Expermental Investigation of Petrol Engine Performance Using Natural Gas as a Dual Fuel

Anteneh Mohammed Tahir[1*], Prabhakar.S[2]

[1*] Dean, Mechanical department, Kombolcha Institute of Technology, WOLLO University, Kombolcha-208, Ethiopia. Email: anteneh67@gmail.com
[2] Associate professor, Mechanical department, Kombolcha Institute of Technology, WOLLO University, Kombolcha-208, Ethiopia. Email: praba.rockson@gmail.com

---

ABSTRACT

The article comments on expermental investigation of natural gas as dual fuel for personal car engine runing on petrol fuel. Now adays, there exist many environmental and natural resource problems such as global warming, fossil fuels resources, and air pollution in urban areas that must be addressed by the automobile industry. The alternative fuel for internal combustion engine and electric motor hybrid vehicles are thought as influential candidates for next generation vehicles to challenge these issues.
The demand for improving engine emissions, performance and efficiency requires the application of advanced identification and control strategies (Poloni M., Svetlik F., 2010). The most promising methods of improving the engine emission performance are combustion optimisation technologies and use of alternative fuels. The main goal of this research work was to optimise the multi-point natural gas fuel injection system of the newly converted spark-ignited dual-fuel Volkswagen (VW) 1.4L 16V AUA engine. Emission tests and measurements were carried out on the engine dynamometer SCHENCK WS-230. The experimental setup consists of multi-port natural gas 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 natural gas. At each operating condition the injection time map of ECU was tuned to achieve optimum emissions under natural gas operation. The value of maximum engine power with Petrol fuel at 5000 rpm was 56.4 kW while the power generated with natural gas 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 natural gas 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 NOx was registered in natural gas fuel operation (especially on partial load), approximately in the range of up to 100 ppm. The CO2 emissions in natural gas fuel operation are about 20-25% lower than in petrol operation.

Key words : Spark-ignited gas-fuelled engine, Alternative fuels, Compressed natural gas, and Emission control

---

INTRODUCTION

Energy demand all over the world increases steadily and, within the next decades, is almost completely met by fossil fuels. This poses increasing pressure on oil supply and reserves. The environmental pollution, especially by carbon dioxide from fossil fuel combustion, is the major risk of global warming. Environmental well-being requires a modified mix of energy sources to emit less carbon dioxide, starting with a move to natural gas and ending with the market penetration of renewable energies (Poloni, M. and Mičan M., 2010) .
Use of natural gas has been recognized for its environmental benefits because it is a cleaner burning fuel relative to gasoline and diesel fuel. The technology for using natural gas as an alternative fuel for motor vehicles has been demonstrated for several years. In Europe and South America, hundreds of thousands of vehicles are operated on natural gas (Gorham, R., 2009).

One of the major drawbacks to using natural gas in motor vehicles is that the driving range of vehicles is limited because of fuel storage capacity constraints. Where needed this problem has been minimized by installing dual-fueled systems (e.g., natural gas, and gasoline or diesel) on the vehicle. Another limitation has been the availability of fuel dispensing facilities. Historically, because of these constraints, the use of natural gas has often been limited to vehicle fleets that return to the same location each day. With expanding natural gas demand and refueling infrastructure, this situation is expected to change (Hien Ly, 2009).

The use of natural gas as a vehicle fuel usually involves the conversion of a gasoline engine to operate on both natural gas and gasoline (i.e., a dual-fueled engine). The conversion process is relatively simple because no internal modifications of the engine are required. Conversion equipment generally includes a variable gas-air mixer as part of the fuel injection system, a series of regulators and valves, which deliver the gas from the storage tanks, and an electronic module to interface with the onboard computer.
The performance of an engine running on natural gas highly depends on the sophistication of the engine and whether the engine will run only on natural gas or not. Normally a power loss due to reduced mixture energy density can be expected when switching from gasoline to natural gas. If the engine is a dual-fuel engine, or originally a gasoline engine, which is converted to natural gas, the engine cannot fully utilise the high knock resistance of methane. If the engine is run on natural gas, the compression ratio can be increased, valve timing and ignition settings can be optimised and thus the power loss in some extent can be reduced (Keller J., Singh G., 2008). At a given compression ratio, engine efficiency on natural gas should be equal compared to gasoline efficiency. Methane easily forms a homogeneous mixture, which is good for combustion but on the other hand, methane is hard to oxidise and this again can cause flame quenching and leave unburned fuel in the crevices of the combustion chamber (Mustafa B., and Daniž M., 2010). The maximum power drop when switching to natural gas is, however, so small that in most cases it will not affect the practicability of the vehicle. A natural gas vehicle, due to the gas tanks, is slightly heavier than a gasoline vehicle that means its mass increases energy consumption of the vehicle. On the other hand, an engine running only on natural gas might be a little more energy efficient than a gasoline engine, so these factors should more or less compensate each other.

The economic analyses show an excellent return of the investment for conversion of passenger cars and city transport buses (Beroun S., 2009).. 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 natural gas-fuelled engine will return in approximately two and half years (Daniž M., 2010 and Shiga

S.,2009). The main goal of this research work is to compare the performance and emissions of a gasoline engine powered by compressed natural gas

.

MATERIAL AND METHODS

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

Experimental setup and method of experiments

The emission tests and measurements were carried out on an engine dynamometer SCHENCK WS-230. The experimental set up consisted of a multi-port injection of natural gas fuel system with close-loop emission control technology with two NGK O2 sensors, one of which is a wide range version installed before the three-way catalytic converter.

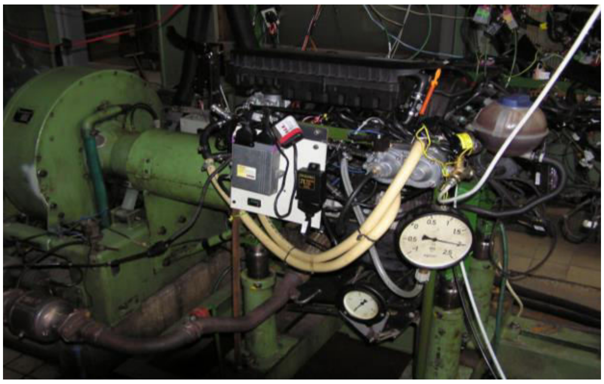


Fig. 1: Photographic view of the converted bi-fuel engine mounted on an engine dynamometer SCHENCK WS-230 with multi-port natural gas injection system
Engine type: VW 1.4/55kW 16V AUA

Fig. 2: Engine dynamometer with on-line PC data acquisition and control program "ADVANTECH GENIE" and digital gas analyzer SUN DGA-1000

Experiments

The test engine and its base vehicle

The test engine is a four-cylinder spark ignited Skoda Fabia VW 1,4l/55kW AUA engine with multi-port CNG fuel injection. The model engine with its original technology and petrol fuel fulfils EURO-4 emission standards that will apply from January 2005 within the EU countries. The engine has two catalytic converters and two lambda sensors with on-board diagnostics EOBD (European on board diagnostics). The NGK lambda sensor mounted before the catalytic converter is a wide range type (0-5V). Any non-compliance in the engine parts, influencing exhaust gas after treatment components is signalled by malfunctioning light (warning light), which is a part of the new EU requisite. Most of the vehicle electronic units (accelerator pedal, engine sensors, power steering control, automatic transmission control, ABS, air bag, indicators, etc.) are interconnected via an innovative CAN bus (control area network). This provides a rapid and save exchange of digital data between the electronic management units. The engine produces maximum power of 55 kW at 5000 min^{-1} and 126Nm maximum torques at 3800 min^{-1}. The maximum speed of the vehicle is 170 km/h with 6,7l/100 km average fuel consumption.

Fig.1 shows a photographic view of the bi-fuel system of the test engine installed on a dynamometer. CNG is stored in a high-pressure cylinder at a pressure up to 20 MPa. The gas pressure is then regulated by the pressure regulator down to 180 kPa and supplied to the engine. For compensating the refrigeration effect of the natural gas expansion, the engine coolant continuously circulates around the regulator body. A wide range NGK-oxygen sensor was used to precisely control the air excess ratio for efficient catalytic converter operation and better gas injector response. To compensate gaseous fuel pressure and temperature fluctuations in the fuel rail, a pressure-temperature sensor has been mounted to measure gas pressure and temperature in the fuel rail at the time of injection. The signal from this sensor is sent to the ECU to inject the exact amount of fuel.

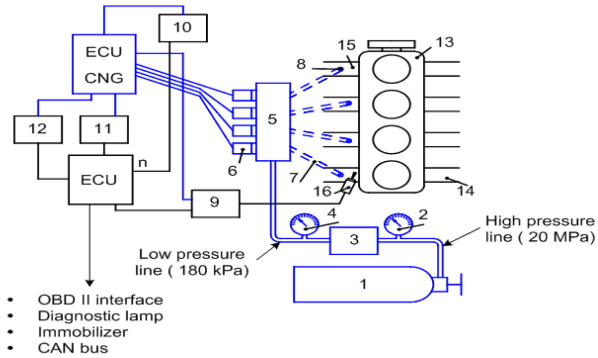
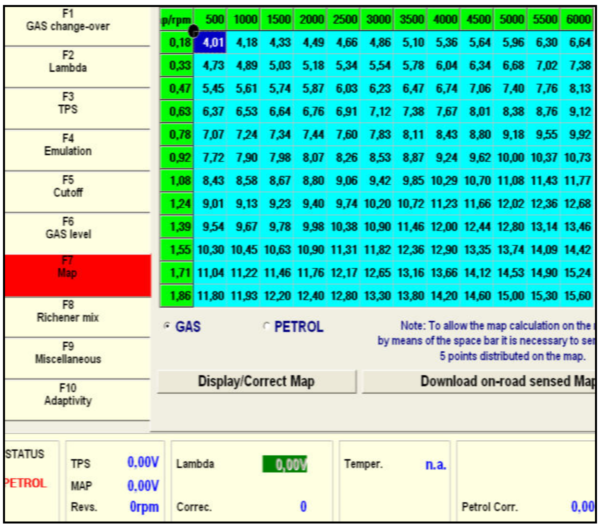


Fig. 3 Scheme of the multi-point CNG injection electronic system mounted for bi-fuel optimisation



p/rpm	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000
0,18	4,01	4,18	4,33	4,49	4,66	4,86	5,10	5,36	5,64	5,96	6,30	6,64
0,33	4,73	4,89	5,03	5,18	5,34	5,54	5,78	6,04	6,34	6,68	7,02	7,38
0,47	5,45	5,61	5,74	5,87	6,03	6,23	6,47	6,74	7,06	7,40	7,76	8,13
0,63	6,37	6,53	6,64	6,76	6,91	7,12	7,38	7,67	8,01	8,38	8,76	9,12
0,78	7,07	7,24	7,34	7,44	7,60	7,83	8,11	8,43	8,80	9,18	9,55	9,92
0,92	7,72	7,90	7,98	8,07	8,26	8,53	8,87	9,24	9,62	10,00	10,37	10,73
1,08	8,43	8,58	8,67	8,80	9,06	9,42	9,85	10,29	10,70	11,08	11,43	11,77
1,24	9,01	9,13	9,23	9,40	9,74	10,20	10,72	11,23	11,66	12,02	12,36	12,68
1,39	9,54	9,67	9,78	9,98	10,38	10,90	11,46	12,00	12,44	12,80	13,14	13,46
1,55	10,30	10,45	10,63	10,90	11,31	11,82	12,36	12,90	13,35	13,74	14,09	14,42
1,71	11,04	11,22	11,46	11,76	12,17	12,65	13,16	13,66	14,12	14,53	14,90	15,24
1,86	11,80	11,93	12,20	12,40	12,80	13,30	13,80	14,20	14,60	15,00	15,30	15,60

Fig. 4: Fuel map window (F7). Fuel injection map software DREAM XXI

RESULTS AND DISCUSSION

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 natural gas fuel and energy efficiency. In this section one can familiarise with:

– Combustion and mixture formation characteristics of natural gas as an engine fuel,

– Emission formation of natural gas engines and their environmental effect compared to petrol or diesel,

– Influence of natural gas composition on emission,

– Exhaust gas emission after treatment technologies for natural gas engines,

– Fuel metering system of the natural gas 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.

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.4. The peak brake effective power (Pe) in natural gas operation was 46.7 kW at 5000 min-1 and 56.4 kW on petrol fuel Petrol at the same engine speed. The peak-measured torque in natural gas engine operation was 93.7 Nm and in Petrol case 120.1 Nm at the engine speed of 3500 rpm. This represents 17% loss of power and 22% loss of torque with natural gas fuel compared to the petrol. Fig.4 to Fig.7 illustrates the exhaust gas emissions of CO [%], CO_2 [%], CHx [ppm] and NOx [ppm] measured after the catalytic converter.

The values of CO under all operating regimes of the engine for natural gas fuel are nearly zero, whereas on Petrol they are relatively higher due to higher values of lambda. The values of CO_2 are by 20-25% lower in natural gas engine operation than in petrol one. Comparing to Petrol, the measured values for CHx and NOx in natural gas 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 natural gas 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.

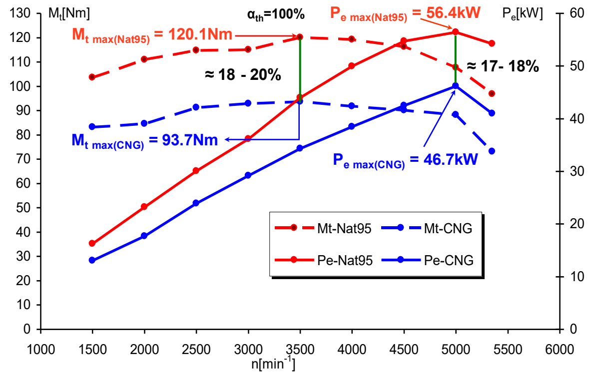


Fig. 5: Engine torque and power curves for both fuels. Parameters: αth = 100%, ε = 10.5, φ Petrol = φ Natural gas

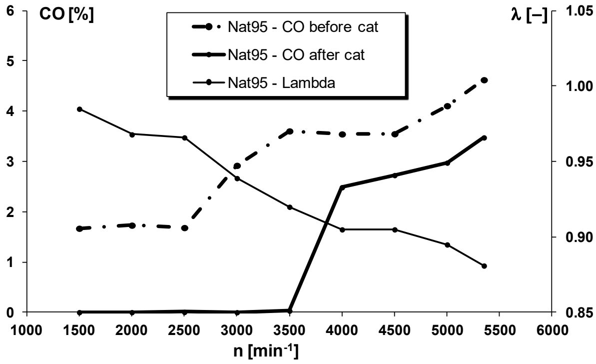


Fig. 6a: Engine dynamometer: CO values measured before and after catalytic converter for Natural gas under engine speed characteristics with respective lambda values. Parameters: α_{th} = 100%, ε = 10.5, φ Petrol = φ Natural gas

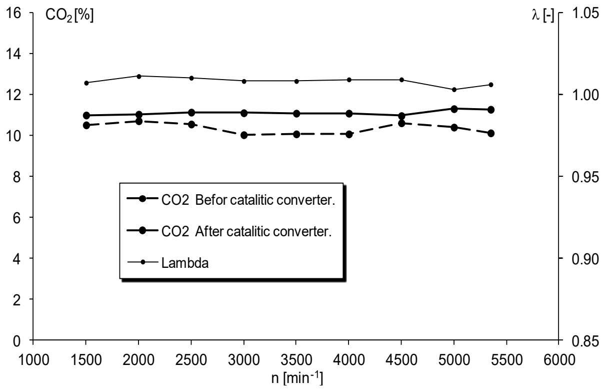


Fig. 6b: Engine dynamometer: CO values measured before and after catalytic converter for Petrol fuel engine under engine speed characteristics with respective lambda values. Parameters: α_{th} = 100%, ε = 10.5, φ Petrol = φ Natural gas

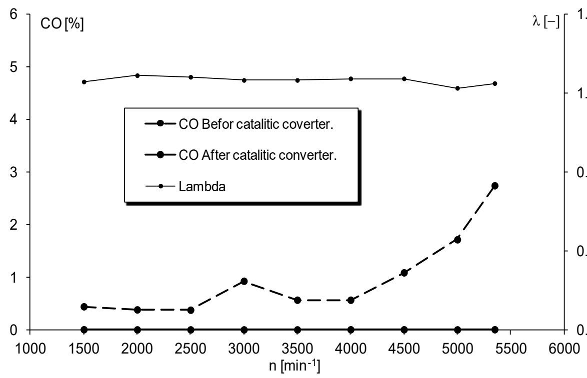


Fig. 7a: Engine dynamometer: CO2 values measured before and after catalytic converter for Natural Gas under engine speed characteristics with respective lambda values. Parameters: α_{th} = 100%, ε = 10.5, φ Petrol = φ Natural gas

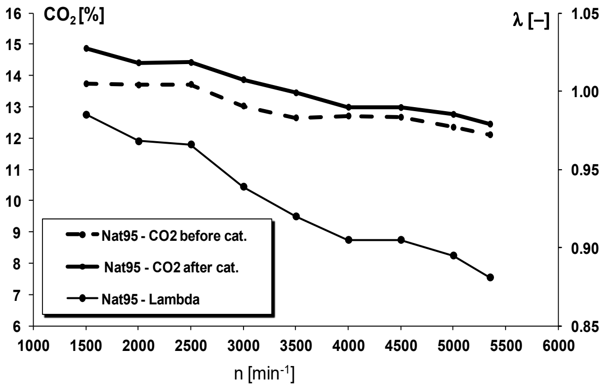


Fig. 7b: Engine dynamometer: CO2 values measured before and after catalytic converter for Petrol fuel under engine speed characteristics with respective lambda values. Parameters: α_{th} = 100%, ε = 10.5, φ Petrol = φ Natural gas

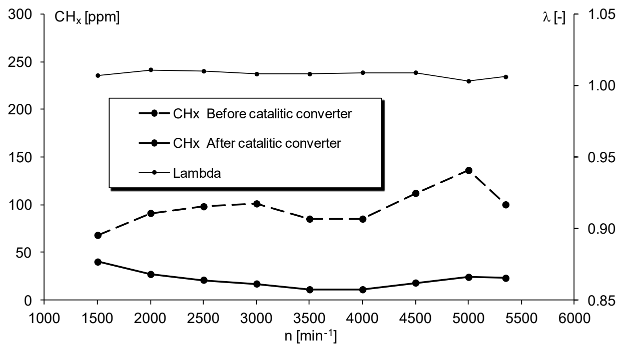


Fig. 8a: Engine dynamometer: CHx values measured before and after the catalytic converter for Natural Gas under engine speed characteristics with respective lambda values. Parameters: αth = 100%, ε = 10.5, φ Petrol = φ Natural gas

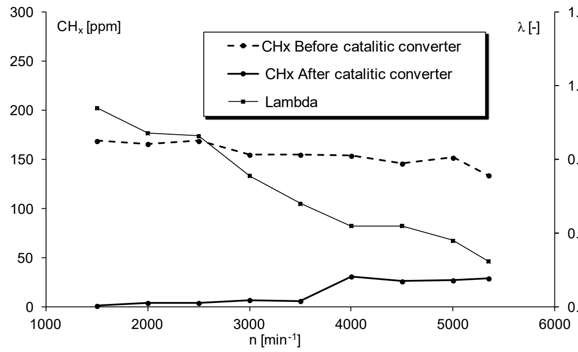


Fig. 8b: Engine dynamometer: CHx values measured before and after the catalytic converter for Petrol fuel under engine speed characteristics with respective lambda values. Parameters: αth = 100%, ε = 10.5, φ Petrol = φ Natural gas

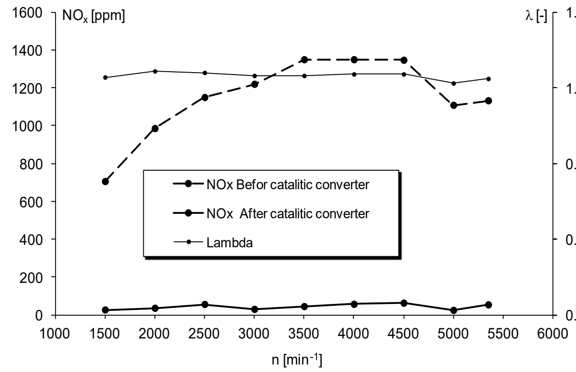


Fig. 9a: Engine dynamometer: NOx values measured before and after the catalytic converter for Natural gas under engine speed characteristics with respective lambda values. Parameters: αth = 100%, ε = 10.5, φPetrol = φ Natural gas

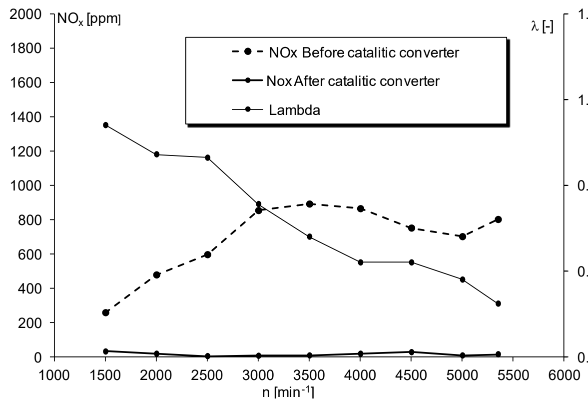


Fig. 9b: Engine dynamometer: NOx values measured before and after the catalytic converter for Petrol fuel under engine speed characteristics with respective lambda values. Parameters: αth = 100%, ε = 10.5, φPetrol = φ Natural gas

Comparison of measured and simulated results

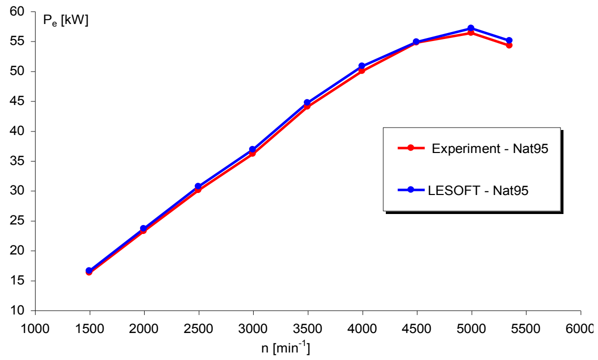


Fig. 10: LESOFT: measured and calculated engine power curve. Engine type: VW 1.4/55kW AUA, Fuel: Petrol. Parameters: α_{th} = 100%, ε=10.5, φ Petrol = φ Natural gas

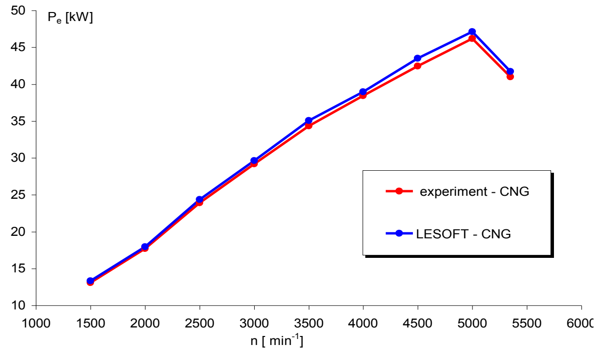


Fig. 11: LESOFT: measured and calculated engine power curve Engine type: VW1.4/55kW AUA, Fuel: Natural gas Parameters: α_{th} = 100%, ε=10.5, φPetrol = φ Natural gas

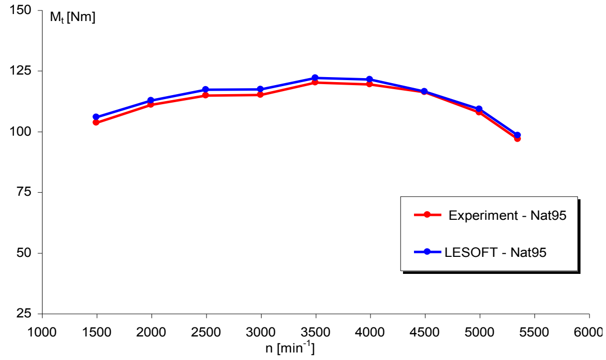


Fig. 12: LESOFT: measured and calculated engine torque. Engine type: VW 1.4/55kW AUA, Fuel: Petrol Parameters: αth = 100%, ε =10.5, φPetrol = φ Natural gas

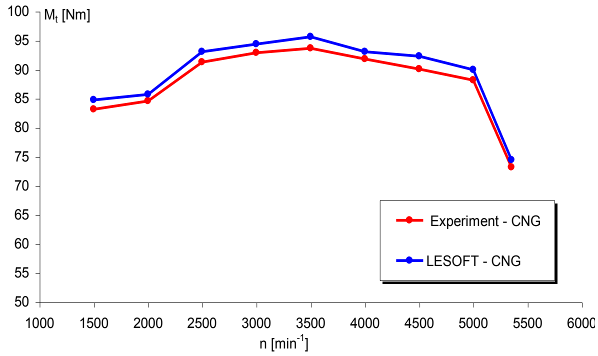


Fig. 13: LESOFT: measured and calculated engine torque. Engine type: VW 1.4/55kW AUA, Fuel: Natural gas Parameters: αth = 100%, ε=10.5, φPetrol = φ Natural gas

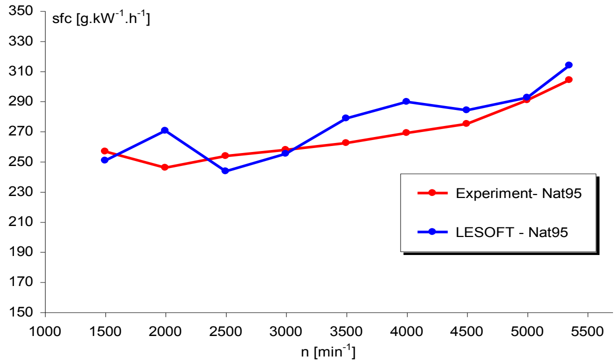


Fig. 14: LESOFT: measured and calculated specific fuel consumption. Engine type: VW 1.4/55kW AUA, Fuel: Petrol. Parameters: αth = 100%, ε=10.5, φPetrol = φ Natural gas

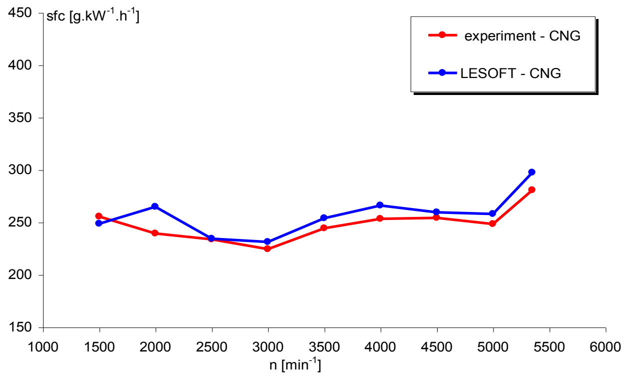


Fig. 14: LESOFT: measured and calculated specific fuel consumption. Engine type: VW 1.4/55kW AUA, Fuel: Natural gas. Parameters: αth = 100%, ε=10.5, φ Petrol = φ Natural gas

CONCLUSION

The conversion of automotive vehicle engine to operate on natural gas 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 natural gas. 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 natural gas engine operation.
- The value of maximum power in Petrol petrol engine operation at 5000 rpm is 56.4 kW. This value meets the one declared by the manufacturer. The power in natural gas 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 natural gas. The CO and CHx values are very low (often zero) on both fuels.
- Due to the lower carbon-to-hydrogen ratio, CO2 emissions in natural gas operation are about 20-25 % lower than in petrol operation.
- The reduction of emissions with natural gas 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 natural gas operation will be necessary (particularly to enrich the mixture approximately to the range of λ = 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.

ACKNOWLEDGEMENTS

I am indebted to many individuals for their care and support given to me during my research work. The first at hand is Assoc. Professor Marián Poloni, PhD who permitted me to use the faculty work shop setup and for his technical assistance. I am also grateful to my colleagues Ing. Tomas Sangala and Ing. Jan Lach for measuring data for my research input.
I would also like to express special thank to staff of Wollo University Research and Community Service Vice President Office and Kombolcha Institute of Technology Department of Mechanical Engineering for their support and shared ideas.

REFERENCES

Poloni, M., Mičan, M., (2010). Emission and power parameters of personal car engines rebuilt for NATURAL GAS, 13th international symposium MOTOR SYMBO, Proceedings, p,228-238 , Brno-Trade Fair Grounds Pavilion A3, Czech Republic

Beroun, S. (2009). Alternative fuels and the conditions of their employment in the low emission piston engines, 9th International Scientific-Technical Conference on Internal Combustion Engines, Automobile Technique and Transport, Scientific-Technical Union of Mechanical Engineering in Bulgaria, Russe, pp, 7, ISBN 954-90272-7-9 Projekt LN00B073, Daniž, M. (2010). Internal Combustion Engine modelling using ID approach, Proceedings from conferences Logistica, p, 140-145, Liptovsky Mikulas 26,11, Slovak Republic, ISBN 80-8040- 213-2

Gono, M., Daniž, Poloni, M. (2011). Modelling of the engine manifold using Lotus Engine Simulation code, XXXV International conference of the Czech and Slovak Universities, Proceedings, p,237-244, Brno, Czech Republic ISBN 80-7157-776-6

Mustafa, B. (2010). Effects of petrol octane number on combustion efficiency, engine performance and fuel economy, Journal of Middle European Constriction and Design of Cars (MECCA), p, (43-48) ISSN 1214-0821

Shiga, S., Ozon, **S.** (2009). A study of the combustion and emission characteristics of compressed-natural-gas direct-injection stratified combustion using a rapid compression machine, JSAE Volume 129, Issues 1-2 , , Pages 1-10

Gorham, R.**:** Air pollution from ground transportation, an assessment of cause, strategies and tactics, UN and the World Bank, published by division for sustainable development department of economic and social affairs, UN, 2009

Hien Ly **:** Effects of natural gas composition variations on the operation performance and exhaust emissions of natural gas–powered vehicles, Prepared for the international association for natural gas vehicles, Sydney, Australia, November 2009

Keller, J., Singh, G**. :** Update on Engine Combustion Research at Sandia National Laboratories, SAE technical paper series 2008-01-2060, Washington, D.C, May 14-16, 2008 ISSN 0148-7191

SYMBOLS, SUBSCRIPTS AND ABBREVIATIONS

CO [%]	- Volume of carbon monoxide in the exhaust gas
CO2 [%]	- Volume of carbon dioxide in the exhaust gas
CHx [ppm]	- Volume of carbon monoxide percent per million in the exhaust gas
NOx [ppm]	- Nitrogen oxides percent per million the exhaust gas
Pe [kW]	- Effective power
α_{th} [^{0}, %]	- Throttle valve opening angle
β [-]	- Riemann variable
φ [^{0}]	- Ignition advance timing angle (before TDC)
λ (Lambda)	- Air excess ratio $(A/F)_{actual}$ / (A/F)s
Mt [N.m]	- Engine torque
sfc [$g.kW^{-1}.h^{-1}$]	- Specific fuel consumption
n [min^{-1}]	- Crankshaft rotation speed, revolution per minute
CNG	- Compressed Natural gas
Nat95	- Petrol (natural) with octane No. 95
LESOFT	- Lotus Engine Simulation software
$(A/F)_{actual}$	- Air-fuel ratio actual
(A/F) s	- Air-fuel ratio stoichiometric