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A Comparative Evaluation of the Performance and Emission Characteristics of Compression Ignition Engine Using Water Diesel Emulsion as Fuel

V.Murali [1*], T.N.Ramamurthy[1], M Krishna[2], R.S. Kulkarni[2]

[1]*RV-TIFAC-Hydrogen Economy Technology Program, R.V.College of Engineering, Bangalore – 560 059, Karnataka, India*
[2]*Dept. of Mechanical Engineering, R.V.College of Engineering, Bangalore – 560 059, Karnataka, India.*

Abstract

The basic intent of present work is to evaluate the potential of using water diesel emulsion for a compression ignition engine. A comparative analysis of the performance and emission characteristics of the engine has been made with respect to diesel and water diesel emulsion as fuels. A multicylinder diesel engine was run on water diesel emulsion and diesel at a constant speed of 2400rpm under variable load conditions and at 13-mode test cycle. Emulsions of 5, 10, 15 and 20 percent by volume of water in diesel were used. The results indicate that the addition of water in the form of emulsion improve the combustion efficiency. The optimum percentage of water in emulsion based on specific fuel consumption and emission characteristics compared to that of diesel fuel operation was 15%.

1.0 Introduction

Compression ignition engines are widely used for mass transportation because of their high thermal efficiency and torque capacity. They are becoming popular in the passenger car segment also, particularly in countries like India where the cost of diesel is significantly lower than that of gasoline. It is well known that fossil fuel reserves are getting exhausted at an alarming rate. Moreover, the combustion of such fuels results in the emission of noxious pollutants, which threaten the very survival of life on this planet. Diesel engines are major sources of oxides of nitrogen (NO_x) and smoke emissions. They operate with mixtures that are considerably leaner than stoichiometric on an overall basis. However, the heterogeneous nature of the charge results in the combustion chamber being too rich, leading to particulate emission. Other sources of particulates are sulfur in fuel and lubricating oil which contains zinc, calcium, etc. High gas temperature in the diesel engine is the major contributing factor for the formation of NO_x. The reason for high temperature is the dominant premixed combustion phase, which is a result of a long ignition delay. It is clear that reducing the gas temperature can control NO_x emissions while particulate emission can be controlled by enhancing the mixing rate of fuel with air. Many methods like retarding the injection timing, use of high injection pressure, exhaust gas recirculation, split injection, oxygen enrichment of the inducted air, enhancing the swirl and squish by modifying the engine combustion chamber geometry etc are being tried to reduce emissions from diesel engines. Generally, techniques that reduce NO_x lead to an increase in smoke and particulate emissions and vice versa [1].

Water diesel emulsions can control both NO_x and smoke emissions [2, 3, 4]. NO_x emission decreases due to reduction in the gas temperature and increase in OH radical concentration [5]. Particulate emission decreases due to the micro-explosion phenomenon of water and increase in OH radical concentration [6, 7, 8]. There is also an improvement in the brake thermal efficiency at

* *Corresponding author: E-mail: murali_v25@yahoo.co.in*

certain operating conditions. Several diesel engine tests using water diesel emulsion have been reported. The combustion characteristics of various water diesel emulsion fuels were investigated in a rapid compression and expansion machine [9]. They found that the best performance of the machine with respect to efficiency, NO_x and soot emissions was when operating at 40% water by volume. Dynamometer tests conducted on a diesel engine using emulsions with 5% and 10% of water by volume, showed no obstacles to the operation of the diesel engine during a series of steady state engine tests and the twenty hour endurance tests [10]. The results show that the accumulation of wear metal debris in crankcase oil samples is lower with emulsion than with the baseline ordinary diesel fuel. An experimental investigation has been conducted to study the effects of water diesel emulsion fuel on heat flow and thermal loading in a diesel engine [11]. It was found that the addition of water to diesel fuel has a great influence on reducing the heat flux, the metal temperatures and the thermal loading of combustion chamber components.

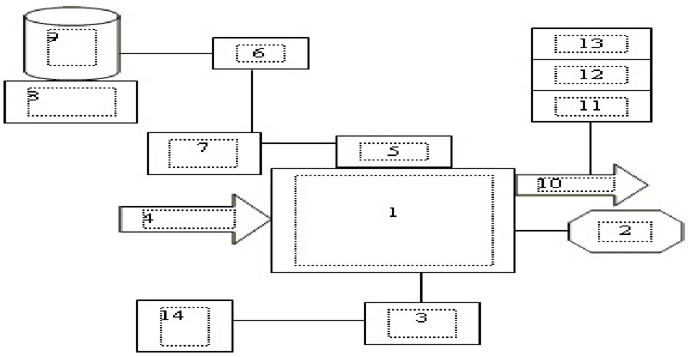
1.2 Present Work

The aim of this work was to study the effect of performance and emission characteristics when water diesel emulsion is used as the fuel in a diesel engine. A multicylinder diesel engine was run on diesel fuel under variable output conditions at a constant speed of 2400 rpm and at 13-mode test cycle [12]. Subsequently the engine was tested on emulsions of 5, 10, 15 and 20 percent by volume of water in diesel. Performance and emission parameters were obtained in all cases.

2.0 Materials & Method

Details of the engine are given in Table 1. The engine was coupled to an eddy current dynamometer. Fuel flow rate was obtained on gravimetric basis using an electronic fuel balance. An exhaust gas analyzer was used to measure the gaseous pollutants in the exhaust. Non-dispersive infrared principle was used to measure hydrocarbon (HC), carbon monoxide (CO) and carbon dioxide (CO_2) levels and NO_x emission measurement was based on chemiluminescence principle. Smoke levels were measured in standard Bosch smoke units (BSU). The data were recorded in a personal computer through the Engine Data Acquisition & Control System.

The schematic layout of the experimental setup is shown in Fig.1.



1. Engine 2. Dynamometer
3. Control Panel 4. Inlet Manifold
5. Fuel Injector system 6. Fuel Management
7. Fuel Injection Pump 8. Fuel Balance
9. Fuel Tank 10.Exhaust Manifold
11 Exhaust Gas Analyzer 12. Bosch Smokemeter

Figure 1 Experimental Setup

Table 1 Specifications of the test engine

Type of Engine	Ashok Leyland HINO WO6D water cooled, naturally aspirated diesel engine
Bore * Stroke (mm)	104 * 113
No. of cylinders	6 in line
Displacement (l)	5.759
Compression Ratio	17.9: 1
Firing Order	1-4-2-6-3-5
Max Output	95 PS @ 2400 rpm
Max Torque	33 Mkg @ 1600 RPM
Application	Vehicular

Using a surfactant with a HLB (Hydrophile Lipophile Balance) of 7, the water diesel emulsion was prepared. The amount of surfactant added was 2% by weight and the stability time was about 6 months. The arrangement used for preparing the emulsion is shown in fig.2. It consists of a pump, nozzle and a steel container. Known quantities of diesel, water and surfactant were poured into the mixing jar and circulated in close loop using the pump. A good emulsion was obtained due to the shearing effects in the pump's impeller and in the jar where the high-speed stream, which ejected out of the nozzle, mixes with the rest of the contents. The emulsion was injected into engine using the standard injection system.

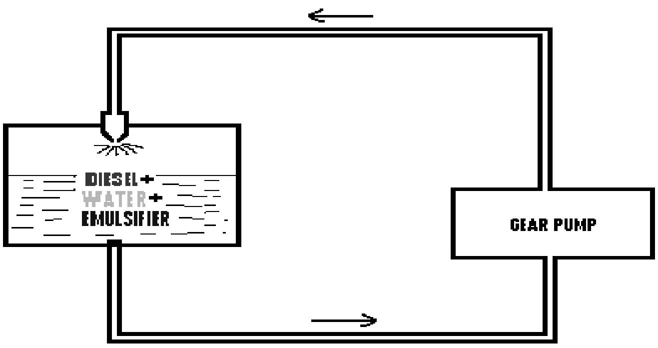


Figure 2 Emulsion Preparation

2.1 A Novel Fuel Management System

The fig.3 shows the schematic of the temperature controller and filter/heater circuit. The controller has a 12V DC power supply. The controller can be set to different temperatures as required. When the set temperature is reached, the relay gets actuated. The DC circuit with the filter/heater comes into the fray and the fuel starts to flow into the engine. If the temperature falls below the set temperature, the controller circuit cuts in and the fuel flow stops.

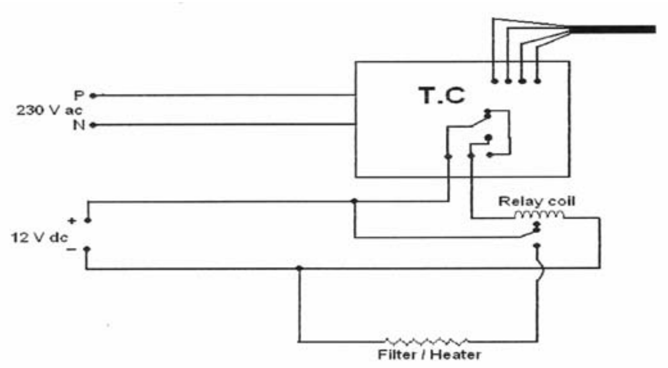


Figure 3 Temperature Controller Circuit of Fuel Management System

3.0 Results and Discussion

The engine was run at a constant speed of 2400 rpm and the power was varied from no load to maximum power in steps of 10kW.The variation of brake thermal efficiency with power output are shown in fig.4. It is clear that there is an improvement in brake thermal efficiency as compared to diesel fuel with increase in percentage of water in the emulsion. Thus the use of water diesel emulsion is advantageous. At the maximum power output of 63kW, the brake thermal efficiency with diesel is 32.05% and rises from 33.39% to 37.14% with increase in percentage of water in the case of emulsion. The maximum increase in brake thermal efficiency occurs when 20% water diesel emulsion is used. The average increase in brake thermal efficiency for 20% emulsion is approximately 8% over the use of diesel for the same engine operating conditions.

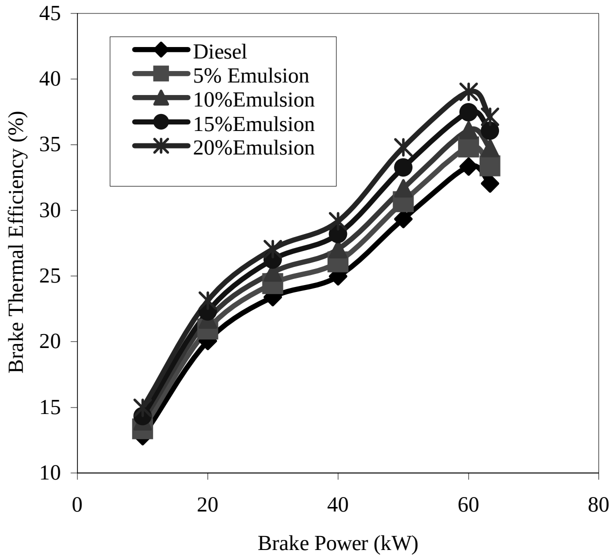


Figure 4 Break Thermal Efficiency Vs Brake Power

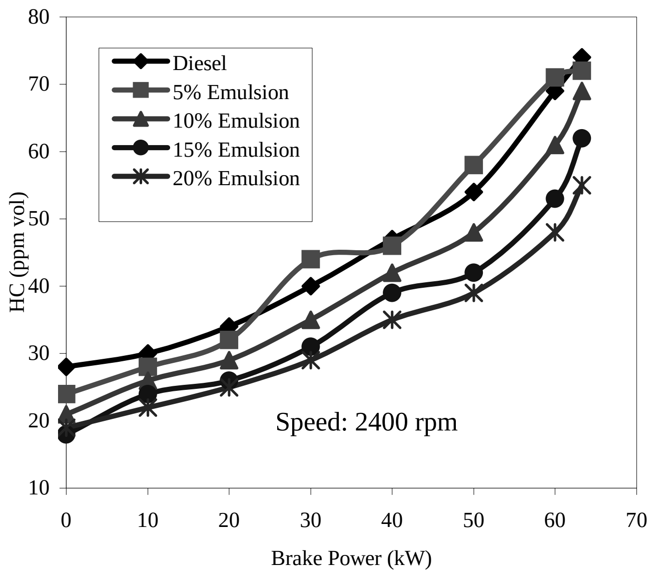


Figure 5 HC Vs Brake Power

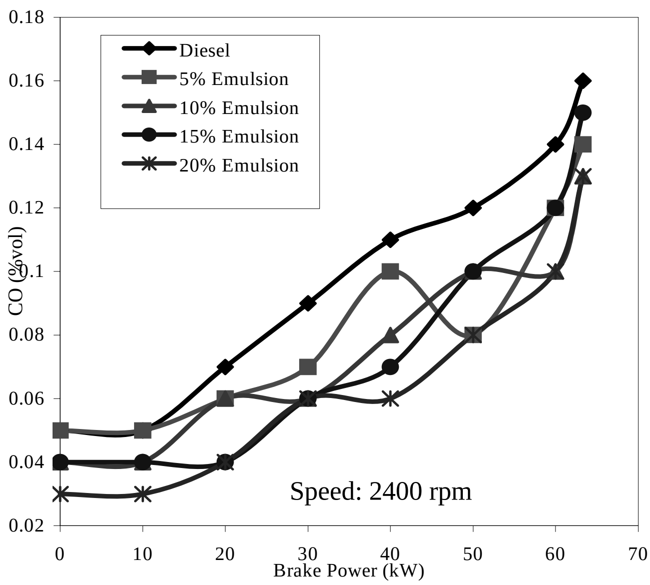


Figure 6 CO Vs Brake Power

It is seen in fig. 5 & 6 that there is a significant decrease in HC and CO emission level with the water diesel emulsion as compared to pure diesel operation. There is a decrease in HC levels from 74 ppm to 55 ppm at the maximum power output of 63kW. The reduction in the emission levels is due to better combustion.

As shown in Fig.7, Smoke density decreased from 6.26 BSU to 5.84 BSU at maximum output of 63 kW. The decrease in smoke density is attributed to the water in the emulsion. The reduction in smoke density is proportional to the increase in percentage of water in the emulsion.

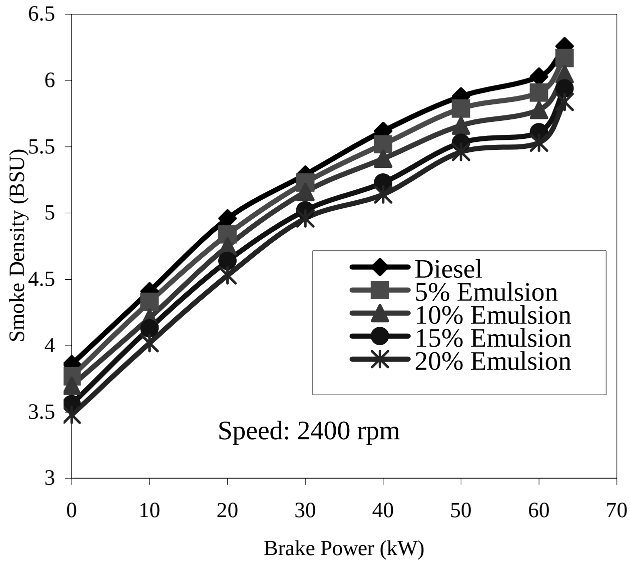


Figure 7 Smoke Density Vs Brake Power

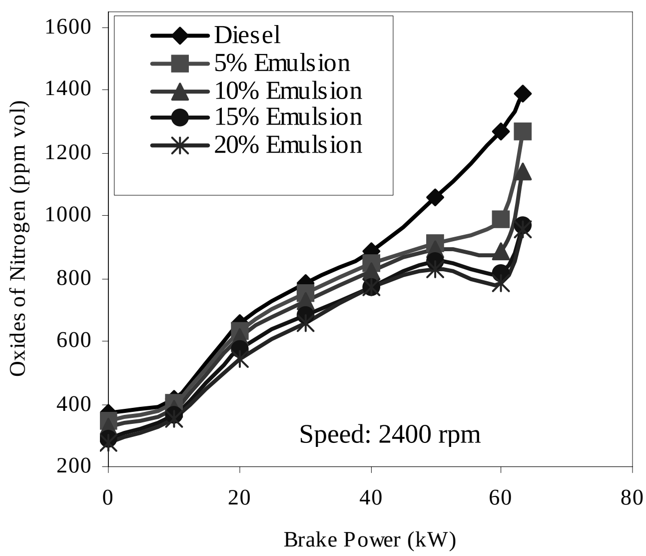


Figure 8 Oxides of nitrogen Vs Brake Power

As shown in fig.8, NO_x emission decreased from 1389 ppm to 955 ppm at maximum output of 63kW with the use of water diesel emulsion. Water brings down the temperature and oxygen concentration in the charge. This leads to reduction in the NOx level.

The variation of specific fuel consumption (SFC) with brake power for emulsions with different percentage of water are shown in fig.9 and 10. Two conventions are adopted for the SFC. The first is calculated by considering the diesel fuel plus water as the total fuel, shown in fig.9. The second is the proper value calculated by considering the total fuel as strictly the amount of diesel that is burned, shown in fig.10. The SFC in both figures is more at the low outputs and decreases at high outputs. At low outputs, the heat loss to the combustion chamber walls is proportionately greater and combustion efficiency is poorer, resulting in higher fuel consumption for the power produced. Fig. 9 shows that as the percentage of water in the emulsion increases, the SFC increases. This is because, as the percentage of water in the emulsion increases, a larger amount of diesel is displaced by an equal amount of water. This means that less diesel fuel is actually contained within each volume of the emulsion. It is clear from fig.10 that as the percentage of water in the emulsion increases, the SFC decreases. The reduction in SFC with water diesel emulsion may be attributed to formation of a finer spray due to rapid evaporation in the water, longer ignition delay results in more fuel burning in premixed combustion and suppression of thermal dissociation due to lower cylinder average temperature. The evaporation and additional mass of water cause the cylinder average temperature to become lower as the water amount was increased. Hsu [13], who conducted similar work, found that water lowers the maximum cylinder average temperature in a medium speed diesel engine.

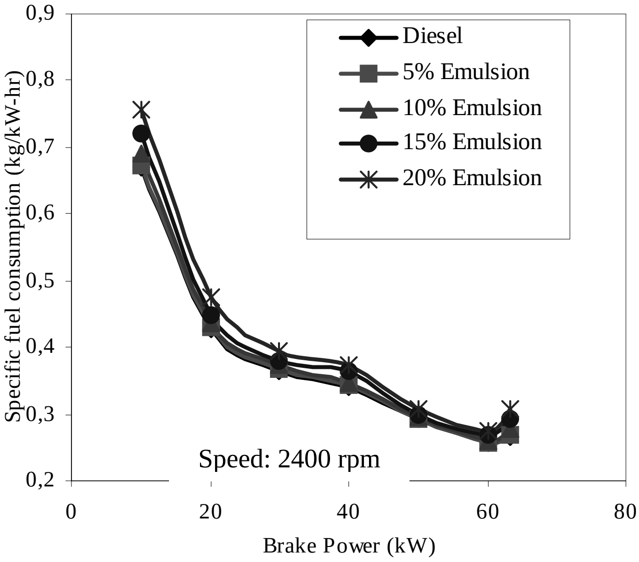


Figure 9 Specific fuel consumption Vs Brake Power using water diesel emulsion by considering water + diesel as total fuel.

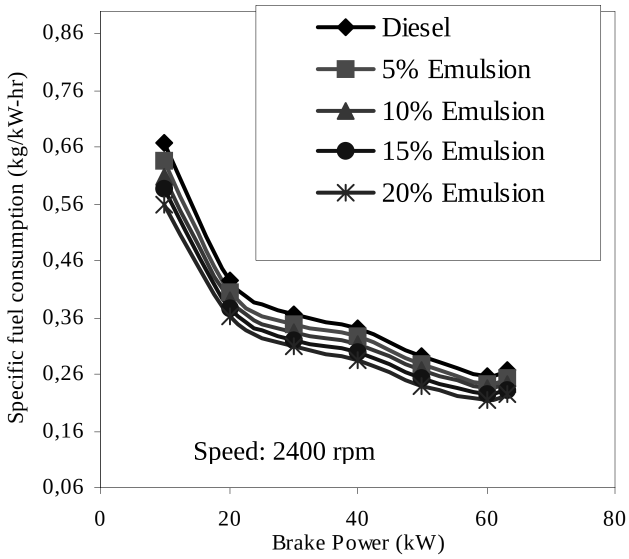


Figure 10 Specific fuel consumption Vs Brake Power using water diesel emulsion by considering diesel as total fuel.

3.1 Mode Test Cycle [12]:

The table 2 shows the 13-mode cycle followed in dynamometer operation on the test engine,

Table 2 13 Mode Test Cycle.

Mode No.	Engine Speed	% Torque
1	Idle	0
2	Intermediate Speed (60% of Rated Speed)	10
3	,,,,	25
4	,,,,	50
5	,,,,	75
6	,,,,	100
7	Idle	0
8	Rated Speed	100
9	,,,,	75
10	,,,,	50
11	,,,,	25
12	,,,,	10
13	Idle	0

The engine is run at different mode of speed and load conditions as mentioned in the table 2 and the engine performance and emission data are recorded. By MIRA Correlation [12], the specific fuel consumption and emissions are calculated in terms of g/kWh.

Tables 3 and 4 show the comparison of SFC and emission characteristics of the engine fuelled by water diesel emulsion in comparison with diesel fuel. Two conventions are adopted for the SFC. The first is calculated by considering the diesel fuel plus water as the total fuel and the second is the proper value calculated by considering the total fuel as strictly the amount of diesel that is burned.

Table 3: Comparison of performance and emission characteristics of the engine using water diesel emulsion by considering water + diesel as total fuel

Fuel / g/kWh	**Diesel**	**5% water diesel emulsion**	**10% water diesel emulsion**	**15% water diesel emulsion**	**20% water diesel emulsion**
BSFC	275.5	282.3	287.9	295.7	320.0
PM	2.2724	2.0363	1.8457	1.6531	1.6455
HC	0.307	0.267	0.267	0.251	0.230
NO_x	9.64	9.41	8.80	8.06	8.00
CO	5.803	5.126	4.744	4.181	4.255

Table 4 Comparison of performance and emission characteristics of the engine using water diesel emulsion by considering diesel as total fuel

Fuel / g/kWh	Diesel	5% water diesel emulsion	10% water diesel emulsion	15% water diesel emulsion	20% water diesel emulsion
BSFC	275.5	268.2	**259.1**	**251.3**	256.0
PM	2.2724	2.0363	**1.8457**	**1.6531**	1.6455
HC	0.307	0.267	**0.267**	**0.251**	0.230
NO_x	9.64	9.41	**8.80**	**8.06**	8.00
CO	5.803	5.126	4.744	4.181	4.255

Figure 11 Comparison of emissions from the engine fuelled by water diesel emulsion with diesel operation

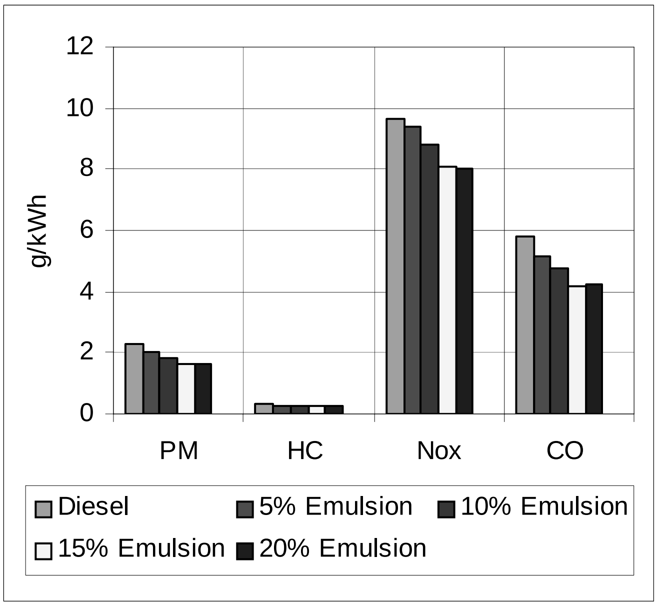


Figure 12 Comparison of specific fuel consumption of the engine fuelled by water diesel emulsion with diesel operation

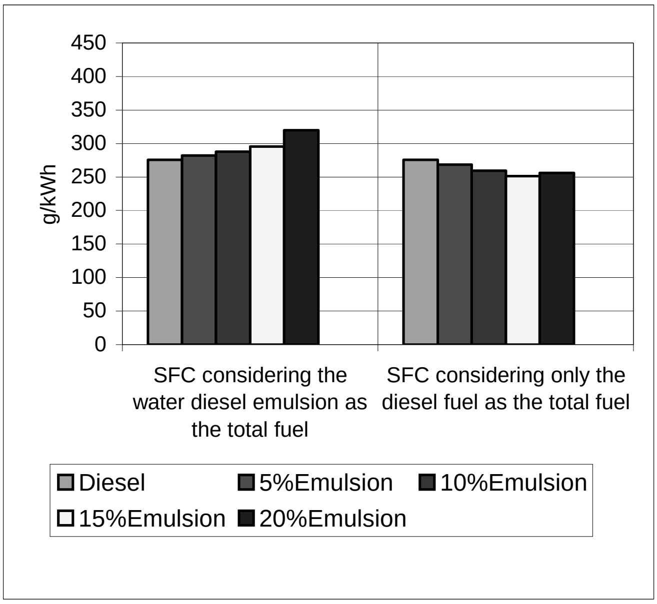
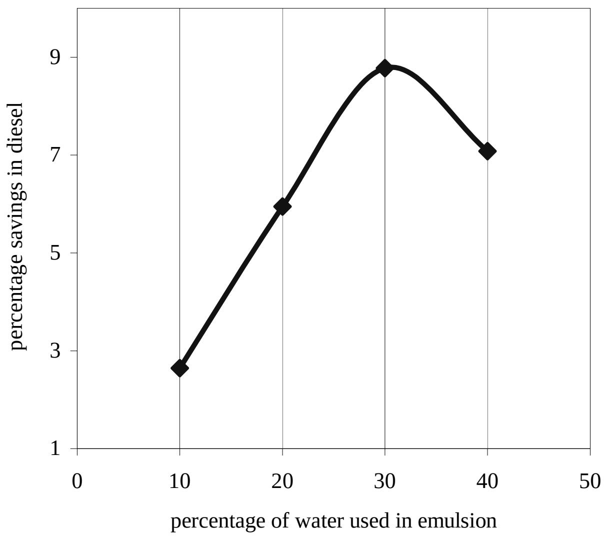


Figure 13 Percentage savings in diesel Vs Percentage of water in emulsion



4.0 Conclusions

The use of water diesel emulsion is found to increase the brake thermal efficiency. At the maximum power output of 63kW, it is 32.05% with diesel and rises from 33.39% to 37.14% with increase in percentage of water in the emulsion. The maximum increase in brake thermal efficiency occurs when 20% water diesel emulsion is used. The average increase in brake thermal efficiency for 20% emulsion is approximately 8% over the use of diesel for the same engine operating conditions.

HC and CO levels decrease with the use of emulsion. The percentage reduction in HC compared to that of diesel operation is proportional to the increasing percentage of water in the emulsion. At the maximum power output of 63kW, the HC level with diesel is 74 ppm and it reduces to a minimum of 55 ppm. CO also shows a similar behaviour particularly at higher outputs. The reduction in the emission levels is due to better combustion.

There is a significant reduction in the smoke density levels at all outputs. It falls from 6.26 BSU to 5.84 BSU at maximum output. The decrease in smoke density is contributed to the water in the emulsion. The reduction in smoke density is proportional to the increase in percentage of water oil in the emulsion.

There is a significant decrease in NO_x with the use of emulsion. It decreases from 1389 ppm to 955 ppm at maximum output of 63kW. Water brings down the temperature and oxygen concentration in the charge. This leads to a reduction in the NOx level.

From 13-mode test cycle, it was observed that the specific fuel consumption of diesel fuel alone decreases with the water diesel emulsion operation. The maximum reduction, 8.78% is achieved with 15% water diesel emulsion [fig. 13]. It is 2.65%, 5.95% and 7.08% with 5%, 10% and 20% water diesel emulsion respectively.

On the whole, use of water diesel emulsion will lead to improvement in performance and emissions of a diesel engine. The emulsion improves the combustion efficiency in the diesel engine, hence the performance of the engine. As the water percentage in the blend increases up to 15% by volume, there is no significant change in engine performance and has almost negligible effects on the engine power, torque and brake thermal efficiency. The SFC calculated by considering the total fuel as strictly the amount of diesel fuel that is burned decreases as the percentage of water increases and is maximum at 15% emulsion. The optimum emulsion based on smoke density decrease and NOx decrease compared to diesel fuel operation is 15% emulsion.

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