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Investigating the Combustion of Diesel Engines Fueled with Hydrogen-Methane Mixture

Reza Nazari, Mohammad Sarabian
rnazari@shirazu.ac.ir

Abstract— Diesel engines are widely used to protect environment due to their high thermal efficiency and low Carbon Dioxide emission, as well as strict principles of Nitrogen Dioxide and particulate matter. Meanwhile, fuel mixtures significantly influence engine exhaust gas pollutants. Considering the appropriate characteristics of Hydrogen as a fuel source, the present study has attempted to investigate the combustion of diesel engines using Methane-Hydrogen mixture as gas fuel. In this regards, all speeds in full load and all loads of engine in two most common speeds have been tested to obtain a complete pattern of Hydrogen effect. The research findings have revealed that the power, torque and volumetric efficiency of the engine are decreased with the increase of Hydrogen fraction in Hythane mixture. Also, the increase of Hydrogen fraction in Hythane mixture cause CO and HC decrease but NOx increases.

Key words— Natural fuel, Methane, Hydrogen, Combustion, Diesel engines.

INTRODUCTION

Supplying and producing energy has been always a main concern for human being. During the recent years, the issue of fuel consumption and pollutants reduction has found high importance. On one hand, fossil fuels will be ended one day and on the other hand, using Gasoline is followed by high pollution. Therefore, the fossil fuel sources limitation and environmental issues have encouraged researchers to more optimal solutions of energy and other resources of energy production. With the aim of finding alternative energy source for Gasoline in combustion engines, some researchers have been done to optimize fossil fuels in addition to using technologies such as fuel power and hybrid engines. For many years, natural gases have been used as an appropriate fuel to be used instead of Gasoline and other conventional fuels due to their less pollutant effect and underground abundance. Engines using the natural gases as fuel produce less CO pollutants, HC and Nox (Jafar Madar and Zehni, 2012). Methane is the main constitute of the natural gases (80% to 90% of total volume) which is the lightest and simplest Hydrocarbon in the nature (Mansouri and Jafar Madar, 2013). Hydrogen by itself is an appropriate source of energy but it has not ever been used as a pure fuel due to some reasons including production problem and transportation.

Diesel engines are the engines initiating to ignition and burn fuel without the need of electrical spark. Compared to Gasoline engines, diesel engines have higher thermal efficiency and persistence. Soot and NOx are the main pollutants while HC and CO emitted from these engines are very little and ignorable. The innovation of internal combustion engines caused a fundamental change in transportation in 19th century and meanwhile, diesel engines had and have a special place. In diesel engines, fuel is ignited through spontaneous combustion phenomenon without the need of spark. Therefore, many studies have investigated the characteristics of the fuel required by these systems. Currently, only Hydrocarbon fuels produced from crude oil are used as diesel fuel. Except than conventional Hydrocarbon fuels, other fuels produced from Methane or coal drew the attention of many researchers from the 1920s.

Diesel engines are considered as a basic section to supply deriving force of agriculture and industry. System simplicity, positive economic aspects, high credibility, and significant lifetime can be mentioned as the advantages of these engines. Diesel engines are regarded as the most important fuel consumers as well as the pollutant factors. It is highly attempted to find and use alternative fuels due to fossil fuel limitation and environmental pollution problems. From an ideal view, appropriate fuel alternative should guarantee the maintenance of diesel engines` advantages (Santos et al., 2010).

METHODOLOGY

The applied tests had been considered for three types of fuels including pure Methane, the mixture of Methane and 15% Hydrogen and the mixture of Methane and 30% Hydrogen (volume percent). A 280 L chamber with a maximum pressure of 150 bar was used to provided the mixture using thermodynamic calculations of full gas and Dalton`s pattern of gases mixture. Partial pressure of each component for the mixture of 15% Hydrogen and 30% Hydrogen was as follow:

The tests were conducted in tow states of partial load and full load. In full load state, data was acquired for 2000 to 6000 rpm with 500 rpm intervals. Using the software of engine regulation and monitoring, combustion time and the ratio of additional air (λ) in programmable engine monitoring system was regulated to obtain the maximum average internal effective pressure. After regulating the average internal effective pressure, data recording including recording the pressure within cylinder, power, torque, fuel consumption, pollutants, and temperature of different parts was done. Data acquisition in each round was recorded in 100 degree cycle and its average was recorded. Partial load state was done only for two speeds of 200 rpm and 3000 rpm in which after regulating engine`s speed, data acquisition from little partial loads such as 2 bars to full load with 1bar interval was done like full load state in 100 degrees cycle and then the data was recorded.

DISCUSSION AND RESULTS

The results of full load test

With regard to figure 1, it can be observed that the more the percentage of Hydrogen in the mixture is increased, the more torques and engine`s power will be decreased. This phenomenon can be justified in this way that gas fuels usually are replaced with a part of air entering into the cylinder and decreases volumetric efficiency due to their weak density and gas form. The presence of Hydrogen in the natural gas fuel increases the effect of such phenomenon and decreases engine`s volumetric efficiency and subsequently, torque. Another factor decreasing the power and torque of engine for full load due to adding Hydrogen is the less thermal value of Hydrogen in volume unit.

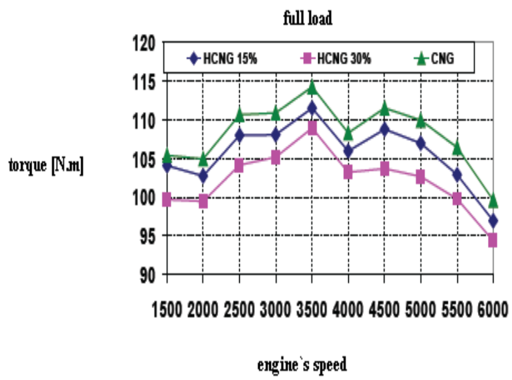

Figure 1- the Torque Changes for Three Consumed Fuels

As the research findings indicate, for different speeds, adding Hydrogen leads to an average decrease of power and torque up to 30% and 6/5%, respectively; while the mixture of Methane and 15% Hydrogen decreases power and torque up to 4/2% averagely. Considering figurer 2, adding Hydrogen to Methane decreases special fuel consumption of engine in full load. The mean of fuel consumption amount in different speeds showed a decrease of 5/3% for the mixture with 15% Hydrogen and 8/6% for the mixture with 30% Hydrogen. It is due to higher energy of Hydrogen in mass unit relative to the open compressive natural gas. On one hand, the combustion speed of Hydrogen is more than Methane leading to the increase of thermal efficiency of engine.

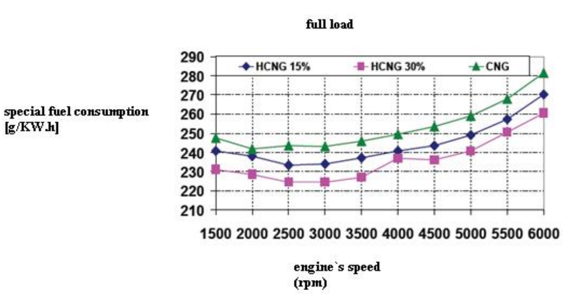

Figure 2- the Special Fuel Consumption and the Effect of Adding Hydrogen

Thermal efficiency has a reverse relation with special fuel consumption; i.e. the more the thermal efficiency is, the special fuel consumption will be decreased. It should be noted that the more the speed of engine is, the more the fuel consumption will be increased since the friction power of engine is relatively increased leading to the increase of fuel consumption. Increasing the friction power causes thermal efficiency drop because more combustion energy should be spent to compensate the friction power of engine. Figure 3 shows the thermal efficiency based on the speed of engine and the effect of adding Hydrogen.

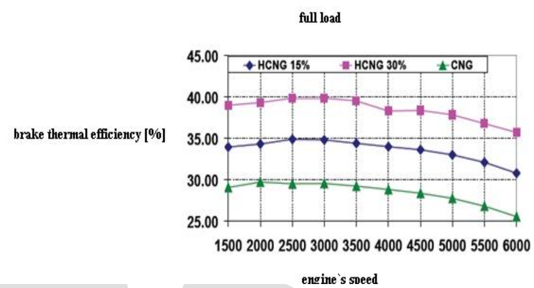

Figure 3- the Thermal Efficiency based on the Speed of Engine and the Effect of Adding Hydrogen

As shown in figure 4, it is observed that adding Hydrogen to the natural gas in full load decreases the fraction of HCs significantly. It can be due to the following causes:

• Increasing the temperature of gases emitted from combustion and the Oxygen of emitted gases leading to the emitted gases reaction and oxidation of these Hydrocarbons in warm temperatures.

• Increasing the temperature of combustion chamber leading to postponing flame off as reaching to cylinder wall.

The obtained test results indicate that the temperature of gases emitted from cylinder when using Hythane is more than the state in which pure Methane gas has been used. Of course, the increase of adding Hydrogen to the emitted gases, when the mixture of Methane and 30% Hydrogen is used, is more than the state in which the mixture of Methane and 15% Hydrogen has been used.

Another point of full load testing is that Hydrocarbons fraction is decreased by increasing the speed of engine because increasing the speed of engine decrease the opportunity of heat transfer from engine; therefore, the temperature of combustion chamber wall is increased leading to the decrease of the thickness outage layer which is followed by full burn of Hydrocarbons. NO is increased by adding Hydrogen to the natural gas (figure 4). The temperature and frequency of Oxygen are the main factors in these pollutants production.

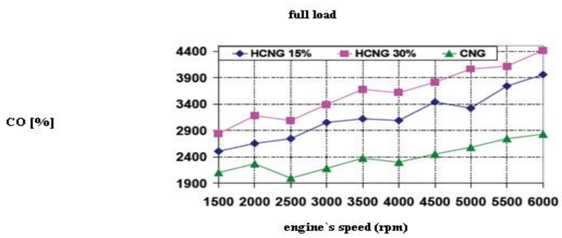

Figure 4- the Changes of NOs Pollutants in Full Load State from Different Fuels

The results of full load test

To achieve the full pattern of engines` performance and pollutants for different fuels, partial load tests were done in 2000 rpm and 3000 rpm. These two specific speeds were selected because they are common speeds in urban cycle, specifically. When an engine works in partial loads state, gas valve is not open completely and makes limitation in air path leading to the decrease of pressure and fluid of fuel and subsequently, the decrease of power. Closing gas valve in partial load leads to the increase of pumping drop which causes to decrease thermal efficiency and increase of special fuel consumption of engine. This fact has been shown in figures 5 to 7 depicting that special fuel consumption and thermal efficiency in 2000 rpm and different pressures are decreased up to 33% and increased up to 31%, respectively.

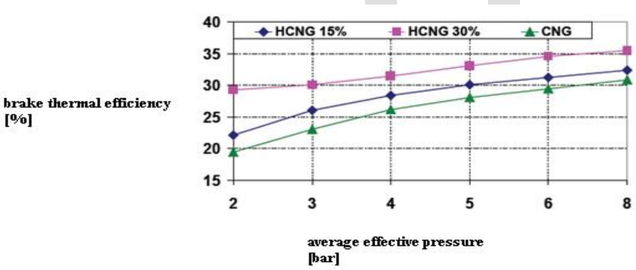

Figure 5- Thermal Efficiency in Partial Load State for Different Effective Average Pressures (BMEP) in 2000 rpm

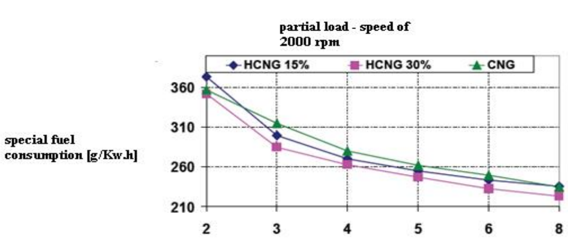

Figure 6- Special Fuel Consumption in Partial Load State for Different Effective Average Pressures (BMEP) in 2000 rpm

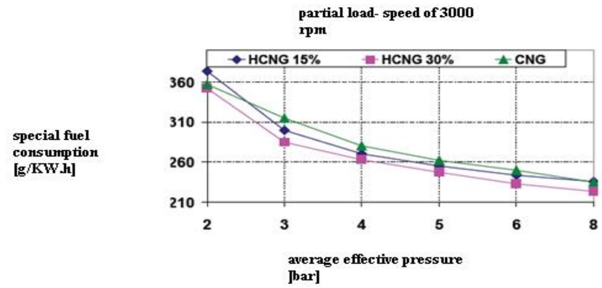

Figure 7- Changes of Special Fuel Consumption relative to the Change of Actual Average Effective Pressure in 3000 rpm for Different Fuels

Moreover, the shown figures indicate that adding Hydrogen in each bar leads to the decrease of special fuel consumption and the increase of thermal efficiency of engine due to the intense combustion speed of Hydrogen. The more the average effective pressure is, the more the thermal efficiency and the less fuel consumption (with a reverse relation with this component) will be. By increasing the average effective pressure, the effect of adding Hydrogen in the thermal efficiency increase is reduced. This phenomenon can be explained in this way that in weak pressures, in which the temperature of combustion chamber is cooler, adding Hydrogen influence the increase of engine`s temperature and heat transfer to a greater extent and subsequently, the thermal efficiency is increased. It should be noted that there are some errors in data acquisition for 2000 rpm and the pressure of 2 bars showing the amount of fuel consumption more than its accurate value.

CONCLUSION

The results obtained from the present study as well as the findings of the previous works revealed that adding Hydrogen and increasing absorption level can enhance engine`s efficiency and its lean-burn behavior. The engine speed slightly influence the behavior of lean-burn but in low loading level, increasing engine speed can enhance the range of lean-burn behavior while it is not observed in higher powers. Adding Hydrogen to the fuel decreases the effect of engine`s speed in the range of lean-burn behavior. The combustion time also influences the range of lean-burn behavior. However, postponed or progressive combustion are not suggested. Furthermore, it has been observed that a limiting amount will be imposed to combustion, as a limit independent from the increase of Hydrogen and engine`s working conditions if the range of lean-burn behavior is not increased (Ma et al., 2008).

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