Performance Characteristics of a Stationary Constant Speed Compression Ignition Engine on Alcohol-Diesel Microemulsions

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ABSTRACT

A 3.73 kW stationary, constant speed CI engine was tested on six selected ethanol-ethyl acetate-diesel microemulsions viz. 200^0-10/9/81, 200^0-15/9.5/75.5, 200^0-20/10/70, 190^0-10/22/68, 190^0-15/25/60 and 190^0-20/29/51. The performance of the engine was evaluated in terms of brake power, fuel consumption, brake specific fuel consumption, brake thermal efficiency, emissions of carbon monoxide, unburnt hydrocarbon, nitrogen dioxide and nitric oxide, exhaust gas and lubricating oil temperature. All the engine and emission parameters were determined at no load, 25, 50, 75, 100 and 110 percent load. The observed parameters were compared to assess the compatibility of microemulsions as CI engine fuel. The study showed that the engine developed almost similar brake power on emulsion fuels. The brake specific fuel consumption of the engine at rated load was found as 302, 345, 338, 341, 339, 308 and 348g/kW-h on diesel and microemulsion specified above respectively. The brake thermal efficiency of the engine was 25.4 percent on diesel. However, on microemulsions it was 22.8, 24.7, 25.0, 25.4, 30.1 and 28.1 percent on the microemulsion at the rated load respectively. A reduction of 1.4 to 44.4 percent of CO on emulsified fuels was observed as compared to diesel. The emission of unburnt hydrocarbon was found marginally higher on the microemulsions but was comparable. A highest reduction of 24 percent in the emission of nitric oxide was found on the 190^0-20/29/51 microemulsion prepared using 190^0 proof ethanol. The emission of nitrogen dioxide was lower on microemulsions for most of the brake load conditions in the comparison to that of diesel. NO_2 was further reduced on microemulsions prepared using 190^0 proof aqueous ethanol.

Key words: CI engine, diesel fuel, ethanol, microemulsions, blends, emission

1. INTRODUCTION

The depletion, environmental degradation, indiscriminate extraction and lavish consumption of fossil fuels have led to reduction in underground petroleum resources. The search for an alternative fuel, which promises a harmonious correlation with sustainable development, energy conservation, efficiency and environmental preservation, has become highly necessary in the present context. Although, both methanol and ethanol have been used as alternate fuels, ethanol is more popular of the two because it can be easily produced by fermentation, is non-

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toxic and has higher heat of combustion than methanol. In view of the proven merits of ethanol as environmentally safe and high performance renewable engine fuel now besides developed countries, the developing countries have focused attention towards its utilization as IC engine fuel.

It is only recently interest was shown on the use of ethanol and methanol as diesel fuels. Ethanol fumigation and injection as well as its blending or emulsification with diesel are the different ways of supplementing ethanol in CI engines. Alcohol fumigation lengthens the ignition delay and the effect is greater with lower proof of alcohol. NO_x and particulate emissions decrease as alcohol substitute increases due to lower combustion temperature but CO tends to increases, particularly at low level of loads. A separate injection system had shown improved thermal efficiency and reduced emission of NO_x and particulates. However, replacement of diesel fuel by ethanol is not substantial at higher engine load under these practices (Owen, K. and Coley, T., 1990).

Another method of using ethanol in diesel engine is to modify fuel instead of modifying the engine which can be done by simple blending of ethanol with diesel fuel but in this technique the amount of diesel substitution is dependent on quality of ethanol i.e. its proof. Blending of locally made ethanol also has been tried to supplement diesel fuel in diesel engines (Ajav, E. A. and O. A. Akingbehin 2002). However, earlier studies have shown that not more than 15 percent diesel substitution under a wide range of engine operatibility (particularly at low temperature conditions) is possible using anhydrous ethanol. The amount of diesel replacement in blending is limited with occurrence of phase separation (immiscibility of ethanol with diesel) in blend while going towards higher amount of diesel substitution or towards blending with lower proof level of ethanol. The commercially available ethanol grades are of 180^0 to 160^0 proof (10 to 20 percent water content) and in compatibility of diesel and water, phase separation occurs in the blend. The engine adjusted to ignite such fuel would produce less power if the ethanol separates from the petroleum fuel (Miller *et al*. 1981).

To overcome the problem of phase separation while preparing the blended fuel by using lower proof of ethanol or going towards higher amount of diesel substitution and to make a compatible fuel, microemulsification is a best technique which will increase water tolerance capacity of the blend. Such a microemulsion of diesel-alcohol is formed by using surfactants like ethyl acetate, 1-butanol etc. Microemulsions of ethanol in diesel fuel by the use of surfactants are well accepted practice in Sweden. Ethanol with ignition improvers has now become an established bus fuel in Sweden (Murthy, B. S.). Stable microemulsions formed by using appropriate surfactants such as ethyl acetate, 1-butanol can be used to sufficiently reduce the interfacial tension between the dispersed and continuous phase in a blend using aqueous ethanol and to make the blend complete miscible (Boruff *et al.* 1982).

In view of above, the study was conducted to determine the performance of a CI engine on diesel-alcohol emulsified fuel prepared using ethyl acetate as surfactant.

2. MATERIALS AND METHODS

2.1 Fuels and Their Properties

Anhydrous (200^0 proof) and aqueous ethanol of 190, 180 and 170^0 proof were emulsified with diesel using ethyl acetate as surfactant. The microemulsions were prepared by adding required minimum amount of ethyl acetate emulsifier in the unstable blends of alcohol-diesel to make stable under 5 to 45 ^{0}C temperature ranges. The characteristics fuel properties such as relative density and API gravity, kinematic viscosity, gross heating value, flash point and fire point, cloud point and pour point of diesel, ethyl acetate, different proofs of ethanol and the microemulsions of ethanol-ethyl acetate-diesel prepared designated as 200^0-10/9/81, 200^0-15/9.5/75.5, 200^0-20/10/70, 190^0-10/22/68, 190^0-15/25/60, 190^0-20/29/51, 180^0-10/35/55, 180^0-15/39/46, 180^0-20/40/40, 170^0-10/43/47, 170^0-15/45/40 and 170^0-20/50/30 (% v/v) measured are shown in Table 1. The relative density at 15^0C was determined in accordance with IS: 1448 [P: 32]: 1992. A Redwood Viscometer No.1 was used for the measurement of kinematic viscosity at 38^0C temperature. Kinematic viscosity in Redwood seconds was measured. The gross heat of combustion as per IS: 1448 [P: 10]:1984 was determined using an Isothermal Bomb Calorimeter. A closed cup Pensky Martens Flash and Fire Point apparatus was used for measuring the flash and fire points of the fuels. The cloud and pour point of fuels were determined as per IS: 1448 [P: 10]: 1970 using the Cloud and Pour Point apparatus.

2.2 Experimental Set-up

A constant speed diesel engine was tested using SAJ-Froude make, EC-15 eddy current dynamometer. A SAJ-Froude make, SFV-75 model electronic volumetric fuel consumption measuring unit was used to measure volumetric fuel consumption of the engine. Exhaust emissions were drawn with the help of a steel tube and PVC gas suction pipe using an air pump. Nucon make HC, NO and NO_2 analysers were used to measure their contents in the exhaust gases and CO was measured using a methanizer ina Nucon make gas chromatograph. The temperature of exhaust gas and lubricating oil was recorded with a chromal-alumal thermocouple connected to a digital display.

2.3 Test Engine and Experimental Procedure

The experiment was conducted on a Kirloskar make single cylinder, water cooled compression ignition engine (Model AV 1) having rated brake power of 3.73 kW at 1500 rpm. The compression ratio of the engine was 16.5:1 and the standard fuel injection timing was 27^0 BTDC. The performance test of the engine was conducted as per IS: 10000 [P: 5]:1980. Initially the engine was run on no load condition and its speed was adjusted to 1600 $\pm$ 10 rpm.

The corresponding torque to be applied to the engine when delivering rated power (3.73 kW) at rated speed of 1500 rpm was calculated using the equation given below:

$$kW = \frac{N \times T}{9549.305}$$

Table 1. Characteristics fuel properties of different fuels

Fuel Types	Fuel Properties							
	Relative Density and API gravity		Kinematic Viscosity	Gross Heat of Combustion	Flash Point	Fire Point	Cloud Point	Pour Point
	Relative Density	API gravity	Redwood Seconds (s)	MJ/kg	(^{0}C)	(^{0}C)	(^{0}C)	(^{0}C)
Diesel	0.8444	36.8	33.4	46.85	60.0	66.7	1.5	-7.5
Ethyl Acetate	0.9060	24.6	24.9	23.47	-0.5	5.0	-	-
Ethanol Proofs								
Ethanol 200^0	0.7920	47.1	27.6	30.73	16.7	21.5	-	-
Ethanol 190^0	0.8110	42.9	27.9	29.33	18.2	23.8	-	-
Ethanol 180^0	0.8260	39.7	27.9	26.51	20.2	25.3	-	-
Ethanol 170^0	0.8420	36.6	28.2	26.11	20.8	26.7	-	-
Ethanol-Ethyl Acetate-Diesel Microemulsions								
200^0 -10/9/81	0.8430	36.3	30.1	45.70	14.7	20.5	-2.3	-
200^0 -15/9.5/75.50	0.8400	36.9	29.5	43.05	15.0	20.3	-2.8	-
200^0 -20/10/70	0.8370	37.6	29.3	42.24	15.0	19.7	-4.0	-
190^0 -10/22/68	0.8500	35.0	28.1	41.84	14.2	19.5	-2.2	-5.3
190^0 -15/25/60	0.8510	34.7	27.9	38.93	13.9	19.8	-1.2	-5.3
190^0 -20/29/51	0.8510	34.7	27.5	36.80	12.8	19.3	-0.7	-4.7
180^0 -10/35/55	0.8600	33.0	27.4	37.62	12.3	17.0	0.0	-5.8
180^0 -15/39/46	0.8610	32.8	27.3	35.99	11.5	16.3	1.0	-0.6
180^0 -20/40/40	0.8620	32.7	26.8	33.51	11.0	15.5	1.4	-3.2
170^0 -10/43/47	0.8660	31.9	26.7	34.73	9.5	14.2	3.2	-2.0
170^0 -15/45/40	0.8670	31.6	26.0	32.88	8.2	12.5	4.0	-0.8
170^0 -20/50/30	0.8700	31.1	25.9	30.47	8.3	11.5	6.7	-0.2

where,

N	=	Engine speed, rpm
T	=	Engine torque, N-m

The calculated torque was taken to be the one at 100 percent load on the engine as specified by the Indian Standard mentioned above. The engine speed at 100 percent load was then set to 1500 ± 10 rpm. The engine was then tested at no load, 25, 50, 75, 100 and 110 percent load. The engine at the above mentioned loads was tested on all selected fuel types. For each load condition, the engine was run for at least three minutes after which data were collected. The experiment was replicated three times.

3. RESULTS AND DISCUSSION

The performance of the engine was evaluated in terms of brake power, fuel consumption, brake specific fuel consumption, brake thermal efficiency, energy input, emissions of carbon monoxide, unburnt hydrocarbon, nitrogen dioxide, nitric oxide, exhaust gas and lubricating oil temperature.

3.1 Brake Power

The brake power developed by the engine on selected fuel types at no load, 25, 50, 75, 100 and 110 percent brake load and at corresponding engine speeds are shown in Table 2. It is evident from the Table 2 that the engine developed 3.73 kW brake power at 1501 rpm on diesel. The rated engine brake power as per manufacturer is 3.73 kW at 1500 rpm. Table 2 also shows that the engine developed 3.82, 3.75, 3.76, 3.74, 3.76, 3.75 kW brake power at the full load condition on 200^0-10/9/81, 200^0-15/9.5/75.5, 200^0-20/10/70, 190^0-10/22/68, 190^0-15/25/60 and 190^0-20/29/51 microemulsions respectively. It is also evident from the table that the engine developed marginally less brake power on the microemulsions compared to diesel at lighter load conditions. In the higher load conditions i.e. at 100 and 110 percent load the brake power on microemulsions was marginally higher than the diesel. This result is in consistent with the finding of Meiring *et al.* (1983) which states that the power reduction in lighter load region occurs due to reduced heat content of microemulsions and increase in ignition delay with alcohol when light loads are encountered. The combustion efficiency of microemulsions improves and ignition delay is reduced at higher load conditions.

3.2 Fuel Consumption

The relationship between the observed fuel consumption (l/h) of the engine at different brake loads on diesel and six selected microemulsions at different brake load conditions is depicted in Figure 1. It is evident from the figure that the fuel consumption of the engine gradually increased with increase in brake load and was found maximum at 110 percent brake load on all fuel types. It was observed that the fuel consumption of the engine at full load condition when the engine developed its rated power was 1.336, 1.564, 1.510, 1.532, 1.491, 1.359 and 1.533 l/h on diesel and 200^0-10/9/81, 200^0-15/9.5/75.5, 200^0-20/10/70, 190^0-10/22/68, 190^0-

15/25/60 and 190^0-20/29/51 microemulsions respectively. It is also evident from the Figure 1 that the fuel consumption of the engine on diesel was lowest at all the brake load conditions compared to the six microemulsion tested. This may be due to reason that the heat values of microemulsions were 2.5 to 21.5 percent less than the diesel. It has been also observed that the fuel consumption on 190^0-20/29/51 microemulsion was very high compared to diesel and other microemulsions between no load to 75 percent load. This may be due to reason that the microemulsion had its heat value 21.5 percent less than the diesel. Further, there was a replacement of 49 percent diesel with 190^0-20/29/51 microemulsion which might have caused poor combustion which is reflected by high emission of UBHC from the engine as presented in Figure 6.

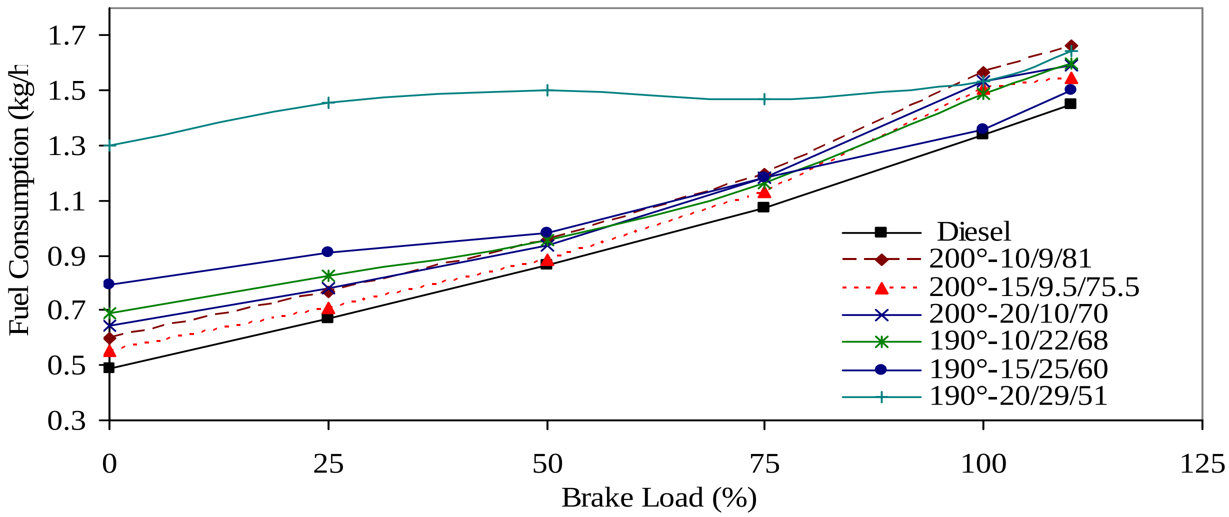

Figure 1 Fuel consumption of the engine at different brake loads

3.3 Brake Specific Fuel Consumption

The relationship between brake specific fuel consumption (BSFC) of the engine on diesel and microemulsions at different brake load is shown in Figure 2. The brake specific fuel consumption of the engine on diesel at full load (100 percent) was found as 302 g/kW-h and on 200^0-10/9/81, 200^0-15/9.5/75.5, 200^0-20/10/70, 190^0-10/22/68, 190^0-15/25/60 and 190^0-20/29/51 ethanol-ethyl acetate-diesel microemulsions was found as 345, 338, 341, 339, 308 and 348 g/kW-h respectively. It is evident from the figure that the BSFC of the engine gradually decreased with increase in brake load due to fact that the brake power of the engine increased the with brake load. Further, it was observed that the BSFC of the engine was highest at 25 percent brake load. At 25 percent brake load the BSFC of the engine was 595 g/kW-h on diesel and on 200^0-10/9/81, 200^0-15/9.5/75.5, 200^0-20/10/70, 190^0-10/22/68, 190^0-15/25/60 and 190^0-20/29/51 microemulsions was 691, 642, 708, 770, 855 and 1296 g/kW-h respectively. The highest BSFC of the engine was found as 1296 g/kW-h on 190^0-20/29/51 microemulsion fuel at brake load of 25 percent. The Figure 4.8 also shows that the drop in the brake specific fuel consumption of the engine was at a higher rate unto 75 percent brake load. The change in the BSFC of the engine between 75 percent to 110 percent brake load was less. This is due to the reason that increase in brake power of the engine from 75 percent to 110

Table 2. Brake power developed by 3.73 kW Kirloskar AV 1 engine on selected fuel types

Sl. No.	Brake Load (%)	Fuel Type													
		Diesel		Alcohol-Diesel Microemulsion											
				200^0-10/9/81		200^0-15/9.5/75.5		200^0-20/10/70		190^0-10/22/68		190^0-15/25/60		190^0-20/29/51	
		Engine Speed (rpm)	Brake Power (kW)	Engine Speed (rpm)	Brake Power (kW)	Engine Speed (rpm)	Brake Power (kW)	Engine Speed (rpm)	Brake Power (kW)	Engine Speed (rpm)	Brake Power (kW)	Engine Speed (rpm)	Brake Power (kW)	Engine Speed (rpm)	Brake Power (kW)
1	No Load	1606	-	1511	-	1493	-	1484	-	1474	-	1467	-	1541	-
2	25	1531	0.95	1503	0.93	1493	0.93	1489	0.93	1462	0.91	1454	0.90	1535	0.95
3	50	1528	1.90	1502	1.87	1506	1.87	1494	1.86	1470	1.83	1508	1.87	1519	1.89
4	75	1504	2.81	1508	2.81	1506	2.81	1497	2.79	1467	2.74	1481	2.76	1519	2.83
5	100	1501	3.73	1536	3.82	1509	3.75	1513	3.76	1504	3.74	1513	3.76	1508	3.75
6	110	1486	4.06	1501	4.11	1490	4.08	1489	4.07	1492	4.08	1500	4.10	1496	4.09

percent brake load was less as compared to increase in brake power between no load to 75 percent brake loads.

It is also evident from the figure that the BSFC of the engine at all brake loads was considerably higher on 190^0-20/29/51 microemulsion (1296 g/kW-h at 25 percent load to 342 g/kW-h at 110 percent load) compared to other microemulsion fuels. The analysis of above results on BSFC indicates that at full load condition when the engine developed its maximum power, the BSFC of the engine on 200^0-10/9/81, 200^0-15/9.5/75.5, 200^0-20/10/70, 190^0-10/22/68, 190^0-15/25/60 and 190^0-20/29/51 microemulsion fuel was 14.3, 11.9, 12.8, 12.2, 1.8 and 15.2 percent higher than that on diesel fuel.

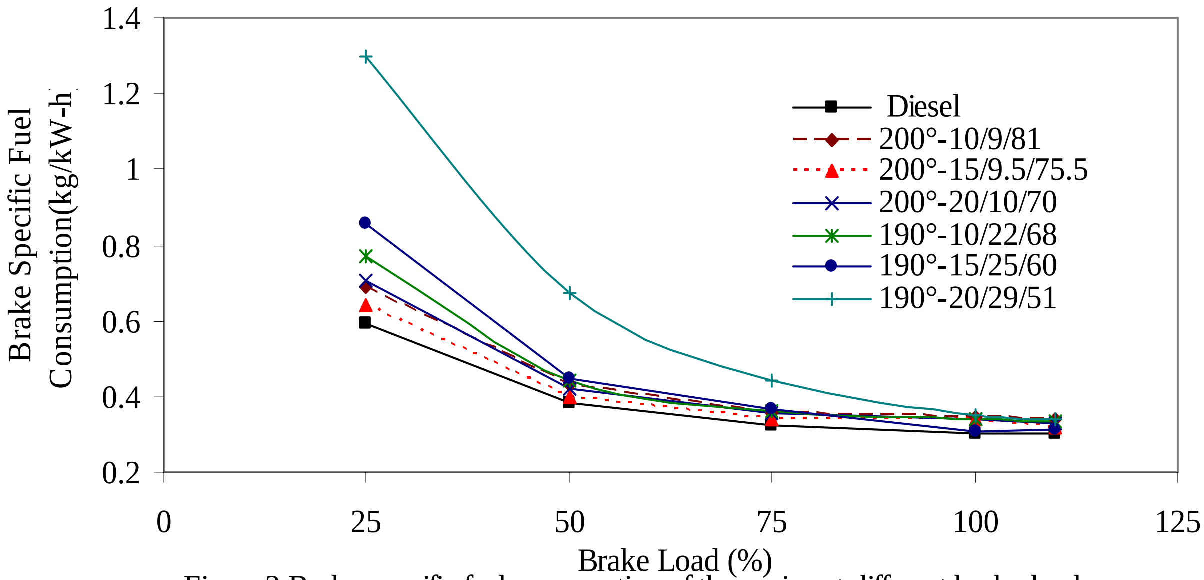

Figure 2 Brake specific fuel consumption of the engine at different brake loads

3.4 Brake Thermal Efficiency

The relationship between brake thermal efficiency of the engine on diesel and microemulsions is presented in Figure 3. The brake thermal efficiency of the engine on diesel at full load (100 percent) was found to be 25.4 percent when the engine developed its rated brake power of 3.73 kW.

The brake thermal efficiency of the engine on 200^0-10/9/81, 200^0-15/9.5/75.5, 200^0-20/10/70, 190^0-10/22/68, 190^0-15/25/60 and 190^0-20/29/51 microemulsions at full load was found as 22.8, 24.7, 25.0, 25.4, 30.1 and 28.1 percent respectively. The maximum brake thermal efficiency of engine was found to be 30.1 percent on 190^0-15/25/60 microemulsion at full load. The brake thermal efficiency of the engine on 190^0-20/29/51 microemulsion at part load conditions (no load to 75 percent load) was found to be lowest compared to other fuels. However, the brake thermal efficiency of the engine on this microemulsion was higher than the other fuels except on 190^0-15/25/60 at 100 and 110 percent load conditions.

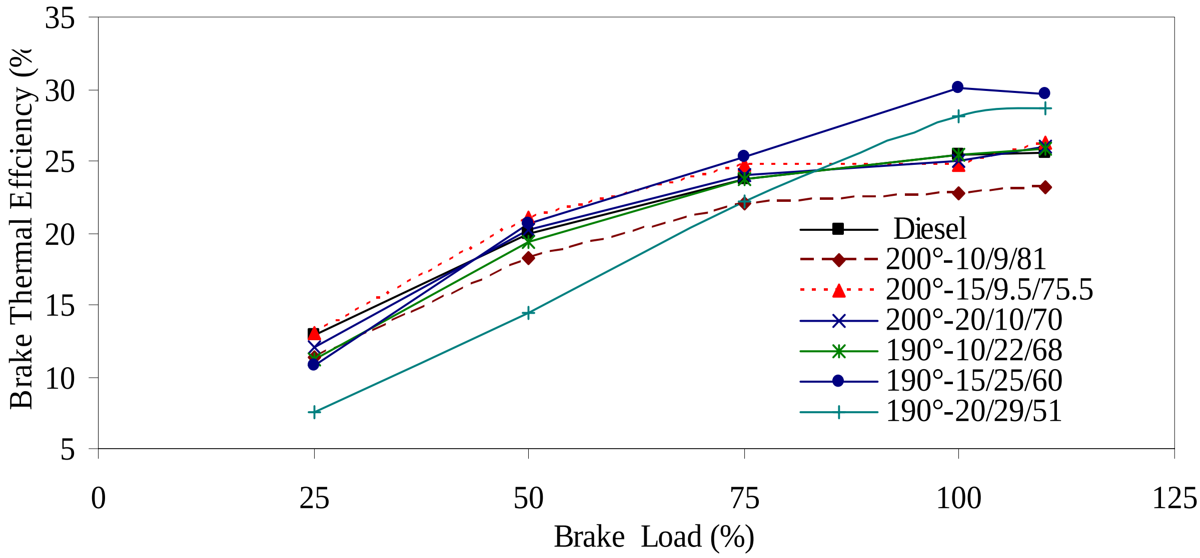

Figure 3. Brake thermal efficiency of the engine at different brake loads

3.5 Energy Input

Figure 4. shows that the fuel energy input into the engine increased with increase in brake load and was observed highest at 110 percent brake load on all fuel types tested. The input fuel energy at full load on diesel and 200^0-10/9/81, 200^0-15/9.5/75.5, 200^0-20/10/70, 190^0-10/22/68, 190^0-15/25/60 and 190^0-20/29/51 microemulsions was found to be 52.84, 60.28, 54.64, 54.15, 53.03, 45.04 and 48.03 MJ/h respectively. The result of input fuel energy shows that the maximum energy input at full load was 60.28 MJ/h on 200^0-10/9/81 microemulsion and at this energy input condition a 3.82 kW brake power was recorded which was maximum among all fuel types tested. The lowest input fuel energy was found as 45.04 MJ/h on 190^0-15/25/60 microemulsion at full engine load at which engine developed 3.76 kW power. However, the input fuel energy on diesel at full load (3.73 kW) was 52.84 MJ/h. Based on results on brake power developed by the engine on diesel and different microemulsions, it can be said that the microemulsions tested had similar power producing capabilities as diesel, though the amount of diesel replacement by microemulsions varied from 19 to 49 percent.

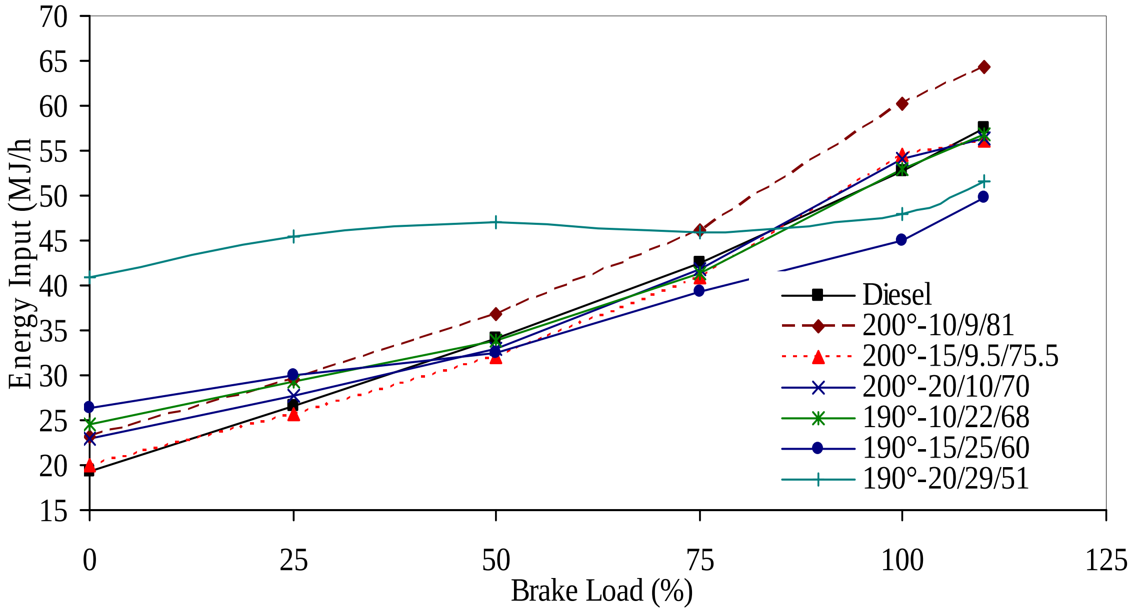

Figure 4. Fuel energy input at different brake loads

3.6 Emission of Carbon Monoxide (CO)

The carbon monoxide (CO) emission from the engine on diesel and microemulsion having 200^0 and 190^0 proof ethanol microemulsions at different brake load condition is shown in Figure 5. The figure indicates that the emission of CO from the engine on diesel was in the range of 0.25 to 1.03 percent between no load to 110 percent brake load. The emission of CO at full load was found as 0.72 percent on diesel.

The range of emission of CO on 200^0-10/9/81, 200^0-15/9.5/75.5, 200^0-20/10/70, 190^0-10/22/68, 190^0-15/25/60 and 190^0-20/29/51 microemulsions was found to be 0.44 to 0.48, 0.42 to 0.81, 0.24 to 0.79, 0.09 to 0.85, 0.30 to 1.08 and 0.26 to 0.61 percent respectively between no load to 110 percent brake load conditions. The comparison of CO emission at full load condition indicates that it was 0.72, 0.48, 0.40, 0.59, 0.55, 0.71 and 0.47 on diesel and 200^0-10/9/81, 200^0-15/9.5/75.5, 200^0-20/10/70, 190^0-10/22/68, 190^0-15/25/60 and 190^0-20/29/51 microemulsions respectively.

It is evident from the result that the lowest emission of CO (0.40 percent) from the engine when it developed its rated power (3.73 kW) was on 200^0-15/9.5/75.5 microemulsion. Further, the result indicates that the emission of CO on microemulsion was lower compared to diesel at higher loads i.e. between 75 to 110 percent load. The above findings are in line with that of Ecklund (1984) which states that a fuel containing alcohol when burnt in a C.I. engine emits lesser amount of CO due to higher air-fuel ratio.

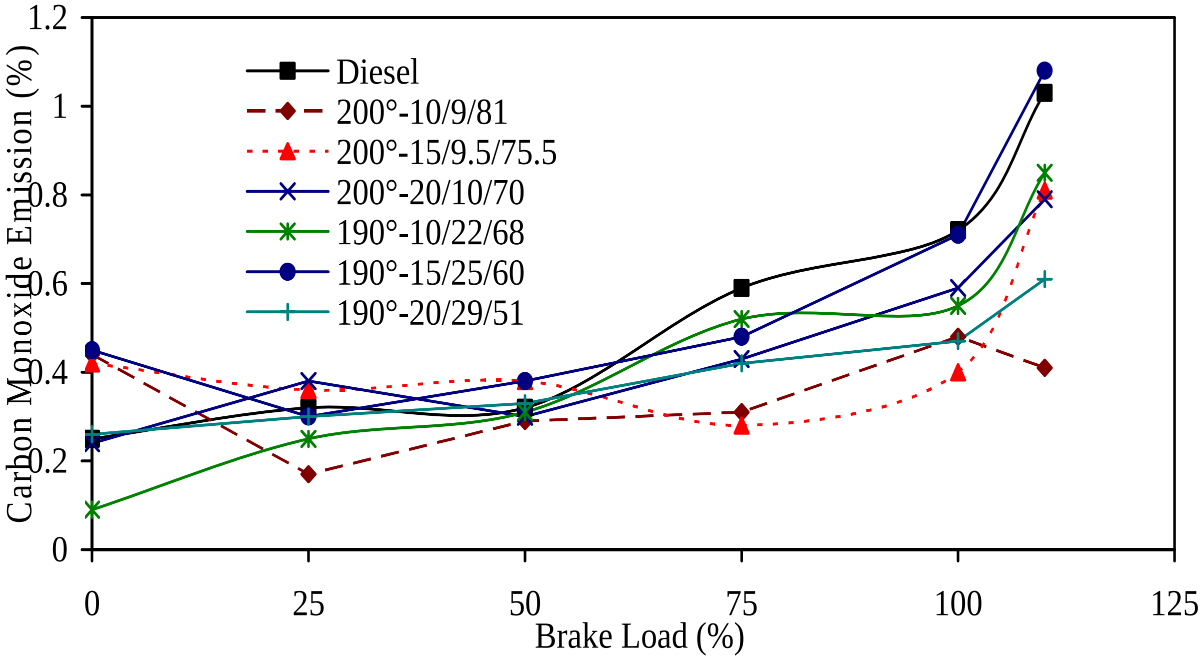

Figure 5. Emission of carbon monoxide at different brake load condition

3.7 Emission of Unburnt Hydrocarbon

The change in UBHC emission from the engine at varying brake load conditions on different fuels is plotted in Figure 6. It has been observed that the emission of UBHC from the exhaust of the engine on diesel was found to vary from 0.01 to 0.05 percent between no laod to 110 percent brake load. It was also observed that the emission of UBHC on diesel remained constant to 0.01 percent upto 75 percent brake load and then increased to 0.03 and 0.05 percent at 100 and 110 percent load respectively.

It is evident from the figure that the emission of UBHC from the exhaust of the engine when operating on 200^0-10/9/81, 200^0-15/9.5/75.5, 200^0-20/10/70, 190^0-10/22/68, 190^0-15/25/60 and 190^0-20/29/51 microemulsions ranged between 0.01 to 0.05, 0.01 to 0.05, 0.01 to 0.04, 0.01 to 0.04, 0.02 to 0.09 and 0.04 to 0.10 percent respectively. Further, comparing the observed values of UBHC emission at full load, it was found that there was increase in UBHC to 40, 25, 40 and 40 percent respectively when engine was operating on 200^0-10/9/81, 200^0-20/10/70, 190^0-15/25/60 and 190^0-20/29/51 microemulsion fuel. However, the emission of UBHC from the exhaust of the engine on 200^0-15/9.5/75.5 at full load was found 33.4 percent lower than that of diesel and on 190^0-10/22/68 was found similar as on diesel (0.03 percent). The emission of UBHC from the exhaust of the engine was found highest as 0.10 percent on 190^0-20/29/51 microemulsion fuel. It was also observed that the emission of UBHC was more on aqueous microemulsions. The higher emission of UBHC on microemulsions particularly with the microemulsions prepared using 190^0 proof ethanol may be due to slow vapourization and fuel-air mixing as indicated by Ecklund (1984).

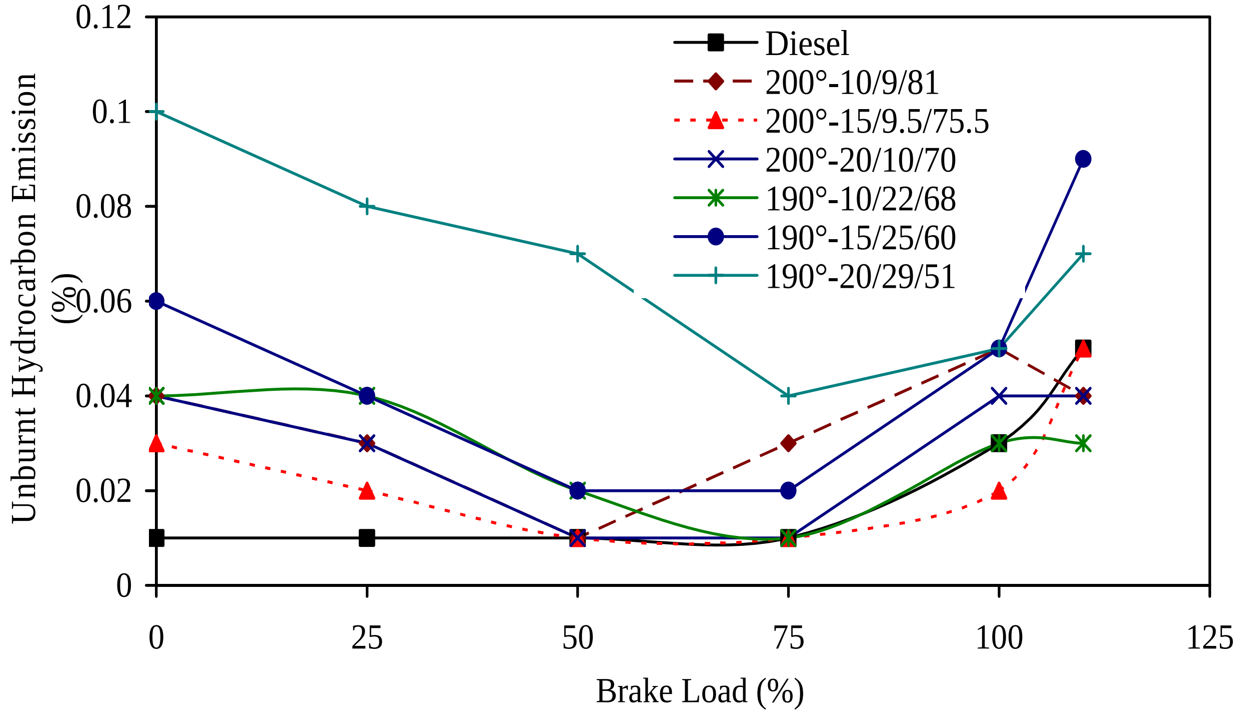

Figure 6. Emission of unburnt hydrocarbon at different brake load condition

3.8 Emission of Nitric Oxide (NO)

The emission of nitric oxide (NO) from the exhaust of the engine operating on diesel and various selected microemulsions is shown in Figure 7. The emission of NO from the engine on diesel was found to vary in the range of 9 ppm to 216 ppm between no load to 110 percent brake load. The level of NO emission from the engine running on 200^0-10/9/81, 200^0-15/9.5/75.5, 200^0-20/10/70, 190^0-10/22/68, 190^0-15/25/60 and 190^0-20/29/51 microemulsion fuel was found to vary in the range of 5 to 198, 6 to 211, 4 to 217, 3 to 173, 1 to 192 and 2 to 164 ppm respectively between no load to 110 percent brake load.

It is evident from the figure that the emission of NO from the exhaust of the engine was found lower on microemulsions than the diesel fuel between all brake loads. It also shows that the emission of NO from the engine running on microemulsions of 200^0 proof ethanol than the microemulsions of 190^0 proof ethanol was higher in almost all brake load conditions. Further, the lowest emission at all brake load conditions was observed using 190^0-20/29/51 microemulsion which indicates that presence of water in ethanol and proportion of ethyl acetate has reduced the emission of NO.

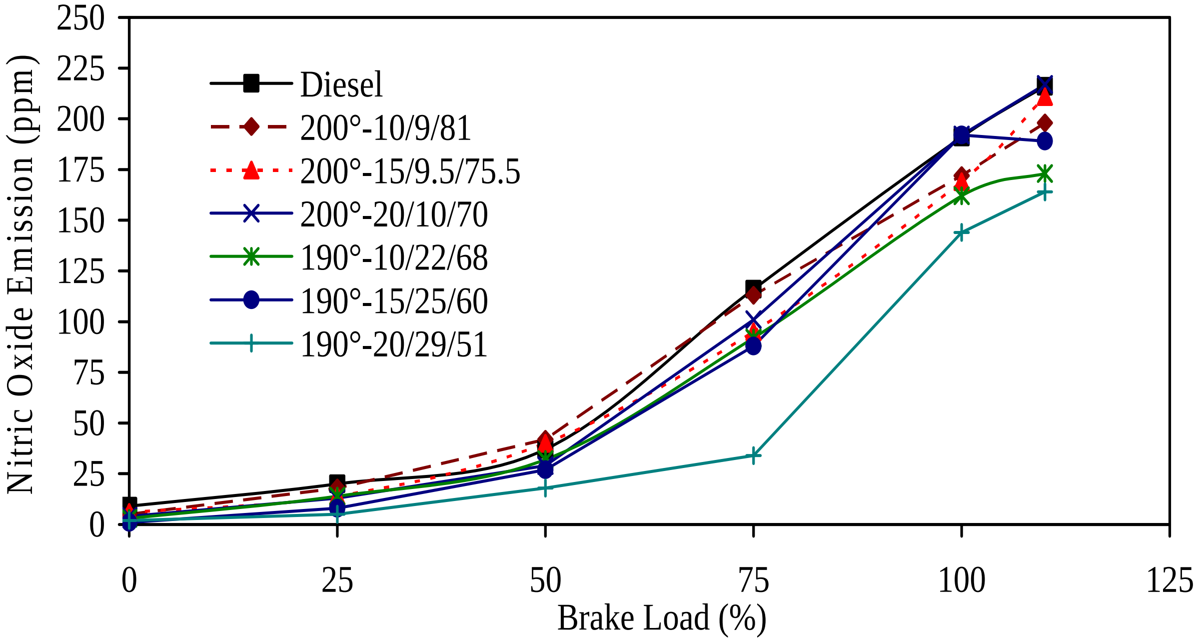

Figure 7. Emission of nitric oxide at different brake load condition

3.9 Emission of Nitrogen Dioxide (NO_2)

The variation in emission of NO_2 from the exhaust of the engine running on diesel and different selected microemulsions is shown in Figure 8. The emission of nitrogen dioxide from exhaust of the engine on diesel was found to be in the range of 4.5 to 22 ppm between no load to 110 percent brake load. The level of NO_2 emission from the engine on 200^0-10/9/81, 200^0-15/9.5/75.5, 200^0-20/10/70, 190^0-10/22/68, 190^0-15/25/60 and 190^0-20/29/51 microemulsions was found to vary from 3.7 to 23.8, 4 to 21.8, 3.9 to 25.1, 3.4 to 21.1, 2.2 to 14.4 and 0.6 to 10.2 ppm respectively between no load to 110 percent brake loads. It is evident from the figure that the emission of NO_2 from the engine was found lower on microemulsions prepared using anhydrous and aqueous ethanol than the diesel fuel under no load to 75 percent and was more on at full load and 110 percent brake load. Further, the emission of NO_2 from the engine on microemulsion having 190^0 proof ethanol was found to be less compared to diesel as well as microemulsions of 200^0 proof ethanol. This may be due to presence of water in 190^0 proof ethanol. Further, NO_2 emission on 190^0-20/29/51 microemulsion was found to be lowest on all brake loads compared to diesel and other microemulsions. This indicates that with increase in proportion of ethanol and ethyl acetate in the microemulsion, the emission of NO_2 has reduced. Ecklund (1984) indicated that the presence of alcohol in a fuel increases ignition delay and causes higher peak combustion temperature due to higher peak cylinder pressure resulting in increased emission of NO_x from the engine, However, in the present study a reverse trend was noticed which could be due to use of ethyl acetate as surfactant which might have helped in reducing emission of NO_x from the engine.

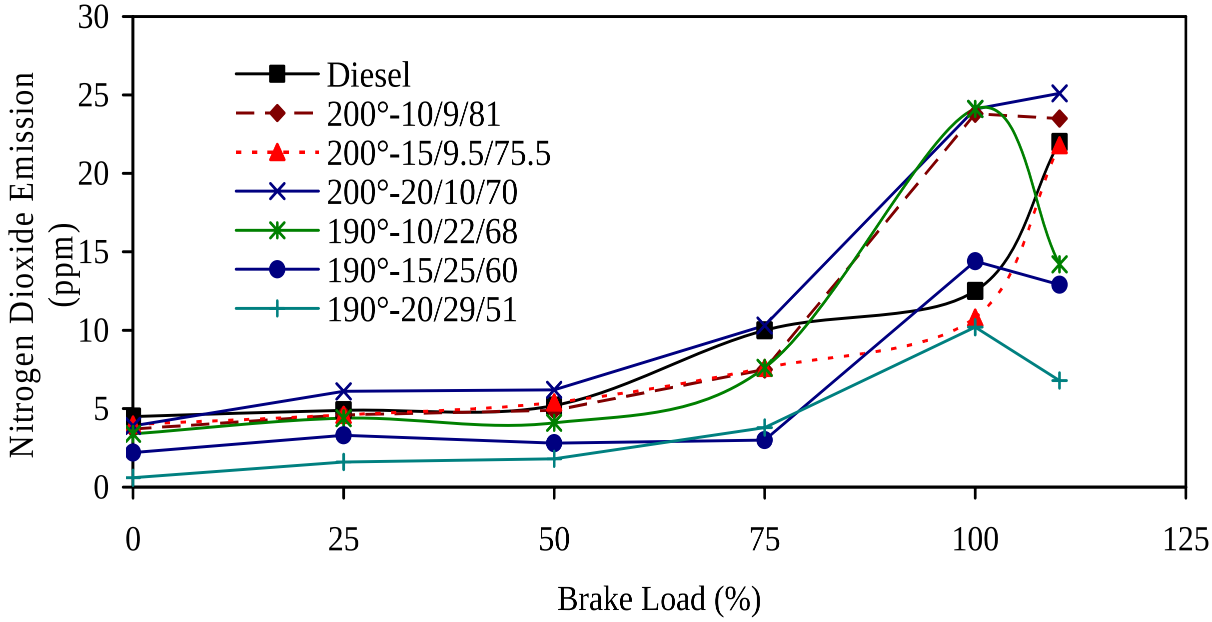

Figure 8. Emission of nitrogen dioxide at different brake load condition

3.10 Exhaust Gas Temperature

The change in observed exhaust gas temperature of the engine on diesel and six selected microemulsions at different brake load is presented in Figure 9. It is evident from the figure that the exhaust gas temperature of the engine on diesel was in the range of 165 to 592^{0}C between no load to 110 percent brake loads. The exhaust temperature of the engine was also found to increase with increase in brake load between the entire ranges of the brake load.

The exhaust gas temperature of the engine on microemulsions was found higher than that on diesel. It was found that at full load condition the exhaust gas temperature on diesel and 200^0-10/9/81, 200^0-15/9.5/75.5, 200^0-20/10/70, 190^0-10/22/68, 190^0-15/25/60 and 190^0-20/29/51 microemulsions was 548^{0}C and 594, 547, 552, 563, 596 and 546^{0}C respectively. The increased exhaust gas temperature of the engine on microemulsions may be due to increase in peak cylinder pressure resulting in higher peak combustion temperature as reported by Ecklund (1984).

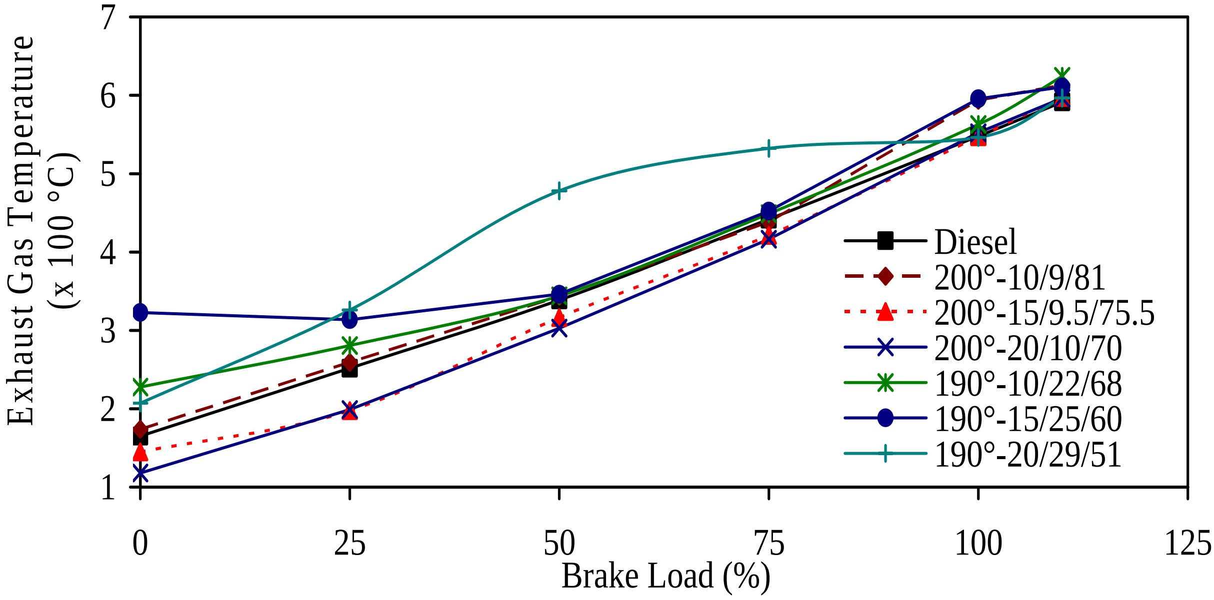

Figure 9. Exhaust gas temperature at different brake load conditions

3.11 Lubricating Oil Temperature

The temperature of the lubricating oil when the engine was operating on diesel and different selected microemulsions prepared from anhydrous and aqueous ethanol is shown in Figure 10. The figure shows that the observed lubricating oil temperature on diesel at no load, 25, 50, 75, 100 and 110 percent was found as 67, 67, 66, 65, 58 and 61^0C respectively. It was also observed that the lubricating oil temperature at no load and 25 percent load remained similar and from 50 percent to full load it gradually decreased and then increased at 110 percent brake load.

It also shows that the engine lubricating oil temperature on microemulsions 200^0-10/9/81, 200^0-15/9.5/75.5, 200^0-20/10/70, 190^0-10/22/68, 190^0-15/25/60 and 190^0-20/29/51 varied in the range of 56 to 66, 58 to 65, 53 to 64, 60 to 63, 54 to 63 and 65 to 66^0C respectively between the whole range of the brake loads. It was also observed from the figure that the trend of the lubricating oil temperature on microemulsion fuel is almost similar to that on of diesel. However, a decreased engine oil temperature was found on microemulsion fuel. This is due to the fact that the ethanol has higher latent heat of vapourization and ethanol burns with lower flame temperature (Owen and Coley, 1990) than diesel and thus it cools the crown of the piston after injection of the fuel in to the combustion chamber. The decreased engine oil temperature maintains proper lubricity and reduces consumption of the engine oil in the sump of the engine.

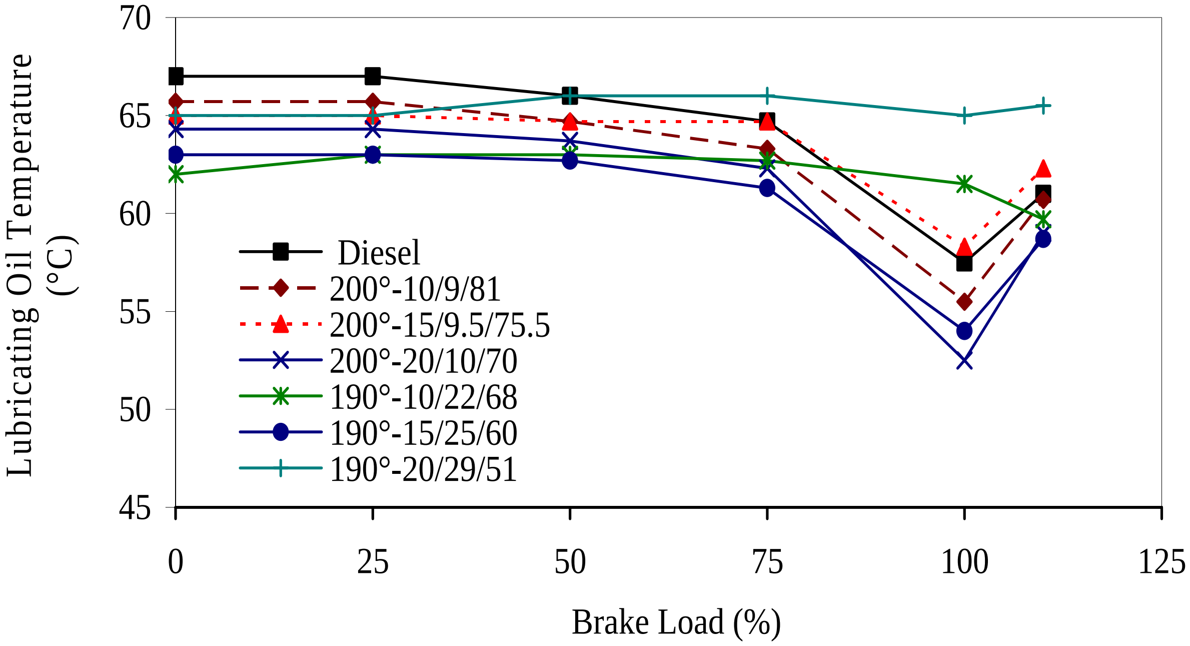

Figure 10. Lubricating oil temperature of the engine at different brake loads

4. CONCLUSIONS

The results of the study have indicated that all tested microemulsion viz. 200^0-10/9/81, 200^0-15/9.5/75.5, 200^0-20/10/70, 190^0-10/22/68, 190^0-15/25/60 and 190^0-20/29/51 fuels of ethanol-ethyl acetate-diesel have similar power producing capabilities as that of diesel. The fuel consumption of the engine was some what higher on the microemulsions compared to diesel fuel due to their lower gross heat of combustion. Brake thermal efficiency of the engine at low load conditions was found little bit lower and at high load condition was higher on microemulsion. The carbon monoxide emission reduction of 1.4 to 44.4 percent was observed as compared to diesel. The emission of unburnt hydrocarbon was found marginally higher on the microemulsions but the values were comparable. The highest reduction of 24 percent in the emission of nitric oxide was found on 190^0-20/29/51 aqueous microemulsion though it was always lower on microemulsions except few. The emission of nitrogen dioxide was always lower on microemulsions for most of the brake load conditions in the comparison to that of diesel except few one at higher engine load conditions. But the values were comparable to that of diesel fuel which has resulted from increase in exhaust gas temperature on microemulsions. It was further reduced on microemulsions prepared using 190^0 proof aqueous ethanol.

The performance of the engine in respect of brake power, brake specific fuel consumption, brake thermal efficiency and emission of CO, UBHC and NO_x revealed that all microemulsion fuel can be used in a compression ignition engine during periods of lean supply of diesel. However, on the basis of results among all microemulsion fuels and the amount of diesel replacement, the use of 190^0-20/29/51 microemulsion could be recommended which has a diesel replacement of 49 percent.

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