Evaluation of the effect of high inlet air pressure on the performance and emission of a diesel engine using regression analysis.

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Abstract: In this study an attempt was made to determine the effects of loading in Kirloskar 3.7 kW single cylinder, four stroke, compression ignition engine with “diesel and biofuel” as fuels. The effects of ‘inlet air pressure’ on performance and emission characteristics were investigated. The inlet air pressure was increased from 1 to 2.5 bar and emissions like CO and HC were found to be decreasing considerably, but, slight increase in brake power and NOx was observed. Through the statistical approach a ‘regression model’ was established to predict performance and emission levels of a diesel engine operating on biofuel. Using multi regression model, an empirical relation was developed for evaluation of BP, HC, CO and NOx for a diesel engine. Key words: Regression model, biofuel, performance, emission.

1. Introduction
The carbon resources will be available for only few decades, as the resources are depleting faster than expected. The researchers are trying to find alternate fuel for diesel and petrol engine. In future biodiesel will be used in all segments like, agriculture, industries, transportation and power. Due to stringent law made by governments biofuels have to be produced only from non-edible oils. From last one decade few non-edible oils have proved, that these biodiesel can be used as substitute fuels. At Present some biofuels used are jatropha and pongemia. The basic properties of these biofuels have almost similar to that of diesel fuel. The diesel engine requires 25% more air to burn the injected fuel in the combustion
chamber. An extra air has to be supplied by additional device known as turbocharger or supercharger. The turbocharged or super charged engine is most preferred in some applications. Nowadays Diesel engines are more attractive for remarkable characteristics in terms of performance, and fuel economy. The biodiesel is used in diesel engines are due to good performance and less emission compared to diesel, leading to be ecofriendly.

2. Literature review

Murat Karabektas [1], have conducted experiment on four stroke supercharged diesel engine with diesel and biodiesel. The result shows that BTE for biofuel was slightly higher than diesel fuel both in natural as well as turbocharged conditions. The work on blended diesel exhibited lesser BP, HC but, higher NOx emissions.

Li Xinling et al [3], have studied the performance of turbocharged diesel engine, and the fuels selected for testing were diesel, gas to liquid and dimethyl ether fuel. Obtained results of GTL were compared with diesel fuel; it shows that using GTL fuel the emission results were reduced for HC, CO and NOx by 15.6%, 21.2%, and 22.1.

Peng Ye et al [2], selected fuels for testing diesel having with low sulfur blended with soybean biodiesel (B40). Fuel injection timing was varied from 9° before TDC and 3° after TDC. The results indicated that as the fuel pressure is increased proportionally NOx also increases. The soybean biodiesel produces higher NOx than diesel fuel.

With biodiesel as fuel [4] there was decrease in HC, and CO emissions but, increase in NOx and BSFC by 11.2% and 13.8%. Diesel fuel emissions were compared with soybean biodiesel, reduction of NOx and BSFC reduced by 16.1% and 1.2%.

T. Leevijit et al [5] Studied the performance and emission of a turbo charged diesel engine. Blend ratio selected for work was B20, B30, and B40. The blend B20 results in higher BSFC and NOx, but produces lower BTE, EGT and CO.

M. Ghazikhani et al [6] studied the effect of changing inlet pressures varying an 0.1, 0.23, 0.26 and 0.52 bar over atmospheric pressure. Their results reported the soot emission decreases for higher intake pressure. This may be due to high intake air temperature, which affects ignition delay that results in late combustion.

Constantine D. et al [8] Observed that using diesel and biodiesel, NOx increases but, there is rapid reduction in smoke. The basic properties of simarouba are closer to normal diesel. The biofuel can be used in existing diesel engine without any substantial software and hardware modifications.

3. Materials and processes

In the present investigation the fuels selected are conventional diesel & simarouba blended biofuel. The chemical modification process has carried out in biofuel laboratory of University Agricultural Sciences Bengaluru. Fuel properties such as density, viscosity, flash point and fire point of Simarouba & Diesel are mentioned in the Table 1.

| Table1. Properties of diesel & simarouba oil. |
|---------------------------------------------|
| Properties | Diesel | Simarouba oil |
| Specific gravity | 0.84 | 0.87 |
| Kinematic viscosity @40°C in CSt | 4.59 | 5.4 |
| Flash point | 45°C | 160°C |
| Fire point | 56°C | 172°C |
| Pour point | -23°C | 2°C |
| Calorific value KJ/kg | 45,000 | 38,480 |
4. Comparison between diesel and simarouba oil

The physical and chemical properties of non-edible oils falls within narrow range of diesel oil. The kinematic viscosity of simarouba being slightly higher than diesel fuel. The higher viscosity of fuel will affect the spray characteristics of oil in the combustion chamber. The viscosity of 4-6 Cst at 40˚C does not become a problem in pumping and atomization system of a diesel engine. The calorific value of the simarouba oil is 10% less than that of the diesel oil, but due to higher oxygen content, it will improve the performance for biofuel blends. Cetane number of biodiesel is 64, whereas the cetane number of the diesel is 47, hence there is reduction in cetane number which reduce the risk of knocking in diesel engine.

One of the limitation of biofuel is viscosity and fire point.

5. Regression analysis [11]:

The general form of a multiple regression equation being

\[ Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \epsilon \]

Y is a dependent variable to be forecast. 
\( x_1 \) and \( x_2 \) are independent variable
\( x_1 \) is blend ratio and \( x_2 \) is pressure

\[
Y = \left( \begin{array}{c}
Y_1 \\
Y_2 \\
\vdots \\
Y_n
\end{array} \right) \quad X = \left( \begin{array}{cccc}
1 & x_{11} & x_{12} & \ldots & x_{1k} \\
1 & x_{21} & x_{22} & \ldots & x_{2k} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
1 & x_{n1} & x_{n2} & \ldots & x_{nk}
\end{array} \right) \quad \beta = \left( \begin{array}{c}
\beta_0 \\
\beta_1 \\
\beta_2 \\
\vdots \\
\beta_k
\end{array} \right) \quad \text{And } \epsilon' = \left( \begin{array}{c}
\epsilon_1 \\
\epsilon_2 \\
\vdots \\
\epsilon_n
\end{array} \right)
\]

Find matrix \( X'X \) matrix
And also find Y vector
Then find least square to estimate \( \beta \)
\[ \hat{\beta} = (X'X)^{-1}X'y \]

The least square fit with the regression coefficient is obtained as follows.

\[ Y = \beta_0 + \beta_1X_1 + \beta_2X_2 \]

6. Experimental set up

The experimental set up requires a little modification at induction manifold. An air compressor is used for raising air intake pressure at suction side. The high pressure air being controlled by pressure valve and volume of air is controlled by a flow control valve. Therequired pressure and quantity of air is fed to induction manifold. The experiment set up is as depicted in figure. 1
Fig.1: Experimental set up

Table 2. The specification of the engine

| Sl. no | parameters                  | Specifications  |
|--------|-----------------------------|-----------------|
| 1      | Number of cylinders         | 1               |
| 2      | Bore                        | 80 mm           |
| 3      | Stroke                      | 110 mm          |
| 4      | Volume                      | 553 cc          |
| 5      | Compression ratio           | 16.5 :1         |
| 6      | Power                       | 3.7 kW(5 HP)    |
| 7      | speed                       | 1500 rpm        |
| 8      | Load                        | Electrical loading |
| 9      | Air compressor              | 20 bar pressure |

7. Experimental procedure:

The tests were conducted on four stroke single cylinder, DI, water cooled diesel engine, and being operated at rated speed. A series of experiments were conducted using diesel & simarouba blended with diesel with varying blends as B10, B20, and B30 as fuel under full loads. In each test, the pressure was adjusted using pressure regulating valve and the engine was run at full speed and full load. The values of voltmeter, and ammeter readings form digital display were recorded. Also the values of emissions such as HC, CO, & NOx, were recorded from exhaust gas analyzer during the tests. The test was repeated for other air pressures [1, 1.5, 2, 2.5, bar] & other biofuel [B0, B10, B20, B30] blends.
8. Results & discussions:

1) Emission levels of NOx at various induction pressures;

Figure 2 indicates that blends B10, B20 and B30 at higher induction pressure resulting in increased NOx emission. The formation of NOx is very sensitive to temperature and it increases with increase of nitrogen content in the fuel together with higher oxygen content, results in the formation of increased NOx emissions for both diesel & biodiesel. The NOx equation calculated from regression analysis is;
\[
NOx = 249.98 + (2.16 \times \text{blend}) + (102 \times \text{pressure})
\]

![Fig.2. NOx variation with inlet pressure](image)

b) Emission levels of CO at various induction pressures.

Figure 3 depicts the formation of CO emission mainly depends upon the basic properties of the fuel used. It was observed that, the CO emission of biodiesel is less than that of diesel fuel. The higher O2 (12 to 14%) in biofuel will promote the oxidation of CO, hence CO emission is less in biofuels. The CO equation calculated from regression analysis is;
\[
CO = 0.1211 - (0.0006 \times \text{blend}) - (0.0029 \times \text{pressure})
\]

![Fig.3. CO variation with inlet pressure](image)

c) Emission levels of HC at various induction pressures.

Biodiesel has higher cetane number as against diesel requiring delay period to be lower, leading to better combustion. With HC emission being low, the content of biodiesel also plays a vital role in reduction of emission of HC.
The HC equation calculated from regression analysis is;
\[
HC = 65.925 - (0.3050 \times \text{blend}) - (20.7 \times \text{pressure})
\]
d) **Engine performance (Brake power) at various induction pressures.**

Higher air pressure tends to more complete combustion of fuel since each fuel molecule is surrounded by air (oxygen) molecules, and hence results in enhancement of brake power. The BP equation calculated from regression analysis is;

\[
BP = 2.65 - (0.0005 \times \text{blend}) - (0.0305 \times \text{pressure})
\]

Fig.4. HC variation with varying inlet pressure

Fig.5. BP variation with varying inlet pressure

**Conclusion:**

- Higher BP was produced at 2.5 bar pressure using diesel fuel and lower BP being produced at 1 bar pressure by B10 biofuel. Percentage of increase in BP is 1.8%.
- Lowest NOx emission was produced at 1 bar pressure by diesel fuel and higher NOx was produced at 2.5 bar pressure by B30 biofuel. Percentage of increase of NOx was 29%.
- Lowest CO emission was produced at 2.5 bar pressure by B30 biofuel and higher CO is produced at 1 bar pressure by diesel fuel. Percentage of decrease in CO is 64%.
- Higher HC emission was observed at 1 bar pressure by diesel fuel and lowest HC being at 2.5 bar pressure by B30 biofuel. Percentage of decrease in HC is 70%.
- Amongst all the simarouba blends considered B30 gives the least emissions of HC and CO at 2.5 bar pressure. BP produced was very close to diesel fuel, but NOx production by B30 is very high.
- High pressure air at 2.5 bar fairly reduces emission levels of a diesel engine like HC and CO, but there is slight increase in BP and NOx.
- From the regression model calculated error for BP = 0.09, HC = -3.56, CO = 11.92 and NOx = 1.27 found to be reasonably matches with experimental data and observed to be within acceptable limits.
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