IJST, Transactions of Mechanical Engineering, Vol. 36, No. M2, pp 155-164
Printed in The Islamic Republic of Iran, 2012

THE ALTERNATIVE FUELS FOR FOUR STROKE COMPRESSION IGNITION ENGINES: PERFORMANCE ANALYSIS*

H. U. MUGHAL, M. M. A. BHUTTA**, M. ATHAR, E. M. SHAHID AND M. S. EHSAN

Dept. of Mechanical Engineering, University of Engineering and Technology, Lahore, Pakistan
Email: drbhutta@uet.edu.pk

Abstract– In this experimental study, the Diesel fuel blends with different percentages of Ethanol and Methanol with a constant percentage (5%) of n-Butanol were used. These percentages were 5%, 10% and 15% for Ethanol and Methanol. The Diesel fuel blends were designated as Z5E5D90, Z5E10D85, Z5E15D80 and Z5M5D90, Z5M10D85, Z5M15D80. The experiments were carried out on a three cylinder, four stroke, direct fuel injection compression ignition engine on different engine speeds at constant load, while engine performance and exhaust gas emissions of Carbon Monoxide (CO) and Hydrocarbons (HC) were also examined. The engine speed was varied from 800 rpm to 1800 rpm with an increment of 200 rpm. During the experimentation the times for consumption of 50 ml of fuel were recorded. The values of Brake Power, Brake Specific Fuel Consumption and Brake Thermal Efficiency were calculated by using the formulas. The experimental outcomes were analyzed, and showed an increase in Brake Specific Fuel Consumption and decrease in Brake Thermal Efficiency and exhaust gas emissions of Carbon Monoxide (CO) and Hydrocarbons (HC) with the use of different Diesel fuel blends.

Keywords– Ethanol, methanol, diesel blends, engine performance analysis, exhaust emissions

1. INTRODUCTION

The need for air quality improvements and the current cost of crude oil demands alternative fuels for automobiles/IC engines. The past and the present day civilization are closely interwoven with energy and in future, our existence will be even more dependent upon it. The conventional sources of energy are being depleted at a faster pace and the world is heading towards a global crisis. The greatest task today is to exploit the non-conventional energy resources for power generation. Alternative fuels are also called non-conventional fuels. Biodiesel, Ethanol, Methanol and Butanol are alternatives to fossil fuels. These can be used with the present day petrol/diesel internal combustion engines with very little or no modification.

In 1895 Dr. Rudolf Diesel used vegetable oil in an engine as a fuel. Meaningful researches have been carried out on pure vegetable oils and biodiesel fuels obtained from various cooking oils. Pure vegetable oils and biodiesel fuels can be used in diesel engines as a replacement for diesel fuel 1-5. Alcohols such as Ethanol and Methanol can be used as an alternative fuel in various gasoline engines 6-7. In Brazil, Ethanol has been accepted as an alternative fuel for the last thirty-five years 8-9. In 1970, Methanol was used as a fuel during the oil crisis. In 1980 and 1990 the blending of Methanol with petrol was also used in different European countries. Both alcohols (Ethanol and Methanol) will be used as alternative fuels in pure form or in the form of blending with conventional fuels in future to reduce the demand for conventional fuels 10-11.

In 2004 Xing-Cai et al. [12] examined the Ethanol-Diesel blend. The Cetane number improver of different percentages such as 0%, 0.2%, 0.4% was used in the fuel blends during experiments in high

*Received by the editors August 17, 2011; Accepted July 3, 2012.
**Corresponding author

speed diesel engine to check engine performance. They observed an increase in Brake Specific Fuel Consumption (BSFC) and thermal efficiency, and a significant decrease in exhaust emissions; the combustion characteristics of Ethanol–Diesel blend fuel at large load are recommenced to conventional diesel oil, although variation remains at smaller load.

In 2004 Huang et al. 13] studied the effects of Diesel-Methanol fuel blends and conducted fundamental ignition activities by using CI engine. They analyzed fundamental combustion performances of CI engine with Diesel and Diesel-Methanol fuel blends. Test results indicated that the rate of heat release in the pre-mixed flaming stage was increased, while diffusive stage burning time was reduced. When the percentage of Methanol was increased in the conventional Diesel-Methanol fuel blend, the fast burning time, total combustion time and detonation time were improved by the increase of fuel blend delivery advance angle, which also increased the peak cylinder pressure.

In 2005 Hansen et al. [14] studied significant properties of different Diesel-Ethanol blends having different percentages of conventional Diesel and Ethanol. They also analyzed the performance of Ethanol-Diesel blends in CI Engines. They concluded that the performance of Ethanol-Diesel blends varied from engine to engine and also varied by varying the engine speed itself. A considerable value of engine performance data was obtained when the Ethanol-Diesel blends were used without changing the engine specifications; Diesel-Ethanol blends were used as fuel additive.

In 2005 Li et al. 15] used different Diesel blended fuels having different percentages of Ethanol and studied performance and exhaust gases of diesel engine. The tests were executed with 0%, 5%, 10% 15% and 20% of ethanol and with 100%, 95%, 90%, 85% and 80% of petroleum diesel respectively on diesel engine. As to overall working conditions, the tests point out Brake Specific Fuel Consumption and Brake Thermal Efficiency were improved, as percentage of Ethanol increased, emissions of smoke were reduced, particularly because E10D90 and E15D85 were used. Exhaust emissions such as Carbon Monoxide and NO_x were decreased although total hydrocarbons increased considerably.

In 2008 Sayin et al. 16] used Methanol-Diesel blend fuels having different percentages of Methanol and conventional Diesel. The tests were performed on a diesel engine to check the injection timing effects on exhaust gas emissions and different Methanol-Diesel blends at different engine loads such as 5 Nm, 10 Nm, 15 Nm and 20 Nm at a speed of 2200 rpm. They demonstrated that Brake Thermal Efficiency, smoke opacity, unburned hydrocarbons and Carbon Monoxide emissions were decreased while Brake Specific Fuel Consumption, NO_x and CO emissions were increased with the increase in percentage of Methanol in Methanol-Diesel fuel blends. They also remarked that smoke opacity, unburned hydrocarbons and carbon monoxide emissions were increased with retarded injection timing of 15^0 CA BTDC, while decreasing at advance injection timing of 25^0 CA BTDC, and NO_x, Carbon Dioxide emissions were increased. The negative outcomes were observed on Brake Specific Fuel Consumption and Brake Thermal Efficiency for both injection timing with all experimental conditions.

In 2010 Zhang et al. [17] studied the mixture of decontaminated Methanol and pure conventional diesel to check exhaust emissions of the diesel engine by using five different loads with constant speed. They showed that engine Brake Thermal Efficiency was reduced at low engine loads with a slight increase at high engine loads; NOx exhaust emissions and particulate mass were decreased but carbon monoxide emissions, nitrogen dioxide emissions, and hydrocarbons emissions were increased. They also found that controlled and uncontrolled exhaust emissions were decreased with the use of diesel oxidation catalyst.

In the year 2010, Tippayawong et al. [18] tested the durability of a small agricultural engine running on dual fuel operation. Diesel and biogas were used for the study. After the completion of 3500 hours run they found that Biogas has the potential to be utilized in a dual fuel long term engine operation without involving any engine modification.

In 2010 Ozsezen et al. 19] used Methanol-Diesel blend fuels having different percentages of Methanol and conventional Diesel. The tests were performed on a diesel engine to check the injection timing effects on exhaust gas emissions and different Methanol-Diesel blends at different injection pressures such as 180 bars, 200 bars and 220 bars with the speed of 2200 rpm and engine load of 20 Nm. They demonstrated that Brake Thermal Efficiency, smoke opacity, unburned hydrocarbons and Carbon Monoxide emanations were decreased while Brake Specific Fuel Consumption, NO_x and Carbon Dioxide emissions were increased with the increase in percentage of Methanol in Methanol-Diesel fuel blends. They also remarked that smoke opacity, unburned hydrocarbons and Carbon Monoxide emissions were decreased and NO_x, Carbon Dioxide emissions were increased by increasing the injection pressure and timing.

2. EXPERIMENTAL PROGRAMME

a) Experimental procedure

In order to draw conclusions the experiments were conducted as per design shown in Table 1a, b and c by varying RPM and volume of Ethanol and Methanol in the blend over wide ranges.

Table 1a. Range of RPM

Values of rpm	800	1000	1200	1400	1800

Table 1b. Composition of ethanol-diesel blends

Name of Blends	Composition*	
	Ethanol	Diesel
Z5E5D90	5%	90%
Z5E10D85	10%	85%
Z5E15D80	15%	80%
Z5E20D75	20%	75%

**5% of n-Butanol was used in all of the blends*

Table 1c. Composition of methanol-diesel blends

Name of Blends	Composition*	
	Methanol	Diesel
Z5M5D90	5%	90%
Z5M10D85	10%	85%
Z5M15D80	15%	80%
Z5M20D75	20%	75%

**5% of n-Butanol was used in all of the blends*

First of all, the experimentation was carried out with the conventional Diesel fuel. In order to do so it was filled in a fuel tank of the Perkins/AD 3.152 Engine. Then the engine was switched on by ignition switch on the engine panel. It was kept running till it reached the operating temperature.

Throughout the experimentation the load was kept constant for various RPM as shown in Table 1a. For all the blends under study and conventional Diesel fuels the currents, voltages, carbon monoxide and hydrocarbons in the exhaust were observed at the RPM. Moreover, time for 50 ml fuel consumption by the engine was also noted to calculate the Specific Fuel Consumption under various conditions. To reduce the effect of dispersion in the data each set of experiment was repeated three times. The Brake Engine Power, Brake Specific Fuel Consumption and Brake Thermal Efficiency were calculated by using the following formulae 20.

Brake Engine Power

$$P = (VI\ COS\ Ø)/1000 \quad (1)$$

Where I is Current (A), V is voltage (V), $Cos\ Ø$ is power factor equal to 0.8, and P is power (KW)

Brake Specific Fuel Consumption

$$BSFC = 3600\ m / t\ P \quad (2)$$

Where $BSFC$ is Brake Specific Fuel Consumption (g/KWh), m is mass of fuel (g), P Brake Engine Power in (KW) and t is time (min).

Brake Thermal Efficiency

$$\eta_{th} = 860/\ ((BSFC)(H_u\ )) \quad (3)$$

Where η_{th} is Brake Thermal Efficiency (%), BSFC is Brake Specific Fuel Consumption (*g/KWh*) and H_u is Specific Calorific value (*Kcal/Kg*)

b) Experimental Set Up

The diesel engine "Perkins /AD3.152" as shown in Fig. 1 and gas analyzer "Altas -110L" were employed.

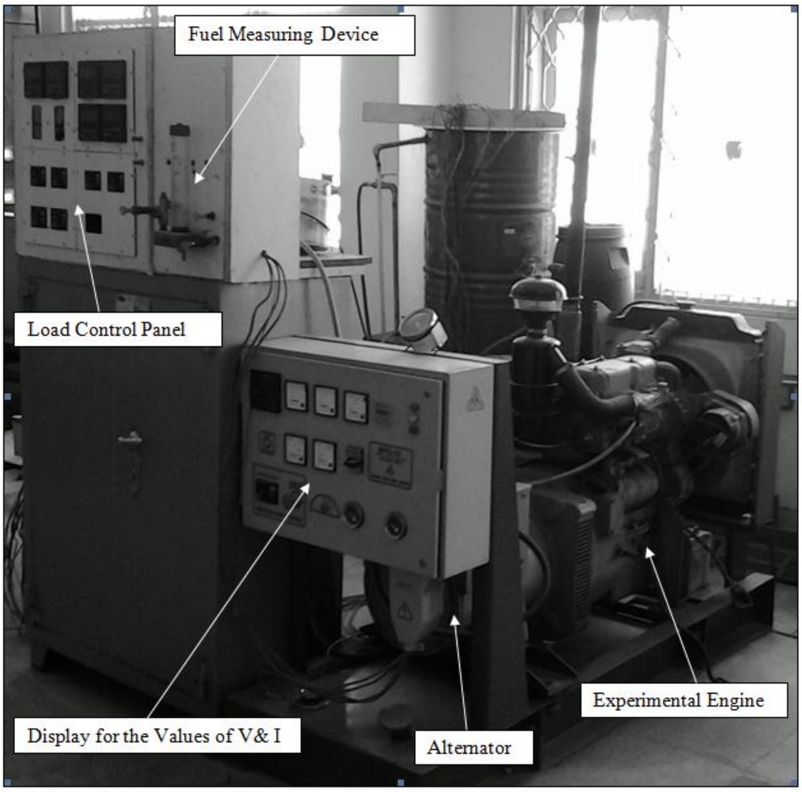

Fig. 1. Experimental setup

To prevent phase separation in the blends a constant amount of n-Butanol of 5% by volume was added in both types of blends. The engine specifications and fuel properties are given in Table 2, and 3 respectively.

c) Engine specification

The technical specifications of the experimental engine are as shown below in Table 2.

Table 2. Engine specifications

Sr. No.	Item Name	Specifications
1	Make/Type	Perkins/AD 3.152
2	Volumetric Efficiency at 25ºC	85%
3	No. of nozzle	3
4	No. of holes of nozzle	4
5	Brake Mean Effective Pressure	7.157 bar
6	Maximum Engine Power @ 2.250 RPM	36.7 KW
7	Bore	91.4 mm
8	Stroke	127.0 mm
9	Compression Ratio	16.5:1
10	Injection Timing	17ºC BTDC
11	Injection/Nozzle Pressure	600 bars
12	Maximum Torque @ 1400 RPM	173.5 N-m

d) Fuel properties

Properties of conventional Diesel, Ethanol, Methanol and n-Butanol are as shown in Table 3.

Table 3. Fuel properties 16

Sr. No.	Fuel Properties	Diesel	Ethanol	Methanol	N-Butanol
1	Chemical formula	$C_{14}H_{28}$	C_2H_5OH	CH_3OH	C_4H_9OH
2	Density at 20ºC (Kg/m^3)	880	789	791	810
3	Cetane Number	50	8	4	25
4	Lower calorific value (MJ/Kg)	42	29.7	22.7	33.075
5	Molecular weight (Kg/K mole)	196	46	32	74
6	Boiling temperature (ºC)	190-280	78	64	118
7	Flash point (ºC)	52	13	11	29
8	Viscosity at 20ºC (10^{-6} m^2/s)	3.3	1.2	0.73	3.0
9	Carbon contents (Wt %)	86	52.2	37.5	64.82
10	Oxygen contents (Wt %)	0	34.8	50	21.58
11	Hydrogen contents (Wt %)	14	13	12.5	13.60

3. EXPERIMENTAL RESULTS

The average values for various test runs were obtained for further calculations and plots were made to make comparisons

4. RESULTS AND DISCUSSIONS

a) Brake engine power

Figure 2 shows the variation in the brake engine power with RPM. Within the investigated range of the RPM, Maximum brake engine power is obtained at 1800 RPM for conventional diesel fuel and its blend fuels with Ethanol and Methanol. The trends show that brake engine power slightly increases with the increase of engine speed. This is due to a reduction in ignition delay at high temperature in engine cylinder at high speeds. The brake engine power decreases as the percentage of Ethanol and Methanol increases as a result of lower energy contents in fuel blends. It is also found that conventional diesel fuel always has higher brake engine power as compared to diesel blends. For various blends the reduction in brake engine power as compared to pure conventional diesel fuel are found to be 3.4%, 5.0%, 5.3%, 5.27%, 7.4% and 10.5% for Z5E5D90, Z5E10D85, Z5E15D80, Z5M5D90, Z5M10D85 and Z5M15D80 respectively. It is evident that with the increase in Ethanol and Methanol volume there is a decrease in brake engine power, however, when Ethanol blends are compared with the Methanol blends, the decrease in brake power is notably more in Methanol blends

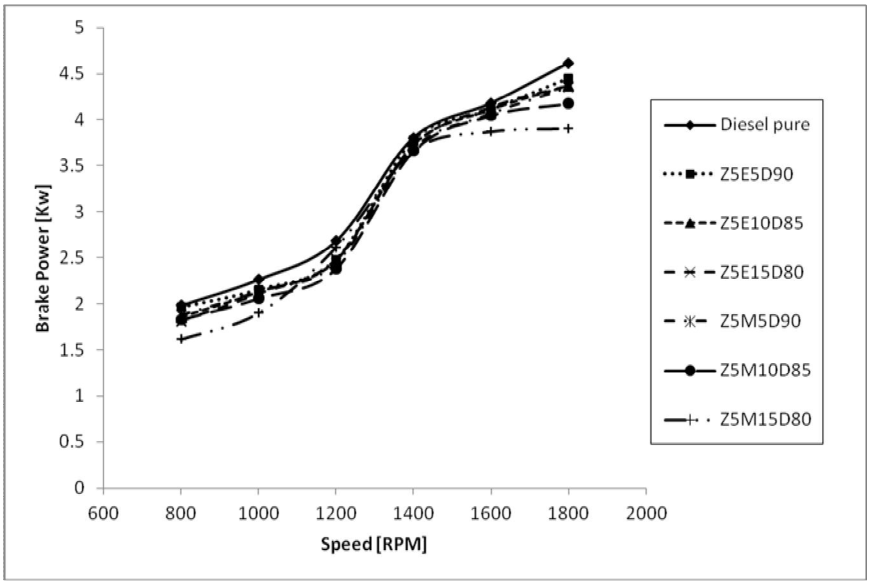

Fig. 2. Variation in brake power at different engine speeds for fuel blends

b) Brake specific fuel consumption

The variation in Brake Specific Fuel Consumption at different engine speeds is shown in Fig. 3. The Brake Specific Fuel Consumption is proportional to mass of fuel consumed as well as brake engine power. The Brake Specific Fuel Consumption increases as the percentage of Ethanol and Methanol increases in the diesel fuel blends as compared to pure conventional diesel fuel. This is due to the lower energy contents in diesel fuel blends with Ethanol and Methanol. The BSFC is increased with the increase or decrease in engine speed because of the decrease in volumetric efficiency of the engine.

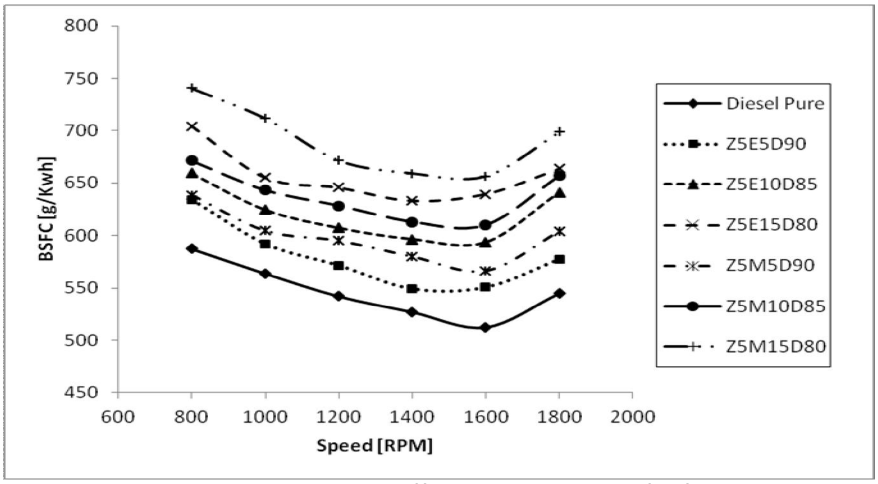

Fig. 3. Variation in BSFC at different engine speeds for fuel blends

c) Brake thermal efficiency

The variation in Brake Thermal Efficiency at different engine speeds is shown in Fig. 4. Due to low BSFC of pure conventional diesel fuel, its Brake Thermal Efficiency is higher than Diesel fuel blends with Ethanol and Methanol. It is evident from the figure that the Brake Thermal Efficiency is decreased as the percentage of Ethanol and Methanol increased. It may be attributed to lower energy contents in fuel blends.

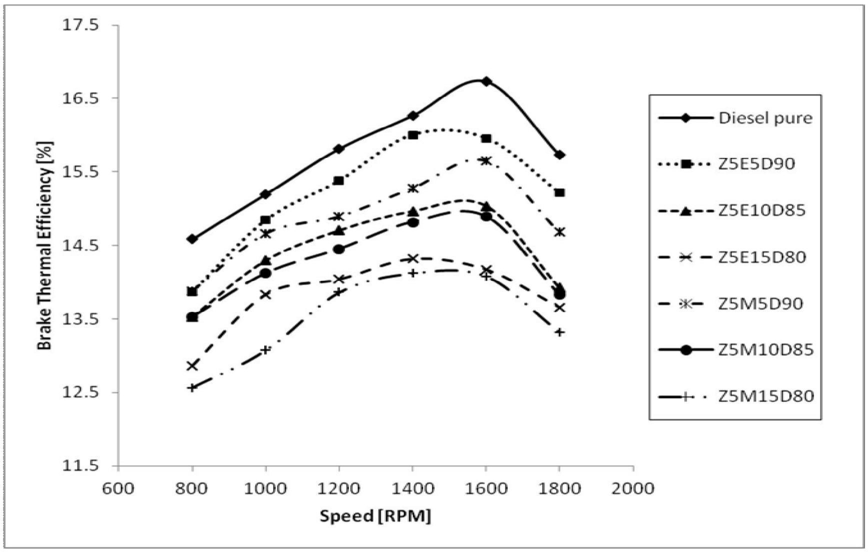

Fig. 4. Variation in brake thermal efficiency at different engine speeds for fuel blends

d) Carbon monoxide (CO) emissions

The CO exhaust emissions emitted from the diesel engine when the speed varied from 800 *rpm* to 1800 *rpm* at an increment of 200 *rpm* at fixed load are shown in Fig. 5. The average decreases in carbon monoxide emissions (CO) as compared to pure conventional diesel fuel are 13.599 %, 21.814 %, 26.834 %, 32.432%, 37.130 % and 42.781% for Z5E5D90, Z5E10D85, Z5E15D80, Z5M5D90, Z5M10D85 and Z5M15D80 respectively.

In engine emission variation, the oxygen-fuel ratio is an important factor. This is influenced by C/H ratio of the fuel. Due to oxygen contents present in Ethanol and Methanol, conversion of CO to CO_2 is higher as compared to pure conventional diesel fuel. The CO exhaust emissions are reduced as compared to diesel fuel because of these factors. In addition, Methanol has more oxygen contents than Ethanol so reduction in CO emission of Methanol-Diesel fuel blends is more than Ethanol-Diesel blends. By increasing the engine speed, the burning process is enhanced; so CO emissions are decreased in all operational circumstances.

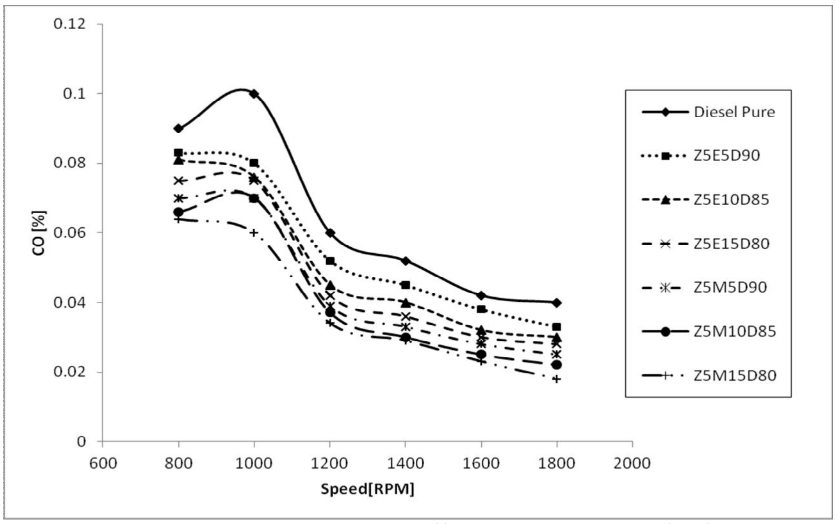

Fig. 5. Variation in CO emissions at different engine speeds for fuel blends

e) Hydrocarbons (HC) emissions

The HC exhaust emissions emitted from the diesel engine when the speed is varied from 800 *rpm* to 1800 *rpm* at an increment of 200 *rpm* at fixed load are shown in Fig. 6. The Hydrocarbons oxidation is enhanced with the accumulation of Ethanol or Methanol which caused high cylinder temperature. Due to this high temperature it becomes easier for fuel to react with O_2 while speed of flame is increased by using Ethanol or Methanol. This results in the reduction in the burning time which in turn leads to an increase in the burning temperature and hence complete burning. The hydrocarbons emissions decreased as the percentages of Ethanol and Methanol increased in diesel fuel blends.

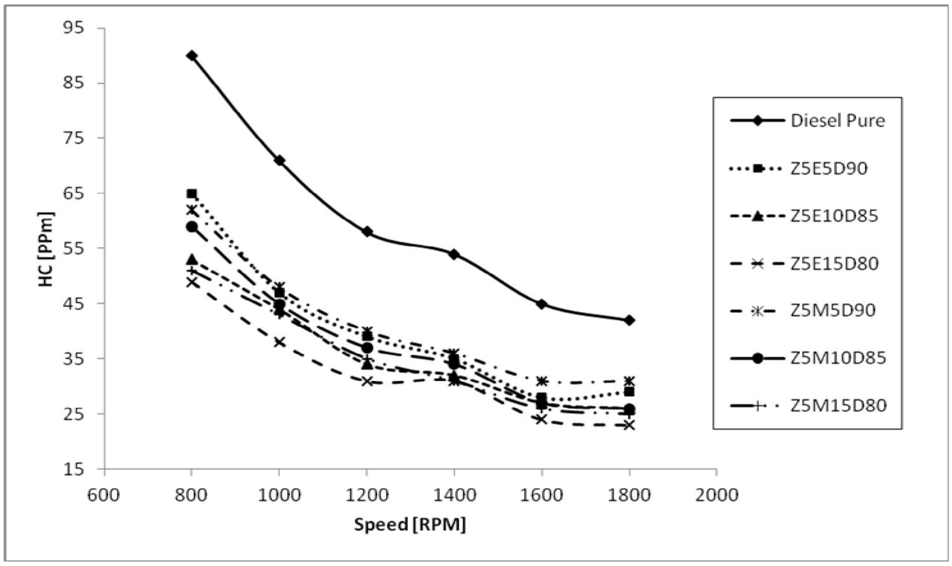

Fig. 6. Variation in HC emission at different engine speeds for fuel blends

5. CONCLUSION

Diesel engine performance and exhaust emissions when operating with different fuel blends (Methanol-Diesel fuel blends and Ethanol-Diesel fuel blends) have been experimentally investigated in the present work and the following conclusions may be drawn.

- n-Butanol is a good additive /stabilizer to avoid phase separation in Methanol-Diesel fuel blends and Ethanol-Diesel fuel blends.
- The Brake Specific Fuel Consumption increased as the percentage of Ethanol and Methanol increased in the Diesel fuel blends as compared to pure conventional diesel fuel. This is due to lower energy contents in diesel fuel blends with Ethanol and Methanol.
- The Brake Thermal Efficiency is decreased as the percentage of Ethanol and Methanol increased as compared to pure conventional diesel fuel. This is due to lower energy contents in diesel fuel blends with Ethanol and Methanol. .
- In both types of fuel blends there is a reduction in CO emissions and HC emissions. The hydrocarbons emissions and Carbon Monoxide emissions decreased as the percentages of Ethanol and Methanol increased in fuel blends as compared to pure conventional diesel fuel.
- The brake engine power decreases as the percentage of Ethanol and Methanol increases. This is due to lower energy contents in fuel blends. It is also found that conventional diesel fuel has higher brake engine power as compared to diesel blend fuels.

REFERENCES

1. Shahid, E. M. & Jamal, Y. (2008). A review of biodiesel as vehicular fuel. *Renewable and Sustainable Energy Reviews*, Vol. 12, No. 9, pp. 2484-2494.
2. Bauer, T., Lorenz, N. & Willson, B. (2004). Emissions characterization of a direct injection retro-fit kit for small two-stroke cycle engines. *Better Air Quality (BAQ) conference*, Agra, India.
3. Kojima, M., Brandon, C. & Shah, J. (2000). Improving urban air quality in south Asia by reducing emissions from two-stroke engine vehicles. *World Bank Report.*
4. Willson, B., Bauer, T. & Lorenz, N. (2002). Colorado State University clean snowmobile challenge 2002. *SAE Technical Paper*, p. 2758.
5. Roskilly, A. P., Nanda, S. K., Wang, Y. D. & Chirkowski, J. (2008). The performance and the gaseous emissions of two small marine craft diesel engines fuelled with biodiesel. *Applied Thermal Engineering*, Vol. 28, Nos. 8-9, pp. 872-880.
6. Sampaio, M. R., Rosa, L. P., Agosto, M. D. A. (2008). Ethanol-electric propulsion as a sustainable technological alternative for urban buses in Brazil. *Renewable and Sustainable Energy Reviews*, Vol. 11, No. 7, pp. 1514-1529.
7. Mak, F. K. (1985). A study of the economics of alcohol-gasoline blend production. *Energy*, Vol. 10, No. 9, pp. 1061-1073.
8. Rosillo-Calle, F. & Cortez, L. A. B. (1998). Towards ProAlcool II- A review of the Brazilian bioethanol programe. *Biomass and Bioenergy*, Vol. 14, No. 2, pp. 115-124.
9. Delgado, R. C. O. B., Araujo, A. S. & Fernandes, Jr. V. J. (2007). Properties of Brazilian gasoline mixed with hydrated Ethanol for flex fuel technology. *Fuel Processing Technology*, Vol. 88, No. 4, pp. 365-368.
10. Kisenyi, J. M., Savage, C. A. & Simmonds, A. C. (1994). The impact of oxygenates on exhaust emissions of six European cars. *SAE Technical Paper*, *940929*.
11. Bayraktar, H. (2008). An experimental study on the performance parameters of an experimental CI engine fueled with –Methanol-dodecanol blends. *Fuel*, Vol. 87, No. 2, pp. 158-64.
12. Xing-cai, L., Jian-guang, Y., Wu-gao, Z. & Zhen, H. (2004). Effect of cetane number improver on heat release rate and emissions of high speed diesel engine fueled with Ethanol–diesel blend fuel. *Fuel*, Vol. 83, pp. 2013–2020.
13. Huang, Z., Lu, H., Jiang, D., Zeng, K., Liu, B., Zhang, J. & Wang, X. (2004). Combustion behaviors of a compression-ignition engine fuelled with diesel/methanol blends under various fuel delivery advance angles. *Bioresource Technology*, Vol. 95, pp. 331–341.
14. Hansen, A. C., Zhang, Q. & Lyne, P.W.L. (2005). Ethanol–diesel fuel blends—a review. *Bioresource Technology*, Vol. 96, pp. 277–285.
15. Li, D., Zhen, H., Xingcai, L., Wu-gao, Z. & Jian-guang, Y. (2005). Physico-chemical properties of ethanol–diesel blend fuel and its effect on performance and emissions of diesel engines. *Renewable Energy*, Vol. 30, No. 6, pp. 967-976.
16. Sayin, C. (2010). Engine performance and exhaust gas emissions of methanol and ethanol–diesel blends. *Fuel*, Vol. 89, pp. 3410-3415.
17. Zhang, Z. H., Cheung, C. S., Chan, T. L. & Yao, C. D. (2010). Experimental investigation of regulated and unregulated emissions from a diesel engine fueled with Euro V diesel fuel and fumigation methanol, *Atmospheric Environment*, Vol. 44, pp. 1054-1061.
18. Tippayawong, N., Promwungkwa, A. & Rerkkriangkrai, P. (2010). Durability of a small agricultural engine on biogas/diesel dual fuel operation. *Iranian Journal of Science & Technology, Transaction B: Engineering*, Vol. 34, No. B2, pp. 167-177.

19. Sayin, C., Ozsezen, A. N. & Canakci, M. (2010). The influence of operating parameters on performance and emissions of DI diesel engine using methanol-blended-diesel fuel. *Fuel*, Vol. 89, pp. 1407-1414.
20. Ozkan, M., Ergenç, A. T. & Deniz, O. (2005). Experimental performance analysis of biodiesel, traditional diesel and biodiesel with glycerine. *Turkish J. Eng. Env. Sci.*, Vol. 29, pp. 89-94.