DIESEL PARTICULATE EMISSIONS EVALUATION FOR SINGLE CYLINDER ENGINE FUELLED WITH ETHANOL AND GAS-OIL SOLUTIONS

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ABSTRACT

Particulate matter (PM) emitted from diesel engine exhaust have been measured in terms of mass, using 99.98 % pure ethanol blended directly, without additives, with conventional diesel fuel (gas – oil),to get 10 % , 15 %, 20 % ethanol emulsions . The resulting PM collected has been compared with those from straight diesel. The engine used is a stationary single cylinder, variable compression ratio Ricardo E6/US. This engine is fully instrumented and could run as a compression or spark ignition. Observations showed that particulate matter (PM) emissions decrease with increasing oxygenate content in the fuel, with some increase of fuel consumption, which is due to the lower heating value of ethanol. The reduction in PM formation increased with load increase, maximum reduction were 58% at 1800 rpm. There was no significant reduction observed at low loads. It could be concluded from the test results that ethanol may be an alternative to / or partially substitute, fossil fuels.

KEYWORDS
Diesel engine, Ethanol – diesel blend, Particulate matter, Performance

الخلاصة :

الغرض من البحث دراسة تأثير زيادة نسبة الأوكسجين المضافة إلى وقود الديزل على معدل تكون (كثافة) المادة الدقائقية. تناول البحث القياس الكتلي لكمية المادة الدقائقية المنبعثة من عادم محرك ديزل يعمل بخليط من الكحول الأثيلي (نسبة نقاوته 99.98 %) ووقود الديزل الأعتيادي، بدون إضافة اي مادة مساعدة أخرى. المستحلبات (الخلائط) المستعملة في التجارب هي 10% ، 15 % ، 20 %، وقد قورنت كمية المادة الدقائقية الناتجة من هذه المستحلبات مع تلك الناتجة من تشغيل المحرك بوقود الديزل النقي بنفس الظروف. المحرك المستخدم في البحث أحادي الاسطوانة، ثابت، ذو نسبة إنضغاط متغيرة، من نوع ريكاردو(E6/US) وله امكانية التشغيل كمحرك انضغاطي الاشتعال أو بالشرارة.

وقد اظهرت النتائج أن إضافة الايثانول إلى وقود الديزل تؤدي إلى تناقص معدل تكون المواد الدقائقية ولمختلف ظروف تشغيل المحرك، مع زيادة طفيفة بمعدل استهلاك الوقود لتعويض انخفاض القيمة الحرارية للوقود. أظهرت النتائج أن معدل تكون المادة الدقائقية يتناقص بزيادة الكحول المضافة وبزيادة الحمل.أكبر معدل إنخفاض تم الحصول عليه هو بحدود 58 % عند إضافة 20 % كحول وعند سرعة 1800 rpm. بينت النتائج ان الكحول الأثيلي يمكن ان يحل محل وقود الديزل جزئيا على الأقل.

INTRODUCTION

The main advantages of diesel engine over gasoline engine are its fuel economy and durability, expectation are that diesel engine use will increase due to their superior performance characteristics. Diesel engine exhaust (DE), however, contains harmful pollutants in a complex mixture of gases and particulates.

Particulate matter (PM) is of concern because of its established relationship with human health and environmental contamination. PM penetrates through the respiratory systems damaging lunges and causing lunge cancer. When particulate settle on ground or water, it changes the nutrient balance in water depleting the nutrient in soil and damaging sensitive forests and farm corps.

In recent years many methods for the reduction of DE pollutants have been introduced, such as using alternative fuels and a variety of fuel additives and fuel blends **((Kowalewicz, 2005 & 2006)**, (**Lauerta, 2002), (Lu, et al, 2000))** development of new engine design (fuel injection optimization, modification of combustion chamber shapes **(Litzinger, et al 200)**) , exhaust gas recirculation (EGR) technique **(Ladommatos, et al 1998)**, as well as improving the quality of the fuel (reducing sulphur content **(Huang, et al, 2007)**).

At present time ambient air quality standards around the world (e.g.: **USEAP, 2002, AQEG, 2005** and many others) have tighten the highest limit of fine particles in the ambient air. This makes reduction in DE emission a major research task in engine development.

Alternative fuels are becoming increasingly important due to environmental concern as well as replacing the conventional depleting fossil fuel. Ethanol is regarded as a kind of renewable fuel because it can be produced from agricultural sources, such as dates, sugar beets, barley, sugar cane, molasses and waste biomass materials etc., by using already improved and demonstrated technologies. In this frame bioethanol has the opportunity to contribute to the gradual substitution of fossil fuels, not only in the gasoline sector but even in the diesel one. Direct blending of ethanol with diesel fuel provides higher oxygen concentration, thus higher potential for particulate emission reduction.

One of the main reasons of PM formation is a local deficiency of oxygen during combustion of fuel in the engine combustion chamber. Hence enhancing the availability of oxygen in the combustion area would limit the intensity of PM formation. Increasing the amount of oxygen locally; can be done by supplying oxygen together with the fuel, this is achieved by: either using oxygenated additives or by dissolving oxygen in the fuel.

Oxygenated fuel additives are materials contain a high percentage of oxygen in their molecular structures, such as alcohols, ethers, carbonates, acetates, glycols and esters. Many researchers **(Litznger, et al, 2000), (Ladommatos, et al, 1998),** and **(Musculus & Diets, 2005)**) have investigated oxygenated additives, and their results indicate a dramatic reduction in PM emission. Oxygenation through gas dissolving in the fuel is also investigated; by dissolving air or diesel exhaust in the fuel **(Kowalewicze, et al, 2002), (Jerzy, et al, 2007).**
Jincheng Huang and co-workers conducted two sets of experiments at 1500 and 2000 rpm, and measured the opacity of diesel exhaust, they claim that they observed a decrease in smoke for the two sets of experiments; at 2000 rpm the reduction rates were from 16.7% to 65% for the 10% ethanol blend, and were from 45.2% to 82.9% for the 20% ethanol blend and 33.3% to 87.5% for the 25% ethanol; and similar trend for 1500 rpm. Their experiments were performed with 5% of n-butanol as a solvent. **Hassan and co-workers** indicated that for a 20% ethanol in diesel fuel cause a 14% reduction in smoke formation. **Lapuerta, et al**

also claim a reduction nearly 50% in smoke opacity for the loads covered in their experiments.

The results obtained in this work are in agreement with most of the literature reviewed, thereby confirming the results of this study.

EXPERIMENTAL INSTALLATION:

Testing was performed in a single cylinder variable compression ratio Ricardo E6/US engine, engine specifications are presented in **Appendix A**. The engine is four strokes, naturally aspirated and mounted on a common bedplate with an electric dynamometer and equipped with controls to regulate engine speed and load. The engine is adaptable to run as either a spark ignition or as a compression ignition engine. Alteration to ignition timing or injection timing can be made while the engine is running. **Figure (1)** shows a schematic diagram of the experimental test rig arrangement. **Figure (2)** shows a cross section of the engine. The fuel flow rate was measured by recording the time required for the consumption of 50ml of fuel, and intake airflow rate was measured using an orifice fitted to a 200 litre air tank connected with the induction manifold to reduce pressure pulsations.

Measurement of the pressure inside combustion chamber was performed by a pressure transducer, AVL 8QP 500C, pressure-time history inside the cylinder could be obtained with the use of a high speed measurement system (previous work (**Salman, 2005**)). **Figure (3)** shows examples of the pressure – crank angle diagrams obtained. Exhaust PM mass concentrations was measured by means of a gravimetric method **(Casati, et al, 2007)**, by sampling through a glass fibre filter fitted inside a specially developed support, shown in **figure (4).** The filters were weighed before and after sampling using an electronic balance to determine the total mass of PM collected on the filters. For each test a sample of exhaust gas (100ml) was carefully taken from the centre-line of the exhaust tail pipe by 100ml syringe and injected through the filter as indicated in **figure (4).**

TEST PROCEDURE:

Investigations were carried out at constant speed and varying load. Four different speeds (900, 1200, 1500, 1800 rpm) were selected to cover a wide range of engine operating conditions.

Four fuels of varying ethanol blend level were included in this work in order to study the effect of ethanol percent on particulate matter emission (the worst drawback on diesel engines). Ethanol blend concentration levels were specified on volume-percent bases and include 0, 10, 15, and 20%.

At each engine speed. The following parameters were recorded:

- Engine torque
- Fuel consumption
- Air consumption
- Intake air temperature
- Exhaust gas temperature
- Particulate matter

In the present study, first all measuring equipment were prepared and calibrated, then the highest useful compression ratio and the best injection timing were determined for each type of fuel and they were found to be 17/1 and 38^{o} BTDC respectively.

At each changes of fuel, lines were drained prior to filling them with the next fuel. Before beginning a new test, the sample syringe was cleaned in order to eliminate deposits of the previous test. After that, the engine was warmed up with the new fuel for at least 30 minutes to purge any of the remaining previously tested fuel. At each test several measurements of air and fuel consumption and three different particulate filters were taken. There were very little differences between the various measurements; however, in order to minimize any experimental inaccuracy averaged values were used for recording the results.

RESULTS AND DISCUSSION:

1) Engine Performance:

The effect of applying different loads on brake specific consumption (**bsfc**) at constant speed, was investigated for; 900, 1200, 1500, and 1800 rpm. **Figure (5)** represent the variation of **bsfc** at 1500 rpm, observation indicates that the more ethanol added in, the more fuel consumption, and generally straight gas-oil has the lowest fuel consumption is consistent in other tested speeds. The small increase of **bsfc** is expected due to the lower heating value of ethanol (26994 kJ/kg) compared to that of gas-oil (45144 kJ/kg), **Appendix B**. The 10, 15 and 20 percent blends have a drop in heating value of 4%, 6%, and 8% respectively. Increase in **bsfc** is not fixed for each blend. The test results show that at low to medium loads, up to 40 N, there was a negligible increase in **bsfc**, but it increases with load increase, and was at most 8% at 50 N load. A similar trend was observed in the other tested speeds.

The differences in **bsfc** reflect the differences in some of the physical properties of the fuel, such as: density, Oxygen content and heating value. **Figure (6)** represent the relation between maximum load and ethanol content, it shows that maximum load produced (power) reduced with increasing ethanol content for all tested speed. Moreover it can be concluded that highest reductions in load (power) were; 4%, 8%, 15%, and 15% for 900, 1200, 1500 and 1800 rpm respectively.

2) Particulate Matter:

It is well known that engine emissions are affected by the air/fuel ratio. In this study, the effect of ethanol content on air/fuel ratio is represented in **figure (7)** at medium load (40N) for the four tested speeds. It is clear that, differences in air/fuel ratio were very slight at each engine speed for as ethanol percentage increased; this was the case for other tested loads. Therefore, the production of emissions was due to different compositions of the fuel, but not to differences in air/fuel ratio.

Figures (8 – 11) show the relationship between PM mean concentration (μg/m^3) and loads applied in N at constant speed, when the engine fuelled with 0, 10, 15 and 20 percent ethanol blends, while **figures (12 – 15)** illustrates the relationship between PM mean concentration and ethanol contents percent by volume at constant load, for the same blends. Results show that the rate PM formation was decreasing as ethanol content (Oxygenate) in gas-oil increased. This was consistent in all four tested speeds. The observations are in accordance with that found in all literature reviewed **(Hassan, 2004)**, **(Lapuerta, 2008), (Huang, 2009), (Xing-cai, 2004)**. This behaviour can be mainly explained to the improvement in the combustion process due to the presence of oxygen, which leads to reduce the probability of PM formation in locally rich zones. Moreover, it can be seen that PM formation decrease more in high loads than that at low loads. This is reasonable since more fuel is needed at high loads.

Adding oxygenates to diesel fuel (gas-oil) had a remarkable affect on the reduction of PM formation, especially at high load at any engine speed. When the engine ran with 10% ethanol blend on different engine speeds of 900, 1200, 1500 1800, PM formation rates were decreased by (7 – 50) %. For 15 % ethanol blend, the reductions were between (5 – 58) %, and for 20% ethanol blend, the reductions were up to 58%.

CONCLUSIONS:

Based on the experimental results of this study, the following can be drawn:

1) With reference to straight diesel fuel, it can be stated that PM collected on the filter decreases significantly as the ethanol content increases in the fuel.

2) The highest reduction in PM emission is at 1800 rpm and load of 45 N. Hence, it reaches about 58 % with 20 % ethanol addition.

3) The reduction in PM is low when the loads are at low level.

4) Ethanol could be used as alternative fuel to substitute diesel fuel partially or totally.

5) The bsfc was increased due to lower heating value of Ethanol.

6) The results obtained on performance and PM emission are in agreement with most of the literature viewed.

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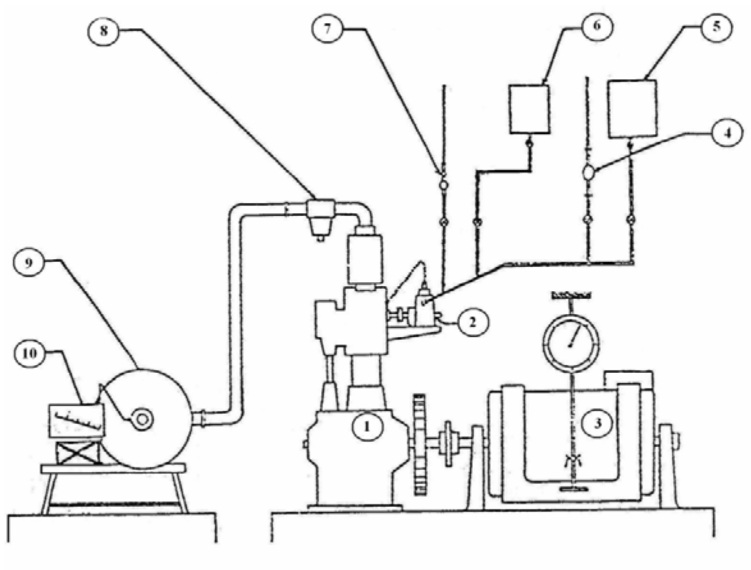


1- Engine	2- Fuel injection pump
3- Electric dynamometer	4- Gas oil fuel meter
5- Gas oil tank	6- Emulsified fuel tank
7- Emulsified fuel meter	8- Air filter
9- Air box	10- Inclined manometer

Fig.1: Schematic of the Engine and Fuel Supply System

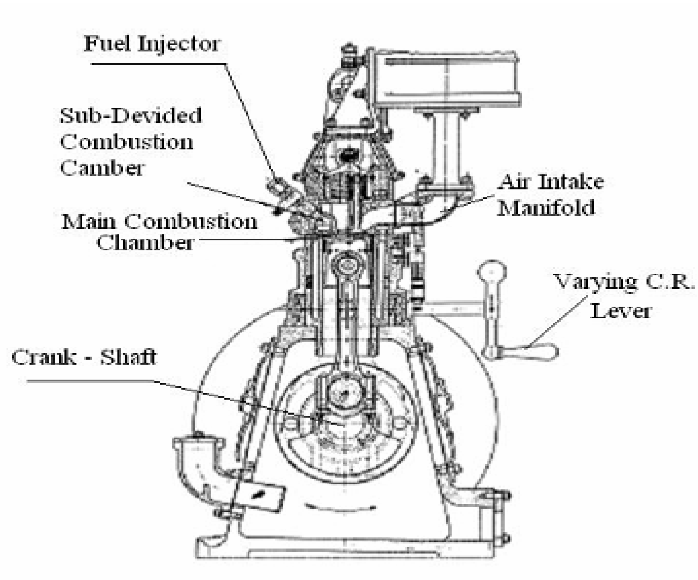
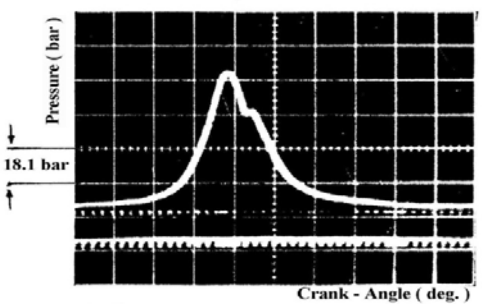
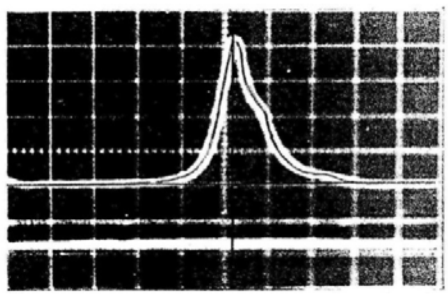


Fig. 2: Cross section of the engine used

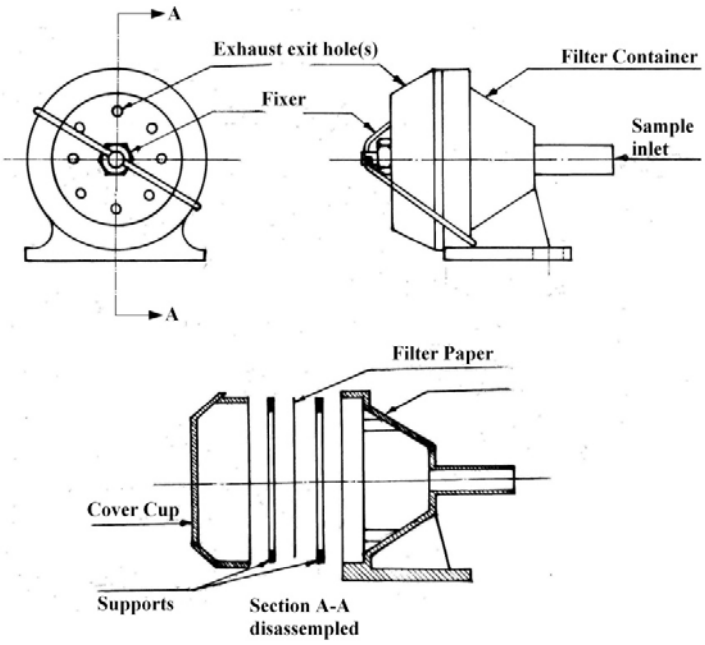




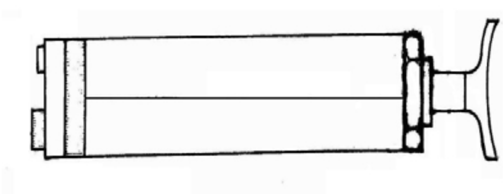
A) 900 rpm engine speed and 5.5 N Load
Fuel : Straight Gas Oil

B) 1200 rpm engine speed and 32 N Load
Fuel : 0.8 Gas Oil + 0.2 Ethanol

Fig. 3: Examples of pressure – crank angle curves obtained from oscilloscope screen for different speeds, Loads and fuel solutions (Salman, 2005).



A) Filter



B) Syringe

Fig. 4: Particulate Matter Measurement equipment

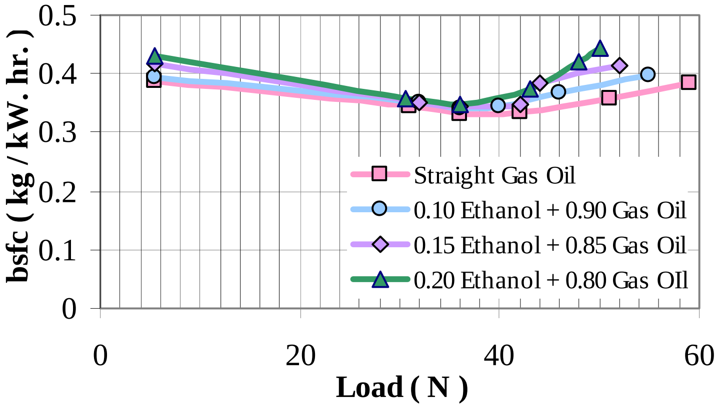


Fig. 5 : Effect of Ethanol Content on *bsfc* at Constant Speed (1500 rpm)

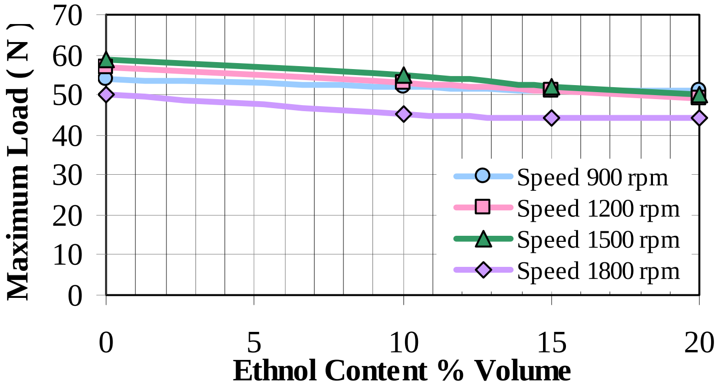


Fig. 6 : Maximum Load Variation with Ethanol Content For Different Speeds

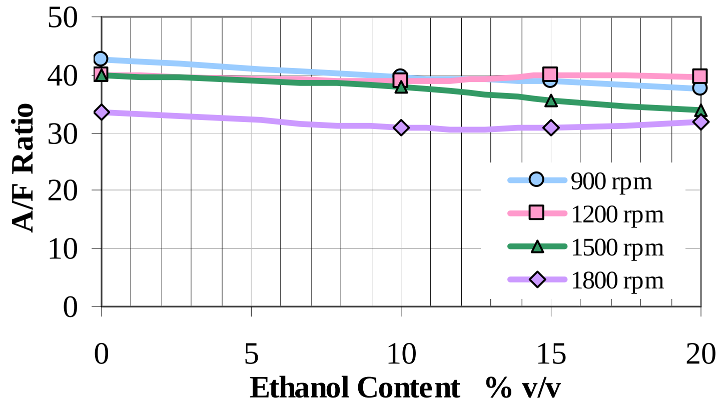


Fig. 7 : Effect of Ethanol Content on A/F Ratio at (25 N) Load for Different Speeds

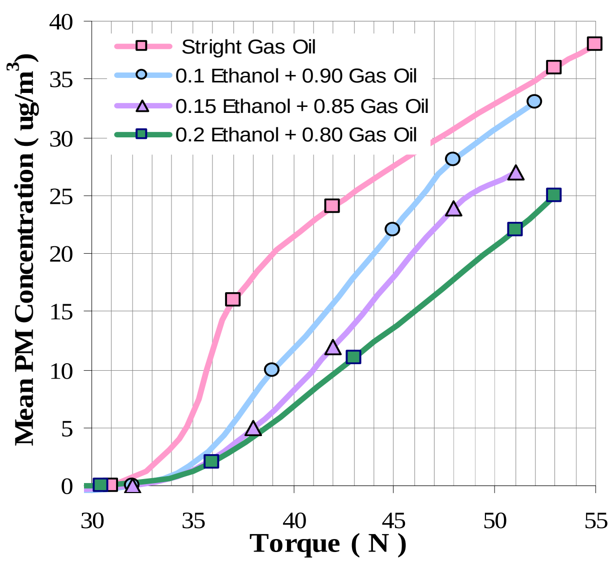


Fig.8:Effect of Ethanol Content on Mean Mass Particulates Concentration in the Exhaust Gasses for different loads at Engine Speed (900 rpm)

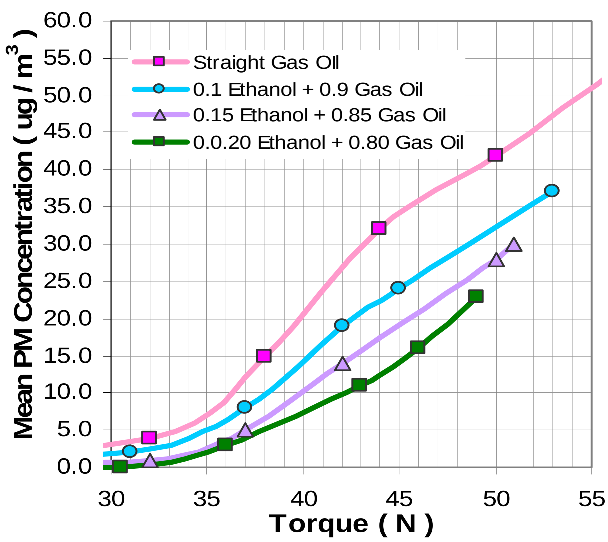


Fig.9: Effect of Ethanol Content on Mean Mass Particulates Concentration in the Exhaust Gasses for different loads at Engine Speed (1200 rpm).

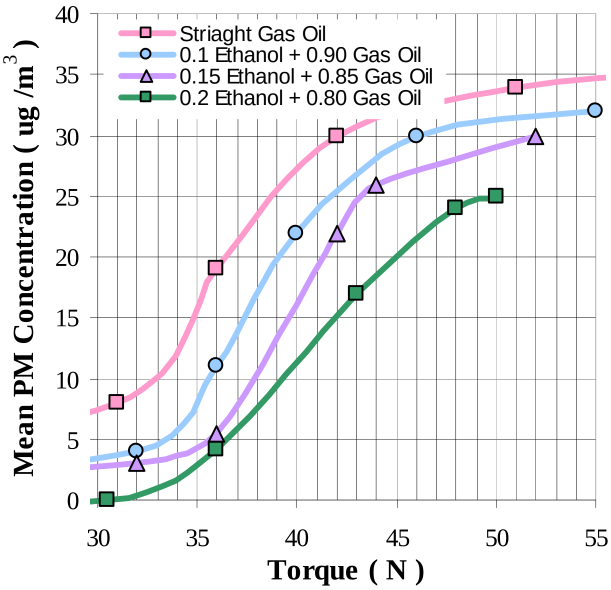


Fig.10: Effect of Ethanol Content on Mean Mass Particulates Concentration in the Exhaust Gasses for different loads at Engine Speed (1500 rpm).

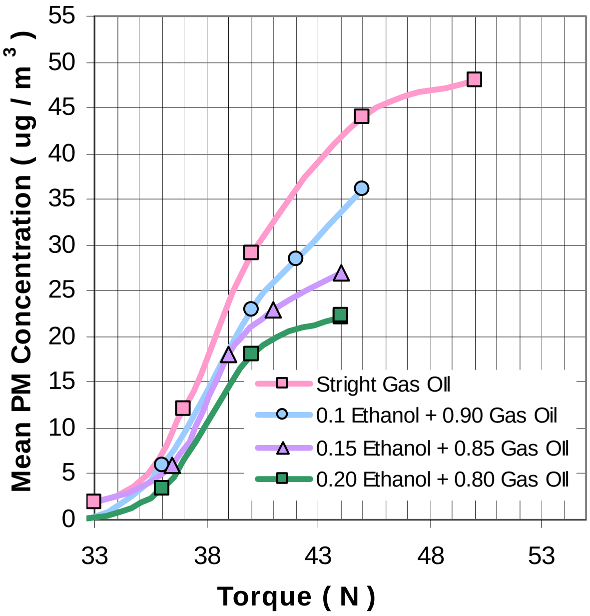


Fig.11: Effect of Ethanol Content on Mean Mass Particulates Concentration in the Exhaust Gasses for different loads at Engine Speed (1800 rpm).

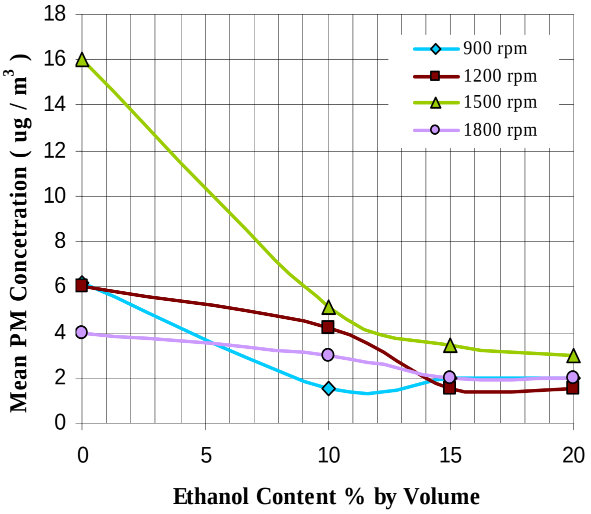


Fig.12:Effect of Ethanol Content on Mean Mass Particulates Concentration in the Exhaust Gases s for different speeds at constant load of 35 N.

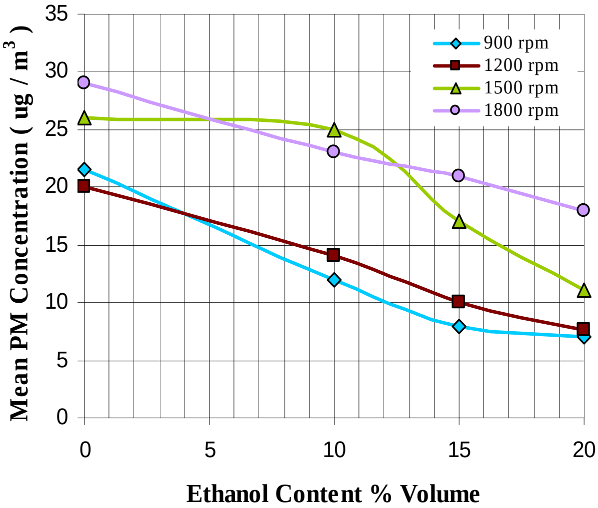


Fig.13:Effect of Ethanol Content on Mean Mass Particulates Concentration in the Exhaust Gases for different speeds at constant load of 40 N.

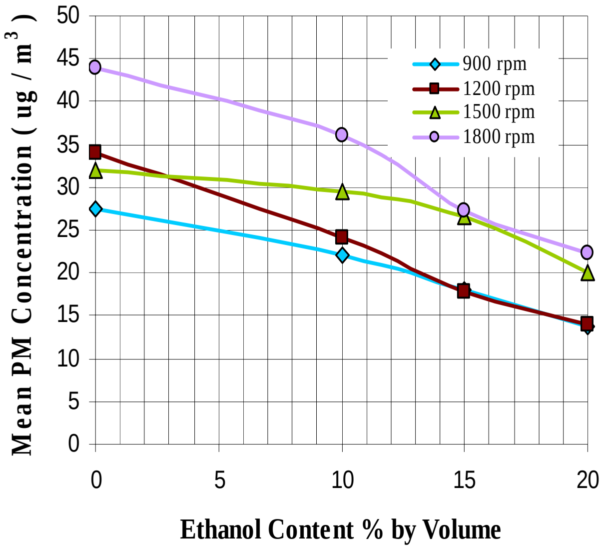


Fig.14: Effect of Ethanol Content on Mean Mass Particulates Concentration in the Exhaust Gasses for different speeds at constant load of 45 N.

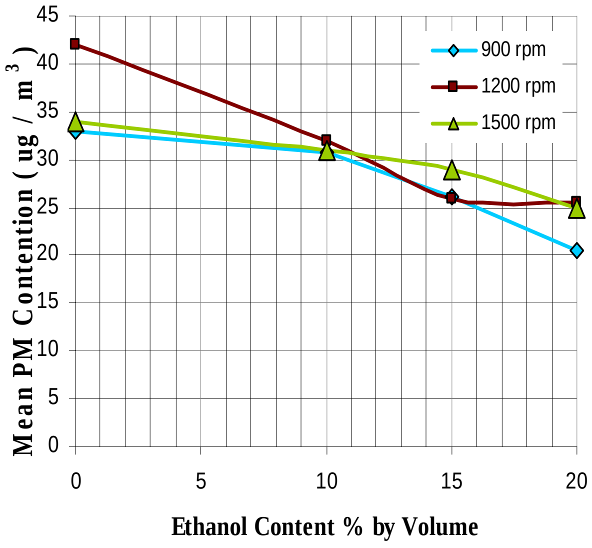


Fig.15: Effect of Ethanol Content on Mean Mass Particulates Concentration in the Exhaust Gasses for different speeds at constant load of 50 N.

APPENDICES:

Appendix – A

Specification of the Engine

No. of Cylinders	1
Bore	76.2 mm
Stroke	110 mm
Capacity	507 CC
Valve Timing	Inlet opens 9^o BTDC
	Inlet closes 38^o BTDC
	Exh. opens 44^o BTDC
	Exh. closes 9^o BTDC

Appendix – B

Properties of Gas Oil and Ethanol

1- Properties of Gas Oil

Chemical Formula	$C_{14}H_{24}$
Specific Gravity	0.84
Flash Point ^oC	54
Viscosity Cst at 38 ^oC	6
Sulphur Content % W	0.2
Diesel Index	55
Cetane No.	53
Calorific Value KJ/ Kg (Gross)	45144

2- Properties of Ethanol

Chemical Formula	C_2H_5OH
Specific Gravity	0.79
Flash Point ^oC	21
Viscosity Cst at 40 ^oC	1.1
Octane No.	89
Cetane No.	8
Calorific Value KJ/ Kg (Gross)	26994