from 0.5 to 2.0. The result shows that the minimum BSFC was obtained when the engine operated between 0.75 to 1.0 stroke/bore ratios.

(v) NO Formation

Figure 6.31 shows the effect of stroke/bore ratios on NO (nitrogen oxide) formation at different engine speed. It has been clear from figure that the NO formation decreases with increasing the stroke/bore ratios from 0.50 to 2.0 and these variations are same for different engine speed. It is due to the decrease in the cylinder surface to volume ratio with an increase in S/B ratio, which allows less heat loss from cylinder to wall, which causes an increase in temperature, and pressure ultimately increases in NO formation. Also, at smaller stroke length, fuel gets the influence of oxygen volatility, so less vaporization occur of fuel. But for higher stroke length, atomization and vaporization occur more, thus decrease NO [288].

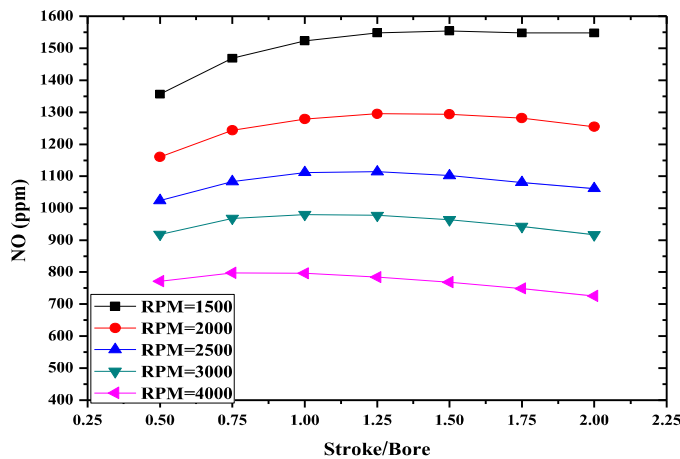


Figure 6.31: Variation of NO formation S/B ratios

The results also shows that the percentage increases of NO formation are 6.02, 2.05 and 0.26 for step wise increment of stroke/bore ratio from 0.5 to 1.0 and after that its value decreased by 0.83%, 1.60% and 1.94 % for increasing the stroke/bore ratio from 1.25 to 2.0. The figure 6.31 also shows the variation of NO formation with engine speed for a particular stroke/bore ratio. The values of NO formation are decreases with enhancing the

engine speed. AK Yadav et al. [290] also reported the similar results. The average value of NO formation is increased by 0.66% when stroke/bore ratio increased from 0.5 to 2.0. Therefore, it is best to choose less than 1.0 S/B ratio for lower NO emission.

(b) With varying compression ratio at fixed rpm

(i) Peak cylinder pressure (P_{max})

Figure 6.32 shows the effect of stroke/bore ratios on the peak cylinder pressure at different compression ratio. The figure shows that the values of peak cylinder pressure are significantly decreased with increasing the stroke/bore ratios from 0.50 to 2.0 for all compression ratios. It is because, as stroke length increases (by increasing the crank length), clearance volume decreases, which tends to increase CR, but due to maintaining desired compression ratio (15 to 18) clearance volume has to be raised by shifting crankshaft and which leads to reduce the maximum pressure. Maximum pressure reduces the advantages of increased compression ratio on both efficiency and IMEP. Similar variation was obtained by [225]. The percentage decreases in peak cylinder pressure are 2.87, 3.96, 4.68, 5.45, 6.09 and 6.17 for step wise increment of stroke/bore ratio from 0.5 to 2. The figure also shows the variation of peak cylinder pressure with compression ratio. The values of peak cylinder pressure are increases with increasing the compression from 15 to 18. The average value of peak cylinder pressure is decreased by 4.87 % when changing the stroke/bore ratio from 0.5 to 2.0.

(ii) BMEP and IMEP

Figure 6.33 shows the effect of stroke/bore ratios on brake mean effective pressure (BMEP) and indicated mean effective pressure (IMEP) at different compression ratio. Both BMEP and IMEP are slightly increased when step wise change in S/B ratio from 0.5 to 1.0 and after that (1.0 to 2.0) its value decreased for all compression ratios. The

variations in initial pressure, inlet temperature, residual gas fraction, and atmospheric moisture fraction have only a modest effect on the fuel conversion efficiency. The effects of variations on IMEP are more substantial; however, it depends directly on the initial charge density that is depends on inhalation capacity [225]. The figure also depicts that the variations of BMEP and IMEP with compression ratio. The value of BMEP and IMEP are increased with increasing the compression ratio from 15 to 18. The average value of BMEP and IMEP are decreased by 0.37% and 0.32% when changing the stroke/bore ratio from 0.5 to 2.0. The results show the maximum value of IMEP and BMEP are between 0.75 to S/B ratios for all CR.

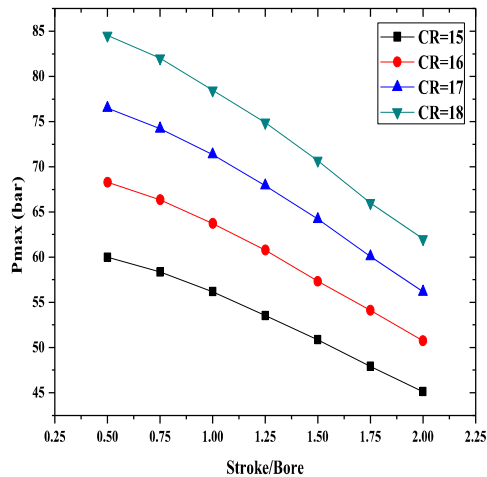


Figure 6.32: Pmax vs S/B ratios

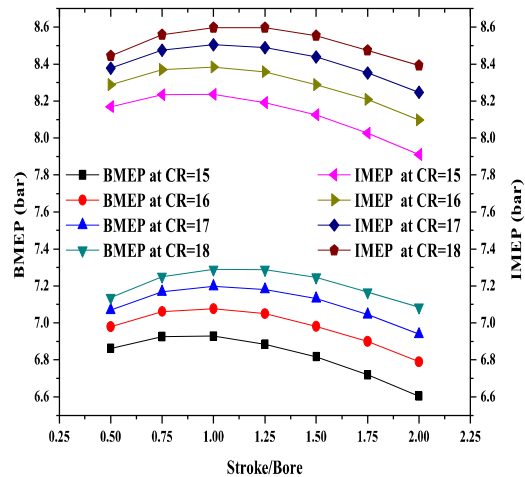


Figure 6.33: BMEP and IMEP vs S/B ratios

(iii) Brake power and indicated power

Figure 6.34 shows the effect of stroke/bore ratios on the brake power and indicated power at different compression ratios (15, 16, 17, and 18). Figure shows that the value of BP and IP are increasing with the variation of the stroke/bore ratios from 0.5 to 2.0 at all compression ratios. As the stroke/bore ratios increase, increased swept volume as well as increasing inhalation capacity for air and hence the indicated work and available work get

increased as well as indicated power and brake power also get increased [288, 289]. The percentage increases of brake power are 51.90, 33.73, 24.61, 19.03, 15.23 and 12.5 corresponding to step wise increment in the stroke/bore ratios from 0.5 to 2.0. Similarly, the values of indicated power are increased by 51.61, 33.67, 24.67, 18.18, 15.4 and 12.85 % when step wise increment in the stroke/bore ratios from 0.5 to 2.0. The figure also depicts that the variation of brake power and indicated power with compression. Both BP and IP are increased with increasing the compression ratio. The average value of brake power and indicated power are increased by 26.18% and 26.24% with increase of stroke/bore ratios from 0.5 to 2.0.

(iv) BSFC and ISFC

Figure 6.35 shows the effect of stroke/bore ratios on the break specific fuel consumption (BSFC) and indicated specific fuel consumption (ISFC) at different compression ratio. The figure show that Both BSFC and ISFC are decreased with step wise increment in the stroke/bore ratios from 0.50 to 1.0 and after that (1.0 to 2.0) its value increased for all compression ratios. This is due the increase in indicated power (IP) and brake power (BP) while increasing the stroke length (for given mass of fuel injected) ultimately this leads to lowering the ISFC and BSFC [290, 291]. The figure also depicts that the variation of BSFC and ISFC with compression ratio, where both BSFC and ISFC are decreased with increasing the compression ratio (CR) from 15 to 18. The average value of BSFC and ISFC are increased by 0.81 and 0.74% respectively when changing the S/B ratio from 0.5 to 2. The minimum BSFC and ISFC were obtained between 0.75 to 1.0 S/B ratios for all CR.

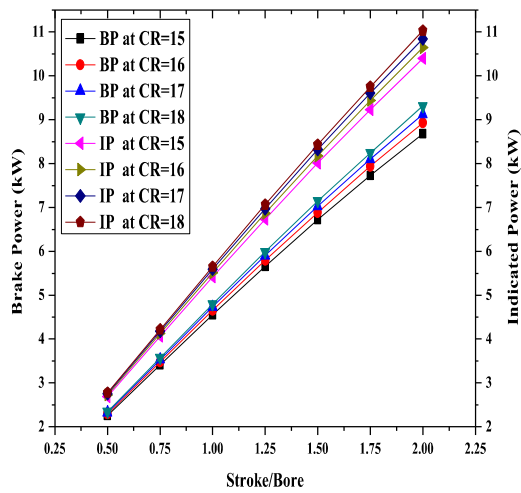


Figure 6.34: BP and IP vs S/B ratios

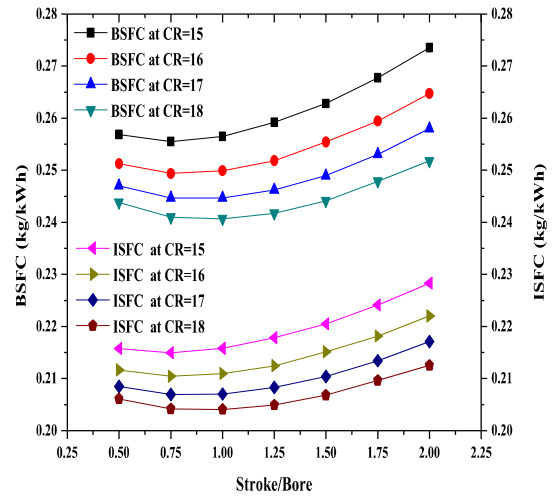


Figure 6.35: BSFC and ISFC vs S/B ratios

(v) NO Formation

Figure 6.36 shows the effect of stroke/bore ratios on NO formation at different compression ratios. The figure depicts that the NO formation decreases with increasing the stroke/bore ratios from 0.50 to 2.0 at all compression ratios. It may be due to the decrease in the cylinder surface to volume ratio with an increase in S/B ratio, which allows less heat loss from cylinder to the wall, which causes an increase in temperature and pressure ultimately increases in NO formation. On the other hand, at smaller stroke length fuel get influence of oxygen volatility so less vaporization occur of fuel but higher stroke length atomization and vaporization occurs more thus decrease NO [288]. The percentage decreases in NO formation are 1.95, 4.97, 6.21, 7.34, 7.88 and 7.69 for step wise increment of stroke/bore ratio from 0.5 to 2. The figure also shows the variation of NO formation with compression ratio. The value of formation NO is increases with increasing the compression ratio from 15 to 18. The average value NO formation is decreased by 5.98% when step wise changing the stroke/bore ratio from 0.5 to 2.0.

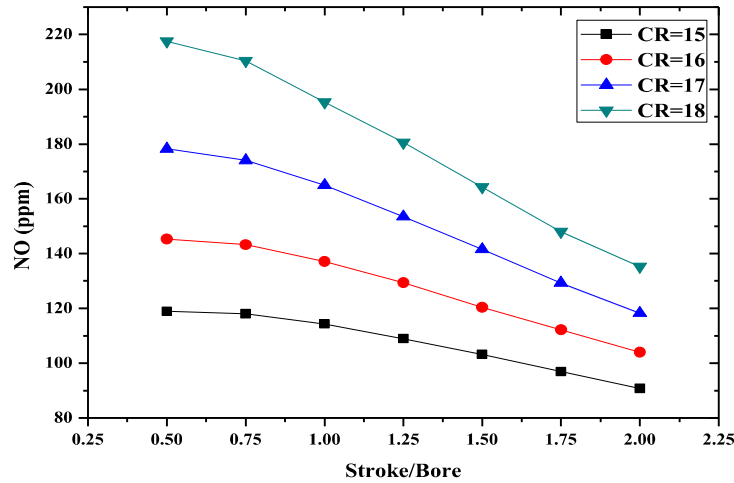


Figure 6.36: NO formation vs S/B ratios

6.3 Energy and Economic analysis of biodiesel plants

The energy and economic viability of vegetable oil plants in the production of biodiesel over the long term are dependent on careful control of input prices. Thus, the various energy and economic indices such as; energy ratio, net energy, energy productivity, fossil energy ratio, energy intensity cost, and economic indices (such as; gross production value, gross return, the net return, the benefit to cost ratio and, productivity, etc. are estimated for the economic viability of bioidesel plants, which are discussed below.

6.3.1 Energy analysis

The table 6.1 shows the different energy indices in the biodiesel production. To maintain the efficiency of biodiesel production, energy use efficiency (output/input) is one of the main parameters. Energy ratio for Jatropha, Mahua, Neem, Palm, Coconut, Karanja, Jojoba and Tung respectively are 3.8150, 4.0859, 5.5164, 1.9908, 2.0238, 3.6554, 3.2492 and 4.1166. Neem shows the highest energy ratio and lowest for palm. Increasing order of average energy productivity of different biodiesel plants are Coconut, Palm, Karanja,

Jojoba, Jatropha, Mahua and Neem (0.0384, 0.0402, 0.04743, 0.0481, 0.0498, 0.0499, 0.0533 and 0.0567 kg MJ⁻¹). This indicates that the Neem provides the higher unit (kg) of biodiesel production per unit (MJ) of energy consumption as compared to other plants. Decreasing order of net energy are Neem, Tung, Mahua, Jatropha, Karanja, Jojoba, Coconut and Palm. Net energy is positive for all the biodiesel plants with maximum value (83.77 MJ kg⁻¹) obtained for Neem and minimum (26.784 MJ kg⁻¹) for Palm. Since, all plants shows positive net energy means energy is saved in biodiesel production. Additionally, from these results, all plants are beneficial and can be recommended for biodiesel production due to positive net energy. Among them, highly recommended plants are Neem, Tung, Mahua and Jatropha. Total energy cost is calculated by converting energy input to the other commodities such as barrel of oil, dollar and rupees in indices of energy intensity cost and energy ratio cost for production of biodiesel. The increasing order of fossil energy ratios (FER) is Coconut (2.4693), palm (2.6929), Jojoba (3.4383), Karanja (3.8671), Jatropha (3.9931), Mahua (4.2628), Tung (4.2720) and Neem (5.6644). The higher fossil ratio indicates, the higher renewable fuel energy output (MJ) obtained per 1 MJ fossil energy input.

6.3.2 Economic analysis

The table 6.2 shows the economical analysis of different plants from cultivation to biodiesel production. Gross output is the total value of sales by producing enterprises (i.e., turnover). Thus, gross production value of Jatropha, Mahua, Neem, Palm, Coconut, Karanja, Jojoba and Tung are 135.58, 169.61, 222.27, 124.70, 141.64, 206.07, 145.97 and 186.83 Rs kg⁻¹ respectively. Neem and Karanja are showing the higher gross production value as compared to other biodiesel plants. Lower variable production cost for Neem (53.571 Rs kg⁻¹) and palm (53.994 Rs kg⁻¹) in comparison other remaining biodiesel plants. Karanja (76.453 Rs kg⁻¹) shows the higher value of variable production cost than

that of others biodiesel plants. Lower value of total production cost is estimated for Neem (78.139 Rs kg⁻¹) and Palm (76.120 Rs kg⁻¹). On the other hand, the total production cost are very high for Tung (143.15 Rs kg⁻¹), Jojoba (121.38 Rs kg⁻¹), Jatropha (124.45 Rs kg⁻¹) and Coconut (118.88 Rs kg⁻¹) biodiesel plant. Increasing order of gross return are Jatropha, Coconut, Jojoba, Tung, Palm, Mahua, Karanja and Neem. The gross return value is very high for Neem (168.70124 Rs kg⁻¹) biodiesel plants in comparison to others. Higher value of net returns are obtained for Neem (144.13 Rs kg⁻¹) and Karanja (102.78 Rs kg⁻¹), on the other hand its lower value for Jatropha (11.127 Rs kg⁻¹), Coconut (22.761 Rs kg⁻¹) and Jojoba (24.595 Rs kg⁻¹) biodiesel plants. According to the result of the economic analysis of biodiesel production, the higher value of the benefit to cost ratios estimated for Neem (2.8446) and Karanja (1.995). On the contrary, its lower value calculated for Jatropha (1.0894), Coconut (1.1914), Jojoba (1.2026), and Tung (1.3052). The table also shows the average productivity of biodiesel. The Neem (0.0122 Kg Rs⁻¹) and Palm (0.0118 Kg Rs⁻¹) shows the higher value of productivity biodiesel than that of other remaining biodiesel plants. This reveals that 12.20 and 11.8 grams of biodiesel production with expenses of one rupee for Neem and Palm, respectively. Tung shows the lowest value of average productivity (0.0062 kg Rs⁻¹). According the above results it was found that Neem shows the higher value of gross return, net return, benefit to cost ratio, productivity from others remaining biodiesel plants.

Table 6.1: Energy input-output ratios in biodiesel production

Items	Unit	Biodiesel								
		Jatropha	Mahua	Neem	Palm	Coconut	Karanja	Jojoba	Tung	
1. Energy input	MJ kg ⁻¹	20.707	19.149	18.548*	27.033**	26.459	21.736	21.428	22.500	
2. Energy output	MJ kg ⁻¹	78.997	78.244	102.32**	53.816	53.549*	79.453	69.623	92.627	
3. Energy ratio	---ND	3.8150	4.0859	5.5164**	1.9908	2.0238	3.6554	3.2492	4.1166	
4. Specific energy	MJ Kg ⁻¹	20.085	18.766	17.621*	24.899	26.036**	21.084	20.785	20.003	
5. Energy productivity	kg MJ ⁻¹	0.0498	0.0533	0.0567**	0.0402*	0.0384	0.0474	0.0481	0.0499	
6. Net energy	MJ kg ⁻¹	58.290	59.094	83.772**	26.784	27.089	57.717	48.195	70.126	
7. Fossil energy ratio	--- ND	3.9931	4.2628	5.6644**	2.6929	2.4693	3.8671	3.4383	4.2720	
8. Energy intensiveness	MJ Rs ⁻¹	0.1664	0.1824	0.2374	0.3551**	0.2226	0.2104	0.1765	0.1572*	
9. Energy intensity cost	Rs kg ⁻¹	62.736	56.050	50.893	49.675*	71.146	74.159**	68.519	61.955	
10. Energy intensiveness value	MJ Rs ⁻¹	0.1527	0.1129	0.0834*	0.2168**	0.1868	0.1055	0.1468	0.1204	
11. Energy ratio cost	--- ND	0.5197	0.5448	0.6856	0.7093**	0.6082	0.7401	0.5819	0.4868*	

ND: Non dimensional, ** : Maximum, * : Minimum

Table 6.2: Economic analysis of different plants for biodiesel production

Cost and return components	Unit	Value							
		Jatropha	Mahua	Neem	Palm	Coconut	Karanja	Jojoba	Tung
1. Gross production value	Rs kg ⁻¹	135.58	169.61	222.27**	124.70*	141.64	206.07	145.97	186.83
2. Variable production cost	Rs kg ⁻¹	64.676	57.194	53.571*	53.994	72.302	76.453**	70.639	69.691
3. Fixed production cost	Rs kg ⁻¹	59.779	47.780	24.568	22.126*	46.580	26.840	50.741	73.456**
4. Total production cost	Rs kg ⁻¹	124.45	104.97	78.139	76.120*	118.88	103.29	121.38	143.15**
5. Gross return	Rs kg ⁻¹	70.906	112.41	168.70**	70.706	69.341*	129.62	75.336	117.14
6. Net return	Rs kg ⁻¹	11.127*	64.636	144.13**	48.580	22.761	102.78	24.595	43.689
7. Benefit to cost ratio	--- ND	1.0894*	1.6157	2.8446**	1.6382	1.1914	1.9950	1.2026	1.3052
8. Productivity	kg Rs ⁻¹	0.0078	0.0093	0.0122**	0.0118	0.0083	0.0094	0.0080	0.0062*

ND: Non dimensional, ** : Maximum, * : Minimum