Experimental Investigations on the Combustion of Gaseous Fuels

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Abstract: The basic objective of the present work is to evaluate the potential of using a clean burning fuel such as CNG in the gasoline internal combustion engine. A comparison is carried out between the exhaust emissions for gasoline and CNG fuels. At idling condition, exhaust emissions concentrations are measured at different engine speeds (500-1800 rpm) and fuel-air equivalence ratios. At different speeds, the reduction of CO and CO₂ for CNG than that gasoline by about 5% and 17%, respectively and nitrogen oxide emission increases for CNG fuel than that for gasoline by about 2.5%. At different equivalence ratios, the reduction of CO and CO₂ for CNG than that gasoline by about 40% and 25%, respectively and nitrogen oxide emission increases for CNG fuel than that for gasoline by about 4%.

Key words: CNG, Carbon monoxide, Carbon dioxide, Nitrogen oxide

Abbreviations

S.I.E Spark Ignition Engine.
CNG Compressed Natural Gas.
CO Carbon Monoxide
CO₂ Carbon Dioxide.
NO Nitrogen Oxide

INTRODUCTION

Considering energy crises and pollution problems today, investigations have been concentrated on decreasing Fossil fuel consumption by using alternative fuels and on lowering the concentration of toxic components in combustion products combined with improvements in efficiency[1]. Among the alternative fuels such as CNG, LPG and Hydrogen have shown excellent performance over other fuels[1]. Natural gas is being regarded as one of the most promising alternative fuels for combustion engines. Natural gas has an effective potential as an engine fuel. Hydrogen is a sustainable fuel that can replace fossil fuels. Hydrogen can improve the performance of automobiles and aircraft while enhancing environmental quality and energy security[2,3].

Experimental Set up: The experimental work has been performed on a four cylinder four stroke S.I.E fueled with gasoline and CNG. The experimental set up used in the present work is designed to study exhaust emissions concentrations using alternative fuels such as CNG. Facilities for engine operation using different fuels such as gasoline and CNG have been designed and attached to the engine. Instrumentation for measuring fuel consumption, intake air flow rate, engine speed and emission analysis are included in the test rig. The specifications of the engine are listed in Table 1. The photographic view of the experimental test rig is illustrated in Fig.1.

Experimental procedure: The engine was prepared to run as a petrol engine during all tests. An additional fuel system for CNG admission, calibration and induction to the engine was designed and installed. Each of the two fuel systems is designed to facilitate safe and accurate metering of the fuel flow rate.

The gasoline fuel consumption is measured by Burette method. In this method, gasoline fuel system design consists of main gasoline fuel tank, gasoline fuel metering system (graduated one liter glass jar) and three control valves to deliver the fuel from the tank to the engine. The gasoline fuel system utilizes the gravity effect to feed the carburetor with gasoline.

The gasoline fuel consumption flow rate is measured directly by using the graduated glass jar (1000 ml capacity and 10 ml division). A digital stopwatch of 0.1 second accuracy is used to measure the time required by the engine to consume a specific volume of gasoline from the graduated glass jar.
CNG was delivered to the laboratory in a network natural gas pipeline which is built by Egypt Gas Company. The conversion kit of petrol engine to run with CNG as a fuel is achieved by installing a conversion kit that consists of a pressure regulator (two regulators, the former with range (0.29 - 1.2 bar), the latter with range (130 – 950 mbar) with flow rate 100 SCMH), gas controlling devices such as manual valves, gas flow meter and hoses. The feeding CNG system to the engine is just before the gasoline carburetor air inlet. An IMPCO gas carburetor (mixer) model CA125 is used to feed the engine with CNG fuel. The volumetric flow rate of CNG is measured directly by a digital flow meter model AC-250 with accuracy 0.001 m³. CNG flow meter is made of die cast aluminum with digital reading.

The engine receives air through an air box fitted with an orifice for measuring the air consumption. The air box is a cylindrical tank with dimensions 98.6 cm length and 64 cm diameter. The air flows from the tank to the carburetor through a pipe connected to the air box through a flexible hose of length 1.2 to 1.5 meter and about 0.076 m in internal diameter to eliminate the effect of engine vibrations when running. A standard sharp edged orifice is fitted to the air box to enable measuring the intake air consumed by the engine. The diameter of the orifice hole was calculated to be 10 mm.

The intake air flow rate is measured by measuring the pressure difference between the two sides of the orifice (inside and outside the air box). A plain U tube manometer is filled with colored water with one limb connected by rubber tubing to the box and the other opening to the atmosphere. The pressure difference may be read directly in mm of water with an accurate dividing scale reading.

A digital photo tachometer model (BRI 5045) is used for engine speed measurement. The tachometer has been fixed on the engine test rig close to the flywheel. A strip of reflective tape is applied to the engine flywheel. This digital photo tachometer has a measurement range up to 100000 rpm with a resolution of 0.1 rpm (0.5 to 999.9 rpm) and one rpm (over 1000 rpm).

The exhaust gas analyzer is used to measure exhaust emissions from the engine during experimental tests was made of brand Madur type GA-21plus-flue gas analyzer as in Fig. 1. The main advantage of this analyzer is that the fuel type is programmable to automatically calculate the air to fuel ratio from the exhaust gases analysis. Fuel type can be chosen to be gasoline or CNG. The exhaust gas analyzer measures some gases such as CO, NO and CO₂ concentrations at every idling engine speed and equivalence ratio.

RESULTS AND DISCUSSION

The main purpose of this work was to evaluate the following:
1. The exhaust emissions concentrations of species CO, CO₂ and NO for S.I.E fueled with gasoline and CNG at different idling engine speeds.
2. The exhaust emissions concentrations of CO, CO₂ and NO for S.I.E fueled with gasoline and CNG for no load at different equivalence ratios.

Effect of Engine Speed on Emission Levels for Gasoline and CNG: When an engine is fueled with CNG, it produces much less CO and CO₂ emissions than gasoline because CNG contains less carbon to hydrogen ratio and improved mixing than gasoline. Actually, gasoline engine produces CO concentrations less than the recorded value at low engine speeds. The reduction of exhaust CO concentrations for gasoline and CNG fuels is at engine idling and starting. If the engine speed increased, the spark timing would have to be advanced and the equivalence ratio is increased. Increasing equivalence ratio leads to lack of oxygen which results in an increase of the degree of dissociation and hence temperature increase, so, CO emission concentration increases.

In Fig.2, the experimental results show that the exhaust emission of CO was less when the engine fuelled with CNG than that for gasoline. CO emission concentration increases for the two fuels at all the idling speed range.

The CO₂ concentrations produced by the engine are lowered when it was operated with CNG fuel than that for gasoline.

Emissions Concentrations of carbon dioxide decrease when the engine speed increases. If the cylinder temperature and the cylinder pressure increase, the concentrations of carbon dioxide decrease as the dissociation increases with temperature.

In Fig. 3, the experimental work depicts the emissions concentrations of CO₂ with speed which are very small as it depends mainly on the fuel - air equivalence ratio. CO₂ concentrations decrease when the engine fuelled with CNG than that for gasoline fuel case. CO₂ concentration decreases for the two fuels at all the range of idling speed.

In Fig. 4, the concentration of NO in the exhaust gases was found to increase when using CNG as a fuel than gasoline fuel case. The nitrogen content in CNG fuel leads to increase in exhaust temperature because more heat is liberated inside the cylinder per unit time and cooling becomes less efficient. When the idling engine speed increases, dissociation of N₂ concentration increases due to the increase in the exhaust gas temperature.
Table 1: Test Engine Specifications

<table>
<thead>
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<th>Engine parameters</th>
<th>Specifications</th>
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<td>Governing speed</td>
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<tr>
<td>Rated power (HP)</td>
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Fig. 1: Photographic view of The Experimental Test Rig

Fig. 2: Variation of CO Concentration with idling engine speeds of S.I.E fueled with gasoline and CNG.

**Effect of Equivalence ratio on Emission Levels for Gasoline and CNG:** As the mixture gets richer, there is a lack of oxygen, so, the emission concentration of CO increases due to incomplete combustion of carbon. As the temperature increases, CO₂ molecules dissociate to form CO molecules and hence the concentration of CO increases as the fuel - air equivalence ratio increases.

In Fig.5, the concentration of CO in the exhaust gases was found to be decreased when using CNG as a fuel than the gasoline fuel case. The hydrogen to carbon ratio in CNG is small, So, CO concentration for CNG increases as the fuel - air mixture becomes richer.

In Fig.6, the concentration of CO₂ in the exhaust gases was found to be decreased when using CNG as a fuel than that for gasoline fuel because hydrogen to carbon ratio is small. CO₂ emission concentration for CNG and gasoline fuels increases as the fuel - air mixture increases from lean to stoichiometric. The CO₂ concentration increases when the fuel – air mixture moves from lean to stoichiometric. From lean to stoichiometric, the temperature increases, so, the emission concentration of carbon dioxide increases.
Fig. 3: Variation of CO₂ Concentration with idling engine speeds of S.I.E fueled with gasoline and CNG

Fig. 4: Variation of NO Concentration with idling engine speeds of S.I.E fueled with gasoline and CNG

Fig. 5: Variation of CO Concentration with equivalence ratio of S.I.E fueled with gasoline and CNG at no load.
Fig. 6: Variation of CO$_2$ Concentration with equivalence ratio of S.I.E. fueled with gasoline and CNG at no load.

Fig. 7: Variation of NO Concentration with equivalence ratio of S.I.E. fueled with gasoline and CNG at no load.

In Fig. 7, the concentration of NO in the exhaust gases was found to be increased when using CNG as a fuel than the gasoline because of its content of nitrogen. Nitrogen oxide concentration increases from lean region to stoichiometric region because the temperature increases and the dissociation of N$_2$ increases. Increase of exhaust temperature is due to increase in equivalence ratio from lean to stoichiometric, so, NO mole fraction increases for CNG and gasoline at all the idling speed range.

The Concentrations of exhaust emissions such as CO, CO$_2$ and NO in experimental work show trends that agree with results reported by other workers and published results[4,5,6,7,8,9].

Conclusion: Experiments were conducted to study the exhaust emissions concentrations (CO, CO$_2$ and NO) at no load. Based on the experimental study the following conclusions are drawn:

1- At no load, CO$_2$ and CO concentrations decrease when the engine fuelled with CNG than that for gasoline fuel case at all the idling speed range, the emissions concentrations of CO$_2$ with engine speed which are very small as it depends mainly on the fuel - air equivalence ratio. The reduction of CO and CO$_2$ for CNG than that gasoline by about 5% and 17%, respectively as in Fig.2 and Fig.3.

2- The concentration of NO in the exhaust gases was found to increase when using CNG as a fuel than gasoline fuel case at all the idling speed range (500-2000 rpm). Nitrogen oxide emission increases for CNG fuel than that for gasoline by about 2.5% as in Fig.4.

3- The concentrations of CO and CO$_2$ in the exhaust gases was found to be decreased when using CNG as a fuel than the gasoline fuel case for no load condition at different equivalence ratios. The reduction of CO and CO$_2$ for CNG than that gasoline by about 40% and 25%, respectively as in Fig.5 and Fig.6.
4- The concentration of NO in the exhaust gases was found to be increased when using CNG as a fuel than the gasoline for no load condition at different equivalence ratios. Nitrogen oxide emission increases for CNG fuel than that for gasoline by about 4% as in Fig.7.

REFERENCES

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