EXPERIMENTAL INVESTIGATION OF PERFORMANCE AND EMISSION CHARACTERISTICS OF A CI ENGINE ENRICHMENT WITH HHO-CNG MIXTURES

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Abstract

In decade years, due to lack of supply-demand balance of petroleum and exhaust emissions within environmental pollution, researchers give more attention to endeavor of using alternative fuels in internal combustion engines. Alternative fuels have got their own behaviors and fuel properties that they affect the engine when used as a fuel, comes by their advantages and disadvantages. It is very important to know and investigate theirs fuel behavior and effects of combustion and exhaust emissions.

In this study, HHO (Hydroxy-Oxyhydrogen) gas and CNG (Compressed Natural Gas) mixtures used in CI (Compression-Ignition) engine as an addition fuels via intake manifold and engine performance & exhaust emissions were investigated experimentally. In experiments engine run under below three conditions; normal diesel operation, 1,5%CNG+Diesel operation and 15%CNG+2,2%HHO+Diesel operation respectively between 1200-2300 rpm engine speeds. Engine performance and exhaust emission parameters explained and illustrated with graphics as engine torque, specific fuel consumption and engine speed; CO, CO_2, NO, NO_2. The obtained results are presented and compared each other.

It was observed that the enrichment of diesel engine with HHO-CNG mixtures reduced the specific fuel consumption, CO_2 and NOx, however increased the CO. At the middle engine speeds addition of HHO to CNG prevent from the decreasing the torque values. Additionally it was observed that HHO and/or CNG, improves the level of engine noise and down the SO_2 values to zero. As a result; this study contains, how the engine performance and exhaust emissions changes with usage of HHO and CNG enrichment in a CI engine, were investigated in detail.

Keywords: HHO gas, CNG, Engine performance, Exhaust emissions, Diesel engine, Fuel-air enrichment.

Introduction

Nowadays energy plays the most critical role in regeneration and development of the countries. Fossil fuels, alternative fuels and dual-fuel fuels obtain the internal combustion engines (ICE) energy requirements. During the manufacturing an ICE, practitioners overseeing some critical items on fuels like; selection of fuel type and engineering properties of fuel, chooses the optimum fuel consumption and election for the least exhaust emissions. Today's fossil fuel supply-demand imbalances increased the preference capacity of alternative or dual fuel systems. Also the exhaust emissions of these fuels have the quite low emissions from currently usage of fossil fuels, the producers and researchers have increased their studies in this direction. Alternative fuels in ICE can be subsume with natural gas, hydrogen, oxy-hydrogen(HHO), biodiesel, bio-alcohol blends, HCNG, propane and other biomass sources. These fuels have specific and different engineering properties. For that reason some of them can be used directly in ICE, neither some of them cannot be used. Knowledge of chemical and thermodynamical properties of these fuels can help that used normal and/or dual fuel engine operations. In previous experiments showed that, especially hydrogen and natural gas blends decreased the exhaust emission parameters and make the engine more environmentally. Also these mixtures of gas fuels affect the engine performance, but this affect will be negligible with addition of hydrogen because of flammability limits and auto-ignition temperature. Hydrogen and natural gas can be diversified with Pure Hydrogen (H_2), Oxy-Hydrogen (HHO), CNG (Compressed Natural Gas) and LNG (Liquid Natural Gas) that used in ICE. Therefore engine specification choosing is an important point (SI or CI) when use these fuels or mixtures. There are several studies about usage of these alternative fuels achieved to literature by the investigators.

In [1, 2, 3, 4, 5] researchers mentioned the important items that natural gas and hydrogen blends physical & chemical properties, the ways of the usage as a fuel, theoretical approach, effect of engine parameters and exhaust emissions, differences between SI and CI engines during usage of these fuels, mixture percentage, effect of engine specification parameters, advantages and challenges of these fuels in ICEs. Summarily, different conditions and different engine parameters, these fuels (single or mixtures) improved the specific fuel consumption, exhaust emissions and engine noise. Studies showed that, engine performance occasionally affect negatively but these degrees can be negligible level next to the other advantages. In [6, 7, 8] authors touched upon the hydrogen and HHO systems which used in ICEs. HHO system is a mixture of hydrogen and oxygen that obtained by water electrolysis, which uses an electric current to dissociate the water molecules. They mentioned how prepared and optimized the electrolysis system and safety, including the HHO gas to the engine intake manifold and mixture with air, modeling and theoretical approach, production details, percentage of usage, effects of engine and emission parameters, advantages and disadvantages and future potential development.

In this experimental investigation, HHO and CNG mixtures used in a CI engine as an addition fuels via intake manifold and engine performance & exhaust emissions were studied. System setup and engine test bench explained detailed. In experiments engine run under below three conditions; normal diesel operation, 1,5%CNG+Diesel operation and 15%CNG+2,2%HHO+Diesel operation respectively between 1200-2300 rpm engine speeds. Engine performance and exhaust emission parameters explained and illustrated with graphics as engine torque, specific fuel consumption and engine speed; CO, CO_2, NO, NO_2. The obtained results are presented and compared each other.

Experimental Setup

A. Engine Specifications and Fuels Properties

In this experimental study; all test were carried out in Automotive Engineering Laboratories, Faculty of Engineering in Çukurova University, TURKEY. CNG, HHO and diesel fuels are used on diesel engine. Engine performance tests were conducted on four cylinders, four-stroke, naturally aspirated, water-cooled direct injection compression ignition engine. Technical specifications of engine were exposed in Table 1. A Netfren mark hydraulic dynamometer was used for loading the test engine and MRU Delta 1600 V gas analyzer was used to measure exhaust gas emissions. Dynamometer and gas analyzer data can be collected via computer programs.

Diesel fuel and gas fuels properties presented in Table2. Properties of CNG with methane and HHO with hydrogen are very similar to each other that gas fuels have been adopted instead of methane and hydrogen.

Table 1. Test engine Specifications

Brand	Mitsubishi Canter
Model	4D34 - In line 4
Type	D.I. diesel with glow plug
Displacement	3567cc
Bore	104mm
Stroke	105mm
Power	89kW @ 3200rpm
Torque	295Nm @ 1800rpm

Table 2. Fuels Properties [9]

Property	No2Diesel	Methane	Hydrogen
Molar Mass (kg/kmol)	≈200	16.04	2.02
Density (kg/m3)	840(L)	0.72(G)	0.082(G)
Stoichiometric air/fuel. weight	14.7	17.2	34.3
Auto-ignition Temperature °C	254-285	595	585
Laminar Flame Speed (cm/s)	128(λ=1.1)	42	230
Lower Heating Value (MJ/kg)	42.61	47.14	120.21
Higher Heating Value (MJ/kg)	45.58	52.23	142.18

B. CNG-HHO System and Measurement Apparatus

In experimental studies, CNG (Compressed Natural Gas) fuel supplied from a cryogenic tank which has capacity of 12.5 m^3 and fixed on 200 bar pressure. A check valve used behind the checkout for hinders the reverse flow through the tank. After check valve, ex-proof pipelines fitting to the 2- stage regulator that brand of

"LOVATO easy fast smart CNG kit reducer". This regulator has high pressure shut-off valve (powered by battery with 12 Volts) and level gauge. System of regulator has 2- stage regulation which throttled in first stage 200 to 12-14 bars and the second stage decreased the 12-14 to 1-0 bar. Additionally regulator consist with high pressure CNG inlet and filter, manifold absolute pressure connection (which added to entrance of intake manifold after air filter by authors), coolant water pipes (rebuilt by authors from engine radiator water), low pressure relief valve and CNG low pressure outlet. Exit form regulators, CNG pass through the needle valve and flow meter.

Basically, HHO system is electrolysis of distilled water with electrolyte to any substance containing free ions that make it electrically conductive. In this experimental study, KOH (potassium hydroxide) is chosen as an electrolyte. System contains double parallel connected dry cells with 14 plate total, water reservoir, bubbler, solenoid relay switch, constant current Pulse Width Monitor (PWM) with liquid crystal display, fittings and electrical wires. HHO generator runs with engine battery (24V), 8-12 amps and 500 hertz frequency. Under these values HHO generator gives 2.5 liter per minute (LPM) HHO and it can be raised with increased the amps. Installed HHO generator gives 7-7.5 LPM oxy-hydrogen when the maximum amps values are used.

In the experiments, several measurement apparatus applied. Needle valves used for controlled the flow, ALICAT flow meters used for measurement of flow mass; ELIMKO PR-100 data logger used for collected the data with main computer. After exist CNG regulator and HHO bubbler, needle valves are added to system to controlled the amount of flow. Additionally these valves assured the gas flow with off situation. After needle valves gas fuels enters the flow meters. ALICAT flow meters specifications can be presented in Table 3. Then mass flow rate of gases measured and streamed to the intake manifold with ex-proof pipes. Gas fuels mixed in the chamber and pass through the engine. By the way, all data can be listed and recording by data logger. All experimental system illustrated detailed in Figure 1.

Table 3. Flow Meters Specifications

PERFORMANCE	ALICAT M SERIES FLOW METER
Accuracy at calibration conditions after tare	± (0.8% of Reading + 0.2% of Full Scale)
High Accuracy at calibration conditions after tare	± (0.4% of Reading + 0.2% of Full Scale)
Repeatability	± 0.2% Full Scale
Typical Response Time	10 ms
Mass Reference Conditions (STP)	25ºC & 14.696 Pisa
Operating Temperature	−10 to +50 ºCelsius

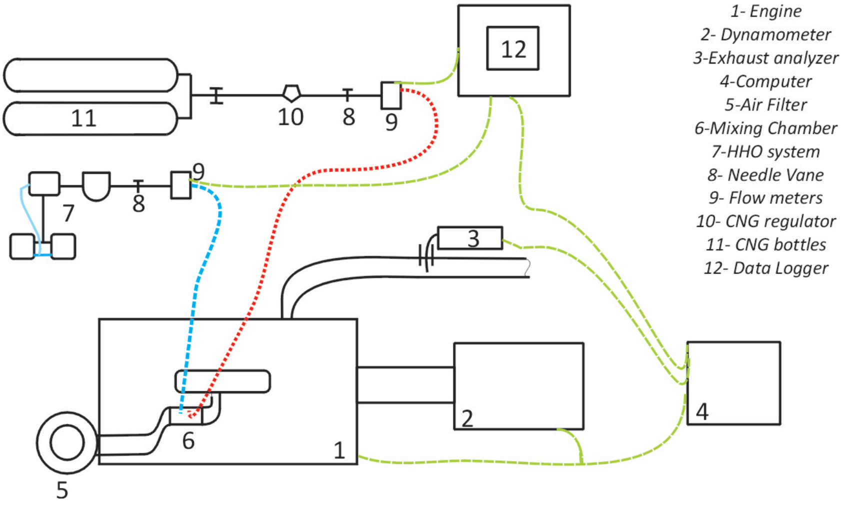

Figure 1. Experimental system and devices

Experimental Results and Discussion

Before the tests, the engine was operated for enough time with diesel fuel to reach the operation temperature. Test fuels were tested from 1200 to 2300 rpm with an interval of 100 rpm at full load condition. In order to optimize of the test results, separately three experiments were performed for each fuel and set case to have an average test results for each fuels were used. Engine run under three different conditions with different fuel and fuel mixtures. First operation on engine is normal diesel operation (ND), second is 1% CNG and diesel mixture (1%CNG+D) and third one is 15% CNG , 2.2% HHO and diesel mixtures (15%CNG+2.2%HHO+D). Engine performance and exhaust emission parameters explained and compared each other. Gas fuels (CNG and HHO) supplied via enrichment of air in intake manifold, liquid fuel (diesel) supplied engine's fuel pump.

A. Engine Performance

Torque versus engine speed and SFC (Specific Fuel Consumption) versus engine speed values illustrated in Figure 2 and Figure 3 respectively. In Figure 2, up to middle engine speeds (≤1550 rpm) additive gas fuels unable to improvement about torque values (Nm); ND has higher torque values from other fuels. Meanwhile enrichment of CNG+HHO followed approximately the same values of ND, but only CNG+D torque values are much less from CNG+HHO. When engine runs under middle engine speeds and starts to lean-burning conditions (1400-1500 rpm), enrichment fuels increases the torque values. Comparison of CNG+D and CNG+HHO+D showed that, addition of HHO gas prevent from the decreasing the torque values.

In Figure 3, specific fuel consumption curves are presented. It is clearly show that, enrichment fuels decreased the need of diesel and obtained less fuel consumption. Additionally HHO+CNG fuel mixtures have better conditions compared to CNG+D and ND. In comparison with diesel fuel consumption, average SFC values decreased with 9.1%, 14.2% with CNG+D and CNG+HHO+D respectively.

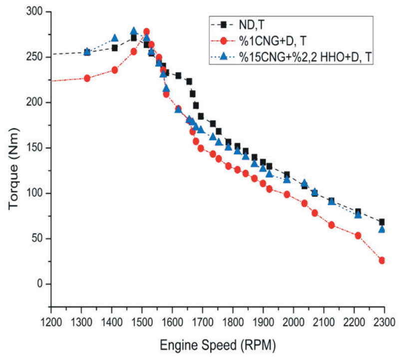

Fig. 2. Torq. vs Eng. Speed of D, CNG+D, CNG+HHO+ D

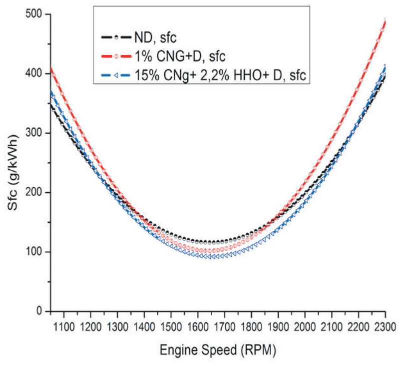

Fig.3. SFC vs Engine Speed of D, CNG+D, CNG+HHO+ D

B. Exhaust Emissions

CO , CO_2 (%) and NO, NO_2 (ppm) versus engine speed values used for determining the exhaust parameters of the experiments. Figure 4 and Figure 5 illustrated the CO (%) and CO_2 (%) values respectively. In Fig.4, enrichment gas fuels increased the CO (%) results compared to diesel. HHO addition is increased the results of CO (%) underestimated. In this study, gas fuel enrichment increased the CO (%) values in all experiments which can be seen in figure. In figure 5, CO_2 (%) values has illustrated versus engine speed. Up to middle engine speeds CNG+D values are more effectively and HHO+CNG values are very similar to normal diesel operation. By the way after middle engine speeds, HHO addition affects improvement on CO_2 (%) results. As an averagely approximation, comparison with diesel, 5.1%, 25.04% reduction can be resulted CNG+D and CNG+HHO+D respectively.

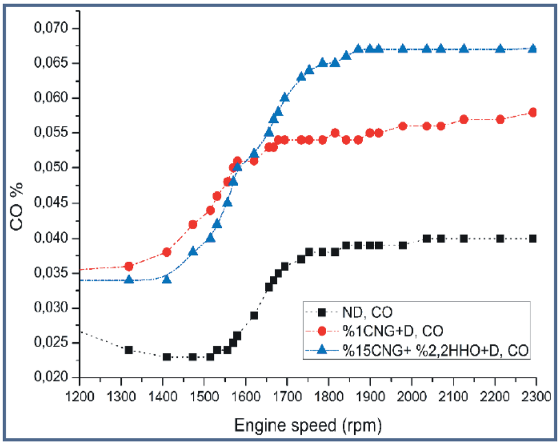

Fig. 4. CO (%) vs E. Speed of D, CNG+D, CNG+HHO+ D

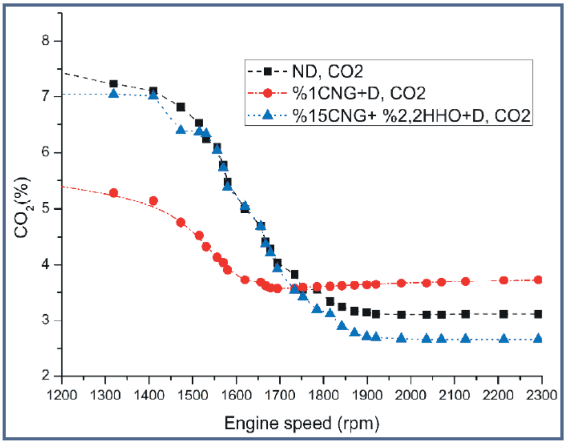

Fig.5. CO_2 (%) vs E. Speed of D, CNG+D, CNG+HHO+ D

NO and NO_2 (ppm) values presented in figure 6 and figure 7 respectively. In Figure 6, it can be seen clearly HHO and CNG addition decreased the NO emissions mono and/or multiple operations. When compared with diesel operation; NO values decreased 11.7% and 38% with CNG+D and CNG+HHO+D, respectively. NO and NO_x values are very important item in diesel engines and they might be reduced as possible which these results satisfied this important phenomena. In Figure 7, NO_2 results are presented according to engine speed. Enrichment of HHO increased the NO_2 values because of contains of hydrogen. CNG+D results are more preferable when comes to NO_2 values. Average No_2 emissions can be summarized with comparison of diesel, CNG+D decreased the value of NO_2 40.4%, where as CNG+HHO+D increased the value of NO_2 21.9%.

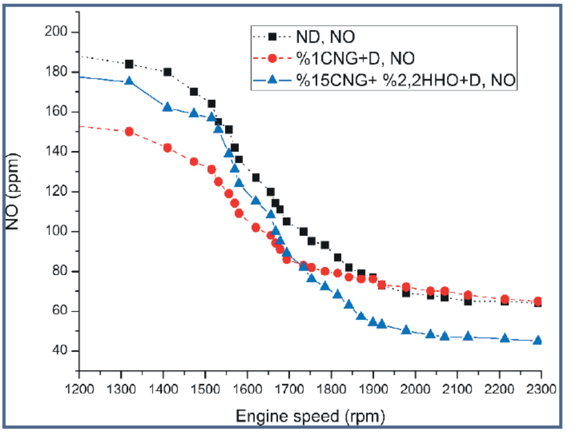

Fig. 6. NO vs E. Speed of D, CNG+D, CNG+HHO+ D

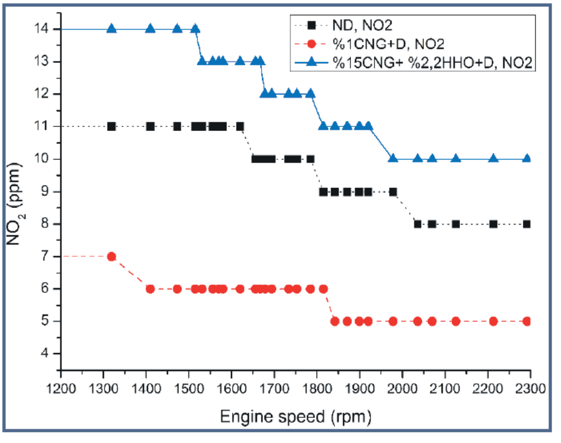

Fig.7. NO_2 vs E. Speed of D, CNG+D, CNG+HHO+ D

Besides, in exhaust emission analyzer results observed that HHO and/or CNG, carried through the SO_2 values to zero. Normal diesel engine operation, there are 10.08 ppm SO_2 emissions occurred. But with the aided of HHO and/or CNG decreased this value to "0(zero)". SO_2 values were not required to illustrate with graphic. Additionally, enrichment gases improve the level of engine noise sensibly.

Conclusions

In this study, HHO (Hydroxy-Oxyhydrogen) gas and CNG (Compressed Natural Gas) mixtures used in CI (Compression-Ignition) engine as an addition fuels via intake manifold and engine performance & exhaust emissions were investigated experimentally. In experiments engine run under below three conditions; normal diesel operation, 1,5%CNG+Diesel operation and 15%CNG+2,2%HHO+Diesel operation respectively between 1200-2300 rpm engine speeds. Engine specification, fuel properties, gas fuels acquisition, measurement devices and enrichment steps were explained detailed. Engine performance and exhaust emission parameters compared, explained and illustrated with graphics as engine torque, specific fuel consumption and engine speed; CO, CO_2, NO, NO_2.

In engine performance results, especially middle engine speeds (1400-1600 rpm's) enrichment gas fuels affect the engine performance positively. In SFC results, CNG and/or HHO decreased the consumption and improvement the fuel economy, that diesel compared the gas fuel additions, average SFC values decreased with 9.1%, 14.2% with CNG+D and CNG+HHO+D respectively.

In exhaust emission results, CO (%) emissions raised with the enrichment of CNG and HHO gases. When comes to CO_2, up to middle engine speeds CNG+D values are more effectively and HHO+CNG values are very similar to normal diesel operation. By the way after middle engine speeds, HHO addition affects improvement on CO_2 (%) results. As an averagely approximation, comparison with diesel, 5.1%, 25.04% reduction can be resulted CNG+D and CNG+HHO+D respectively. In NO and NO_2 (ppm) results, HHO and CNG addition decreased the NO emissions mono and/or multiple operations. When compared with diesel operation; NO values decreased 11.7% and 38% with CNG+D and CNG+HHO+D, respectively. When comes to NO_2, average No_2 emissions can be summarized with comparison of diesel, CNG+D decreased the value of NO_2 40.4%, where as CNG+HHO+D increased the value of NO_2 21.9%.

As a result; this study investigated and explained, how the engine performance and exhaust emissions changes with usage of HHO and CNG enrichment in a CI engine.

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