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Implementation of Predictive Modelling Techniques for determining Exhaust Engine Emissions

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Abstract. The world is going through the biggest change in modern world, the climate change. And this is majorly due to our utmost reliance over fossil fuels. Researchers, industrialists and scientists around the globe are trying to figure out the alternate energy sources or at least the ones with the least poisonous emissions. To design an automobile machinery with such parameters that they would cause possibly the least pollution, a huge sum of money is spent on majorly executing experimentations repeatedly. The paper has shown the objective of testing of such emissions and with the help of known machine learning algorithms, predicting those harmful emissions. In other words, using statistical modelling to predict the engine emissions which is traditionally measured by an exhaust gas analyser. In this research, data of real-time engine emissions produced by burning of Bio-Diesel fuel is recorded and fed into machine learning algorithms for their training. Three machine learning emission models were built up to illustrate their emission ranges. Out of the three, results showed that Decision Tree based engine emission model showed the best results.

1. Introduction

Energy and its conservation is one of the most imperative parameter for a sustainable environment to be looked upon. Energy in the form of fuel plays an important role in driving the world's economy and provides the support for vehicles to run [1]. Fossil fuels can't be counted in the list of renewable energy sources as their formation takes around millions of years [2]. Due to all this, there is core dependence of every sector on fuels to operate [3]. In addition, use of such fuels lead to pollution, depletion of ozone layer and global warming because of their emissions in the form of smoke or heat waves [4]. Talking about alternative fuel, Bio-diesel as promising alternative has increasingly gained attention. Due to negative environmental consequences of petroleum fuels and their increased demand, bio-diesel as an option requires a detailed analysis and research. It can easily be formed by chemically combining the natural oils, alcohol and fatty acids. Methanol is a form of alcohol which is mainly being used in the preparation of bio-diesel. Its combustion properties and easy formation make it a favorable and similar option for petroleum derived diesel [5].

2. Bio-fuel

A biofuel is a kind of fuel which is processed through modern processes from biomass, instead of a fuel produced by gradual geological process resulting in the formation of fossil fuels. These fuels are basically derived from vegetable oils, plants like Jatropha, [6] edible oils, fatty acids and many more through the process of biomass conversion and finally blended with either diesel or petrol to get



converted into bio-fuel. Bio-fuels have gained attention due to several alarming issues regarding environment like global warming, depletion of fossil fuels [7]. Although the process of manufacturing of bio-fuels is bit complex but there are several advantages too.

3. Preparation Techniques and Extraction

Below are the methods to extract bio-fuel from various organic oils –

- One step transesterification.
- Flame test to ensure proper burning of fuel. [8]

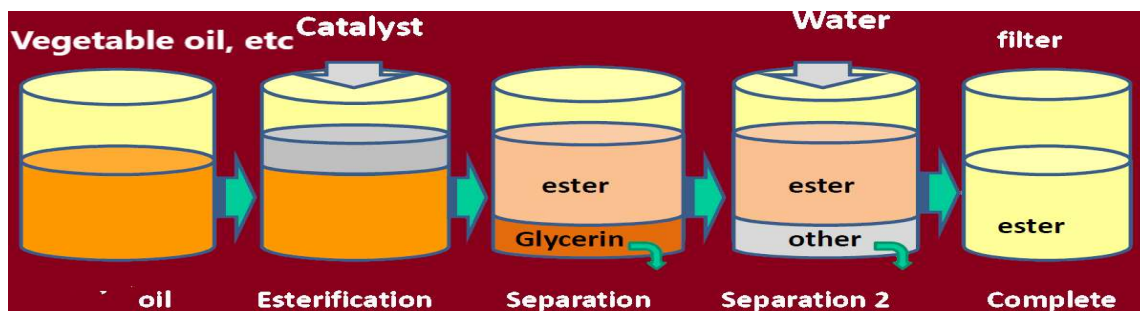
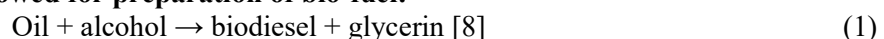


Figure 1. Process of manufacturing of bio-fuel from cooking oils.

4. Emissions

Bio-fuel emissions are the major indicators of quality of fuel [9]. It completely depends on the blend ratio and source of extraction of bio-diesel. Various sectors such as transportation sector, oil sector, and industrial sector are active drivers of increasing pollution level majorly in urban regions where dependency on these sectors is more rather than others. The complete combustion of fuels usually results in emission of CO₂, N₂, water vapors and other matter in gaseous state.

5. General Procedure followed for preparation of bio-fuel:



- The above process is called “Transesterification”.
- The manufacturing of biofuel can come from many natural sources. The sources which consists of chemicals called triglycerides, are very much appropriate.
- Methanol used as a catalyst.
- Mainly NaOH / KOH and methanol is used as catalyst.
- In this process, we mix methanol and NaOH/KOH in fixed proportion and then pour the mixture into heated oil so as to separate glycerin [10].

6. Experimental Setup

The experimentation process includes two main components: a VCR engine Test rig, and an exhaust gas analyzer.

6.1. VCR Engine Test Setup (Computerized).

It is a 1 cylinder, 4 stroke, variable compression ratio diesel engine. This testing rig is connected to a dynamometer for loading. The main feature of this component is that compression ratio can be altered without bringing the engine to a halt [11]. The setup is equipped with many instruments such as

measuring gauges, safety valves, fuel flow measurements along with a computer desktop for recording all the necessary observations (See figure 2).



Figure 2. VCR Engine.

Some of the key features of this equipment are: CR changing without stopping the engine, online measurement and performance analysis, data logging, IP, IMEP, FP indication [11]. The technical specification is given below in table 1 and shown in figure 3.



Figure 3. Main Equipment mounted on test rig.

Table 1. The following table shows the characteristics of VCR engine setup.

Engine making	Kirloskar
No. of cylinders	1
No of strokes	4
Stroke size	110mm
Bore size`	87.5mm
Compression ratio	12 to 18 variable
Load indicator	Digital
Load range	0-10 kg
Software used	EnginesoftLV

6.2. Emission analyser

The gas analyser used has the capability to measure 5 exhaust gases simultaneously. It measures Carbon Monoxide, Carbon Dioxide, Hydro Carbons, Oxygen and Nitric Oxide. It is a ready-to-use gas analyser which comes in a hard case equipped with all accessories [12].

7. Steps for experimental observations:

Table 2. The following table shows constituents of Bio-diesel

Type of blend	Diesel	Bio-fuel
B10	90%	10%
B20	80%	20%

Step 1: Make the blend of bio-diesel by mixing parts of diesel and parts of manufactured bio-fuel as shown in table 2.

Step 2: Load the Bio-diesel in fuel tank of VCR engine test rig by following all the protocols.

Step 3: Set the load and Compression Ratio to the desired value ranging from 0-10 kg for load and 12-18 for CR.

Step 4: Start the engine

Step 5: Put the analyser probe in exhaust pipe of the engine.

Step 6: Note down all the readings given by exhaust gas analyser.

Step 7: Repeat again from Step 3 until all the readings are observed/noted down for all the values of load and CR.

7.1. Exhaust gas emissions

The exhaust gases are emitted from the combustion process of petrol, diesel, gasoline or other alternative fuels. They are discharged directly into the atmosphere hence it is necessary to observe the emissions emitted from a vehicle engine. The largest part of emissions constitutes O_2 , H_2O , and CO_2 [13]. These gases are non-toxic but play huge role in global warming [14]. A relatively small part of emissions are CO and NO_x gases. Although their volume is small but these gases are toxic poses a great threat to human health [15, 20].

8. Model Generation:

8.1. Model Selection

It is seen that every single feature in the dataset obtained is continuous in nature. Mainly three machine learning regression techniques were used and their corresponding root mean squared error was observed [16]. The results are shown in the following table (See Table 3):

Table 3. Model used and its RMSE value

S.no	Regression Model	Root-mean Squared error
1.	Multiple linear regression	1558.9647
2.	k-nearest neighbor	656.4290
3.	Decision Trees	1.3006

After considering the lowest Root mean squared error, Decision trees [16] was implemented as it showed the best outcome for this particular data set [17].

8.2. Model working:

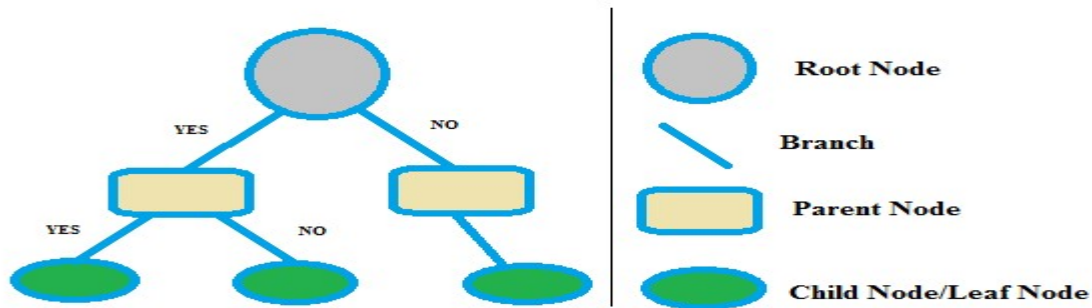


Figure 4. Showing working of a leaf node taken as an example.

(See figure 4) A decision tree works by deciding which among all the factor is important, then deciding upon other factors and putting them in the hierarchy. The order in which the questions have to be asked is evaluated by the model. These factors are decided by obtaining entropy and net information gain for each factor. If for a particular factor, there is less net entropy and model see that information gain is more, then that factor becomes a parent node and steps are repeated for other factors [16].

By adopting this approach, the model eventually reaches a prediction (leaf node). The main reason for lesser the number of splits the better is that each node has its own entropy, entropy is the impurity of an individual node. Later on the combination of these nodes forming the structure of the tree has a collective information gain.

8.3. Entropy:

The Following Formula is used in Decision trees model [18]:

$$E(S) = \sum - P_i \log_2 P_i \quad (i \text{ ranges from } 1 \text{ to } c) \quad (2)$$

P_i stands for probability for randomly picking up of elements of class i .

8.4. Information Gain:

It tells us that how much entropy is removed. Therefore: [18]

$$IG = \text{Parent node entropy} - \text{child node entropy} \quad (3)$$

9. Outcome

Following results were obtained from predictive analysis of blends under the given parameters. These results were given by implementation of decision trees algorithm on the given data set.

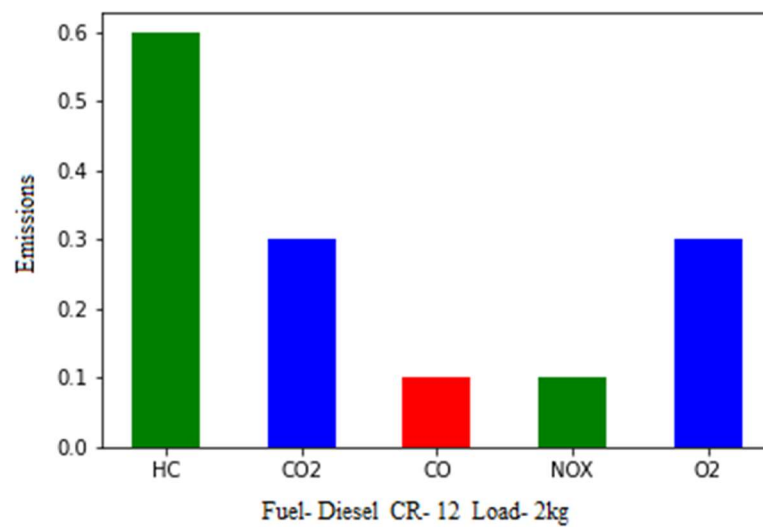


Figure 5. Predictive Emissions for Diesel under 2kg load

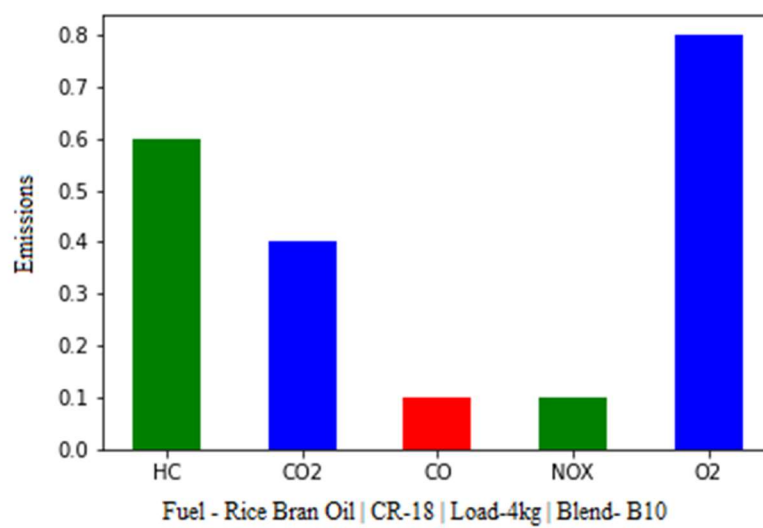


Figure 6. Predictive Emissions for Rice Bran bio-diesel

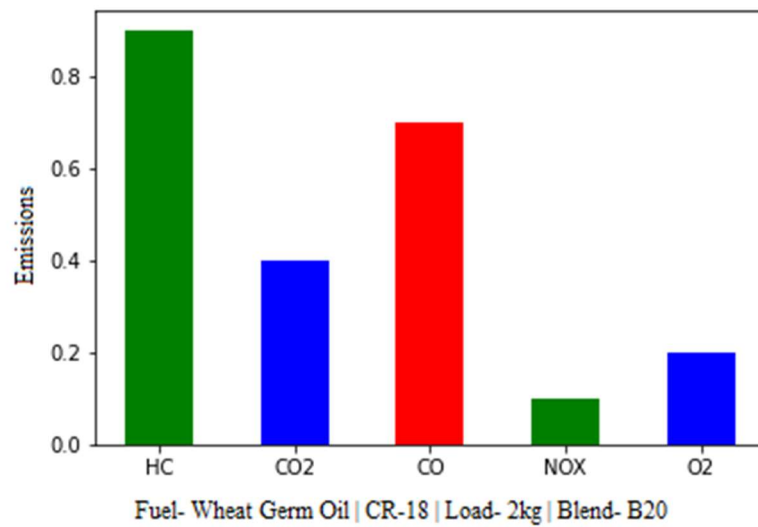


Figure 7. Predictive Emissions for Wheat Germ bio-diesel

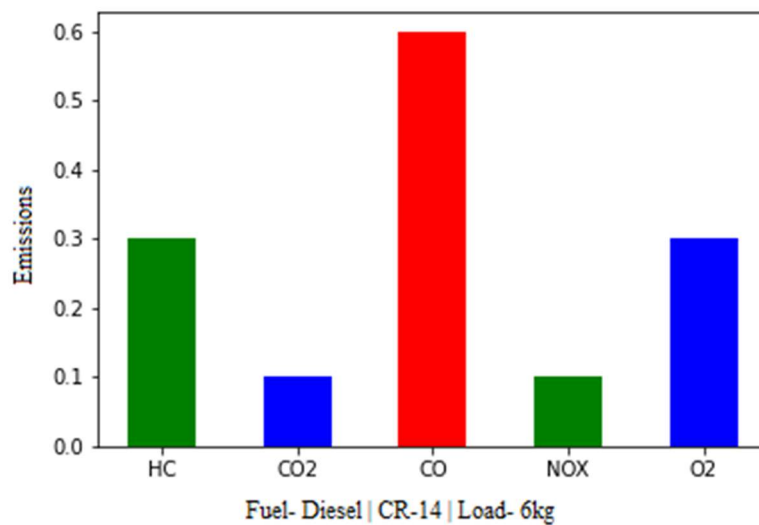


Figure 8. Predictive Emissions for Diesel under 6kg load

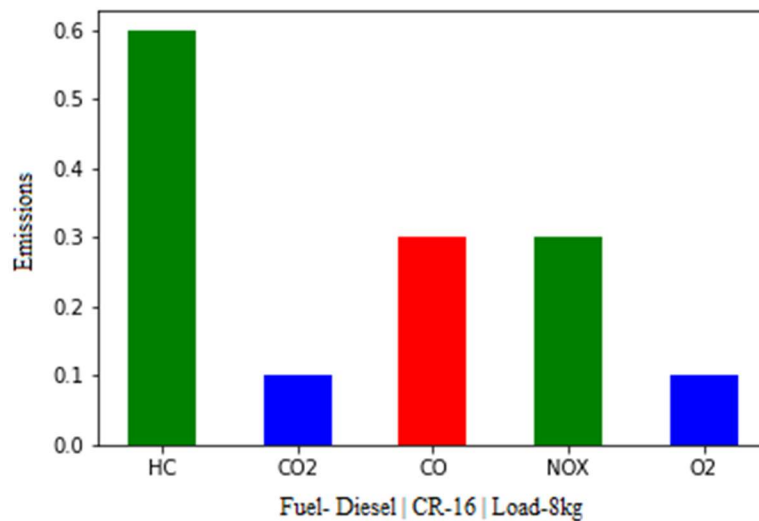


Figure 9. Predictive Emissions for Diesel under 8kg load

A website, using python and flask framework [19] is created which consists of a form fill page (See figure 5) and a result page (See figure 6). The user has to enter all the details of bio-fuel he/she wants to test and based on training data fed to the model, the output is shown on results page of the website. The database of the tested input is also stored in an excel file along with all the predicted values automatically. The whole project source code is uploaded to github profile: <https://github.com/Shivansh1612/Engine-Emissions>

Emission Calculator

Type

Brand

Compression ratio

Load(n KG)

Submit

Website created by Shivansh Khurana

Figure 10. Form Fill Page

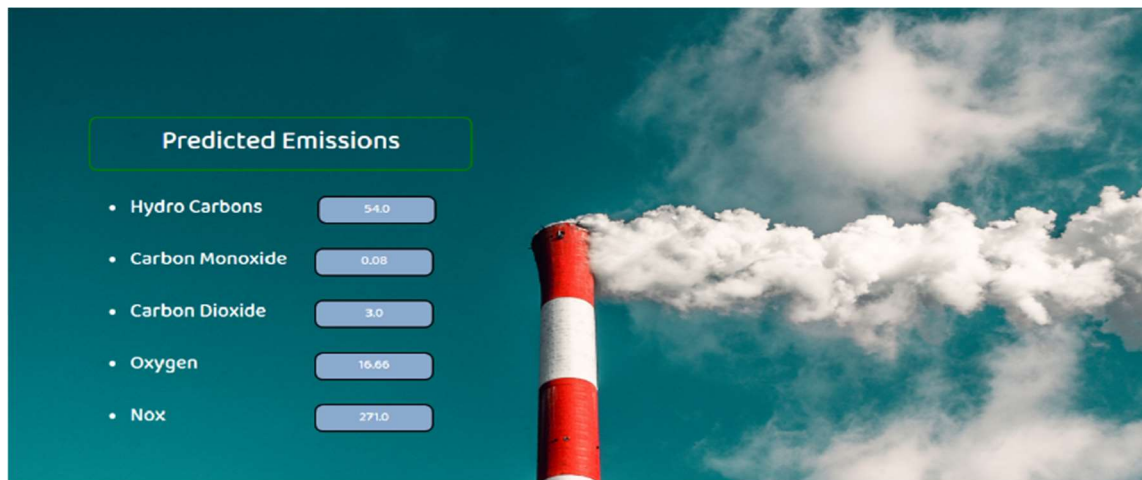


Figure 11. Results Page

10. Conclusion

Real-time measurement of engine emissions was conducted by varying various important parameters of a compression ignition engine. For every change in a parameter, all the five emissions were recorded as precisely as possible. In total, three machine learning models were built. Among the three, Decision tree model presented best predictions with lowest RMSE value. Hence it came out to be the best fit model as the estimated emissions were very closely related to observed emission rates by exhaust gas analyzer.

This type of model can be easily deployed on mobile apps as well as a website similar to the one created. Imagine the scalability of this concept once implemented commercially or on an industrial scale. Or, developing a product which could be used by the industries worldwide, an example to this is Google Cloud Platform which saves IT firms from spending trillions on GPU's, hence it can help industries a huge sum of resources using this simple concept where they won't have to spend money and their resources on repeated experimentations. This concept of using the pre-existing data can save millions of dollars annually if done on an industrial scale.

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