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Orginal Research Article

The impact of natural gas addition to liquefied petroleum gas on the NOx emission of a spark ignition engine

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Abstract: This paper study the NOx pollutants emitted from a single cylinder, 4-stroke spark ignition engine type Prodit; fueled with supplementary Natural gas to LPG. The study focused on the impact of equivalence ratio, spark timing, engine speed, and the added NG volumetric ratio on NOx emissions. The results showed that NOx levels depend mainly on the equivalence ratio, as the higher value of NOx concentrations was on the lean side near the stoichiometric equivalence ratio, and it was reduced when getting far from this ratio. It was observed that retarding spark timing reduces the NOx concentrations by a significant percentage. The NOx levels became higher at medium speeds and reduced in higher and low speeds. NOx levels increased with increasing NG volumetric ratio in the mixture.
Keywords: : LPG, methane, equivalence ratio, compression ratio, spark timing, nitrogen oxides

INTRODUCTION

Climate change has become a significant and well-known problem [1, 2]. This phenomenon has affected Iraq significantly, as two decades of drought caused the transformation of Iraq to the source of dust storms of his neighbors [3]. As well as, the proportion of arable land was reduced up to 60% and increased salinity of rivers [4]. Iraq was also affected by the invasion of many wars since 1980 until its occupation in 2003 and after the sectarian war and the fight against terrorism [5]. These conditions had a severe impact on the infrastructure of the country and reduced the production of electricity to less than 40% of the actual need in 2012 [6]. To date, Iraqis rely on the public and private (diesel and gasoline) generators to make up for the shortage of processed energy. These generators use diesel and gasoline fuels that are produced locally. These fuels are tagged as the worst fuels globally because it contains a high proportion of sulfur and lead compounds [7-9].

Iraqi researchers have worked diligently to find quick and acceptable alternatives to consumers for gasoline and diesel. Ref. [10] has proposed using LPG as a real alternative to petrol. Chaichan, M. T [11] suggested using methane or natural gas. He studied the use of hydrogen in ignition engines and found great potential for this gas in operating these engines with the lowest percentage of pollutants.

NOx is the most typical of exhaust gases from the spark ignition engines. Salim, A.A, *et al.* [12] stated that nitrogen oxides are composed at high temperatures, due to the unbalanced reaction of oxygen and nitrogen, and this occurs in the early stages of combustion (i.e., immediately after the electric spark and start of the combustion process). At the second stage, expansion phase, the maximum cycle temperature goes down, causing a slow reaction between the chemical reactants, which usually leads to the determination of NOx and it is known as a freezing process. Chaichan, M.T [13] declared that nitrogen oxides are also converted into nitric acid in the wet atmosphere, a key element of smog. It is also an important factor in increasing the ozone effect in metals and materials for its oxidative properties.

Chaichan, M. T [14] and Chaichan, M. T. [15] revealed that nitrogen oxide is produced in the combustion chamber by the interaction of oxygen and nitrogen, according to the equation ($N_2 + O_2 \leftrightarrow 2NO$). When the temperature drop rate is slow, the nitrogen oxide breaks down into oxygen and nitrogen, In the case of a sudden or rapid drop in temperature, some nitrogen oxide remains undisturbed. Most nitrogen oxides remain NO and the remainder NO2 while N2 and O2 by volume of less than 2% [16]. The main factors influencing the increase of NOx formation levels in the combustion chamber are the spark timing, the equivalence ratio, the engine speed and compression ratio [17].

Chaichan, M.T, *et al*. [18] experimented with a single-cylinder engine, using LPG, NG, and gasoline, and compared the resulting exhaust pollutants to both fuels at full throttle conditions, constant velocity and optimum timing for evaporation. The researchers noted that NOx concentrations are greater when using LPG than it is for gasoline or NG, and the limit of (Ø = 0.75-0.95), and explained this because of the timing of sparks to give the best determination of each ratio of air - fuel, and from previous research.

Chaichan, M.T [19] noted that increasing the compression ratio reduces NOx, within an equivalent ratio (Ø = 0.77-1.076), due to the delay of the sparks associated with increasing the compression ratio. Ref. [20] modified the 1.8-liter four-stroke engine to operate with liquefied petroleum gas (LPG), noting that NOx concentrations were higher using LPG than gasoline for an optimal time for spills.

Reza, K.S, *et al*. [21] studied the S.I.E. pollutants using three types of fuel: gasoline, CNG, and LPG. The researchers noted that some pollutants were lower when CNG and LPG are used compared to gasoline, and pointed out that advanced spark timing increased NOx for all the used fuels.

Chaichan, M.T [22] noted that the value of the equivalent ratio at which the maximum concentration of NOx obtained is close to the right on the lean side, and for the NG it is closer to the correct equivalence ratio than it is for LPG. Also, the NOx concentration when using natural gas is lower than that of liquefied petroleum gas under all operating conditions.

Chaichan, M. T, [23] and Chaichan, M. T [24] indicated that increased velocity reduces the NOx levels. As Chaichan, M. T [25] and Chaichan, M. T [26] observed that the flame propagation speed of NG is lower than that of LPG. Chaichan, M. T, *et al*. [27] found that hydrogen laminar burning velocity is the highest between all known fuels. These references results relate between the emitted NOx levels of each fuel and its flame propagation rate.

This paper studies the effect of some engine's operational factors on the emitted NOx levels, when the engine was fueled with NG, supplemented LPG. The engine operation variables investigated were equivalence ratio, spark timing, engine speed, and NG volumetric fraction in the fuel.

Experimental Setup

Internal combustion engine and its accessories

The experiments were carried out using the Prodit rig, which a four-stroke single-cylinder with compression ratio, spark timing, air-to-fuel ratio, and variable speed. It is connected to a hydraulic dynamometer. The engine is lubricated by a gear pump operated separately from the engine. Fig. 1 represents the used test rig.

Fig-1: The Engine Used in Tests

LPG engine processing system

The system used in the research to fuel the engine with liquefied petroleum gas consists of the following parts:

- Fuel tank
- Fuel filter.
- Electromagnetic valve.
- Liquefied petroleum gas evaporator.
- Gas Flow Meter.
- Damping box.
- Gas feeder.

The NG engine supply system

The system consists of the following parts:

- NG cylinder.
- Pressure regulator.
- Gas Flow Meter consist of Chocked trumpets System.

Air flow measurement

The amount of air entering is measured by an Alcock viscous flow meter connected to a flame trap.

- Engine Speed Measurement
- Engine speed is measured by a tachometer.
- Nitrogen Oxide Analyzer

NOx pollutants were measured employing Multigas mode 4880 emissions analyzer that uses the chemical luminescent method. The chemical radiometer is used to measure the ratios of nitrogen monoxide (NO), so nitrogen oxides are converted to NO before entering the measuring device, and the exhaust gas is passed on thermal aids at a temperature.

The exhaust gas sample enters the reaction chamber where it interacts with the ozone in the ozone-forming device. The reaction results in nitrogen dioxide and oxygen, some particles are irritating (containing extra energy in their atoms), and chemical radiation stabilizes the light. Light is measured in the photo multiplier tube. This device was calibrated in the laboratory by comparing its readings with a calibrated new device.

NOx analysis tests

NOx in the exhaust gases were analyzed for different factors affecting its concentration. The tests included:

- The engine compression ratio impact on the NOx concentration in the exhaust. The compression ratio was changed from (8: 1) to (13: 1) with an optimum spark timing, and the engine speed was fixed at (1500 rpm), and the equivalence ratio was varied from lean to rich ratios.
- The effect of the engine speed on the NOx concentrations was investigated when the engine speed was changed (1200, 1500, 1800, 2100) rpm, at the optimum compression ratio and spark timing.
- The effect of the equivalent ratio of the NOx concentrations was tested. The equivalent ratio was changed from the weakest ratio at which the engine can be operated at 1500 rpm, to the richest equivalent ratio of which the engine can be operated at the same speed.
- Spark timing effect on NOx level was examined. Spark timing was changed to provide the optimum timing for each equivalence ratio when working at the higher useful compression ratio and 1500 rpm.

RESULTS AND DISCUSSIONS

Compression ratio effect

Fig. 2 shows the effect of the addition of four volume ratios of NG (NG volumetric ratio = 30, 50, 70, and 100%) to LPG on the emitted NOx wide range of equivalent ratios, optimum spark timing, and 1500 rpm. The test was conducted at compression ratio (CR= 10.5: 1) which is the highly useful CR for LPG fuel as confirmed by Ahmed, W.K. [28].

The addition of NG to LPG reduced NOx concentrations for the studied range of equivalent ratios. It is noted from the figure that the maximum concentration of NOx when using LPG alone as fuel was 2150 ppm at an equivalence ratio of 0.94. When using an NG volume fraction of 30%, the maximum concentration of NOx was 2012 ppm at Ø = 0.95. At a volume mixing ratio of 70%, the highest NOx level was 1975 ppm at Ø = 0.96. When the engine was fueled with NG only, the maximum NOx concentration was 1880 ppm at Ø = 0.99. These results indicate that the addition of NG to LPG the highest value for NOx moving closer to the correct equivalent ratio toward the rich side. Higher NG volume fraction in the fuel reduced the flame propagation rate which reduced the pressure and temperature of the combustion chamber and crept the maximum NOx late to the rich side of the mixture.

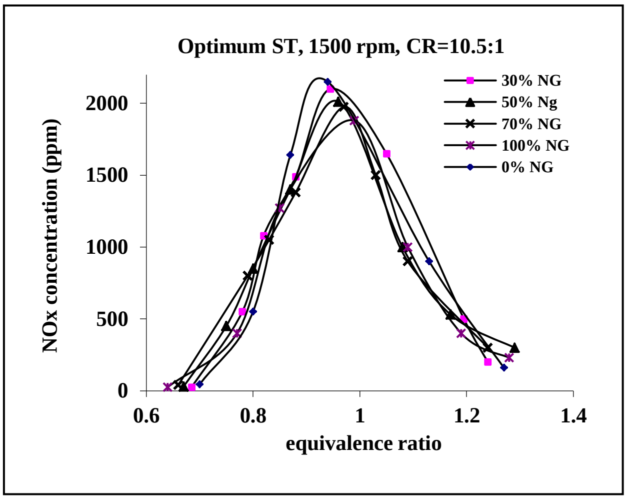

Fig-2: The impact of adding NG in four volume fractions to LPG on resulted NOx levels

Fig. 3 shows the effect of adding NG at different volume rates to LPG, with the engine operating at the HUCR of each mixing ratio, for a broad range of equivalence ratios, optimum spark timing for each added volume fraction and engine speed of 1500 rpm.

It is noted that in all NG volumetric mixing ratios increased the compression ratio when the engine was operated at optimum spark timing, resulting in a decrease in the maximum value of the NOx concentration to a certain extent. The increase in the compression ratio with the stability of the spark timing significantly enhances the temperature of the cycle. The effect of the compression ratio is significant, which increases the NOx concentrations, but with the retarding of the spark timing to operate the optimum timing. NOx levels were increased by increasing the compression ratio. This comes from the impact of two important factors: the first is the available oxygen needed for the reaction, and the temperature of the cycle is very high because inside the combustion chamber due to the increase in the compression ratio.

Increasing the volume fraction of NG in the mixture will reduce the NOx concentration while increasing the compression ratio increases the maximum temperature, which causes the growth of NOx levels, although the timing of the sparks associated with the process is delayed. Therefore NOx concentrations are the result of the above factors.

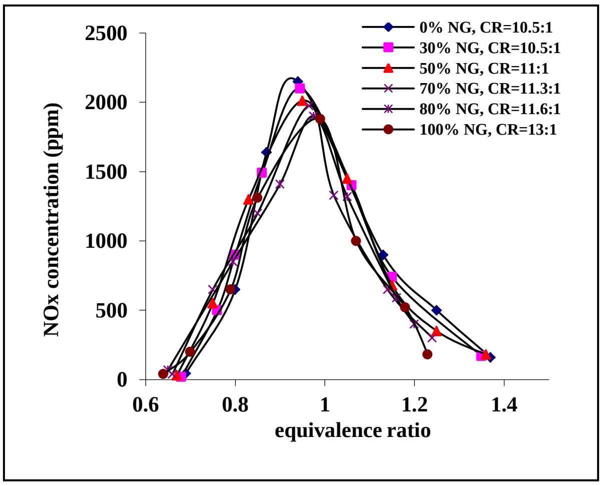

Fig-3: The impact of adding NG in variable volume fraction to LPG o the emitted NOx when the engine was run at the HUCR for each added NG ratio

Equivalence ratio effect

Fig. 4 illustrates the effect of equivalence ratio on the NOx for different volumetric mixing ratios, various compression ratios, 1500 rpm engine speed and optimum spark timing. Note that the minimum NOx concentration is on the very lean side, and increases by the growth of the equivalence ratio, due to the increase in the combustion temperature, to reach its maximum value near the right of the lean side. The maximum temperature here is high, to burn most of the fuel and to provide oxygen NOx concentrations are less than the equivalence ratio of the above limits.

The highest values of NOx levels are reduced by increasing the volume of NG in the mixture, which is the primary factor in the NOx dilution because the temperature of the great cycle is reduced by increasing the amount of NG compared to the operation of the engine with liquefied petroleum gas alone. The low temperature of the flame front of NG compared to liquefied petroleum gas is the main reasons for this result.

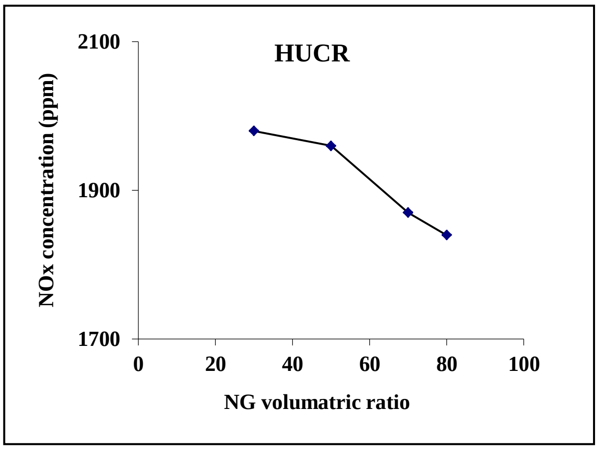

Fig-4: The impact of NG volume fraction on NOx levels

Engine speed effect

Figures 5 and 6 represent the relationship between NOx concentrations and the equivalence ratio of 50% volume mixing ratios (Fig. 5) and 80% (Fig. 6) when the engine works at the higher useful compression ratio. For these ratios, the engine speed is different, and the timing is optimum. In general, it is noted that the maximum concentrations of NOx are at a moderate speed (1500-1800) rpm, NOx levels were decreased at a low speed of 1200 rpm and high speed of 2100 rpm. The maximum concentrations of NOx are also observed to be decreased by increasing the NG volume fraction for all mixing ratios

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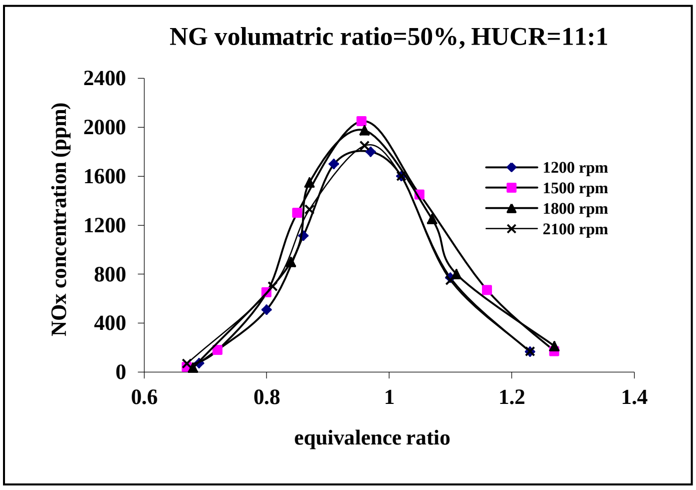

Fig-5: The effect of engine speed on NOx levels for wide equivalence ratios and NG volume fraction =50%

The spark timing effect

Fig. 7 shows the relationship between the NOx concentrations and the spark timing of three equivalence ratios (Ø = .75, .95, and 1.25) for the LPG and methane mixture where the volumetric NG ratio is 30%. We chose this rate because it emitted the highest NOx concentration at its HUCR and engine speed of 1500 rpm. Retarding the spark timing at an equivalent rate (Ø = 0.75) for 15 degrees from the optimum timing reduced NOx concentrations by 80%. At equivalence ratio (Ø = 0.95), at which lied the maximum value for NOx concentrations, these concentrations were reduced by 70%, while at the ratio of (Ø = 1.25), NOx levels are less than the other ratios. Delay timing is an important factor for identifying and reducing NOx concentrations. Conversely, the spark timing advancing increases contaminants.

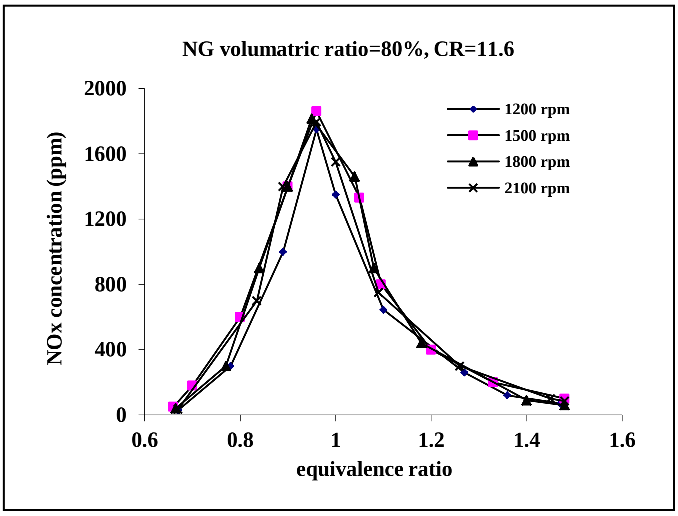

Fig-6: The effect of engine speed on NOx levels for wide equivalence ratios and NG volume fraction =80%

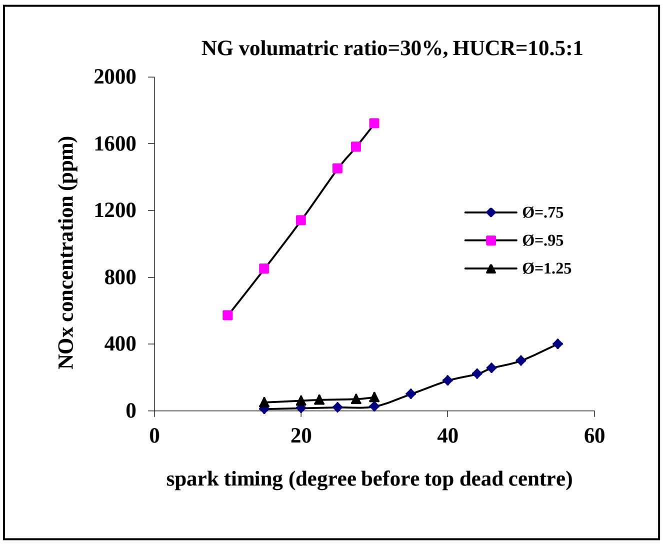

Fig-7: the impact of spark timing on NOx levels for three specific equivalence ratios

CONCLUSIONS

From the studied effective parameters, the most effective one was the equivalence, at which NOx concentration reached its highest value near the right of the stoichiometric equivalence ratio on the lean side. The maximum value of NOx levels is increased by increasing the compression ratio for all the mixing ratios when the engine is operating at fixed spark timing. These values are reduced by increasing the compression ratio with the engine run at optimum spark timing, but these concentrations increased slightly on the weak side. NOx levels are increased by increasing the engine speed from slow to medium, and with a greater increase in speed, these concentrations decreased for all fuel mixing ratios. NOx levels are significantly reduced by retarding the spark timing on the weak side, as well as the maximum value of concentrations. On the rich side, the effect is limited for all fuel mixing ratios. NOx levels of NG are lower than those of LPG when compared with a constant CR or at the higher useful compression ratio for both fuels, and these concentrations are reduced when the volume of methane is increased in the mixture.

REFERENCES

1. Al-Maamary, H. M. S., Kazem, H. A., Chaichan, M. T. (2017). Climate change: the game changer in the GCC region, Renewable and Sustainable Energy Reviews, *76*, 555-576.
2. Al-Maamary, H. M. S., Kazem, H. A., Chaichan, M. T. (2016). Changing the energy profile of the GCC States: A review, International Journal of Applied Engineering Research (IJAER), 11(3), 1980-1988.
3. Kazem, A. A., Chaichan, M. T. & Kazem, H. A. (2014). Effect of dust on photovoltaic utilization in Iraq: review article, Renewable and Sustainable Energy Reviews, 37, 734-749.
4. Yaseen, B. R., Al Asaady, K. A., Kazem, A. A., Chaichan, M. T. (2016). Environmental impacts of salt tide in Shatt al-Arab-Basra/Iraq, IOSR Journal of Environmental Science, Toxicology and Food Technology, 10(1-2), 35-43. DOI: 10.9790/2402-10123543
5. Alwaely, A. A., Al-qaralocy, H. N., Al-Asadi, K. A., Chaichan, M. T., Kazem, H. A. (2015). The environmental aftermath resulted from chemical bombardment of Halabja Territory for the period 1988-2014, International Journal of Scientific & Engineering Research, 6(9), 40-44.
6. Chaichan, M. T. & Kazem, H. A. (2012). Status and future prospects of renewable energy in Iraq, Renewable and Sustainable Energy Reviews, 16(1), 6007–6012.
7. Ahmed, S. T. & Chaichan, M. T. (2012). Effect of fuel cetane number on multi-cylinders direct injection diesel engine performance and emissions, Al-Khwarizmi Eng. Journal, 8(1), 65-75.
8. Chaichan, M. T. (2013). Practical investigation of the performance and emission characteristics of DI compression ignition engine using water diesel emulsion as fuel, Al-Rafidain Engineering Journal, 21(4), 29-41.
9. Chaichan, M. T. (2013). Experimental evaluation of the effect of some engine variables on emitted PM and Pb for single cylinder SIE, Association of Arab Universities Journal of Engineering Science, 2(20), 1-13.
10. Salim, A. A. & Chaichan, M. T. (2003). Study of SIE performance fueled with LPG, Sabha University Journal, 4(4), 67-82.
11. Chaichan, M. T. & Al-Sheikh, S. A. (2001). Study of SIE performance fueled with methane, Al-Jufra University Journal, 1(1), 15-27.
12. Salim, A. A. & Chaichan, M. T. (2002). Study of NOx and CO emissions for SIE fueled with LPG, Sabha University Journal, 1(1), 106- 125.
13. Chaichan, M. T. (2013). EGR effect on performance of a spark ignition engine fueled with blend of methanol-gasoline, Wassit Journal of Engineering Science, 1(2), 93-110.
14. Chaichan, M. T. (2012). Characterization of lean misfire limits of alternative gaseous fuels used for spark ignition engines, Tikrit Journal of Engineering Sciences, 19(1), 50-61.
15. Chaichan, M. T. (2009). Study of NOx and CO emissions for SIE fueled with Supplementary hydrogen to LPG, Association of Arab Universities Journal of Engineering Science, 16(2), 32-47.
16. Chaichan, M. T. (2010). Study of NOx and CO emissions for SIE fueled with Supplementary hydrogen to gasoline, Baghdad Engineering Collage Journal, 16(1), 4606-4617.
17. Chaichan, M. T. (2007). Study of performance of SIE fueled with Supplementary methane to LPG, The Iraqi Journal for Mechanical and Material Engineering, 7(4), 25-44.
18. Chaichan, M. T. and Saleh, A. M. (2010). Practical investigation of single cylinder SI Engine performance operated with various hydrocarbon fuels and hydrogen, Al Mostaseria Journal for engineering and development, 14(2), 183-197.
19. Chaichan, M. T. (2006). Study of NOx and CO emissions for SIE fueled with different kinds of hydrocarbon fuels, Association of Arab Universities Journal of Engineering Science, 13(2), 85-105.
20. Chaichan, M. T., Kadhum, J. A., Riza, K. S. (2016). Spark Ignition Engine Performance When Fueled with NG, LPG and Gasoline, Saudi Journal of Engineering and Technology, 1(3), 105-116.
21. Reza, K. S., Kadhem, J. A., Ahmed, W. K., Mahdi, A. M. J. (2017). The effect of some operational and design parameters on the emitted nox pollutant of a spark ignition engine, International Journal of Scientific Engineering and Science, 1(1), 1-6.
22. Chaichan, M. T. (2006). Study of NOx and CO emissions for SIE fueled with Supplementary methane to LPG, The Iraqi Journal for Mechanical and Material Engineering, 6(2), 85-97.

23. Chaichan, M. T. (2014). Evaluation of the effect of cooled EGR on knock of SI engine fueled with alternative gaseous fuels, Sulaimani Journal for Engineering Science, 1(1), 7-15.
24. Chaichan, M. T. (2014). Exhaust gas recirculation (EGR) and injection timing effect on emitted emissions at idle period, Al-Khwarizmi Engineering Journal, Al-Khwarizmi Engineering Journal, 10(4), 33-44.
25. Chaichan, M. T. (2013). Measurements of laminar burning velocities and Markstein length for LPG–hydrogen–air mixtures, International Journal of Engineering Research and Development, 9(3), 1-9.
26. Chaichan, M. T. (2013). The measurement of laminar burning velocities and Markstein numbers for hydrogen enriched natural gas, International Journal of Mechanical Engineering & Technology (IJMET), 4(6), 110-121.
27. Chaichan, M. T. & Saleh, A. M. (2013). Experimental measurements of laminar burning velocities and Markstein number of hydrogen–air mixtures, The 3rd Scientific International Conference, Technical College, Najaf, Iraq.
28. Ahmed, W. K., Reza, K. S., Jawad, R. S., Al-Zubidi, D. S. M. (2017). The effect of adding NG to LPG on a spark ignition engine, International Journal of Civil, Mechanical and Energy Science, 3(3), 166-173.