Gas Engine with Hydrogen Scavenged Pre-chamber

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Introduction

Extremely lean homogeneous mixture operation of spark ignition gas engine leads to a low temperature combustion and low heat losses as well as a low NO_X formation. Lean mixture causes problems with initiation of combustion process. This can be improved by the use of scavenged pre-chamber ignition. At the spark discharge event the pre-chamber contains enriched mixture, which supports the start of combustion. Pre-chamber combustion generates amount of energy approximately one thousand times higher than the spark itself. Hot combustion products from the pre-chamber rapidly penetrate the main combustion chamber and help to ignite lean mixture in the main combustion chamber. In this way the engine can be operated with significantly leaner mixture than the conventional spark ignited one.

This combustion strategy is well established in the field of stationary, large bore gas engines fueled with natural gas both as a main fuel supplied into the intake manifold and as a secondary fuel delivered into the pre-chamber. The authors work on a miniaturization of the pre-chamber structure to enable its implementation in automotive size engine.

The engine with the pre-chamber fueled completely with natural gas shows at low load significant improvement of indicated efficiency compared to the original spark ignition engine and at the same time a very low content of nitrogen oxides in raw exhaust gas. Promising results were acquired on engine test bench in a steady state operation of the experimental single cylinder engine.

Engine efficiency was improved additionally when the pre-chamber was scavenged and filled with hydrogen, still maintaining the low NOx content in raw exhaust gas, which is the main outcome of this work.

Experimental Setup

Experiments were performed on a single cylinder engine, converted from a 4-cylinder 4-stroke natural gas one by deactivation of three cylinders. The main engine parameters can be found in Table 1.

Table 1 Main engine parameters

Stroke	102 mm
Bore	120 mm
Compression volume	80 cm^3
Compression ratio	12:1
Number of valves/cylinder	4

Metering and delivery of natural gas is performed in the engine intake manifold. It is possible to manually control the fuel flow or to operate with a closed loop lambda control. The engine was fueled with natural gas (with approximately 98% of methane content by volume). Mixture inflow is controlled by a conventional throttle valve. A capacitive

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ignition system (UNIMA TC+) enables independent adjustment of the spark timing. All actuators and selected set of sensors are connected to the engine electronic control unit (ECU) developed in the authors' department using Field-Programmable-Gate-Array as a HW platform. The ECU is fully accessible and allows an open loop control as well. The detailed test setup description can be found in [1].
The cylinder head was modified, and in-house developed scavenged pre-chamber was installed into it. The pre-chamber assembly was designed in a modular way and allows modifications of size, geometry and orifices. The pre-chamber shape is cylindrical (Fig. 1) and the specifications of its geometry are shown in Table 2. The orientation of the orifices was designed with regard to the shape of the main combustion chamber and the uniform distribution of jets leaving the chamber. The pre-chamber with twelve orifices was selected as the best of the tested variants from previous study [2].

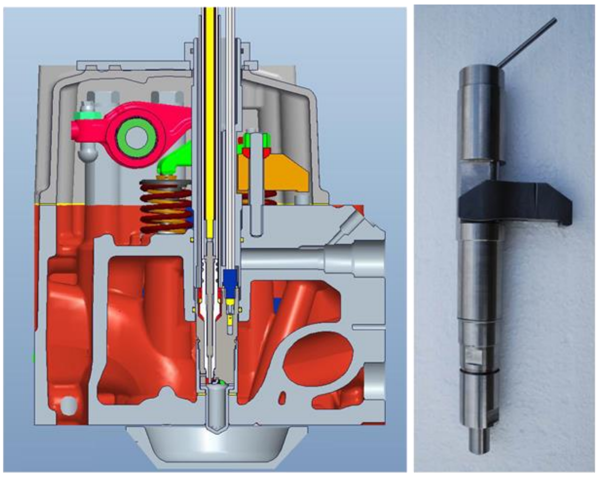
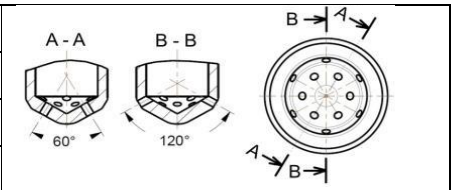


Fig. 1 Pre-chamber design

The pre-chamber is filled with hydrogen through a check valve. The filling and scavenging mainly occurs during an intake stroke, based on a pressure difference between the fuel line and the pre-chamber. Hydrogen flow to the pre-chamber was measured and controlled by an OMEGA FMA2610A mass flow controller. The combustible mixture in the pre-chamber is formed during the compression stroke in which the pre-chamber is being filled with the lean mixture from the main combustion chamber. Ideally, a stoichiometric or moderately rich mixture should be present in the vicinity of the spark plug gap at the time of spark discharge.

Table 2 Pre-chamber geometry

Volume	1.92 cm^3	
Fraction of compression volume	2.4 %	
Number of holes	12	
Hole diameter	1.2 mm	

An AVL GU13Z-24 uncooled miniature cylinder pressure transducer with M5 thread was installed in the cylinder head. Another uncooled AVL GH15D pressure transducer was installed in the pre-chamber. The pressure signals were amplified using a two-channel Kistler charge amplifier. High speed data recording was performed using an in-house developed data acquisition software and an angle calculator system compiled in a National Instruments (NI) LabVIEW integrated development environment and NI hardware. An in-house low speed data acquisition (DAQ) also compiled in LabVIEW records the signals from the sensors of slowly changing physical quantities mainly temperatures, pressures and fuel consumption. The main gaseous emission components have been measured in a raw exhaust gas sample. The test cell is equipped with an emission bench based on ABB gas analyzers that sampled a raw and dried exhaust gas (NDIR for CO, CO_2 and CH_4, CLA for NO_X and PMD for O_2).

Results and Conclusions

Experimental results are displayed in Fig. 3. Tests were performed at a constant engine speed of 1800 rpm with fully open throttle. NG delivery to the intake manifold was gradually reduced to obtain engine performance depending on lambda. Ignition timing was adjusted to maintain combustion phasing CA50=10°aTDC. Blue lines with circles represent engine operation with pre-chamber fueling with natural gas (0.2 standard m^3/h which corresponds to range between 5 – 10% of energy input). Red lines with squares represent operation with pre-chamber fueling with hydrogen (1.0 standard m^3/h which is 13 to 19% of energy input). Pre-chamber engine is able to operate at significantly higher lambda than the standard spark ignition engine (lambda ~1.65) [3]. Pre-chamber scavenged with H_2 allows additional widening of the lambda range. Lean operation allows achievement of NOx emission below current emission limit for automotive operation. With H_2 delivery to the pre-chamber further reduction of NOx was observed. Chemical efficiency together with indicated efficiency were also improved with H_2 fueling to the pre-chamber.

At present a CFD simulations with both turbulent flow and chemical kinetics models, with the experimental experience, used as a calibration data are in progress. A detailed description of pre-chamber ignited engine behavior will be obtained in this way.

References

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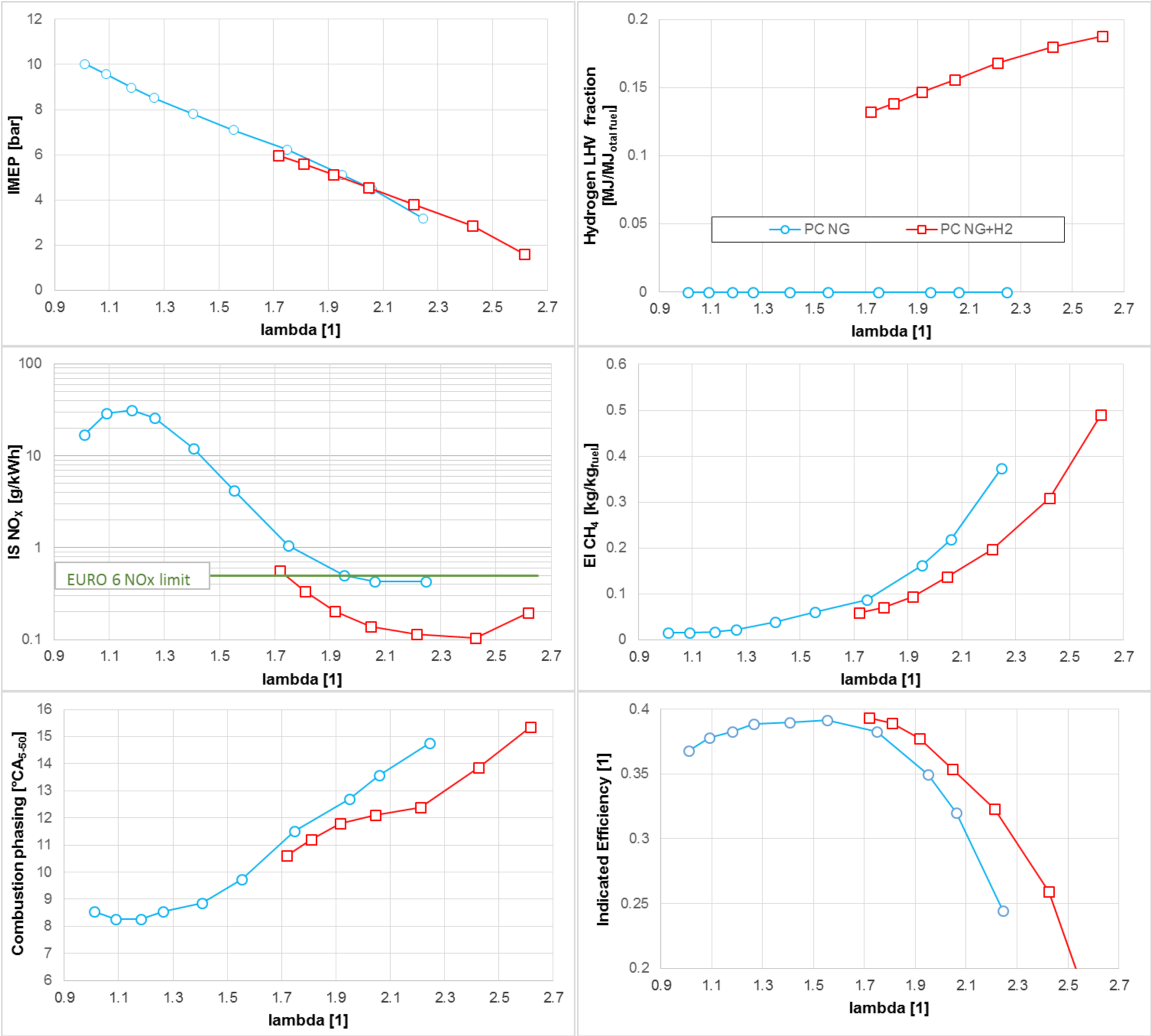

Fig. 2 Engine mean indicated pressure IMEP, hydrogen share on energy input H_2 LHV, indicated specific NOx IS NOx, methane emission index EI CH_4, combustion duration (5-50% mass fraction burned) and indicated efficiency vs. air excess ratio lambda.

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