International Journal for Multidisciplinary Research (IJFMR)

E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Emission and Performance Analysis of a Multi-Fuel Engine

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Abstract

The demand for improving engine emissions, performance and efficiency requires the application of advanced identification and control strategies.[1] The most promising methods of improving the engine emission performance are: combustion optimisation, use of alternative fuels and after-treatment technologies.

The main objective of this research work was to optimise the multi-point CNG fuel injection system of the newly converted spark-ignited bi-fuel engine VW 1.4L 16V AUA such that it would meet the Euro 4 emission limits. Emission tests and measurements were carried out on the engine dynamometer SCHENCK WS-230. The experimental setup consists of multi-port CNG fuel injection system DREAM XXI, developed by OMVL of Italy, with close-loop emission control technology. The air-excess ratio and the emissions were monitored over a range of speeds (1500 to 5350 min^{-1}) and loads (25, 40, 60 and 100%) of the newly integrated MPI for CNG. At each operating condition the injection time map of ECU was tuned to achieve optimum emissions under CNG operation. The value of maximum engine power with Nat95 petrol fuel at 5000 rpm was 56.4 kW while the power generated with CNG fuel at the same rpm was 46.2 kW; that means 18% power loss with unchanged compression ratio and ignition advance angle.

The results of emission measurements on CNG fuel give positive provision to fulfil the Euro 4 emission standard. The CO and CH values are very low (often zero) on both fuels. Compared to gasoline, higher value of NO_x was registered in CNG fuel operation (especially on partial load), approximately in the range of up to 100 ppm. The CO_2 emissions in CNG fuel operation are about 20-25% lower than in petrol operation.

Keywords: MPI spark-ignited gas-fuelled engine, alternative fuels, compressed natural gas, and emission control

INTRODUCTION

Natural gas is composed primarily of methane which dominates its emission characteristics. Methane mixes readily with air and has a high octane rating which makes it efficient SI engine fuel [1]. Because of its high hydrogen-to-carbon ratio, the combustion of methane produces less CO2 than combustion of the energy-equivalent amount of gasoline or diesel. The NG is also very safe fuel in terms of its properties and containment safety. A conversion of the existing petrol and diesel engines to NG designs has been widely discussed. The economic analyses show an excellent return of the investment for conversion of passenger cars and city transport buses. According to the Slovak Gas Industry Co. (the main distributor of the Russian gas across the Europe), the investment cost of repowering of city bus with CNG-fuelled engine will return in approximately two and half years.

OBJECTIVES

The main objective of this research work is to optimise the performance and emissions of a gasoline engine powered by Compressed Natural Gas (CNG).

- To optimise the bi-fuel engine for low emissions on CNG;
- To achieve optimum lambda value (air excess ratio lambda (λ) in the range λ=0.99 - 0.999) for low emissions by adjusting the gas injection time map of DREAM XXI
- To compare the measured results of performance and emission parameters for both CNG and petrol fuels;
- To achieve optimum values of emissions on CNG fuel by correcting the advance angle;
- To simulate the test engine by using the Lotus Engine Simulation program;
- Compare the measured and simulated (calculated) parameters of the engine.

METHODOLOGY

The research work consists of three parts, theoretical, experimental and computer simulation.

RESULTS AND DISCUSSION

A. Theoretical Analysis

The theoretical part is devoted to some information about alternative fuels and deeply examined natural gas as an alternative fuel for spark-ignition internal combustion engines, emission reduction potential of vehicles powered by CNG fuel and energy efficiency. In this section one can familiarise with:

- Combustion and mixture formation characteristics of CNG as an engine fuel,
- Emission formation of natural gas engines and their environmental effect compared to petrol or diesel,
- Influence of CNG composition on emission,
- Exhaust gas emission after treatment technologies for natural gas engines,
- Fuel metering system of the CNG engine, gas exchange process and methods of air-fuel mixture control for optimum engine operation. The theoretical part also partly over view the advantages and disadvantages of other alternative fuels used and planned to use as a future vehicles fuel.

B. Comparison of measured results

Each test was run on engine dynamometer under engine speed and load characteristics at selected throttle valve opening angles (25%, 40%, 60% and 100%). All measured and calculated values of the engine parameters on both fuels are presented. Comparisons of measured performance parameters are shown in Fig.1. The peak brake effective power (P_e) in CNG operation was 46.7 kW at 5000 min^{-1} and 56.4 kW on petrol fuel Nat95 at the same engine speed. The peak-measured torque in CNG engine operation was 93.7 Nm and in Nat95 case 120.1 Nm at the engine speed of 3500 rpm. This represents 17% loss of power and 22% loss of torque with CNG fuel compared to the petrol. Fig.2 to Fig.5 illustrates the exhaust gas emissions of CO [%], CO_2 [%], CH_x [ppm] and NO_x [ppm] measured after the catalytic converter. The values of CO under all operating regimes of the engine for CNG fuel are nearly zero, whereas on Nat95 they are relatively higher due to higher values of lambda. The values of CO_2 are by 20-25% lower in CNG engine operation than in petrol one. Comparing to Nat95, the measured values for CH_x and NO_x in CNG operation behind the catalytic converter were slightly increased. Even though, our objective to meet Euro 4 emission limits for personal cars is in place; we suggest, that to achieve better performance on CNG fuel at full load, further optimisation of the injection timing map will be necessary by enriching the mixture approximately in the range of λ = 0.90 – 0.95.

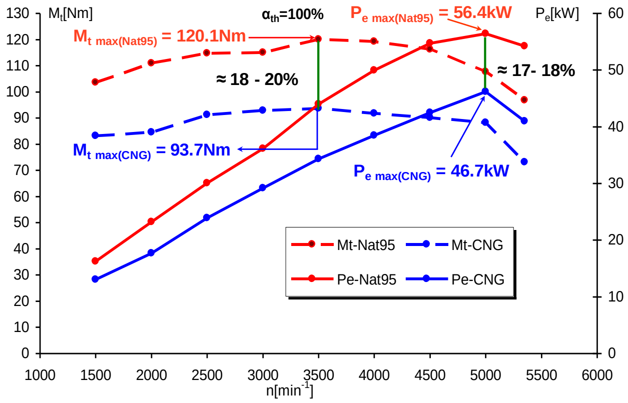

Fig. 1 Engine torque and power curves for both fuels. Parameters: αth = 100%, ε = 10.5, φNat95 = φCNG

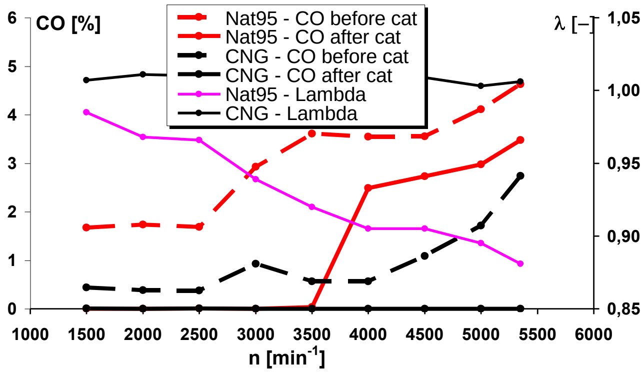

Fig. 2 Engine dynamometer: CO values measured before and after catalytic converter for both fuels under engine speed characteristics with respective lambda values. Parameters: αth = 100%, ε = 10.5, φNat95 = CNG

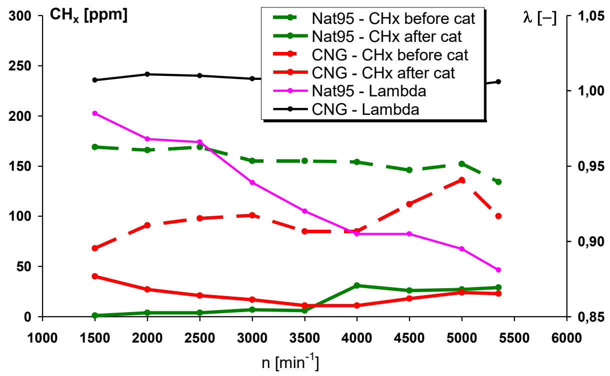

Fig. 3 Engine dynamometer: CHx values measured before and after the catalytic converter for both fuel under engine speed characteristics with respective lambda values. Parameters: αth = 100%, ε = 10.5, φNat95 = φCNG

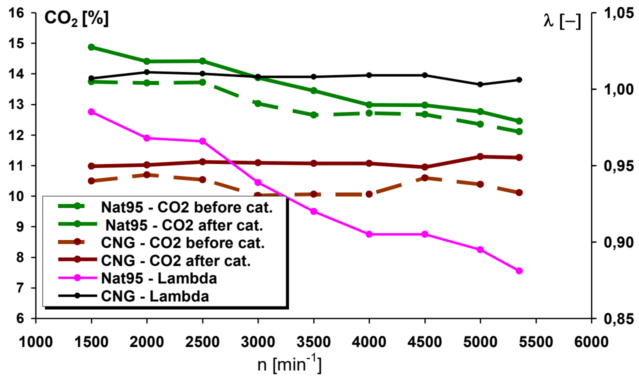

Fig. 4 Engine dynamometer: CO2 values measured before and after the catalytic converter for both fuels under engine speed characteristics with respective lambda values. Parameters: αth = 100%, ε = 10.5, φNat95 = φCNG

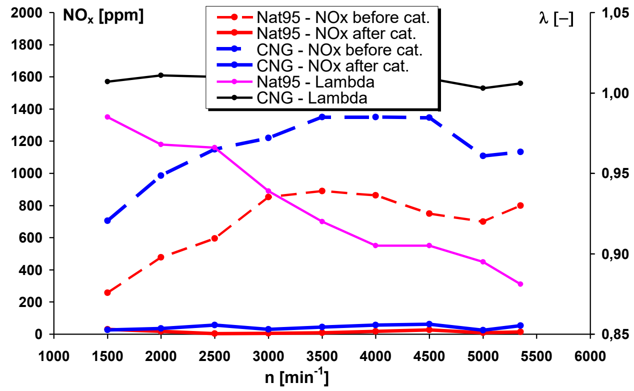

Fig. 5 Engine dynamometer: Nox values measured before and after the catalytic converter for both fuels under engine speed characteristics with respective lambda values. Parameters: αth = 100%, ε = 10.5, φNat95 = φCNG

C. Comparison of measured and simulated results

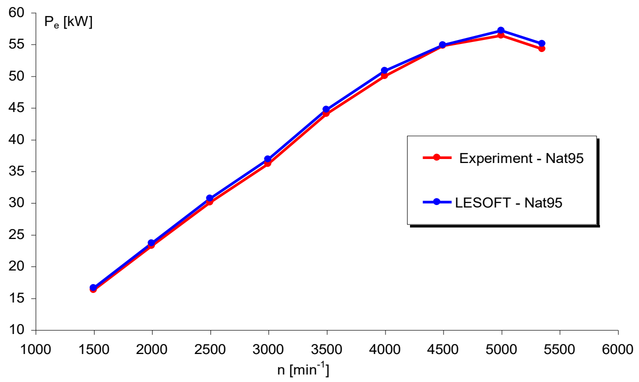

Fig. 6 LESOFT: measured and calculated engine power curve. Engine type: VW 1.4/55kW AUA, Fuel: Nat95. Parameters: αth = 100%, ε=10.5, φNat95 = φCNG

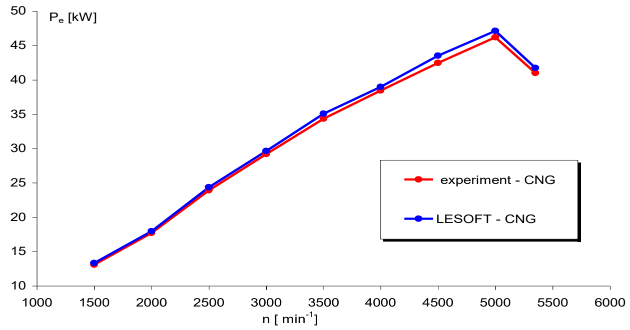

Fig. 7 LESOFT: measured and calculated engine power curve Engine type: VW1.4/55kW AUA, Fuel: CNG Parameters: αth = 100%, ε=10.5, φNat95 = φCNG

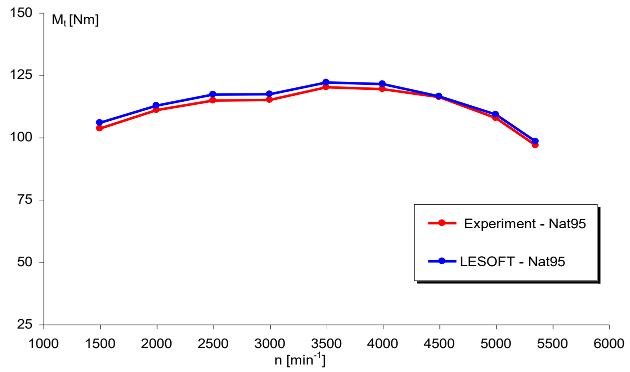

Fig. 8 LESOFT: measured and calculated engine torque. Engine type: VW 1.4/55kW AUA, Fuel: Nat95 Parameters: αth = 100%, ε=10.5, φNat95 = φCNG

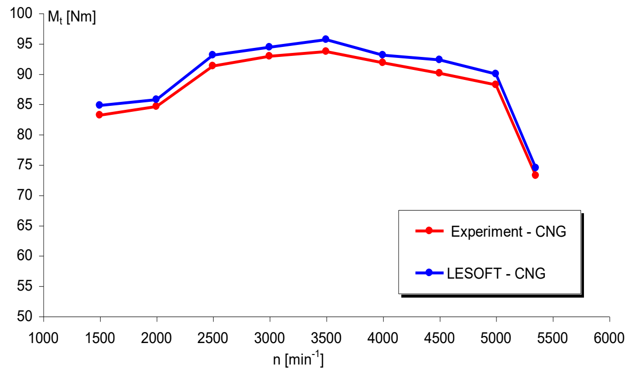

Fig. 9 LESOFT: measured and calculated engine torque. Engine type: VW 1.4/55kW AUA, Fuel: CNG Parameters: αth = 100%, ε=10.5, φNat95 = φCNG

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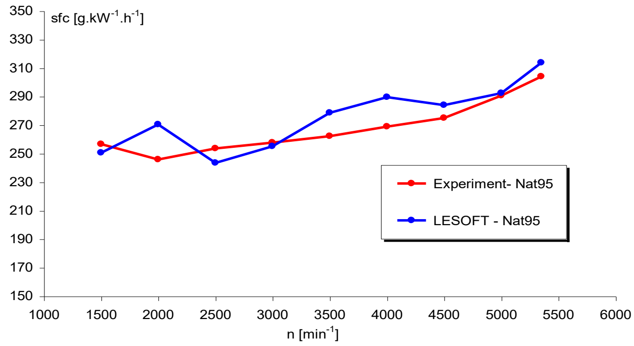

Fig. 10 LESOFT: measured and calculated specific fuel consumption. Engine type: VW 1.4/55kW AUA, Fuel: Nat95. Parameters: αth = 100%, ε=10.5, φNat95 = φCNG

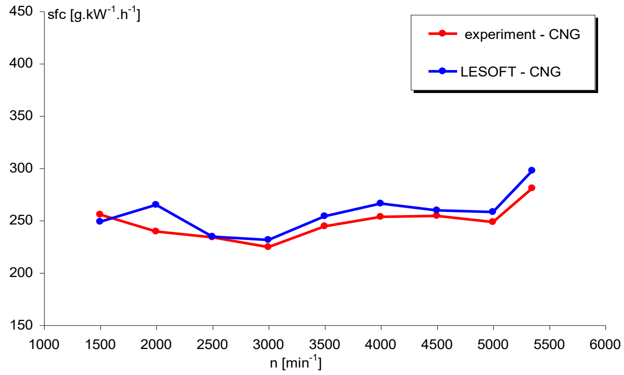

Fig. 11 LESOFT: measured and calculated specific fuel consumption. Engine type: VW 1.4/55kW AUA, Fuel: CNG. Parameters: αth = 100%, ε=10.5, φNat95 = φCN

CONCLUSION

The conversion of automotive vehicle engine to operate on CNG as an alternative fuel has become one of the modern trends in solving the problem of the air pollution (besides its economical benefit). However, the bi-fuel operation of the engine is usually associated with some drawbacks, such as performance deterioration, manifested through a drop in power and torque by about 10 to 15% with unchanged compression ratio and spark advance angle. This affects the converted vehicle cruising ability and might cause traffic problems in the case of need of a surge of power in the critical situations. The results achieved by the experimental work and the computer simulation can be summarised as follow

- The λ values were monitored over a range of speeds (1500 to 5350 min-1) and loads (25, 40, 60 and 100%) of the newly integrated MPI for CNG. At each operating condition, the injection time map of ECU was tuned up by correcting the corresponding lambda value in order to achieve optimum emissions for CNG engine operation.
- The value of maximum power in Nat95 petrol engine operation at 5000 rpm is 56.4 kW. This value meets the one declared by the manufacturer. The power in CNG engine operation at 5000 rpm is 46.7 kW, which means 17% power loss. This is explained by the known fact, that with the same compression ratio and the spark advance angle, the amount of air entering the cylinder is lower in gas fuel operation, since gas occupies more space than liquid fuel.

- The results of emission measurements give positive provision to fulfil the Euro 4 emission limits for vehicles powered by CNG. The CO and CH_x values are very low (often zero) on both fuels.
- Due to the lower carbon-to-hydrogen ratio, CO_2 emissions in CNG operation are about 20-25 % lower than in petrol operation.
- The reduction of emissions with CNG fuel has been achieved by optimisation of the injection system. Even though, our objective to meet Euro 4 emission standards of passenger cars is in place, we suggest, for better power parameters and vehicle drivability at full load, further optimisation of the injection timing map in CNG operation will be necessary (particularly to enrich the mixture approximately to the range of $\lambda = 0.90 – 0.95$); because in this range the engine produces higher power at stable run and ensures the catalytic converter to operate at high efficiency without its over-heating.
- The comparisons of the values calculated by LESOFT and those measured experimentally are in good agreement across the entire engine speed range.

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