https://dx.doi.org/10.24001/ijcmes.3.3.2 ISSN: 2455-5304

The effect of adding NG to LPG on a spark ignition engine

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Abstract*—*LPG and natural gas are both available in large quantities in Iraq, but unfortunately, they are not used as fuel for internal combustion engines. The current study aims to evaluate the possibility of operating the spark ignition engines by enriching the liquefied petroleum gas with volumetric fractions of natural gas, such as 30, 50, 70 and 80%. The influence of some design factors such as compression ratio and some operational factors such as the equivalent ratio, spark timing, and engine speed have been studied in detail.

The study showed that the highest useful pressure of LPG is 10.5: 1 while natural gas was 13: 1. When adding natural gas to LPG, the compression ratio can be increased to a certain limit to be the highest increase in the mixing ratio of 80% with a compression ratio of 11.6: 1. The natural gas has a low flame propagation speed so the spark timing should be provided when added to the LPG. The addition of this addition reduces the induced power at a low speed due to this natural gas characteristic. Natural gas reduces the engine's output power by reducing the engine's volumetric efficiency by entering the combustion chamber with its gas phase.

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

I. INTRODUCTION

The challenges facing the world today are numerous and dangerous and focus on the negative consequences of human activities over the past centuries [1]. Perhaps the most significant of these disadvantages is the high pollution of the environment [2], including air pollution [3], in addition to global warming and the ozone hole [4]. One of the main reasons for these risks is the burning of fossil fuels for the production of energy, whether electricity or for transportation [5]. Internal combustion engines consume more than 40% of the world's fossil fuels, and the bulk of them are consumed by spark ignition engines [6].

Gasoline is the fuel used in the spark ignition engines, and it is ideal for it in all respects, it is economical, has an appropriate price, and gives appropriate thermal and volumetric efficiency [7]. What is wrong with this fuel is its high emitted pollutant, which started to worry governments because of its adverse effects on the environment [8, 9]. So, many countries have begun to develop specific laws and legislations for pollutants emitted from gasoline engines and these limits are becoming restricted day by day [10]. The motor manufacturers and car companies started from years to search, a long march, and to find an alternative for this fuel [11].

The search for renewable and alternative energies is not new [12]. Since the 1970s, clean and renewable energy alternatives have been introduced [13]. These alternatives include wind power, solar power, tidal energy, geothermal energy and so on [14, 15, 16, and 17]. Many researchers to date are working on improving and marketing solar products such as photovoltaic cells [18, 19, and 20], concentrated power plants [21, 22], solar towers [21, 22], and solar saline ponds [23, 24]. There has also been a lot of research going on today about fuel cells [25]. This technology is a promising one, and it is expected to share a part of the energy production in the near future. Hydrogen has been considered by scientists as the fuel of this century [26, 27, 28], and they made precious research days to introduce it in the internal combustion engines and cut a great deal in this regard [29, 30, 31, 32].

Working with natural gas as a fuel for spark ignition engines is not new, and has been around for years [32, 33]. As natural gas is produced from its own wells and is called dry gas or from oil wells as a byproduct and both cases are available in Iraq [34]. Iraq is the third country in the world in natural gas reserves [35]. To date, the use of natural gas in Iraq is still lagging behind and has not been as important as its size and its ability to support the country's national income [36]. Natural gas is made up of methane, which is more than 90%, while the rest is ethane, propane, hydrogen and sulfur hydroxide in small quantities [37]. Which affects the natural gas; its components vary from one place to another and from one location to another, causing some of the bottlenecks for the manufacturers of engines [36]. When the engine fueled with NG, and to make it reaches its the highest efficiency possible compared to gasoline, the engine needs to change some of its properties [38].

Ref. [39] studied the possibility of working with an engine fueled by natural gas produced by Iraq and found that the use of this fuel requires raising the compression ratio of the engine too much higher than gasoline; as this fuel has a high octane number and resistance to great knock. Ref. [40] explained that the flame propagation of natural gas is little compared to gasoline, which requires advancing the sparks timing to obtain the maximum productive capacity. Ref. [41] concluded that natural gas has a lower heating value on the volume basis than gasoline. As a result, the power of the natural gas engine is less than that of gasoline.

LPG is a group of hydrocarbon gases produced in the oil distillation tower [42]. It is characterized by being a gas that can be liquefied at normal atmospheric temperatures by pressure above atmospheric pressure [43]. LPG is characterized by its high thermal value compared to natural gas [44]. As the LPG flame propagation has a higher speed than those of gasoline and the number of octane high up to 98 [45].

Ref. [46] studied the operation of the LPG engine and found that the resistance of this gas to the knock enables the engine to increase the compression ratio to 10.0: 1. Its work at this ratio produces a higher brake power than that of gasoline at an equivalent ratio of 8: 1. Ref. [47] compared the performance of a single-cylinder engine when it runs with gasoline, LPG, and NG. Gasoline has the maximum brake power when compared at CR= 8: 1 and LPG have the maximum brake power compared to the other fuels.

This work is an effort of the Energy and Renewable Energies Technology Center as part of many years' efforts to find solutions to the energy problems facing Iraq [48-67], finding practical solutions to reduce air pollution [68-82]. This study aims to evaluate the impact of several designs and operating variables for NG enriched LPG as alternative fuels for Iraqi gasoline. LPG and NG use as fuels for SIE is a wise option; these gases are available and at low prices compared to gasoline.

II. EXPERIMENTAL SETUP

A. The tests engine

The experimental was done in this research work using Prodit engine which is a single cylinder, four strokes with variable compression and equivalence ratios, controlled spark timing, air to fuel ratio and speed. The engine is connected to a hydraulic dynamometer. The engine cooling water is cycling by a central rundown pump. Fig. 1 shows a photo of the experimental engine used in this research.

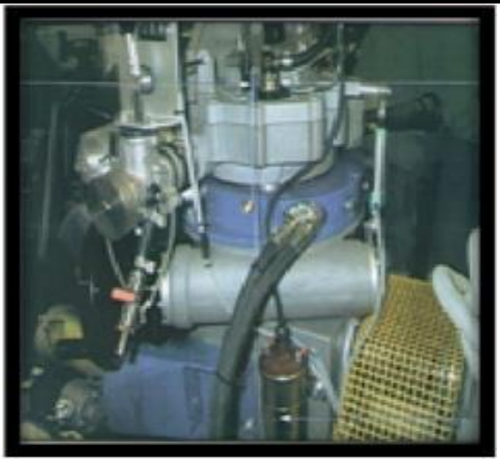

Fig. 1: The Engine Used in Tests

B. LPG supplying system

The system used in this research for supplying the engine with the LPG is composed of the fuel tank fuel filter, electromagnetic diode, and LPG evaporator, orifice plate to measure the LPG flow, quenching box, and gas feeder.

C. NG supplying system

The system of supplying the engine with NG is composed of NG gas cylinder, pressure organizer, orifice plate system.

D. Air flow measuring system

The quantity of air entered into the engine is measured by a lock viscous flow meter connected to a flame trap.

E. Brake power measuring dynamometer

A hydraulic dynamometer was used to measure the braking power, and used fluid was water.

Experimental procedure

As it is known is that the pure methane has a high octane number about 130, so that this fuel has a high resistance for knocking and can operate at high pressure ratios. This specification characterizes NG as the large proportion of it is methane. So, when it is enriched LPG, it will permit to work with high compression ratios such it improves the engine performance due to the effect of two important factors: The NG's flame propagation speed is slow causing a decrease in engine performance. Secondly, NG has a little heating value based on volume, which means that the energy released from its combustion will be few compared to LPG.

The tests were started using LPG to evaluate the higher useful compression ratio of the engine, and then this ratio was considered as a base rate while the natural gas was added. When NG was added the compression ratio was increased while the spark timing was varied until optimum spark timing was achieved. This procedure was used because in the case of lower compression ratio, the brake power will be little in any case and one of the research goals is to find the HUCR for the variable added

NG volumetric ratios which were (CH4 VF=0.3, 0.5, 0.7, 0.8). The variable Added VF calculated by the equation:

$$\text{Added NG volumetric fraction} = \frac{V_{CH_4}}{V_{CH_4}+V_{LPG}}$$

III. RESULTS AND DISCUSSINS

The first set of tests was conducted to evaluate the HUCR of LPG and LPG+NG at each mixing ratio. Fig 2 shows the variance of compression ratio from 8:1 to 11:1on the braking power when the engine is fueled with LPG for a wide range of equivalence ratios and optimum spark timing (the timing at which the engine produces the maximum moment at the studied equivalence ratio). The tests were conducted at 1500 rpm engine speed to limit the tests number. The figure declares that increasing compression ratio causes an increase of the brake power. The HUCR of LPG is (10.5:1) as the results reveal. Increasing the compression ratio increases the pressure and temperature inside the combustion chamber which enhances the burning of the air/fuel mixture. So, increasing compression ratio increases brake power until the engine reaches HUCR, after it, heavy knock occurs which force to retarded the spark timing to reduce the combustion temperature. Increasing compression ratio caused an improvement in the flame diffusion speed. AT CR=11:1 the resulted brake power was decreased due to the knock occurrence.

Fig. 3 shows brake power variation for wide equivalence ratio at CR=10.5:1 and engine speed 1500 rpm, when NG was added with volume fractions of 0, 30, 50, 70, 80, 100%. Adding NG reduced the generated brake power when the engine was run at HUCR for LPG =10.5:1. This reduction referred to the increased VF of NG which has slow flame diffusion speed and lower heating value on the volume basis compared with LPG. When NG was added to LPG, the CR was increased as a result of this addition. The NG addition made the maximum brake power achieved on the rich side at equivalence ratios ranged between Ø=(1.1-1.165).

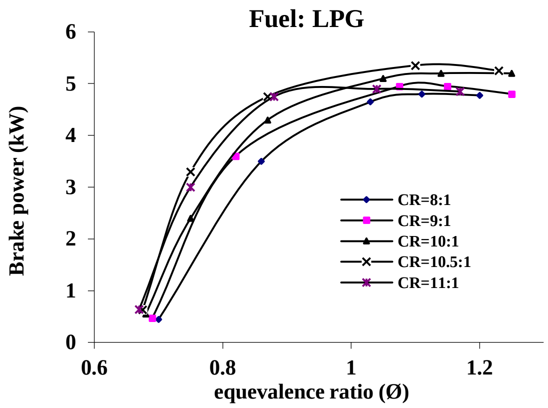

Fig. 2: The Effect of CR variation on Brake Power for Wide Range of Equivalence Ratios

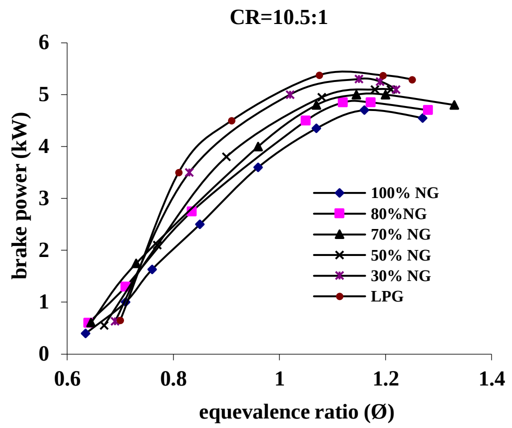

Fig. 3: The Effect of Adding Ng in Several VF on the Brake Power at CR=10.5:1

Fig. 4 shows the impact of equivalence ratio on brake power when NG was added in variable VF at HUCR for each mixing ratio, engine speed of 1500 rpm, and optimum spark timing. The LPG HUCR =10.5:1 and the maximum value of brake power achieved were (5.37 kW) at an equivalence ratio of (Ø=1.1). When NG was added in a VF of (30%), the brake power reduced to (5.2 kW) and the maximum brake power achieved was at an equivalence ratio of (Ø=1.1115). At NG added by 50% the highest achieved brake power was (5.27 kW) at equivalence ratio (Ø=1.125) while when the mixing ratio was 70%, the HUCR increased to 11.3:1, and the brake power was reduced compared with the case on CR= 11:1 or 10.5:1. When NG was added in a mixing ratio of 80%, the maximum brake power achieved was (5.1 kW). The brake power was reduced by increasing the NG volume ratio in the mixture in spite of the increase in compression ratio because increasing NG volume fraction in the mixture reduced its heating value. Increasing NG's VF in the mixture widened the operation equivalence ratio limits. The slow flame propagation of NG affected the combination outcome and reduced the resulted brake power.

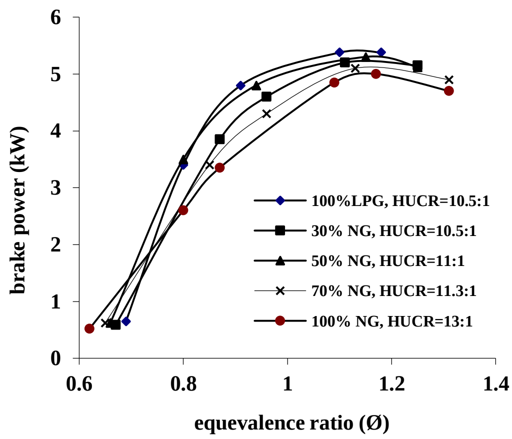

Fig. 4: The Effect of Adding NG in Variable VF on Brake Power at HUCR for Every Adding Ratio

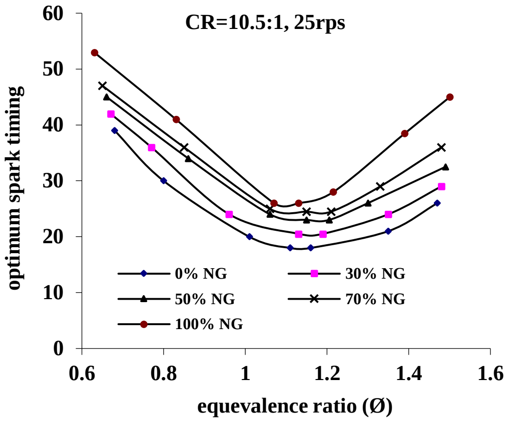

Fig. 5: The Effect of Added NGvolumetric ratio on the optimum sparks timing

Fig. 5 reveals the relation between the optimum spark time and equivalence ratio at HUCR for the used VF and engine speed 1500 rpm. The results declared that increasing the NG volume ratio forced to advance the spark timing for a wide range of equivalence ratios. The optimum spark timing depends on the effect of two opposing factors: first increasing the compression ratio and secondly, increasing the NG volume ratio in the mixture. Increasing the compression ratio forced the spark timing to be delayed as the combustion chamber temperature increases with this factor. Increasing the NG volume ratio causes the spark time to be advanced, and the optimum spark timing will be a resultant of these two conflict factors in their effects.

Fig. 6 represents the relation between the typical consumption for the fuel and the equivalent ratio at HUCR for mixing ratios of 0, 50, and 100%. The least specific fuel consumption will be when using NG was at its HUCR= 13:1. Also, the regular fuel consumption reduced by adding NG to the LPG especially when the engine was run at the HUCR and optimum spark time for each ratio.

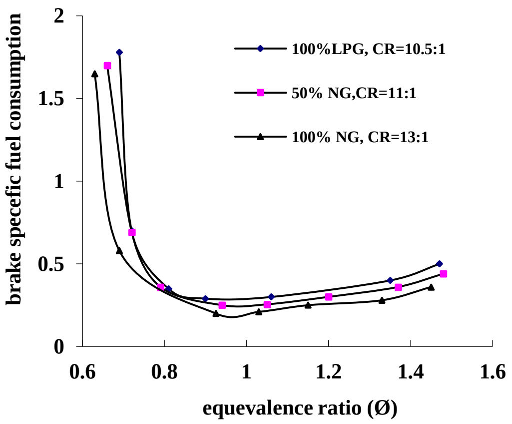

Fig. 6: A Comparison between the fuel consumption when LPG, NG, and 50% Added NG

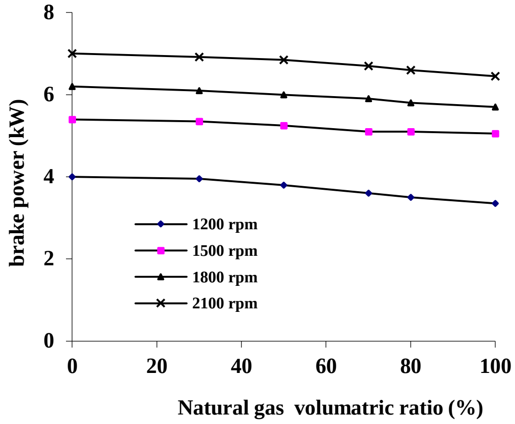

Fig. 7: The Effect of NG Addition on the Maximum Brake Power

Fig. 7 shows the relationship between the highest brake powers achieved at different VF of NG enriched LPG and a different engine speed. The results indicate that the brake powers are reduced with all velocity by adding NG and for all mixing ratios. The brake power drop rate with engine speed variation of 1200, 1500, 1800, 2100 rpm were 32, 15, 14.5, and 22%. The maximum reduction of the brake power was at the low speed (1200 rpm), as at this engine speed, the flame propagation spread inside the combustion chamber is low due to NG addition, besides the low turbulence within the combustion chamber. Increase engine speed increases the disturbance and causes the spread of flame better; as a result, the reduction in brake power at 1800 rpm was only 14.5%. At 2100 rpm, the decline in the volumetric efficiency of the engine at this speed caused a decrement of the brake power with 22%.

IV. CONCLUSION

The effect of variables such as compression ratio, equivalence ratio, spark timing, and engine speed were studied on a single-cylinder spark ignition engine. The study was carried out by adding natural gas to the LPG with several volume ratios of 30, 50, 70 and 80%. The optimum spark timing was used to evaluate the behavior of the fuel at each mixing ratio, as well as, to find the higher useful compression ratio.

The results showed that the HUCR of LPG is 10.5: 1, when using natural gas alone is 13: 1, and when mixing the two gases it did not exceed 11.6: 1 at the mixing rate of 80%. The addition of NG to LPG caused a reduction in the power output values due to the reduction of the volumetric efficiency of the engine in addition to reducing the speed of flame spread. Therefore, when adding natural gas, the spark timing should be advanced to achieve higher brake powers. The resulting brake power decreased at low speeds due to the low flame propagation speed and increased at medium speed and decreased again at high speeds due to the low volumetric efficiency of the engine. The highest value of the brake power was in the rich side and the equivalent ratio that gave the highest brake power was increased when LPG enriched with natural gas.

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