CHAPTER IV
RESULTS AND DISCUSSIONS

4.1 Ternary Plot Area Studied

Ternary Plot Area was used to depict the physical appearances of 3 components by using the symbols to describe the characteristic of the blends. And it was used to investigate the optimum ratio of the 3 components that still be single phase clear solution at any given conditions.

4.1.1 Comparison of Tendency of Phase Behaviour of Three – Component System at Room Temperature

The ternary plot area of diesel fuel – ethanol (95%, 99.5%, 99.9%) – ethyl acetate system at room temperature are given in Figures 4.1-4.3.

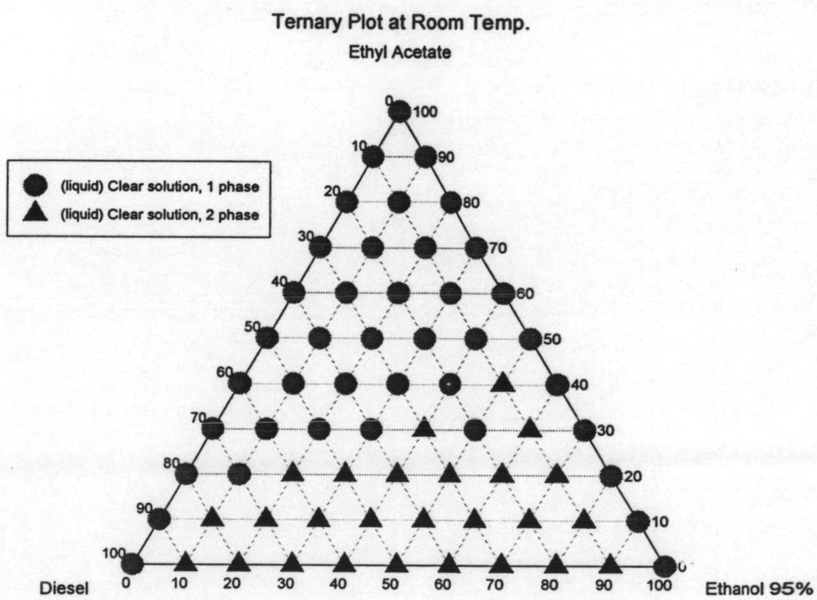

Figure 4.1 Ternary plot areas of diesel – ethanol (95% purity) – ethyl acetate at room temperature.

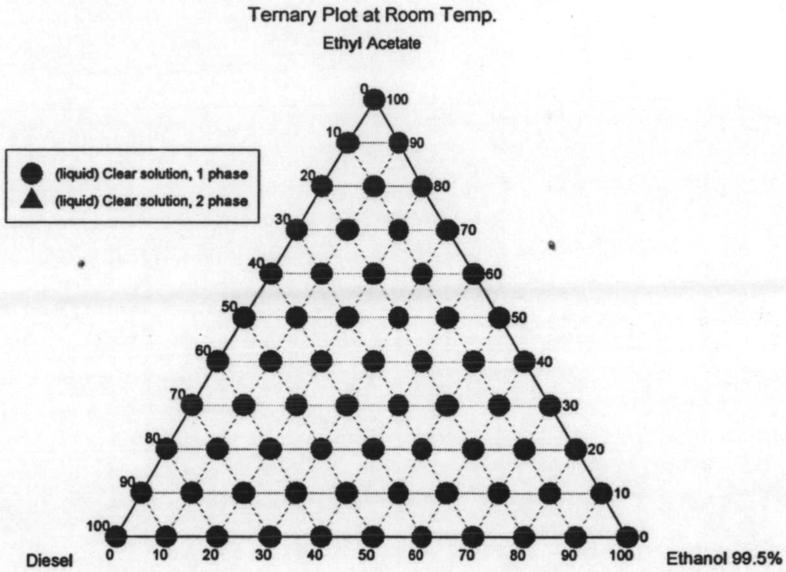

Figure 4.2 Ternary plot areas of diesel – ethanol (99.5% purity) – ethyl acetate at room temperature.

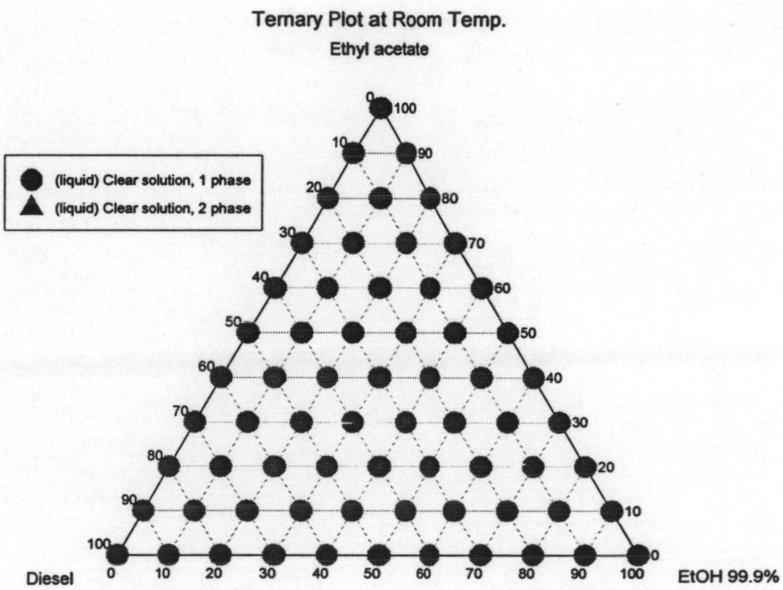

Figure 4.3 Ternary plot areas of diesel – ethanol (99.9% purity) – ethyl acetate at room temperature.

The addition of ethyl acetate to the fuel system made ethanol and diesel miscible in each other at room temperature (20°C). This miscibility was due to the fact that ethyl acetate acted as a co-solvent which improves the solubility of ethanol-diesel blend. Solubility of diesel fuel in ethyl acetate and ethanol 99.5%, 99.9% is not limited as shown in Figures 4.2 - 4.3. However, solubility of diesel fuel in ethyl acetate and ethanol 95% is limited as shown in Figure 4.1. It seems that the production and usage of such diesel fuel in ethyl acetate and ethanol 95% is not viable because of low solubility. However, using anhydrous ethanol (99.5%) can be used to stabilize tri-component diesohol mixtures in a relatively wide range of component concentrations and it is less expensive than using ethanol 99.9%. Therefore, 99.5% ethanol was used to study further in next parameter.

4.1.2 Comparison of Tendency of Phase Behaviour of Three – component System at Various Temperatures

The interest of the ethyl acetate is to prevent any risk of mixture separation when the temperature drops, make it suitable for winter fuel formulation. At the low temperatures, anhydrous ethanol (99.5%) is highly soluble in diesel fuel at contents of approximately 0–10% and 90–100% for 10°C, but at 0–20% and 80–100% for 20°C as shown in Figures 4.4 – 4.5. Within these zones of miscibility it can be observed cloudiness in the mixture followed by separation.

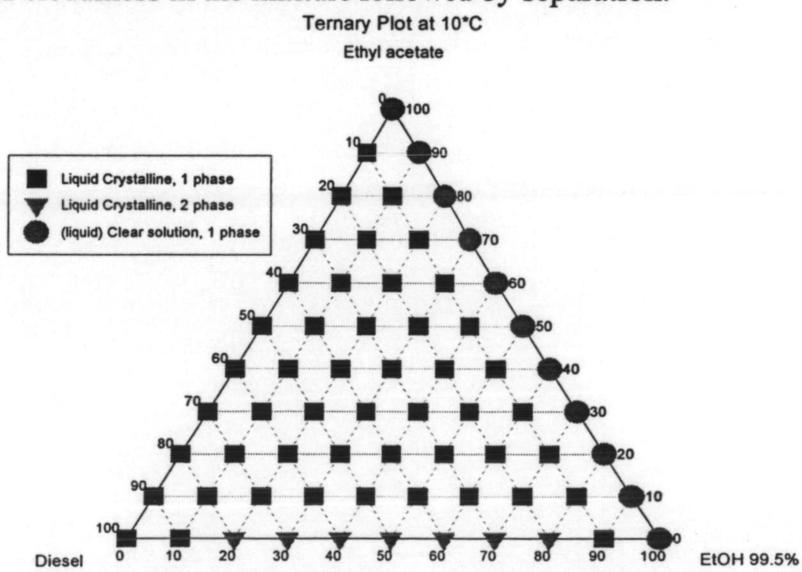

Figure 4.4 Ternary plot areas of diesel – ethanol (99.5% purity) – ethyl acetate at 10°C.

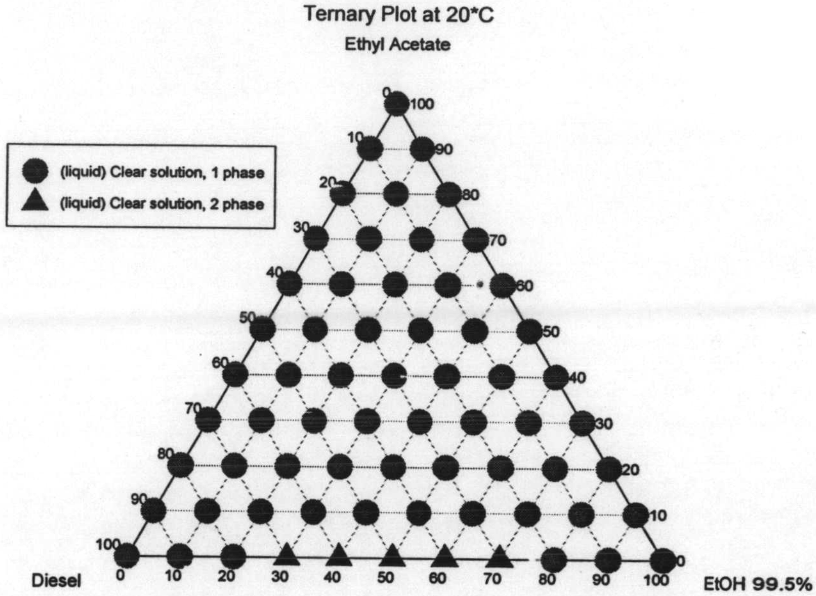

Figure 4.5 Ternary plot areas of diesel – ethanol (99.5% purity) – ethyl acetate at 20°C.

Moreover, at high temperatures (30 and 40°C) as shown in Figures 4.6 - 4.7, ethyl acetate can be used to produce the clear solution (one phase) area without any risk of diesel-ethanol mixture separation.

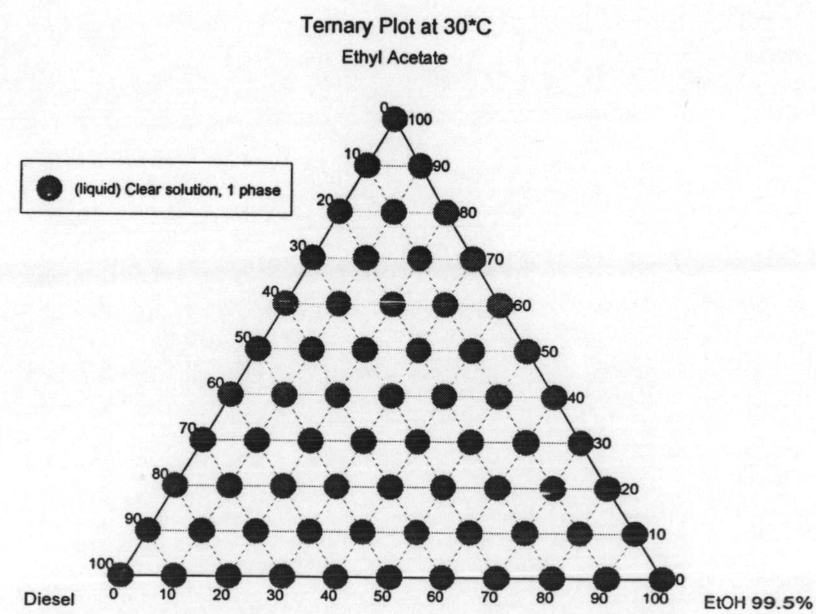

Figure 4.6 Ternary plot areas of diesel – ethanol (99.5% purity) – ethyl acetate at 30°C.

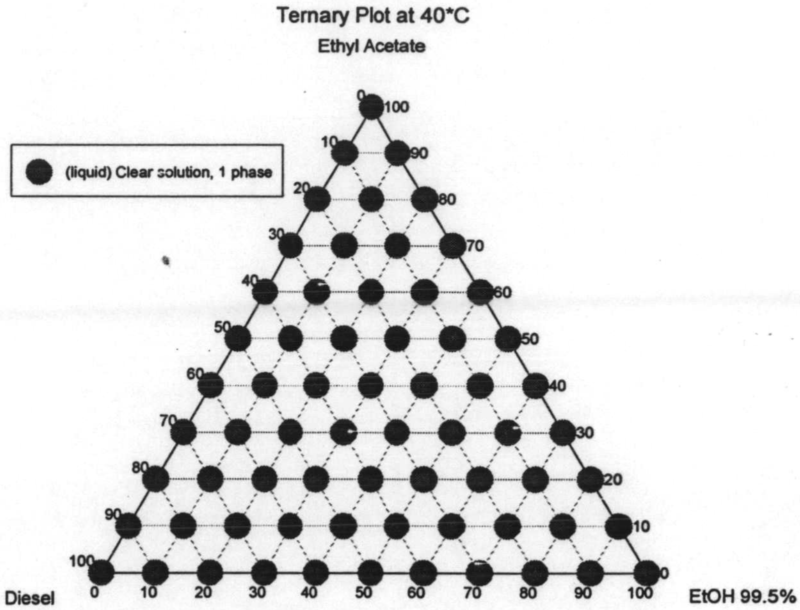

Figure 4.7 Ternary plot areas of diesel – ethanol (99.5% purity) – ethyl acetate at 40°C.

As a result, it can be stated that an ethyl acetate added benefit was that the fuel remained a liquid at these temperatures. Besides, ethanol-diesel blends require less ethyl acetate at high temperatures (summer conditions) as compared to low temperatures (winter conditions) to produce the clear solution (one phase) area. And ethanol and ethyl acetate present good fuel fluidity at low temperatures.

4.2 Turbidity Measurement

Turbidity is the degree of opacity of a fluid. The degree of downgrade in turbidity can illustrate the stability of the emulsion (Lin and Wang, 2003). Table 4.1 shows the preliminary results of turbidity value with different concentrations of ethanol (95%, 99.5%, 99.9%) at room temperature. Turbidity value of diesel fuel in ethyl acetate and ethanol 95% as shown in Table 4.1 can encourage the result from the ternary plot area that it is not viable for using as a fuel. But turbidity value of diesel fuel in ethyl acetate and ethanol 99.5% and 99.9% could indicate that it is possible to obtain the best clearity and stability of tri-component diesohol mixtures.

Table 4.1 Turbidity values of diesel – ethyl acetate ethanol blended at room temperature

Ratio			Turbidity Value		
%Diesel	%Ethyl acetate	%EtOH	Average ($EtOH_{95\%}$)	Average ($EtOH_{99.5\%}$)	Average ($EtOH_{99.9\%}$)
90	0	10	0.26	0.01	0.01
90	5	5	0.33	0.01	0.01
90	10	0	0.67	0.01	0.01
85	0	15	0.56	0.01	0.01
85	5	10	0.58	0.01	0.01
85	10	5	3.02	0.01	0.01
85	15	0	0.92	0.01	0.01
80	5	15	0.59	0.01	0.01
80	10	10	0.63	0.01	0.01
80	15	5	0.50	0.01	0.01

4.3 Fuel Properties Testing

There are a number of fuel properties that are essential to the proper operation of diesel engine (Hansen *et al.,* 2005). The addition of ethanol to diesel fuel affects certain key properties with particular reference to blend stability, density, viscosity, pour point, energy content and cetane number. Properties should be foremost in any fuel evaluation, this include flashpoint. Finally the appropriate content of ethyl acetate in diesel-ethanol (99.5%) blend would be collected to be the diesohol formula.

4.3.1 <u>Density</u>

Density is an important property of diesel, for the injection system, pump and injectors are adjusted to deliver a predetermined volume of fuel, the determining parameter in the combustion chamber being the air-fuel mass ratio. The linear changes in density that occur in relation to ethanol and ethyl acetate are shown in Figures 4.8. With the inverse relationship of density of ethanol and ethyl acetate, it can be observed that as the percentage of ethanol in the blends was increased, the relative densities decreased. This is due to the fact that ethanol has very lower density than ethyl acetate and as such will lower the density when mixed more ethanol with diesel. in general, it is recognized that density directly affects on viscosity. The higher density, the more higher viscosity resulting in the higher flow resistance of fuel oil.

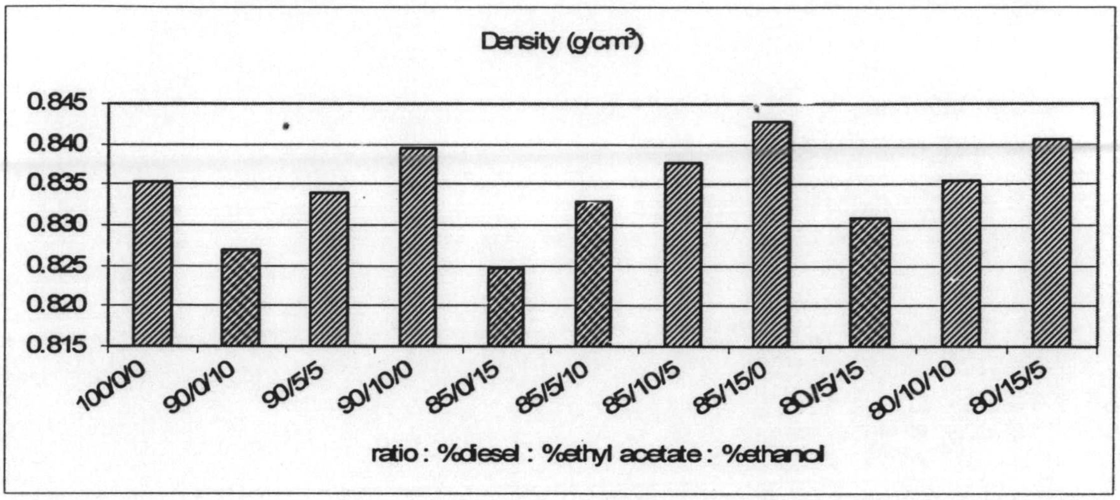

Figure 4.8 Density of fuel at different concentrations.

4.3.2 Viscosity

Viscosity is a measure of the flow resistance of diesel. This property directly affects the engine's operation and combustion process, whose efficiency depends on the maximum power developed by the engine. The purpose of controlling viscosity is to allow for the good atomization of the oil and for the preservation of its lubricating characteristics. From Figure 4.9 it shows that the measured viscosities decreased as the percentage of ethanol in the blends increased. There was however no significant difference in the viscosity of 5 and 10% blends of ethanol. The reduction in the viscosity of the blends was mainly due to the presence of ethanol and ethyl acetate in the blends. These findings are in agreement with those reported by the other researchers (Boruff *et al.,* 1982; Ziejewski, 1983; Ali and Hanna, 1996; Ajav and Akingbehin, 2002). However, it should be known that lower fuel viscosities will lead to greater pump and injector leakage, which reduces maximum fuel delivery and power output.

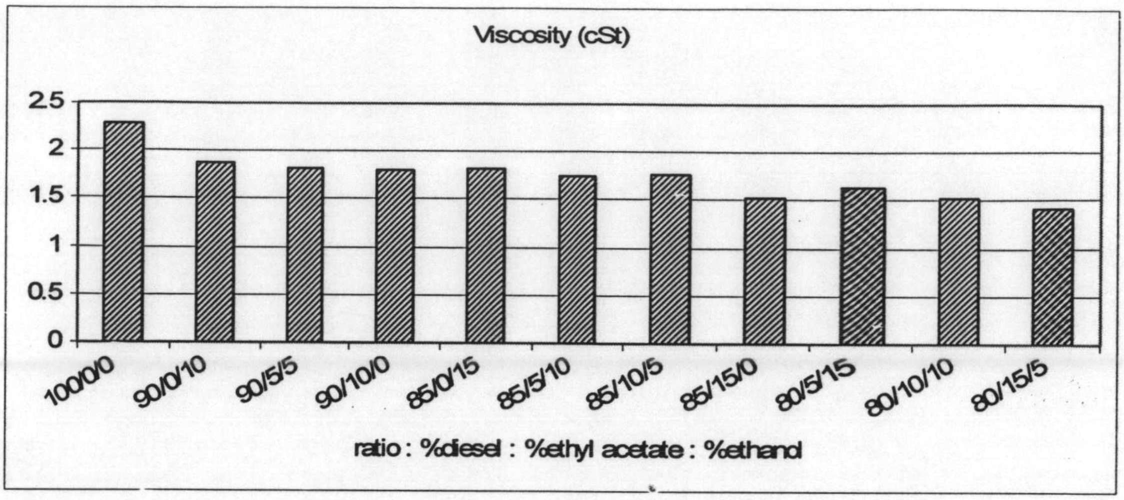

Figure 4.9 Viscosity of fuel at different concentrations.

4.3.3 Flash point

Flashpoint is the lowest temperature at which the vapor pressure of a liquid is sufficient to produce a flammable mixture in the air above the liquid surface within a vessel (Hansen *et al.,* 2005). The flash points of the fuels are given in Figures 4.10. The flash point gives the safe storage temperature for the blends. All the blends had a flash point that was 85% lower than diesel. The reduction in flash point (due to the addition of alcohol and ethyl acetate) means that diesohol has different safety requirements than diesel. They would also be classified as Class I liquids and need to be handled like ethanol or gasoline.

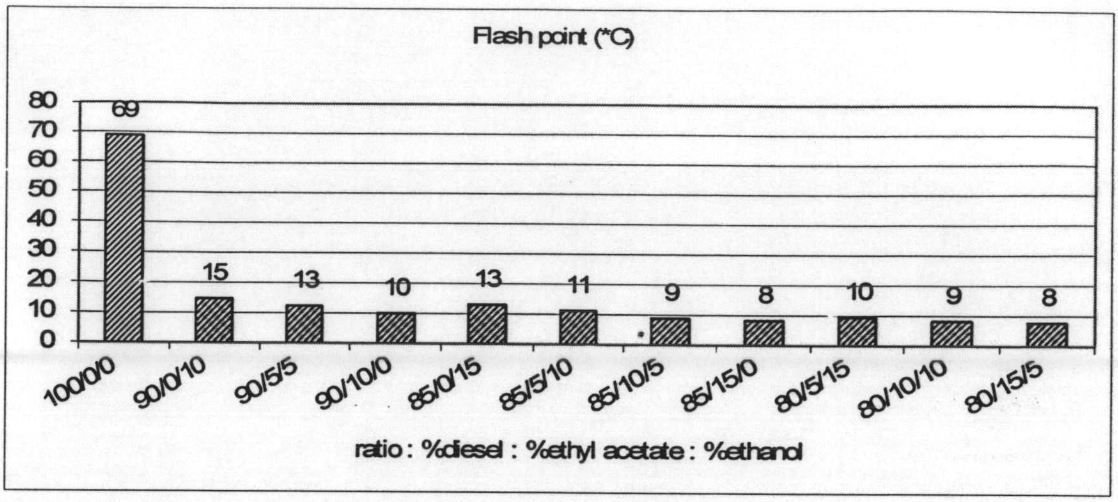

Figure 4.10 Flash point of fuel at different concentrations.

4.3.4 Pour Point

Pour point is the temperature below which the fuel will not pour, using a definition specific to the ASTM D97 procedure (McCormick and Parish, 2001). It is important in knowing the behaviour of fuels in a cold weather.

Figure 4.11 shows that the cold properties of mixtures containing ethyl acetate and ethanol are somewhat better than those of commercial diesel fuel. The ethanol and ethyl acetate present good fuel fluidity at low temperatures. These lower temperatures, 3°C, obtained for 5-15% ethanol and ethyl acetate content in the blends. It is due to the fact that ethanol and ethyl acetate have very low freezing point that is -117.3°C and -84°C relative to diesel fuel (6°C). It might be expected that diesohol would have improved low temperature flow properties, as long as the ethanol and ethyl acetate remains soluble. However, there was no significant difference in the pour point of these blends.

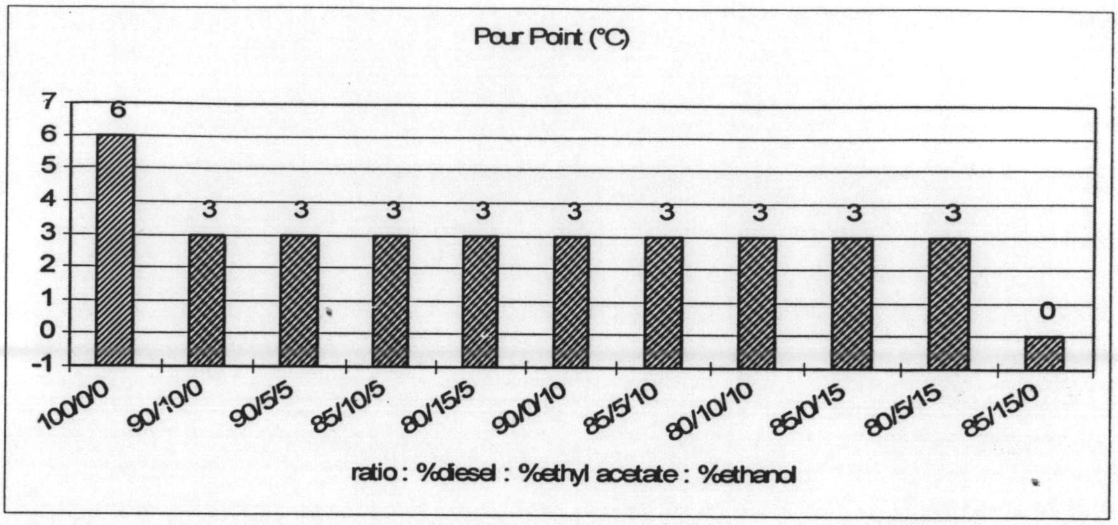

Figure 4.11 Pour point of fuel at different concentrations.

4.3.6 <u>Cetane Index</u>

The minimum cetane number specified for diesel fuel in Thailand is 47. The cetane number of commercial diesel fuel using in this work is 47.64. Hardenberg and Ehnert (1981) estimated that the cetane number of ethanol was between 5 and 15. Hence, ethanol has an extremely low cetane number. The cetane number in the blends decreased as the percentage of ethanol and ethyl acetate in the blends increased. The linear changes in cetane number that occur in relation to ethanol and ethyl acetate content are shown in Figures 4.13. It should be noted that lower cetane numbers mean longer ignition delays, allowing more time for fuel to vaporize before combustion starts. But high cetane number ensures good cold starting, reduce noise and emission. If this reduction in cetane number results in a fuel cetane < 40, the fuel is no longer within specifications and cause poor engine operation. The best way to solve this problem is to add cetane improver fuel bring the fuel within specifications.

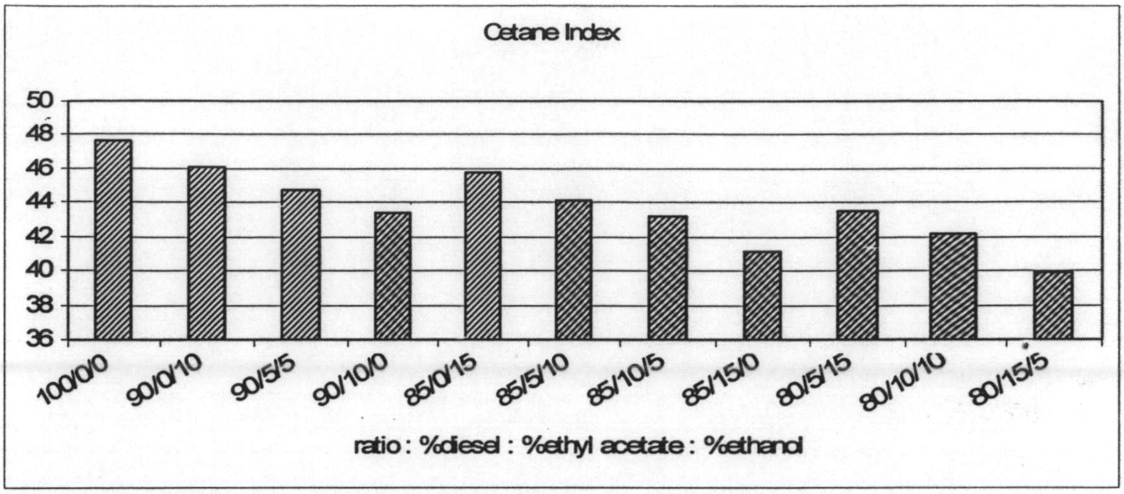

Figure 4.12 Cetane Index of fuel at different concentrations.

4.3.5 Heat Content

The energy content of a fuel has a direct influence on the power output of the engine. The lower heating value of ethanol is 40% and ethyl acetate is 48.66% lower than that of a commercial diesel fuel on a volume basis, as shown in Table 4. The heat content values decreased as the percentage of ethanol and ethyl acetate in the blends increased as shown in Figure 4.12. However, the blends had a heat content that was only a few percents decrease when compared to that of diesel fuel.

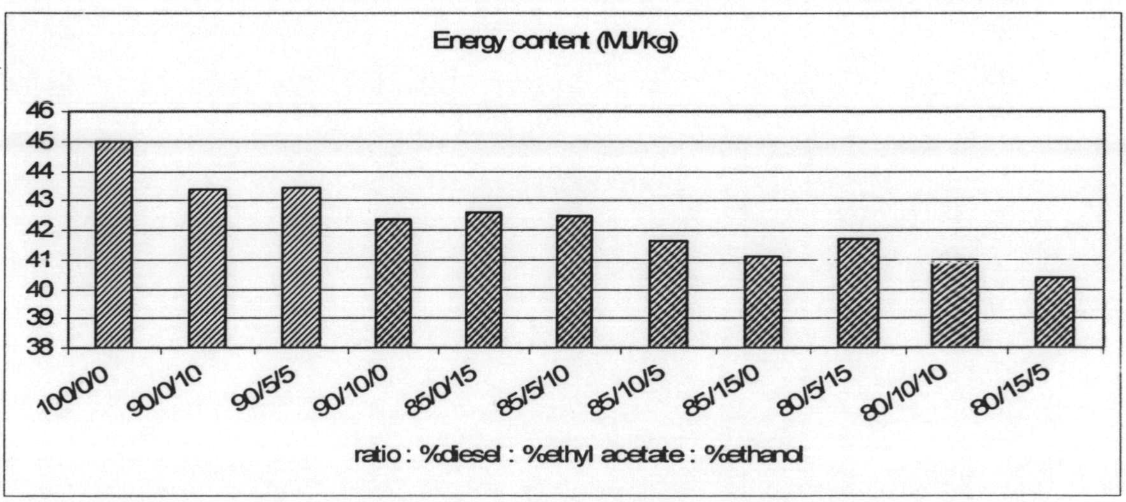

Figure 4.13 Energy content of fuel at different concentrations.

4.4 Engine Test

The use of an oxygenate agent with diesel fuel to adjust the fuel constitution has been considered as one of possible approaches for improving the emission characteristics of diesel engines. Then, in the last section of this thesis work, gaseous pollutants (CO, HC and NOx) will be measured and compared with those of diesel fuel.

4.4.1 CO

The variations of CO concentration with respect to engine loads are presented in Figures 4.14-4.16. As shown in this figure, there was no much difference in the CO concentration at 0, 30 and 60% of loads. But at full load (100%), the CO emissions decreased significantly with the addition of both ethanol and ethyl acetate when compared with that of diesel fuel, moreover the tendency was more evident as increased the load to full load because of increased the fuel quantity. This could be explained by the fact that the CO emissions are generally reduced at full load because ethyl acetate has less carbon than diesel fuel and its oxygen content increases the oxygen to fuel ratio lead to more complete combustion. This shows the same result when compared with ethanol-diesel blends of the previous work reported by Fanick *et al.* (2002)

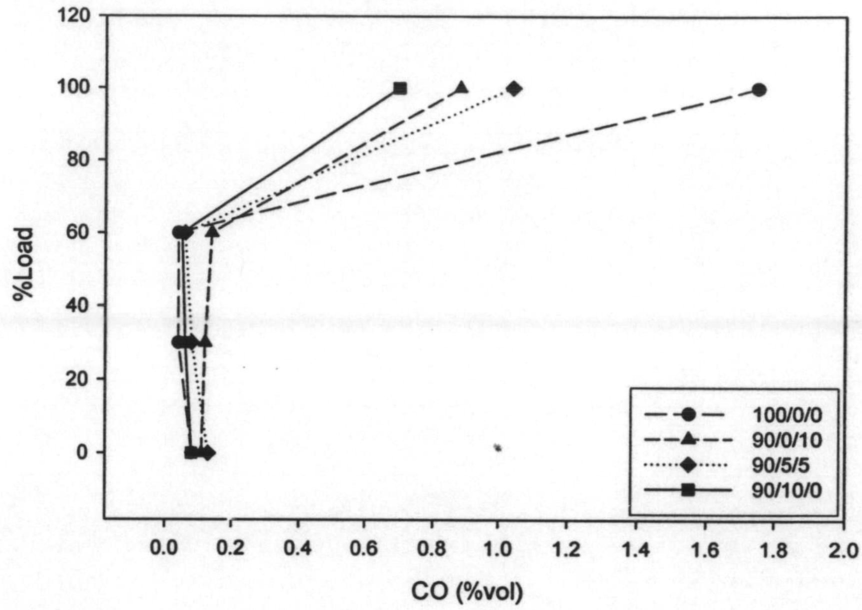

Figure 4.14 CO emissions of diesohol fuels of 90% diesel proportion at different engine loads.

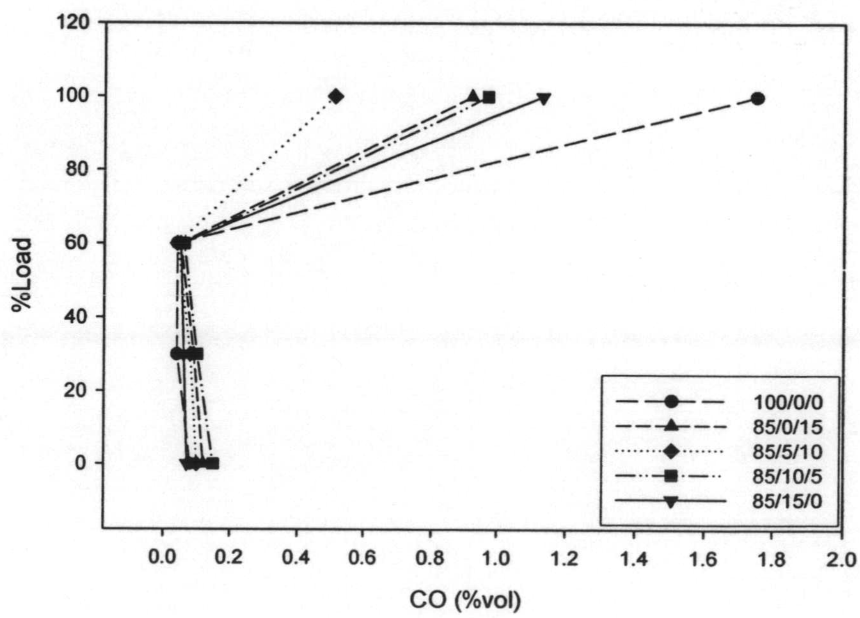

Figure 4.15 CO emissions of diesohol fuels of 85% diesel proportion at different engine loads.

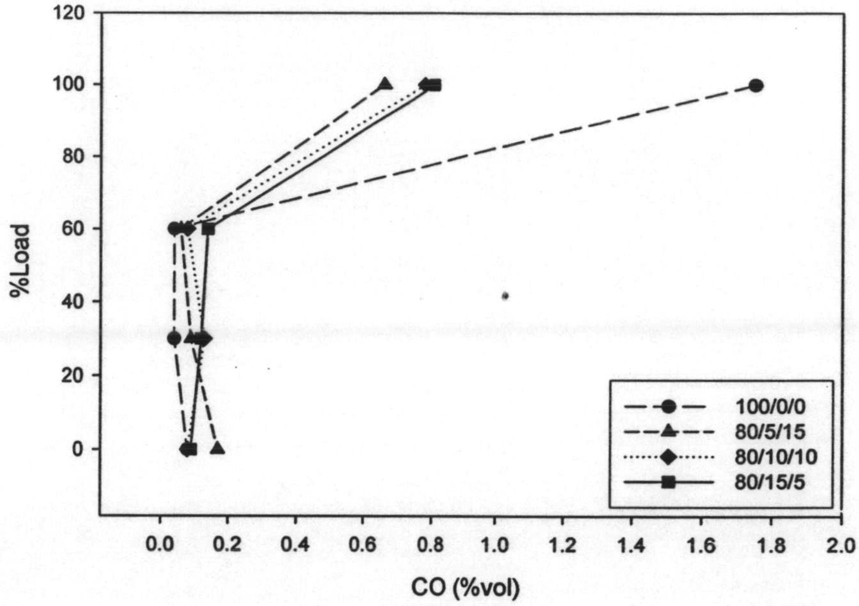

Figure 4.16 CO emissions of diesohol fuels of 80% diesel proportion at different engine loads.

4.4.2 NOx

Nitrogen oxide emissions from diesel engines consist of mainly nitric oxide (NO) and nitrogen dioxide (NO_2), commonly referred to as NOx emission. Typically, more than 95% of NOx emission is in the form of NO, and less than 5% is NO_2 (Docent, P.K., and Akademi, A., 2000). The NOx emissions with respect to fuels at various loads are presented in Figures 4.17-4.19. As shown in these figures, a reduction in NOx with the addition of ethanol and ethyl acetate to diesel, especially at no load, is clearly observed. However, the NOx emission of the blends are higher than that of diesel fuel at low, medium and high load. On the whole, at no load condition is caused by very strong effect due to its more lower combustion temperature, resulting in low temperatures and low NOx formation.

In principle, it should be noted that an increase of the NOx can be explained by 2 way; first the present of oxygenated agent might be the essential factor for the increase of NOx due to more complete combustion that lead to a higher combustion temperature which effect on a high NOx formation. Second, the decrease of the cetane number with the addition of the oxygenates. A fuel with a low cetane number resists auto-ignition and has a longer ignition delay period, which causes a steep heat release in the beginning of the combustion, resultant in high temperatures. With this high temperature, combustion temperatures reach a high enough level to actually burn some of the nitrogen in the air, yielding various oxides of nitrogen and produce high NOx formation (Shi *et al.,* 2005). It was well related with Lin *et al.* (2003). They stated that when the oxygen content in the fuel oil increases, the ignition delay is shortened. The amount of premixed fuel and peak burning temperature were lowered, leading to the drop in NOx emissions.

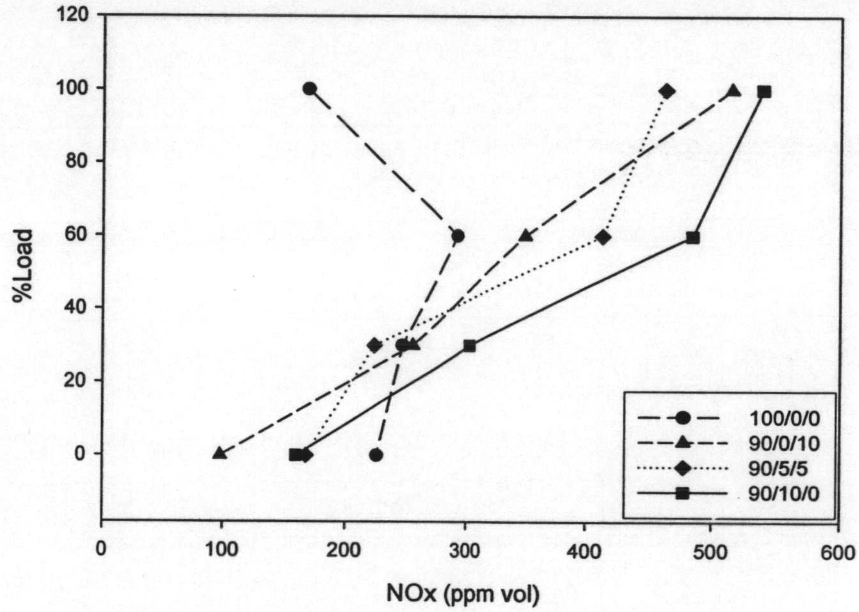

Figure 4.17 NOx emissions of diesohol fuels of 90% diesel proportion at different engine loads.

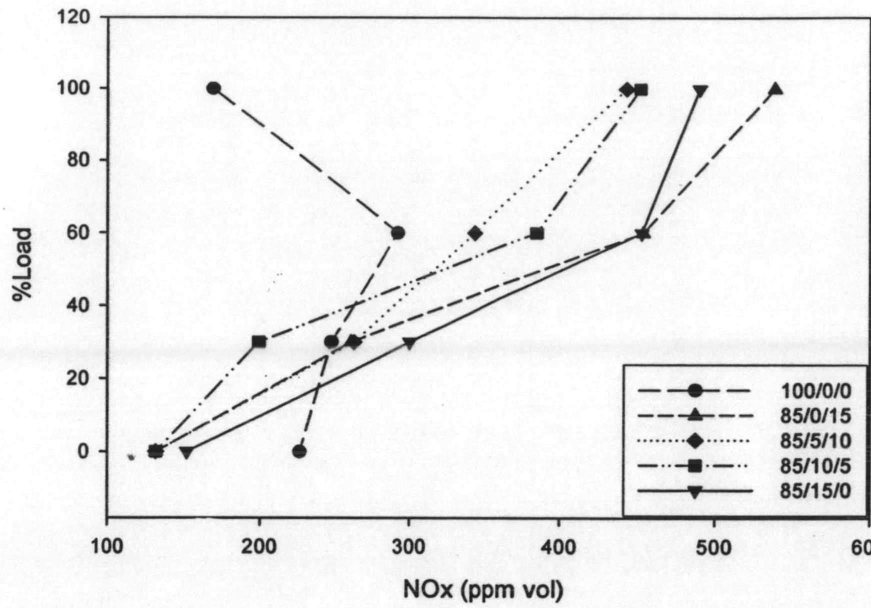

Figure 4.18 NOx emissions of diesohol fuels of 85% diesel proportion at different engine loads.

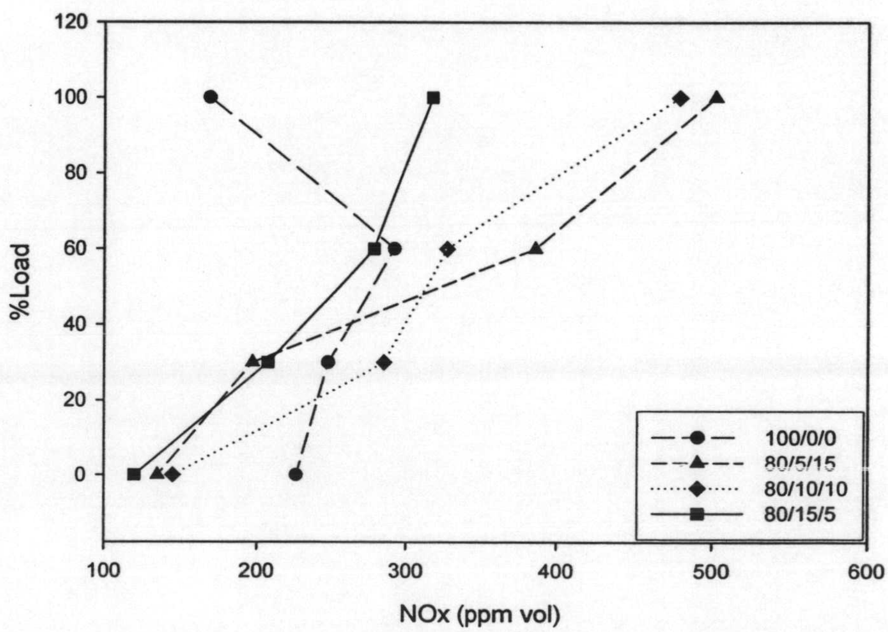

Figure 4.19 NOx emissions of diesohol fuels of 80% diesel proportion at different engine loads.

4.4.3 HC emissions

The trends of the HC emission are shown in Figures 4.19-4.21. HC emissions of the blends are found to be much higher when compared to those of diesel fuel at various conditions. When engine was operated with increasing engine load, the HC emissions showed similar trends at all the selected operation conditions. That the increase oxygenates in the blends produced more HC emission compound. Except in the case of full load, which is the HC emission of diesel rapidly higher than those blends. In principle, HC emissions are partially due to unburned fuel components, which emitted in the exhaust. Normally, the higher cetane number, the more complete combustion which can reduce HC emission. However, when increasing load means an increase in the ignition delay can cause incomplete combustion lead to produce HC emission of diesel fuel at high load.

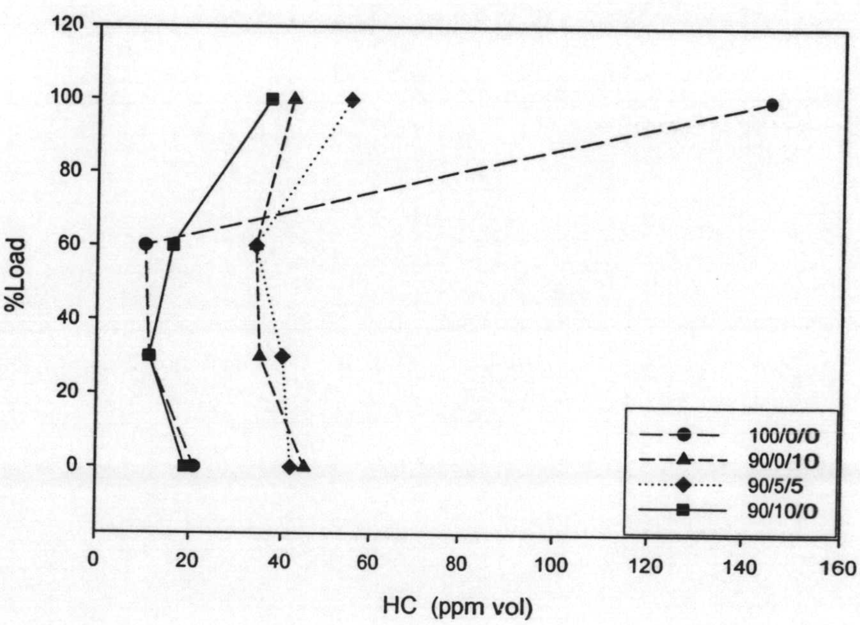

Figure 4.20 HC emissions of diesohol fuels of 90% diesel proportion at different engine loads.

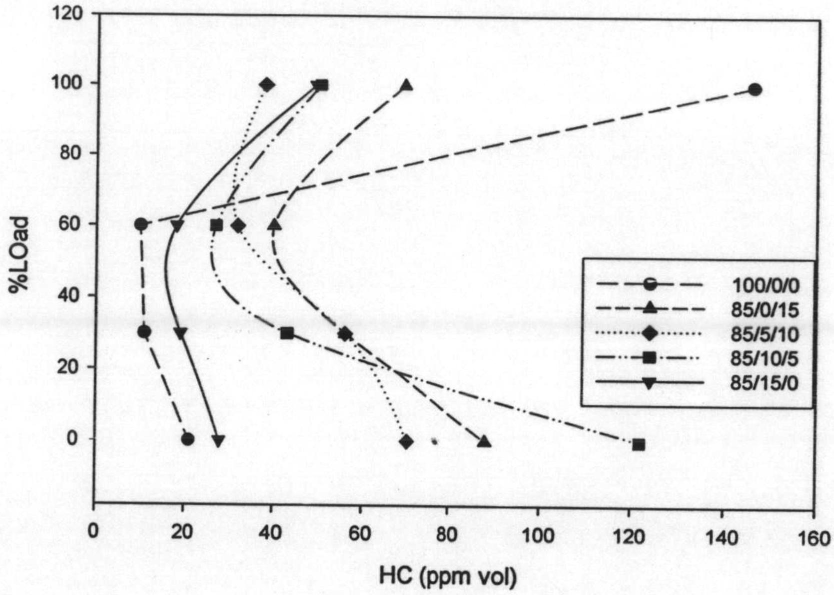

Figure 4.21 HC emissions of diesohol fuels of 85% diesel proportion at different engine loads.

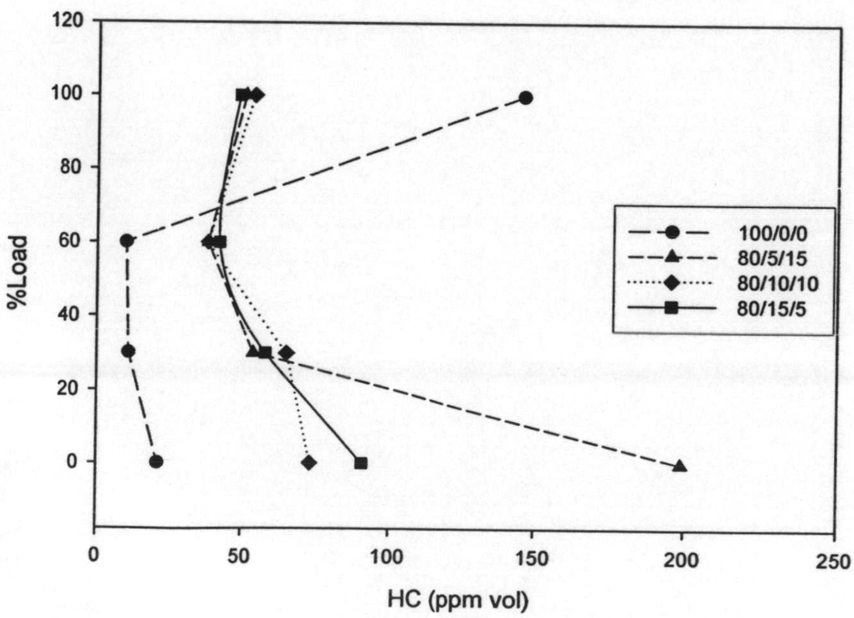

Figure 4.22 HC emissions of diesohol fuels of 80% diesel proportion at different engine loads.

4.4.4 Fuel Consumption Rate

This is a measure which many people use at some time or other, even if it is only in a casual rather than a calculated way. Fuel Consumption Rate is how much fuel the engine burns each hour. Measured in terms of fuel used (in gallons, litres, kilograms etc.) per measure of electricity generated (kilowatt-hours etc.) or time, which can be changed so we could have 'litre per hour' or 'kilogram per hour' and so on whatever happens to be convenient (www.projects.ex.ac.uk). Figures 4.22-4.24 show the fuel consumption rate of the blend in unit litre per hour. The figure indicates that the engine load increase cause a rise in fuel consumption rate. This is because a higher fuel consumption rate follows a higher engine load which leads to less air to fuel ratio. Moreover, these figure presented that fuel consumption of those blend were higher than diesel fuel. This may be due to the direct consequence of the reduction in cetane number and the increase in fuel consumption, increase in the content of unburned hydrocarbons, and reduction of the engine's service life. Therefore, the design of the engine should be modified to adapt it to operating with fuels having lower cetane number.

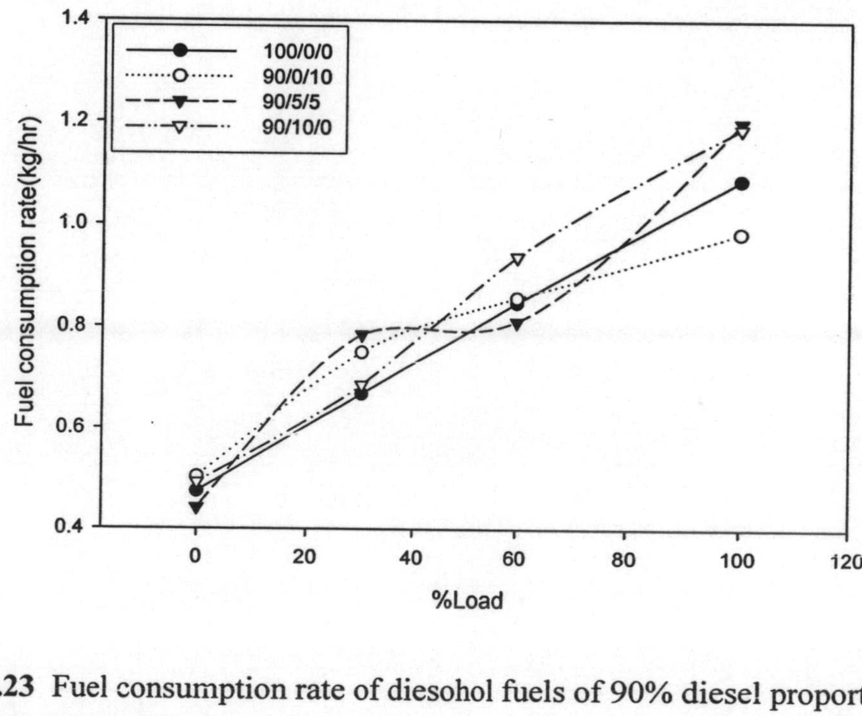

Figure 4.23 Fuel consumption rate of diesohol fuels of 90% diesel proportion at different engine loads.

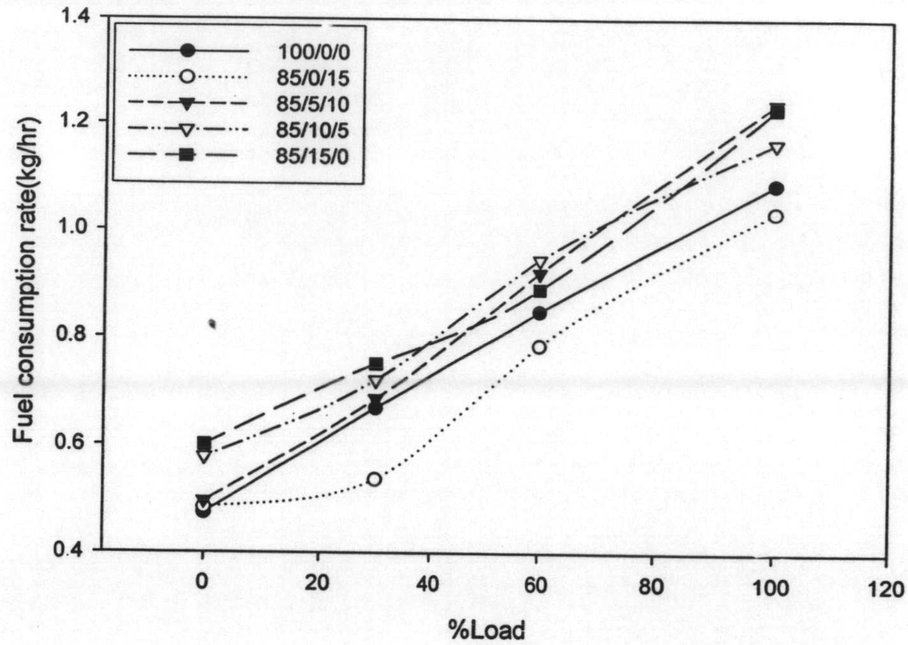

Figure 4.24 Fuel consumption rate of diesohol fuels of 85% diesel proportion at different engine loads.

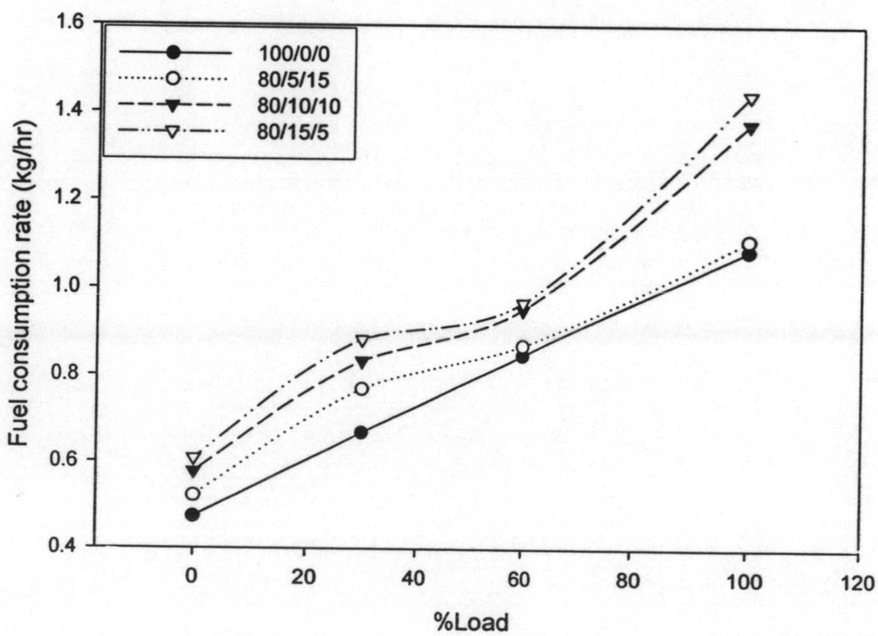

Figure 4.25 Fuel consumption rate of diesohol fuels of 80% diesel proportion at different engine loads.