



# Comparison of Practical Investigations for CO Emissions Emitted From Single Cylinder S. I. Engine Fueled With Different Kinds of Hydrocarbon Fuels and Hydrogen

**Khalil Ibrahim Abaas**

*Department of Machines & Equipments Engineering/ University of Technology*

(Received 18 April 2010; Accepted 23 December 2010)

## Abstract

Liquefied petroleum gas (LPG), Natural gas (NG) and hydrogen were all used to operate spark ignition internal combustion engine Ricardo E6. A comparison of CO emissions emitted from each case, with emissions emitted from engine fueled with gasoline as a fuel is conducted.

The study was accomplished when engine operated at HUCR for gasoline n(8:1), was compared with its operation at HUCR for each fuel. Compression ratio, equivalence ratio and spark timing were studied at constant speed 1500 rpm.

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 showed that CO emissions resulted from gasoline engine were higher than that resulted from using LPG and NG all the time; while hydrogen engine emitted extremely low CO concentrations.

**Keywords:** CO, gasoline, LPG, NG, hydrogen, compression ratio, equivalence ratio, spark timing.

## 1. Introduction

Mainly, there are two 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, 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 742.875 kg/m<sup>3</sup> 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 and Muthuraman, 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 and Chaichan, 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 clear. An octane rating of 100 simply means that a fuel produces knock at the same compression ratio as when the engine is running on iso-octane (Idris and Abu Baker, 2009). Regardless of the technical problems in defining octane number for gaseous fuels, it is clear 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, 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 in USA and Europe. With the enforcement of super-ultra low emissions auto manufactures will be forced to reduce vehicle emissions even further (Wayne, 2004 and Rahman 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, 2006).

Spark-ignition (SI) engines are a major source of air pollution. The SI engine exhaust gases contain oxides of nitrogen (ie, NO<sub>x</sub>, including nitric oxide NO, and small amounts of nitrogen dioxide NO<sub>2</sub>), carbon monoxide (CO), organic compounds which are unburned hydrocarbons

(HC), carbon dioxide (CO<sub>2</sub>) and oxides of sulfur (SO<sub>x</sub>) (Heywood, 1998 and Pulkrabek, 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<sub>3</sub> in the upper atmosphere, producing carbon dioxide (CO<sub>2</sub>), which depletes the ozone layer (Sorge, 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, 2007).

## 2. Experimental Setup

The investigation were carried out by 4 stroke single cylinder, with variable compression ratio, spark timing, a/f ratio and speed Ricardo E6 (Fig. 1), the engine connected to electrical dynamometer, and lubricated by gear pump operated separately from it, the cooling water circulated by centrifugal pump. Table 1 includes the main engine characteristics.



Fig. 1, Ricardo Engine and Its Accessories Used in This Study.

**Table 1,  
Engine Characteristics.**

Model	Ricardo E6
Type	IDI with the pre-combustion chamber
Number of cylinders	1
Bore × Stroke (mm)	76.2×111.1
Cycle	4-stroke
Compression ratio	From 5 to 22
Maximum power (kW)	9 naturally aspirated
Maximum speed (rpm)	3000
Injection timing	Variable

Gasoline supply system: This system consisted of major tank (6 liter capacity), minor tank (1 liter capacity), and gasoline carburetor. While LPG supply system consisted of: LPG tank, fuel drier, solenoid valve, LPG carburetor, gaseous fuel flow measuring device (orifice plate), damping box.

CNG supply system consisted of: CNG tank, fuel drier, solenoid valve, CNG carburetor,

gaseous fuel flow measuring device (orifice plate), damping box.

Hydrogen supply system: This system consists of hydrogen cylinder, pressure regulator and gaseous fuel flow measuring device (choked nozzles system).

Air flow measurement: Air entering the engine was measured by Alock viscous flow meter connected to flame trap.

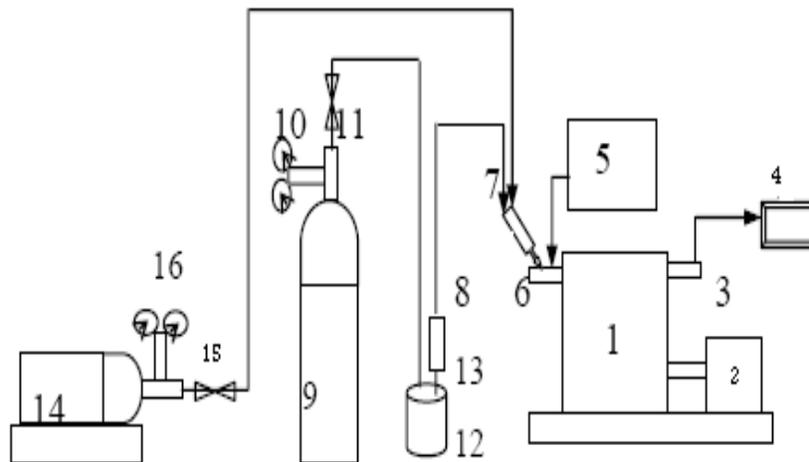
Speed measurement: Engine speed was measured by tachometer.

Power measurement: In addition to the use of dynamometer to measure power; it is used as electric motor also, to rotate the engine in the starting. The dynamometer is used to measure indicated power, brake mean effective pressure and friction lost power.

Exhaust gas temperatures measurement: Exhaust gas temperatures were measured by nickel chrome/ nickel alumel thermocouple, which was calibrated before it was used. Fig. 2 represents a schematic diagram for the test rig and its accessories.

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

- A non – dispersing infrared analyzer for CO.
- A magnetic oxygen analyzer for O<sub>2</sub>.



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

**Fig.2, Schematic Diagram of the Engine Test Rig.**

## 2.1. Test Procedure

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 1500 rpm engine speed were studied.

Experiments were carried out after running the engine for some time until it reached a steady state and oil temperature was at  $60\text{ }^{\circ}\text{C}\pm 5$ , and cooling water temperature was at  $70\text{ }^{\circ}\text{C}\pm 5$ . The engine design and operating parameters varied at the following levels:

1. Type of fuel included gasoline, LPG, NG and hydrogen.
2. The engine load varied from no load to full load.
3. The spark timing varied from 10 to  $45^{\circ}$  BTDC in steps of  $5^{\circ}$  CA.
4. The engine speed varied from 1000 to 2500 rpm.

In the first case, the engine was operated with gasoline, until it reached its steady state. Engine compression ratio varied starting from CR=5:1 to 9:1 in gasoline case. Experiments in LPG case were conducted starting with CR= 7:1. Compression ratio was increased until the engine reached the higher useful compression ratio for LPG which was 10.5:1. In NG case the experiments started with CR=8:1 and ended with CR=15:1. For hydrogen tests it started with CR=8:1 until 11:1.

At each tested compression ratio the engine was run at constant speed 1500 rpm. CO concentrations were measured for wide range of equivalence ratios. At each equivalence ratio spark timing varied from  $20^{\circ}$  to  $45^{\circ}$  BTDC in  $5^{\circ}$  CA each step. After that the engine speed varied to 1000 rpm. The tests were repeated at engine speed 2500 rpm. In each case CO concentrations were measured for wide range of equivalence ratios with changing spark timing as mentioned earlier.

## 3. Results and Discussion

### 3.1. Compression Ratio Effect

Figures 3, 4 and 5 represent the relation between CO concentrations emitted from single cylinder spark ignition engine, for wide range of equivalence ratios 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  $\text{CO}_2$  molecules to CO, by increased burning temperatures. For the lean side the CR effect did not exist, 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.

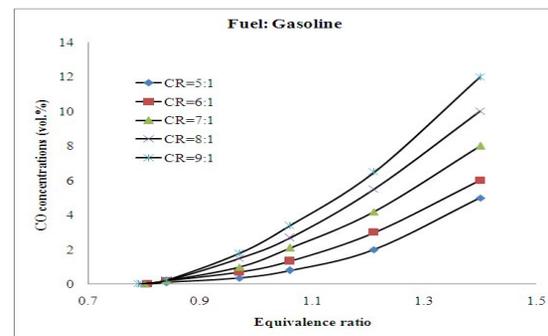


Fig.3. CR influence on CO Concentrations for Wide Range of Equivalence Ratios for Gasoline Fuel.

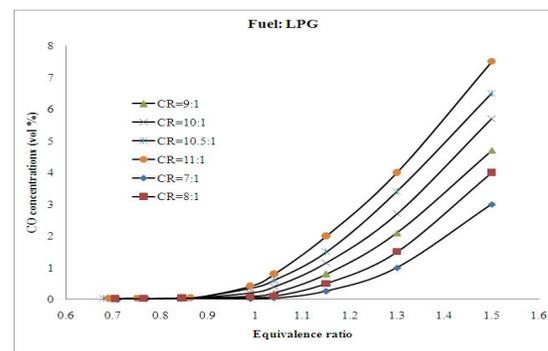


Fig. 4. CR Influence on CO Concentrations for Wide Range of Equivalence Ratios for LPG Fuel.

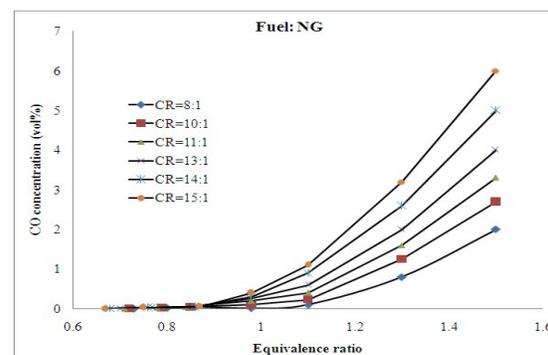
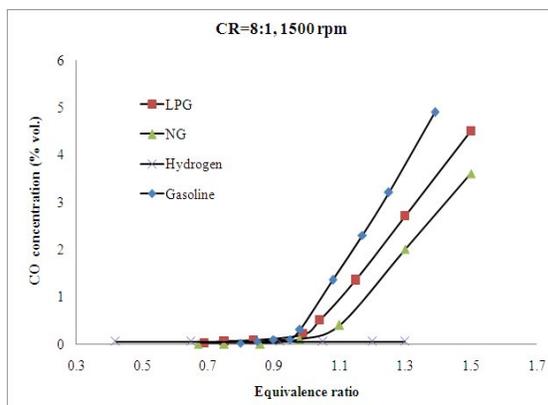
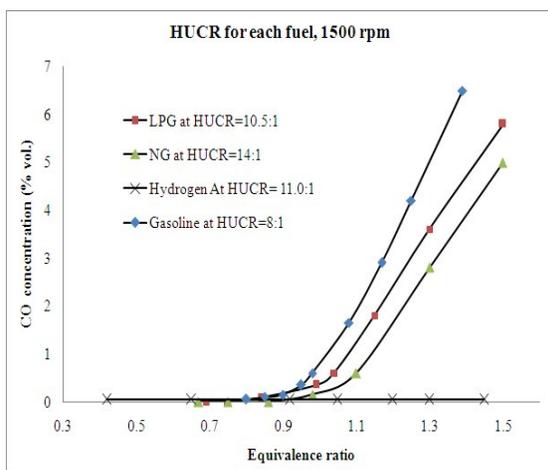


Fig. 5. CR Influence on CO Concentrations for Wide Range of Equivalence Ratios for NG Fuel.

Figure 6 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. 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.



**Fig.6. CO Concentrations for Wide Range of Equivalence Ratios for the Four Fuels Used in Research at CR=8:1.**



**Fig.7. 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).**

Hydrocarbon fuels emitted high CO concentrations with engine exhaust gas. Gasoline

still had the higher concentrations, while hydrogen emitted very low traces. That's what Figure 7 results show, when the four fuels operated at the HUCR for each fuel. Increasing CR increases CO concentrations because of increased temperature inside combustion chamber, which leads to increase dissociation of CO<sub>2</sub> molecules to CO. Emission of CO in gasoline fuel remain higher due to its molecular structure.

### 3.2. Equivalence Ratio Effect

CO concentrations didn't appear in lean side as figures 3 to 5 represent. Due to oxygen abundance needed for reactions, these concentrations appeared obviously at equivalence ratios higher than ( $\phi=0.96$ ). The resulted concentrations in this side which were less than 0.15 by volume are considered acceptable in the European and American standards in 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 of oxygen needed for reactions, dissociation increased as mentioned early.

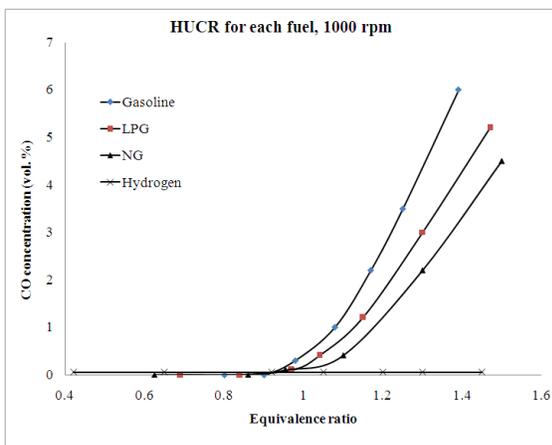
CO concentrations for gasoline is higher than that resulted by using LPG or NG. This is reasonable because of reduction in carbon atoms to hydrogen atoms percentage in these fuels molecular structure. The minimum value for CO concentrations was when using NG. NG owns the highest hydrogen to carbon percentage (4:1), in addition to two important characteristics: heating value reduces 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, and reduced therefore, reducing dissociation from CO<sub>2</sub> to CO. Hydrogen engine emitted extremely low levels of CO resulted from burning some lubrication oil particles, and so for highly maintained engine it is supposed there will be no CO concentrations.

### 3.3. Spark Timing Effect

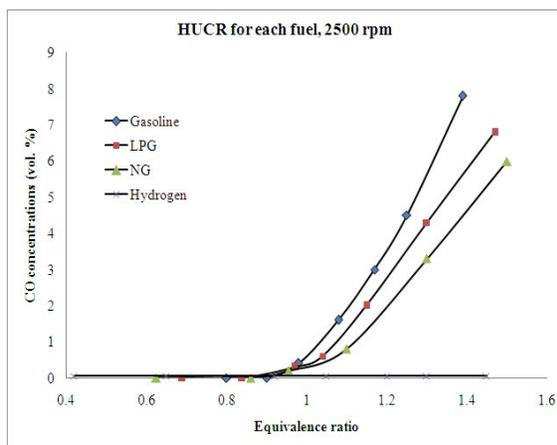
There was no effect observed for spark timing on CO concentrations. Retarding spark timing is used to reduce NO<sub>x</sub> emissions by reducing the time needed for these emissions to be formed. Studying this method clarifies that it has no influence on CO formation. Advancing spark timing has no effect on resultant CO also. From this it can be said that spark timing has no effect on CO concentrations.

### 3.4. Engine Speed Effect

Figure 8 represents CO concentrations at low engine speed (1000rpm), and figure 9 represents CO concentrations at high engine speed (2500 rpm). CO concentrations increased with increasing engine speed about 24.8% for gasoline, 29.28% for LPG and 31% for NG. Increasing engine effects observed for equivalence ratios equal or more than  $\phi=1.0$ . The increments in CO concentrations were due to oxygen lack, increasing chemical dissociation referred to increased cycle maximum temperatures, and reduction of required time to finish oxidation reactions operation.



**Fig.8. 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).**



**Fig. 9. 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).**

### 4. Conclusions

1. CO concentrations increased by increasing CR. The concentrations resulted from gasoline were higher than those resulted from LPG or NG. This is always true when the engine was running at a fixed CR=8:1, or when it was running at HUCR for each fuel.
2. Hydrogen emitted extremely low CO emissions 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  $\phi=0.96$ , for all the fuels used in the tests.
4. CO concentrations started to increase after  $\phi=0.96$ , and reached high concentrations at rich equivalence ratios.
5. CO concentrations didn't affect by equivalence ratio with hydrogen fuel, and the measured concentrations were not from the fuel burning but from burning some engine oil particles.
6. Increasing engine speed increase CO concentrations in exhaust gas.
7. Spark timing has no effect on CO concentrations.

### 5. References

- [1] 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.
- [2] 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, Lybia.
- [3] 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, No. 3, p: 371-381.
- [4] 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.
- [5] 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.

- [6] Dhaliwal B, 2000, Alternative fuel effects on vehicle emissions and indoor air quality, M.Sc. Thesis, University of Alberta, Canada.
- [7] Heywood J, 1998, Internal combustion Engine Fundamentals, McGraw Hill Inc.
- [8] 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.
- [9] 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.
- [10] 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.
- [11] 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.
- [12] Pulkrabek W, 1997, Engineering Fundamentals of the Internal Combustion Engine, Prentice Hall Inc.
- [13] 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.
- [14] Sorge G, 1995, A White Paper on Gas Engine Emissions Technology, Waukesha Engine Division, Dresser Industries Inc., Wisconsin, U.S.A.
- [15] Walsh M P, 1997, Air Pollution: Automobile, The Wiley Encyclopedia of Energy and the Environment, Volume 1; Wiley, New York.
- [16] Wayne A, 2004, Operation of hydrogen fueled internal combustion engines, M.Sc. Thesis, Texas Tech. University, USA.
- [17] 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.

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

خليل ابراهيم عباس

قسم هندسة المكنان والمعدات / الجامعة التكنولوجية

### الخلاصة

استخدم الغاز النفطي المسال، الغاز الطبيعي وبلهوجين لتشغيل محرك احتراق داخلي يعمل بالشرارة ذوع 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 ومقارنتها بعمله بنسبة الانضغاط النافعة العليا الكلاسيكية ود على حدة، ودراسة تأثير نسبة الانضغاط والنسبة المكافئة وتوقيت الشرر والسرعة على تراكيز الملوث الناتجة. أظهرت النتائج أن تراكيز CO قليلة في الجاذب الضعيف وتزداد قليلاً بالنسبة المكافئة، وتزداد في الجاذب القوي، وتزداد بشكل كبير بالنسبة المكافئة، وأظهرت النتائج أن ملوثات CO الناتجة باستخدام الجازولين أكبر من تلك الناتجة عن استخدام LPG و NG إلى الدوام، بينما لا يزداد من استخدام الهيدروجين كوقود تراكيز CO قليلة جداً.