Comparative study of California reformulated gasoline (CARB), Finnish gasoline (RFG 2) and Egyptian commercial gasoline and its environmental impacts

Mohsen Mohamed Osman
Faculty of Engineering, Alexandria University, Alexandria 21544, Egypt

The environmental impacts of four types of unleaded gasoline fuels with different oxygenate additives but comparable standard octane numbers, has been analyzed using a fixed compression ratio FIAT engine. The aim of the work was to identify the potential of using tertiary amyl methyl ether (TAME) and methyl tertiary butyl ether (MTBE) – blended gasoline as a lower emissions and lower toxic substitute for non-oxygenated Egyptian commercial gasoline and the prospective MTBE- blended Egyptian gasoline. One of the tested fuels was a typical Egyptian unleaded gasoline, the other gasoline had different oxygenate contents depending upon the mass percent of MTBE and TAME ethers added. Taking into consideration the raised concern over the safety of MTBE and its impact on urban aquifers and wells, the new suggested gasoline blend comprises of lower mass percent (4%) of MTBE and higher mass percent (9%) of TAME than other blends, gave better results. The new suggested gasoline blend gave best performance, highest thermal efficiency, lowest CO and NO_x emissions among all fuel blends under full-load operating condition. Test results indicate also that the new suggested gasoline blends gave lowest NO_x and HC emissions among all fuel blends used under part-load operating conditions. Finnish reformulated gasoline (RFG2) with (7wt % TAME+4 wt % MTBE) gave best engine performance, highest thermal efficiency among all fuel blends used under part-load operating conditions. It is concluded that tertiary amyl methyl ether (TAME) is an attractive and environmentally –safe blending component for gasoline manufacture.

تم تحليل الآثار البيئية لأربع أنواع من وقود البنزين الخالي من الرصاص بإضافات أوكسجنية مختلفة ورقم أوكتان قياسى متقارب وذلك باستخدام محرك فيات ذو نسبة انضغاط ثابتة. يهدف هذا البحث الى بيان امكانية استخدام وقود البنزين المخلوط مع كل من ثلاثى اميل الاثير المثيلى وثلاثى بيوتال الاثير المثيلى كوقود بديل ذو نسب انبعاثات أقل وملوثات أقل فى سموميتها للبنزين التجارى فى السوق المصرية والبنزين المصرى المزمع انتاجه مضافا اليه ثلاثى بيوتال الاثير المثيلى. أحد أنواع الوقود المختبرة فى البحث هو بنزين مصرى خالى من الرصاص والأنواع الأخرى بها اضافات مختلفة لمكون الأوكسجين بتغيير النسبة المئوية للأضافة الخاصة بثلاثى اميل الاثير المثيلى وثلاثى بيوتال الاثير المثيلى. آخذين فى الاعتبار الأهتمام المتزايد بشأن الأمان البيئى لاستخدام ثلاثى بيوتال الاثير المثيلى وتأثيره على منابع مياه المناطق السكانية والآبار. وجد أن استخدام البنزين المقترح تركيبه بنسبة مخفضة (٤%) من ثلاثى بيوتال الاتثير المثيلى ونسبة أكبر من ثلاثى اميل الاثير المثيلى (٩%) عن الخلطات الأخرى قد أعطى نتائج أفضل. أعطى وقود البنزين المقترح الجديد أفضل اداء للمحرك مع أعلى كفاءة حرارية، وأقل نسب انبعاث لملوثات أول أكسيد الكربون وأكاسيد النيتروجين بين كل خلطات الوقود المختلفة المستخدمة فى البحث عند التشغيل على الحمل الكامل للمحرك. كما أوضحت النتائج أن البنزين المستخدم فى كاليفورنيا أعطى أقل نسبة انبعاث للهيدروكربونات الغير محترقة فى حالة الأحمال الجزئية للمحرك بين كل خلطات الوقود المستخدمة.أعطى وقود البنزين المقترح الجديد بنسبة (٩%) من اضافة اميل الاثير المثيلى و (٤%) من اضافة ثلاثى بيوتال الاثير المثيلى أحسن اداء للمحرك وأعلى كفاءة حرارية بين كل خلطات الوقود المستخدمة فى حالة الأحمال الجزئية للمحرك. أمكن استنتاج أن ثلاثى اميل الاثير المثيلى يعتبر اضافة مهمة بيئيا يمكن لمنتجى وقود البنزين استخدامها.

Keywords: Alternative fuels, Fuel additives, Ether-Gasoline, Blends.

1. Introduction

The phasing out of lead additives has created another conflict. Engine have been designed around the fuel octane rating , which was lowered by the reduction in lead content. The octane ratings of unleaded petrol were maintained by an increase in the proportion of aromatics – as lead content fell from 0.7 to 0.15 g/l., average aromatic content rose from 28 to 42 %, but is currently back down to 35%. In terms of overall use, there were 10 kt

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of lead and 6 Mt of aromatics in UK petrol in 1985; by 1993 the lead content had dropped to 1600 tons while the aromatics had risen to 9 Mt. This would present little problem if all the cars running on unleaded petrol were fitted with catalytic converters.

Although there are some industrial source of benzene, 78% of atmospheric benzene in the UK derived from petrol engine exhausts. This means that the range of daily benzene intake varies by at least a factor of ten, from a few tens to a few hundreds of micrograms. Another class of materials emitted from vehicle exhausts that has caused concern due to their carcinogenicity is the polycyclic aromatic hydrocarbons PAH such as benzo (a) pyrene (Bap) and benzo (e) pyrene (Bep). The world Health Organization (WHO) guideline is that a life time exposure to 1 ng/m^3 will cause 90 additional respiratory cancers per 106 individuals.

The observation that oxygen-bearing fuels lead to lower HC and CO emissions has led to the 1990 Clean Air Amendments [1] requiring regions with severe winter CO problems to use only gasoline that contains at least 2.7 weight percent oxygen during the winter months. It appears that this requirement will be mostly met by blending into the gasoline methanol or ethanol or methyl tert-butyl ether (MTBE), which is made from isobutene and methanol. All three of these improve the octane number of the fuel they are blended into. Incomplete combustion of methanol produces formaldehyde, which must be remove from the exhaust because of its negative health impacts.

One of the reasons motivating the development of alternate fuels for the IC engine is concern over the emission problems of gasoline engines. Combined with other air-polluting systems, the, large number of automobiles is a major contributor to the air quality problem of the world. Actually the net improvement in cleaning up automobile exhaust since the 1950s, when the problem became apparent, is over 95%. However, additional improvement is needed due to the ever-increasing number of automobiles.

Reformulated gasoline is normal-type gasoline with a slightly modified formulation and additives to help reduce engine emissions. Included in the fuel are oxidation inhibitors, corrosion inhibitors, metal deactivators, detergents, combustion aids, and deposit control additives.

On the plus side is that all gasoline-fueled engines, old and new, can use this fuel without modification. On the negative side is that only moderate emission reduction is realized, cost is increased, and the use of petroleum products is not reduced [2].

The use of oxygenates (oxygen containing organic compounds) as extenders or substitutes for gasoline is increasing, [3]. In some cases, this is because the oxygenate can be produced from non-petroleum sources (e.g., biomass, coal) and thus may offer strategic or economic benefits. In other case, the good antiknock blending characteristics of oxygenates can aid in meeting octane quality demands where increasingly stringent regulations limit lead alkyl use. Several oxygenates have been used as automotive fuels; those of major interest are methanol (CH_3 OH), ethanol (C_2 H_5 OH), tertiary butyl alcohol (TBA) (C_4 H_g OH), and methyl tertiary butyl ether (MTBE). They are added such that there is 1-3% oxygen by weight. This is to help reduce CO in the exhaust. Levels of benzene, aromatics, and high boiling components are reduced, as is the vapor pressure.

The effect of gasoline composition on exhaust emissions from modern BMW vehicles was studied by Lange et al., for thirteen different hydrocarbon groups of fuels with widely varying physical properties and chemical composition [4]. For all fuels tested, CO and HC emissions were lowest for fuels with MTBE, low aromatics and high volatility. They concluded that the effect of fuel quality on NO_x emissions varied for the different vehicles. The MTBE containing volatile, low-aromatic fuel reduced NO_x emissions from the BMW 525i, had negligible effect on the BMW 316i but increased NO_x from the BMW 740 i.

McDonald et al. [5], tested six full range gasoline fuels in two engines (one with a catalyst) operated at 4 steady states. They showed that changing fuel composition will primarily alter the production of CO and NO_x emissions by modifying the stoichiometric air/fuel ratio, projecting engine operation onto another part of the equivalence ratio (ϕ) response curve.

Investigations made by Jeune et al. [6], into fuel compositional effects on emissions using model and full range fuels suggest aromatic components promote NO_x conversion over the catalyst. Toluene formed more combustion chamber NO_x, offest by increased catalyst conversion efficiency giving lower tailpipe NO_x than isooctane in the vehicle with the better catalyst light-off and air fuel ratio control.

A comparison of the effects of MTBE and TAME on exhaust and evaporative emissions was performed in the US Auto/Oil study. No significant differences were found between the two oxygenates in exhaust mass THC nonmethane hydrocarbons, NMHC, CO, NO_x or total toxic pollutants [7].

An evaluation of the total toxic emissions (formaldehyde, acetaldehyde, 1,3- butadiene and benzene) of both Finnish reformulated gasoline containing MTBE (RFG1), or MTBE + TAME + heavier ethers (RFG2) and non-oxygenated Eurograde gasoline (EN228) was jointly searched by Technical Research Center of Finland and Neste Oil Refinery [8]. Their results showed that a decrease of 30% on average in the total toxic emissions of catalytic cars at + 22°c test temperature and approximately 40% at -7°c test temperature for both RFG1 and RFG2 when compared to the reference Eurograde gasoline fuel EN228 because of oxygenates. By using TAME and heavier ethers in RFG, octane is more evenly distributed along the entire boiling range. They have higher boiling points than MTBE and they have also higher octane numbers than corresponding olefins used in gasoline.

MTBE- gasoline blends have good water stability, and MTBE has little effect on vapor pressure (i.e. the vapor pressure of MTBE at 25°c is about 1/3 of an atmosphere) and material compatibility. Water solubility allows MTBE to transfer easily from gasoline to air and then to water or from gasoline directly to water. MTBE will reversibly transfer back and forth between water and air depending upon which stream has the relatively higher (non-equilibrium) concentration. MTBE has only weakly partitions to soils and generally moves along with groundwater in the subsurface.

Several events have raised concern over the safety of MTBE. In 1996, the city of Santa Monica, USA closed some at its major drinking water wells after discovering MTBE contamination. In addition, the U.S. Geological Survey recently reported MTBE to be the second most common contaminate in shallow urban aquifers. Three percent of the USGS shallow urban wells (They were not drinking water supplies) tested exceeded the minimum US EPA draft health advisory level of 20 μg/l. Very little toxicological data can be found on MTBE in published literature [9].

The purpose of this research is to clearly identify the potential of using (TAME + MTBE) - blended gasoline as a lower emissions and lower toxice substitute for non- oxygenated Egyptian commercial gasoline and the prospective MTBE -blended Egyptian gasoline.

2. Experimental

2.1. Test fuels

Four test fuels were experimentally investigated during this research. The first fuel, unleaded gasoline, represented typical Egyptian commercial gasoline sold in Egypt: high aromatic content and no oxygenates. The second fuel is similar to California Reformulated Gasoline (CARB) with one exception: basic fuel blend was prepared by mixing reformat 70 vol. % and petroleum ether 20 vol. % and light straight run naphtha (LSRN) 10 vol. %. Methyl tertiary Butyl Ether (MTBE) with a purity of 99 % from Saudi-British Petrochemical Co. (Ibn Zahr) in Jubail, Saudi Arabia was used in preparing the second, third and forth oxygenated fuel blends. The third fuel, RFG2, represented similar Finnish reformulated gasoline with different basic fuel blend and without heavier ethers, like TH_x ME and Ne_x TAME.

Tertiary Amyl Methyl Ether (TAME) from Neste Porvoo Refinery in Finland was used in preparing the third and forth oxygenated fuel blends.

The fourth fuel was blended to a slightly higher aromatic content than second fuel (CARB). The difference between this fourth fuel and other fuels was the increase of TAME weight percent in fuel blend.

Results of complete fuel blends analyses according to ASTM procedure are shown in Table 1.

3. Test engine and apparatus

The experiments were performed on a four-stroke, four-cylinder, carbureted spark - ignition Fiat engine (type 138 B 3.00). Cylinder bore, stroke and compression ratio were 86.4 mm, 63.9 mm and 8:1 respectively. The engine displacement was 1498 cm^3 with a maximum power of 54 kW at 5500 RPM. For tests conducted in a wide - open - throttle (WOT) condition, the range of speed investigated was 1200 – 3500 RPM. The speed was adjusted to the required values by controlling engine load obtained through the dynamometer load control.

The rate of fuel consumption was measured by the constant - volume method (50 - ml burette and a stop watch). The rate of air flow was measured by a surge-tank system consisting of 180 liters tank, Venturi flow meter by Flow - Dyne Engineering, USA, and mercury U-tube manometer.

The engine was coupled to a hydraulic dynamometer of the Froude type. The dynamometer is equipped with a load control and engine tachometer. fig. 1 shows schematic diagram of the experimental set - up

One sample line of engine exhaust was taken downstream of the engine exhaust manifold to an exhaust Multigas gas analyzer by Tecnotest of Italy. CO, CO_2 and HC were measured by a non-dispersive infrared technique while NO_x and O_2 were measured by special chemical kind sensors.

3.1. Test Procedures

The engine was started and warmed up for 25 minutes in order to reach steady state operational conditions for each fuel. The effect of mixture composition change on engine operating and emission characteristics was considered in two regimes. In the first type of experiments the throttle valve of the engine is set permanently to the fully open position or wide open throttle (WOT), and the braking load is changed on the engine via the dynamometer thus changing the RPM at which the engine was operated, i.e. the throttle position is set as our fixed variable.

In the second set of experiments; constant engine speed test, the readings were taken at the same set RPM's as before, but this time each RPM reading was taken at four different throttle positions, ¼, ½, ¾, and full load. The following quantities were routinely measured during each test:

- ☐ Intake-maniflod vacuum, (kPa)
- ☐ Exhaust gas temperature, (°c),
- ☐ Fuel mass flow rate, (kg/h),
- ☐ Engine coolant mass flow rate, (kg/h),
- ☐ Engine rotational speed, (RPM), with an accuracy of 10 RPM
- ☐ Engine load, (N),
- ☐ Carbon monoxide (CO) emission by percentage volume, (vol. %) with an accuracy of 0.01%

Table 1
Test Fuel Properties

Test / Fuel blend	Density @ 15°c g/ml ASTM D-1298	Research. Octane No. ASTM D-2699	FIA Analysis ASTM D- 1319			Net heat of combustion ASTM D-1405 MJ/kg
			Aromatics	Olefins	Paraffin	
1- Commercial gasoline	0.7550	88.2	44.3	Nil	55.7	42.129
2- 10.3 wt % MTBE fuel blends	0.7341	85.0	33.5	Nil	66.5	42.176
3- 4 wt % MTBE + 7 wt % TAME fuel blend	0.7225	83.6	26.95	Nil	73.05	42.166
4- 4wt % MTBE + 9 wt % TAME fuel blend	0.7442	87.1	37.2	Nil	62.8	42.09

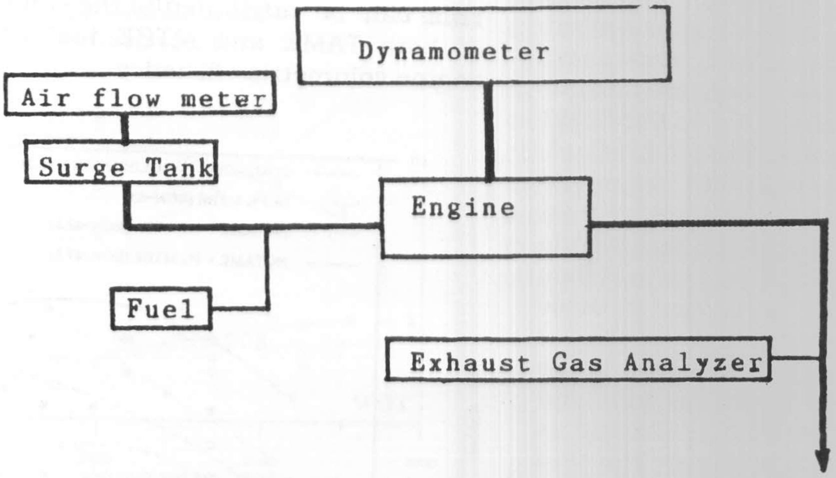


Fig. 1. Schematic diagram of the experimental set-up.

- Carbon dioxide (CO_2) emission by percentage volume, (vol. %). with an accuracy of 0.1 %
- Exhaust gases unconsumed oxygen (O_2) by percentage volume, (% vol) with an accuracy of 0.01-0.1 % .
- Unburned hydrocarbon emission in parts per million, (ppm), with an accuracy of 1 ppm
- Nitrogen- oxides (NO_x) emission in Parts Per Million (ppm) with an accuracy of 5 ppm.
- Excess air factor (λ). with an accuracy of 0.001

Uncertainties in measuring brake power and brake specific fuel consumption are estimated. Error in measuring engine load and rate of fuel consumption indicate uncertainties within 1.5%' t0 2.5% for brake power and within 5 % for brake specific fuel consumption.

4. Results and discussion

4.1. Effect of fuel blends on engine performance under full-load operating conditions

The effect of fuel blends on the engine torque, brake power, brake mean effective pressure, volumetric efficiency, brake thermal efficiency and brake specific fuel consumption at full load operating conditions are discussed below based on the present test results.

Fig. 2 showed the relation between engine driving torque in N.m and engine speed for different fuel blends and under full load operating conditions. It can be noticed that for all fuel blends, the engine driving torque increases in general as engine speed increases. The (9 wt % TAME + 4 wt % MTBE) fuel blend gives highest engine driving torque followed by 10.3 wt % MTBE fuel blend, commercial gasoline and (7 wt % TAME + 4 wt % MTBE) fuel blend.

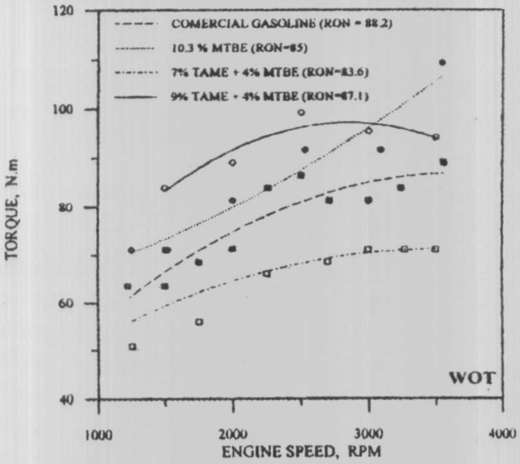


Fig. 2. Variation of engine driving torque with engine speed for different fuel blends at full load.

The relation between engine brake power in kW and engine speed for different fuel blends and under full–load operating condition is shown in fig. 3. The engine output power increases in general with increasing engine speed with highest engine output gained with (9 wt % TAME + 4 wt % MTBE) fuel blend followed by 10.3% MTBE fuel blend. This can be attributed to improved combustion efficiency of (9 wt %TAME + 4 wt % MTBE) and 10.3 wt % MTBE fuel blends over the commercial gasoline due to presence of 2.1 wt % and 1.9 wt % oxygen in these blends, respectively.

Fig. 4 shows the relation between brake mean effective pressure (bmep) in kPa and engine speed in RPM. It has similar trend as fig. 3 for engine output brake power. The best engine performance in terms of highest brake mean effective pressure is achieved with (9 wt % TAME + 4 wt % MTBE) fuel blend.

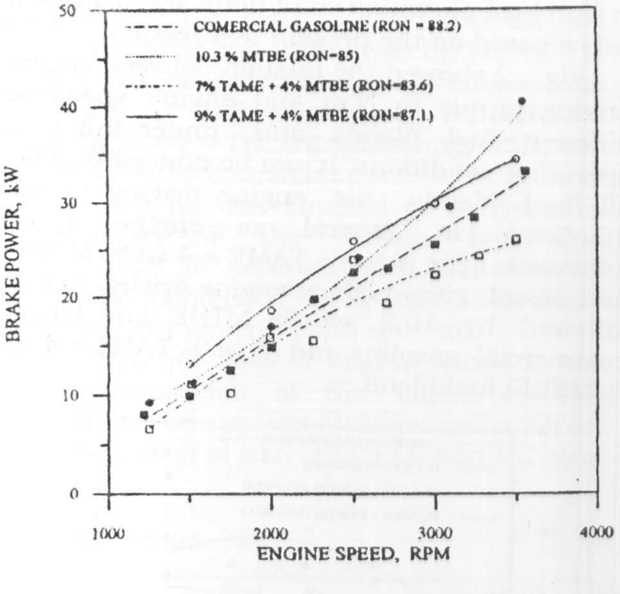


Fig. 3. Variation of engine brake power with engine speed for different fuel blends at full load.

The engine thermal efficiency increases with increasing the engine speed as shown in fig. 5. The best fuel blend achieving highest thermal efficiency is (9 wt % TAME + 4 wt % MTBE) fuel; blend up to engine speed of 3000 RPM where thermal efficiency of 10.3 wt % MTBE fuel blend exceeded. An average increase of 13 % in the absolute value of engine thermal efficiency can be noticed for (9 wt % TAME + 4 wt MTBE) fuel blend (RON = 87.1) over commercial gasoline (RON = 88.2). This can be attributed to the combined effect of both TAME and MTBE fuel additives on engine volumetric efficiency.

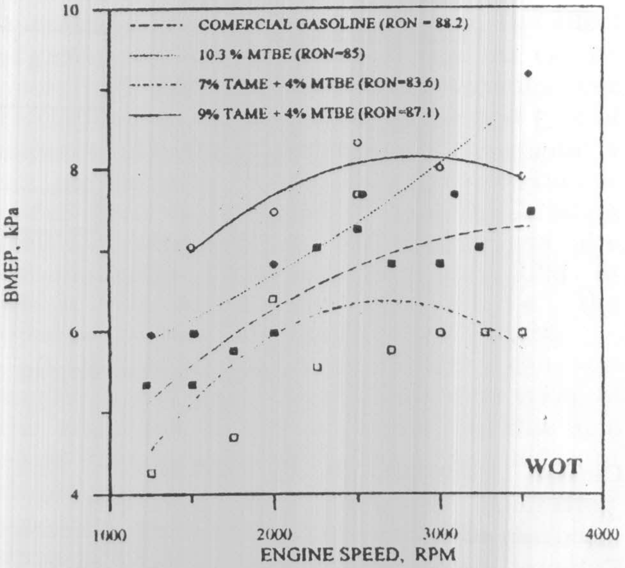


Fig. 4. Variation of engine brake mean effective pressure (b .m.e.p) with engine speed for different fuel blends at full load.

The fuel-air mixture temperature decreases as liquid fuel is vaporized. The decrease in air temperature that accompanies liquid fuel evaporation more than offsets the reduction in air partial pressure due to the increased amount of fuel vapor: for the same heating rate, volumetric efficiency with commercial gasoline vaporization is higher than (9 wt % TAME + 4 wt % MTBE) fuel blend.

Fig. 6 shows the relation between the brake specific fuel consumption (bsfc) in kg / kWh and engine speed in RPM for different fuel blends under wide open throttle (WOT) operating condition. It can be seen that (9 wt % TAME + 4 wt % MTBE) fuel blend achieves the lowest bsfc up to engine speed of 3000 RPM where 10.3 wt % MTBE fuel blend achieves the lowest brake specific fuel consumption after that.

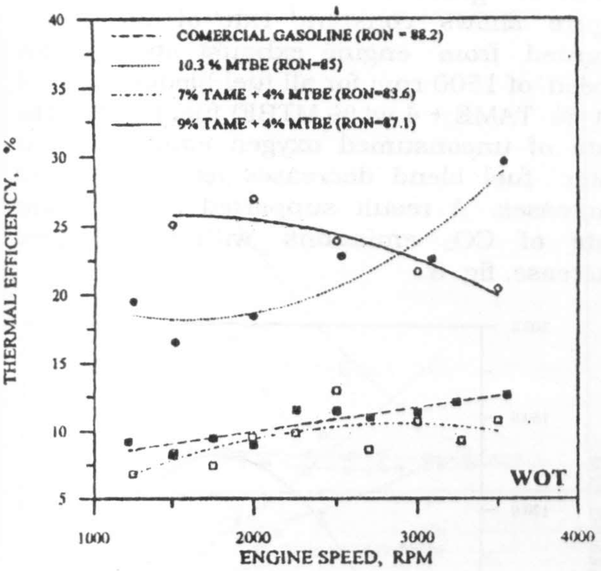


Fig. 5. Variation of engine thermal efficiency with engine speed for different fuel blends at full load.

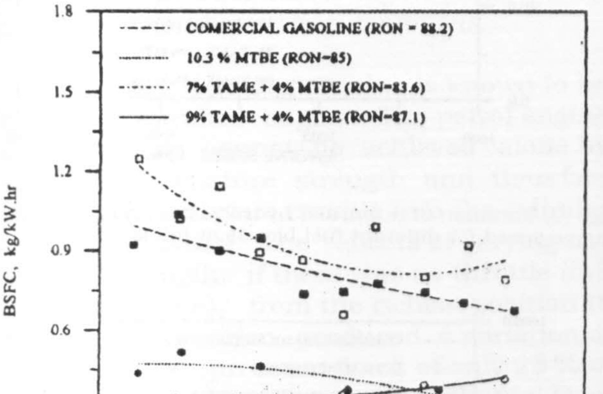


Fig. 6. Variation of engine brake specific fuel consumption (b.s.f.c) with engine speed for different fuel blends at full load.

4.2. *Effect of fuel blends on engine emissions characteristics under full - load-operating conditions*

Fig. 7 shows lower carbon - monoxide (CO) emissions for both (9 wt % TAME + 4 wt % MTBE) and 10.3 wt % MTBE fuel blends up to engine speed of 3000 RPM where (7 wt % TAME + 4 wt % MTBE) fuel blend and commercial gasoline achieve lower CO emissions after that.

This can be attributed to the improvement in combustion process and the presence of an oxygen atom in both methyl-tertiary-butyl ether (MTBE) molecule and tertiary - amyl - methyl ether (TAME) molecule which is weakly bonded to two carbon atoms (an ether linkage) that facilitates the complete combustion of the ether to carbon dioxide and water.

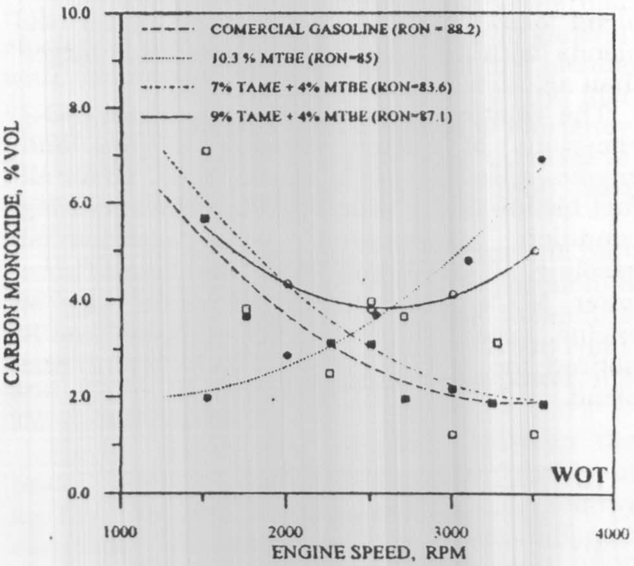
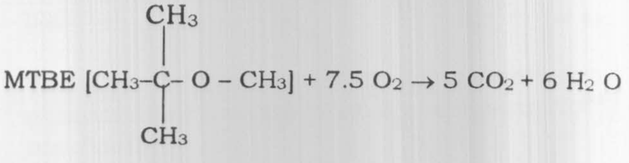
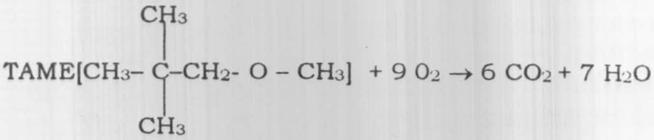


Fig. 7. Variation of carbon monoxide emissions with engine speed for different fuel blends at full load.



$$\text{MTBE } [CH_3-\overset{CH_3}{\underset{CH_3}{C}}-O-CH_3] + 7.5\,O_2 \rightarrow 5\,CO_2 + 6\,H_2O$$



$$\text{TAME}[CH_3-\overset{CH_3}{\underset{CH_3}{C}}-CH_2-O-CH_3] + 9\,O_2 \rightarrow 6\,CO_2 + 7\,H_2O$$

The activation energy for the combustion of hydrocarbons specially aromatics which are major constituents of gasoline is relatively higher than that for ethers.

It can be observed in fig. 8 that carbon dioxide emission increases with increasing engine speed. The highest improvement in combustion efficiency is achieved with (7 wt % TAME + 4 wt % MTBE) fuel blend and commercial gasoline over the whole full- load engine speed range.

As engine speed increases, exhaust unburned hydrocarbon, (HC) emission decrease for 10.3 wt % MTBE fuel blend, fig. 9. For both commercial gasoline and (7 wt % TAME + 4 wt % MTBE) fuel blend, exhaust HC emission increases as engine speed increases up to 2500 RPM and then decreases with lower HC values than 10.3 w% MTBE fuel blends. (9 wt% TAME + 4 wt % MTBE) fuel blend follows the same trend of the former two blends with HC emission peak value larger than all other blends.

The relation between nitrogen oxides (NO_X) emissions of engine exhaust in ppm and engine speed in rpm is shown in fig. 10 for all fuel blends under wide-open throttle operating condition. Compared with commercial gasoline, all MTBE and TAME fuel blends have lower NO_x emission rate in the useful range of engine speed. The lowest NO_x emission rate is noticed for (9 t % TAME + 4 wt % MTBE) fuel blend.

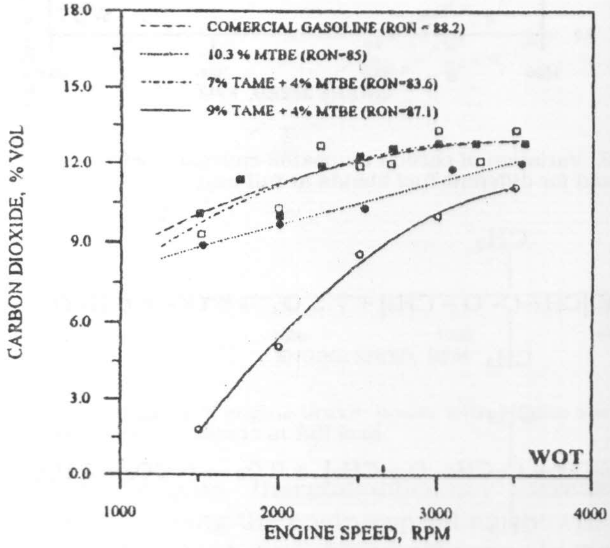


Fig. 8. Variation of carbon dioxide emissions with engine speed for different fuel blends at full load.

The effect of oxygenates (MTBE & TAME) on unconsumed oxygen emitted with engine exhaust gases is illustrated in fig. 11 The figure shows constant rate of oxygen less emitted from engine exhaust above engine speed of 1500 rpm for all fuel blends except (9 wt % TAME + 4 wt % MTBE) fuel blends. The rate of unconsumed oxygen emitted for the later fuel blend decreases as engine speed increases. A result supported by increasing rate of CO_2 emissions with engine speed increase, fig. 8.

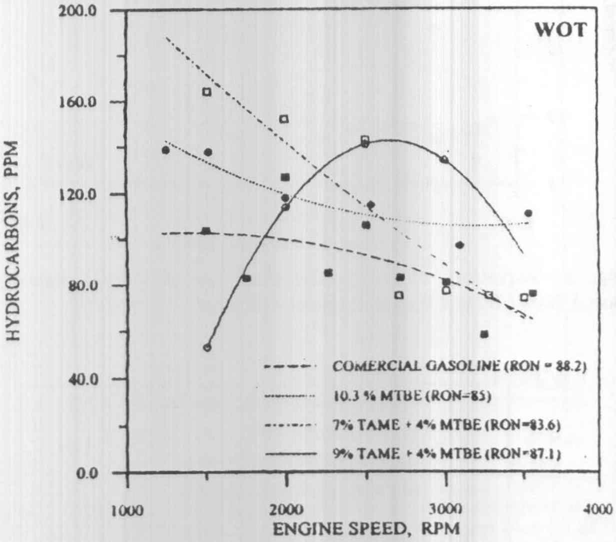


Fig. 9. Variation of unburned hydrocarbon emission with engine speed for different fuel blends at full load.

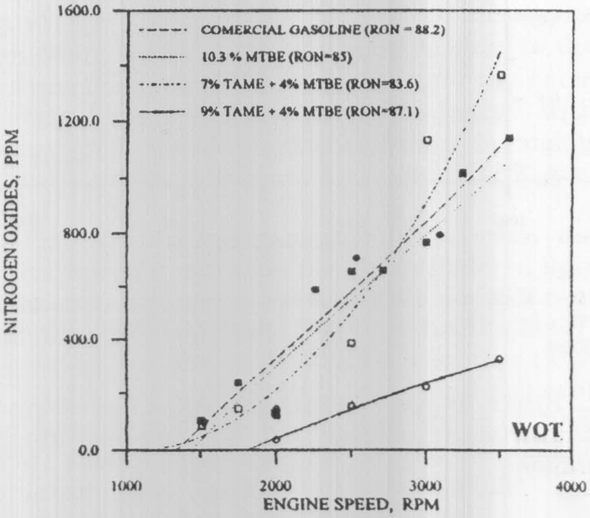


Fig. 10. Variation of nitrogen oxides emission with engine speed for different fuel blends at full Load.

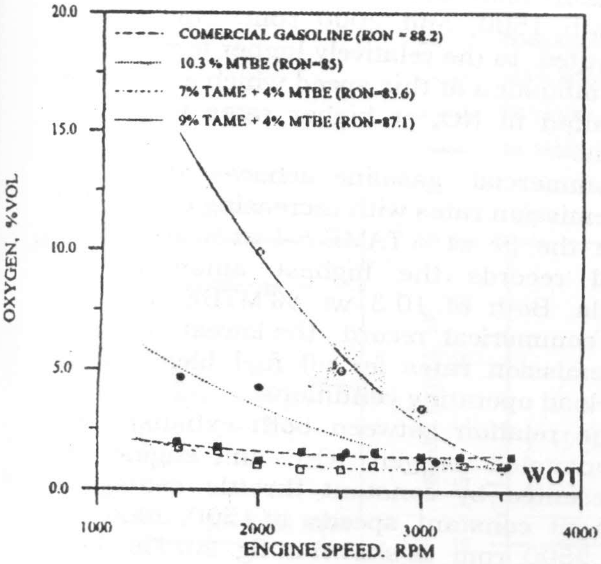


Fig. 11. Variation of unconsumed oxygen with engine speed for different fuel blends at full load.

4.3. Effect of fuel blends on engine performance under part – load operating conditions.

The spark ignition engine is known to be quantity controlled engine. The petrol engine output control cannot be achieved alone by varying the mixture strength and therefore throttling the mixture coming into the cylinder becomes essential. The effects of varying the mixture strength, if there was no throttle (full throttle position), from the richest position to the weakest position produced a variation of mean effective pressure (load) of only 25 % of the maximum possible b.m.e.p. that is, from 75 - 100 % of maximum b.m.e.p. The effect of throttling and adjusting the mixture-strength are done roughly by the ¼. ½, ¾, and full throttle setting of the throttle butterfly.

fig. 12 indicates that (9 wt % TAME + 4 wt % MTBE) fuel blend achieves the highest engine driving torque among all fuel blends for engine speeds of 1500 and 2000 rpm. At engine speed of 2500 rpm, both 10.3 wt% MTBE fuel blends and (7 wt % TAME + 4 wt % MTBE) fuel blend record higher rate of increase of engine driving torque with increasing engine load.

The relation between the engine output brake power in kW and engine load represented by constant throttle setting for different constant speeds, at 1500, 2000, and 2500 r p m is shown in fig. 13. Similar to the relation between engine driving torque and engine, load, the engine brake power increases in general with increasing engine load for any fixed engine speed. Engine power is directly proportional to engine driving torque and engine speed.

Fig. 14 shows the relation between engine thermal efficiency and engine load represented by constant throttle settings for different constant speed at 1500, 2000, and 2500 rpm. The highest thermal efficiency is recognized with the largest constant engine speed of 2500 rpm for all fuel blends. The engine thermal efficiency remains almost constant in general with increasing engine load for all fuel blends except (7 wt % TAME + 4 wt % MTBE) fuel blend with which engine thermal efficiency fluctuates between decrease and increase at different engine speeds of 1500, 2000, and 2500 rpm.

It should be mentioned here that the part load operating conditions for this experimental part represent just 85 % of the maximum engine driving torque (113 Nm @ 3000 rpm), and 45 % of the maximum brake power, (55 kW @ 5600 rpm).

Fig.15 shows the relation between the brake specific fuel consumption (bsfc) in kg/kW. hr and engine load represented by constant throttle settings for different constant speeds at 1500, 2000, and 2500 rpm. (9 wt % TAME + 4 wt % MTBE) fuel blend achieves the lowest bsfc among all fuel blends while comerical gasoline records the highest bsfc.

4.4. Effect of fuel blends on engine emission characteristics under part – load operating conditions

Figs.16 and 17 show the relation between both CO emissions, CO_2 emissions in volume % and engine load represented by constant throttle settings for different constant speeds of 1500, 2000 and 2500 rpm. Increasing the engine load results in increasing the CO emissions and reducing the CO_2, emission for all fuel blends at different constant engine speeds. 10.3 wt % MTBE fuel blend records lowest rate of CO emissions with increasing engine load among all fuel blends. Consequently, the highest CO_2 emission rate is achieved by 10.3 wt % MTBE fuel blend under part – load operating condition, fig. 17.

Figs. 18 and 19 show the relation between both unburned HC emissions and NO_x emissions in ppm and engine load represented by constant throttle settings for different constant speeds of 1500, 2000, and 2500 rpm. At engine constant speed of 1500 rpm, increasing the engine load results in increasing the HC emissions and reducing the NO_x emissions for all fuel blends. This can be attributed to the relatively low temperature of combustion at this speed. For engine constant speed of 2000 and 2500 rpm and starting from the minimum unburned HC emissions at about 50-60% of the maximum engine load, increasing the engine load results in increasing the unburned HC emissions for all fuel blends due to the enrichment of mixture with fuel. Decreasing the engine load below this minimum point results also in increasing the unburned HC emissions for all fuel blends. For this engine constant speed of 2000 and 2500 rpm, the NO_x emission increases first up to 50% of the maximum engine load then decreases to a minimum at full load WOT operating condition. Running the engine at a speed of 2500 rpm increases the rate of NO_x emissions more than the corresponding values of both 1500, and 2000 rpm. This can be attributed to the relatively higher temperature of combustion at this speed which encourages formation of NO_x at higher rates for all fuel blends.

Commercial gasoline achieves the lowest NO_x emission rates with increasing engine load while the (9 wt % TAME + 4 wt % MTBE) fuel blend records the highest among all fuel blends. Both of 10.3 wt % MTBE fuel blend and commerical record the lowest unburned HC emission rates for all fuel blends under part-load operating conditions.

The relation between both exhaust gases unconsumed oxygen (O_2) and engine load represented by constant throttle settings for different constant speeds of 1500, 2000, and and 2500 rpm is shown in fig. 20. The figure shows constant rate of oxygen (around 2 vol %) emitted from engine exhaust for all fuel blends under part-load operating conditions. (9 wt % TAME + 4 wt % MTBE) fuel blend behaves slightly different. The rate of unconsumed oxygen (O_2) emitted for this blend decreases as engine load increases. These results support the increasing rate of CO_2 emissions with engine load increase, fig. 17.

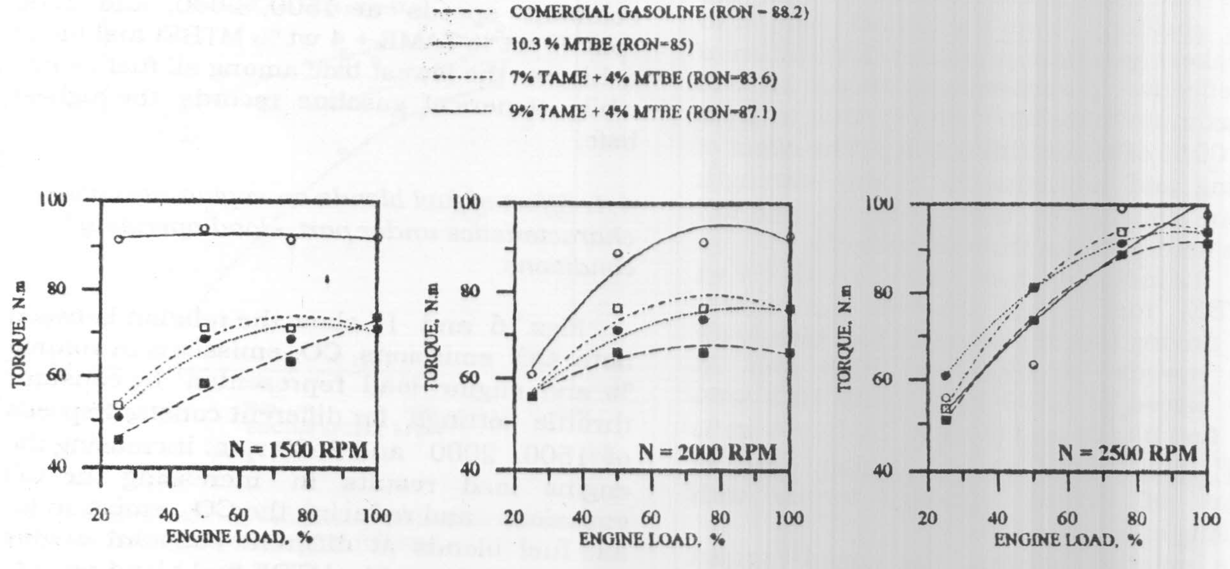


Fig. 12. Variation of engine driving torque with engine load for different fuel blends at 1500, 2000, and 2500 rpm part load.

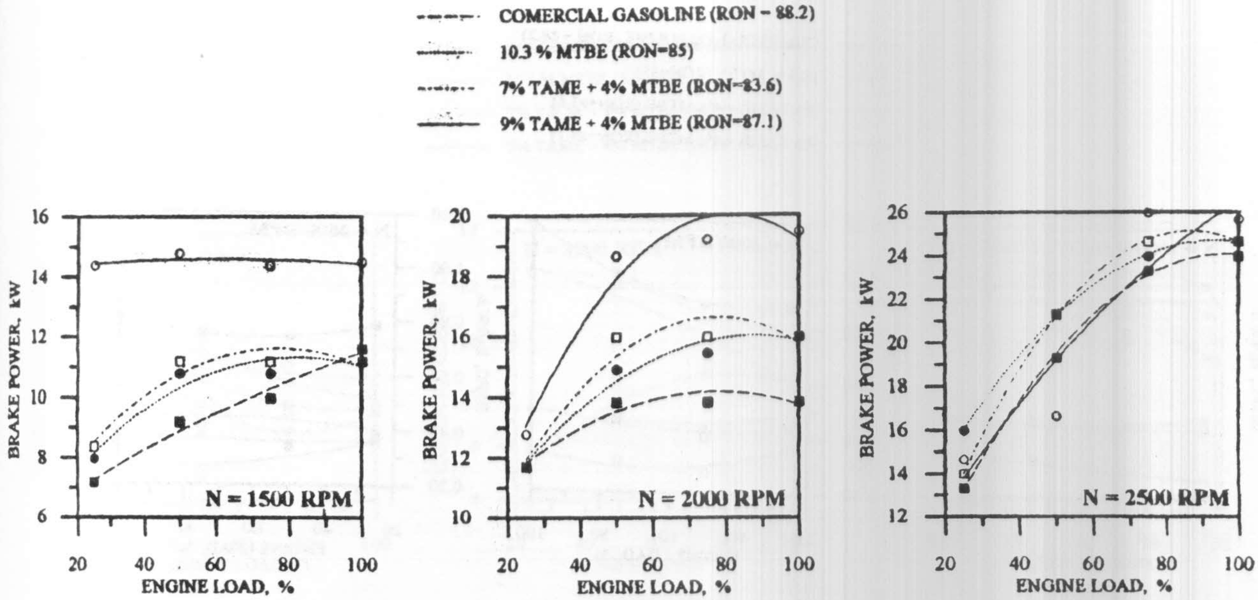


Fig. 13. Variation of engine brake power with engine load for different fuel blends at 1500, 2000, and 2500 rpm part load.

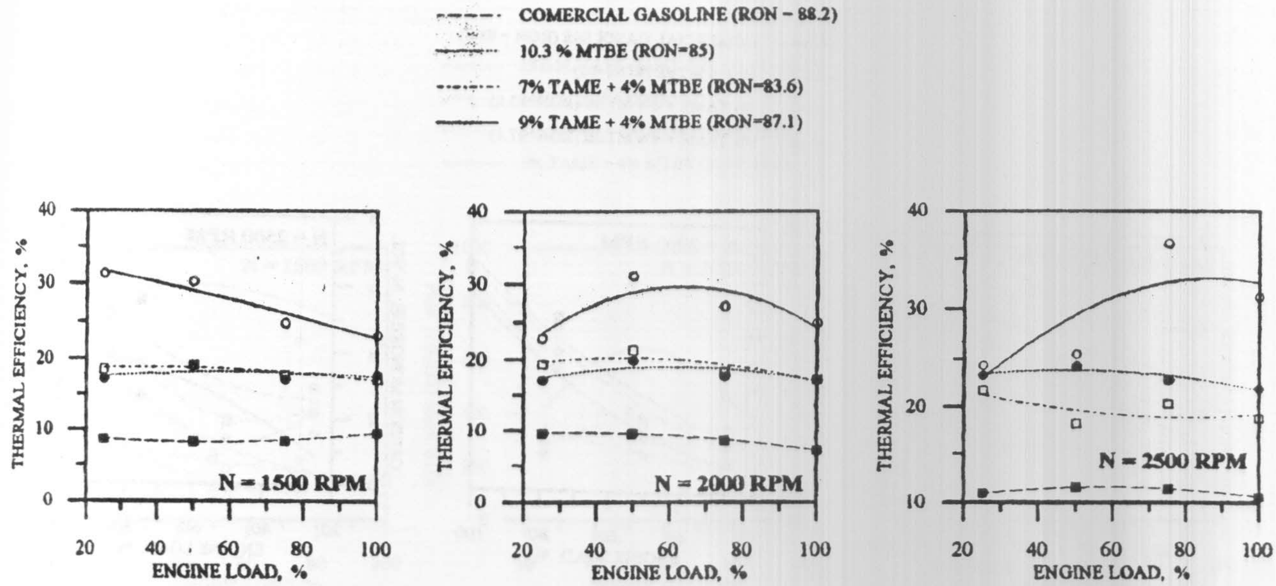


Fig. 14. Variation of engine thermal efficiency with engine load for different fuel blends at 1500, 2000, and 2500 rpm part load.

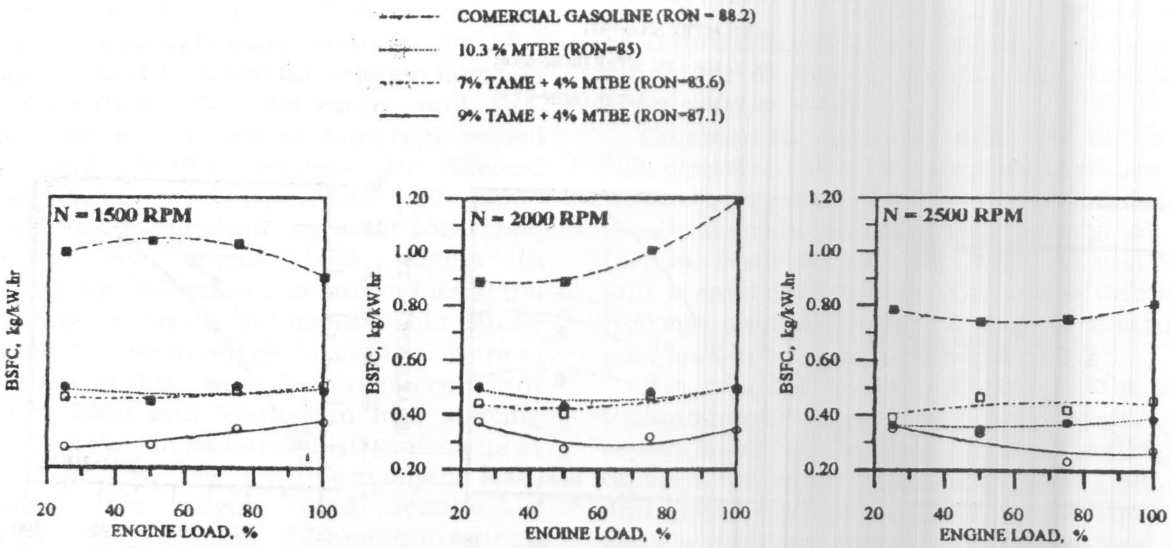


Fig. 15. Variation of engine brake specific fuel consumption (b.s.f.c) with engine load for different fuel blends at 1500, 2000, and 2500 rpm part load

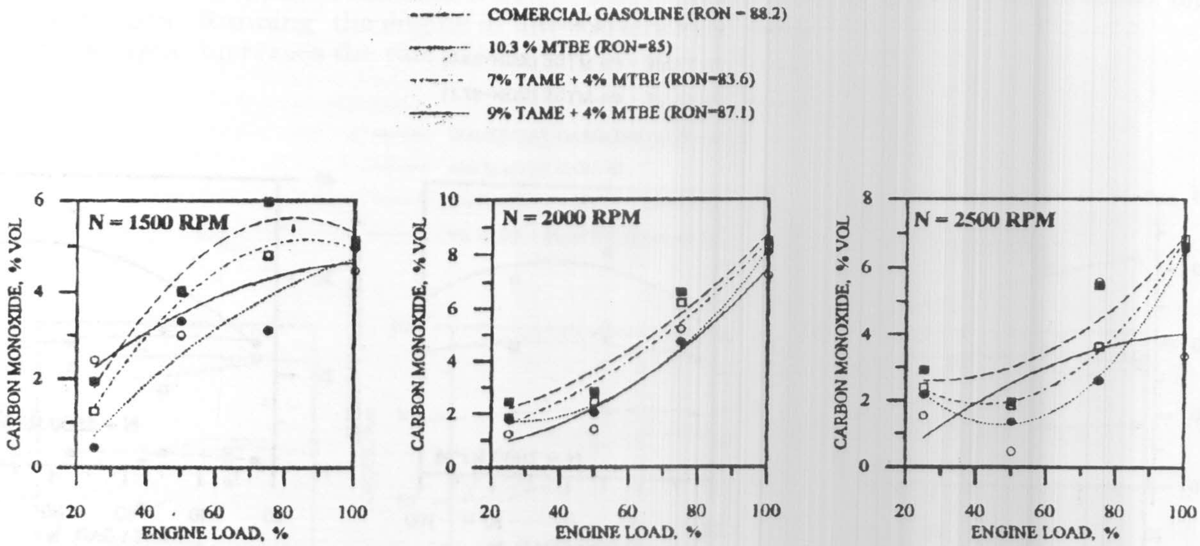


Fig. 16. Variation of carbon monoxide emissions with engine load for different fuel blends at 1500, 2000, and 2500 rpm part load.

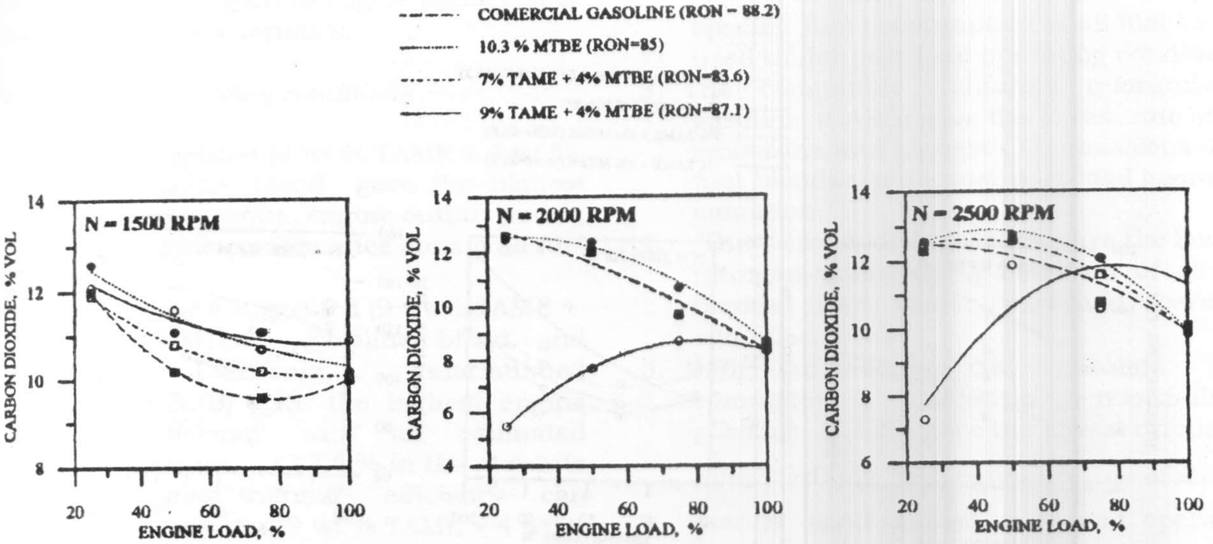


Fig. 17. Variation of carbon dioxide emissions with engine load for different fuel blends at 1500, 2000, and 2500 rpm part load.

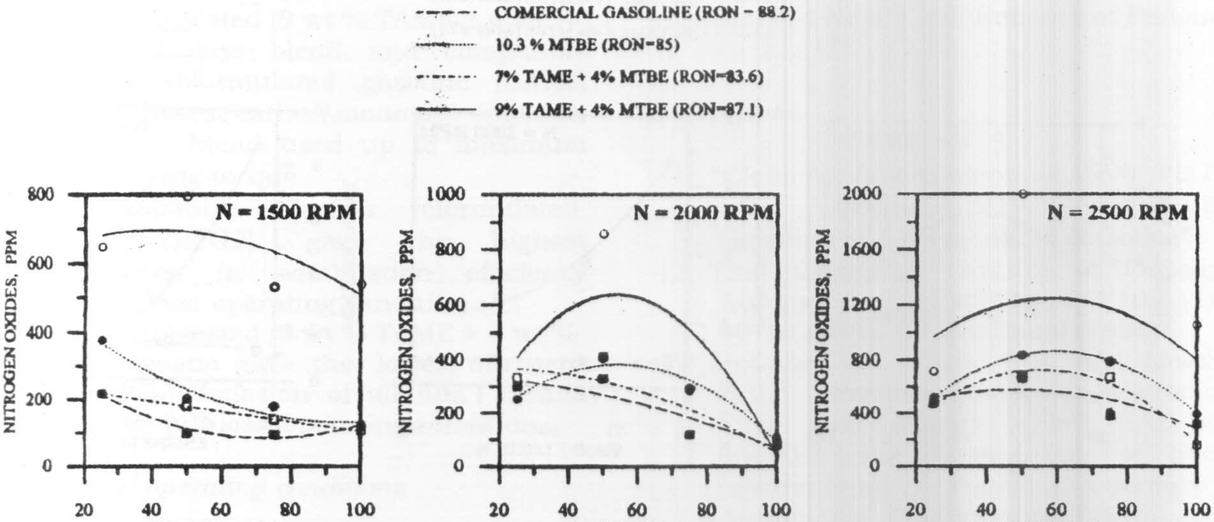


Fig. 18. Variation of unburned hydrocarbon emissions with engine load for different fuel blends at 1500, 2000, and 2500 rpm part load.

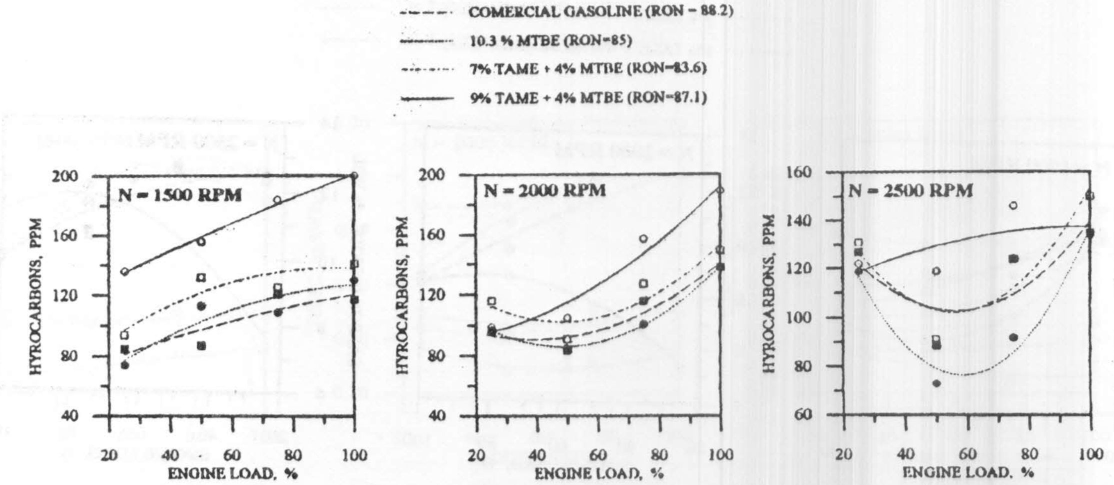


Fig. 19. Variation of nitrogen oxides emissions with engine load for different fuel blends at 1500, 2000, and 2500 rpm part load.

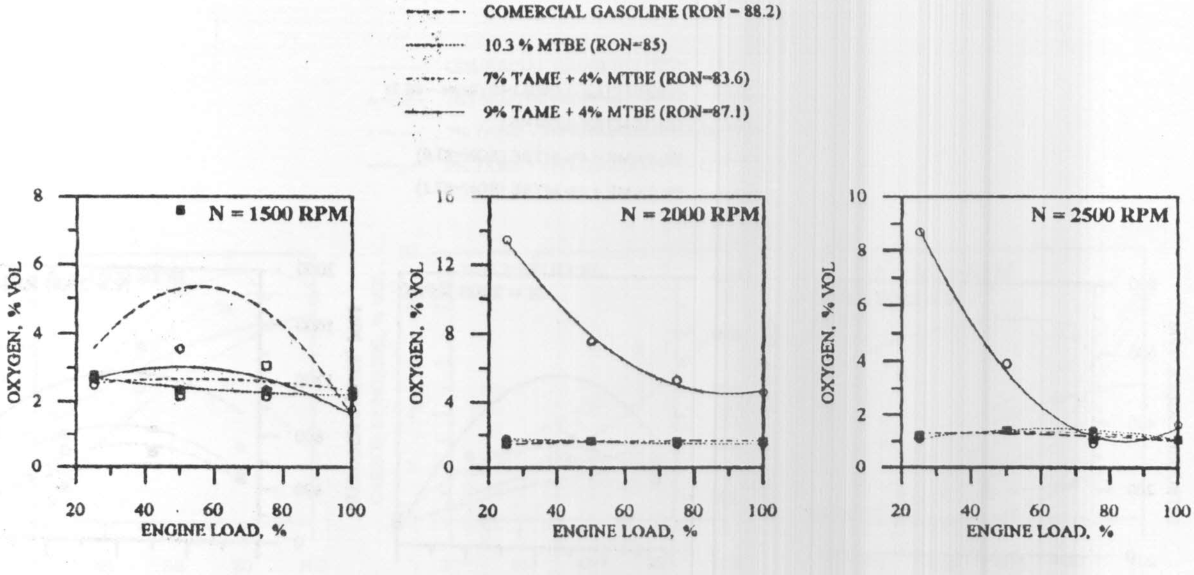


Fig. 20. Variation of unconsumed oxygen emissions with engine load for different fuel blends at 1500, 2000, and 2500 rpm part load.

5. Conclusions

Based on the present investigation of four different fuel blends; representing Egyptian commercial gasoline, compatible California reformulated gasoline (CARB) , compatible Finnish reformulated gasoline (RFG2) and a new suggested (9 wt % TAME + 4 wt % MTBE) gasoline blend, at fixed compression ratio Fiat 1500 C.C. engine, the following conclusions are drawn with regard to engine performance and emission characteristics.

For full – load operating conditions

1. The new suggested (9 wt % TAME + 4 wt % MTBE) gasoline blend gave the highest engine driving torque, engine output power, and best engine performance among all fuel blends.
2. Both of the new suggested (9 wt % TAME + 4 wt % MTBE) gasoline blend and compatible California, reformulated gasoline (CARB) gave the highest engine thermal efficiency with an estimated average increase of 13.5 % in the absolute value of engine thermal efficiency can be noticed for (9 wt % TAME + 4 wt % MTBE) fuel blend (RON = 87.1) over Egyptian commercial gasoline (RON = 88.2)
3. The new suggested (9 wt % TAME + 4 wt % MTBE) gasoline blend gave the lowest brake specific fuel consumption up to maximum engine braking torque where the compatible California reformulated gasoline (CARB) gave the lowest bsfc after that.
4. The new suggested (9 wt % TAME + 4 wt % MTBE) gasoline blend and compatible California reformulated gasoline (CARB) gave the lowest carbon monoxide emission of all fuel blend used up to maximum engine braking torque.
5. The compatible Finnish reformulated gasoline (RFG2) gave the highest improvement in combustion efficiency under full-load operating condition.
6. The new suggested (9 wt % TAME + 4 wt % MTBE) gasoline gave the lowest nitrogen-oxides (NO_x) emission of all fuel blends used under full-load operating condition.

For part-load operating conditions

1. The new suggested (9 wt % TAME + 4 wt % MTBE) gasoline blend gave the highest engine driving torque and engine output brake power of all fuel blends used under part-load engine speed range of 1500 – 2000 rpm.
2. The new suggested (9 wt % TAME + 4 wt % MTBE) gasoline blend gave the highest engine thermal efficiency and lowest brake specific fuel consumption of all fuel blends used under part-load operating condition.
3. The compatible California reformulated gasoline (CARB) gave the lowest rate of CO emissions and highest CO_2 emissions of all fuel blends used under part-load operating condition.
4. The commercial gasoline gave the lowest nitrogen-oxides (NO_x) emission of all fuel blends used under part-load operating condition.
5. Both of commercial gasoline and compatible California reformulated gasoline (CARB) gave the lowest unburned hydrocarbons (HC) emission rate of all fuel blends used under part-load operating condition.

All this confirms that tertiary amyl methyl ether (TAME) is an attractive blending component for gasoline manufacture.

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