Abstract - The objective of this study is to investigate the emission characteristics of a Kirloskar diesel engine fuelled with diesel and its different blends with WCME biodiesel (10, 20, 30% by vol). The experiment was performed on a single cylinder, four stroke VCR diesel engine at different loads and a constant speed of 1500 rpm. The compression ratio was kept 18:1. Exhaust gas emissions were measured by AVL 4-gas analyzer. The parameters used to measure engine emissions were CO, CO₂, HC and NOx. The results were compared with pure diesel and also among different biodiesel blends. The experimental results showed that CO and HC emissions decreases with addition of biodiesel in the blends with diesel. Diesel has lowest CO₂ emissions. NOx and CO₂ emissions increases with addition of biodiesel percentage in blends.

Key Words: Emission, Performance, Diesel Engine, Biodiesel, Alternate Fuels.

1. INTRODUCTION

1.1 Background

Petroleum is the largest contributing energy source to mankind, surpassing all other resources like; coal, nuclear, hydro, natural gas and wind [3].

In the world of today, energy is a lifeline of all human activities. It has now become a necessity for day to day routine life. It is essential in the fields of industrial, food and agricultural production, the fuel for transportation as well as for the generation of electricity.

The number of diesel engines is increasing continuously every year because of having high efficiency, enhanced fuel economy. Diesel engines are preferred over spark ignition engines in almost all heavy-duty applications due to their reliability and durability. Therefore, the world’s demand for diesel fuel increases every year. Since the fossil fuel resources are limited and non-renewable and will gradually diminish. Also fossil fuels causes air pollution and global warming hence it is required to find renewable energy sources and fuels [4].

In India, the total consumption of petroleum products increased considerably to 184.674 million tonnes in 2015-16 over the previous year which was 165.52 million tonnes. Imports of crude petroleum increased to 202.851 million tonnes in 2015-16, over the preceding year level of 189.435 million tonnes with an increase of 7.08% [5].

Presently the major portion of the energy supply depend upon petroleum-based fossil fuel supplies. This supply is heavily stressed due to the increasing number of vehicles on roads every year. In addition, diesel engines have been considered one of the major air pollution sources with emissions of particulate matter (PM), NOx, HC, CO [6].

Currently, biofuel derived from waste cooking oil is being investigated in detail for application in diesel engine with an intent to explore potential opportunities in energy security improvement and exhaust gas emissions reduction.

1.2 Motivation for Alternate Fuels

The future oil supplies are not stable and concentration of pollutants emitted to the atmosphere is increasing day by day. This has motivated the development of alternative energy sources and engine technology [2].

1.3 Emission Legislation

The stringent emission regulations that has established in most countries shows the concern for the environment. Newly produced engines have to pass certain emission limits in order to get approved for sale. The test differs for different regions and also for different types of vehicles [2].

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Source</th>
<th>Description</th>
<th>Environmental and health effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>Reaction between oxygen and nitrogen in the engine combustion chamber</td>
<td>It consists of 90% NO and 10% NO₂.</td>
<td>Damages lung tissue and plants. Formation of ground level ozone &amp; smog and contributes to global warming.</td>
</tr>
<tr>
<td>PM</td>
<td>Product of fuel or lubricating oil consumption</td>
<td>Tiny carbon particles (soot or smoke) with toxic organic compounds</td>
<td>PM affect respiratory system and carry toxic substances into lungs and blood stream.</td>
</tr>
<tr>
<td>CO</td>
<td>Incomplete combustion of carbon-containing fuels</td>
<td>Higher toxic gas</td>
<td>CO is hazardous in high concentration because it binds with hemoglobin in the blood, impairing its ability to transport oxygen to the brain and other vital organs.</td>
</tr>
<tr>
<td>HC and NMHC</td>
<td>Unburned or partially burned fuel, fuel spills</td>
<td>HC contains both reactive species, called VOCs and nonreactive species, such as methane</td>
<td>HC are ozone precursors.</td>
</tr>
</tbody>
</table>
1.4 Responsive Solutions to reduce Exhaust Emissions

One of the main reasons to use alternate fuels is to replace petroleum oil, this study focuses on the engine emissions aspects of alternate fuels. Several techniques can be employed to reduce emissions. To achieve this goal, the following can be done:
1. Improve engine technology
2. Use of improved fuels

1.5 Biodiesel

Biodiesel is an alternative fuel similar to conventional or ‘fossil’ diesel. Biodiesel can be produced from vegetable oil, animal oil/fats, tallow and waste cooking oil. The process used to convert these oils to Biodiesel is called transesterification. The largest possible source of suitable oil comes from oil crops such as rapeseed, palm or soybean. Most biodiesel produced at present is produced from waste vegetable oil sourced from restaurants, industrial food producers. Though oil straight from the agricultural industry represents the greatest potential source it is not being produced commercially simply because the raw oil is too expensive. After the cost of converting it to biodiesel has been added on it is simply too expensive to compete with fossil diesel. Waste vegetable oil can often be sourced for free or sourced already treated for a small price. (The waste oil must be treated before conversion to biodiesel to remove impurities). The result is Biodiesel produced from waste vegetable oil can compete with fossil diesel. Biodiesel is safe, biodegradable, and reduces serious air pollutants such as particulates, carbon monoxide, hydrocarbons, and air toxins. [11].

1.6 Properties of WCME Biodiesel

There is a lot of research going on in the use of vegetable oils for making renewable diesel, due to its less polluting nature than conventional diesel fuel. Renewable fuels such as biodiesel, hydrogen fuels and ethanol are important because they have a tendency to replace petroleum fuels. They also offer many advantages like rural development, sustainability and the security in fuel supply [2].

Some of the properties of WCME are as follows:

<table>
<thead>
<tr>
<th>Properties</th>
<th>Diesel</th>
<th>WCME Biodiesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cetane number</td>
<td>40-55</td>
<td>55-65</td>
</tr>
<tr>
<td>Energy density(MJ/kg)</td>
<td>43</td>
<td>38</td>
</tr>
<tr>
<td>Density (kg/m3)</td>
<td>838</td>
<td>872</td>
</tr>
<tr>
<td>Viscosity at 40°C (mm²/s)</td>
<td>3.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Lubricity</td>
<td>Baseline</td>
<td>Good</td>
</tr>
<tr>
<td>Oxygen content wt%</td>
<td>0</td>
<td>10</td>
</tr>
</tbody>
</table>

2. EXPERIMENTAL SETUP

Experimental study on a VCR diesel engine (computerized), fuelled with diesel and different percentages of WCME blended with diesel were investigated with respect to the emission characteristics.

The setup consists of single cylinder, four stroke, Diesel engine connected to eddy current type dynamometer for loading purpose. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The setup has stand-alone panel box consisting of air box, fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters are provided for cooling water and calorimeter water flow measurement.

The setup enables study of engine performance and emission characteristics but the study is focused on engine emissions.

A brief specification of the test engine, used for the study is given in the Table 3 and schematic arrangement of the experimental setup is shown in Figure 1.

<table>
<thead>
<tr>
<th>Make</th>
<th>Kirloskar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine Model</td>
<td>TV 1</td>
</tr>
<tr>
<td>Engine Type</td>
<td>Vertical, 4-stroke, water cooled, VCR diesel engine</td>
</tr>
<tr>
<td>No. of Cylinder</td>
<td>One</td>
</tr>
<tr>
<td>Maximum power</td>
<td>5.2 kW@1500 RPM</td>
</tr>
<tr>
<td>Bore</td>
<td>87.5 mm</td>
</tr>
<tr>
<td>Stroke</td>
<td>110.0 mm</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>18:1</td>
</tr>
<tr>
<td>Capacity</td>
<td>661.45 cc</td>
</tr>
</tbody>
</table>
Exhaust gas emissions was measured using NDIR based exhaust gas analyzer [Make: AVL; Model: Digas 444]. The analyzer measures CO, CO\textsubscript{2}, HC and NO\textsubscript{x} in the exhaust.

### 3. TESTING PROCEDURE

1. Start the cooling water supply to ensure proper circulation for eddy current dynamometer, engine and calorimeter.
2. Start the experimental set up and run the engine at no load about 5 minutes.
3. Switch the computer on and run “EnginesoftLV” software. Confirm the configuration data of EnginesoftLV.
4. Gradually increase load on the engine.
5. Wait for steady state to be achieved (for about 5 minutes) and log the data in the “EnginesoftLV” software.
6. Gradually decrease the load on the engine.
7. Emission readings for exhaust gases CO, CO\textsubscript{2}, HC, NO\textsubscript{x} are also noted from exhaust gas analyzer.
8. View the results and corresponding plots in “EnginesoftLV”.

Experiments were conducted with diesel and WCME blends having 10%, 20%, 30% WCME on volume basis at different load levels. Engine emission tests were also conducted on pure diesel as a basis for comparison. The experiments were repeated thrice and the average values were taken for emission measurements.

### 4. RESULTS AND DISCUSSIONS

#### 4.1 Engine Emissions

Chart 1 shows variation of Carbon monoxide (CO) with load. The result shows that CO emission increases with increase in load for all the fuels tested. Diesel has higher CO emission than all biodiesel blends. Among the blends, CO decreases with increasing percentage of biodiesel in diesel. This is due to the oxygen content in biodiesel which allows more carbon molecules to oxidize when compared with diesel fuel.

Chart 2 shows variation of Carbon dioxide (CO\textsubscript{2}) with load. The result shows that CO\textsubscript{2} emission increases with increase in load for all fuels tested. Diesel has the lowest CO\textsubscript{2} emissions. Among the blends, CO\textsubscript{2} increases with increasing percentage of biodiesel due to increase in oxygen content.

Chart 3 shows variation of Hydrocarbon (HC) with load. The result shows that HC emission decreases with increase in percentage of WCME in the blends. HC emission increases as load increases with diesel and blends of WCME as the result of increase in fuel consumption at high engine loads.
and emissions, there have been inconsistent trends for WCME engine performances and its emissions due to the different tested engines, the different operating conditions, the different measurement techniques or instruments, etc. Therefore, in the present study, efforts have been made to perform the engine performance and emissions tests under controlled conditions [1].

The following conclusions have been made from this study:

1. CO and HC emissions decreases with increasing percentage of biodiesel in blends with diesel.
2. Diesel has lowest CO₂ emission and among all fuel blends CO₂ emission decreases with increasing percentage of biodiesel.
3. NOx emission increases with increasing percentage of biodiesel in blends.

**NOMENCLATURES**

WCME Waste cooking oil methyl ester  
VCR Variable compression ratio  
RPM Revolutions per minute  
CO Carbon monoxide  
CO₂ Carbon dioxide  
HC Hydro carbon  
NOx Nitrogen oxides  
CI Compression Ignition  
PM Particulate matter  
N₂ Nitrogen dioxide  
H₂O Water  
H₂ Hydrogen  
O₂ Oxygen  
IC Internal Combustion  
AFR Air-Fuel ratio  
NDIR Non-dispersive Infra-red

**REFERENCES**


Combustion at SVNIT, Surat, Gujarat, India, 13-16 Dec, 2013


