# Effect of Fuel Injection Pressure on Performance and Emission Characteristics of Diesel Engine Fueled with Cashew Nut Shell Biodiesel

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**Abstract:** ***The world's fossil fuel recreations are depleting speedily due to exponential growth of population and increased usage of technology. According to the literature survey, the production of fossil fuels is decreased day by day. It is necessary to reduce the gap between supply and demand. Developing countries like India, invests heavily on imports of petroleum fuels. In such countries most of automotive and transport vehicles are run on diesel fuel. Diesel fuelled vehicles discharge significant amount of pollutants like CO, UHC, $NO_x$, lead, soot, which are harmful for environment and society. However, to overcome this menace, the bio-fuels are being used as alternative fuels in IC engines. For complete combustion of the fuel in the cylinder the fuel injection parameters are play a major role in engine. The major parameters are mainly fuel nozzle holes, fuel droplet size and fuel injection pressure. These parameters can influence the engine performance and emission characteristics of an I.C. engine. In this experimental study was carried out tests used a blend of cashew nut shell oil and diesel in a single cylinder, 4-stroke water cooled light duty injection diesel engine at different injection pressures 180, 195 and 210 bar. The tests were carried out for pure diesel and blend of 20 % CNSL oil by volume in diesel at constant speed with varied loads. The performance results at 180 to 195 bars of blend very nearer to pure diesel results. The emissions UHC, CO and $CO_2$ are very less at 180 bars compared to pure diesel. The $NO_x$ emissions are lesser for blend at 210 bars than pure diesel. The overall performance is good at 180 and 195 bars. But the emissions are decreased when increasing injections pressure.***

**Keywords:** Cashew nut shell oil (CNSL), Diesel engines, performance, fuel injection pressure, UHC- Unburned hydro carbons, CO- Carbon monoxide, NOX emissions.

## 1. Introduction

The definition of engine is to convert heat in to work called heat engine .In this heat is low grade energy and work is high grade energy. Heat engines are either external combustion engines or internal combustion engines. The Internal combustion engines having higher efficiency than the external combustion engines and emits fewer pollutants in this diesel used as a fuel. The main idea of alternative fuels is good reserves in the sector of transportation because they will not only assist to the environmental quality but also has distinct positive socioeconomic results. From last century many number of scientists had suggested that the bio-fuels are good alternatives to fossil fuels. As of now India is the largest producer and exporter of cashew nuts in the world. In present research we will introduce CNSL oil as an alternative fuel and it is a bi-product of cashew nut industry. In this CNSL means cashew nut shell liquid. A thickness of cashew nut shell is 1/8 inches and it is soft honey comb structure inside the shell. It contains dark brown liquid, called CNSL. In present experimental investigation we are purchased cashew nut shell oil at Shree Kumarasamy Poly chemicals Ltd in panruti. It is in Cuddalore district at Tamil Nadu. The cost of 1 liter CNSL oil is Rs 50. The CNSL oil is very cheap and easy available alternative fuel in the world. In present day's major pollutants from automobiles are unburned hydrocarbons (UHC), oxides of Nitrogen ($NO_x$), Carbon monoxide (CO), sulfur compounds and lead compounds and particulates.

The emissive pollutants are high for large engines than that of small engines and these pollutants are disposed into the atmosphere mainly depend on the vehicle population. The total human beings are 7 million in the world. Out of the total population the number of vehicles which we are having 1 billion i.e., every $7^{th}$ person having vehicle in the world. The daily population of human beings will be increasing 4% for every year. But number of vehicles is increasing 24% .The total energy which world is having petroleum products, USA using 50% but there population is 4% of the world. We people are consuming 1.5% but our population is 121 crore. When we people are consuming 1.5% of petroleum products only but still we saying pollution of India is very high. At present the Indian people having 15% of vehicles. But in USA every person has a vehicle. The Indian people have per capital income is one thousand dollar. In India 40 crore people are earning less than 1 dollar and 10% are earning people who are richer than the USA that much difference we people are having. The efficiency of petroleum engine is 11% only then remaining 89% destroy the environment but in the case of Diesel engines the efficiency is 30 to 35%. In India highest number of vehicles are 2-stroke two wheeler engines .In many countries these vehicles banned because there emit large number of pollutants. One of the authors A.Velmugan was conducted experimental test on I.C engine with different blends of CNSL with Diesel B20 to B100 i.e., B20, B40, B60, B80 and B100. He was concluded that the performance and emission results are good and very nearer to pure diesel for B20 blend among remaining blends of CNSL.

In present diesel engines, the fuel injectors are designed to maintain higher injection pressure for the purpose of acquiring better performance results. The main intention of this design is decrease the exhaust emissions and increasing the efficiency of the engine. The fuel injection pressure is inversely proportional to the fuel droplet size. The fuel droplets diameter is increases at lower injection pressures then the ignition delay period is increases during the combustion. This situation leads to increase the injection pressure. Engine performance will be decrease since combustion process goes to bad condition. When injection pressure increased the fuel particle size decreased. The mixture of fuel and air formation becomes better from that complete combustion was done in the cylinder during the ignition period. When injection pressure is high the ignition delay period is shorter. The homogeneous mixture is leads to higher combustion efficiency.

## 2. The Injection Pressure Variation

To acquire high degree of fuel atomization needs high injection pressure in the fuel injection system. For the purpose of sufficient evaporation of fuel in very short time. From that the fuel particles achieve sufficient spray penetration in order to exploit the fuel air charge in the cylinder. The fuel injection system should have measured the amount fuel desired, depending upon engine load and speed, and inject the fuel at desired rate in correct time. The appropriate shape and size of fuel particle obtained based on the particular combustion chamber. Generally, a supply pump withdraws the fuel from fuel tank and carries it's via a filter to the fuel injector. In present investigation the injection pressure varied from 180 to 210 bars. Normally the injection pressure is 180 bars for high speed diesel engines. In this the injection pressure is varying by tightening or loosening the screw provided top of the injector as shown in fig. 1. For measurement of fuel injection pressure on fuel injector system by using fuel injector pressure tester as shown in fig.2


**Figure 1:** Fuel Injector

**Figure 2:** Pressure Tester Gauge

**Figure 3:** Diesel engine fuel injector

In present research Experimental tests were carried out on 4-stroke single cylinder diesel engine used CNSL oil as fuel and with proportion of diesel at different injection pressures usually 180,195 and 210 bars. The injection pressure is one of the main characteristics which affect the performance and emission characteristics of a diesel engine. The tests were carried out for pure diesel and blend of 20% cashew nut shell oil by volume in diesel by varying loads at different rates.

**Table 1:** Engine Specification

| | |
|---|---|
| *Make* | KIRLOSKAR |
| *Type* | Single Cylinder, Four Strokes, Water Cooled |
| *Capacity* | 5 HP |
| *Bore Diameter* | 80 Mm |
| *Stroke Length* | 110 Mm |
| *Speed* | 1500 Rpm |

**Eddy Current Dynamometer Temperature Points**

1. Inlet
2. Water Inlet To Engine
3. Water Inlet To Calorimeter
4. Water Outlet From Engine
5. Water Outlet From Calorimeter
6. Exhaust Gas Inlet To Calorimeter
7. Exhaust Gas Outlet From Calorimeter

## 3. Test Engine and Fuel Properties

The experiments were carried out on a naturally aspirated, water cooled, single cylinder, direct-injection diesel engine. The specifications of the engine are shown in table 1.

**Table 2:** Properties of Diesel and CNSL Oil (Source: Fuels Laboratory JNTUA-Anantapur)

| Properties | Diesel | CNSL | B20 |
|---|---|---|---|
| Density (Kg/M$^3$) | 850 | 957 | 870 |
| Kinematic Viscosity @ 45 $^0$C (c St) | 2.82 | 17.1 | 4.53 |
| Calorific Values (KJ/Kg) | 42570 | 41700 | 42340 |
| Fire Point ($^0$C) | 87 | 205 | 97 |
| Flash Point ($^0$C) | 81 | 197 | 85 |
| Cetane Number | 46 | 54 | 51 |
| Lower Heating Value | 42.3 | 39.4 | 42.25 |

## 4. Engine Procedure

The experimental work had conducted on 4-stroke diesel engine. In diesel engine four strokes are utilized namely suction, compression, power and exhaust strokes for completion of cycle. The 4-stroke diesel engine consist s of two valves i.e., inlet valve and exhaust valve. In this the inlet valve is used for sucking the fuel charge or pure air in to the chamber at beginning of the suction stroke and the exhaust valve is used for removal of exhaust gases from engine cylinder at the end of combustion stroke. The piston is moving from top dead centre to bottom dead center at starting the cycle. The piston begins from TDC to BDC at suction stroke the inlet valve opens and the fuel charge is sucked in to the combustion chamber then compressed at compression stroke between piston and cylinder head until piston reaches TDC at end of compression stroke. At end of compression stroke spray of fuel injected in to the cylinder the fuel complete combustion obtained in cylinder at power stroke. End of power stroke the exhaust gases are releases. The exhaust gases are sent to out through exhaust manifold at exhaust stroke. This cycle follows by 4-stroke diesel engine.

## 5. Engine Equipment

A single cylinder 4-stroke water cooled diesel engine having 5 hp as rated power at 1500 rpm was used for the research work. The engine was coupled to an electrical dynamometer for loading it. The engine equipment is completely digital system. The speed and different temperatures are note down from the digital indicator. The experimental set-up of the engine is shown in figure.

**Precautions:**

(1) Give the necessary electrical connections to the panel and also check the lubricating oil level in the engine
(2) Check the fuel level in the tank.

## 6. Procedure of Experiment

1. Allow the water to flow to the engine and calorimeter and adjust the flow rate to 6lpm & 3lpm.
2. Release the load if any on the dynamometer.
3. Open the three-way cock so that fuel flows to the engine.
4. Start the engine by cranking.
5. Allow to attain the steady state.
6. Load the engine by switching on the loading switches.
7. Note the following readings for particular condition,
   a. Engine speed
   b. Time taken for 5cc of fuel consumption
   c. Rota meter reading
   d. Manometer readings, in cm of water &
   e. Temperatures at different locations
   f. Voltmeter and Ammeter readings
   g. Note pollution values from the pollution setup i.e., multi gas analyzer system.
8. Repeat the experiment for different loads at different fuel injection pressures i.e., 180,195 & 210 bar and note down the above readings
9. After the completion release the load and then switch of the engine.
10. Allow the water to flow for few minutes and then turn it off.

## 7. Results and Discussions

Experimental investigation is performed on diesel engine by varying fuel injection pressure (IP) visually 180, 195 & 210 bars. The results are discussed below.

### A. Effect on Brake Thermal Efficiency (BTE)

The variation in brake thermal efficiency with different loads at varied the injector opening pressures like 180 195 and 210 bar when diesel and B20 CNSL fuels used as a injected fuel, is shown in fig.3. A higher brake thermal efficiency is obtained for B20 blend at 210 bars compared to diesel at 60% load. When increasing the load up to full load the efficiency is decreased due to very improper combustion and very fine droplets of fuel have less momentum. Since viscosity of the bio-diesel is high, it requires large heat source for combustion of fuel at lower injector opening pressure. But at higher injector opening pressure, atomization and penetration of injected fuel is good and hence the injector opening pressure 210 results in higher brake thermal efficiency at 60% of full load. The overall brake thermal efficiency is increased for diesel from lower to higher load at 180 and 210 bars. This is due to that reduction of heat loss from the engine and the producing power increases with increasing load. The overall thermal efficiency of B20 CNSL is slightly lesser than that of the diesel at all pressures. The main reason behind that the poor mixture formation i.e., due to higher viscosity, higher density and lower volatility of CNSL fuel.

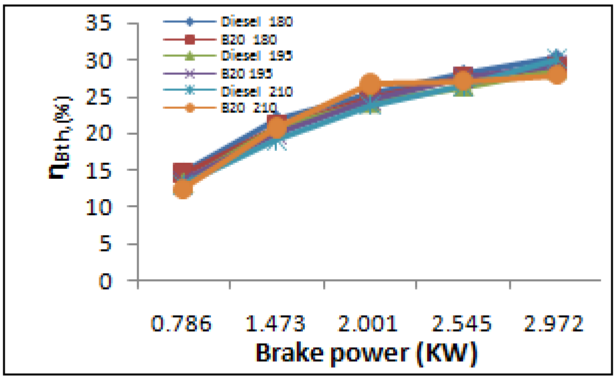


**Figure 3:** Comparison of brake thermal efficiency

### B. Effect on Brake Specific Fuel Consumption

The specific fuel consumption is changed with load at different pressures for diesel and B20 CNSL oil was presented in fig.4. The BSFC is decreases with increasing loads for all pressures. This result may due to poor mixture formation CNSL and effect of higher viscosity. The specific fuel consumption of B20 blend is lesser than that of diesel for 3rd and 4$^{th}$ loads at 210bar compared to other injection pressure for both sources. This result caused when increasing the injection pressure the fuel droplets size decreases and then the fuel droplets momentum increases. And they have collided on the engine cylinder wall then produce same power, the fuel consumption also increased. From all pressure the diesel has lower BSFC value at 180 bars at full load condition.

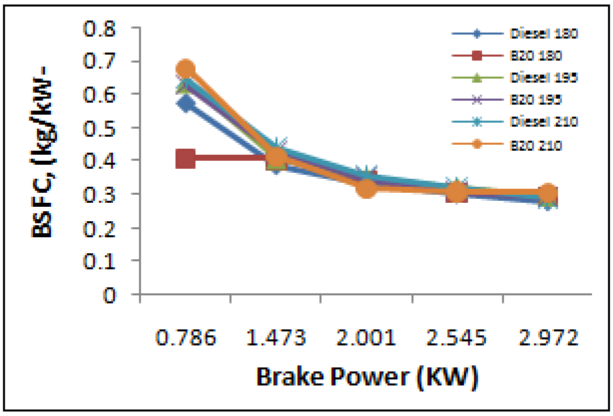


**Figure 4:** Comparison of specific fuel consumption

### C. Unburned Hydrocarbon Emissions

The Unburned hydrocarbons are varied at three different injection pressures for diesel and B20 CNSL shown in fig.5. As the opening pressure increases the HC emissions are reducing because, higher injection opening pressures will lead to proper spray while the injection starts. This will enhance the performance with B20 CNSL oil have higher viscosity. This is probably because of the improvement in the spray, which can lead to a lower physical delay. The improved spray also leads to better combustion and thermal efficiency. The unburned HC Emission is highest in the case of 180 bars and is least in the case of 210bar. This is because at 210 bar proper diffusion and combustion of the biodiesel takes place which results in lower emissions. At 180bar and 210bar there is very less time for the diffusion of the fuel to takes place which leads to increase in emissions. The concentration of biodiesel increases in the blend the unburned hydro carbons are decreases due to that the oxygen content present in the biodiesel is higher this leads to complete combustion in the cylinder.

### D. Carbon Monoxide (CO) Emissions

The variation of carbon monoxide emissions with load at different injector pressure, when pure diesel and B20 CNSL are used as a injected fuel, is shown in fig.6. At full load, for the injector opening pressure of B20 CNSL oil, due to higher injection pressure, atomization and mixing process are improved. Due to high viscosity of CNSL oil compared to diesel, high injection pressure are required for improving atomization and better mixing process resulting in low CO emissions. The CO emissions are decreased when increasing loads at all pressures. The CO emissions20 CNSL oil is lower if compared to pure diesel. The CNSL oil produces a greater combustion efficiency leading to lower amounts of CO. The CO emissions are very less at 180 bars for B20 Blend compared to diesel at all pressures and higher for diesel at 180 bars.

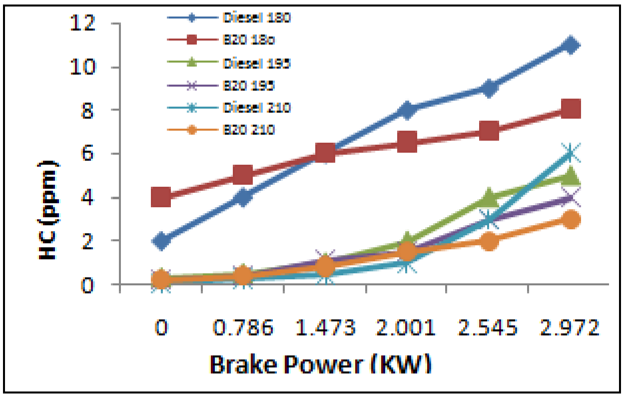


**Figure 5:** Comparison of HC emissions

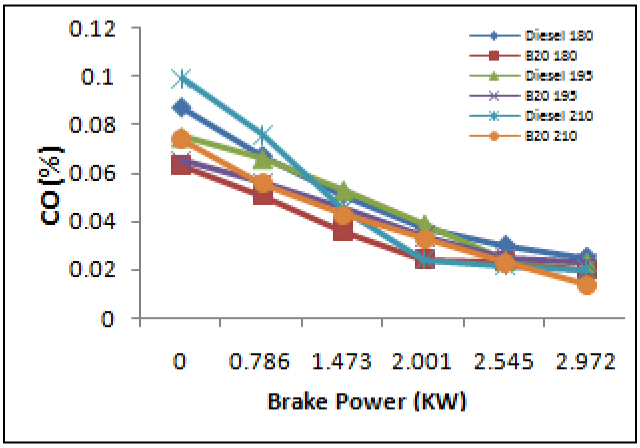


**Figure 6:** Comparison of CO emissions

### E. Oxides of Nitrogen (NOx) Emissions

Fig.7 shows $NO_x$ variation with increasing loads at all pressures for B20 CNSL oil pure diesel. From graph the $NO_x$ emissions are increased with increasing loads for all pressures due to the increase in combustion temperature. . The important factor that causes $NO_x$ formation is due to high combustion temperatures and availability of oxygen. The $NO_x$ graph indicates that B20 blend of CNSL contain lower $NO_x$ emission when compared to pure diesel fuel. This is due to poor atomization of CNSL oil leads to poor combustion and lead lower $NO_x$ emission. The $NO_x$ emissions are increased with increasing the load for both fuels. But less $NO_x$ emissions are obtained for B20 CNSL oil than that of diesel at all pressures. The reasons may be due to:

(I) Smaller calorific value of blend
(II) Lower localized gas temperature in the cylinder, (III) oxidation rate
(IV) Poor atomization due to high viscosity

The diesel fuel contains high volatile nitrogen compounds in their composition which contributes to a higher level of nitrogen concentration in the combustion chamber. Since diesel engine operates primarily in the lean region when diesel fuel is consumed, there is excess air and oxygen for nitrogen compounds to form NOx when the combustion temperature is high.

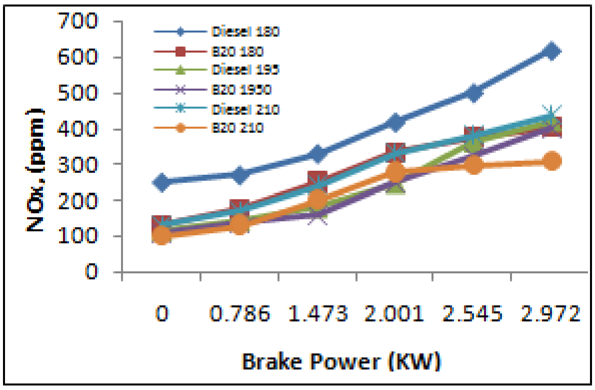


**Figure 7:** Comparison of NOx emissions

### F. Carbon Dioxide ($CO_2$) Emissions

A variation in the values of $CO_2$ emissions for diesel and B20 blend at all injection pressures are shown in Fig.8. The $CO_2$ emissions are increased with increasing loads for diesel and blend for all loads. Carbon dioxide is a desirable byproduct compared to CO emission that is produced when the carbon from the Fuel is fully oxidized during the combustion process. From the graph lower $CO_2$ emissions obtained for B20 CNSL oil than that diesel at all pressures. The lowest emissions obtained for B20 blend at 195 bars because of lower carbon content of biodiesel and highest emissions obtained for diesel at 180 bars. This is mainly due to improper combustion of fuel efficiency.

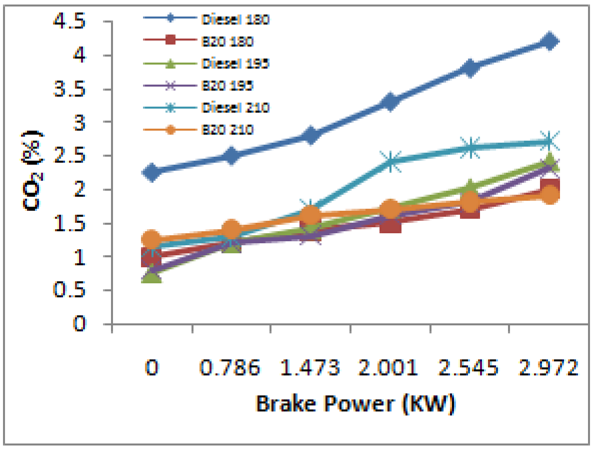


**Figure 8:** comparison of $CO_2$ emissions

### G. Exhaust Gas Temperature ( $^0$C )

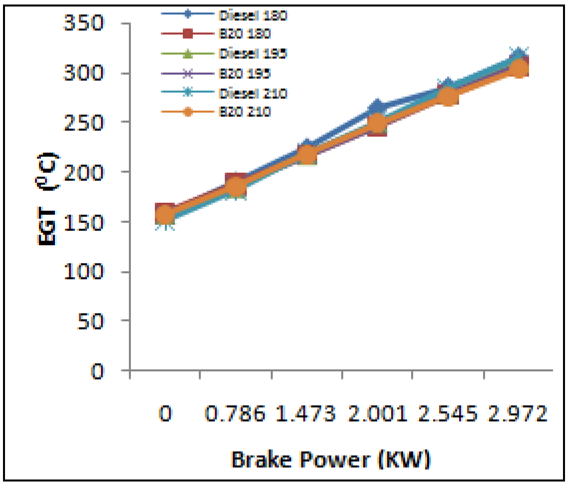


**Figure 9:** The change of Exhaust Gas Temperature

The change of exhaust gas temperature with varying the applied load for diesel and B20 CNSL oil tested is shown in Fig.9. The fig.9 shows the exhaust gas temperatures of CNSL oil is decreases when compared to neat diesel. From that the exhaust gas temperature is slightly increases for both fuels from 180 to 210 bars injection pressure. The reason behind this the fuel atomization is increases then the complete combustion done in the combustion chamber. The complete combustion was done up to 210 bars injection pressure then decreases when increases the injection pressure. At higher injection pressure than 210 bars the scavenging efficiency is decreases due to that the knocking will occurs in chamber. Because of the fuel pre-ignition will obtain before the compression stroke. Finally it is observed that the exhaust gas temperatures for both fuels are higher at 210 bars of injection pressure.

## 8. Conclusions

From the experimental study following conclusions were drawn:

- The Brake specific fuel consumption is high for the blend of CNSL oil and diesel mode. As the injection pressure increased, the Brake specific fuel consumption is decreased.
- The BSFC of blend taken was minimum at 210 bar injection pressure.
- The brake thermal efficiency of biodiesel is very close to diesel from 180 to 210 bars. However, at 60% load BTE is higher for biodiesel at 210 bars than diesel.
- The mechanical efficiency ofB20 is higher at 180 bars than 195 and 210 bars.
- The CO and $CO_2$ emissions are low for B20 at 210 bars than diesel.
- Lower exhaust temperatures were observed at higher injection pressures.
- The NOx emissions are very low for B20 than diesel at 210bar when compared to 180, 195 bar injection pressures.
- The UHC emission of B20 is less at all loads compared to diesel.

- Based on the experimental investigation it can be concluded that B20 of CNSL oil can be adopted as an alternative fuel for existing conventional engine without any major modification required in the system hardware.

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