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Emitted NOx from a Spark Ignition Engine Fueled With Natural Gas

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Abstract— *Gaseous fuels are widely accepted as an alternative to gasoline because it reduces emissions from the engine after burning. Iraq today is considered one of the most countries with a large stock of natural gas and has begun to produce and export to the world. So, using this gas as a vehicle fuel has become a matter of time. In this study, we investigated the NOx exhaust pollutants emitted by a single-cylinder spark ignition engine.*

The results showed that natural gas can act as a fuel in spark ignition engines with no change in engine design with low NOx levels. If the compression ratio of the engine is increased to the higher useful compression ratio of natural gas, the NOx concentrations increase. These concentrations are also increased by advancing the spark timing away from the optimal timing. The results showed that the most significant parameter that affects the increase of NOx is the equivalent ratio. NOx levels rise at an equivalence ratio of 0.95 and reduce in the lean and rich sides.

Keywords— *Natural gas, Iraq, NOx, compression ratio, equivalence ratio.*

I. Introduction

The world today has major problems, including air pollution, global warming and climate change [1]. All these problems resulted from the wasteful use of fossil fuels for energy production for electricity and transportation purposes [2, 3]. Oil dependence has become an issue that needs to be re-examined because of pollutants from it that cause global warming and pollute the environment. The price volatility and near-depletion over the next seven decades at best should lead to alternative fuels [4]. Although natural gas is considered to be a fossil fuel, it produces fewer contaminants when combustible [5]. Most geological studies show that it is possible to continue using it for 150 years, so it is an available and important alternative [6]. Today, natural gas is extracted from its reservoirs and used as fuel to produce electricity and heating, and several countries have turned to use it as fuel for vehicles [7].

Iraq has a huge reservoir of natural gas and is currently ranked fourth after Russia, Iran, and Qatar [8]. Natural gas production began late in Iraq as previous governments burned this gas associated with oil because of the lack of potential for isolation [9]. Today, this gas is being collected and used as a material to be exported abroad. Several promising programs have been put in place to benefit from it through the deployment of a pipeline network to make the taxis work [10].

Iraq is a country with high levels of environmental pollution by all standards. Heavy black oil is used in power plants with diesel. There are also more than two million melodic with varying capacities from 1 to 1000 thousand to work to fill the shortfall in the processing of electricity [11]. If we add to all this, the large number of cars, trucks and heavy equipment that do not adhere to the limits of contaminants like Europe or the United States and spend millions of tons of pollutants in the atmosphere of the country. One of the main disadvantages of diesel and Iraqi gasoline is that it contains a high sulfur content that exceeds its global levels [12].

The Iraqi researcher studied with great interest the use of gaseous fuel as an alternative to gasoline [13-15]. Also they studied the addition of these gases to diesel in a dual fuel engine [16-23]. This interest came mainly because Iraq is an oil country full of gaseous fuels, either liquefied petroleum gas (LPG) or natural gas [24, 25]. Besides, this country is capable of producing hydrogen from natural gas by large amounts through the steam reforming process [26].

Gaseous fuels have low levels of exhaust pollutants compared to gasoline or diesel fuel because they are a low carb or carbonless compound, as in the case of hydrogen [27-29]. So most researchers have found that pollutants emitted from a gas-fired engine are very little hydrocarbon exhaust pollutants (CO, CO2 and HC) compared to diesel and gasoline or none as in the case of hydrogen [30-32]. However, most studies have confirmed that liquefied petroleum gas and hydrogen produce high NOx levels [33, 34]. While natural gas produces lower rates when compared to gasoline under the same conditions [35]. The reason for this is due to the low flame spread of natural gas compared to liquefied petroleum gas or hydrogen [36-40]. Therefore, when using natural gas, the spark timing must be advanced in order to reach the optimum spark timing for the fuel [41].

Nitrogen oxides are formed from the oxygen and nitrogen union at temperatures higher than 980 and in the flame front from the moment of the spark ignition [42]. When the piston goes down in the power stroke, the NOx concentrations are frozen and stabilized [43]. These contaminants when interacting with unburned hydrocarbons in the presence of solar radiation form photochemical smog, which have serious effects on humans, animals, plants, and the environment [44, 45].

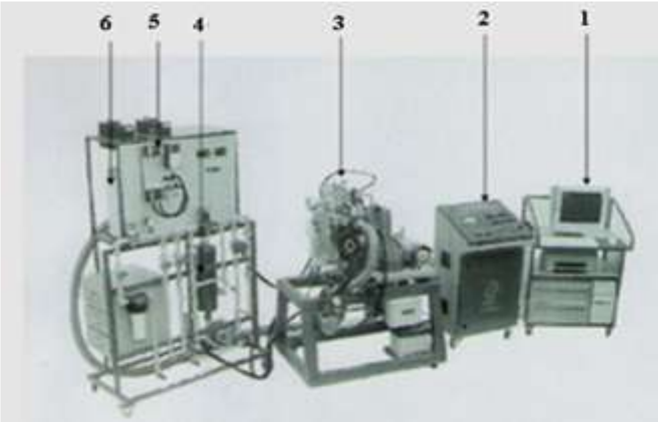
The research work aims to study the possibility of relying on natural gas to reduce the levels of NOx emitted from spark ignition engine. The impact of operational and design conditions on these concentrations will be studied also to identify the best conditions for the engine to reach the lowest rate.

II. Experimental Setup

The experiments were carried out using a single-cylinder, four-stroke internal combustion engine with a variable compression ratio type (GR0306/000/ 037A, Prodit Company, Italy). The engine is connected to a hydraulic dynamometer, which is used to vary and measure the torque projected on the engine. The air supplied to the engine is measured by an orifice plate. The air processing system is composed of: air intake pipe, damping chamber, and differential power switch. The exhaust gas temperature measured using thermocouples type K, installed at the beginning of the exhaust pipe.

NG feeding system:

The system used to supply the engine with LPG composed from the following parts: fuel tank, fuel filter, electromagnetic valve, NG gas evaporator, gaseous fuel flow meter, damping box, gas feeder and flame trap. Fig. 1 shows the engine used in experiments with all its accessories.



1. Computer and its accessories 2. Control panel 3. The engine 4. Engine's cooling unit 5. The engine's fuel unit 6. The air supply system
Fig. 1. The system used in experiments.

NOx measuring device

Multi gas meter 4800 was used to measure the emitted NOx from the engine. The probe of the meter was put at the exit of the exhaust gas pipe. This meter uses light emission in a chemical reaction to evaluate NOx levels. This meter was calibrated and its uncertainty was less than 2% which makes the reading accuracy acceptable.

Materials

The natural gas produced by Kirkuk refinery was used in this work. This gas contains 93% methane, 4.5 ethane, 2.5 propane.

III. Results and Discussions

Figure 2 shows the relationship between NOx concentrations and the equivalence ratio for a single cylinder engine fueled by natural gas and operated at higher useful compression ratio (HUCR), 1500 rpm, and optimum spark timing. NOx levels are as low as possible at the lean equivalence ratios (ϴ=0.62), and increase to their highest value at a lean equivalent ratio close to the stoichiometric equivalence ratio (0.945). NOx concentrations are reduced when the engine was working at a rich equivalence ratios to their lowest values. NOx concentrations increased on the lean side because of the availability of excess oxygen for the reaction, and due to most of the fuel was burned resulting in high temperatures in the combustion chamber, which fit the formation of NOx. These concentrations reduced at the rich side because of the reduction of oxygen and the deterioration of combustion due to reduced volumetric efficiency of the engine.

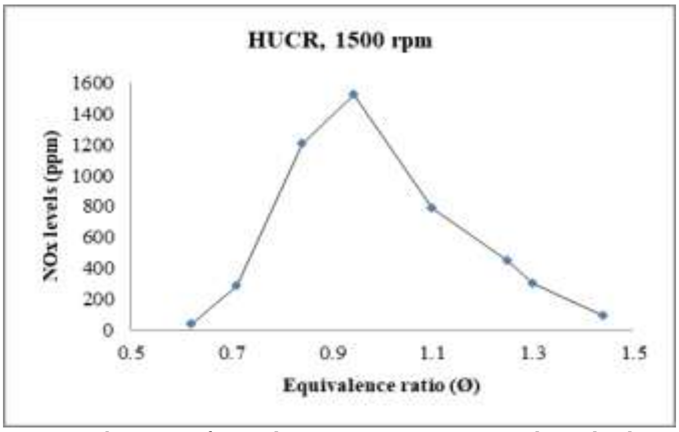


Fig. 2. The impact of equivalence ratio variation on emitted NOx levels.

Figure 3 shows the relation between the spark timing variation and the resulted NOx levels when the engine operated at HUCR=13:1 and engine speed 1500 rpm. Three equivalence ratios were chosen: the first represents the lean mixture (Ø=0.75); the second represents the mixture at the point that yields the highest levels of NOx (Ø=0.95); and the third represents the rich mixture (Ø=1.25). Results show that retarding spark timing play an important role in determining the NOx levels emitted from the engine. When the spark timing was retarded for 5°BTDC for Ø=0.95 mixture, the NOx concentration reduced more than 80%, while at the case of Ø=0.75 the reduction was about 85%. At the rich side, retarding the spark timing by 5°BTDC reduced the NOx levels less than 2.5%; which indicate the low impact of retarding spark timing on NOx levels at rich equivalence ratios. Normally, natural gas engines operate at lean equivalence ratios because of the gas phase of the fuel, which takes up space in the combustion chamber at the expense of incoming air, thus reducing the engine's volumetric efficiency.

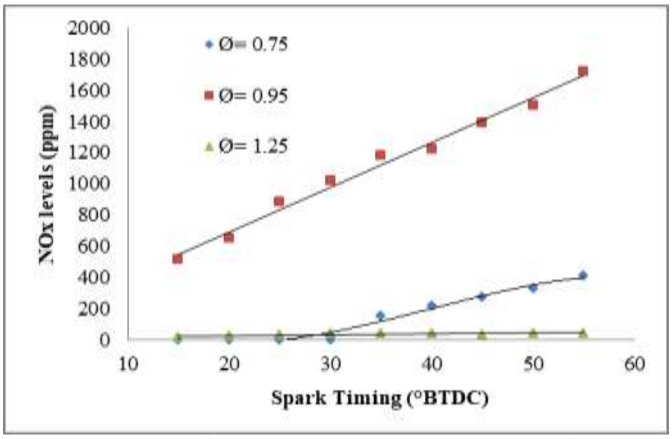


Fig. 3. The impact of spark timing variation on the NOx levels for three specific equivalence ratios.

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Fig. 4 shows the impact of compression ratio variation on NOx levels for wide range of equivalence ratios at engine speed 1500 rpm and optimum spark timing. The curves took the same trend as they were at the minimum values at ultra-lean mixtures and increased to its maximum values between Ø= 0.945 to Ø=0.98, after this ratio the levels reduced again when the mixtures became richer. The increase in compression ratio needs retarding the optimum sparks timing, which caused the NOx levels to increase in the lean side Ø≤0.75 and at the rich side Ø≥1.2. Here, we must confirm that the increment in both sides was limited. The spark timing impact conflicts with the compression ratio effect. The resulted NOx level is the outcome of these two parameters.

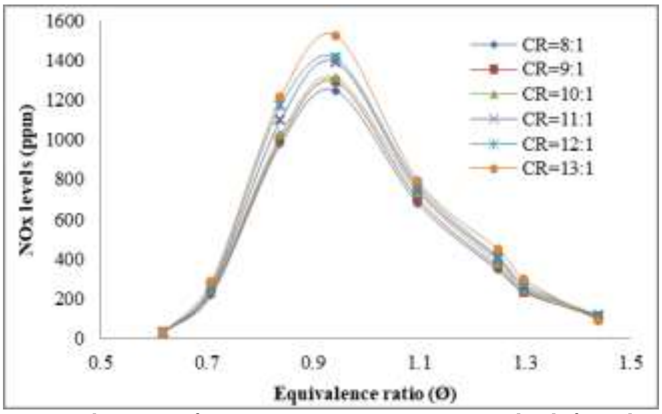

Fig. 4. The impact of compression ratio variation on NOx levels for wide range of equivalence ratios.

It is shown from the curves that the maximum value of NOx concentrations increased with the compression ratio and that the maximum value was at the highest useful compression ratio because of the higher temperature at this ratio within the combustion chamber, which increases these levels.

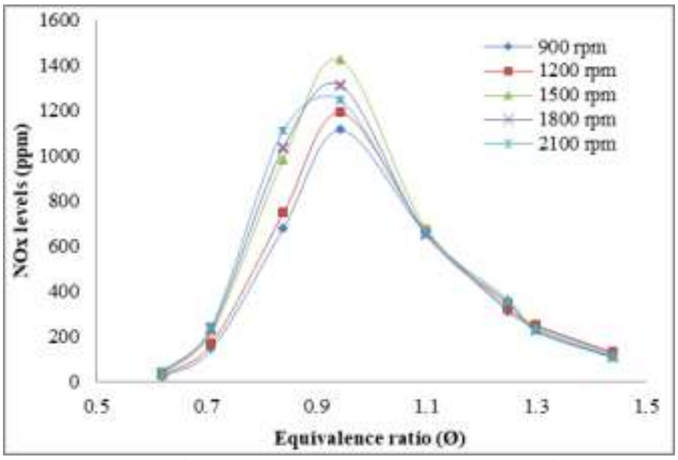

Fig. 5. The impact of engine speed variation on the NOx levels for wide range of equivalence ratio.

Figure 5 shows the effect of engine speed variation on the NOx levels for wide range of equivalence ratio when the engine was operated at HUCR and 1500 rpm. Increasing engine speed increases the heat inside the combustion chamber because of more combusted fuel, which results in higher NOx. The increase in NOx was in the lean side due to oxygen availability while at rich mixture the NOx levels were relatively equal. The maximum NOx levels increased at medium speeds as 1500 and 1800rpm and reduced at high speed as 2100 rpm. At medium speed the time required to NOx formation is available in contrast to the high-speed state where the available time for NOx formation is lower than medium speeds case.

IV. CONCLUSIONS

The equivalence ratio is the main parameters that affect the NOx concentration as the maximum concentrations lied at the lean side near the stoichiometric equivalence ratio, these levels reduced when the equivalence ratio moves away from it in both lean and rich sides. The NOx levels increase with increasing compression ratio and engine speed in the lean side. Retarding spark timing reduced the NOx levels highly at the lean side and the maximum concentrations while its effect was limited at the rich side. NOx levels increased with compression ratio increase with fixed spark timing operation, but when optimum spark timing was used the compression ratio impact was reversed to the spark timing effect.

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