THE EFFECT OF GASOLINE FUEL TYPE ON SI ENGINE NITROGEN-OXIDES AND CARBON MONOXIDE EMISSIONS UNDER PART-LOAD OPERATING CONDITIONS

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ABSTRACT

Six different gasoline blends with different antiknock agents and aromatics content were investigated for its influence on SI engine nitrogen- oxides and carbon monoxide emissions at part- load operating conditions. The six fuel types used were leaded gasoline with 0.5 g Pb/l, commercial unleaded gasoline, unleaded synthetic gasoline and its blends with different proportions of methyl tertiary butyl ether MTBE (10, 15 and 20 vol%). A four- stroke, four- cylinder, spark- ignition Regata engine (type 138 B 3.000) was used for conducting this study. The exhaust gases were analyzed for nitrogen-oxides and carbon monoxide emitted at part-load operating conditions for the speed range of 1000 to 3000 rpm. The results of this investigation have shown that blending unleaded synthetic gasoline with ethers such as MTBE reduces the aromatic content of the fuel. The 20 vol% MTBE-fuel blend gave the lowest carbon monoxide emissions of all blends used at part load condition. On the other hand, the 10 vol% MTBE-fuel blend gave the lowest nitrogen-oxides emission of all blends at part-load condition. The carbon monoxide concentration in engine exhaust differs between increase and decrease at part-load condition when fuel aromatics content increases. It was also found that as the gasoline aromatics content increases in the blend, the nitrogen-oxides concentration in engine exhaust increases. So, substitution of MTBE for the higher aromatics gasoline blends may help improving state environment and air quality.

Keywords: Alternative Fuels, Fuel Additives, Ether-Gasoline Blends.

INTRODUCTION

The effect of gasoline octane requirement on the environment has attracted the interest of many scientists for research. On Dec.18, 1990, three US major auto companies and 14 oil companies jointly released the finding of their program on the influence of gasoline composition on air quality [1]. Their results indicated that oxygenates can improve air quality by reducing the amount of exhaust emission. Also, they found that the reduction of gasoline aromatics can either reduce or increase exhaust emission, depending upon vehicle type.

The effect of oxygenates in gasoline on exhaust emission and performance was studied by Taljaard et al. in a single cylinder four- stroke spark-ignition engine [2]. They concluded that oxygenates significantly decreased CO, NOx, and HC emissions at the stoichiometric air/fuel ratio. In 1991, Peyla [3] showed that the improved fuel economy and emission control are major goals in many countries, and high- precision engines are increasingly used world-wide. He emphasized on the role of fuel deposit control additives in reducing NOx and HC emissions with the reduction of combustion chamber deposits. Gasoline blends containing ethers can be used for the reduction of ozone formation in summer months through control of volatility [4,5]. Their use can reduce CO formation in metropolitan area in winter and reduce public exposure to carcinogens by reducing the aromatic concentration of marketed gasoline. A mix of ethers such as MTBE to gasoline could compensate for the octane loss from aromatic reduction. The rapid increase in gasoline aromatics over the past decade was associated with the lead phase down with recent demand for premium gasoline, the aromatic content climbed to about 60% vol. These aromatics are reactive hydrocarbons that contribute to the formation of ozone. They, particularly benzene, are known carcinogens. Kazuo et al [6] investigated the effect of reformulated gasoline and methanol on exhaust emissions. They found that in case of gasoline, as Non-methane Organic Gas(NMOG) is reduced, the proportion of speciated emissions with high ozone reactivity decreases, and this tends to lower Ozone Forming Potential (OFP). In the case of reformulated gasoline, OFP does not decrease, but Non- methane Hydrocarbons (NMHC) do as NMOG is reduced. In case of methanol, it is difficult to find a general correlation between NMOG and OFP. In a previous paper [7] it was reported that carbon monoxide and hydrocarbon emission can be reduced to the order of 13-43% and 10-30% respectively for SI engines under full load operating conditions when using 20 vol% MTBE- fuel blend.

It is the objective of the present paper to investigate the effect of fuel type with different lead additives, aromatics content, and methyl tertiary butyl ether (MTBE) additives on SI engine nitrogen-oxides and carbon monoxide emission under part- load operating conditions.

EXPERIMENTAL EQUIPMENT AND PROCEDURES.

Fuels used for the test.

Six different fuel samples were experimentally investigated during this study. Unleaded synthetic gasoline prepared by mixing platformate 60 vol% and petroleum ether 40 vol%. The two components were cooled to 15C before mixing. The sample used for preparing the unleaded synthetic gasoline were obtained from Saudi- Aramco and Alexandria Petroleum Companies. Leaded gasoline containing 0.5 g Pb/liter and a RON of 100 was obtained from Misr Petroleum CO. Unleaded gasoline was locally purchased for comparison.

Methyl-Tertiary Butyl Ether (MTBE) with a purity of 99% was used in preparing the blends. The samples were obtained from Saudi-British Petrochemical CO. (Ibn Zahr) in Jubail , Saudi Arabia.

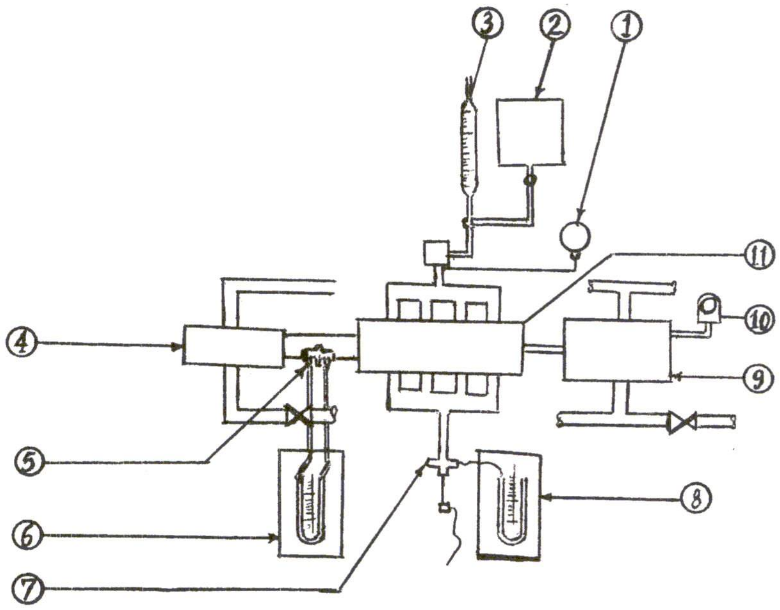
The prepared unleaded synthetic gasoline was blended with MTBE to get three test blends:10 vol% MTBE, 15 vol% MTBE and 20 vol% MTBE with the unleaded synthetic gasoline.

Engine and Apparatus used

A Co-operative Fuel Research (CFR) single cylinder engine manufactured by Waukesha Motor Co. at Alexandria Petroleum Co. Mex, Alexandria, was used to determine the research octane number (RON) for all used fuel samples according to ASTM method D-2699. Results of complete fuel blends analyses according to ASTM procedure are shown in Table (1).

A four-stroke, four-cylinder, spark- ignition Regata engine (type 138 B 3.000) was used for conducting this study. The engine has a bore of 86.4 mm, a stroke of 63.9 mm , a displacement of 1498 cm3, a compression ratio of 8:1 and a maximum power of 54 KW at 5500 RPM. The engine was coupled to a hydraulic dynamometer of the Froude type. The dynamometer is equipped with a load control and engine tachometer. Figure (1) shows schematic layout of the experimental set- up.A photograph of all measuring instrumentation are shown in Figure (2).

In order to determine the effect of gasoline fuel type on the natural aspiration condition of the engine, the intake-manifold pressure was measured by using a vacuum gauge connected to the intake manifold immediately after the carburetor throttle. U-tube manometers were used to measure exhaust-gas pressure and the pressure-drop across the coolant orifice meter. Engine exhaust gas temperature was routinely measured by J-type thermocouple connected to a temperature compensated digital readout with an accuracy of 1C. The fuel consumption was measured by using a calibrated burette and a stop watch. The CO emission concentration was measured by an infrared SUN SGA 5000 CO gas analyser connected to the exhaust tailpipe. The accuracy of measurements was 0.01 vol% for CO concentration from 0 to 1 vol % and 0.1vol% for CO concentration from 1 to 10 vol%. The NOx emission concentration was measured by a portable DRAGER Gas Detector analysing system, consisting of the gas detector pump and DRAGER scale tubes with different range of measurements. In these tubes, the length of indicating layer discoloration is a measure of the NOx gas concentration. The measured value is read-off on the printed tube scale. The relative standard deviation of the entire NOx concentrations read- off was 15 to 10% for lower and upper limit of standard range of measurement, respectively.



1. Vacuum pressure gauge
2. Fuel tank
3. Fuel burette
4. Heat exchanger
5. Coolant orifice meter
6. Coolant U-tube manometer
7. Exhaust measuring tap
8. Exhaust U-tube manometer
9. Hydraulic dynamometer
10. Engine tachometer
11. Engine

Figure 1. Schematic Layout of the Experimental Set up.

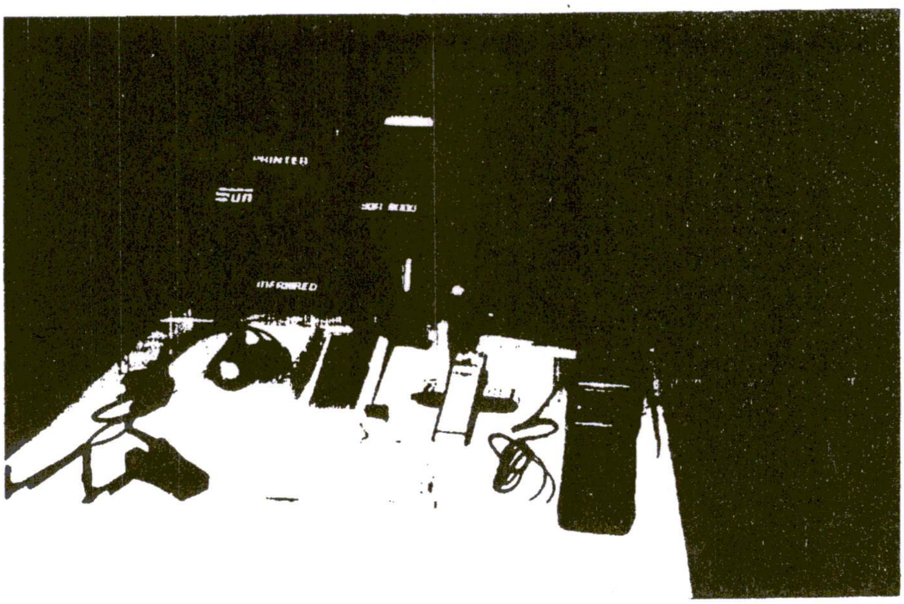


Figure 2. Photograph of Measuring Instrumentation.

Test Procedures

The engine was started and warmed up for 20 to 30 minutes in order to reach steady-state operational conditions for each running case of the used fuel type. Then speed was adjusted to the required value. The required engine load was obtained through the dynamometer control. The following quantities were routinely measured during each test:

- Intake - manifold vacuum, (KPa),
- Exhaust pressure, (KPa),
- Exhaust gas temperature, (°C),
- Mass rate of flow of fuel, (Kg/h),
- Mass rate of flow of engine coolant, (Kg/h),
- Engine rotational speed, (RPM),
- Engine load, (N),
- Carbon monoxide (CO) emission by percentage volume, (% vol),
- Nitrogen - oxides (NOx)concentration in parts per million., (ppm).

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 % to 2.5 % for brake power and within 5% for brake specific fuel consumption.

RESULTS AND DISCUSSION

The effect of fuel type with different lead additives, aromatics content, and methyl tertiary butyl ether (MTBE) additives on SI engine performance, nitrogen oxides, and carbon monoxide emissions at part-load was investigated. The range of speed investigated was 1000- 3000 rpm for different part-load conditions. Ignition timing was investigated for the manufacturer specification setting of 10 BTDC at an idle speed of 750 rpm.

Fuel Economy

The effect of using six different fuel blends on the engine brake specific fuel consumption is illustrated in Figure (3) a & b. Leaded g(0.5 g Pb/l) give the lowest bsfc for all the six fuel- blend samples under constant driving torques of 25 and 38 N.m in the part- load speed range of 1000- 2000 rpm. For part-load speed range of 2000- 3000 rpm, 10-15% MTBE- fuel blend achieve the best fuel economy. These results can be attributed to the combined effect of higher heating value of leaded gasoline (48.5 MJ /Kg) in the lower speed range and the improvement in combustion process due to presence of 2-4 wt % oxygen in MTBE- Fuel blends (Heating value ranges between 44-45 MJ/Kg), in the upper speed range.

Intake - Manifold Vacuum.

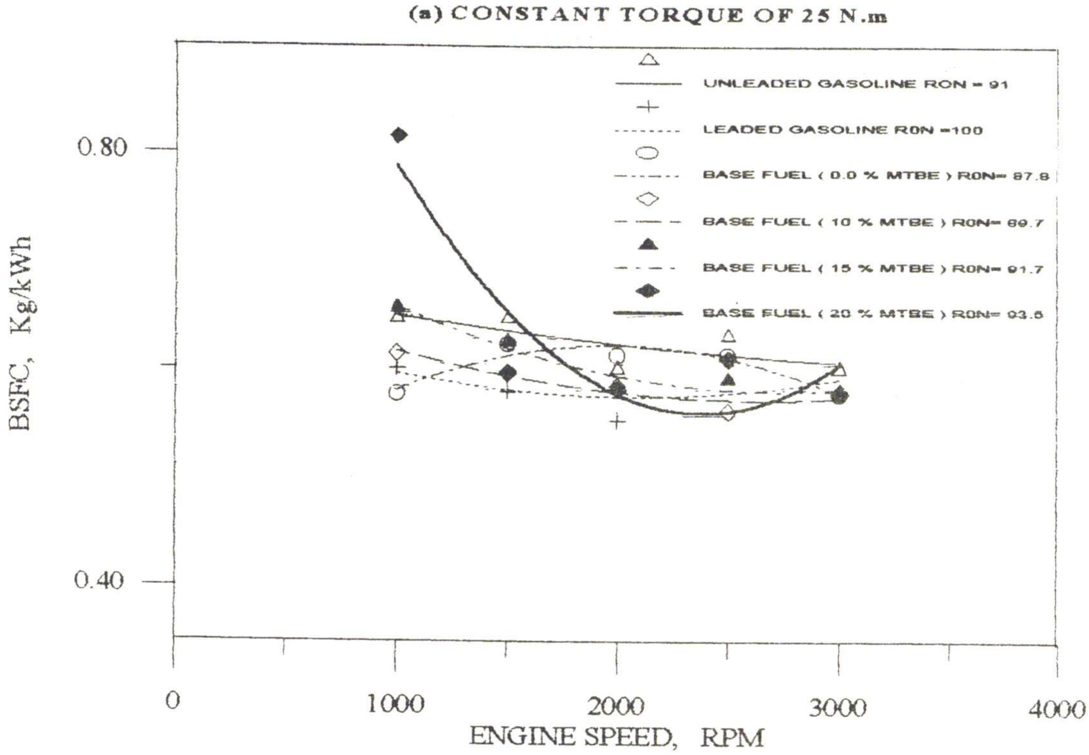
Figure (4) a & b presents the effect of using six different fuel blends on the intake-manifold vacuum at part- load conditions. The 15% and 20% MTBE-fuel blends record the least vacuum for both constant driving torque of 38 N.m and 25 N.m, respectively due to the presence of an oxygen atom in the methyl- tertiary- butyl ether and the good natural aspiration condition of the engine in this case.

Engine Thermal Efficiency

The effect of using unleaded gasoline and gasoline with different fuel additive of lead and different proportions of MTBE on the engine thermal efficiency is shown in Figure (5) a & b. The best engine thermal efficiency is achieved by the 20% MTBE- fuel blend in the part- load speed range of 1000- 2000 rpm at constant driving torques of 25 and 38 N.m. The highest thermal efficiency in the part-load speed range of 2000-3000 rpm is recorded with 10% and 15% MTBE- fuel blends. this is a normal consequence of Figure (3) of the engine brake specific fuel consumption.

Exhaust Temperature

Figure (6) a & b shows the effect of using six different fuel blends on the exhaust tailpipe temperature at part- load conditions. The 20% MTBE- fuel blend caused the lowest exhaust tailpipe temperature among all the six different fuel blends due to reduction in the combustion temperature with increasing volume percentage of MTBE in the fuel blend.



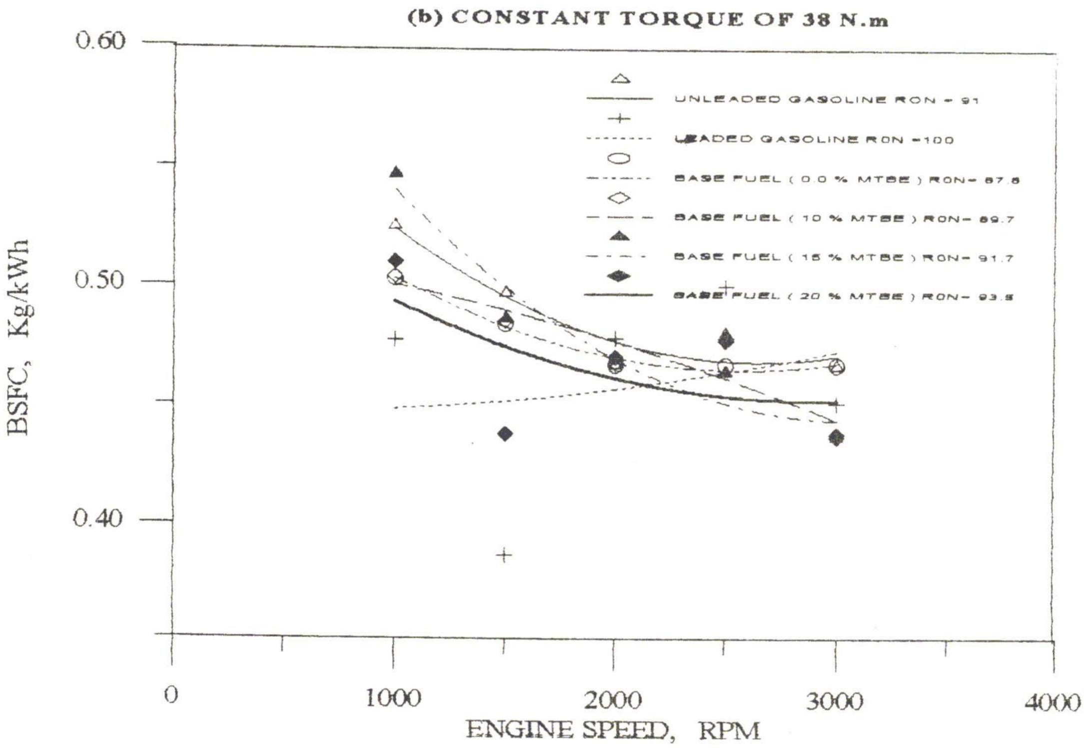


FIG.(3) VARIATION OF ENGINE BSFC WITH SIX DIFFERENT FUEL BLENDS AT PART LOAD

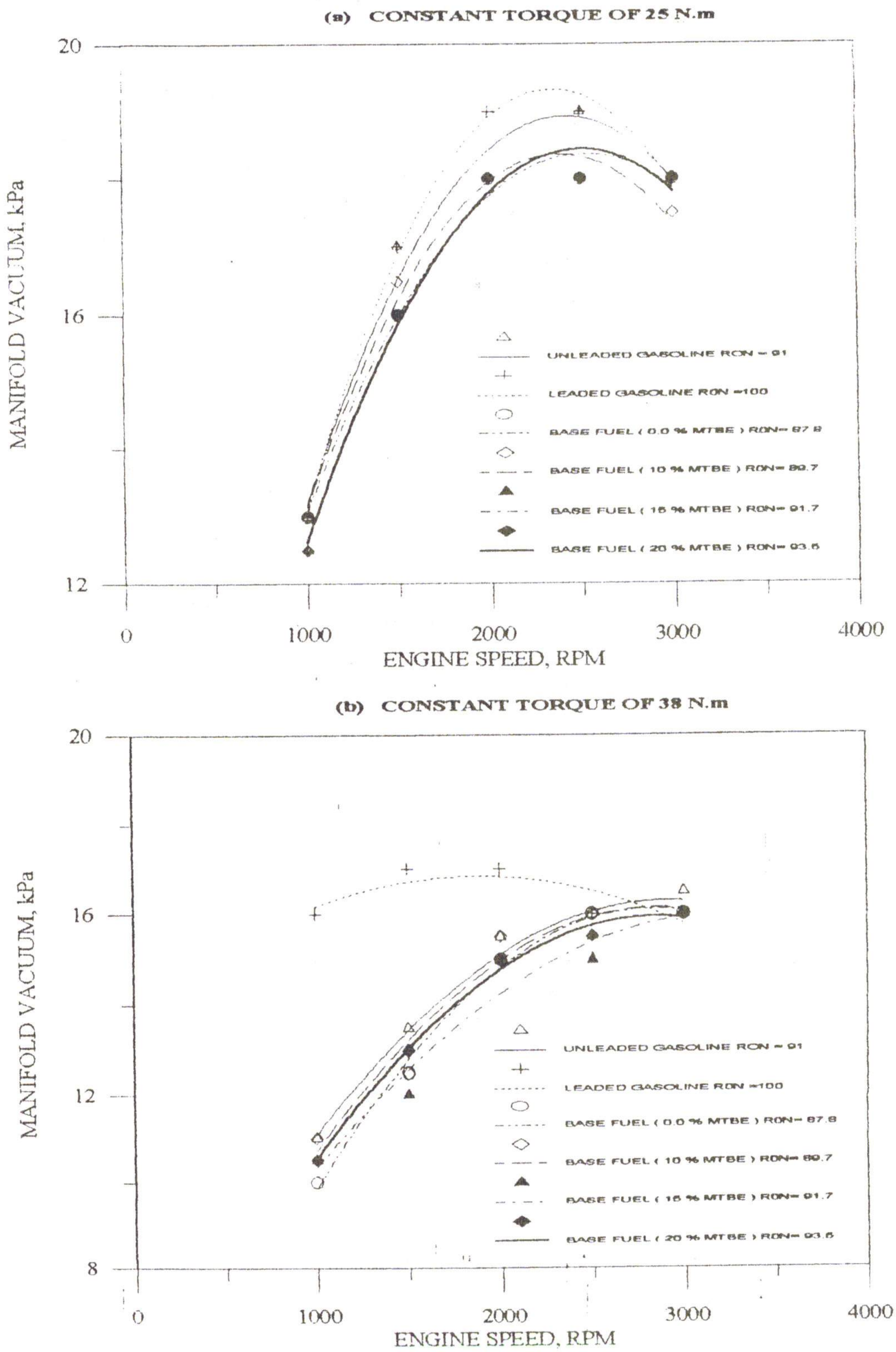


FIG. (4) VARIATION OF ENGINE INTAKE MANIFOLD VACUUM WITH SIX DIFFERENT FUEL BLENDS AT PART LOAD

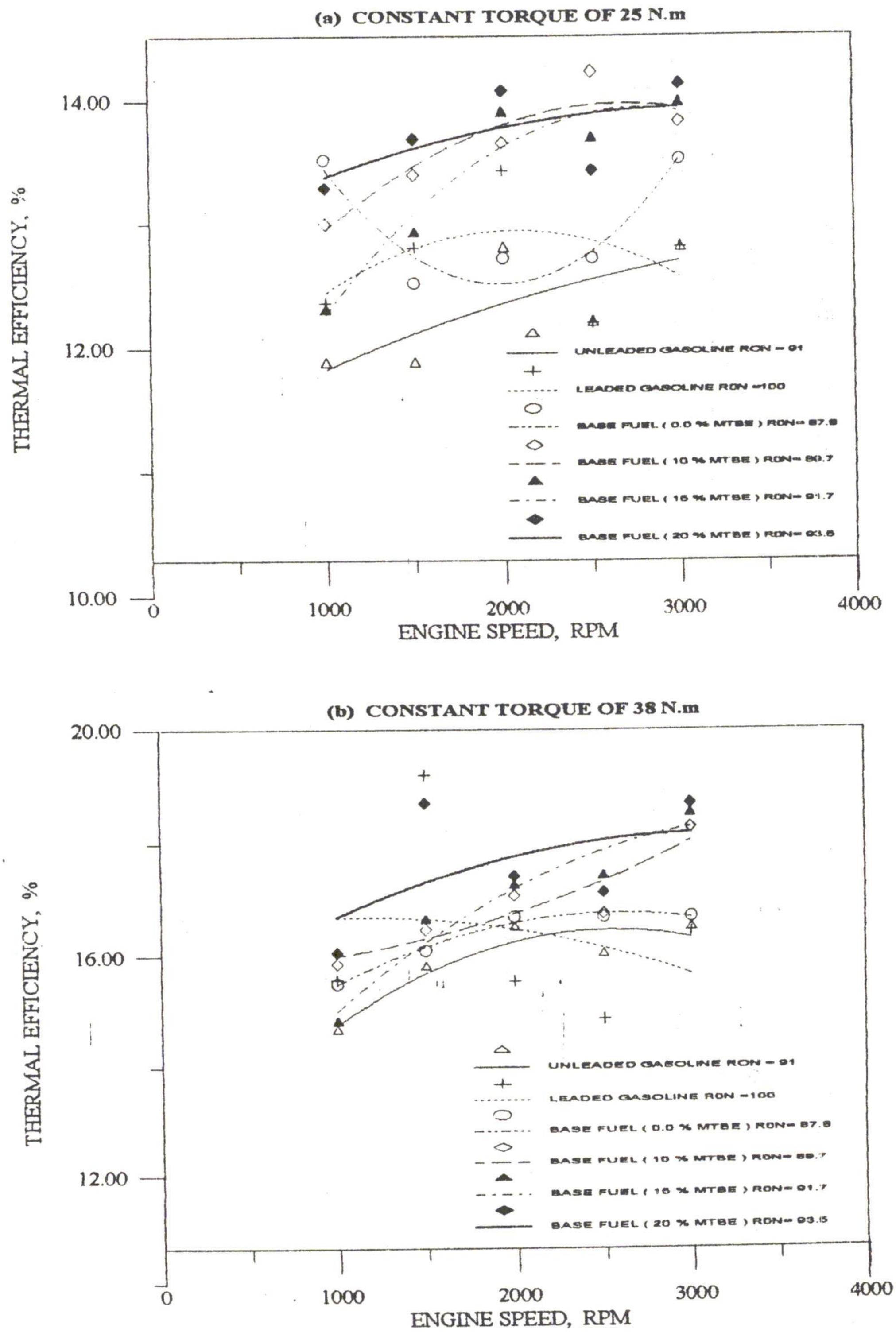


FIG.(5) VARIATION OF ENGINE THERMAL EFFICIENCY WITH SIX DIFFERENT FUEL BLENDS AT PART LOAD

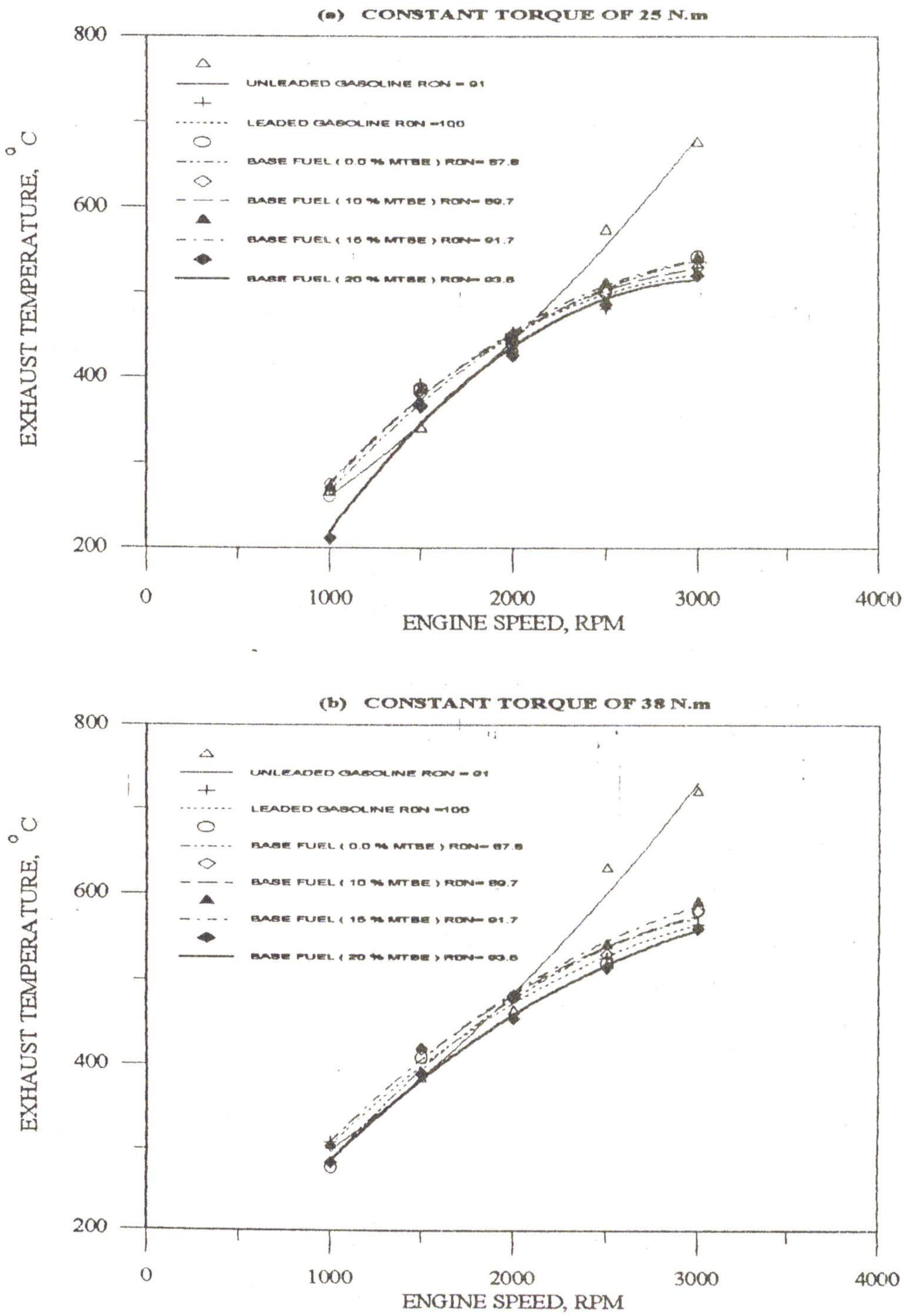


FIG. (6) VARIATION OF ENGINE EXHAUST TEMPERATURE WITH SIX DIFFERENT FUEL BLENDS AT PART LOAD

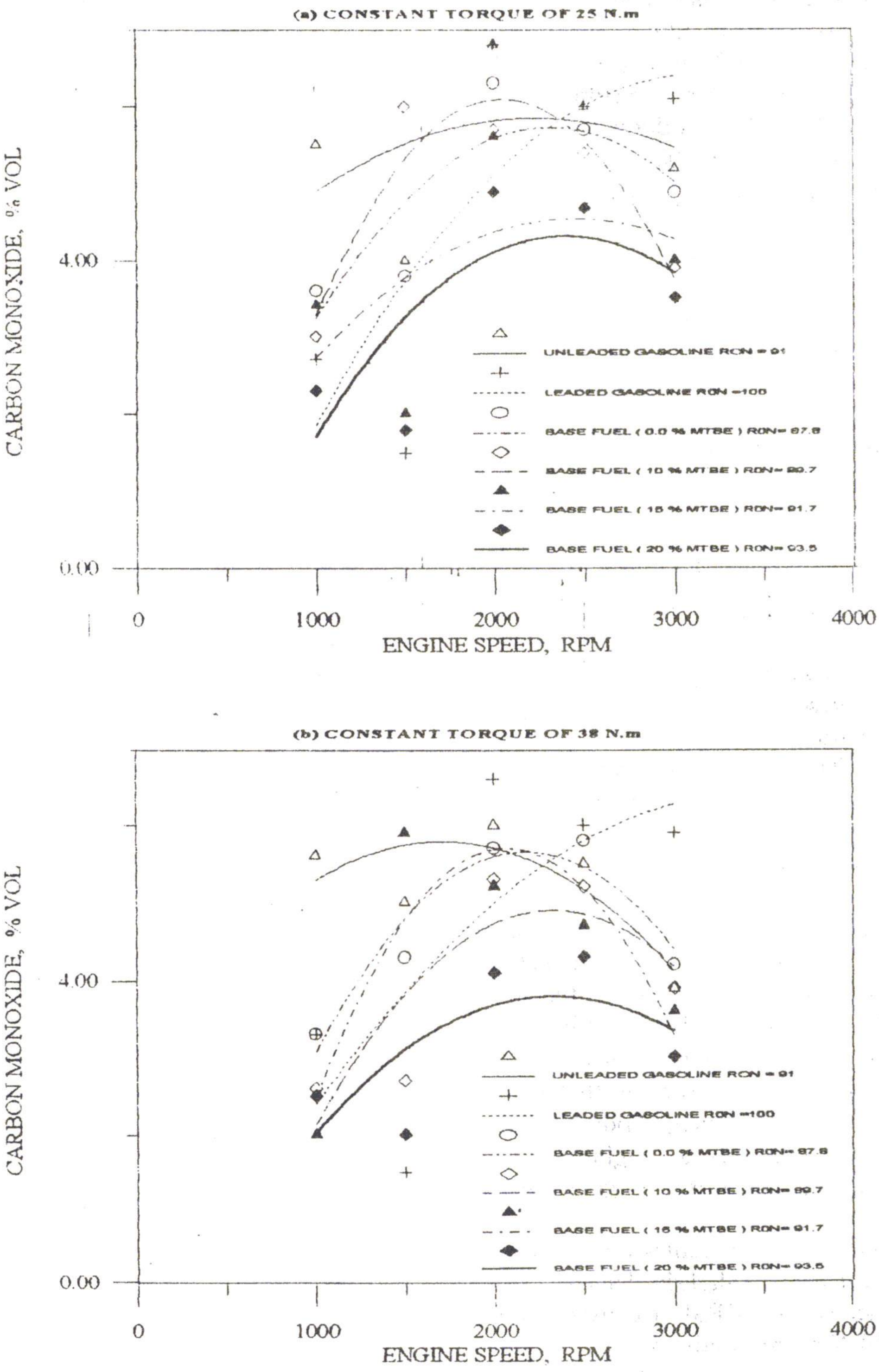


FIG.(7) VARIATION OF ENGINE CARBON MONOXIDE EMISSION WITH SIX DIFFERENT FUEL BLENDS AT PART LOAD

Carbon Monoxide Emissions

As expected, the 20% MTBE- fuel blend gave the lowest carbon monoxide emission of all samples investigated at part- load conditions and constant driving torque of 25 and 38 N.m, Figure (7) a & b.

The 20% MTBE-fuel blend resulted in an estimated of 24- 60% CO reduction over the part-load test speed range of 1000- 3000 RPM in comparison with the commercial unleaded gasoline. This can be attributed to an oxygen atom in MTBE that facilitates the complete combustion of the ether to carbon dioxide and water.

Nitrogen- Oxides Emissions

Figure (8) a & b shows the effect of using six different fuel blend on the concentration of nitrogen oxides emitted from the engine at part-load operating conditions and constant driving torques of 25 N.m. and 38 N.m.

The 10% MTBE-fuel blend gave the lowest NOx concentrations in engine exhaust emission among all the six fuel blends during the part-load conditions. The relatively high concentrations of NOx emission in engine exhaust gases is resulted from using 20% MTBE- fuel blend under the same operating conditions. The NOx concentrations in present work are within the same level of measurements recorded by previous investigators [8 and 9].

Carbon Monoxide and Aromatics Content

The effect of gasoline aromatics content on the carbon monoxide concentrations was investigated at part-load condition and constant driving torques of 25 N.m and 38 N.m for all fuel blends, Figure (9) a & b illustrates the obtained results of measurements. From the figure, one can see that as the gasoline aromatics content increases, the carbon monoxide emission remarkably increases at engine speed of 1000 RPM and slightly increases at engine speed of 2000 RPM.

The carbon monoxide concentration in engine exhaust remains constant or slightly decreases when engine speed reaches 3000 RPM at constant torque of 25 N.m and 38 N.m, respectively.

Nitrogen- oxides and Aromatics Content.

Figure (10) a & b shows the effect of using different fuel blend with different aromatics content on the nitrogen- oxides concentration in engine exhaust at part-load and constant driving torque of 25 N.m and 38 N.m. It is clear that as the gasoline aromatics content increases in the fuel blend, the nitrogen- oxides concentration in engine exhaust increases exponentially. This rate of increase is elevated with engine speed increase from 1000 to 3000 RPM for both constant driving torque of 25 N.m and 38 N.m at part-load operating conditions.

CONCLUSIONS

From the obtained results of experiments conducted on a Regata 1500 C.C. engine under part-load conditions, the following conclusions can be deduced:

1- Blending unleaded synthetic gasoline with ethers such as MTBE reduces the aromatic content of the fuel.
2- The 20 vol% MTBE-fuel blend gave the lowest carbon monoxide emission of all fuel blend used under part-load condition.
3- The 10 vol% MTBE-fuel blend gave the lowest nitrogen- oxides emission of all blends used under part-load condition.
4- The effect of gasoline aromatics content on carbon monoxide concentration in engine exhaust differs between increase and decrease with engine speed range of 1000-3000 RPM under part-load condition.
5- As the gasoline aromatics content increases in the fuel blend, the nitrogen-oxides concentration in engine exhaust increases.
6- The substitution of MTBE for the high aromatics gasoline blend helps improving state environment and air quality by reducing the level of exhaust pollutants.

Acknowledgement

The author would like to thank the technical staff of ICE laboratory at Faculty of Engineering, Alexandria University, and Chemical Laboratories at Alexandria Petroleum Company.

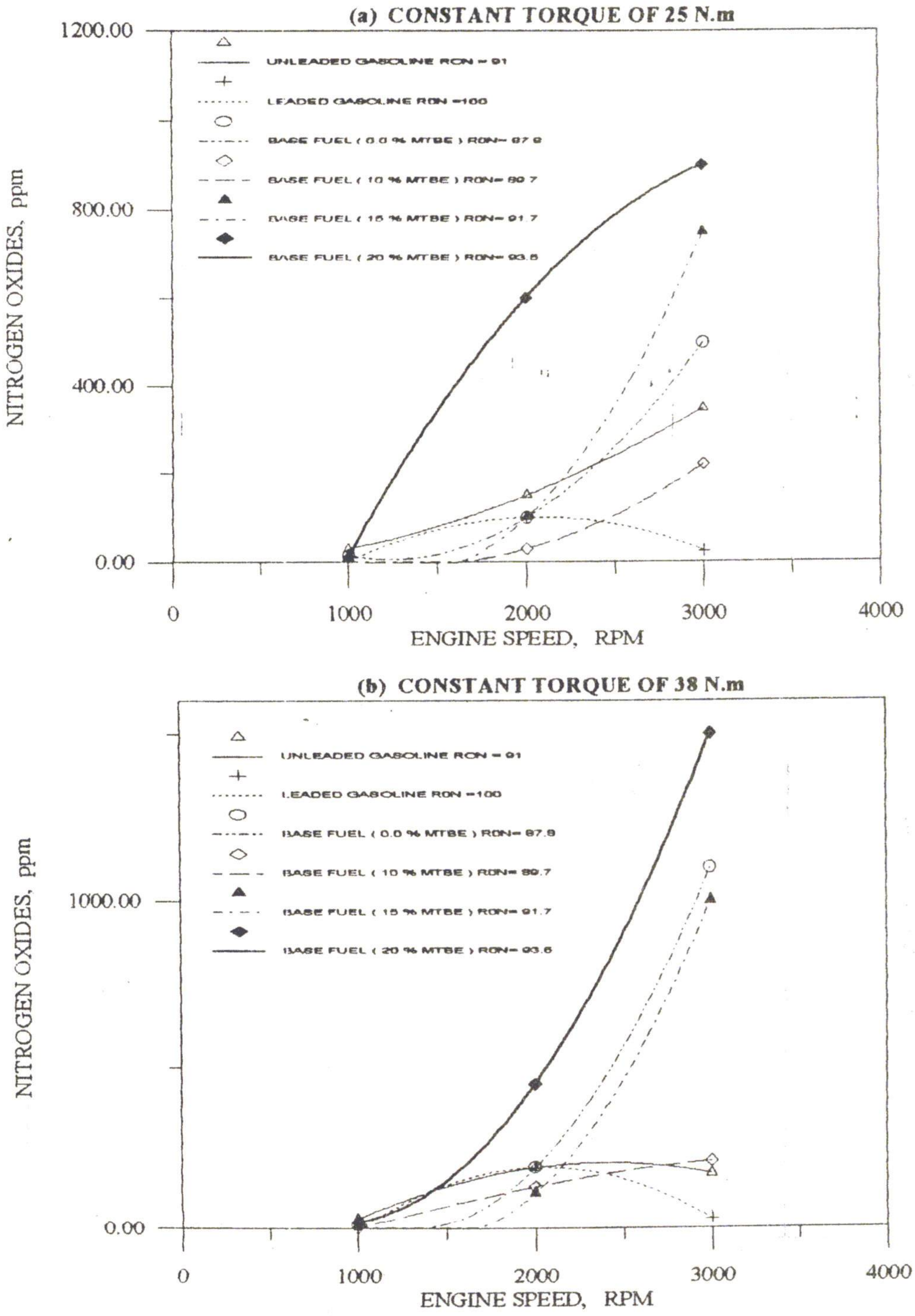


FIG. (8) VARIATION OF ENGINE NITROGEN OXIDES EMISSIONS WITH SIX DIFFERENT FUEL BLENDS AT PART LOAD

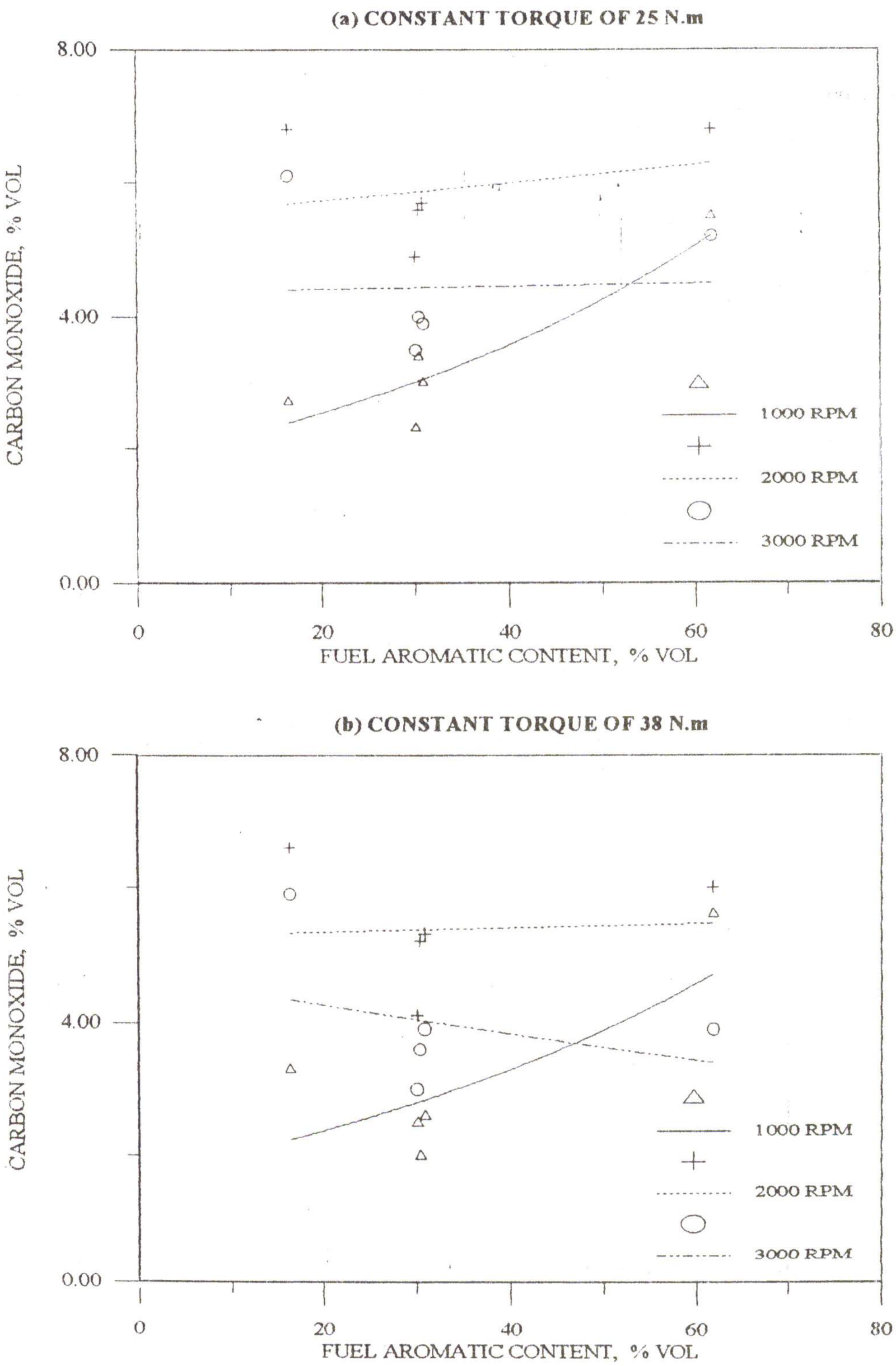


FIG. (9) EFFECT OF GASOLINE AROMATICS CONTENT ON SI ENGINE CARBON MONOXIDE EMISSION AT PART LOAD

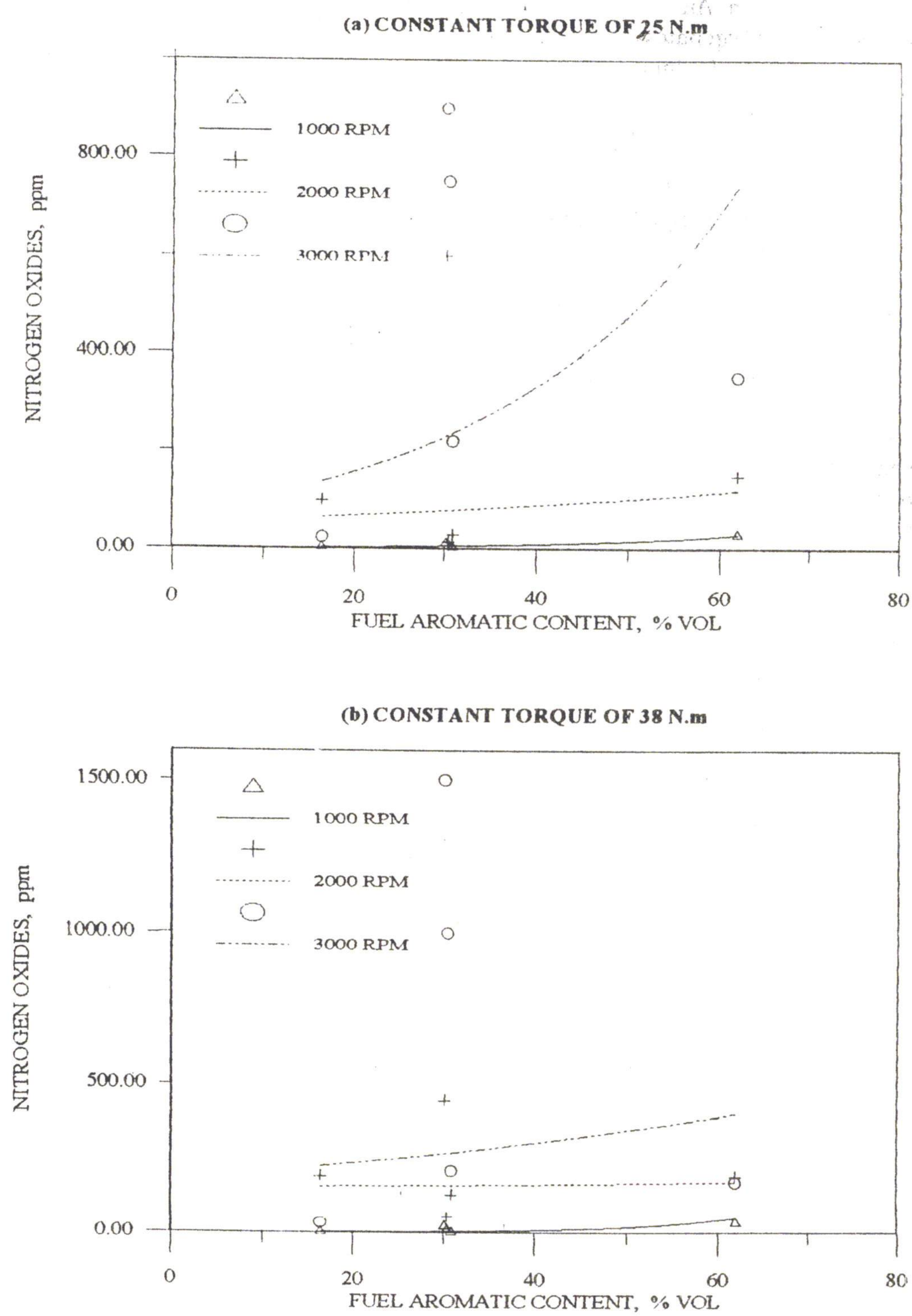


FIG. (10) EFFECT OF GASOLINE AROMATICS CONTENT ON ENGINE NITROGEN OXIDES EMISSION AT PART LOAD

REFERENCES

[1] G.H. Unzelman, U.S. Clean Air Act expands role for oxygenates; Oxygenates for the Future-1, *Oil & Gas Journal*, *Apr.* 15, 1991, 44-48.

[2] H.C. Taljaard, C.F.P. Jaardaan, J.J. Botha, The effect of Oxygen Content in Different Oxygenate-Gasoline Blends on Performance and Emission in A Single Cylinder, Spark Ignition Engine, *SAE Paper*, 910379, 1991.

[3] R.J. Peyla, Additives to have key role in new gasoline era, *Oil & Gas Journal;*, *Feb.* 11, 1991, 53-57.

[4] G.H. Unzelman, Ethers have good gasoline-blending attributes; Ethers in gasoline-1 *Oil & Gas Journal, Apr.* 10, 1989, 33-37.

[5] G.H. Unzelman, Ethers will play larger role in octane, environmental specifications for gasoline blends; Ethers in Gasoline- Conclusion, *Oil & Gas Journal, Apr.*17, 1989, 44-50.

[6] Kazuo, K.; Hirota, T.; Yakushiji, K., Oda, K.; Iwakiri, Y.; Akutsu, Y., Effect of Reformulated Gasoline and Methanol on Exhaust Emissions, *SAE Paper*, 912431, 1991.

[7] M.M. Osmam, M.S. Matar, S. Koriesh, Effect of Methyl Tertiary Butyl Ether (MTBE) as a Gasoline Additive on Engine Performance and Exhaust Emission. *Alexandria Engineering Journal, Oct.*, 1992, vol.31, No.4.

[8] J.C. Hilliard and R.W. Wheeler,: Nitrogen Dioxide in Engine Exhaust, *SAE Paper*, 790691, SAE Trans., Vol. 88, 1979.

[9] T. Toda, H. Nohira and K. Kabashi,: Evaluation of Burened Gas Ratio (BGR) as a Predominant Factor to NOx, *SAE Paper*, 760765, *SAE Trans.*, vol. 85, 1976.