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EXPERIMENTAL INVESTIGATIONS ON THE PERFORMANCE AND NITROGEN OXIDES EMISSIONS OF AN IDLED AND PART LOAD SI ENGINE

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Abstract

The experimental work of this paper was conducted on a FIAT 1.5-L engine. The concentrations of nitrogen oxides emitted from the engine were measured at idling as well as part- load conditions for the speed range of 800 to 2400 rpm. An ultraviolet spectrophotometer was used for measuring the concentrations of nitrogen oxides. The results of this investigation show that the engine speed has a minor effect on nitrogen oxides emissions under no-load conditions. On the other hand, the engine speed increases nitrogen oxides emissions at part loads due to the increase in peak cycle temperature and pressure. Advancing the spark from zero to 10 degrees results in an increase of nitrogen oxides concentrations, but further advance reduces emissions. It was also found that coolant temperature has no significant effect on nitrogen oxides emissions under both idling and part-load conditions.

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Nomenclature

AF	air-fuel ratio
ATDC	after top dead center
BSFC	brake specific fuel consumption, gm. $kW^{-1}.hr^{-1}$
BTDC	before top dead center

Introduction

Nitrogen oxides are categorized as a severe sort of air pollution that adversely affects both public health and the environment. The internal combustion engine is one of the main sources of the presence of nitrogen oxides in the atmosphere. The extremely high combustion temperature inside the engine oxidizes nitrogen. Malpractice by engine mechanics (such as misadjustment of both air-fuel ratio and ignition timing according to the manufacturer's instructions) could cause dangerous levels of exhaust emissions. Another side of the problem is engine operation at severe idling conditions because of the traffic jam during rush hours. The major oxides of nitrogen emitted from the engine are nitric oxide (NO) and nitrogen dioxide (NO_2) . NO and NO_2 are usually lumped together under the generic formula NO_x. The concentration of NO in exhaust depends on the difference between the rate of its formation at the highest temperature in the cycle and the rate of its decomposition as temperature decreases during the expansion stroke. Most investigators agree that NO which appears in the exhaust is mainly associated with maximum cycle temperature. NO is formed in appreciable quantities in the flame front, and a limited NO decomposition occurs in the post flame period. In other words, NO is kinetically limited during the expansion stroke [1,2] . Alperstein and Bradow [1] found that increasing air-fuel ratio results in a reduction of NO emission. On the other hand, running the engine under very rich mixtures conditions has the same effect of reducing NO [2-7]. Spark advance was found to increase NO emissions as reported by Patterson and Henein[3]. Retarding the spark was reported to decrease NO emissions[2]. Engine speed has only a minimal effect on the formation of NO as reported by Newhall [8]. Kataoka and Hirako [2] in their mathematical model concluded that increasing the speed reduces NO emissions. Increasing coolant temperature was found to increase NO emissions as it also reduces heat losses thus increases the peak cycle temperature [3]. Huls et al.[4] agreed with that result and added that the effect of coolant temperature on NO emisions is slight.

It has been noticed from the literature review that the area of very rich Fuel-Air ratio (AF < 13) has not been studied thoroughly. It is the purpose of this investigation to study the effect of engine operating parameters on the concentration of nitrogen oxides under idling and part-load conditions that represent the conditions under which engines are run during heavy traffic. The independent parameters under consideration were speed, spark timing, load Air-Fuel ratio&coolant temperature. Exhaust gases were absorbed (after being oxidized by an oxidizing reagent) in the Saltzman reagent. The concentrations of nitrogen oxides were then determined by using an ultraviolet spectrophotometer.

Experimental Apparatus And Procedures

A four-stroke, four-cylinder, spark-ignition FIAT engine was used for conducting this study in the Internal Combustion Engine Laboratory, Faculty of Engineering, Alexandria. The engine has a displacement of 1481 cm^3 and a compression ratio of 7.2 : 1. The engine cooler is a double-pass, liquid- liquid heat exchanger of the shell-and-tube type.

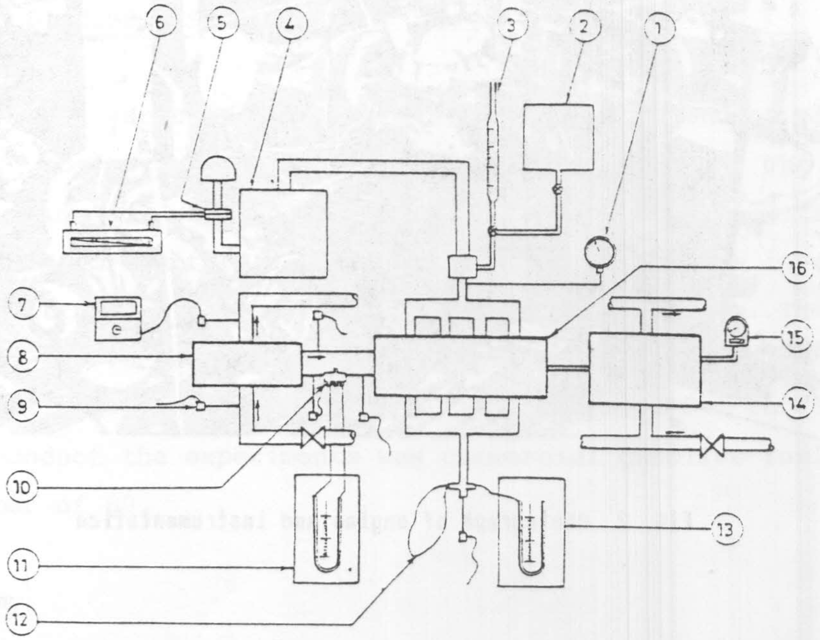
The engine coolant (hot flow) is pumped through tubes. The city water is used as the cold flow on the shell side. The tubular surface area is 0.452 m^2. The engine is coupled to a hydraulic dynamometer of the Froude type. The dynamometer is equipped with a load control, a tachometer, and a revolution counter. A schematic layout and a photograph of the experimental set-up are shown in Figures 1 and 2, respectively.

The engine was started and warmed up for 20 to 30 minutes in order to reach steady-state operating conditions. The speed was adjusted to the required value. The flow rate of shell water through the cooler was regulated until the required coolant temperature was attained. The required engine load was obtained through the dynamometer controls. The following quantities were routinely measured during each test:

- Intake-manifold vacuum.	(± 1.69 kPa)
- Exhaust pressure.	(± 10 Pa)
- Intake-air temperature.	(± 1 degree celsius)
- Engine coolant temperatures.	(± 1 degree celsius)
- Exhaust-gas temperature.	(± 1 degree celsius)
- Mass tate of flow of fuel.	(Accuracy ± 1.3 %)
- Mass rate of flow of intake air.	(Accuracy ± 7.2 %)
- Mass rate of flow of coolant.	(Accuracy ± 1.3 %)
- Engine rotational speed.	(Accuracy ± 5 %)
- Engine load .	

Exhaust Sampling and NO Measurements

Exhaust gases were sampled as close as possible to exhaust port, passed through an oxidizing reagent (in order to oxidize NO to NO_2),



1. Vacuum pressure gauge
2. Fuel tank
3. Fuel burette
4. Surge tank
5. Air orifice meter
6. Intake air inclined manometer
7. Temperature read-out
8. Heat exchanger
9. Thermocouple
10. Coolant orifice meter
11. Coolant U-tube manometer
12. Sampling bag
13. Exhaust U-tube manometer
14. Hydraulic dynamometer
15. Engine tachometer
16. Engine

FIG. 1 Schematic layout of experimental set-up

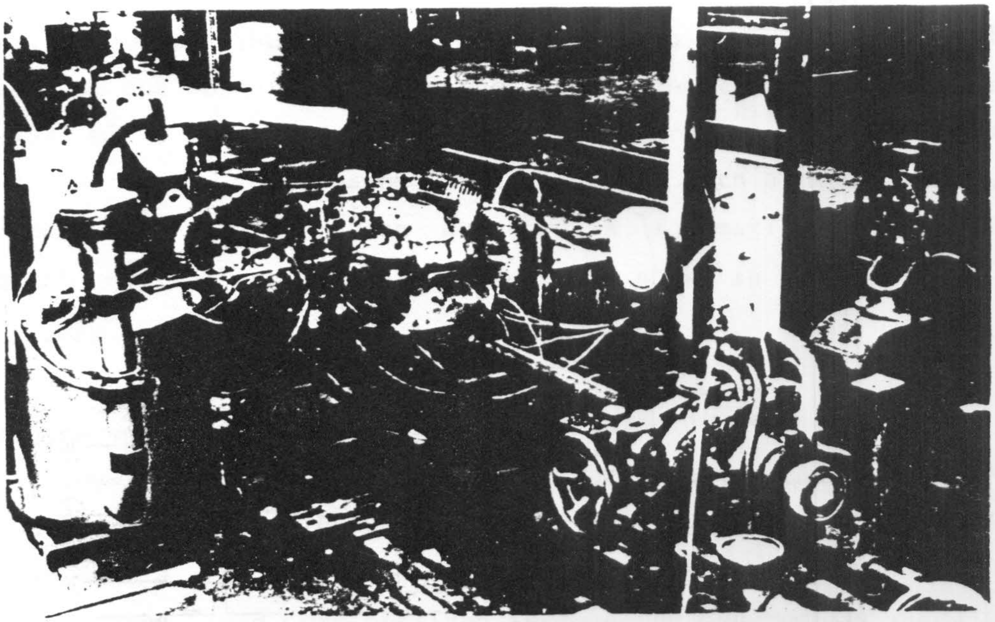


FIG. 2 Photograph of engine and instrumentation

and then admitted to a sampling bag (1750 ml). As soon as the bag was inflated, 40 ml of exhaust gases were withdrawn into a sampling syringe containing 10 ml of the Saltzman absorbing reagent.

It must be pointed out that if the sample was not immediately withdrawn into the syringe, the spectrophotometer readings would not be accurate. If the change of color of the solution was not sufficient , the absorption would be completed by vigorously shaking the syringe for a couple of minutes. After sample absorption, a red-violet color would appear. Color development was complete within 15 minutes at the room temperature. The sample was then analyzed by the ultraviolet spectrophotometer using an unexposed Saltzman reagent as a reference. The spectrophotometer reading was multiplied by the Saltzman standardization factor to determine the concentration of NO_x in the sample.

RESULTS AND DISCUSSIONS

The performance variables that were studied as independent parameters are speed, spark timing, load, and coolant temperature. The range of speed investigated was 800-1200 rpm for no-load conditions and 1200-2400 rpm for part-load conditions. Spark timing was investigated for the settings of zero , 10, 20 and 40-degree advance. The coolant temperature was varied from 45 to 85 degree celsius with an increment of 10 degrees. The range of air- fuel ratio was from 8:1 to 13:1. Fuel used to conduct the experiments was commercial gasoline fuel with an Octane number of 80.

Fuel Economy

Figure 3 presents the relation between the engine speed and the brake specific fuel consumption (BSFC) at a constant torque of 25 N.m for various spark timings. The figure shows that the BSFC is independent of engine speed at any spark timing . Moreover, the values of the BSFC for the zero and 40-degree advance are higher than those of the 10 and 20-degree spark advance. By advancing the spark by 10 to 20-degree, the integral $\int$ Pdv for the engine would increase and fuel economy would improve.

Air- Fuel Ratio

Figure 4 shows the effect of both engine speed and spark timing on the air-fuel ratio under no-load conditions. For the 800-1200 rpm range,

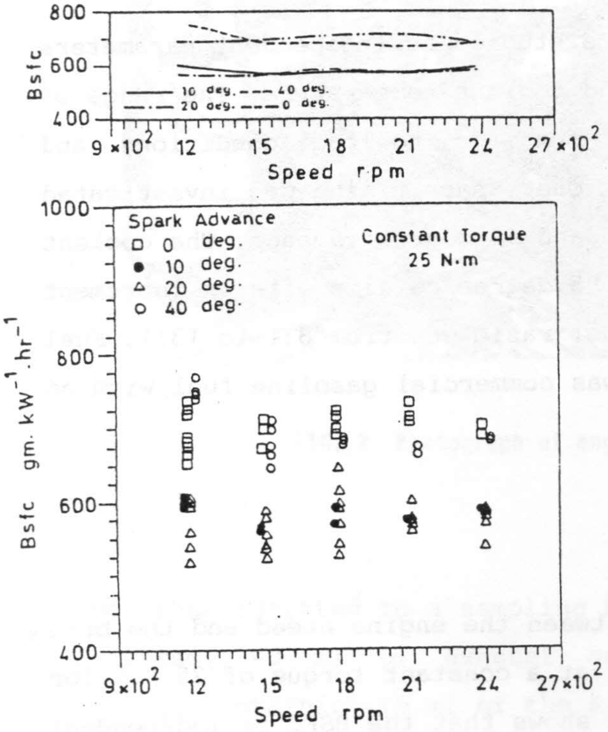


FIG. 3 Fuel economy at part load

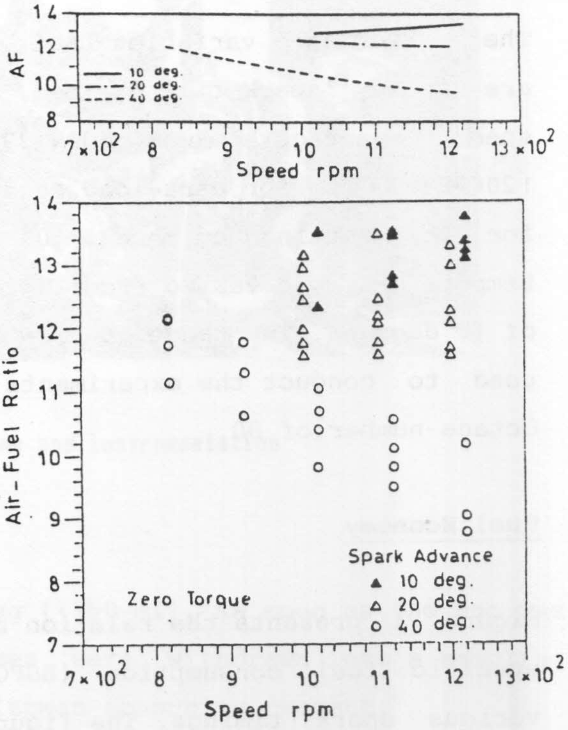


FIG. 4 Air-Fuel ratio at no load

the air-fuel ratio decreases slightly as the speed is increased. A spark advance of 10 degrees would make the air-fuel ratio leaner. More spark advance would require a richer mixture again .

Intake-Manifold Vacuum

Figure 5 presents the effects of engine speed and spark timing on the intake-manifold vacuum at idling conditions. The figure shows the following:

1. At zero advance timing, the vacuum decreases as the engine speed is increased due to the progressive opening of the carburetor throttle.
2. At the 10 and 20-degree advance timings, the vacuum increases slightly with engine speed. Although this behaviour seems strange, it can be explained as follows. As the throttle opening is increased in order to allow more charge to the engine, the throttle vacuum tends to decrease. At the same time, the increase in engine speed tends to increase vacuum at the throttle valve. The latter effect would overcome the former and the result would be a slight increase in throttle vacuum as the engine speed is increased from 1000 to 1200 rpm.
3. At the 40-degree spark advance , the vacuum increases with engine speed between 800 and 900 rpm, then stays unchanged between 900 and 1100 rpm and finally decreases slightly between 1100 and 1200 rpm.
4. The highest vacuum occurs at the 10 and 20-degree advance timings followed by the 40-degree timing . The lowest vacuum is attained at the zero-advance timing. This may be explained with the aid of the data on the rate of fuel consumption. The lowest consumption (corresponding to least throttle opening) occurs at the 10-and

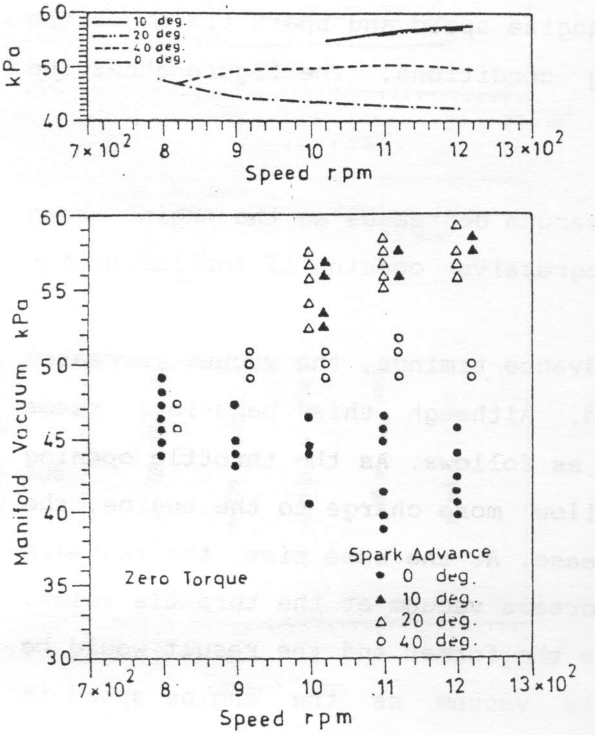


FIG. 5 Intake-manifold vacuum at no load

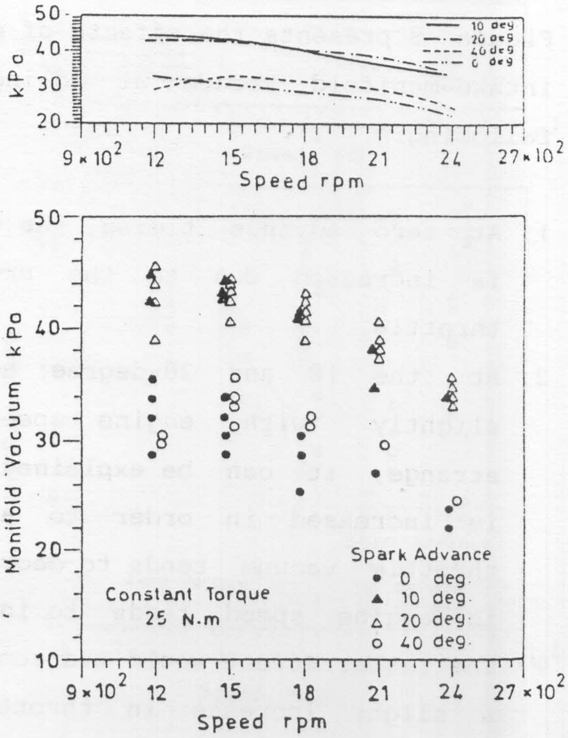


FIG. 6 Intake-manifold vacuum at part load

20-degree advances meanwhile a higher consumption(corresponding to a greater throttle opening) occurs at the zero-advance timing.

5. The lowest possible idling speed was 800 rpm for the zero and 40-degree advance timings. In the case of the 10-and 20-degree advance timings, the lowest idling speed was 1000 rpm.

Figure 6 shows the relation between engine speed and intake-manifold vacuum for various spark timings at the constant torque of 25 N.m. The figure shows a continuous drop in the intake-manifold vacuum as the speed is increased due to the progressive opening of the carburetor throttle. The zero-advance timing appears to cause the least vacuum (greatest throttle opening) meanwhile the 10-20 degree advance timings would cause the highest vacuum (least throttle opening).

Exhaust Temperature

Figure 7 shows the effect of engine speed on the exhaust tailpipe temperature for various spark timings at no load conditions. The figure shows a continuous increase in exhaust temperature with engine speed. This may be explained with the aid of figure 4 on the air-fuel ratio. As the speed is increased, the charge mixture becomes slightly richer, and the turbulence within the combustion chamber improves. Therefore, the spark temperature of combustion rises, and the exhaust temperature consequently increases.

Figure 8 presents the effects of both speed and spark timing on the exhaust temperature (at the beginning of tail pipe) under a constant torque of 25 N.m. The figure shows that for all spark timings exhaust temperature has a minimum in the vicinity of 1500 rpm. For speeds below 1500 rpm, it appears that turbulence slightly enhances the rate of heat loss from the engine. This would reduce the exhaust

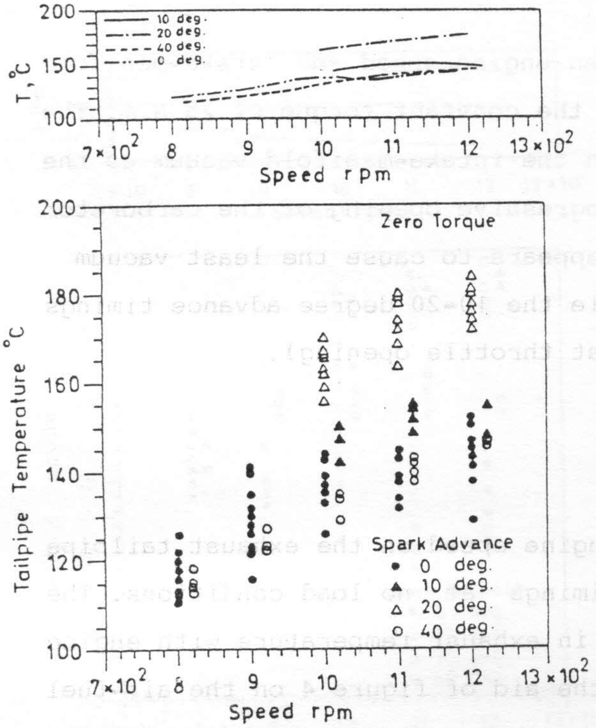


FIG. 7 Exhaust temperature at no load

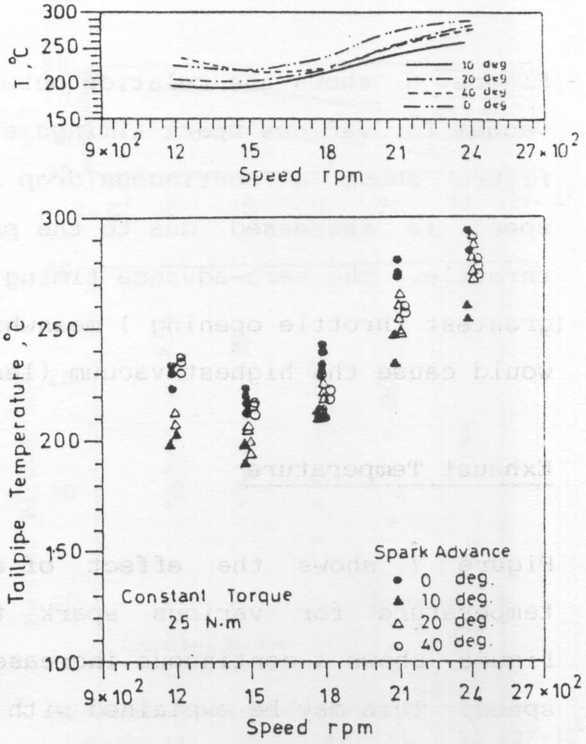


FIG. 8 Exhaust temperature at part load

temperature with increasing the speed up to 1500 rpm . On the other hand, as the engine speed is increased over 1500 rpm, the turbulence of combustion would increase and raise the peak temperature within the combustion chamber . In addition, the " adiabaticity" of the engine would increase and the fraction of heat loss would drop leading to a higher exhaust temperature.

Nitrogen Oxides Emissions

Figure 9 shows the effect of both engine speed and spark timing on the concentration of nitrogen oxides emitted from the engine at zero-torque conditions. It is clear from the figure that speed has only a minor effect on nitrogen oxides concentration. For the condition of 40-degree advance, NO concentration decreases slightly with increasing speed . To explain this one may refer to figure 5 in which the manifold vacuum increases slightly with speed. This means that the pressure in the intake manifold is much less than that of the residual. So, a portion of the exhaust gases will flow from the combustion chamber into the intake manifold resulting in a remarkable dilution of the fresh charge and so decreasing the amount of nitrogen oxides in the exhaust gases. The reason for the peak found in the case of 10-degree advance is the relatively higher air-fuel ratio.

Nitrogen oxides concentration is nearly the same for the spark timing range 10-to 40-degree advance and decreases for the condition of 20-degree advance. This may be attributed to the increase in the manifold vacuum in this case. The slight decrease in nitrogen oxides concentration has been concluded by Kataoka and Hirako[2] in their mathematical model. Henein and Patterson [3] reported that speed has nearly no effect upon nitrogen oxides concentration.

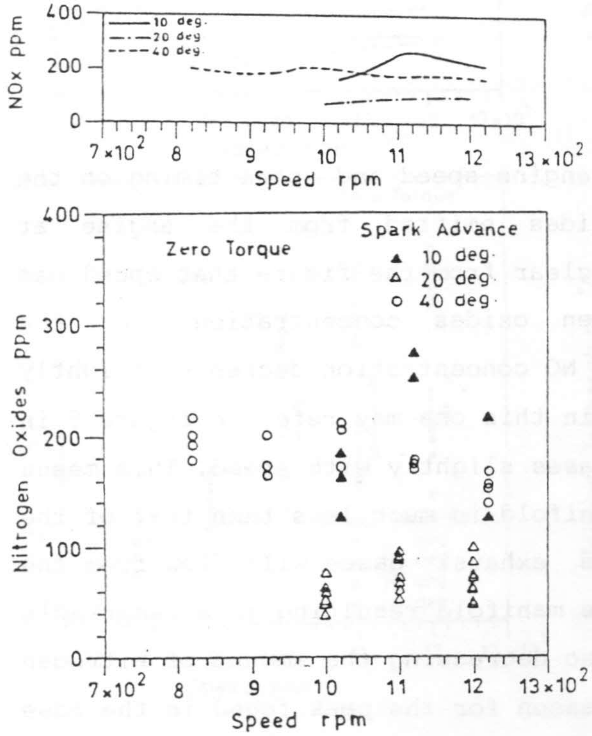


FIG. 9 Nitrogen oxides emissions at noload

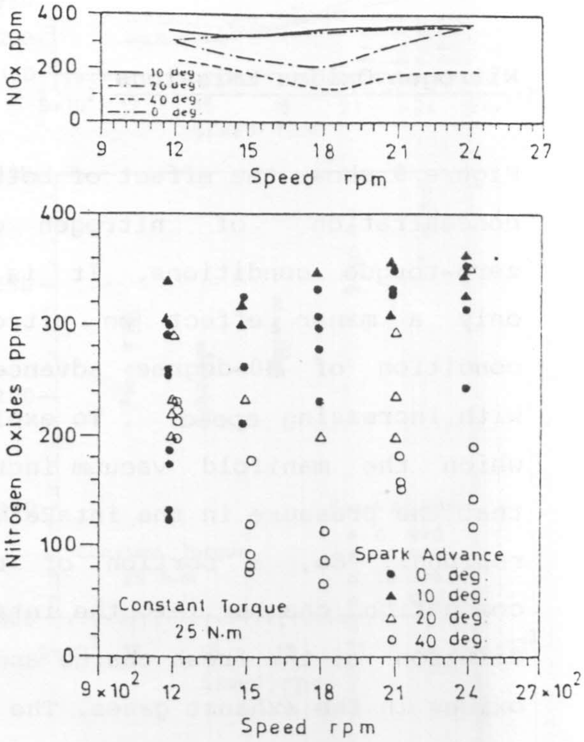


FIG. 10 Nitrogen oxides emissions at part load

Figure 10 shows the relation between engine speed and nitrogen oxides concentration at a constant torque of 25 N.m. Nitrogen oxides concentration follows the temperature profile shown in figure 8. NO concentration decreases as speed is increased from 1200 rpm to 1800 rpm, and then increases as speed is increased to 2100 and 2400 rpm due to the increased peak cycle temperature. Fig. 10 also shows that advancing the spark timing from zero to 10-deg. results in an increase in NO emissions . This result agrees with the results found in the literature [1,3] . However, further increase to 20 and 40 deg would reduce the NO emission level.

The effect of engine coolant temperature on the nitrogen oxides concentration was investigated for the coolant temperature range of 45-85 degrees C. Figures 11,12 show that no significant correlation is observed for the conditions under which the engine was tested. It appears from figure 12 which describes the effect of coolant temperature on nitrogen oxides concentration that running the engine under the zero advance condition and low rotational speed results in hunting operation and wide scattering in the levels of nitrogen oxides emission between 50 and 360 ppm.

Comparison with Literature

Although the study of nitrogen oxides emissions from engines running under very rich mixtures conditions has not been thoroughly covered, some figures that describe the relationship between air- fuel ratio (the whole range of rich and lean mixtures) and nitrogen oxides concentrations were selected and the results of the present study were superimposed on them in order to verify the effect of very rich mixing ratios upon nitrogen oxides concentrataon. The present results are not

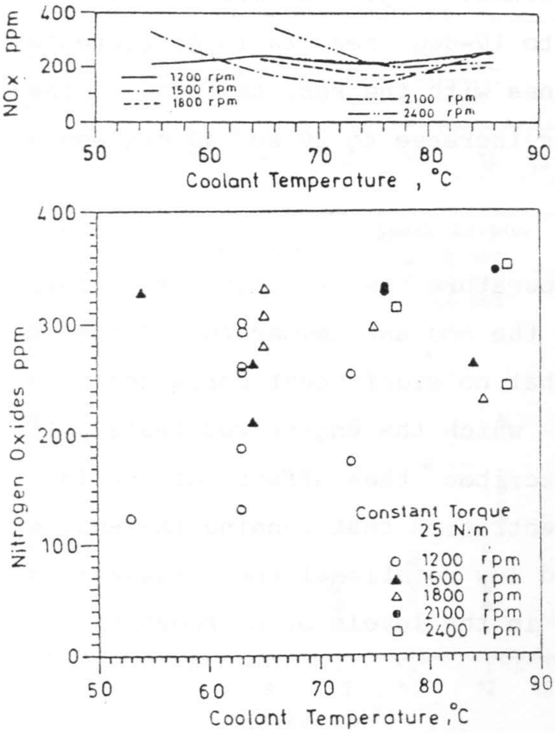


FIG. 11 Effect of coolant temperature on nitrogen oxides emissions at part load

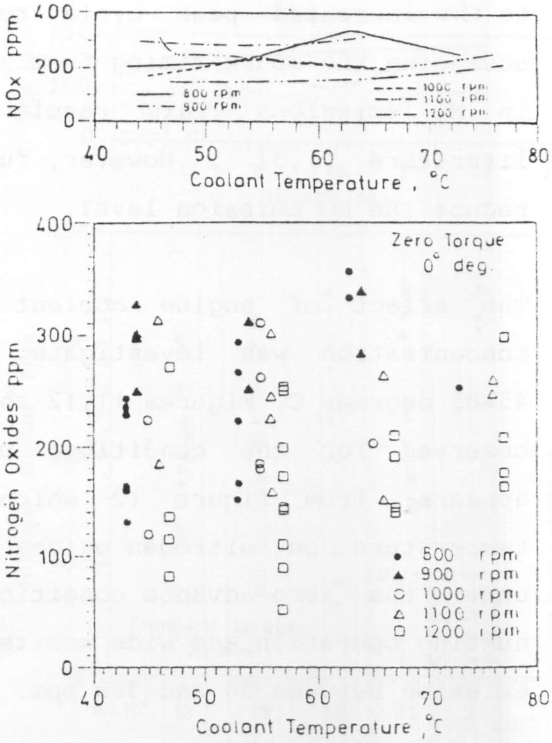


FIG. 12 Effect of of coolant temperature on nitrogen oxides emissions at no load.

expected to coincide with those of the literature because of the differences in engine dimensions, method of fuel management, as well as the technique of sampling and measuring the concentration of nitrogen oxides.

Figure 13 shows the present work as compared to the experimental results reported by Campau and Neerman [5], Komiyama and Heywood [6], and Starkman [12] . The spark timing for Starkman's experiments was adjusted to zero-advance and so, this condition was selected for the sake of comparing his results to the results of the present work. It is clear from the figure that concentrations measured in the present work constitute an extension to Starkman's work. Figure 13 also shows the results of the present work as compared to the experimental results of Komiyama and Heywood [6] . Nitrogen oxides concentrations were measured with a chemiluminescent NO analyzer. The results of the present work are in good agreement with Heywood's results in the vicinity of the air-fuel ratio of 11. The figure shows that the present work may be considered as an extension to Reference [6]. The present work is also compared to the results reported by Campau and Neerman [5]. They ran their experiments on a six-cylinder engine at 1500 rpm, and measured the concentration of nitrogen oxides by the Phenoldesulfonic acid method as well as mass spectroscopy. The results of the present work appear to be an extension to the work of Campau and Neerman [5].

In figure 14, the mathematical model of Yuen and Servati [9] considered only the air-fuel ratio as an independent variable affecting the emissions of nitrogen oxides leading to a correlation that was used in the computer program. Yuen and Servati limited their study to rapid transient operation(sudden acceleration or

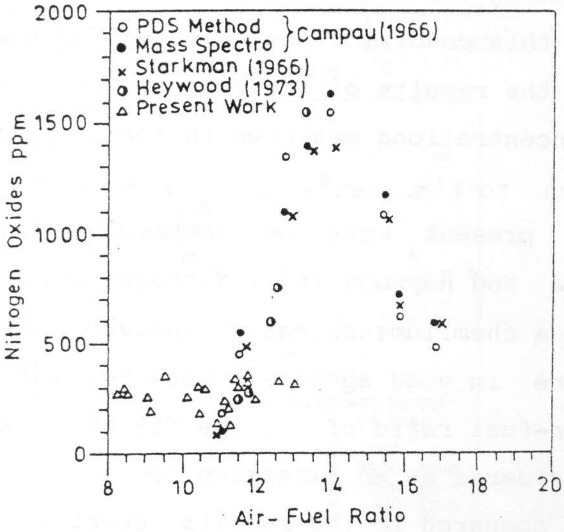


FIG. 13 Present results as compared to experimental literature.

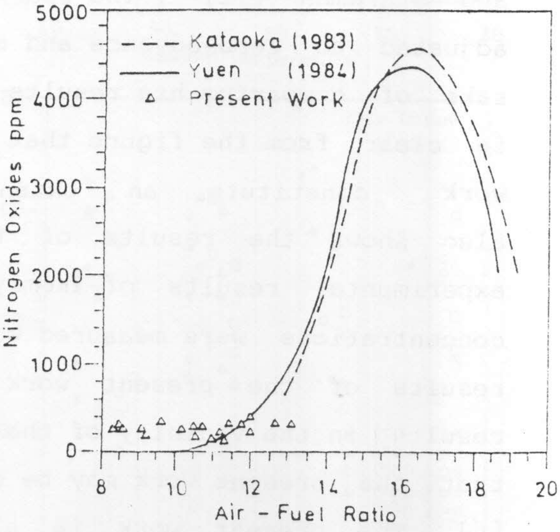


FIG. 14 Present results as compared to numerical literature.

deceleration) while the present study was conducted at steady-state conditions. It appears that the model agrees well with the present experimental work in the range of $11 < AF < 13$. However, the model fails to predict the NO concentrations for air-fuel ratios below 11. The model of Kataoka and Hirako [2] which is also shown in figure 14 seems to overestimate the concentrations of nitrogen oxides in the rich air-fuel ratio zone. Their engine conditions were:

Compression ratio : 8.5 : 1
Engine speed rpm : 2000
Period of combustion: 5 deg. BTDC to 10 deg ATDC.

The compression ratio is higher than that of the engine used for the present study (7.2: 1) and that may be responsible for the higher values of nitrogen oxides concentrations since it is known that increasing the compression ratio has a significant effect on the concentrations of nitrogen oxides[3] .

The above comparisons show that the present study has investigated the effects of no-load conditions of spark-ignition engines on the emissions of nitrogen oxides within the range of air-fuel ratio that was not thoroughly covered in the literature ($8 < AF < 13$). The results of the present study may constitute an extension to the results of the literature.

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Conclusions

Based on experiments conducted on a FIAT 1500 c.c engine under no-load and part-load conditions, the following conclusions can be deduced:

1. Engine speed has only a minor effect upon the concentrations of nitrogen oxides under no-load conditions(zero torque). At part-load conditions, the concentration of nitrogen oxides follows the temperature and pressure profiles, i.e. a decrease in the concentration occurs as speed is increased from 1200 to 1500 rpm then concentration increases significantly as speed is increased to 2400 rpm.
2. Advancing the spark from zero to 10 degrees results in an increase in nitrogen oxides concentration. But further advance to 20 and then to 40 degrees decreases the amount of NO emitted from the engine.
3. For the condition of zero-torque operation, the spark timing which results in the lowest emission level is 20 deg. advance, while for the part-load condition, the 40 deg. advance produces minimum emissions level.
4. The coolant temperature in the range of from 45 to 85 C has no significant influence on nitrogen oxides emission.
5. The results of the present study may contribute to the literature regarding the NO emissions for very rich mixtures of air-fuel ratio from 8 to 13.

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