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The impact of natural gas addition to liquefied petroleum gas on the carbon monoxide emitted from a spark ignition engine

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Abstract: A single cylinder, 4-stroke spark ignition engine type Prodit; fueled with supplementary Natural gas to liquefied petroleum gas (LPG) was used in this paper to investigate the emitted CO pollutants. The effect of equivalence ratio, spark ignition timing, engine speed, and the added NG volumetric ratio on CO emissions were tested experimentally. The study outcomes revealed that CO levels depend mainly on the equivalence ratio, as the maximum value of CO concentrations existed at the very rich equivalence ratios and it low at lean side. Retarding spark timing increased the CO concentrations by a significant percentage. The CO levels became higher at high speeds and reduced at medium speeds. Increasing natural gas volumetric ratio in the mixture caused a reduction in CO levels.
Keywords: LPG, NG, equivalence ratio, compression ratio, spark timing, CO

INTRODUCTION

Since the beginning of the 21st century, the globe has been experiencing many problems, including global warming and climate change [1, 2]. Also, since 2008 the whole world suffered from the collapse of oil prices and the consequent fluctuation of it [3]. High pollution levels have been measured especially in large cities and reaching dangerous borders [4].

The heavy traffic due to lack of public transport services and dependence on personal cars exacerbated this problem [5]. The fact that many countries rely on personal generators to generate energy instead of national electricity has increased the mud [6].

In Europe, the road traffic is blamed for more than 50 to 70% of the environmental NOx, and about 50% of volatile organic compounds [7]. Ref. [8] in 1990 showed that traffic sources accounted for 63% of CO, 38% of NOx, 34% or HC. According to other sources, the contribution of cars to air pollution in CO is 50% during winter in the Northwest Pacific, USA. Cars and trucks are responsible for about 68.5% of the CO in the People's Republic of China, and up to 98% in Tehran, Iran [9]. Ref. [10] declared that CO is formed by incomplete combustion when there is insufficient oxygen or when combustion is quenched near a cold surface in the cylinder. CO is a poisonous gas, which causes nausea, headache and fatigue, and in heavy concentrations can cause even death.

The shift to new renewable energies is still at the research and development stage in most parts of the world. Today, these energies have only taken a small share of fossil fuels [11]. It is probably best to think about other types of fuel. Gas fuels such as liquefied petroleum gas [12], natural gas [13], and hydrogen can be considered an excellent alternative to gasoline and diesel [14]. Ref. [15] indicated that Iraq atmosphere is highly polluted because of the high load of automobiles and trucks as well as power stations. Iraq has been subjected to a series of wars and severe economic blockade for more than 40 years continued to affect all infrastructures and caused a significant deterioration in services provided to Iraqi citizens.

Benson [16, 17] stated that the appearance of carbon monoxide in the exhaust gas due to the disintegration of the combustion process at high temperatures, especially in the weak mixture. In the rich mixture, the amount of CO increases due to incomplete combustion and insufficient oxygen to burn the entire fuel, which requires increasing the ratio of air to fuel to complete the combustion. Refs. [18 & 19] noted that increasing engine speed increased CO concentrations. Also, Ref. [20] observed that CO concentration increased with the addition of propane gas to a methane gas engine at different volume rates due to the increase in the maximum temperature of the cycle due to the high thermal value of propane on the basis of volume, CO and O2, in addition to increasing the ratio of the number of carbon atoms to hydrogen in propane compared with methane [21].

In Iraq, liquefied petroleum gas (LPG) is available from crude oil refinery operations in ample quantities [22]. LPG consists of low carbon hydrocarbons from 1 to 5 carbon atoms and it is gaseous state in natural and is liquefied by using medium or high pressure in the normal atmosphere. This gas is safe (when appropriate conditions are used) and gives good performance when used in spark ignition engines [23]. Ref. [24] studied the pollutants produced by the Ricardo engine when it was fueled by LPG, and found that the resulting CO concentrations are less than those resulting from the use of gasoline, because of the composition of the gas a few carbon atoms. Ref. [25] studied the pollutants resulting from the work of a single cylinder engine with a number of hydrocarbon fuels (gasoline, LPG, and NG). The results of the study showed that the CO rates are controlled by the number of carbon atoms composed of fuel. The higher the carbon atoms number, the higher the concentration of CO. Also, certainly there is an impact for the rest of the operational and design factors in the increase or decrease of these pollutants. When Ref. [26] compared the contaminants produced from hydrocarbon fuels above with a hydrogen engine, it was found that hydrogen produces very low CO rates due to the combustion of oil residues in the combustion chamber. Several experiments have been carried out by adding gaseous fuel to liquid fuel [27], or gaseous gas to another gas fuel to control contaminants [28]. Ref. [29] tested the impact of the addition on NG to LPG on a SIE performance. The tests results showed that the higher useful compression ration (HUCR) for the tested LPG was 10.5:1, and for variable NG volume added fractions of (30, 50, 70, 80%) were (10.5:1, 11:1, 11.3:1, and 11.6:1), respectively. NG employments caused a reduction in the engine brake power. Adding NG to LPG widened the equivalence ratio range that the engine can operate by compared with LPG working range. Ref. [30] added methane fuel to LPG and observed a decrease in CO concentrations in all operational conditions and the value of the decrease was increased with the increase in the volumetric fraction of methane in the mixture.

In Iraq, unfortunately, millions of cubic feet of natural gas are still being burned daily from oil wells. This precious material is fully available in this country, but there are no suitable infrastructures for its use till today. However, natural gas, which its majority is of methane, is considered an appropriate fuel for spark ignition engines [31]. This fuel is characterized by ignition at the very lean equivalence ratios leaner than gasoline [32]. It is also characterized by higher resistance to the roads in the ignition engines, allowing the engine to operate at a higher compression ratio of 14: 1 compared to gasoline 9: 1, and liquefied petroleum gas 10: 1 [33]. Ref. [34] studied the nitrogen oxides emitted from a spark ignition engine fueled with natural gas enriched LPG. The results showed that nitrogen oxides levels were mainly based on the equivalence ratio, and retarding the timing of the spark would reduce these concentrations. At medium speeds, NOx levels increased, and decreased at high and low speeds. Ref. [35] added hydrogen to natural gas and studied the engine performance using a Ricardo single cylinder engine with variable compression ratios. The results of the study showed that the addition of hydrogen to natural gas caused an increase in the compression ratio increased the indicated thermal efficiency, and decreased in the specific fuel consumption, the volumetric efficiency, and the exhaust gas temperature.

This study aims to find out the possibility of adding natural gas to liquefied petroleum gas and the effect of this addition to CO pollutants emitted from a single cylinder engine. The NG addition will be in volumetric fractions to determine the effect of these ratios as well.

Experimental Setup

The LPG fueling system used in this research consists of fuel tank contained 80 kg of compressed gas, a fuel filter to filter the flowing gas from any accompanied impurities. An electromagnetic valve used to open and close the gas flow. LPG evaporator is a simple incinerator because the flowing fuel is gaseous and does not need evaporation. The gas flow meter used in the tests was an orifice plate located on the LPG line before the carburetor.

The NG supply system consisted of a NG cylinder contained about 22 kg of compressed gas. A pressure regulator was fixed on the cylinder exit to regulate the flowing gas quantity and pressure. The gas flow meter consisted of three chocked nozzles used to measure the NG flow and as a back-fire flame trap.

The internal combustion engine used in the experiments was the four-stroke single-cylinder with variable compression ratio, spark timing, air-to-fuel ratio, and variable speed type Prodet (Italy made). The engine is connected to a hydraulic dynamometer using water as a hydraulic fluid. Fig. 1 represents the used test rig. Multigas mode 4880 emissions analyzer used to measure CO concentrations.

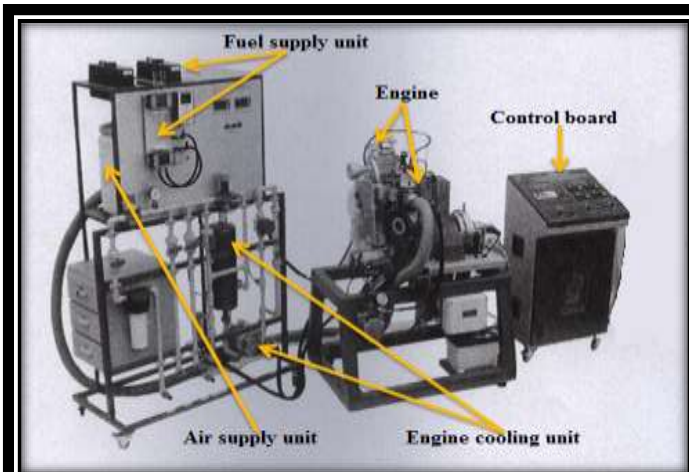

Fig-1: The Engine Used in Tests

RESULTS AND DISCUSSIONS

Compression ratio effect

Fig. 2 shows the relationship between CO concentrations and the equivalence ratio at compression ratio of 10.5: 1, which is the higher useful compression ratio (HUCR) of the LPG used in the experiments. Different mixing ratios, 25rps engine speed and optimum spark timing were used in this experiment. The addition of natural gas caused a reduction of CO concentrations for all equivalence ratios and for different NG volume fractions mixing ratios. This can be clearly observed within the equivalence ratios (Ø = 1.0) to (Ø = 1.48) due to the low ratio of the number of carbon atoms to hydrogen in the mixture when NG was added.

Fig. 3 illustrates the effect of adding NG with different volume ratios to the LPG on the resulting CO concentrations emitted from the engine, with the engine working at the HUCR for each mixture, for a wide range of equivalence ratios, optimum spark timing and speed of 1500 rpm. Increasing the compression ratio increased CO concentrations in the exhaust gas for all mixing ratios. The amount of this increase depends on the volume of NG in the mixture, as well as on the compression ratio of each volumetric fraction. However, increasing the compression ratio increased the CO concentrations because of the maximum cycle temperature increased, which increased the dissociation of CO_2 to CO. The concentrations of CO measured at each mixing ratio were a result of these two variables.

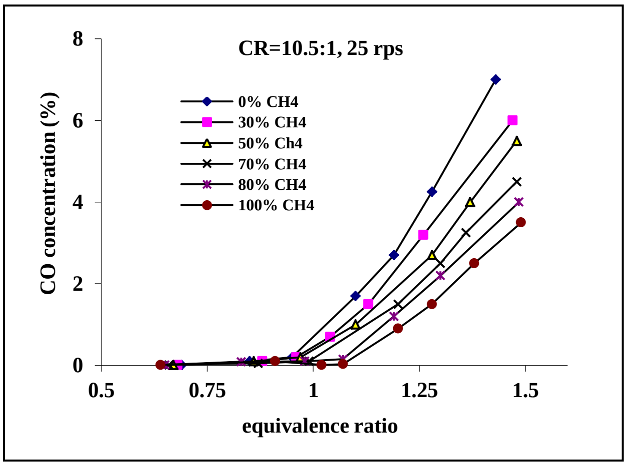

Fig-2: The impact of adding NG in four volume fractions to LPG on resulted CO levels

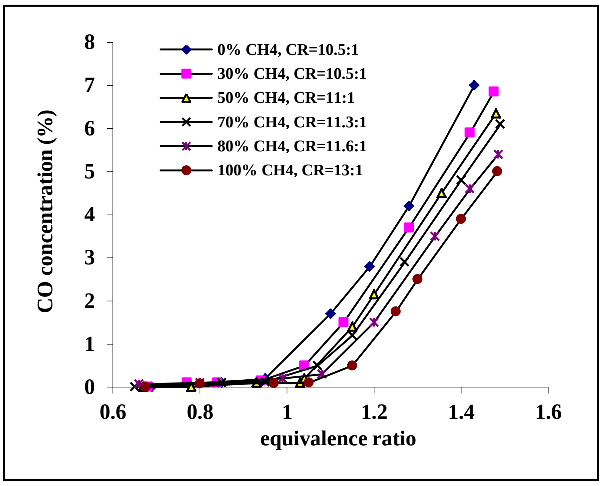

Fig-3: The impact of adding NG in variable volume fraction when the engine was run at the HUCR for each added NG ratio

Equivalence ratio effect

Fig. 3 shows that the concentration of CO is slightly in the lean side, and is slightly affected by the equivalence ratio variation because of the oxygen availability for all the highest useful compression ratios. Note that the significant CO concentrations for all NG volume fractions were observed in the rich side, from (Ø = 1.05) and onward. This increase referred to the combustion degradation after this equivalence ratio due to lack of oxygen.

Fig. 4 shows the relationship between the CO levels for variable volumetric fractions of NG, when the engine was run at the HUCR for each mixing ratio, for three equivalence ratios (Ø = 1.25, 1.35, and 1.45), 1500 rpm engine speed, and the optimum spark timing. The increase in the NG volume significantly reduces CO concentrations in the exhaust gas, especially when the NG concentration increased from 30 to 70%. However, when the NG levels were increased from 70 to 80%, no significant decrease can be observed. There are two opposite factors affect the CO concentrations, the NG volume fraction in the mixture that increases the CO, and at the same time the limits of the increase in the compression ratio, which in turn increased the cycle maximum temperature, which increased the CO concentration due to dissociation. CO concentrations are the result of these two factors.

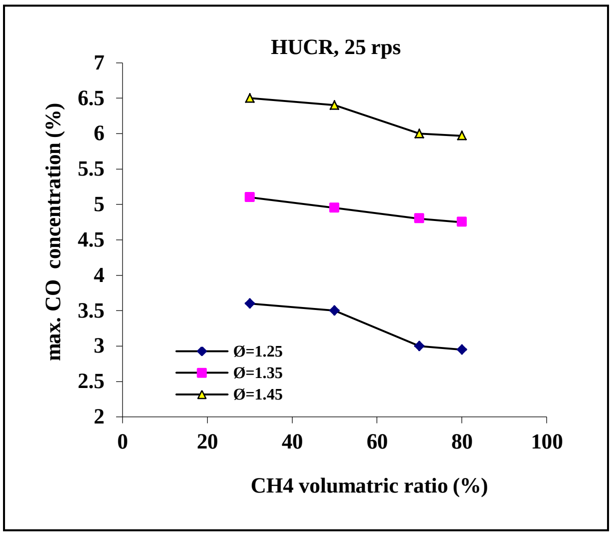

Fig-4: The impact of NG volume fraction on CO levels

Engine speed effect

Figs. 5 and 6 show the relationship between the CO concentration with the equivalence ratio at NG volume fraction of 50% (Fig. 5) and 80% (Fig. 6) at HUCR for each mixing ratio, variable engine speeds and optimum spark timing.

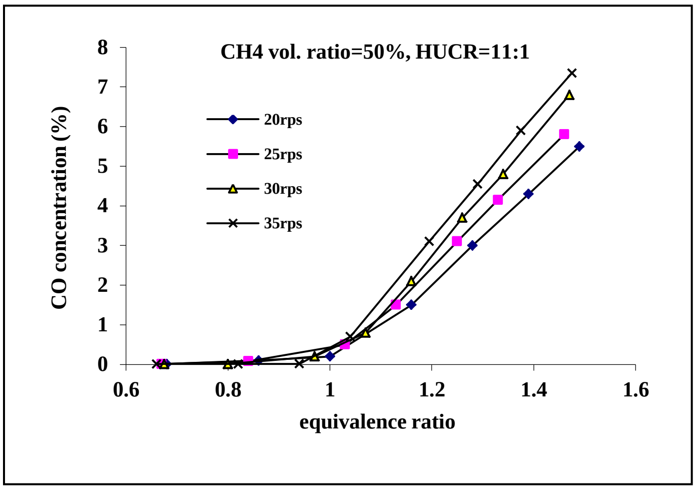

Fig-5: the effect of engine speed on CO levels for wide equivalence ratios and NG volume fraction =50%

It is generally observed that increasing the engine speed led to increased CO concentrations in the exhaust gas, for equivalence ratios greater than (Ø = 1.05), due to the increase in the chemical degradation because of high temperature of the cycle, shortening the time required to complete the combustion process and low oxygen. The increase in the NG volume fraction in the mixture reduced CO concentrations for all different engine speeds. This effect is greater than the compression ratio increase effect, which increased CO concentrations for all engine speed.

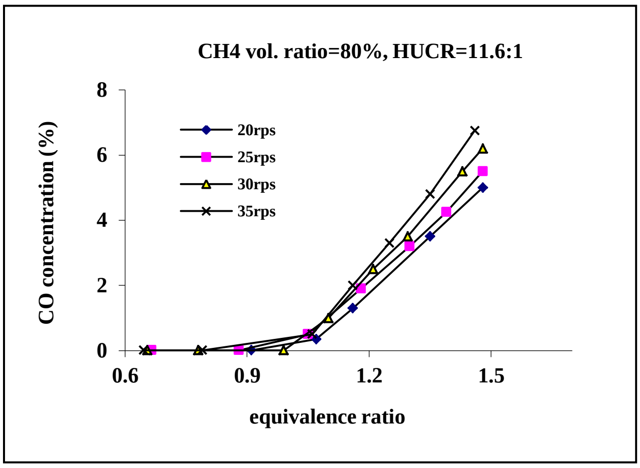

Fig-6: the effect of engine speed on CO levels for wide equivalence ratios and NG volume fraction =80%

The spark timing effect

No effect was observed due to the engine spark timing variation on CO contaminants.

CONCLUSIONS

The study contains many effective parameters, the most effective one was the equivalence ratio, at which CO concentration reached its maximum value on the rich side. The CO levels were increased by increasing the compression ratio for all the mixing ratios. CO levels were increased by increasing the engine speed from slow to high speeds as a greater increase in speed reduces the time for complete oxidation. CO levels were not affected by the spark timing variation. On the rich side, the CO levels of NG were observed to be lower than those of LPG when compared with a constant CR or at the higher useful compression ratio for both fuels. These concentrations were reduced when the NG volumetric fraction was increased in the mixture.

REFERENCES

1. 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.
2. 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.
3. Al-Maamary, H. M. S., Kazem, H. A., Chaichan, M. T. (2017). The impact of the oil price fluctuations on common renewable energies in GCC countries, Renewable and Sustainable Energy Reviews, 75, 989-1007.
4. Chaichan, M. T., Kazem, H. A., Abid, T. A. (2016). The environmental impact of transportation in Baghdad, Iraq, Environment, Development and Sustainability. DOI: 10.1007/s10668-016-9900-x.
5. Chaichan, M. T. and Al-Asadi, K. A. H. (2015). Environmental Impact Assessment of traffic in Oman, International Journal of Scientific & Engineering Research, 6(7), 493-496.
6. Al-Waeely, A. A., Salman, S. D., Abdol-Reza, W. K., Chaichan, M. T., Kazem, H. A. and Al-Jibori, H. S. S. (2014). Evaluation of the spatial distribution of shared electrical generators and their environmental effects at Al-Sader City-Baghdad-Iraq, International Journal of Engineering & Technology IJET-IJENS, 14(2), 16-23.
7. Walsh, M. P. (1997). Air pollution: Automobile, The Wiley Encyclopedia of Energy and the Environment, Volume 1; Wiley, New York, 1997
8. Zhang, Y., Stedman, D. H., Bishop, G. A., Guenther, P. L. and Beaton, S. P. (1995). Worldwide on-road vehicle exhaust emissions study by remote sensing, Environment Science and Technology, 29(9), 2286-2294.
9. Rahman, M. M., Mohammed, K. M., Rosli, A. B. and Sani, M. S. M. (2009). Study of air fuel ratio and instantaneous behavior on crank angle of four cylinder direct injection hydrogen fueled engine, Proceedings of the world congress on engineering, Vol II, July 1 - 3, London, U.K.
10. Abass, K. I. (2011). Comparison of practical investigations for CO emissions emitted from single cylinder S. I. Engine fueled with different kinds of hydrocarbon fuels and hydrogen, Al-Khwarizmi Engineering Journal, 7(1), 22-29.
11. 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.
12. Salim, A. A. & Chaichan, M. T. (2003). Study of SIE performance fueled with LPG, Sabha University Journal, 4(4), 67-82.
13. Chaichan, M. T. & Al Sheikh, S. A. (2001). Study of SIE performance fueled with methane, Al-Jufra University Journal, 1(1), 15-27.
14. Salim, A. A. & Chaichan, M. T. (2004). Study of SIE performance fueled with hydrogen, Sabha University Journal, 6(3), 32-57.
15. Kadhem, J. A., Reza, K. S., Ahmed, W. K. (2017). Alternative fuel use in Iraq: A way to reduce air pollution, European Journal of Engineering Research and Science, 2(5), 20-30.
16. Benson, S. R. and Barruah, F. (1977). Performance and emission for a multi cylinder S.I.E., SAE paper No. 770727.
17. Benson, S. R. and Whitehouse, H. (1979). Internal combustion engine, 1st edition, William Clowes Son Ltd.
18. Wong, J. K. (1972). Study of mixtures of methane and carbon dioxide as fuels in a single cylinder engine CFR, SAE paper No. 720370.
19. Gunkel, W. W. (1974). Methane carbon dioxide mixture in an internal combustion engine, The energy crisis, New York state horticultural society proceeding volume 11.
20. Karim, G. A. and Weirzba, I. (1983). Comparative studies of methane and propane as fuels for S.I.E. and C.I.E., SAE paper No. 831196.
21. Bhigash, S.F. (1970). Study of ignition lag and flame propagation in SIE, JSME, 13(64), 1970.
22. Chaichan, M. T. (2007). Study of performance of SIE fueled with different kinds of hydrocarbon fuels, Association of Arab Universities Journal of Engineering Science, 14(1), 25-44.
23. Chaichan, M. T. (2009). Study of performance of SIE fueled with Supplementary hydrogen to LPG, Association of Arab Universities Journal of Engineering Science, 16(1), 125-145.
24. 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.
25. 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.
26. Chaichan, M. T. and Abaas, K. I. (2010). Experimental comparison of CO emissions emitted from single cylinder S I engine fueled with different kinds of hydrocarbon fuels and hydrogen, Iraqi Journal for Mechanical and Material Eng., 10(3), 397-405.
27. 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.
28. 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.

29. Reza, K. S., Ahmed, W. K. and Jawad, R. S. (2017). The effect of compression and equivalence ratios on a spark ignition engine fueled with LPG enriched NG, International Journal of Trend in Research and Development, 4(3), 282-287.
30. 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.
31. Chaichan, M. T. & Al-Sheikh, S. (2003). Study of NOx and CO emissions for SIE fueled with methane, proceeding to International Conference for Energy and Environment, Brack, Libya.
32. 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.
33. 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.
34. Ahmed, W. K., Reza, K. S., Sheet, I. I., Al-Zubaidi, D. S. M. (2017). The impact of natural gas addition to liquefied petroleum gas on the NOx emission of a spark ignition engine, Saudi Journal of Engineering and Technology, 2(7), 256-263.
35. Al-Zubaidi, D. S. M. (2013). Study of performance of SI engine fueled with supplemented hydrogen to natural gas, The Iraqi Journal for Mechanical and Material Engineering, 13(2), 350-363.