CHAPTER 3

OBJECTIVE AND METHODOLOGY

In this experimental investigation all the tests were carried out by keeping diesel as the reference fuel and test fuels being biodiesel blend, diesel water emulsion, and biodiesel (nerium) water emulsion.

3.1 OBJECTIVES OF THE STUDY

The objectives of this experimental investigation are:

(i) to conduct the complete experimental investigation without altering the engine settings such as injection timing, injection pressure, and compression ratio.

(ii) to compare the performance, combustion, and emission parameters of the fuel under research for past two decades (biodiesel) and with emulsified fuels in both uncoated and coated (LHR) engine.

(iii) to conduct the experiments with biodiesel blend, diesel water emulsion and biodiesel (nerium) water emulsion in conventional and LHR engine.

(iv) to reduce the smoke and NO\textsubscript{x} simultaneously without much loss in brake thermal efficiency.
3.2 PARAMETERS CHOSEN FOR THE INVESTIGATION

The following parameters were chosen for the experimental investigation.

(a) Performance parameters

(i) Brake thermal efficiency

(ii) Specific energy consumption (SEC)

(b) Combustion parameters

(i) Cylinder pressure and crank angle graph

(ii) Heat release rate

(c) Emission parameters

(i) Unburnt hydrocarbon (HC)

(ii) Carbon monoxide (CO)

(iii) Smoke opacity

(iv) Oxides of nitrogen emission (NOₓ)

Apart from these properties exhaust gas temperature was measured as an additional parameter in all the phases of experimental work.

3.3 METHODOLOGY OF THE INVESTIGATION

The experimental investigation was divided into five phases. They are,

1. Phase 1: Experiments with diesel and various biodiesel as fuels (For choosing test blend)
2. Phase 2: Experiments with diesel, N20 biodiesel, and diesel-water
emulsions in conventional engine.


5. Phase 5: Experiments with diesel, N20 biodiesel, and nerium-water emulsion in LHR engine.

3.3.1 Phase 1: Experiments with diesel and various blends of biodiesel fuel

In phase 1, experiments were conducted with various blends of biodiesel and neat diesel. The various biodiesel fuels taken for the comparison were jatropha biodiesel, pongamia biodiesel, mahua biodiesel and nerium biodiesel. The performance, combustion, and emission parameters were compared with diesel (reference fuel). The best biodiesel blend was to be chosen for the preparation of emulsion and further testing in the conventional and Low Heat Rejection (LHR) engines. The experimental work was mainly focused on overcoming the limitations of biodiesel fuel. From the literature review, the limitations were found to be reduced brake thermal efficiency and increased regulated pollutant oxides of nitrogen (NOx) emission. Hence the effect of combining LHR engine and emulsified biodiesel fuel were analyzed further.
Figure 3.1 Research methodologies to compare the performance and emission characteristics of diesel and various blends of biodiesel

Figure 3.1 shows the block diagram showing the details of reference fuel and test fuels with the parameters chosen for the comparison.
3.3.2 Phase 2: Experiments with diesel, N20 biodiesel, and diesel-water emulsion in the conventional engine

In phase 2, performance, combustion, and emission characteristics of diesel (reference fuel), N20 biodiesel, and diesel-water emulsion were analyzed in the conventional engine. Based on the comparison, tests would be further carried out LHR engine. Figure 3.2 shows the block diagram giving the details of fuels and parameters in the phase 2.

![Block Diagram]

Figure 3.2 Research methodologies to compare the performance, combustion, and emission characteristics of diesel, N20, and diesel water emulsion in the conventional engine.
3.3.3 Phase 3: Experiments with diesel, N20 biodiesel, and diesel-water emulsion in LHR engine

In phase 3, performance, combustion, and emission characteristics of diesel (reference fuel), N20 biodiesel, and diesel-water emulsion were analyzed in the LHR engine.

Figure 3.3 Research methodologies to compare the performance, combustion, and emission characteristics of diesel, N20, and diesel water emulsion in LHR engine
In diesel-water emulsion, the water content would be varied from 5%, 10%, and 15% by volume with diesel and termed as DWM1, DWM2, and DWM3 respectively. Micro-explosion of water droplets in emulsified fuel would have been further rapid in LHR engine due to the heat retained in the combustion chamber, due to thermal barrier coating. Figure 3.3 shows the details of the fuels used and parameters in phase 3.

### 3.3.4 Phase 4: Experiments with diesel, N20 biodiesel, and nerium-water emulsion in conventional engine

In phase 4, nerium water emulsion was taken as the main test fuel to be analyzed. Nerium biodiesel was used 20% by volume with diesel and content of water has been varied to 5%, 10%, and 15% by volume with diesel and accordingly varying the quantity of diesel and termed as NWM1, NWM2, and NWM 3 respectively. The performance, combustion, and emission parameters of conventional engine were analyzed for reference fuel and test fuels. Figure 3.4 shows the block diagram of the fuels used and parameters chosen for experimental work to be carried out in phase 4.
3.3.5 Phase 5: Experiments with diesel, N20 biodiesel, and nerium-water emulsion in LHR engine

Figure 3.5 shows the block diagram of the fuels used and parameters chosen for experimental work to be carried out in final phase. In phase 5, nerium water emulsion was taken as the main test fuel to be analyzed. Nerium biodiesel was used 20% by volume with petroleum diesel and content of water was varied to
5%, 10%, and 15% by volume with diesel. The performance, combustion, and emission characteristics of nerium-water emulsion were analyzed in LHR engine.

Figure 3.5 Research methodologies to compare the performance, combustion, and emission characteristics of diesel, N20 biodiesel, and nerium-water emulsion in LHR engine
3.4 METHODOLOGY TO PREPARE BIODIESEL

In this experimental investigation “transesterification” method of producing biodiesel was adopted to obtain biodiesel fuel. Transesterification process is also known as alcoholysis method of producing biodiesel.

![Flow diagram of transesterification process](image)

**Figure 3.6 Flow diagram of transesterification process**

Figure 3.6 shows the flow diagram of transesterification process. The complete procedure of preparation of biodiesel from raw vegetable oil is given below.

i. In a three way flask 1000 ml of raw nerium oil was taken.

ii. Sodium hydroxide (Na OH) was weighed in a weighing machine and 12 gms of pellets was mixed with 200 ml of methanol in a conical flask.

iii. Continuous stirring of the mixture was carried out until the
sodium pellets were completely dissolved in sodium hydroxide.  
iv. The mixture of Na OH and CH₃OH was dissolved with raw nerium oil in the three way flask.  
v. The mixture was heated upto 60° C with a continuous stirring for 60 minutes.  
vi. The solution was then taken out and kept in a separate vessel for 8 hours for settling down.  
vii. It was observed that coarse biodiesel was at the top and glycerol had settled down at the bottom of the vessel.  
viii. The untreated methanol was removed by heating the mixture to 100° C and maintaining the mixture for 10 to 15 minutes.  
ix. It was observed that impurities like sodium hydroxide were present in the coarse biodiesel.  
x. Those impurities were removed by washing with water.  
xi. The cleaned biodiesel was kept in a separate tank (vessel) for the experimental investigation.  

The properties of nerium biodiesel were tested and compared with the other biodiesel blends.
Table 3.1 Comparison of properties of diesel and other biodiesel fuels

<table>
<thead>
<tr>
<th>Property</th>
<th>Diesel</th>
<th>Nerium oil</th>
<th>Jatropha oil</th>
<th>Pongamia oil</th>
<th>Mahua oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematic viscosity</td>
<td>3.09</td>
<td>3.56</td>
<td>4.66</td>
<td>4.84</td>
<td>6.4</td>
</tr>
<tr>
<td>at 40°C (cSt)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calorific value</td>
<td>43198</td>
<td>42823</td>
<td>36694</td>
<td>36409</td>
<td>34597</td>
</tr>
<tr>
<td>(kJ/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density at 15°C</td>
<td>830</td>
<td>850</td>
<td>876</td>
<td>904</td>
<td>910</td>
</tr>
<tr>
<td>(kg/mm³)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flash point (°C)</td>
<td>56</td>
<td>70</td>
<td>85</td>
<td>87</td>
<td>91</td>
</tr>
<tr>
<td>Fire point (°C)</td>
<td>64</td>
<td>83</td>
<td>92</td>
<td>96</td>
<td>104</td>
</tr>
</tbody>
</table>

Table 3.1 shows the properties of diesel (reference fuel) and various biodiesel fuels. It is observed that the properties of esterified nerium oil are close to each other and comparatively has better calorific value than other biodiesel fuels.

Figure 3.7 Experimental apparatus for finding flash and fire point
Figures 3.7 and 3.8 show photographs of the experimental apparatus used for determining the flash point, fire point, and viscosity of biodiesel fuels.

3.5 METHODOLOGY TO PREPARE EMULSION

3.5.1 Surfactants span and tween

An emulsion can be defined as a mixture of two immiscible fluids. Emulsions are further classified into the following types:

i. Water-in-oil emulsion

ii. Oil-in-water emulsion

iii. Water-in-oil-in-water emulsion

iv. Oil-in-water-in-oil emulsion

Emulsions are inherently unstable. Based upon the preparatory methods separation will occur into stable states of dispersed and continuous phase.
materials. To maintain the composition of emulsion the surface active agents which are otherwise known as “surfactants” have been added into production of an oil phased emulsion. These surfactants encase the droplets of water distributed throughout the continuous oil phase. The most widely used to form emulsified fuels are Span and Tween.

The “span” is known by its chemical name “sorbitan ester” and “tween” by its chemical name “polyethoxylated sorbitan ester”. Both span and tween are non-ionic surfactants used to form emulsification of two immiscible liquids of this experimental work, namely, diesel and water.

In their research Zeng et al (2006) stated that the surfactants should be so chosen that they should easily take part in the combustion and burn easily without soot. They also mentioned that it should be free from sulphur and nitrogen.

HLB number is known as Hydrophilic Liphophilic Balance number which decides the suitable surfactant to form an emulsion. Table 3.2 shows the name of the surfactant and its HLB number. In general low value of HLB number forms water-in-oil emulsion and high value of HLB number forms oil-in-water emulsion. The range of HLB number varies from 1 to 20.
Table 3.2 Surfactants and HLB values

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Name of the surfactant</th>
<th>HLB value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Span20</td>
<td>8.6</td>
</tr>
<tr>
<td>2</td>
<td>Span80</td>
<td>4.3</td>
</tr>
<tr>
<td>3</td>
<td>Tween20</td>
<td>16.7</td>
</tr>
<tr>
<td>4</td>
<td>Tween80</td>
<td>15.6</td>
</tr>
<tr>
<td>5</td>
<td>Tween60</td>
<td>14.9</td>
</tr>
</tbody>
</table>

The surfactants span80 and tween80 were chosen because their HLB<sub>resultant</sub> (Hydrophilic Liphophilic Balance) value is 9.95, which is suitable for water-in-oil emulsion. The calculation for the HLB<sub>resultant</sub> has been given below.

\[
\text{HLB}_{\text{resultant}} = (\text{HLB}_1 \text{ value x weight percentage}) + (\text{HLB}_2 \text{ x weight percentage})
\]

Where,

\[
\text{HLB}_1 = \text{HLB number of Span80 (4.3)}
\]

\[
\text{HLB}_2 = \text{HLB number of Tween80 (15.6)}
\]

3.5.2 Concept of micro-explosion

Emulsion and micro-emulsion are two different phrases which are distinguished by few factors. Emulsion is unstable and eventually separates with its droplet size ranging from 1 to 10 mm, whereas micro-emulsion is thermodynamically stable and droplets are small aggregate of size -10 nm.
When the emulsified fuel is injected into the combustion chamber, it is exposed to high combustion temperature. Since water has a lower boiling point than diesel fuel (or biodiesel fuel) water explodes and expands approximately 1700 times in volume, causing more surface area of contact for the fuel. The more contact surface area of the fuel with oxygen improves the combustion efficiency. The better combustion reduces the particulate matter (PM), smoke density, oxides of nitrogen (NO\textsubscript{x}) emission, and reduction in other emission gases.

Figure 3.9 illustrates the phenomena of micro-explosion process. First stage shows the dispersion of water droplets in the fuel. Second stage shows the explosion of water droplets due to the high combustion temperature as the boiling point of water is lower than that of the fuel. The third stage shows the finely atomized fuel droplets. The phenomenon of micro-explosion is independent of viscosity of emulsion. Degassing the emulsion would slow down the micro-explosion process because dissolved gas would reduce the superheat temperature of water (Anna et al 2006).

3.5.3 Composition of emulsified fuels

Table 3.3 shows the composition of diesel-water emulsions used for this experimental investigation.
Table 3.3 Composition of diesel-water emulsion

<table>
<thead>
<tr>
<th></th>
<th>DWM1</th>
<th>DWM2</th>
<th>DWM3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>94%</td>
<td>89%</td>
<td>84%</td>
</tr>
<tr>
<td>Water</td>
<td>5%</td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>Span80</td>
<td>0.5%</td>
<td>0.5%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Tween80</td>
<td>0.5%</td>
<td>0.5%</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

Table 3.4 shows the composition of nerium-water emulsions used for this experimental investigation

Table 3.4 Composition of nerium-water emulsion

<table>
<thead>
<tr>
<th></th>
<th>NWM1</th>
<th>NWM2</th>
<th>NWM3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>74%</td>
<td>69%</td>
<td>64%</td>
</tr>
<tr>
<td>Nerium</td>
<td>20%</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>Water</td>
<td>5%</td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>Span80</td>
<td>0.5%</td>
<td>0.5%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Tween80</td>
<td>0.5%</td>
<td>0.5%</td>
<td>0.5%</td>
</tr>
</tbody>
</table>
Table 3.5 Comparison of fuel properties of diesel and diesel-water emulsion

<table>
<thead>
<tr>
<th></th>
<th>Diesel</th>
<th>DWM1</th>
<th>DWM2</th>
<th>DWM3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>830</td>
<td>833</td>
<td>836</td>
<td>841</td>
</tr>
<tr>
<td>Calorific value</td>
<td>43.2</td>
<td>40.72</td>
<td>38.48</td>
<td>36.32</td>
</tr>
<tr>
<td>(MJ/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flash point (°C)</td>
<td>56</td>
<td>58</td>
<td>60</td>
<td>62</td>
</tr>
<tr>
<td>Fire point (°C)</td>
<td>64</td>
<td>65</td>
<td>66</td>
<td>68</td>
</tr>
</tbody>
</table>

Table 3.6 Comparison of fuel properties of diesel and nerium-water emulsion

<table>
<thead>
<tr>
<th></th>
<th>Diesel</th>
<th>NWM1</th>
<th>NWM2</th>
<th>NWM3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>830</td>
<td>838</td>
<td>843</td>
<td>844</td>
</tr>
<tr>
<td>Calorific value</td>
<td>43.2</td>
<td>40.51</td>
<td>38.37</td>
<td>36.20</td>
</tr>
<tr>
<td>(MJ/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flash point (°C)</td>
<td>56</td>
<td>72</td>
<td>74</td>
<td>75</td>
</tr>
<tr>
<td>Fire point (°C)</td>
<td>64</td>
<td>84</td>
<td>85</td>
<td>86</td>
</tr>
</tbody>
</table>

Table 3.5 shows the comparison of fuel properties of diesel-water emulsion. It is observed that there was an increase in the density, flash point, and fire point of diesel-water emulsion more than for diesel. It is also observed that there was a decrease in calorific value of diesel-water emulsion, as water has no energy content in it. The increase in density might be due to the increasing content of water, as density of water is more than that of diesel. Since water has no heating value, the calorific value of diesel-water emulsion would be lesser than that of diesel.

Table 3.6 shows the comparison of fuel properties of diesel and nerium-water emulsion. It is evident that the density of nerium-water emulsion is higher than that of diesel and diesel-water emulsion as the density of N20 biodiesel and
water is more than that of diesel. But calorific value of nerium-water emulsion was approximately equal to the same composition of diesel water emulsion as the calorific value of nerium biodiesel is almost close to that of diesel fuel.

Flash and fire point of both diesel-water emulsion and nerium-water emulsion are more than diesel because of its increased viscosity of biodiesel, decreased volatility, and decreased energy content due to water addition.

### 3.5.4 Visual study of emulsified fuel

Diesel-water emulsion was prepared with various compositions shown in Table 3.5. The surfactants for this emulsion were span 80 and tween 80. The mixture of all these were agitated with a speed of approximately 10,000 rpm for 10 minutes. The stability of the diesel-water emulsion was studied upto 10 hours. It was found that diesel water emulsion was stable and no separation occurred. Figure 3.10 shows the photograph taken during visual observation of diesel-water emulsion with various compositions of water.

![Figure 3.10 Photograph taken during visual study of diesel-water emulsion](image)

**Figure 3.10 Photograph taken during visual study of diesel-water emulsion**
Nerium-water emulsion was prepared according to the composition mentioned in Table 3.6. Nerium biodiesel blend of 20% was kept constant and the quantity of water was varied as 5%, 10%, and 15% by volume with diesel. The proportion of surfactants (span 80 and tween 80) was 0.5% each.

Figure 3.11 shows the photographs taken during the visual observation of nerium-water emulsion for 10 hours and it was observed that the emulsion was stable. Both diesel-water emulsion and nerium-water emulsion looked like light skimmed milk, a dark vanilla ice cream shake, or even thick and chunky like cottage cheese or cheese curds.

The future scope of this experimental investigation is on-board production of emulsion. In the preliminary study of its performance, combustion, and emission characteristics, stability for 10 hours was taken as an appreciable finding for its future testing.