# CHAPTER IV
# RESULTS AND DISCUSSIONS

## 4.1 Effect of Ethanol Concentration on Phase Stability

The effect of ethanol concentration on phase stability has been studied by using 3 concentrations of ethanol; 95%, 99.5%, and 99.9%, at room temperature. And the results are presented in the 3 phase diagrams of diesel - biodiesel and ethanol components which denoted by D, B and E, respectively.

### 4.1.1 Phase Behavior of Diesel-Biodiesel-Ethanol95% System at Room Temperature

Figure 4.1 shows the phase behavior of diesel - biodiesel and ethanol 95% system at room temperature. The circle points represents liquid 1 phase and the triangle up points represents liquid 2 phases. In case of ethanol 95%, diesel and ethanol 95% purity were insoluble in each other. That because ethanol 95%, also called hydrous ethanol, has 5% water in its mixture. Due to the high polarity of the water, this amount of water will enhance polar part in ethanol molecule. Consequently, diesel which is the non-polar molecule can not be compatible with ethanol 95% purity. Solubility of the pair diesel - biodiesel was not limited as well as the pair biodiesel - ethanol 95%. Due to the fact that biodiesel has both polar and non-polar part in its molecule, biodiesel is soluble in both diesel and ethanol. In this case, it seemed that adding biodiesel can not improve intersolubility of diesel and ethanol 95% because after 7 days the mixtures of the three components had been splited into two phases which are polar phase and non-polar phase. The reason might be explained that the water content in ethanol 95% has a stronger effect than biodiesel, resulting in poor emulsion stabilities. Therefore, ethanol 95% was not suitable for diesohol production.

### 4.1.2 <u>Phase Behavior of Diesel-Biodiesel-Ethanol99.5% System at Room Temperature</u>

In case of ethanol 99.5%, intersolubility of the three -components was not limited. They could be mixed together into a homogeneous solution at any ratios as shown in Figure 4.2. Because ethanol 99.5% has lower water content than that of ethanol 95%, consequently; ethanol 99.5% was more soluble in diesel fuel than ethanol 95%. However, after 3 months, some ratios of the mixtures between diesel and ethanol 99.5% (60% diesel, 40% ethanol; 50% diesel, 50% ethanol and 40% diesel, 60% ethanol) became 2 phases but the mixtures that have biodiesel as an additive still be liquid 1 phase. This homogeneity was due to the fact that biodiesel can act as an amphiphile (a surface-active agent) and form micelles that have non-polar tails and polar heads. These molecules were attracted to liquid/liquid interfacial films and each other. These micelles acted as polar or non-polar solutes, depending on the orientation of the biodiesel molecules. When diesel fuel was in the continuous phase, the polar head in a biodiesel molecule oriented itself with the ethanol and the non-polar tail was oriented with the diesel. This phenomenon held the micelles in a thermodynamically stable state, depending on the component concentrations and other physical parameters (Fernando and Hanna, 2004).

### 4.1.3 <u>Phase Behavior of Diesel-Biodiesel-Ethanol99.9% System at Room Temperature</u>

Ethanol 99.9% also showed the same result as ethanol 99.5%. Ethanol 99.9% and diesel could be mixed together into a homogeneous solution at any ratios. However, since ethanol 99.5% was much cheaper than ethanol 99.9% and could be produced in our country, therefore; ethanol 99.5% was chosen to blend with diesel and biodiesel in order to study fuel properties.

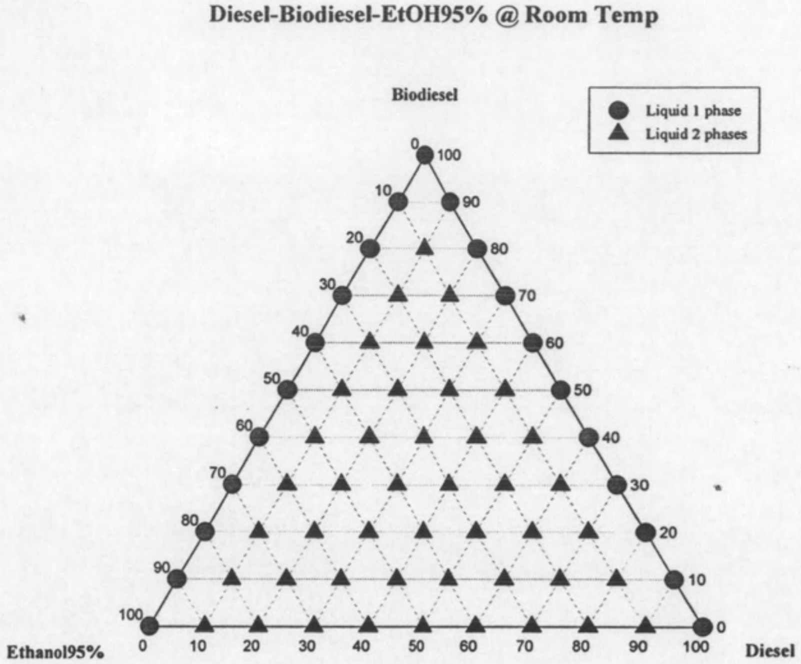


**Figure 4.1** Phase Behavior of Diesel-Biodiesel-Ethanol95% (D-B-E95%) System at Room Temperature.

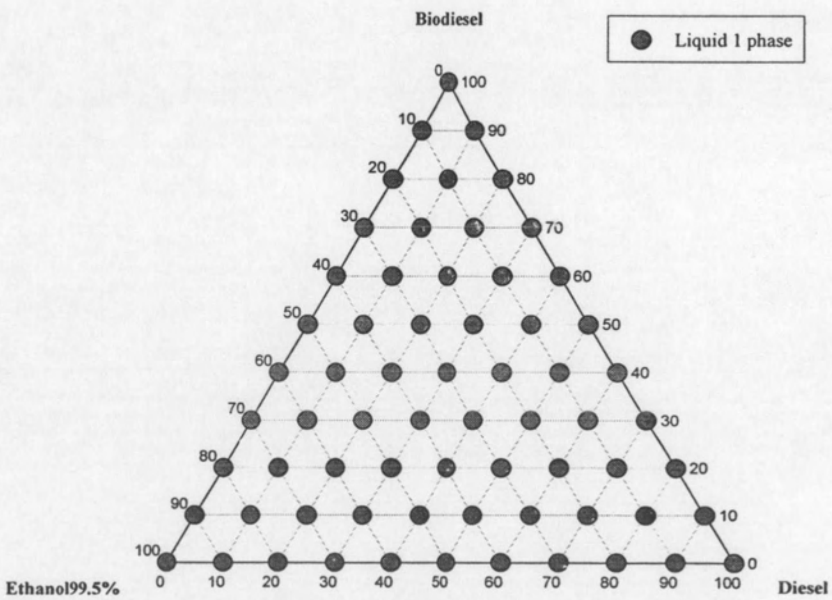


**Figure 4.2** Phase Behavior of Diesel-Biodiesel-Ethanol99.5% (D-B-E99.5%) System at Room Temperature.

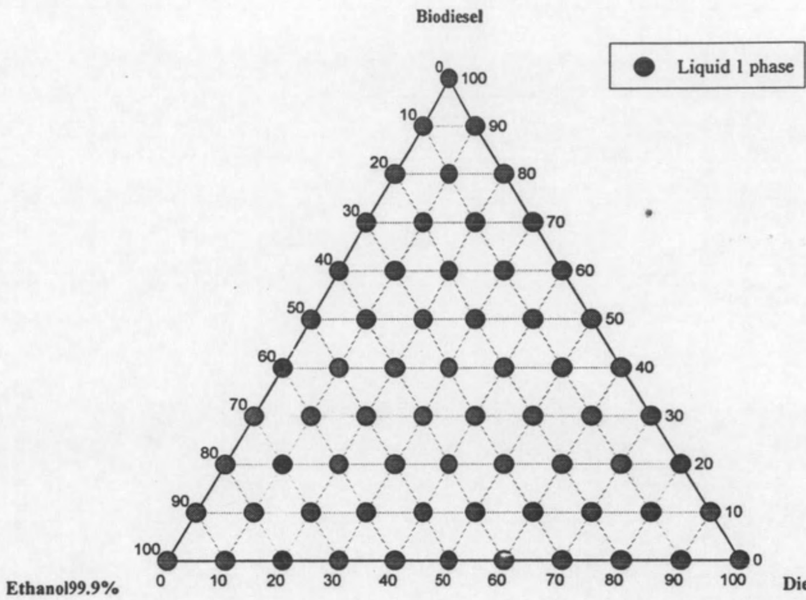


**Figure 4.3** Phase Behavior of Diesel-Biodiesel-Ethanol99.9% (D-B-E99.9%) System at Room Temperature.

## 4.2 Effect of Temperature on Phase Stability

### 4.2.1 Phase Behavior of Diesel-Biodiesel-Ethanol99.5% System at 10°C

From Figure 4.4, the circle point represents liquid 1 phase, the square point represents liquid crystalline 1 phase, the triangle point down represents liquid crystalline 2 phases and the diamond point represents gel condition. At the temperature of 10°C, it can be observed the tendency that the mixtures of diesel and ethanol in the range of 20-80% by volume were liquid crystalline 2 phases. The mixtures of biodiesel and ethanol were liquid 1 phase. The mixtures containing biodiesel from 70 up to 100% without ethanol become gel. This might be the effect of fatty acid in biodiesel component. And the other ratios were liquid crystalline 1 phase.

4.2.2 Phase Behavior of Diesel-Biodiesel-Ethanol99.5% System at 20°C

As shown in Figure 4.5, the circle point represents liquid 1 phase and the triangle up point represents liquid 2 phases. At 20 °C, almost all the blends were liquid 1 phase except the ratios of ethanol 30 to 70%with diesel. These ratios were liquid 2 phases. Therefore, at 20 °C, fuel ethanol was completely miscible in diesel when the diesel concentration was lower than 30% or higher than 70%.

4.2.3 Phase Behavior of Diesel-Biodiesel-Ethanol99.5% System at 30°C

At 30 °C, all the blends were liquid 1 phase as shown in Figure 4.6. Fuel ethanol could be mixed with diesel at any ratios. Therefore, at this temperature, it does not have any problem of phase separation.

4.2.4 Phase Behavior of Diesel-Biodiesel-Ethanol99.5% System at 40°C

Figure 4.7 shows the phase behavior of diesel-biodiesel-ethanol 99.5% System at 40°C and the result was similar to that of 30 °C. This result proves that diesohol emulsions will be stable as a liquid single phase fuel at rather high ambient temperature (30-40 °C). Consequently, due to the normal temperature range in Thailand, diesohol emulsions can be used as a liquid fuel without the problem of phase separation.

4.2.5 Long Term Stability of Diesel-Biodiesel-Ethanol99.5% System at Room Temperature

For the long term stability, after observing the stability of the blends at different temperature for 7 days, we observed the long term stability of the blends by kept them motionless further for 3 months at room temperature. As shown in Figure 4.8, the result showed that the mixture of diesel and ethanol 99.5% in the range of 40-60% by volume split into 2 phases. However, the mixtures that have biodiesel as an additive still be liquid 1 phase clear solution. This indicated that the addition of biodiesel can improve intersolubility of diesel and ethanol99.5%. Therefore, biodiesel really act as an effective additive in stabilizing diesohol.

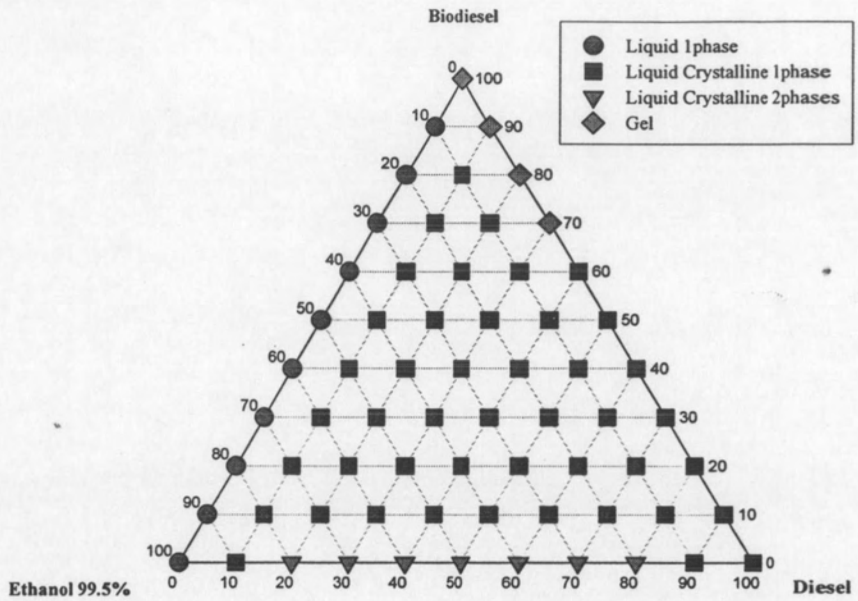


**Figure 4.4** Phase Behavior of Diesel-Biodiesel-Ethanol99.5% (D-B-E99.5%) System at 10°C.

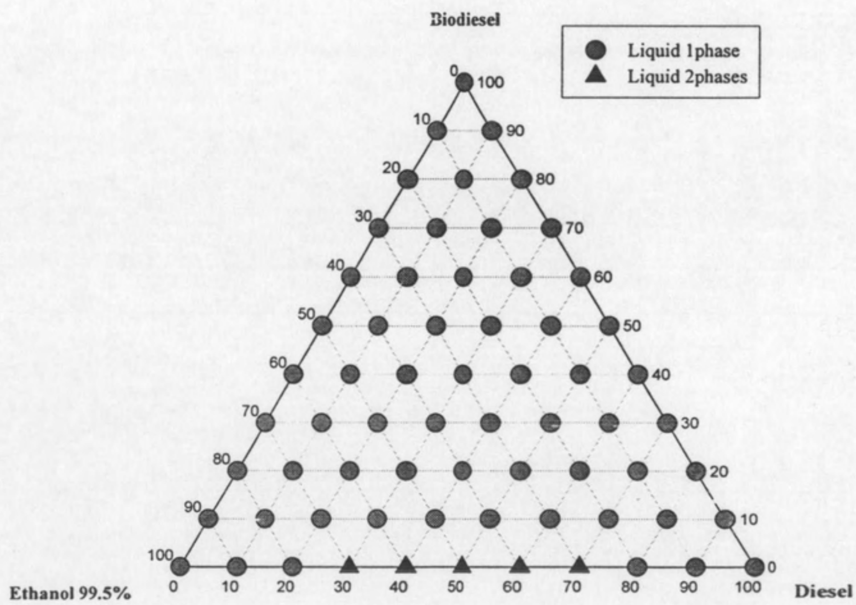


**Figure 4.5** Phase Behavior of Diesel-Biodiesel-Ethanol99.5% (D-B-E99.5%) System at 20°C.

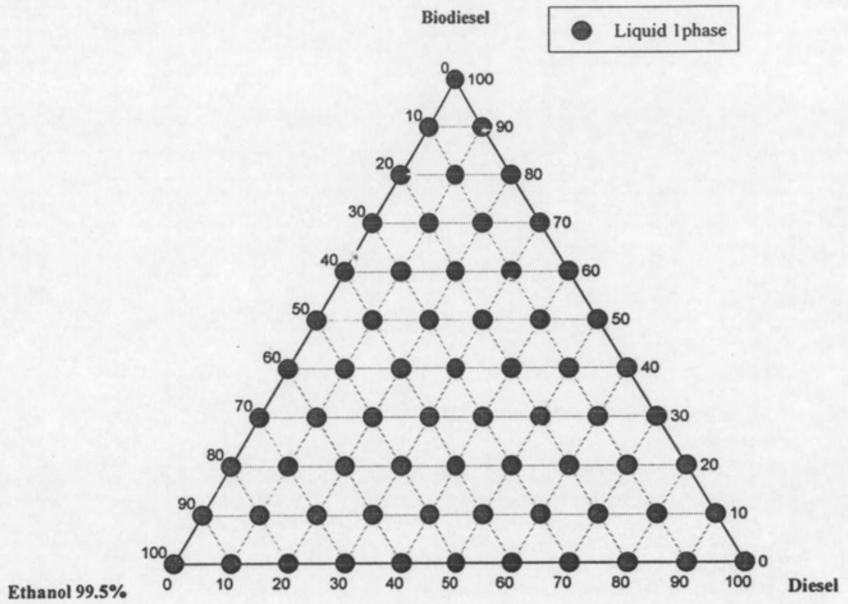


**Figure 4.6** Phase Behavior of Diesel-Biodiesel-Ethanol99.5% (D-B-E99.5%) System at 30°C.

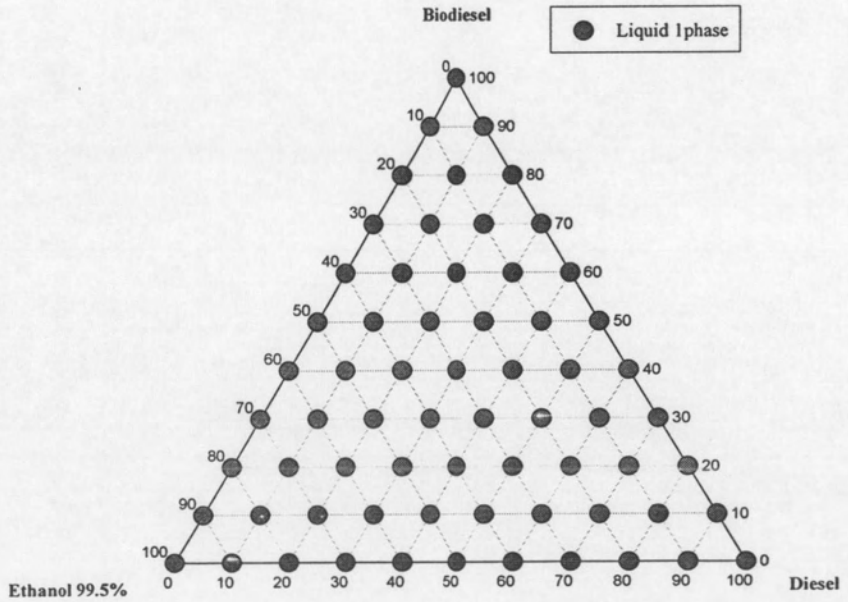


**Figure 4.7** Phase Behavior of Diesel-Biodiesel-Ethanol99.5% (D-B-E99.5%) System at 40°C.

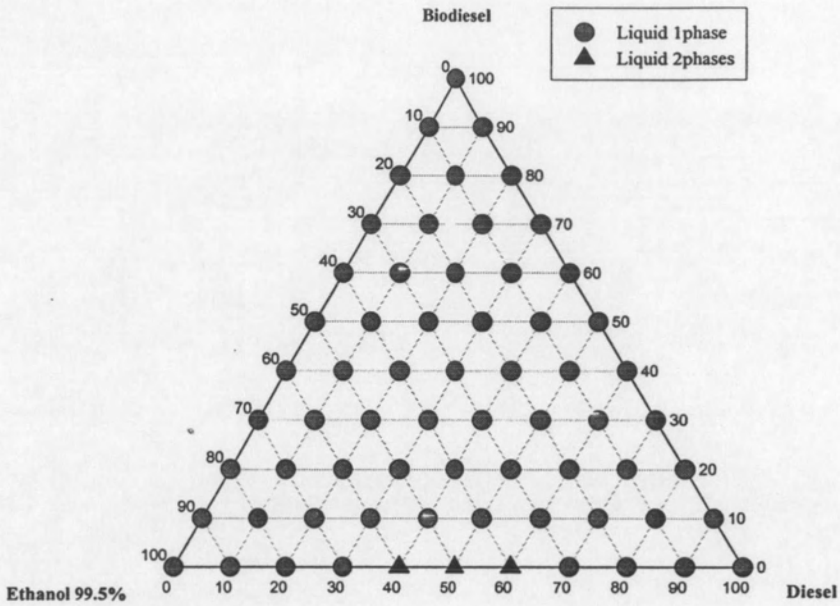


**Figure 4.8** Long Term Stability of Diesel-Biodiesel-Ethanol99.5% (D-B-E99.5%) System at Room Temperature.

## 4.3 Fuel Properties Testing

### 4.3.1 Density at 15 °C

For the density, it can be observed from Figure 4.8 that the density of the blends decreased with increasing the percentage of ethanol in the blends. This is attributed to the fact that ethanol has lower density and as such will lower the density of the mixture. But when percentage of biodiesel was increased, the density increased. This is due to the fact that the palm-oil biodiesel has higher density than the other two components. Normally, it is recognized that the higher density leads to the higher flow resistance of fuel oil, resulting in higher viscosity. This finding suggests that the higher viscosity can bring to the inferior fuel injection. However, all the blends had density values that were acceptable by the standard limit for the high-speed diesel. These results have the same tendency as those earlier work reported by Ajav and Akingbehin (2002), and Cheenkachorn *et al.* (2004).

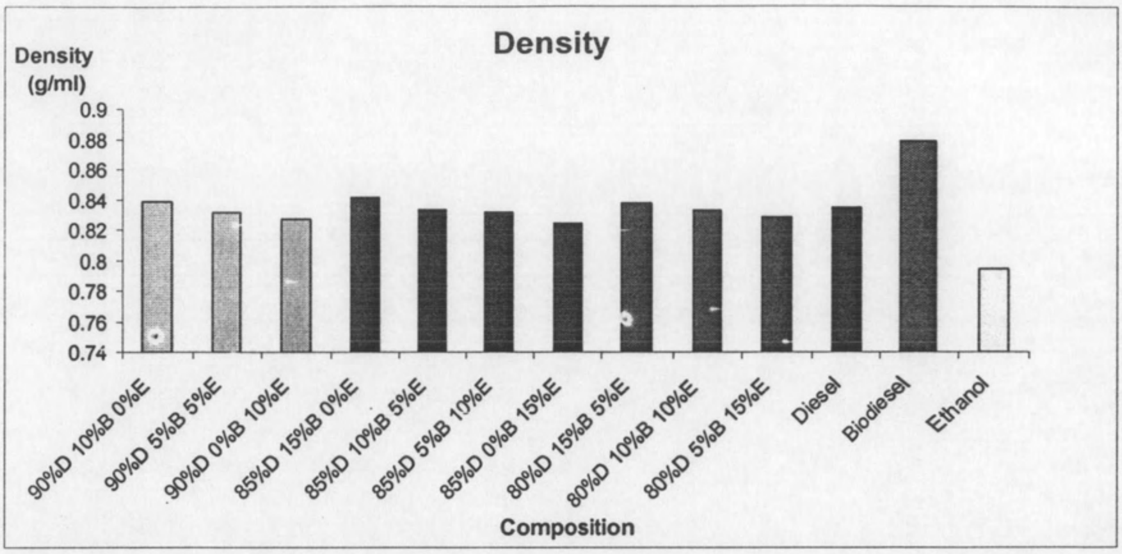


**Figure 4.9** Density of diesohol emulsion at different ratios of diesel, biodiesel and ethanol.

4.3.2 Cetane Index

The cetane index is also in proportional relation with density value, it was observed that the cetane index of diesohol mixture decreased when increasing the amount of ethanol added because ethanol itself has very low cetane, approximately 5-8. The lower the cetane index is, the poorer the ignition property will be. Cetane index also has affected on the engine start up, combustion control, and engine performance. However, biodiesel, due to its high cetane value, could improve this property. As shown in Figure 4.9, some of the fuel blends had cetane index higher than based diesel. In this result, the sample consisting of 80%diesel, 15%biodiesel and 5%ethanol had the highest cetane index.

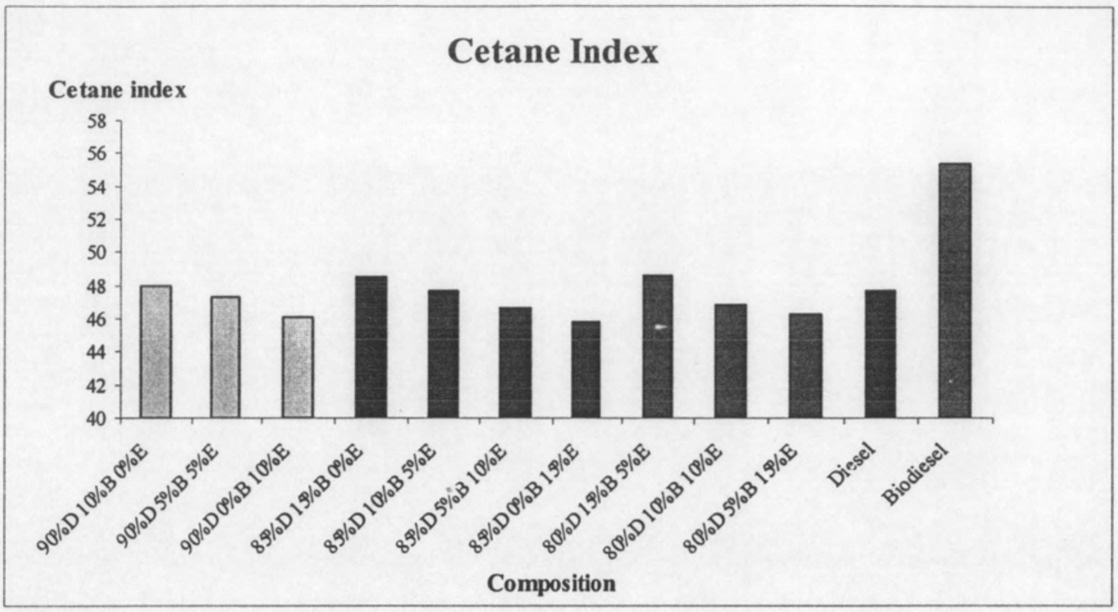


**Figure 4.10** Cetane index of diesohol emulsion at different ratios of diesel and biodiesel.

4.3.3 <u>Heat of Combustion</u>

Heat of combustion is one of the most important fuel properties. The result showed that heat of combustion of diesohol decreased when more amount of ethanol and biodiesel were added as shown in Figure 4.10. This is owing to the lesser in the heating value of biodiesel and ethanol. These results have the same trend as those earlier reported by Ajav and Akingbehin (2002), Fernando and Hanna (2004), and Cheenkachorn *et al.* (2004). The lower heating value of a fuel has a direct influence on the power output of the engine. However, it seems that heating value of the blends containing ethanol lower than 10% were not much different from conventional diesel.

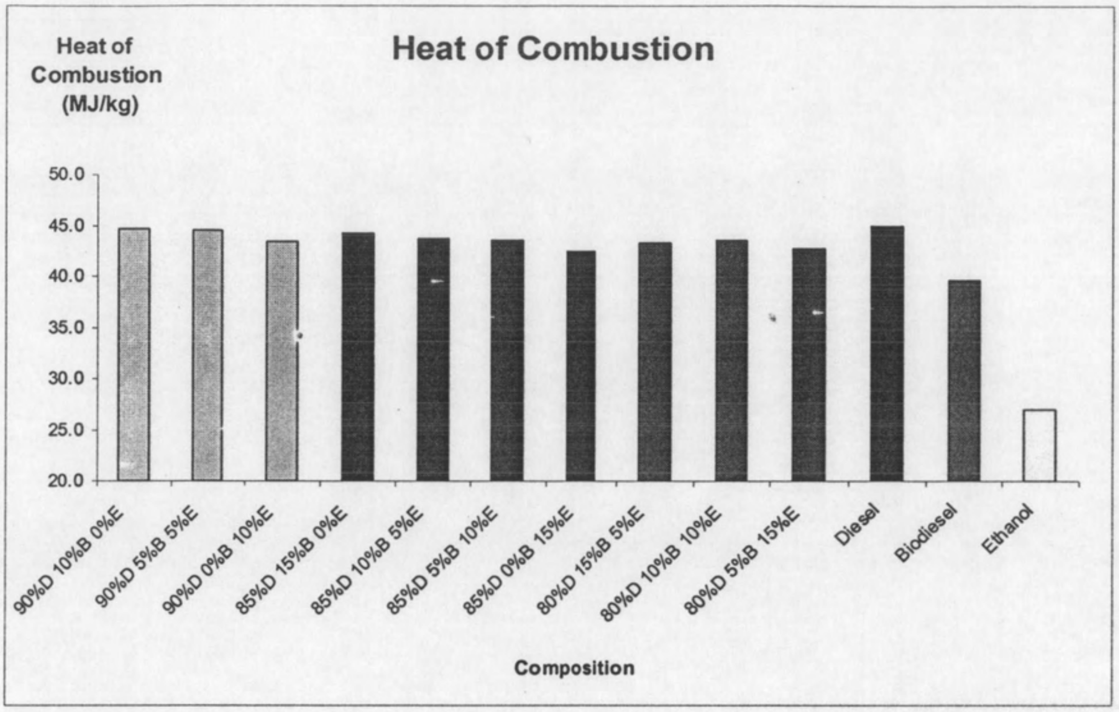


**Figure 4.11** Heat of combustion of diesohol emulsion at different ratios of diesel, biodiesel and ethanol.

### 4.3.4 Pour Point

All of the blends, except sample containing 90%diesel, 10%biodiesel and 85%diesel, 15%biodiesel, were found to have the same pour point at 3°C while the samples which contained only diesel and biodiesel had the same pour point as that of based diesel as shown in Figure 4.11. The reason is that ethanol has very low pour point and biodiesel normally has pour point higher than conventional diesel but all of the blends have diesel as a major component. Therefore, pour points of the fuel blends were found to be not much different from conventional diesel.

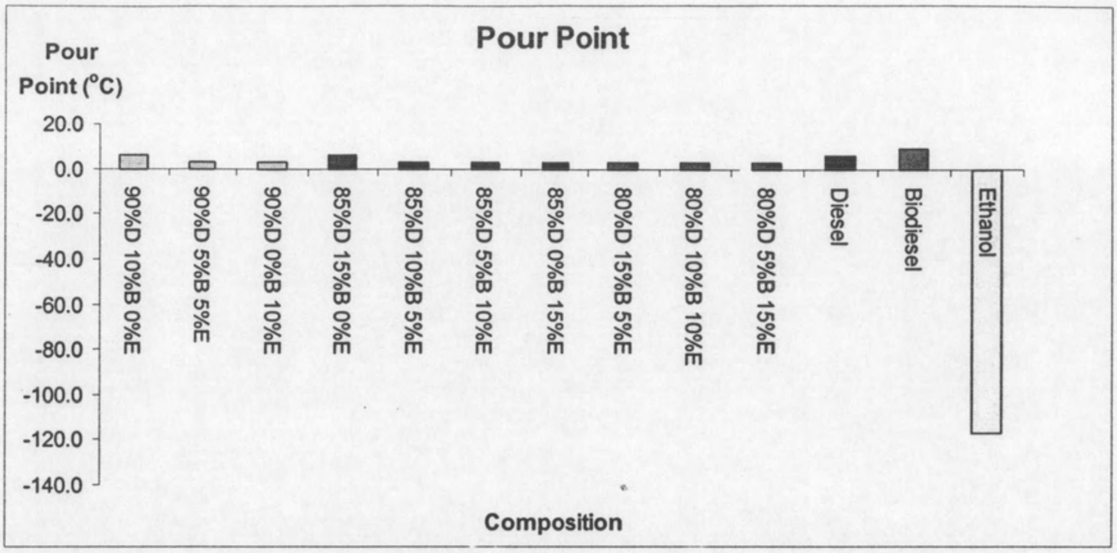


**Figure 4.12** Pour point of diesohol emulsion at different ratios of diesel, biodiesel and ethanol.

### 4.3.5 Flash Point

The flash point is the lowest temperature at which a fuel will ignite when exposed to an ignition source. In this study, the flash point for all diesohol mixture were also investigated and found to be extremely low in the range of 12-17°C as presented in Figure 4.12. Except the sample containing 90%diesel, 10%biodiesel and 85%diesel, 15%biodiesel, that contained only diesel and biodiesel had flash point higher than normal diesel. The flash point of the fuel affects the shipping and storage classification of fuels and the precaution that should be used in handling and transporting the fuel. In general, flash point measurements are typically dominated by the fuel component in the blend with the lowest flash point. The flash point of diesohol mixture is mainly dominated by ethanol. As a result, the storage and transportation of diesohol must be taken care of in a special and proper way, in order to avoid an explosion. These facts were also discussed in those earlier reported by Ajav and Akingbehin (2002), Fernando and Hanna (2004), Cheenkachorn *et al.* (2004), and De-gang *et al.* (2005).

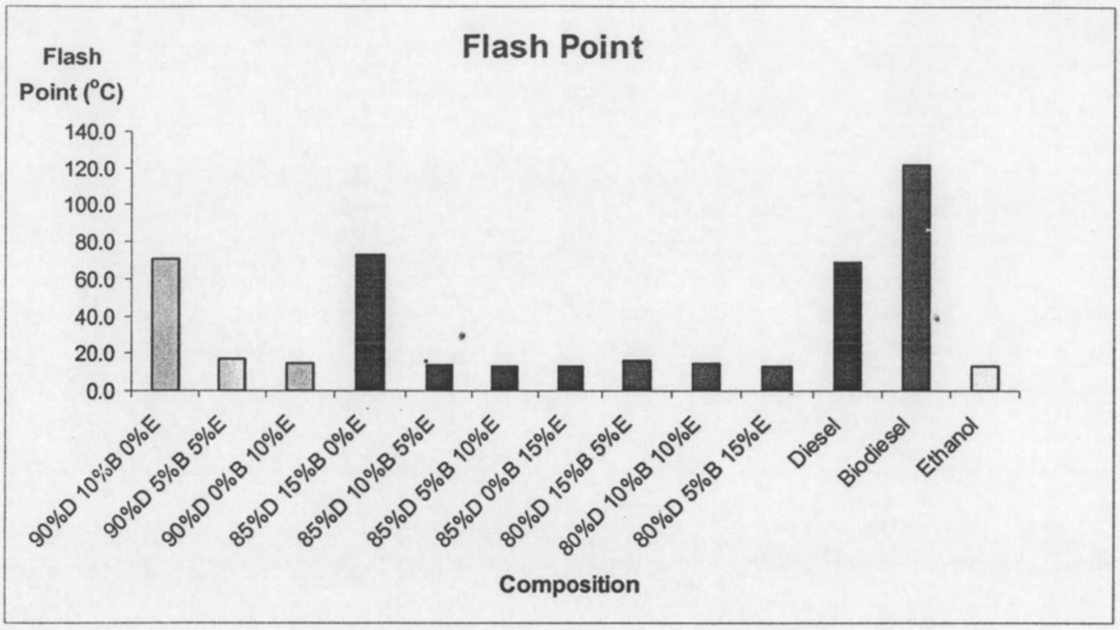


**Figure 4.13** Flash point of diesohol emulsion at different ratios of diesel, biodiesel and ethanol.

## 4.4 Emissions Testing

### 4.4.1 CO Emissions

The variations of CO emission with respect to fuels at various loads are presented in Figures 4.13, 4.14 and 4.15 which the proportion of diesel was fixed at 90, 85 and 80% by volume, respectively. As shown in these figures, at low and medium loads (0, 30 and 60% load), CO emissions of the blends were not much different from that of conventional diesel. However, at full load (100% load), CO emissions of the blends decreased significantly when compared with those of conventional diesel. This can be explained by the enrichment of oxygen owing to ethanol and biodiesel addition, as increasing the proportion of oxygen will promote the further oxidation of CO during the engine exhaust process. In this result, the blend of 80% diesel, 15% biodiesel and 5% ethanol produced the smallest amount of CO (~ 0.6-0.8 %Vol) at full engine load. The addition of oxygenates into the diesel fuel resulted in a slight effect in CO emissions at low and medium load but significantly reduced CO emissions at high or full load. This result is comparable with the previous work reported by De-gang *et al.* (2005).

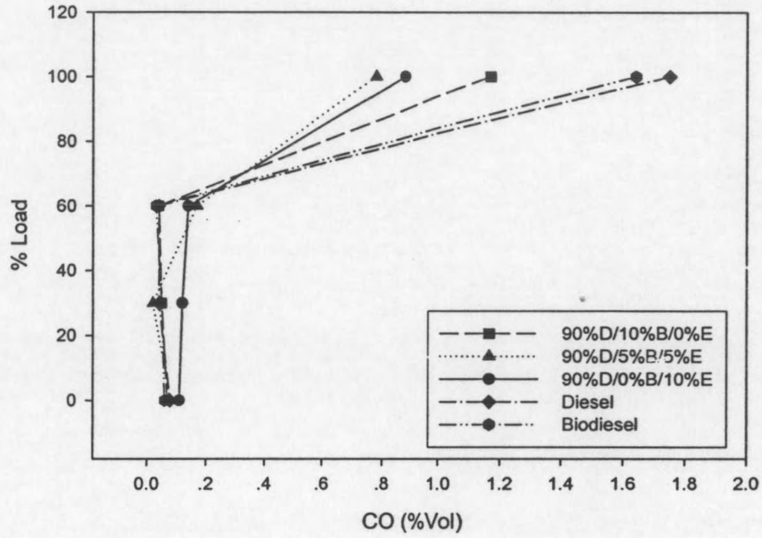


**Figure 4.14** CO emission of diesohol emulsions at 90% diesel proportion at different loads.

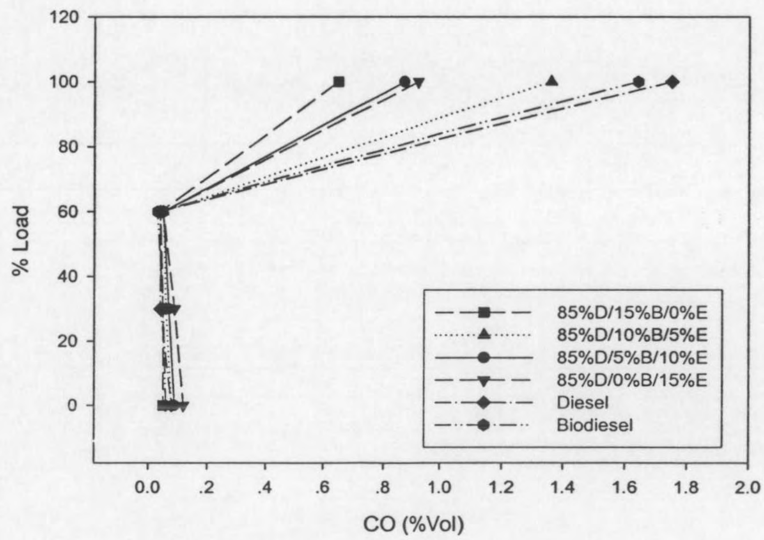


**Figure 4.15** CO emission of diesohol emulsions at 85% diesel proportion at different loads.

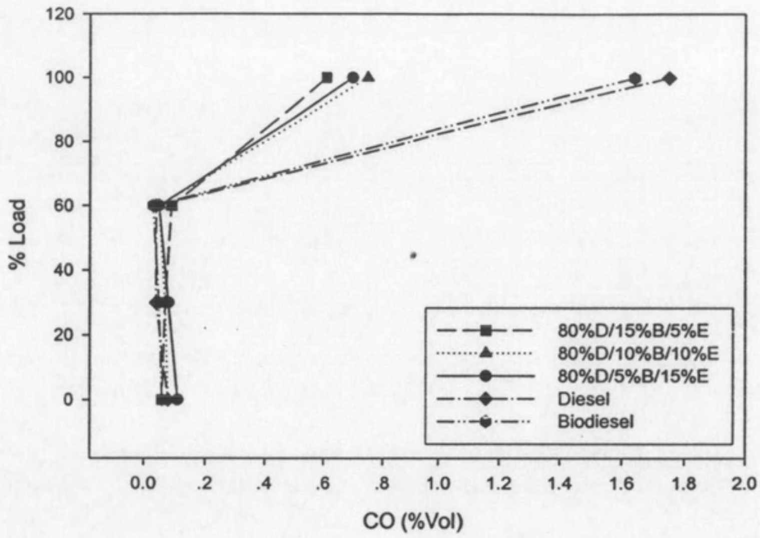


**Figure 4.16** CO emission of diesohol emulsions at 80% diesel proportion at different loads.

4.4.2 <u>HC Emissions</u>

Figures 4.16, 4.17 and 4.18 illustrate that sample containing diesel at 90, 85 and 80% by volume respectively show the same tendency that at low and medium load, the blends that contain higher percentage of ethanol will have higher HC emission. On the other hand, it was also observed that the blends containing higher percentage of biodiesel will have lower HC emission. This indicates that the presence of ethanol might be the essential factor for the increase of HC emissions. High HC emission means that there is some unburned ethanol emitted in the exhaust due to the larger ethanol dispersion region in the combustion chamber. Biodiesel has a higher cetane number than conventional diesel, resulting in more complete combustion in the cylinder. At medium load, diesel, biodiesel and fuel blends had lower HC emissions than those emitted from lower or higher load. The reason is that normally, better combustion can be achieved at a medium speed and with a medium-sized load. However, at full load, diesel had the highest HC emission. Thus, at this condition the fuel blends had less HC emissions than conventional diesel fuel. In this study, the blend of 85% diesel and 15% biodiesel had the lowest HC emission at full load condition. Thc lower HC emission means that the fuel has higher combustion efficiency resulting in higher energy out put and cleaner combustion chamber.

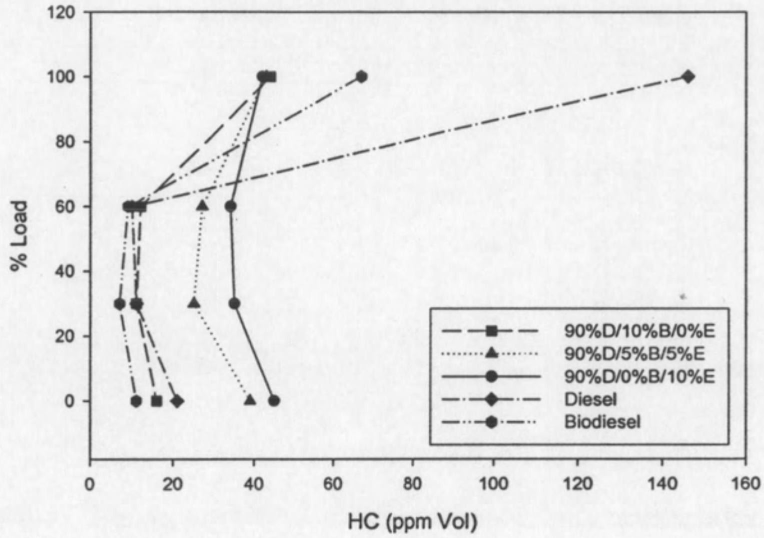


**Figure 4.17** HC emission of diesohol emulsions at 90% diesel proportion at different loads.

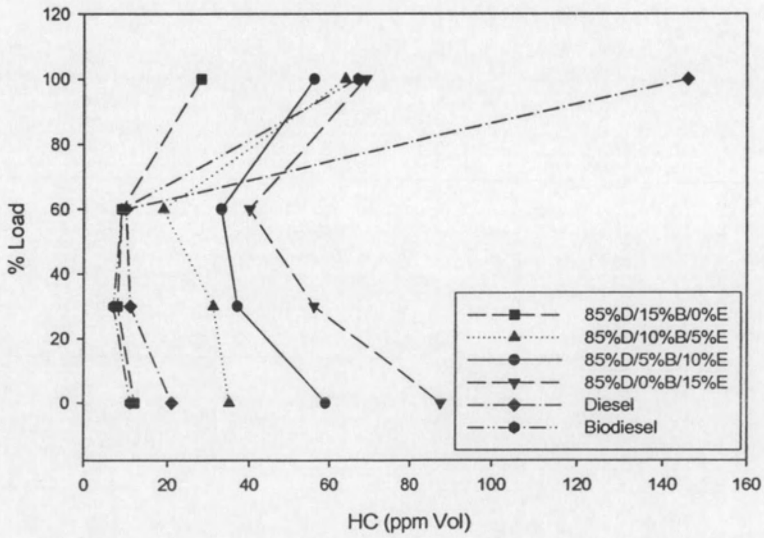


**Figure 4.18** HC emission of diesohol emulsions at 85% diesel proportion at different loads.

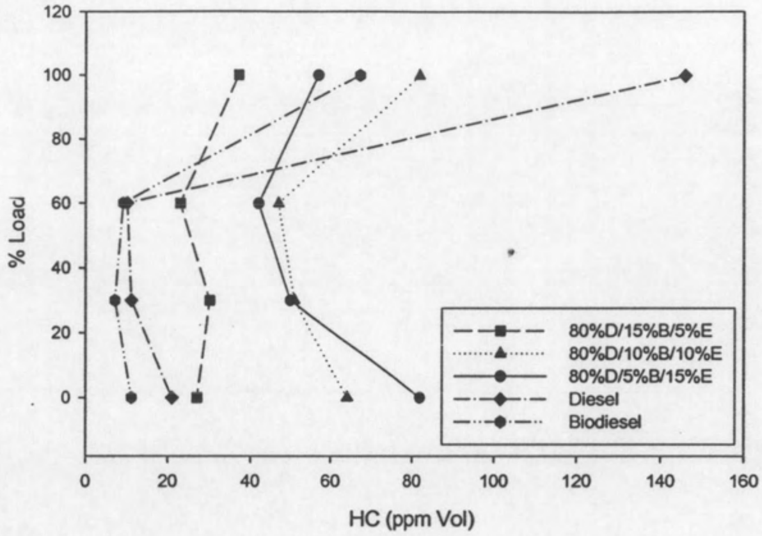


**Figure 4.19** HC emission of diesohol emulsions at 80% diesel proportion at different loads.

4.4.3 $NO_X$ Emissions

The $NO_X$ emissions of the engine using different blended fuels under various engine loads are shown in Figures 4.19, 4.20 and 4.21. At every diesel proportion (90, 85 and 80% by volume), it can be observed that all fuel blends and biodiesel reduced the $NO_X$ emissions at no-load condition. However, at low, medium and high load, $NO_X$ emissions are higher for the blended fuels than base diesel. Especially, at full load, all fuel blends increased $NO_X$ significantly relative to diesel fuel. Normally, if we can make a more complete combustion, we can get a higher combustion temperature, which will cause a high $NO_X$ formation. Therefore, adding biodiesel and ethanol into diesel as oxygenates can enhance combustion efficiency of the fuel. Another reason for explaining the increase of $NO_X$ emissions is the decrease of the cetane number with the addition of ethanol. It is well known that the cetane number has a significant influence on combustion. A lower cetane number means an increase in the ignition delay and more accumulated fuel/air mixture, which causes a steep heat release in the beginning of the combustion, resulting in high temperature and high $NO_X$ formation (Shi *et al.*, 2005). The cetane number of the fuel reduced with the increase of ethanol content in the fuel because of the low cetane number of ethanol. It should be noted that biodiesel increased $NO_X$ but had a substantially higher cetane number than diesel fuel. The $NO_X$ behavior of biodiesel blended fuels is complex and is not conclusive. Many studies indicate that oxygenate fuel blends can cause the increase of $NO_X$ emissions. However, some studies also found no $NO_X$ increase or even a decrease in $NO_X$ as reported by Lee *et al.* (2004). In the case of ethanol – diesel blended fuels, Ajav *et al.* (1999) and Caro *et al.* (2001) reported a significant benefit in terms of $NO_X$ emissions. However, Ozer *et al.* (2004) showed the opposite results.

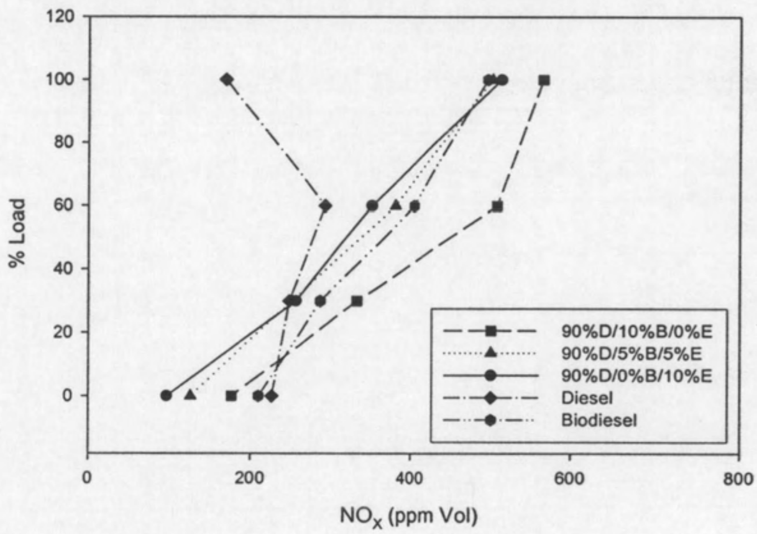


**Figure 4.20** $NO_X$ emission of diesohol emulsions at 90% diesel proportion at different loads.

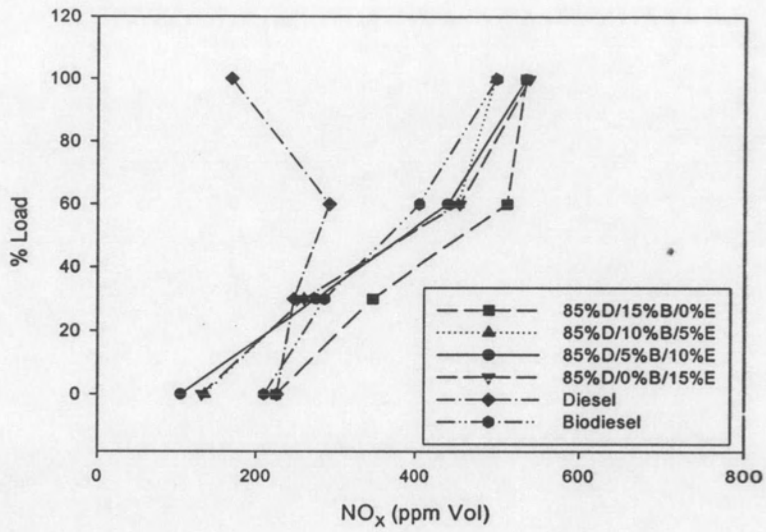


**Figure 4.21** $NO_X$ emission of diesohol emulsions at 85% diesel proportion at different loads.

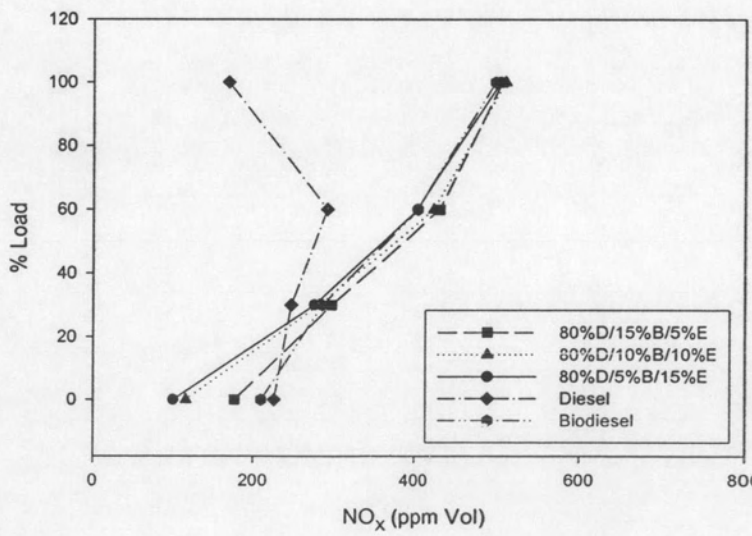


**Figure 4.22** $NO_X$ emission of diesohol emulsions at 80% diesel proportion at different loads.

4.4.4 Fuel Consumption Rates

Figures 4.22, 4.23 and 4.24 show the fuel consumption rates of different blended fuels at various loads at 90, 85 and 80% diesel proportion, respectively. It was observed that the fuel consumption rates increased with increasing the engine load. Fuel consumption rate of diesel increased in a straight line, whereas those of the blended fuels and biodiesel were fluctuated. In theory, the fuel consumption rate should increase with an increase in the ethanol and biodiesel content in the fuel blends because of the reduced energy content. In this study, the fuel blends showed much fluctuated change in fuel consumption rate compared with diesel. This may be due to the different characteristics of the fuel blends such as volatility, heating value and cetane index that affected the engine performance. Therefore, the engine modification might be needed to optimize the engine performance for each ratio of the fuel blends.

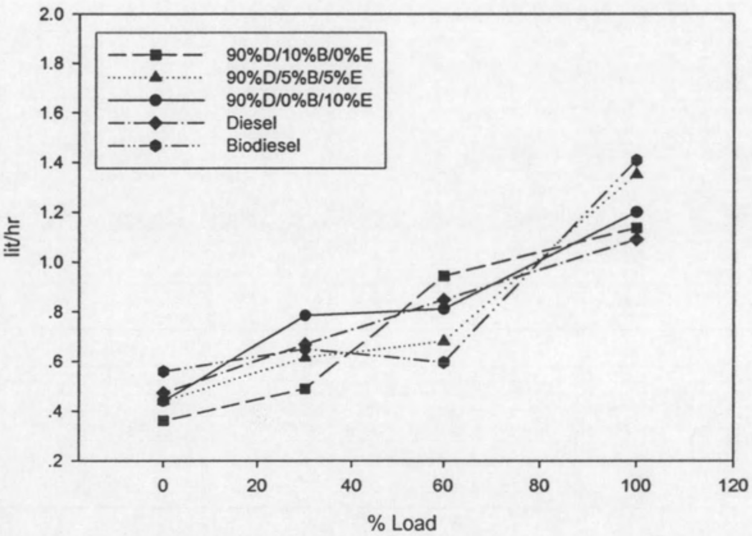


**Figure 4.23** Fuel consumption rate of diesohol emulsions at 90% diesel proportion at different loads.

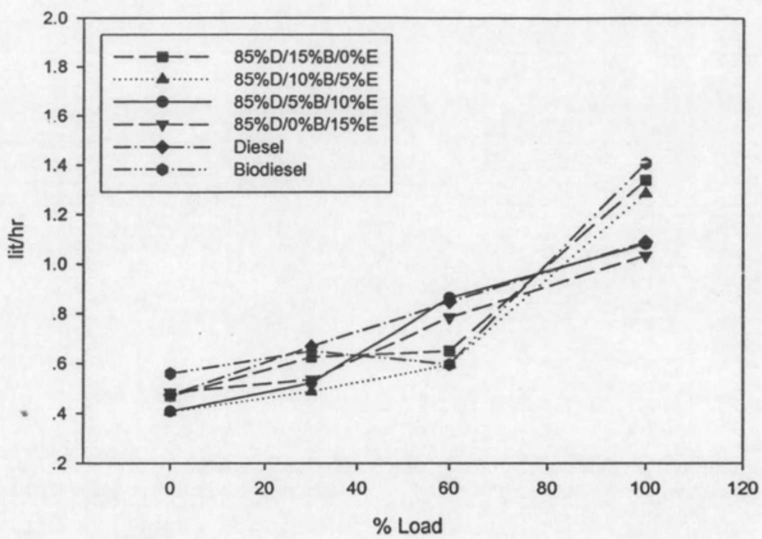


**Figure 4.24** Fuel consumption rate of diesohol emulsions at 85% diesel proportion at different loads.

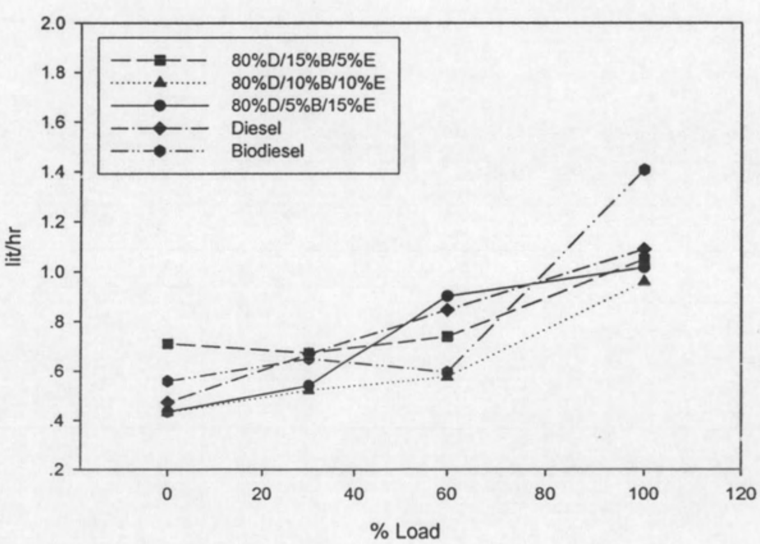


**Figure 4.25** Fuel consumption rate of diesohol emulsions at 80% diesel proportion at different loads.