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The Effect of Some Operational and Design Parameters on the Emitted NOx Pollutant of a Spark Ignition Engine

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Abstract**—** *Liquefied petroleum gas and natural gas were used to run a spark ignition type Prodit. Some operational and design parameters effects on the NOx pollutants emitted from the engine were investigated practically. The studied parameters were the equivalence ratio, compression ratio, engine speed and spark timing variation. The resultant pollutants were studied when the engine is running at the higher useful compression ratio, which was 8;1 for gasoline and comparing its results when the engine was run at the higher useful compression ratio for each fuel alone. The results show that the highest value for NOx is laid always on the weak side near the stoichiometric equivalence ratio and its concentrations decreased by going away from that value to run at lean or rich mixtures. NOx maximum concentrations were achieved when the engine was run with LPG at 8:1 compression ratio. This value converges when the engine works on the highest useful compression ratio for each fuel. The major effective parameter on the NOx levels was for the spark timing.*

Keywords— *LPG, NG, Gasoline, NOx, compression ratio, equivalence ratio, spark timing*.

I. INTRODUCTION

Internal combustion engines play an important role in public life as it facilitates transporting of persons and goods [1]. Spark ignition engines are considered of the most important types of motors which are used widely around the world [2]. However, the world began to care much about the pollutants emitted from these engines, and the most dangerous are the nitrogen oxides (NOx) resulting from nitrogen oxidation at elevated temperatures during the power stroke [3]. The researchers worked dramatically in an expanded way to find solutions to reduce this contaminated [4-7]. One of these solutions is the use of new types of alternative fuel that results from it burning less exhaust pollutants [8-10]. Natural gas (NG) and liquefied petroleum gas (LPG) were considered for decades as a good alternative to gasoline fuel in the spark ignition engines (SIE) [11-14].

Natural gas produced from underground reservoirs, and in this case it is called dry natural gas, or accompanying oil when extracted [15]. LPG produced from oil as low carbon atoms from 2 to 5 in refineries. Although the two gasses are oil products and is composed of carbon and hydrogen, but the small number of carbon atoms make their burning produce less exhaust pollutants [16].

Although the invading two oil producer and is composed of carbon and hydrogen, but the small number of carbon atoms makes burning produces less exhaust pollutants [17-20]. The experience of using these gases as a fuel for cars exist and successful for decades in Europe and America, and has finally spread to Iran, India and Egypt [21]. Unfortunately, to this day, the gaseous fuels have not been widespread use in Iraq, but across the limited experiences of a small number of government vehicles [22]. Despite the fact that Iraq burns everyday cubic thousands of natural gas in air, which can be utilized as a fuel for cars [23].

The researchers [24-26] declared that NOx concentrations are much less in weak equivalence ratios (Ø) and increased to have maximum values on the weak side near the stoichiometric ratio due to the high burning temperature and because of the burning of most of the fuel and for existence of oxygen. By increasing or reducing the equivalence ratio these concentration decreases [27]. NO is greatly affected by the spark timing such that the delay of spark timing highly decreases NOx concentrations for all the equivalence ratios because of the reduction of the maximum burning temperature and the short time required for oxygen and nitrogen to react [28-30]. Advancing the spark timing increases NOx concentrations as the spark time being earlier which represents higher pressure in the combustion chamber and higher temperatures [31].

The effect of increasing compression ratio (CR) acts inversely to the effect of spark timing, as increasing the compression ratio causes increasing in NOx concentrations on both sides (lean and rich mixtures) due to the rise in the temperature inside the combustion chamber [32-35]. Retarding the spark timing from the optimum time attendants the increase of compression ratio as it decreases the NOx concentrations [36].

NOx concentrations are little at low speeds because the temperature of maximum cycle is relatively low due to the dilution increasing and the increase in burning interval [37]. At medium speeds, NOx concentrations are increased because of the rising in the maximum cycle temperature [38]. At high speeds, these concentrations decrease due to the short time required to interact of Oxygen and Nitrogen and the chemical dissociation increase because of the high rising in the temperature of the maximum cycle [39].

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Ref. [40] measured the pollutants emitted when an engine was fuelled with CNG and LPG comparing it with gasoline NOx emissions. The author noticed that the equivalent ratio value where the highest concentrations occur is near to stoichiometric equivalence ratio in natural gas case more than that with the LPG.

This paper aims to evaluate the NOx concentrations emitted from a spark ignition engine when fuelled with NG and LPG, to find the possibilities of using these fuels in Iraqi cars as an alternative to gasoline. This work is a part of the Energy and Renewable Energies Technology Centre in University of Technology, Baghdad, Iraq [41-80].

II. EXPERIMENTAL SETUP

A. Used Devices

The engine used in this research was Prodit (Italy) with four strokes, single cylinder, and variable compression ratio, air fuel ratio, spark timing, and engine speed. This engine is connected to a hydraulic dynamometer fixed on a steel base designed for this purpose.

The system of gasoline supplying the engine consists of a main tank with 6 litres and a secondary tank with one litre and a set of valves working to open and close the fuel flow. The system of supplying the engine with the LPG consists of a fuel tank (80 kg), fuel filter, electromagnetic valve, orifice type flow meter, gas evaporator (adaptor) in addition to the damping box and the gas feeder. The system used to supply the engine with natural gas consists of a natural gas cylinder, pressure regulator, and chocked nozzles system and gas feeder.

The average of air flow to the engine is measured by viscous fluidity cubit device and the pressure comparison for the device is measured by an inclined water manometer. The ignition system is an evacuation conductance type and the spark time can be changed manually from 0° BTDC to 60°BTDC of the crank shaft angles.

NOx pollutants have been measured using Multigas mode 4880 emissions analyser device which operates on the chemical luminescent. This device was calibrated by comparing its readings with a calibrated new device.

B. Used Fuels

In this research, gasoline fuel produced from Al-Doura Refinery with Octane No. 82 was used in the experiments. Iraqi gasoline has low octane number and high Sulfur content about 500 ppm. In addition to high lead content. LPG produced from Al-Taji company- Iraq consist of 0.08% Ethane, 48.38% Propane, 18.37% isobutene, 3.245% n. butane. The used natural gas was produced from North gas company (Kirkuk-Iraq) consists of 84.32% Methane, 13.27% Ethane, 2.15% Propane, 0.015% isobutene, 0.017% n. butane, 0.03% Pentane.

C. Test Procedure

The first experiments were conducted to determine the highest useful compression ratio (HUCR) for wide range of equivalence ratios at optimum spark timing for each fuel alone. At this ratio, the effect of each equivalence ratio, speed, spark timing have been studied on the resulted NOx emitted from the engine.

III. RESULTS AND DISCUSSIONS

A. Compression Ratio Effect

Figure 1 shows the effect of compression ratio (CR) when gasoline is used as engine fuel. The increasing of CR causes increasing of NOx concentrations at the weak side equivalence ratios less than Ø = 0.09, and that is happens due to the increasing of the temperature of the exhausted gas resulted at this equivalence ratios.

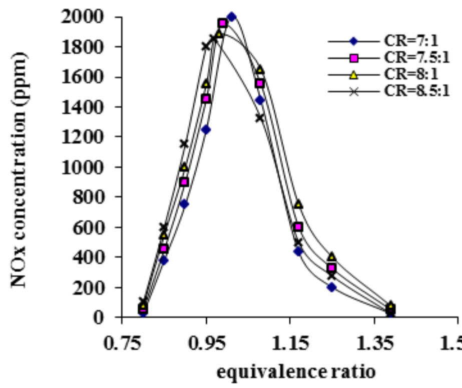

Fig. 1. The effect of variable CR on NOx levels for wide range of equivalence ratios for Gasoline.

NOx concentrations decreased on the rich side at equivalence ratios greater than Ø =1.1, because as rising the temperature of maximum cycle by increasing CR, but there is alack in available oxygen for reaction with nitrogen. At equivalence ratios of (Ø = 0.09-1.1) where the highest brake power is achieved, the NOx concentrations decreases by increasing CR because of the existence of another effecting factor on NOx concentrations, which is the optimum spark timing (OST). OST is the reason for the decrements happened by increasing CR as the temperature of the mixture inside the combustion chamber will be increased which will improve the burning and which will increase the speed of the flame diffusion and causes delay of the optimum spark timing to insure not to have knocking. So, the time for NOx pollutant reactions will be less and that is clear when studying the effect of spark timing on NOx concentrations. However, these concentrations will be increased at CR= 8.5: 1, at this CR, as the figure shows, increasing CR overcomes the spark timing effect especially when knocking phenomenon occurred.

Figure 2 shows the same trends when using LPG as an engine fuel with expansion of the weak equivalence ratio which makes the effect of CR clear on this side for ratios less than (Ø =0.75). Natural gas is used as a fuel in Figure 3 to evaluate the effect of the compression ratio on NOx concentrations that are emitted from the engine. As the previous figures, the highest values of NOx are on equivalence ratios (Ø =0.95-0.98) for natural gas. While it is (Ø = 0.92-095) for LPG, and (Θ =0.90-0.93) for gasoline. When the engine is working with equivalence ratios less than Ø=0.8 emits NOx with concentrations within the limitation of Europe

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(Euro 3) and USA (Tier 2) with condition that a guarantee that the burning of gasoline and LPG is not failed at this lean equivalence ratio[27].

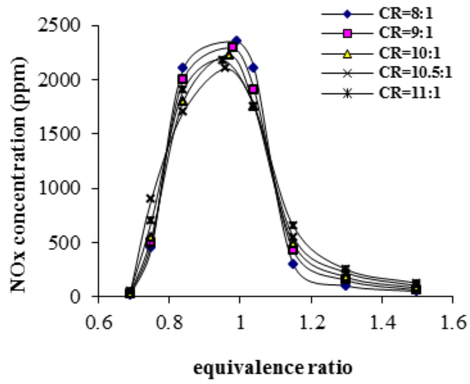

Fig. 2. The effect of variable CR on NOx levels for wide range of equivalence ratios for LPG.

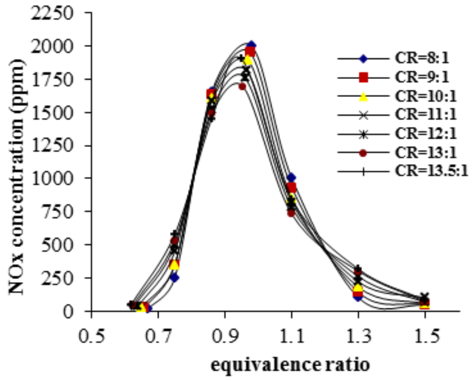

Fig. 3. The effect of variable CR on NOx levels for wide range of equivalence ratios for NG.

Figure 4 represents the maximum value of NOx levels on each CR for each fuel. The figure shows that the LPG gives the maximum values of NOx concentrations, when comparing at fixed CR and optimum spark timing. These values converge when they engine run at the HUCR.

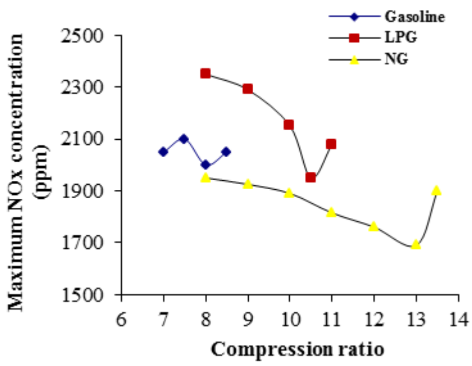

Fig. 4. The effect of variable CR on maximum NOx levels for the tested fuels at 1500 rpm

B. Equivalence Ratio Effect

In the figures 1, 2 and 3 we noticed that NOx concentrations are low on the very lean and very rich sides for each fuel, and it was increased heavily on the lean side to reach its maximum value near the stoichiometric equivalence ratio from the lean side. Then, these concentrations were reduced by enriching the mixture with fuel. The availability of oxygen and high burning temperature resulted from the combustion of most of the available fuel with the availability of the required time for reaction is the reasons of increasing the concentrations in the lean side. In the rich side, the reduction in NOx concentrations with increasing the compression ratio is due to the lack in required oxygen for interaction, which also causes low average burning temperatures.

C. Spark Timing Effect

Figure 5 manifests the effect of spark timing on NOx levels in the exhaust gas when the engine operates at the stoichiometric equivalent ratio for each fuel and 1500 rpm engine speed for the three selected lean equivalence ratios for each fuel. For gasoline we choose equivalence ratio Ø= 0.83, for LPG the ratio was Ø= 0.75, for NG Ø=0.75 to declare the effect of spark timing on every lean equivalence ratio. Figure 6 clarifies high reduction in NOx levels for equivalence ratios near the stoichiometric one. For gasoline, NOx concentrations reduced by ratio of 42% by retarding the spark timing 10° BTDC. The reduction of NOx concentration for LPG was 37% by decreasing spark timing 10°BTDC. While for the natural gas the ratio is decreased to 89% by retarding the spark timing 12°BTDC.

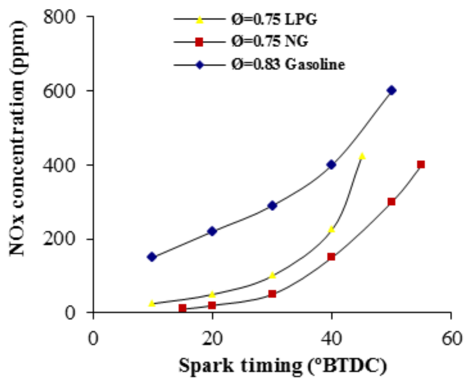

Fig. 5. The effect of variable ST and specific lean equivalence ratio on NOx levels for the tested fuels.

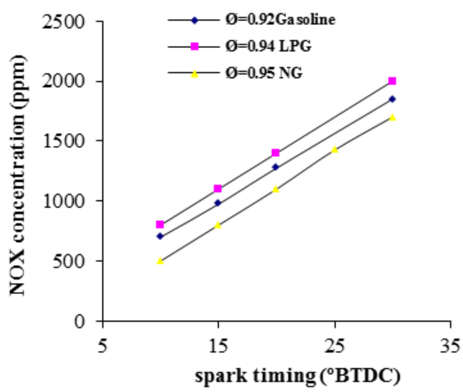

Fig. 6. The effect of variable ST on the emitted NOx levels for the tested fuels at equivalence ratios of maximum pollutant.

Figure 7 shows that in spite of the retarding spark timing within 10° BTDC away from the OST, for rich equivalence ratio like Ø= 1.3, for gasoline, the NOx concentrations reduced about 12%. The same trend was obtained when using LPG at equivalence ratio of Ø=1.3, NOx concentrations reduced about 15%. For natural gas at equivalence ratio Ø=1.25, the reduction was within 12.5% which shows that the effect of changing spark timing on the rich side for the three types of fuel has a limited effect.

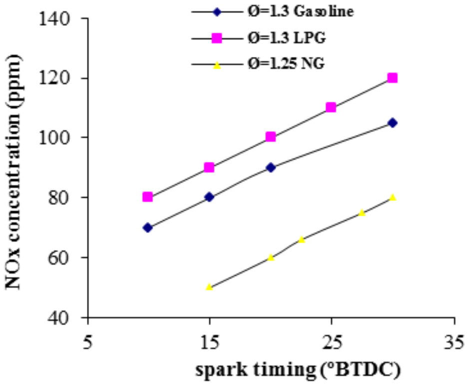

Fig. 7. The effect of variable ST on the emitted NOx levels for the tested fuels at rich equivalence ratios

D. Engine Speed Effect

NOx concentrations were increased with engine speed increasing, and the maximum value of it was at 1500 rpm and decreased for high speeds like 1200 rpm (figure 8).

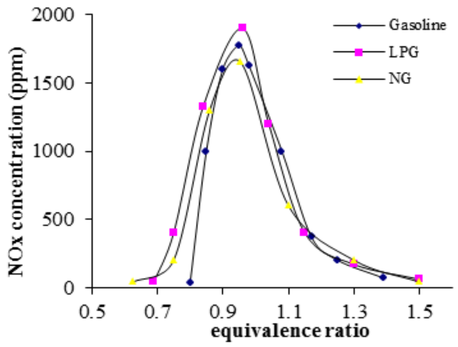

Fig. 8. A comparison between the emitted NOx levels for the tested fuels at engine speed of 1200 rpm.

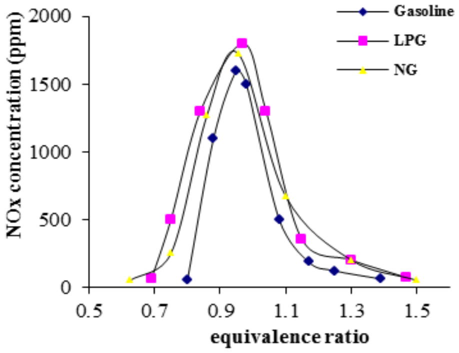

Fig. 9. A comparison between the emitted NOx levels for the tested fuels at engine speed of 2100 rpm.

This results comes from that the maximum temperature is relatively low at low speeds because of the dilution increased and the combustion time extend while at medium speeds (1500 rpm) the NOx concentrations was increased as a result of the rising of the maximum cycle temperature. At high engine speeds these concentrations are reduced because of the lack of the time required for interaction between oxygen and nitrogen, and increasing of the chemical dissociation at the high maximum cycle temperatures.

Figure 9 shows that NOx concentrations for the three types of fuel are closed when the engine works with HUCR for each fuel for speed of 2100 rpm. LPG engine has emitted more NOx levels because of two factors high temperature values, and good speed for flame diffusion.

IV. CONCLUSSIONS

In this paper, the effect of some design and operation parameters was evaluated experimentally on single cylinder Prodit engine. The study results reveal that NOx concentrations increased by increasing compression ratio on the lean and rich side while the maximum value is decreased with this rising. The resulted concentrations from the LPG engine was higher that of gasoline and NG when the engine was run at fixed compression ratio or HUCR for each fuel because of the higher calorific value of the fuel and due to higher flame speed for it comparing with the other two fuels. Spark timing can be considered as the primary factor in controlling the resulted NOx levels from the engine. Retarding the spark timing caused a reduction in NOx concentrations with high ratio when working with the three types of fuels at lean equivalence ratios. The NOx levels were reduced on the rich side but with less average.

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