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Spark ignition engine performance fueled with hydrogen enriched liquified petruluom gas (LPG)

Miqdam T. Chaichan
Energy and Renewable Energies Technology Center, University of Technology, Baghdad, Iraq

***Corresponding Author:**
Miqdam T. Chaichan
Email: 20185@uotechnology.eru.iq

Abstract: This paper studies the performance of single cylinder, 4-stroke, variable compression ratio, spark timing, and equivalence ratio, spark ignition Ricardo E6 engine, fuelled with supplemented hydrogen to LPG. The results indicated that the higher useful compression ratio (HUCR) for a mixture of two gasses was (10.5:1). The brake power when the engine was fueled with LPG had higher than that when it was fed with hydrogen. However, when mixing two fuels, the brake power increased and became greater than that when fueled with LPG to a certain limit (the hydrogen volumetric ratio in the mixture reached 70%). After this limit the brake power reduced by increasing hydrogen volumetric ratio. At equivalence ratios between (Ø=1-1.1), the brake power got its highest value when mixing the two fuels. The results showed that the engine could be operated with very lean equivalence ratios with additional hydrogen. The brake specific fuel consumption reduced while the indicated thermal efficiency increased when hydrogen volumetric fraction was increased.

Keywords: Hydrogen, LPG, compression ratio, equivalence ratio, optimum spark timing.

INTRODUCTION

Many researchers tried to use dual- fuel engines, especially the spark ignition engines, for the purpose of improving combustion, increasing engine resulting capabilities, and reduce specific fuel consumption and reducing pollutants emitted from it [1].

In this work, the study was conducted on a spark ignition engine fuelled with a mixture of liquefied petroleum gas (LPG) and hydrogen. LPG is an excellent fuel for engine ignition spark because it has a high calorific value [2], and a relatively high-octane number compared to gasoline, which is up to (110). Therefore, LPG resistance for knock phenomenon is much higher of gasoline. On this basis, the engine compression ratio engine can be increased when using LPG [3]. Besides, LPG composes a homogeneous mixture with air and gives a "homogeneous" distribution for the fuel with air in the manifold entry better than gasoline. LPG has rapid spread combustion, and it contains lower sulfur compounds and thereby reduces engine's parts wear [4].

However, these features are accompanied by some factors that are limiting its use in internal combustion engines. Such as it reduces the volumetric density of the engine [5], and its compounds differ from season to season and from location to another. The capacity of gaseous fuel tank is limited; also, it occupies a significant part, and it has heavy weights. Besides, it causes a change in the properties of lubricating oil. LPG works to make the oil layer as a gelatin and then oxidizes oil, and this affects the properties of the oil especially at low temperatures [6].

The hydrogen hasn't lost the attention of researchers since a long time ago because it is the only fuel in the universe that has the two features: the exuberance without burnout (as can be obtained from the most significant sources water). Hydrogen combustion produces water which means it will never reserve dry at all. Also, it's burning is clean and produces no pollutants as that produced from the hydrocarbon fuels. It has positive properties make it an excellent fuel for spark ignition engine from which it mixes easily with air, and has a wide air-hydrogen mixture limits of Ø = 0.1 up to Ø = 2.5. Hydrogen fueled engine produces high thermal efficiency, and fewer pollutants resulting from combustion. It does not produce unburned hydrocarbons or carbon monoxide and produces small amounts of nitrogen oxides [7].

The speed of the flame of hydrogen is high from 265 up to 325cm/sec that causes rapid burning that can be described as nearly the ideal combustion required for the Otto cycle. This rapid flame propagation velocity increases the engine thermal efficiency, and can control the resulting power by organizing the fuel flow rate with the airflow without throttle. As the hydrogen ignition limits are wide, this qualitative control gives an overall efficiency higher than gasoline engines [8].

The researchers studied some of the phenomena and attributes associated with hydrogen when it is used as a fuel for spark ignition engines which need more researches and studies to overcome the harm and harmful effects when employed in engines. From these negatives properties the safety of hydrogen usage in vehicles; the heat of evaporation of liquid hydrogen (452.5kJ / kg) is relatively high [9]. This property means that when using an engine with a carburetor, several procedures must be taken to transfer enough heat to the entry manifold to vaporize the fuel. Liquid hydrogen can be injected directly into the combustion chamber, but injection process requires expensive additional costs [10].

The Pre-ignition phenomenon happens in the hydrogen engines when the combustible air-hydrogen mixture ignites before the ignition of the spark plug due to it touches some hot parts of the combustion chamber and the spark plug or the remained emission. The energy required for ignition of the hydrogen-air mixture is very small (10mJ), and the repeating of this phenomenon makes the backfire of the mixture happens in the entering manifold. The backfire phenomenon occurs efficiently in engines that use hydrogen as fuel, and this phenomenon forces the engine to stop the motor rotation [11, 12].

Adding hydrogen to gasoline has been studied too much, and found that it produces distinct improvement in the thermal efficiency of the engine, and reduces the exhaust pollutant gasses compared to the gasoline engine, and gives safe combustion of the lean mixtures which increase the fuel saving. To date, no fixed engine was developed to work with excess air so the equivalence ratio less than 0.8 ($Ø < 0.8$). There are many reasons for this; the most important is the homogeneity of the mixture and the poor distribution of the charge from one cylinder to the other [13].

It has been observed that adding hydrogen to any hydrocarbon fuel helps in making the mixture leaner than double of that which is possible to work in it with gasoline. The influence of hydrogen comes from the effect of the hydrogen-air fuel mixture in the ignition period and the first phase of combustion. As it provides the mixture with a heat source and increases the reactive centers with the increase in the proportion of air even when at these equivalent ratios that do not react with air-gasoline mixture easily [14].

Chaichan [15] described the process resulting from the addition of hydrogen to internal combustion engines, including backfire in the entry manifold problems. The researchers found that it increases whenever the mixture was enriched with hydrogen, and with the increase of load. The control of this issue (as the study advised) was by using exhaust gas recirculation mode, or water injection or fuel injection directly into the combustion chamber.

Chaichan studied [16] the effect of adding different ratios of hydrogen to liquefied petroleum gas to find the lean limit, and concluded that it reduced with the increase of added hydrogen to a certain extent, and then the effect of the added hydrogen fraction increase does not appear any impact on the lean limit.

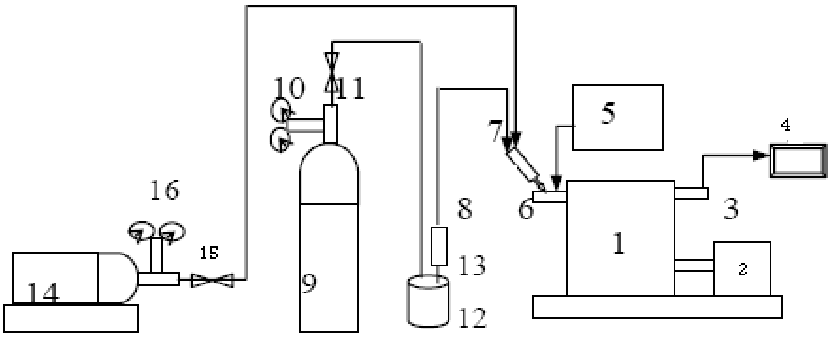
Verma [17] mentioned that the resulted brake power (bp) increased to its maximum value, and then it reduced when the volumetric ratio of hydrogen to the first fuel (methane) was increased from 0 to 80%. The increasing of the concentration of hydrogen in the mixture is followed by a delay in the spark ignition timing for all equivalent ratios apparently, and the combustion time reduced. The higher cylinder pressure value increases across all equivalent ratios [18].

The primary aim of this study is to evaluate the impact of adding hydrogen to LPG in several volumetric fractions on the engine performance experimentally. The search for alternative fuels for internal combustion engines was one of the main tasks of the Energy and Renewable Energies Technology Center in the University of Technology, Baghdad, Iraq [19-61].

Experimental Setup

The experiments of this research were conducted using Ricardo E6, which is a single-cylinder four- stroke engine with variable compression ratios, spark timing air to fuel ratio, and speed. This engine is attached to an electric dynamometer, and the engine lubrication by a gear pump operates separately from the engine. The cooling water rotates by a centrifugal pump; Fig. 1 illustrates a photo of the system used in the research. The amount of air entering the engine was measured by scale air type (Alock viscous flow meter) connected to a flame trap. A tachometer was used to measure engine speed. The dynamometer was used in addition to measuring the brake power and the average effective pressure as an electric motor that rotate the engine at the beginning of the operation. The exhaust gas temperature was measured by thermocouple type nickel chrome/ nickel Aleomal type B; this thermocouple was calibrated.

Two feeding systems were used to feed the engine with LPG and hydrogen. The system used the liquefied petroleum gas supplied to the engine consists of the following parts: fuel tank, fuel filter, electromagnetic valve, liquefied petroleum gas evaporator, gaseous fuel flow gauge, damping box and gas carburetor. The system used to supply the engine with hydrogen consists of hydrogen gas cylinder, pressure regulator, and chock nozzles system which was used a backfire damping in addition to its primary objective as hydrogen flow measuring device.



1. Single cylinder engine, 2. Dynamometer, 3. Engine exhausts manifold, 4. Exhaust gas analyzer, 5. Air drum,6. Engine intake manifold, 7. Gas carburetor, 8. Solenoid valve, 9. Hydrogen gas cylinder, 10. Pressure gauge, 11. Non return valve, 12.Flame trap, 13. Choked nozzles system, 14. LPG cylinder, 15.LPG flow meter, 16. Pressure gauge and pressure regulator

Fig. 1 explanatory diagram of the device used in the search

The equations used to evaluate the engine performance variables are the followings [61]:

1- The equivalence ratio was determined as:

$$\emptyset = \frac{\text{stoichiometric fuel/air ratio}}{\text{actual fuel/air ratio}}$$

2- Brake power

$$bp = \frac{2\pi * N * T}{60 * 1000} kW$$

3- Brake mean effective pressure

$$bmep = bp \times \frac{2 * 60}{V_{sn} * N} kN/m^2$$

4- Fuel mass flow rate

$$\dot{m}_f = \frac{v_f \times 10^{-6}}{1000} \times \frac{\rho_f}{time} \, {}^{kg}/_{sec}$$

5- Air mass flow rate

$$\dot{m}_{a,act.} = \frac{12\sqrt{h_o * 0.85}}{3600} \times \rho_{air} \frac{kg}{sec}$$

$$\dot{m}_{a_{theo.}} = V_{s.n} \times \frac{N}{60 * 2} \times \rho_{air} \frac{kg}{sec}$$

6- Brake specific fuel consumpotion

$$bsfc = \frac{\dot{m}_f}{bp} \times 3600 \quad \frac{kg}{kW.hr}$$

7- Total fuel heat

$$Q_t = \dot{m}_f \times LCV kW$$

8- Brake thermal efficiency

$$\eta_{bth.} = \frac{bp}{Q_t} \times 100 \quad \%$$

9- Hydrogen volume fraction

$$HF = \frac{V_{H_2}}{V_{H_2} + V_{LPG}}$$

RESULTS AND DISCUSSIONS

Many designs and operating variables impact on the engine was fuelled with hydrogen enriched LPG were studied. These variables effects on engine performance declare the possibilities of using hydrogen as an alternative fuel in gaseous engines. For this purpose several hydrogen volumetric fractions (HVF = 0.3, 0.5, 0.7, 0.8) were added to liquefied petroleum gas, to evaluate the best mixing ratio for the two gasses.

Compression ratio effect

The effect of compression ratio was studied to determine the higher useful compression ratio for each mixture. The experiments started with compression ratio 8: 1 up to 11: 1. Fig. 2 shows the relationship between brake power and equivalence for variable HVF from 0 to 100% at optimum spark timing and engine speed of 25rps. The results indicate that the brake power increased with increasing HVF from 0 to 70% for compression ratios of (10.5, 10, 9.8) and HVF of (0-60 %) at a compression ratio of 11: 1. This brake power increase was expected because the presence of hydrogen into the combustion chamber gives a distinct improvement in the released energy. Also, hydrogen addition increased the combustion rate, giving better burning and approximately complete combustion. The brake power reduced with the growth of HVF to 80%, as this ratio compensated large part of the liquefied petroleum gas with hydrogen, causing a decrement of heat released by combustion, due to the lower calorific value of hydrogen on the size basis compared to the calorific value of the LPG. The use of neat hydrogen was clarified this issue, as the resulted brake power became less than those resulting from the use of LPG. It appears in the figure, the mixture behavior at a compression ratio of 11: 1 was different from lower ratios; at this ratio the combustion was challenging, and the violent knock phenomenon occurred with increasing load.

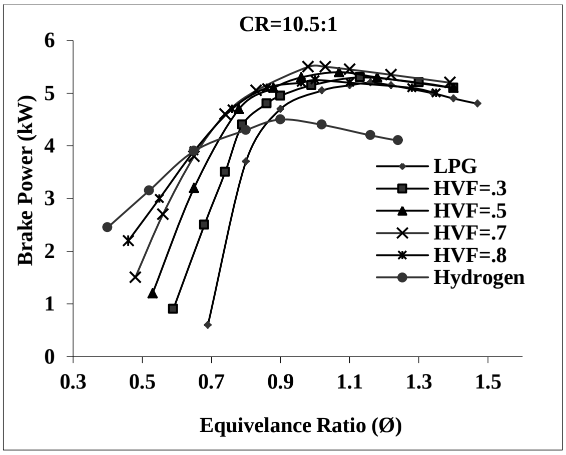


Fig-2: The relationship between brake power and equivalence ratiowith mixing different HVF at the optimal spark timing and speed of 25 rps

Fig. 3 declares the relationship between the mixing ratio and the highest bp of the engine at every HVF and compression ratios. The results manifest that the higher useful compression ratio for the LPG-hydrogen mixture is 10.5: 1, at which the higher brake power was achieved. This compression ratio value was obtained by adding HVF of (70%).

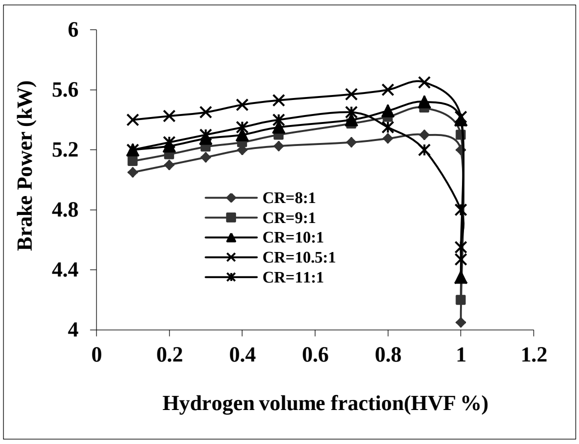


Fig-3: The relationship between the HVF the maximum bp of the engine at each tested compression ratios

Fig. 4 shows the effect of various mixing ratios and studied compression ratio on the optimum spark timing. The increase in volumetric hydrogen ratio of the fuel delay the optimum spark timing, as well as increasing the compression ratio. This result is expected, as the hydrogen has high burning velocity compared to LPG. Besides, the burning speed increases with compression ratio increase, as it enhances the temperature of the mixture in the combustion chamber.

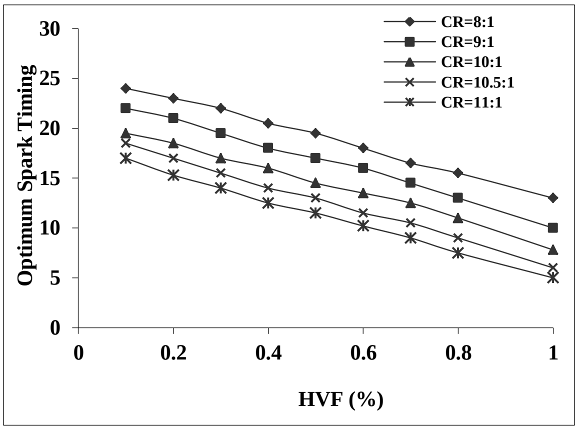


Fig-4: The effect of variable HVF and engine compression ratios on the optimumspark timing

Equivalence ratio effect

Fig. 5 shows that the higher brake power in the case of liquefied petroleum gas to be when Ø = 1. 10, and at the addition of hydrogen it reduced to the stoichiometric equivalence ratio (Ø = 1.0). The figure clarifies that the effect of adding hydrogen is significant on the lean side. The results show that the bp at Ø = 0.7 increased with increasing the HVF additive from 0 up to 70% was excellent, as the increased bp raised up to 270 % compared to LPG case. At equivalence ratio Ø = 0.8, the bp was increased about 35%. These bp increments were due to the meeting of three factors: the availability of necessary oxygen to interact, the presence of hydrogen that improves combustion and increases the speed, and the presence of LPG with high calorific value. The effect of adding hydrogen at equivalence ratios greater than Ø = 0.8 was limited because the lower amount of air entering the engine as hydrogen and LPG shifted amount of the air volume, which means that the increase in energy resulting from the interaction will be limited. This can be observed from the figure as the ratio of the increment of bp at Ø = 1 is around 7%, and it was about 4% at an equivalence ratio of Ø = 1.1. The previous results clarified that the addition of hydrogen at lean equivalence ratios improves the resulted bp dramatically.

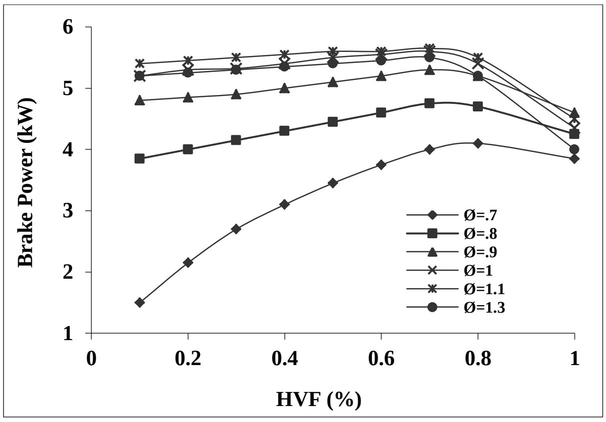


Fig-5: The relationship between HVF and bp for five equivalence ratios, optimum spark timing,and speed 25rps, at HUCR= 10.5 : 1.

The spark timing delayed from the optimum one by adding hydrogen for all equivalence ratios as 6 and 7 shows. The spark timing on the lean side was 17°BTDC with HVF of 80%. At the stoichiometric and rich equivalence ratios, the optimum spark timing became 10°BTDC.

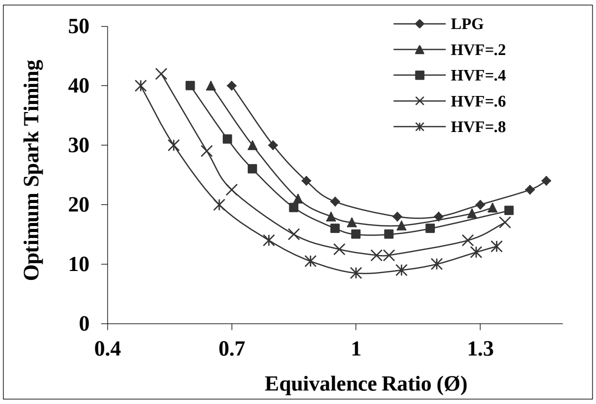


Fig-6: The relationship between the optimal timing of the sparks and the equivalence ratio at variable HVF, HUCR, and 25rps engine speed

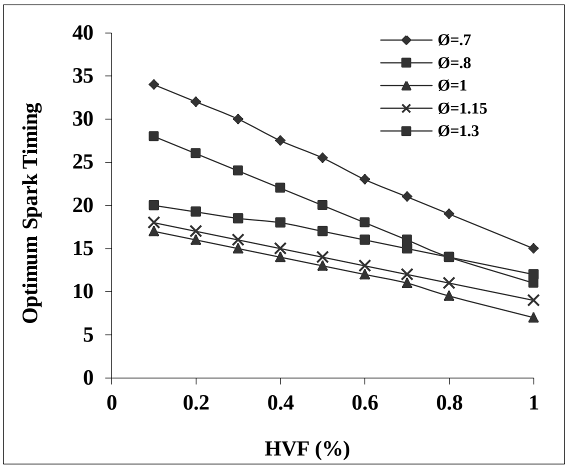


Fig-7: The effect of variable HVFwith LPGon the optimumsparktiming of specific equivalence ratios

Fig. 8 declares that the specific fuel consumption reduced significantly, especially for lean equivalence ratios by hydrogen addition. At Ø = 0.7 and the HVF= 70 %, for example, a decrease in specific fuel consumption up to 62% was achieved, and when Ø = 1.0 at the same HVF, the decrement was up to 16%.

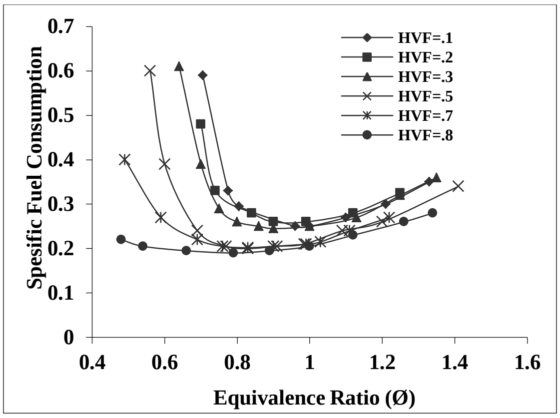


Fig-8: The effect of variable HVF on specific fuel consumption at HUCR compression, 25 rpsspeed,and optimum spark timing

Fig. 9 reveals that the indicated thermal efficiency increased by adding hydrogen on the lean side dramatically, as it reached its maximum value in this aspect, and then quickly went down when the mixture of fuel was enriched. The rapid rise of the thermal efficiency of the charts in the weak side confirms that the combustion in this aspect is improving in a large, clear and efficient by adding hydrogen, the rapid decline of this efficiency at lean equivalence ratios after their arrival to their highest value, clearly shows the difficulty of combustion. The addition of hydrogen gas to LPG in a rich mixture did not improve the combustion or the thermal efficiency except in small limits.

The results show that the maximum value of thermal efficiency graphs was at low rates, and they became lower by adding hydrogen. For example, when using LPG, the highest value of this efficiency was at Ø = 0.9, and then it became the equivalent ratios (Ø = 0.83, 0.8, 0.77) with HVF added by ratios (HVF = 0.3, 0.5, 0.7), respectively. At neat hydrogen engine, the highest indicated thermal efficiency value was at Ø = 0.4.

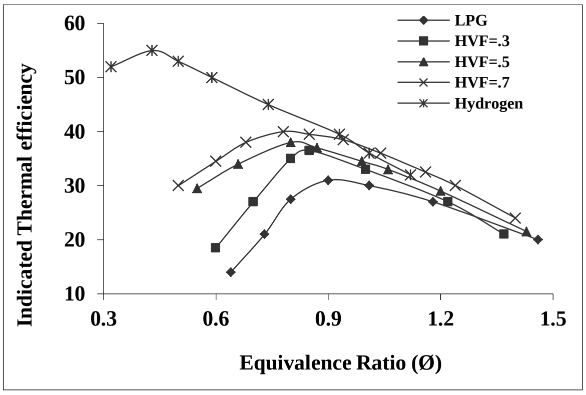


Fig-9: The effect of variable HVF on the indicated thermal efficiency at HUCR and the optimum sparktiming

The addition of hydrogen causes a decrease in the exhaust gas temperatures at all equivalence ratios, as Fig. 10 illustrates. The exhaust gas temperature when the engine fuelled with neat hydrogen was lowest of all equivalence ratios. This result can be explained by the fact that the combustion in the presence of hydrogen in the mixture became quickly "and complete," especially when the engine operated at optimum spark timing. So, when the expansion stroke happened, the mixture is mostly turned into burnt gasses are cooled in this stroke, and when the exhaust valve opened, these exhaust gasses had cooled dramatically. The exhaust gasses existed at much lower temperatures degree than the case of the use of any hydrocarbon fuel. In addition to the heat transfer rate from the cylinder was increased due to the lack of the inner layer thickness of the cylinder wall near the unburned gasses.

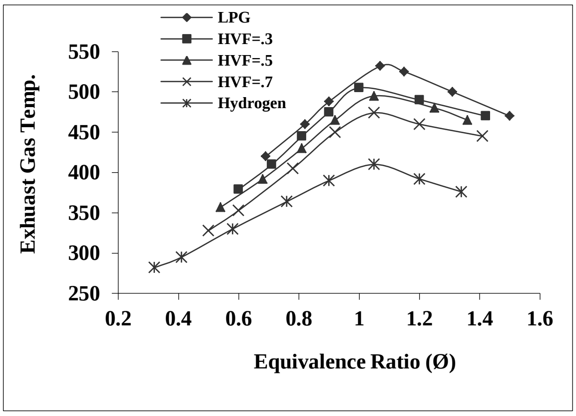


Fig-10: HVF impact on exhaust gas temperature for variable equivalence ratiosat HUCRand 25 rpsspeed

Engine speed effect

Fig. 11 declares that the speed impact is the same in the case of the use of any tested fuel alone, as the bp was increased with speed increase for all the measured velocities, although the increment rate varies. The bp increment of slow velocities to the medium was significant; this rate reduced when the engine was run at medium or high speeds due to the increase in friction power with the speed increase.

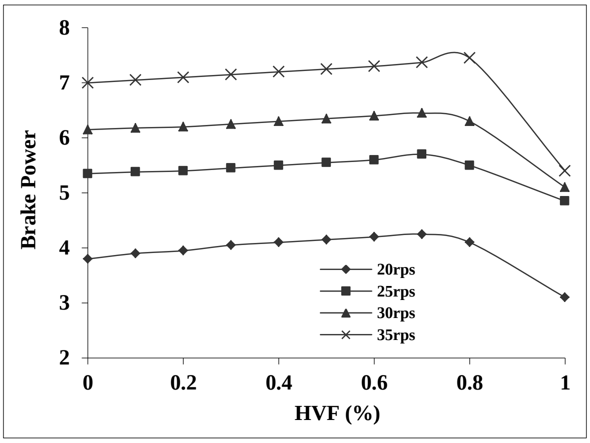


Fig-11: The effect of HVF on bpof the engine at variable engine speed

Fig. 12 shows the effect of different HVF on the optimum spark timing of at variable engine speeds. It is noted that the addition of hydrogen caused a delay to the optimum spark timing up to 17 °BTDC for all the tested velocities. The increase in engine speed caused advancing the optimum spark timing compared to the case when the engine ran with any of the used fuel in its pure state.

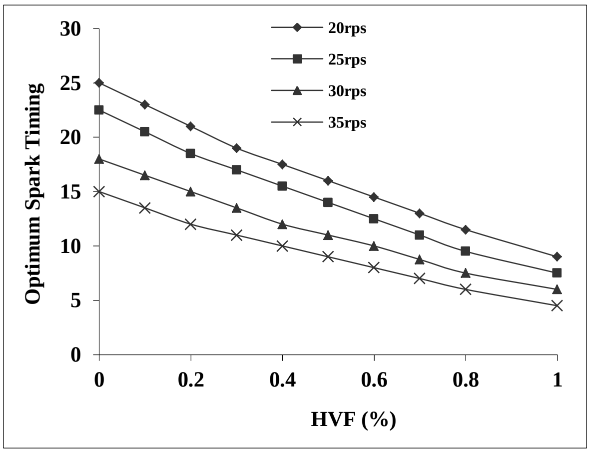


Fig-12: The effect of variable HVF on the optimumspark timing at different speeds

Spark timing effect

Figures 13 to 15 represent the relationship between the engine bp with the equivalence ratio for three spark timings (10, 15, 20)°BTDC when hydrogen is added to LPG in three volumetric ratios (HVF = 0.3, 0.5, 0.7), at higher useful compression ratio and the engine speed was 25 rps.

The spark timing of 10°BTDC is too late for LPG as Fig. 13 reveals, where the engine bp reduced, but with the addition of hydrogen the bp rose clearly and dramatically, especially for some equivalence ratios between (Ø = 0.85-1.1) as this timing approached the optimum spark timing. The timing of 15°BTDC can be considered as a better timing for LPG as the bp increased for all ratios. The bp increased clearly with adding hydrogen by a volumetric ratio of 30% to the mixtures of (Ø = 0.8-1.3), as Fig. 14 shows.

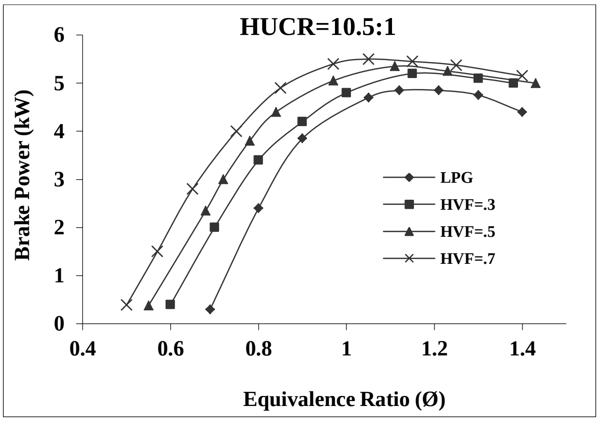


Fig-13: The effect of equivalence ratio variation on bp at variable HVF ratios, HUCR, 25rps, and10°BTDC

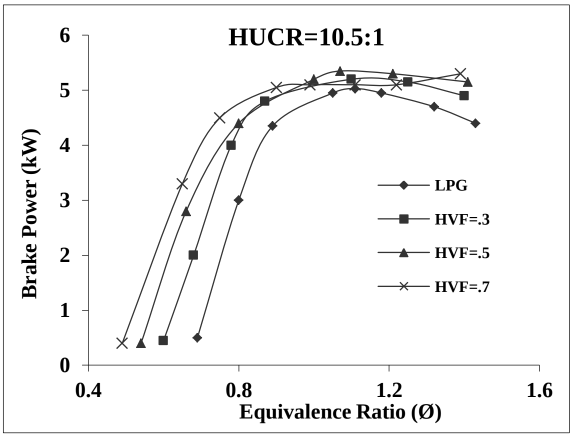


Fig-14: The effect of equivalence ratio variation on bp at variable HVF ratios, HUCR, 25rps, and15°BTDC

The bp was increased by adding 60% of hydrogen as volume, but with a smaller increase in the former equivalence ratios mentioned above, because this timing is considered a little bit advanced from the optimum spark timing of these ratios.

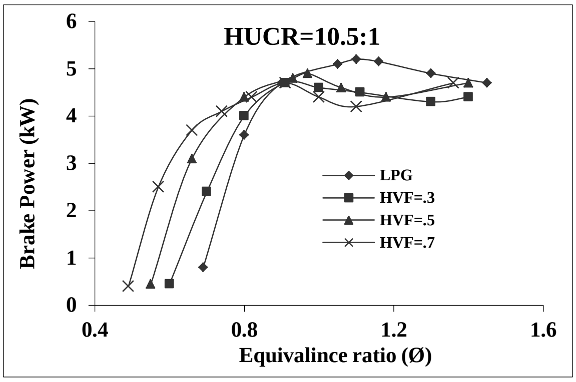


Fig-15: The effect of equivalence ratio variation on bp at variable HVF ratios, HUCR, 25rps, and20°BTDC

However, when hydrogen was added in a volumetric ratio of 70%, the bp increased on the lean side, and reduced at equivalence ratio (Ø = 0.8-1.3). The shape of the curve changed, and this is expected as this timing can be considered advance from the OST for these equivalence ratios significantly.

The curves of bp took different forms in Fig. 15, as the bp for LPG, increased because this spark timing was close to the optimum timing for the equivalence ratios that produce the highest bp (Ø = 1-1.15). The bp reduced by adding volumetric ratios of hydrogen from (30-50%) for the equivalence ratios ranged from (Ø = 0.9-1.35). Starting the engine at HVF= 70% was hard. At this equivalence ratio and for this spark timing, as it was advanced from the optimum spark timing for these equivalent ratios, also causes high-pressure rates to occur before the top dead center causing negative work on the engine.

CONCLUSIONS

The study was conducted to evaluate the performance a SIE fueled with LPG enriched with variable hydrogen volumetric fractions the results indicated that the higher useful compression ratio for a mixture of hydrogen and LPG gaseous is (10.5: 1). The OST delayed by adding hydrogen to LPG at all equivalence ratios. The spark timing delayed with the increase of the engine compression ratio for all fuels. The OST advanced with increasing the speed for the tested fuels. The addition of hydrogen to the air-LPG mixture with volumetric rates increased the bp to a certain extent (volumetric ratio of hydrogen in the mixture of 70%) and then began a decline with increasing the proportion of hydrogen in the mixture. By adding hydrogen to LPG, the engine can run at lean equivalence ratios that cannot access it when the engine is fueled with LPG alone. The equivalence ratio can be reduced more when the HVF was increased in the mixture. The addition of hydrogen to LPG when the engine has a compression ratio of (8: 1) and get bp larger than that produced using gasoline alone. The indicated thermal efficiency increased by adding hydrogen to LPG, and the maximum value achieved when hydrogen alone was used at very lean equivalence ratio. The exhaust gas temperatures were reduced by adding hydrogen to liquefied petroleum gas.

REFERENCE

1. 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.
2. 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.
3. Khan, M. S., Ahmed, I., Abdul Mutalib, M. I., Nadeem, S.& Ali, S. (2014). Influence of H_2O_2 on LPG fuel performance evaluation, AIP Conference Proceedings pp. 763-768, doi: 10.1063/1.4898553
4. Mustafa, K. F., Gitano-Briggs, H. W. (2008). Effect of variation in liquefied petroleum gas (LPG) proportions in spark ignition engine emissions, in International Conference on Environment 2008: Environmental Management On Technology Towards Sustainable Development, Penang, Malaysia.
5. 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.
6. 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.
7. Chaichan, M. T. & Abaas, Q. A. (2010). Study of NOx emissions of SI engine fueled with different kinds of hydrocarbon fuels and hydrogen. Al Khwarizmi Eng. Journal, 6(2), 11-20.
8. Chaichan, M. T. (2010).Practical measurements of laminar burning velocities for hydrogen-air mixtures using thermocouples.Association of Arab Universities Journal of Engineering Science, 17(2).
9. Chaichan, M. T. (2008). Practical study of compression ratio, spark timing and equivalence ratio effects on SIE fueled with hydrogen. Proceeding to Industrial Applications of Energy Systems, Sohar University, Oman, 2008.
10. Miao, J., Leung, C. W., Cheung, C. S., Huang, Z., Jin, W. (2016). Effect of H_2 addition on OH distribution of LPG/Air circumferential inverse diffusion flame. international journal of hydrogen energy, 41, 9653 -9663.
11. Verhelst, S., Wallner, T. (2009). Hydrogen-fueled internal combustion engines, Prog. Energ. Comb. Sci., 35, 490-527.
12. Ji, C., Liu, X., Wang, S. (2009). Effect of hydrogen addition on combustion and emissions performance of a spark ignition gasoline engine at lean conditions. Int. J Hydrogen Energy, 34, 7823-7834.
13. Wang, S. Ji, C. (2011). Cyclic variation in a hydrogenenriched spark-ignition gasoline engine under various operating conditions. Int. J Hydrogen Energy, 37, 1112-1119.
14. Chaichan, M. T. & 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.
15. Chaichan, M. T. (2016). EGR effects on hydrogen engines performance and emissions. International Journal of Scientific & Engineering Research, 7(3), 80-90.
16. 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.
17. Verma, G., Prasad, R. K., Agarwal, R. A., Jain, S., Agarwa, A. K. (2016). Experimental investigations of combustion, performance and emission characteristics of a hydrogen enriched natural gas fuelled prototype spark ignition engine. Fuel, 178, 209–217.
18. Liu, Y. F., Liu, B., Zeng, K., Huang, Z., Zhou, L. &Sun, L . (2012). Performance and emission characteristics of a hydrogen-enriched compressed-natural-gas direct-injection spark ignition engine diluted with exhaust gas recirculation. Proceedings of the Institution of Mechanical Engineers Part D Journal of Automobile Engineering · January. DOI: 10.1177/0954407011413047.
19. Chaichan, M. T. & Salih, A. M. (2010). Study of compression ignition engine performance when fueled with mixtures of diesel fuel and alcohols.Association of Arab Universities Journal of Engineering Science. 17(1), 1-22.
20. Chaichan, M. T. (2010). Emissions and performance characteristics of ethanol-diesel blends in CI engines. Engineering and Technology J, 28(21), 6365-6383.
21. Chaichan, M. T. & 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.
22. Chaichan, M. T. & 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.
23. Chaichan, M. T. (2011). Exhaustanalysis and performance of a single cylinder diesel engine run on dual fuelsmode. Baghdad Engineering Collage Journal, 17(4), 873-885.
24. Chaichan, M. T. & Abaas, K. I. (2012). Emissions characteristics of methanol-diesel blends in CI engines. Wassit Journal for Science & Medicine, 5(1), 177-189.

25. Chaichan, M. T. & Al Zubaidi, D. S. (2012). Practical study of performance and emissions of diesel engine using biodiesel fuels. Association of Arab Universities Journal of Engineering Science, 18(1), 43-56.
26. 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.
27. 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.
28. Chaichan, M. T. & Ahmed, S. T. (2013). Evaluation of performance and emissions characteristics for compression ignition engine operated with disposal yellow grease, International Journal of Engineering and Science, 2(2), 111-122.
29. Chaichan, M. T. & Saleh, A. M. (2013). Practical investigation of the effect of EGR on DI multi cylinders diesel engine emissions. Anbar Journal for Engineering Science (AJES), 6(3), 401-410.
30. Chaichan, M. T. & Saleh, A. M. (2013) Practical investigation of performance of single cylinder compression ignition engine fueled with duel fuel. The Iraqi Journal for Mechanical and Material Engineering, 13(2), 198-211.
31. Chaichan, M. T. (2013). Practical measurements of laminar burning velocities and Markstein Numbers for Iraqi diesel-oxygenates blends. The Iraqi Journal for Mechanical and Material Engineering, 13(2), 289-306.
32. Chaichan, M. T., Abaas, K. I.& Naser, A. H. (2013). Study of the effect of exhaust gas recirculation on performance and emitted noise of an engine fueled with diesel fuel. Association of Arab Universities Journal of Engineering Science, 20(1), 43-59.
33. 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.
34. 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.
35. Al-Waeely, A. A., Salman, S. D., Abdol-Reza, W. K., Chaichan, M. T., Kazem, H. A.& 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.
36. 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.
37. Chaichan, M. T. (2014). Combustion and emissions characteristics for DI diesel engine run by partially-premixed (PPCI) low temperature combustion (LTC) mode. International Journal of Mechanical Engineering (IIJME), 2(10), 7-16.
38. Chaichan, M. T., Al-Zubaidi, D. S. M. (2014). A practical study of using hydrogen in dual–fuel compression ignition engine. International Journal of Mechanical Engineering (IIJME), 2(11), 1-10.
39. Salih, A. M.&Chaichan, M. T. (2014). The effect of initial pressure and temperature upon the laminar burning velocity and flame stability for propane-air mixtures. Global Advanced Research Journal of Engineering, Technology and Innovation, 3(7), 154-2011.
40. Chaichan, M. T. (2014). Combustion of dual fuel type natural gas/liquid diesel fuel in compression ignition engine. Journal of Mechanical and Civil Engineering (IOSR JMCE), 11(6), 48-58.
41. Chaichan, M. T., Salam, A. Q.& Abdul-Aziz, S. A. (2014). Impact of EGR on engine performance and emissions for CIE fueled with diesel-ethanol blends. Arabic universities Union Journal, 27(2), 2014.
42. Chaichan, M. T. (2014). Exhaust gas recirculation (EGR) and injection timing effect on emitted emissions at idle period. Al-Khwarizmi Engineering Journal, 10(4), 33-44.
43. Chaichan, M. T., Al-Zubaidi, D. S. M.(2014). Operational parameters influence on resulted noise of multi-cylinders engine runs on dual fuels mode. Journal of Al-Rafidain University Collage for Science, 35, 186-204.
44. Chaichan, M. T. & Faris, S. S. (2015). Practical investigation of the environmental hazards of idle time and speed of compression ignition engine fueled with Iraqi diesel fuel. International J for Mechanical and Civil Eng., 12(1), 29-34.
45. Chaichan, M. T., Abaas, K. I. (2015). EGR and injection timing variation effects of an engine run in HCCI mode performance and emitted emissions. International Journal of Engineering Trends and Technology (IJETT), 19(3), 120-130. DOI:10.14445/22315381/IJETT-V19P221
46. Chaichan, M. T. (2015). Performance and emission study of diesel engine using sunflowers oil-based biodiesel fuels. International Journal of Scientific and Engineering Research, 6(4), 260-269.
47. Chaichan, M. T. (2015). The impact of equivalence ratio on performance and emissions of a hydrogen-diesel dual fuel engine with cooled exhaust gas recirculation. International Journal of Scientific & Engineering Research, 6(6), 938-941.
48. Chaichan, M. T. (2015). The effects of hydrogen addition to diesel fuel on the emitted particulate matters. International Journal of Scientific & Engineering Research, 6(6), 1081-1087.
49. Chaichan, M. T.& Al-Asadi, K. A. H. (2015). Environmental impact assessment of traffic in

Oman. International Journal of Scientific & Engineering Research, 6(7), 493-496.

50. Khudhur, S. H., Saleh, A. M. &Chaichan, M. T. (2015). The effect of variable valve timing on SIE performance and emissions. International Journal of Scientific & Engineering Research, 6(8), 173-179.
51. Chaichan, M. T., Al-Zubaidi, D. S. M. (2015). Control of hydraulic transients in the water piping system in Badra–pumping station No.5. Al-Nahrain University, College of Engineering Journal (NUCEJ), 18(2), 229-239.
52. Chaichan, M. T. (2015). The impact of engine operating variables on emitted PM and Pb for an SIE fueled with variable ethanol-Iraqi gasoline blends. IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE), 12(6-1), 72-79. DOI: 10.9790/1684-12617279).
53. Chaichan, M. T. (2015). Improvement of NOx-PM trade-off in CIE though blends of ethanol or methanol and EGR. International Advanced Research Journal in Science, Engineering and Technology, 2(12), 121-128.(DOI: 10.17148/IARJSET.2015.21222)
54. Chaichan, M. T. (2016). Evaluation of emitted particulate matters emissions in multi-cylinder diesel engine fuelled with biodiesel. American Journal of Mechanical Engineering, 4(1), 1-6. DOI: 10.12691/ajme-4-1-1.
55. Chaichan, M. T.& Abass, Q. A. (2016). Effect of cool and hot EGR on performance of multi-cylinder CIE fueled with blends of diesel and methanol.Al-Nahrain University, College of Engineering Journal (NUCEJ), 19(1), 76-85.
56. Chaichan, M. T., Maroon, O. K. & Abaas, K. I. (2016). The effect of diesel engine cold start period on the emitted emissions. International Journal of Scientific & Engineering Research, 7(3), 749-753.
57. Chaichan, M. T. (2016). Effect of injection timing and coolant temperatures of DI diesel engine on cold and hot engine startability and emissions. IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE), 13(3-6), 62-70.
58. Al-Khishali, K. J., Saleh, A. M., Mohammed, H., Chaichan, M. T. (2015). Experimental and CFD simulation for Iraqi diesel fuel combustion, The 1st. International Babylon Conference, Babylon, Iraq.
59. Salih, A. M., Chaichan, M. T., Mahdy, A. M. J. (2015). Study of the effect of elevated pressures on the laminar burning velocity of propane-air mixtures. The 2nd Scientific Conference of Engineering Science, Diyala, Iraq.
60. 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.
61. Chaichan, M. T. (2009). Practical study of performance of compression ignition engine fueled with mixture of diesel fuel and ethanol. Proceeding to the 3rd International Conference on Modeling, Simulation and Applied Optimization (ICMSAO’09), Al-Sharija, UAE.