EXPERIMENTAL COMPARISON OF CO EMISSIONS EMITTED FROM SINGLE CYLINDER S. I. ENGINE FUELED WITH DIFFERENT KINDS OF HYDROCARBON FUELS AND HYDROGEN

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ABSTRACT:

Liquefied petroleum gas (LPG), Natural gas (NG) and hydrogen were used to operate spark ignition internal combustion engine Ricardo E6, and compare CO emissions emitted from the engine, with emissions emitted from engine fueled with gasoline as a fuel.

The study was done when engine operated at higher useful compression ratio (HUCR) for gasoline 8:1, compared with its operation at HUCR for each fuel. Compression ratio, equivalence ratio and spark timing at constant speed 1500 rpm were studied there effects on the emitted emissions.

CO concentrations were little at lean ratios; it appeared to be effected a little with equivalence ratio in this side, at rich side its values became higher, and it appeared to be effected by equivalence ratio highly. The results appeared that CO emissions resulted from gasoline engine higher than that resulted from using LPG and NG all the time, while hydrogen engine emitted extremely low CO concentrations.

KEY WORDS: LPG, NG, equivalence ratio, compression ratio, optimum spark timing, brake power, CO concentrations.

مقارنة عملية لملوثات CO الناتجة من محرك اشتعال بالشرارة أحادي الاسطوانة يعمل بأنواع مختلفة ن الوقود الهيدروكاربوني والهيدروجين

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الخلاصة

استخدم الغاز النفطي المسال، الغاز الطبيعي والهيدروجين لتشغيل محرك احتراق داخلي يعمل بالشرارة نوع Ricardo E6 ، ومقارنة ملوثات CO المنبعثة من المحرك مع مثيلاتها عند عمل المحرك بالجازولين.

تمت دراسة الملوثات الناتجة عند عمل المحرك بنسبة الانضغاط النافعة العليا للجازولين 8:1، ومقارنتها بعمله بنسبة الانضغاط النافعة العليا لكل وقود على حدة، ودراسة تأثير نسبة الانضغاط والنسبة المكافئة وتوقيت الشرر عند سرعة ثابتة 1500 دورة/دقيقة على تراكيز الملوث الناتجة.

أظهرت النتائج أن تراكيز CO تكون قليلة في الجانب الضعيف وتتأثر قليلا بالنسبة المكافئة، وتزداد في الجانب الغني، وتتأثر بشكل كبير بالنسبة المكافئة، وأظهرت النتائج أن ملوثات CO الناتجة باستخدام الجازولين أكبر من تلك الناتجة عن استخدام LPG و NG على الدوام، بينما ينتج من استخدام الهيدروجين كوقود تراكيز CO قليلة جدا.

INTRODUCTION

There are two main reasons for using alternative fuels in the transportation sector. One is to reduce the dependence on petroleum oil. The other is to reduce emissions produced by on-road vehicles. The contribution of vehicle emissions to air pollution can be significant (Dhaliwal B, 2000).

The US. Environmental Protection Agency (EPA) in 1990, estimated that transportation sources were responsible for 63% of the CO, 38% of the NO, and 34% or higher of the HC's (national contribution of transportation emissions in the U.S.). In Europe, road transportation is blamed for roughly 50-70% of the NO, and around 50% of volatile organic compounds (VOC) (Walsh M P, 1997). Other sources report the contribution of automobiles to CO air pollution being 50% during wintertime in the Pacific Northwest, USA; about 68.5% in Peoples Republic of China; and as high as 98% in Tehran, Iran (Zhang et al, 1995).

There are four main factors, which are used by the automotive industry, government and public to value or assess the success of new alternatives. They are: availability, performance, environmental “friendliness” and cost-effectiveness (Geok et al, 2009).

Gasoline, being a normal liquid, exhibits a narrow range of properties when either ambient temperature or pressure is varied. It can be assumed, for example, that gasoline weighs about 6.2 pounds per gallon no matter where it may be encountered in storage, distribution, or retail dispensing systems, or within the vehicle fuel storage and metering system. Both methane and propane, however, are gases at normal temperatures and pressures. Their physical properties depend strongly on the temperature and pressure at which they are being stored. Comparisons of energy density or vehicle range have little meaning unless the assumed temperatures and pressures are carefully specified (Bose R S C and Muthuraman S, 2007).

The term LPG applies widely to any mixture of propane and butane, the two constituents occurring naturally in oil and gas reservoirs that are gaseous at normal atmospheric conditions but can be liquefied by pressure alone. Components heavier than butane are liquids at normal conditions and components lighter than propane cannot be liquefied without refrigeration. The composition of LPG used as an automotive fuel varies from almost pure propane to almost pure butane (Awidat A S and Chaichan M T, 2002).

Both gaseous fuels have higher ignition temperatures and higher octane numbers than gasoline. The subject of octane number (index of resistance to engine knock) is somewhat murky for the gaseous fuels because the meaning of their octane number of more than 100 is not dear. An octane rating of 100 simply means that a fuel produces knock at the same compression ratio as when the engine is running on isooctane (Idris S A and Abu Baker R, 2009). Regardless of the technical problems in defining octane number for gaseous fuels, it is dear that methane should theoretically be usable at higher compression ratios (therefore higher efficiency) than gasoline, and that propane falls between the two. With respect to almost all defined fuel characteristics, values for propane lie between those for methane and gasoline (Chaichan M T, 2006).

Hydrogen has advantages over conventional fuels when used in an internal combustion engine. The characteristics of hydrogen improve engine efficiencies as well as dramatically reducing emissions. The primary motivation for hydrogen experimentation is to meet ultra low emissions standards proposed by government agencies. With the enforcement of super-ultra low emissions auto manufactures will be forced to reduce vehicle emissions even further (Wayne A, 2004 and Rahman and et al, 2009).

Hydrogen is considered an ideal alternative fuel. The use of hydrogen as an automotive fuel, as a primary or supplementary fuel, appears to promise a significant improvement in the performance of a spark ignition engine. Besides being the cleanest burning chemical fuel, hydrogen can be produced from water (using non-fossil energy) and, conversely, on combustion forms water again by closed cycle (Al Baghdadi M S A, 2006).

Spark-ignition (SI) engines are a major source of air pollution. The SI engine exhaust gases contain oxides of nitrogen (ie, NOx, including nitric oxide NO, and small amounts of nitrogen dioxide NO_2), carbon monoxide (CO), organic compounds which are unburned hydrocarbons (UHC), carbon dioxide (CO_2) and oxides of sulfur (SOx) (Heywood J, 1998 and Pulkrabek W, 1997).

Carbon monoxide is formed by incomplete combustion. This occurs when there is insufficient oxygen near the fuel (hydrocarbon) for complete combustion 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.

In addition, it reacts with O_3 in the upper atmosphere, producing carbon dioxide (CO_2), which depletes the ozone layer (Sorge G, 1995).

Variation of the emission levels from SI engines depends on the engine operating parameters. Basically, there are four major operating variables that affect not only spark ignition engine emissions but also the performance and the efficiency of the unit. They are the (1) Air/fuel ratio, (2) Speed, (3) Load and (4) Spark timing (Bakar R A and Ismail A R, 2009). These parameters can be defined as engine control parameters due to the fact that they can be manipulated to achieve a specific engine performance (Iyengar K S, 2007).

The objective of this study is to show the relationship between fuel and engine CO emissions and whether some of the more currently viable alternative fuels are capable of reducing emissions and in turn improving air quality. Experimental test were conducted to compare CO emissions emitted from single cylinder spark ignition engine, when it is run with four different fuels (gasoline, LPG, NG and hydrogen). The effect of some variables as compression ratio, equivalence ratio, spark timing and engine speed are studied.

EXPERMINTAL SETUP

The investigation were carried out on single cylinder, 4-stroke spark ignition Ricardo E6 engine with variable compression ratio, spark timing and equivalence ratio, operated with gasoline, LPG, NG and hydrogen. NG and hydrogen were supplied to air manifold by means of choked nozzles system and pressure regulator to achieve mixing rate.

LPG was supplied to air manifold by means of orifice plate and pressure regulator, gasoline was supplied by means of carburetor type Zenith WIP supplied with a choke, 26 mm, consists of a main variable spray, supplied with needle valve to control gasoline flow rate through spray opening.

Fig. 1, Recardo engine and its accessories used in this study

The following instruments were used for the analysis of the emissions:

- A non – dispersing infrared analyzer for CO.
- A magnetic oxygen analyzer for O_2.

The engine was operated with pure gasoline, LPG, NG and hydrogen. A wide range of equivalence ratio effect on CO emission concentrations at HUCR and 25 rps engine speed were studied.

RESULTS and DISCUSSION

1- Compression Ratio Effect

Figures 1, 2 and 3 represents CO concentrations emitted from single cylinder spark ignition engine at different compression ratios (CR), from the figures it is obvious that CO concentrations increased in exhaust gas with increasing CR in the rich side, because of insufficient oxygen, and the increased of dissociation from CO_2 molecules to CO, by increased burning temperatures. For the lean side the CR effect was not existed, because of oxygen abundance, low exhaust gas temperature and low fuel quantity. Hydrogen engine emitted extremely low traces of CO, owing to some engine lubricating oil burned inside the combustion chamber.

Fig. (4) represents CO emitted from the four fuels at CR= 8:1, which is the higher useful compression ratio (HUCR) for gasoline, the figure shows that CO concentrations for gasoline at this CR was much higher than that emitted by LPG or NG. This is because of the gasoline atomic structure which consists of much more carbon atoms. While hydrogen engine emitted extremely low traces of CO, this is due to nonexistence of carbon molecules in this fuel, and the traces appeared in these tests were from burning lubrication oil. LPG fuel emitted more CO concentrations than NG fuel, because of its atomic structure which has more carbon molecules than NG.

CO concentrations emitted from the engine increased when using the three hydrocarbon fuels. Gasoline still had the higher concentrations, while hydrogen emitted very low traces. That's what **Fig. (5)** results show, where the four fuels worked at the HUCR for each fuel. Increasing CR increased CO concentrations because of increased temperature inside combustion chamber, which lead to increase dissociation of CO_2 molecules to CO. Gasoline concentration remaining higher due to its molecular structure.

2- Equivalence Ratio Effect

CO concentrations didn't appear in lean side as **figures 1 to 3** represent, due to oxygen abundance needed for reactions, these concentrations appeared obviously at equivalence ratios higher than (Ø=0.96), the resulted concentrations in this side which were less than 0.15 volume are considered acceptable in the European and American standards in year 2003 for accepted pollutants levels (Faiz, A., Weaver, C. S. and Walsh, M. P., 2006). CO concentrations increased with air fuel mixture enriched with fuel, because of the lack in oxygen needed for reactions, dissociation increased as mentioned early.

CO concentrations for gasoline higher than that resulted by using LPG or NG, this is reasonable because of reduction of carbon atoms for hydrogen atoms percentage for the two gases. The minimum value for CO concentrations were when using NG, because of two reasons: heating value reduction for NG compared with LPG and gasoline, and the low flame propagation speed for it compared with the other used fuels, these two factors reduced the maximum temperature inside the combustion chamber. Hydrogen engine emitted extremely low levels of CO resulted from burning some lubrication oil particles, so for highly maintained engine it is supposed there will be no CO concentrations.

3- Spark Timing Effect

There was no effect observed for spark timing on CO concentrations, where retarding spark timing is used to reduce emissions by reducing the time needed for these emissions to be formed, and there were no influence for time on CO formation, because of this there was no effect for this factor on this pollutant concentrations.

4- Engine Speed Effect

Fig. (6) represents CO concentrations at low engine speed (1000rpm), and **fig. (7)** represents CO concentrations at high engine speed (2500 rpm). CO concentrations increased with increasing engine speed for equivalence ratios equal or more than Ø=1.0, because of oxygen lack, increasing chemical dissociation referred to increased cycle maximum temperatures, and reduction of required time to finish reaction operation.

The above mentioned resultes were compared with some similer former publised papers like refrences 1, 2, 5 and 8. The reported results didn't vary a lot from present work, excpt in the polutant concentrations and the equivalnc ratio range used; this is natural because they used different engines.

CONCLUSSIONS

1. CO concentrations increased by increasing CR. The concentrations resulted from gasoline was higher than that resulted from LPG or NG, when the engine was run at fixed CR=8:1, or when it was run at HUCR for each fuel.
2. Hydrogen emitted extremely low CO concentrations related to lubrication oil burning inside combustion chamber.
3. CO concentrations were very low when the engine was run at lean equivalence ratio less than Ø=0.96, for all the fuels used in the tests.
4. CO concentrations started to increase after Ø=0.96, and reached high concentrations at rich equivalence ratios.
5. CO concentrations didn't affect by equivalence ratio with hydrogen fuel, because the resulted concentrations were not from the fuel but from the engine oil.
6. Increasing engine speed increase CO concentrations in exhaust gas.
7. Spark timing has no effect on CO concentrations.

REFERANCES

Al Baghdadi M S A, 2006, A simulation model for a single cylinder four-stroke spark ignition engine fueled with alternative fuels, Turkish J. Eng. Env. Sci., Vol.30, p: 331 – 350.

Awidat A S and Chaichan M T, 2002, Investigation study of polluted spark ignition engine using LPG, Journal of Sabha University, vol.1, p: 106-125.

Bakar R A and Ismail A R, 2009, Green engines development using compressed natural gas as an alternative fuel: a review, American journal of environmental science, vol. 5, N0. 3, p: 371-381.

Bose R S C and Muthuraman S, 2007, study of combustion phenomena in petrol engine for proper development of power with less detonation, Research journal of applied science, vol.2 No. 4, p: 349-356.

Chaichan M T, 2006, Study of NOx and CO emissions of SIE fueled with different kinds of hydrocarbon fuels, Association of Arab Universities journal of engineering science, vol.13, No. 2, p: 85-105.

Dhaliwal B, 2000, Alterative fuel effects on vehicle emissions and indoor air quality, MSc. Thesis, University of Alberta, Canada.

Heywood J, 1998, Internal combustion Engine Fundamentals, McGraw Hill Inc.

Faiz A, Weaver C S and Walsh M P, 2006, Air pollution from motor vehicles: standards and technologies for controlling emissions. The international bank for reconstruction and development, USA.

Idris S A and Abu Baker R, 2009, An overview of compressed natural gas as an alternative fuel and Malaysian scenario, European journal of scientific research, Vol.34, No.1, pp.6-15.

Iyengar K S, 2007, Development of BS-III CNG Engine for a Light Commercial Vehicle, 2007-26-028 Symposium of Automotive Technology, Jan. 17-20, pp: 484-492.

Geok H H, Mohamad T I, Abdullah S, Ali Y, Shamsudeen A and Adril E, 2009, Experimental investigation of performance and emission of a sequential port injection natural gas engine, European Journal of Scientific Research, Vol.30, No.2, pp.204-214.

Pulkrabek W, 1997, Engineering Fundamentals of the Internal Combustion Engine, Prentice Hall Inc.

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.

Sorge G, 1995, A White Paper on Gas Engine Emissions Technology, Waukesha Engine Division, Dresser Industries Inc., Wisconsin, U.S.A.

Walsh M P, 1997, Air Pollution: Automobile, The Wiley Encyclopedia of Energy and the Environment, Volume 1; Wiley, New York.

Wayne A, 2004, Operation of hydrogen fueled internal combustion engines, MSc. Thesis, Texas Tech. University, USA.

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, Vol. 29, No. 9, p. 2286-2294.

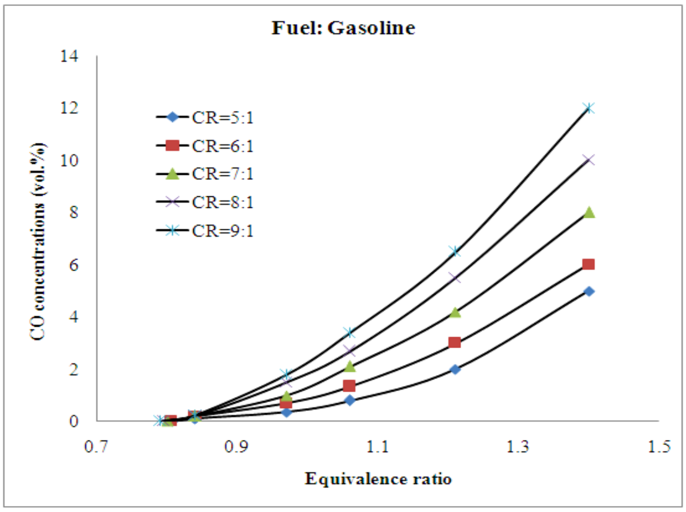

Figure 1, CR influence on CO concentrations for wide range of equivalence ratios for gasoline fuel

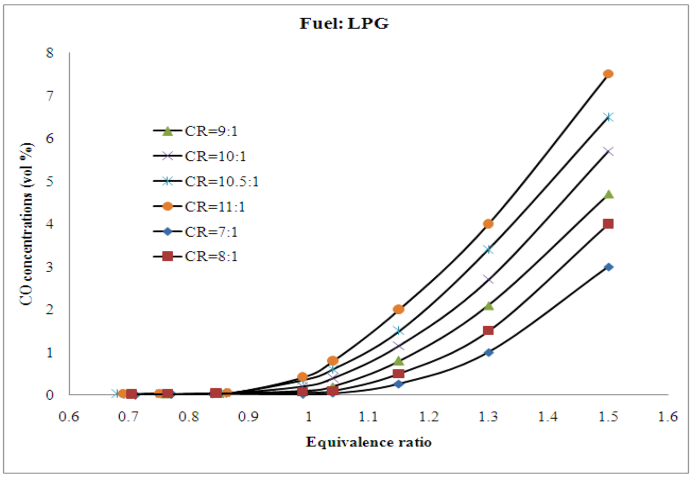

Figure 2, CR influence on CO concentrations for wide range of equivalence ratios for LPG fuel

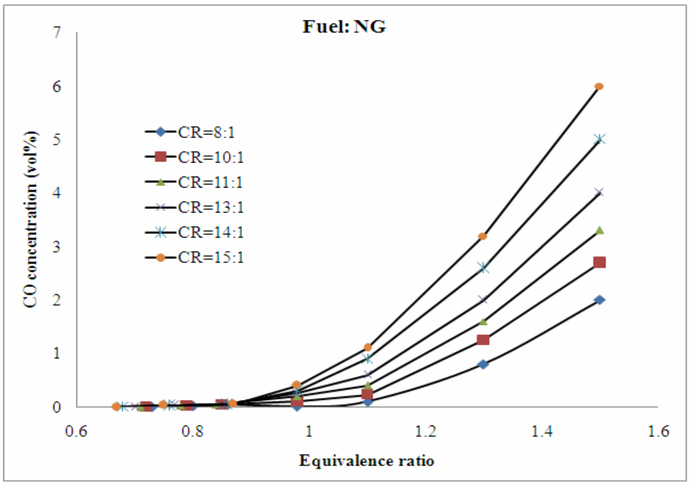

Figure 3, CR influence on CO concentrations for wide range of equivalence ratios for NG fuel

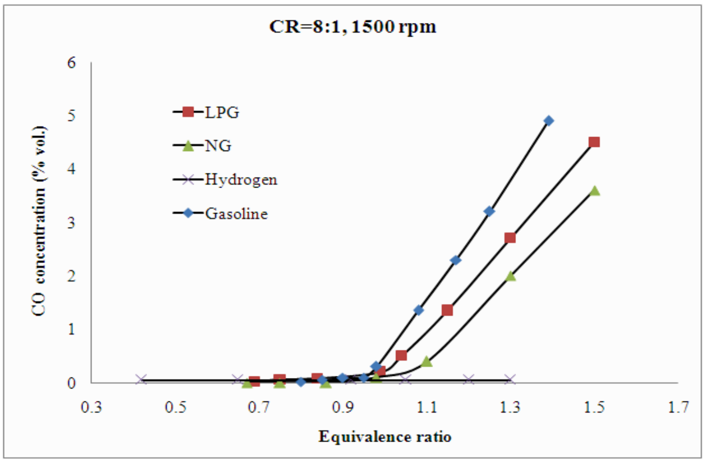

Figure 4, CO concentrations for wide range of equivalence ratios for the four fuels used in research at CR=8:1

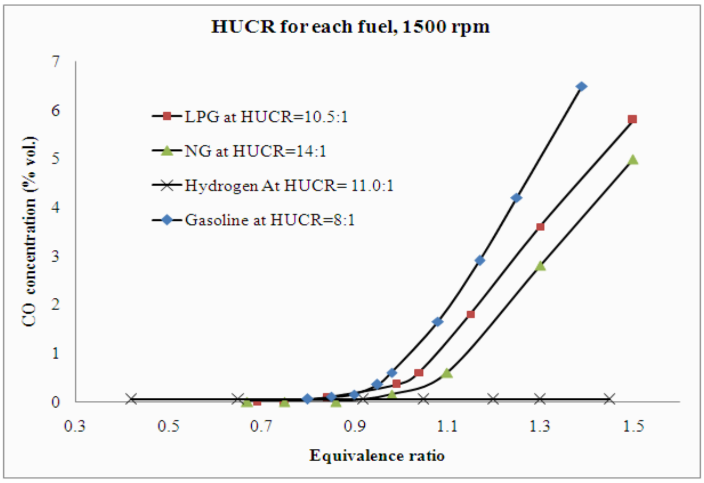

Figure 5, CO concentrations for wide range of equivalence ratios for the four fuels used in research at HUCR for each fuel and 1500 rpm engine speed (medium speed)

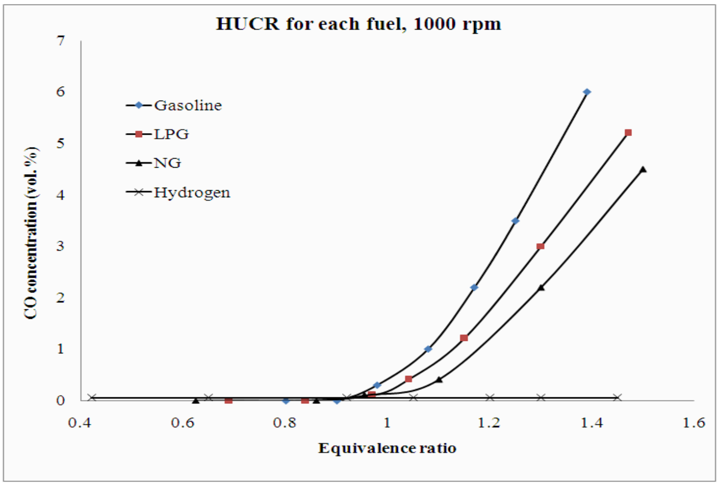

Figure 6, CO concentrations for wide range of equivalence ratios for the four fuels used in research at HUCR for each fuel and 1000 rpm engine speed (low speed)

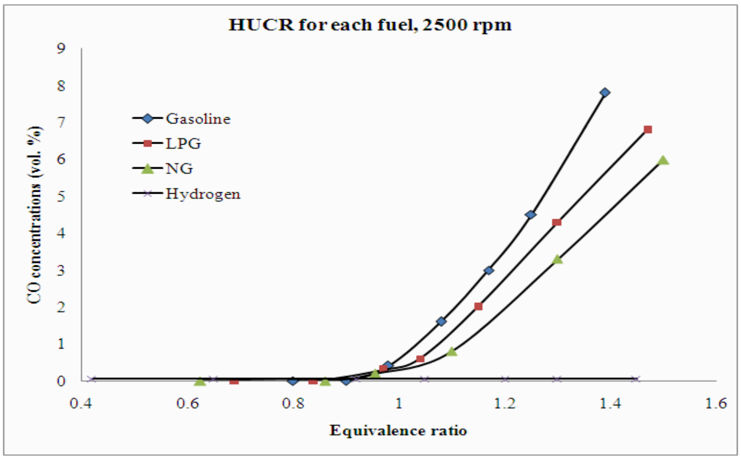

Figure 7, CO concentrations for wide range of equivalence ratios for the four fuels used in research at HUCR for each fuel and 2500 rpm engine speed (high speed)