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How Hythane with 25% Hydrogen can Affect the Combustion in a 6-Cylinder Natural-gas Engine

2010-01-1466
Published
05/05/2010

Mehrzad Kaiadi
Lund Univ.

Per Tunestål and Bengt Johansson
Lund University

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ABSTRACT

Using alternative fuels like Natural Gas (NG) has shown good potentials on heavy duty engines. Heavy duty NG engines can be operated either lean or stoichiometric diluted with EGR. Extending Dilution limit has been identified as a beneficial strategy for increasing efficiency and decreasing emissions. However dilution limit is limited in these types of engines because of the lower burnings rate of NG. One way to extend the dilution limit of a NG engine is to run the engine on Hythane (natural gas + some percentage hydrogen). Previously effects of Hythane with 10% hydrogen by volume in a stoichiometric heavy duty NG engine were studied and no significant changes in terms of efficiency and emissions were observed.

This paper presents results from measurements made on a heavy duty 6-cylinder NG engine. The engine is operated with NG and Hythane with 25% hydrogen by volume and the effects of these fuels on the engine performance are studied. Different experiments were designed and performed to investigate the parameters like knocking margin, dilution limit, lean limit, different efficiencies, emissions and maximum load of the engine. The experiments were performed successfully and the results showed modest improvement in lean, and dilution limit. Slightly changes in emissions and knocking margins are also observed.

INTRODUCTION

In the recent years, environmental improvement and energy issues have become more and more important as worldwide concerns. Road transport is one of the biggest energy consuming sectors which have a great impact on environment. The fuels mainly used in internal combustion engines are petroleum products namely gasoline and diesel. One way for reducing these impacts is to use alternative fuels. NG consisting highly of methane (~90%) is a good alternative fuel to improve environmental problems because of its plentiful availability and clean burning characteristics. NG generates less emission than Diesel engines and the efficiency can be increased compared to spark ignited gasoline engines due to higher compression-ratio tolerance [9].

Adding some hydrogen to the NG can increase the efficiency and decrease the environmental impacts even further. Hydrogen and methane are complimentary fuels in some ways. Methane has a relatively narrow flammability range which is especially a problem with lean burn or diluted operation. This limit can be extended by adding some hydrogen which has a wide flammability range. Methane has a slow laminar flame speed, especially in lean operation, while hydrogen has a much faster laminar flame speed [2], [3[]. Methane is a fairly stable molecule that can be difficult to ignite, but hydrogen has an ignition energy requirement much lower than methane. In [4], [5] and [6] some benefits of using Hythane are also established.

Heavy duty SI NG-engines can be operated either lean or stoichiometric [7]. In [1] benefits of hydrogen addition to a lean burn natural-gas fueled engine were investigated. In [8] a study was performed to investigate the effect of Hythane on stoichiometric operation. The percentage of hydrogen was 10% by volume in that study but no significant changes between Hythane and NG were observed in that experiment.

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This paper presents results from measurements made on a heavy duty 6-cylinder NG engine which operates stoichiometric diluted with EGR. The main objective of this work is to investigate the engine behavior and possible benefits and disadvantages of running the engine with Hythane enriched with 25% hydrogen when the engine operates stoichiometric.

The paper consists of the different sections and subsections. In the first section the engine and its setup, information about the measurement equipment and gas data is discussed. Second section presents the design of the experiment. The results are presented in the third section followed by summary and conclusion. An appendix with more detailed results is also attached.

ENGINE SETUP

This section covers the description about the engine, emissions and other measurement equipment and also the information about the NG and the Hythane.

The engine

The engine is heavy-duty NG engine equipped with both short and long EGR rout (see Figure 1). In this work only the long rout was used. More engine specifications are available in Table 1. Recently the piston of the engine was changed (see Figure 2). The main feature of this piston is its high turbulence generating which results in fast combustion [11]. This effect of the piston should be kept in mind during reading this report.

Table 1. Engine Specification

Number of Cylinders	6
Displacement	9,4 Liter
Bore	120 mm
Stroke	138 mm
Compression ratio	12,5 :1
Injection System	Multi-Port

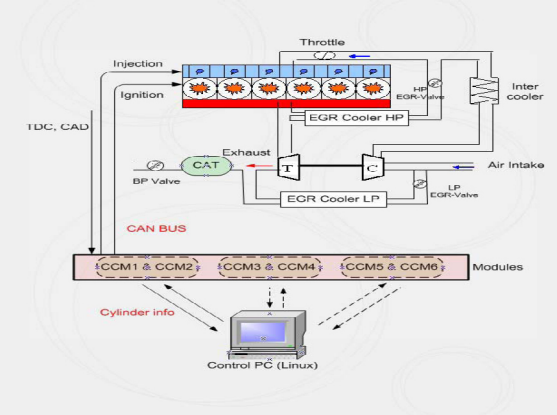


Figure 1. The engine setup



Figure 2. Piston of the engine

Measurement Systems

Each cylinder head is equipped with a piezo electric pressure transducer of type Kistler 7061B to monitor cylinder pressures for heat release calculations. Cylinder pressure is sampled by a Microstar 5400A data acquisition processor. EGR was calculated by measuring CO2 at inlet and exhaust. Emissions (HC, CO, NO, NO2, NOX, CO2, O2) are measured before and after catalyst. The emission system consists of a Heated Flame Ionization Detector (HFID) for measuring HC, a Heated Chemiluminescence Detector (HCLD) for measuring NOX, two Non Dispersive Infrared Detector (NDIR) for measuring CO and CO2 and a Para-Magnetic Detector (PMD) for measuring O2.

Temperatures at inlet/exhaust, pressures at inlet/exhaust, fuel and air flow, lambda, torque and engine speed are also measured.

Gas Data

The compositions of NG and Hythane are respectively presented in Table 2 and Table 3.

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Table 2. Natural Gas composition

Compositions	%	Structure
Methane	89.82	CH4
Ethane	5.87	C2H6
Propane	2.23	C3H8
I-Butane	0.37	C4H10
N-Butane	0.51	C4H10
I-Pentane	0.13	C5H12
N-Pentane	0.08	C5H12
Hexane	0.06	C6H14
Nitrogen	0.3	N2
CO2	0.63	CO2

Table 3. Hythane composition

Compositions	%	Structure
Methane	67.4	CH4
Ethane	4.3	C2H6
Propane	1.7	C3H8
I-Butane	0.2	C4H10
N-Butane	0.4	C4H10
I-Pentane	0.11	C5H12
N-Pentane	0.09	C5H12
Hexane	0	C6H14
Nitrogen	0.3	N2
CO2	0.5	CO2
Hydrogen	25	H2

More important properties of the fuels are presented in Table 4.

Table 4. More properties of the fuels

Property	Natural Gas	Hythane
H/C Ratio	3.7	4.32
Stoichiometric AFR	16.9	17.56
LHV (MJ/kg)	48.4	50.76
Density (Kg/Nm$^{3)}$	0.82	0.638

EXPERIMENT

The experiment is performed in three different stages. Since the objective is to compare the effects of the NG and the Hythane on the engine, the engine is operated twice for each stage, once with NG and once with Hythane. Details about the experiments are as follow:

1. ***Lambda sweep***: in this experiment the engine operated at 1000 RPM with Wide Open Throttle (WOT). The sweep is started at lambda equal with 0.8 and lambda was increased up to the engine lean limit. In this experiment the air flow is constant and fuel flow is varied to achieve the desired lambda value. The engine is operated on Maximum Brake Torque (MBT) timing.

2. ***EGR Sweep***: In this experiment the engine is operated with stoichiometric operation at 1000 RPM with WOT. The EGR is increased until the dilution limit is achieved.

3. ***Map***: the engine is operated stoichiometric at different loads and speeds to see the overall performance of the engine at all operating areas. The test point matrix can be seen in Table 5. This should be kept mind that in this experiment EGR was only used to suppress knocking and not to increase efficiency[1].

Table 5. The test point Matrix

Speed	Load
1000	Max
	8
	4
1250	Max
	11
	8
	4
1400	Max
	12
	8
	4
1600	Max
	11
	8
	4
1700	Max
	11
	7
	4
1800	Max
	11
	8
	4

Since the stoichiometric value is not the same for both fuels, this value was calculated for each fuel and the lambda sensor was calibrated once the fuel was changed. For each operating point 300 cycles measurement are collected and an average of that is presented.

[1]EGR can also be used to increase the efficiency by minimizing the throttling losses but this was not the case in this paper

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RESULTS

In this section the results from the performed experiments are discussed. The results are discussed in three parts as the experiment is performed.

Lambda Sweep

In the first experiment the lean limit of the engine is investigated. Comparing the lean limit between NG and Hythane shows an improvement from lambda 1.6 to 1.8. This can clearly be seen in Figure 3. Extension of the lean limit is due to the faster burning rate of the Hythane. Misfire and sudden increase in cyclic variation of Indicated Mean Effective Pressure (IMEP) is an indication for lean limit.

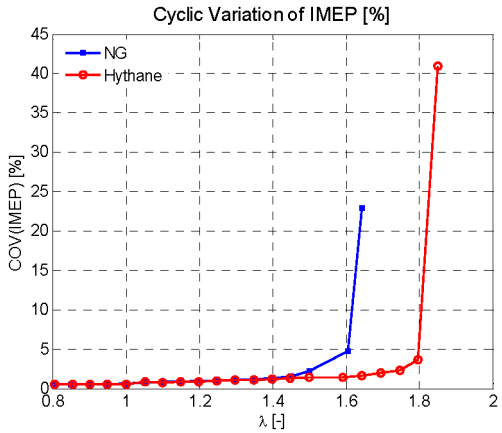


Figure 3. COV(IMEP) versus lambda

In Figure 4 combustion duration are plotted versus different lambda for both fuels. Combustion duration is defined as the difference between the Crank Angle Degree (CAD) where 10% of the total heat is released (CA10) and the CAD where 90% of the total heat is released (CA90). Combustion duration is shorter with Hythane due to the faster flame speed. The difference is not much but as the engine operates leaner the difference is more obvious. Figure 5 and Figure 6 show CA10 and CA90 for both fuels at different lambda. Since burning rate of Hythane is higher, the ignition timing can be retarded and as Figure 5 and Figure 6 shows the CA10 will be retarded due on that effect but CA90 will be the same for both fuels.

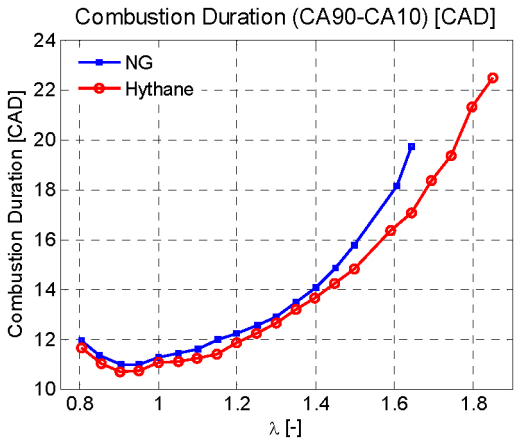


Figure 4. Combustion duration versus lambda

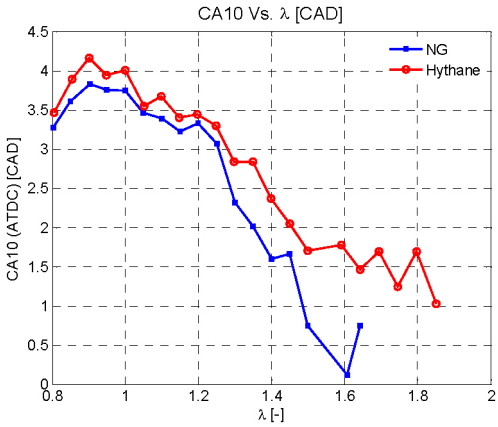


Figure 5. CA10 versus lambda

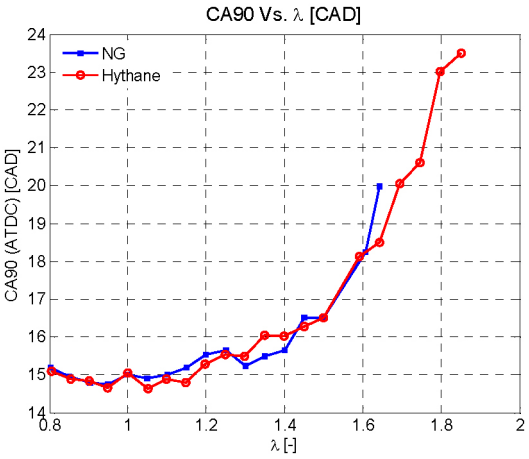


Figure 6. CA90 versus lambda

All emissions versus lambda are plotted and they are available in appendix. The emissions are unburned Hydro Carbon (HC), Carbon Monoxide (CO) and Nitrogen Oxides (NOX).

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