

# THE ENVIRONMENTAL SAFETY OF THE FIAT 0.9 TWINAIR COMPRESSED NATURAL GAS ENGINE

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## Abstract

The article presents the results of measurements of concentrations of selected exhaust components of the Fiat 0.9 TwinAir spark ignition engine operating according to load characteristics. The tested engine has an indirect, multi-point petrol supply system and has been retrofitted with an indirect CNG injection system. The results of the tests are a comparison of selected economic, ecological and energetic indicators of engine operation obtained when fuelled with CNG and 95 octane petrol. The operation of the engine fuelled with gaseous fuel was preceded by autocalibration of the controller of the fuelling system. The article presents the results of tests of concentrations of harmful components of exhaust gases: carbon dioxide CO<sub>2</sub>, carbon monoxide CO, nitrogen oxides NO<sub>x</sub> and HC hydrocarbons. Moreover, the values of lambda  $\lambda$  air excess coefficient are presented and fuel consumption is compared. The obtained results of the tests of the engine fuelled with CNG gas show a significant decrease in the value of the obtained torque in comparison to the engine torque when fuelled with petrol. The engine fuelled with compressed natural gas contributed to the improvement of its ecological properties and a reduction of fuel consumption, which are important factors of ecological and energy safety. Exhaust gas analysis showed a reduction in the concentration of harmful components of exhaust gases, mainly hydrocarbons and nitrogen oxides. A positive effect of the operation of the engine powered by CNG was also a significant reduction of carbon dioxide in the exhaust gases compared to the engine powered with gasoline.

**Keywords:** spark ignition engines; gas engines; CNG engines; load characteristics; emission of gas engines

## 1. Introduction

In recent years, the automotive industry has been showing trends towards the development of electromobility [1, 17, 39]. Due to the significant share of transport in global greenhouse gas emissions, solutions are being sought to improve the environmental indicators relating to means of transport [27, 36, 46]. Despite significant investments in the development of electromobility means of transport, research on the further development of thermal engines is still ongoing, as evidenced by numerous research works, patents and implementations [8, 19, 38]. Research on the ecological assessment of vehicles taking into account the impact of the conditions their use is being conducted [26, 33, 39]. The reciprocating internal

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combustion engine is the primary source of air pollution and noise emissions from vehicles [33]. The continued use of on-road vehicles may be possible provided that their environmental performance is improved. One of the rational solutions that can be implemented in internal combustion piston engines without the need for significant modifications is their supply with alternative fuels [18, 29, 41]. The natural gas supply enables a significant reduction in the emissions of harmful exhaust components [15, 44, 45]. Considering the usefulness of natural gas as a fuel powering internal combustion piston engines, it can be concluded that it has undoubted potential [16, 35, 42]. This is indicated by the benefits of sustainable development and geopolitical aspects [10]. The properties of natural gas enable its use as a fuel for both spark-ignition and compression-ignition engines [4, 7, 16].

The compressed natural gas CNG used to power spark-ignition internal combustion piston engines enables the reduction of the emissions of harmful components of exhaust gases as compared to the emissions obtained when running on petrol [12]. The use of natural gas to power compression-ignition internal combustion piston engines has a positive impact primarily with regard to emissions of particulate matter [9, 30]. It also contributes to the reduction of nitrogen oxide concentration and noise [10, 22, 31]. In Europe, this fuel has gained many supporters, as evidenced by the number of vehicles adapted to run on CNG gas. The social and economic policy of the European Union in the field of sustainable development includes the area of transport activities, which is mentioned as one of the main causes of excessive air pollution and high carbon dioxide emissions [2, 13, 25]. Actions in this area are aimed not only at protecting the environment but also at ensuring human safety [9, 28]. Due to the climate policy, the sector of gaseous fuels is being prepared for the large scale introduction of natural gas as a fuel to run internal combustion piston engines [14, 40]. This is evidenced by numerous investments to facilitate the distribution of natural gas and the diversification of supply, which contributes to improving energy security. Unfortunately, the natural gas distribution infrastructure in Poland still does not allow the free movement of vehicles adapted to be supplied with compressed natural gas CNG or natural gas in the form of liquid LNG [9]. Analysts indicate that the use of gaseous fuels, mainly natural gas, is only an interim solution constituting a bridge for fuel cell technology [5, 16, 37]. Implementation of the provisions of the Act on Electromobility and Alternative Fuels is a major problem for many communities and towns. Their implementation requires the purchase of low-emission vehicles with electric or hybrid drives to operate public transport and perform municipal tasks [6, 11]. At present, these activities are not a comprehensive solution to urban air pollution. The effect of the work of research and development centers on the use of natural gas for the operation of reciprocating internal combustion engines is visible with vehicles that are factory fitted for this fuel [20]. Truck manufacturers have started the serial production of cars factory fitted with CNG. The use of CNG-fuelled trucks, in addition to the economic advantages resulting from the lower price of gaseous fuel and a significant reduction of their harmful impact on the environment, also brings with it the possibility of exemption from the road toll charges [3]. This solution for hauliers has been introduced in Germany for CNG trucks.

## 2. CNG as an alternative fuel

In addition to the conventional petrol and diesel fuels, reciprocating internal combustion engines can run on gaseous fuels as an alternative [24]. Natural gas is one of the natural fossil

fuels. Its main advantages include its high resistance to detonation combustion [26, 34, 43]. Natural gas is classified as an alternative fuel. It is characterized by its purity and high combustion energy [16]. The preparation of natural gas as a fuel for powering internal combustion piston engines does not require complicated processes [21]. Natural gas occurs in gaseous form under the name of CNG (compressed natural gas) and in the form of liquid LNG (liquefied natural gas) [22]. The disadvantage of natural gas as an engine fuel is the high energy of combustion process initiation [35]. The use of natural gas to power compression-ignition engines requires the use of an additional ignition source of the mixture in the cylinder [32]. This is related to the very low value of the cetane number of natural gas [34].

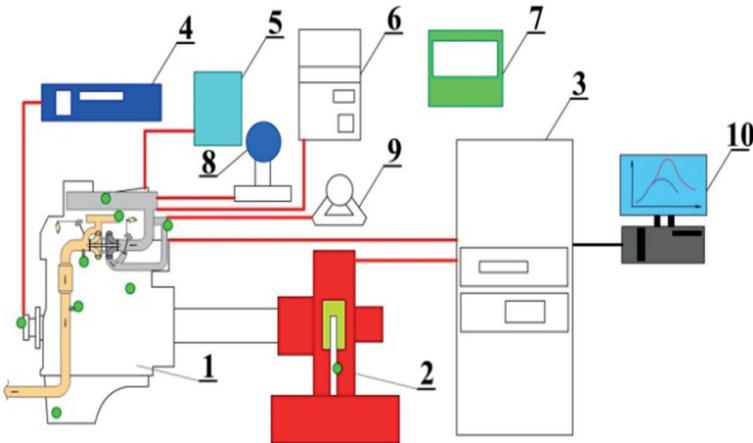
### 3. Test stand

The tests were carried out on an engine dynamometer. The base of the dynamometer is a rigid frame mounted on the floor with the use of metal and rubber elements, which simultaneously have a leveling and vibration-damping function. On the frame of the bench, the Fiat 0.9 TwinAir engine, the Automex EMX 100/10000 eddy current brake and the auxiliary frame of the converter-control cabinet were mounted. The tested engine reaches a maximum power of 85 bhp at 5500 rpm and maximum torque of 145 Nm at 1900 rpm. The Fiat 0.9 TwinAir engine uses patented technology with regard to the intake valve control, enabling them to work according to one of six strategies. The control strategies differ in the size of angles of opening, closing and lift of the intake valves [23]. The test stand is presented in Figure 1. The engine and brake are controlled by means of a control and measuring cabinet. The measuring system of the stand enables reading in real time and the archiving of measurement data and engine operation parameters, including the pressures and temperatures of: lubricating oil, air in the intake system before the turbocharger, air behind the intercooler and exhaust gases in the engine outlet system.



Fig. 1. View of the Fiat 0.9 TwinAir engine test bench

An AVL DiCom 4000 exhaust gas analyzer was used to measure the concentrations of selected exhaust gas components and to assess the composition of the combustible mixture. Petrol consumption was measured with the Automex ATMX 2040 gravimetric fuel meter. The consumption of compressed natural gas was measured with the Emerson Elite Micro Motion Coriolis flow meter. A diagram of the stand together with the testing equipment is shown in Figure 2.



**Fig. 2. Diagram of the test stand: 1 - Fiat 0.9 TwinAir engine, 2 - Automex AMX 100/10000 eddy current brake, 3 - control unit, 4 - AVL IndiSmart 612 indicator system, 5 - ATMX 2040 gravimetric fuel meter, 6 - AVL DiCom 4000 exhaust gas analyzer, 7 - KTS 540 diagnostic tester, 8 - ABB Sensy Flow air flow meter, 9 - EMERSON Elite gas flow meter, 10 - PC computer**

The station allows the engine to work according to the speed and load characteristics. The measuring equipment of the station cooperating with the software of the dynamometer enables determination of the indicators of engine work. The program for processing and data archiving determines engine power based on readings of the crankshaft speed and the torque. Pressure and temperature sensors installed in the inlet and outlet system allow the performing of measurements of the thermodynamic parameters of the engine. Pressure measurement is conducted with the use of pressure transducers located on the transducer-control cabinet of the station. This makes it much easier to take measurements, especially in hard to reach places where it would be impossible to install a conventional pressure sensor. This solution also reduces the influence of the high temperature of the working medium as well as reducing vibrations on the sensors. The station is also equipped with an engine indicator system. The pressure in the combustion chamber is measured using a sensor integrated into the spark plug, while the crankshaft angle is measured using a crankshaft angle encoder placed on the crankshaft pulley. Signals from the pressure sensor and the crankshaft angle encoder are sent to the amplifier, from which they are sent to a PC equipped with a data processing and archiving program via a LAN.

## 4. Fiat 0.9 TwinAir natural gas engine supply system

The engine has been adapted to run on compressed natural gas CNG. The adaptation of the engine to the CNG supply consisted in the assembly of elements of the gas supply system and elements of its control system. The installed power supply system consists of a stack of four steel cylinders with a total volume of 240 L, a Tomasetto Alaska model 09 evaporator (also acting as a natural gas pressure reducer), injectors and the injector control system which included the Stella Elpigaz controller. The task of the control system is to optimally drive the gas injectors in order to achieve the best possible engine performance, similar to that achieved with petrol. In practice, this means constant, automatic modification of injector control signals as a function of crankshaft speed and engine load. The start of self-adaptation option enables to collect points of the petrol map. On the basis of the readout of the petrol map, the system builds a map of gas injector control. The correction of the opening time of the injectors when supplying the engine with compressed natural gas depends on the speed and load conditions of engine operation. In addition, the system must ensure the correct composition of the combustible mixture, which plays a key role in ensuring the correct course of the combustion process. To a large extent, long term, failure free engine operation depends on its implementation. A diagram of the compressed natural gas supply system is presented in Figure 3.

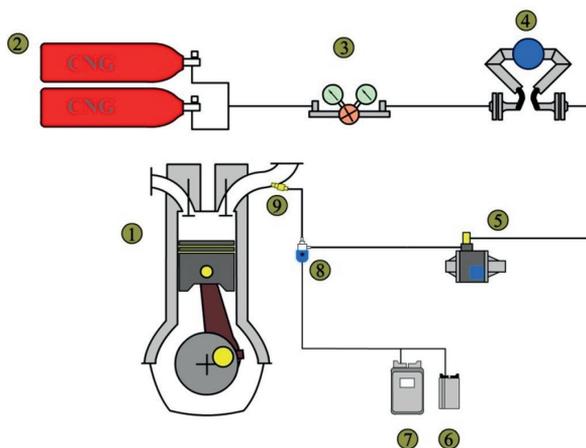


Fig. 3. Scheme of CNG engine supply system: 1 - Fiat 0.9 TwinAir engine, 2 - CNG compressed natural gas tanks, 3 - gas pressure regulator, 4 - Emerson Elite gas flow meter, 5 - evaporator, 6 - gas injector controller, 7 - engine controller, 8 - CNG gas injector in gaseous phase, 9 - spray nozzle in engine intake system

## 5. Scope and test program

The tests were carried out on an engine dynamometer in the Laboratory of Heat Engines at Kielce University of Technology. The aim of the tests was to assess the concentrations

of selected components of exhaust gases when the engine was powered by CNG and petrol. The range of tests included tests of the engine operating according to the load characteristics on the engine dynamometer at a crankshaft speed of 1900 rpm. The engine load on the brake was between 10 Nm and 120 Nm and it was delivered in steps 10 Nm. The tests were carried out with the engine running on CNG and, for the purpose of comparison, with petrol. During the tests, power and torque were measured as were exhaust gas concentrations of: carbon monoxide CO, carbon dioxide CO<sub>2</sub>, HC hydrocarbons and NO<sub>x</sub> nitrogen oxides. Moreover, values of the lambda  $\lambda$  air excess coefficient were recorded and the consumption of petrol and gaseous fuel was measured.

## 6. Test results

The results obtained during the tests of the Fiat 0.9 TwinAir engine on the engine dynamometer were presented in the form of bar graphs enabling the comparison of values obtained for CNG and petrol. Figure 4 shows the values of hourly fuel consumption of the Fiat 0.9 TwinAir engine operating according to load characteristics for a crankshaft speed of 1900 rpm and powering the engine with the tested fuels. At each operating point of the engine, a lower hourly consumption of natural gas was achieved compared to the hourly consumption of petrol. The greatest economic benefits are visible with a low engine load. In the engine load range from 10 Nm to 30 Nm, a fuel consumption reduction of around 20% was achieved when using a natural gas supply.

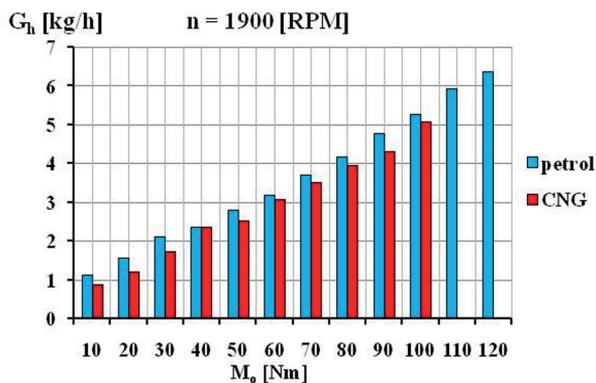


Fig. 4. Hourly fuel consumption of the Fiat 0.9 TwinAir engine operating according to load characteristics with a crankshaft speed of 1900 rpm and supplied with the tested fuels

The results of measurements of specific fuel consumption are shown in Figure 5. The smallest specific fuel consumption was obtained when the engine was powered with compressed natural gas at 90 Nm load. Comparing the unit consumption values for both fuels, it can be stated that it is more advantageous to power the engine with compressed natural gas. Only at one point of operation, at a load of 40 Nm, were higher values of this indicator obtained when supplied with compressed natural gas. When the engine was

supplied with gaseous fuel, the increase of load above 100 Nm caused throttling of the engine and consequently its stalling.

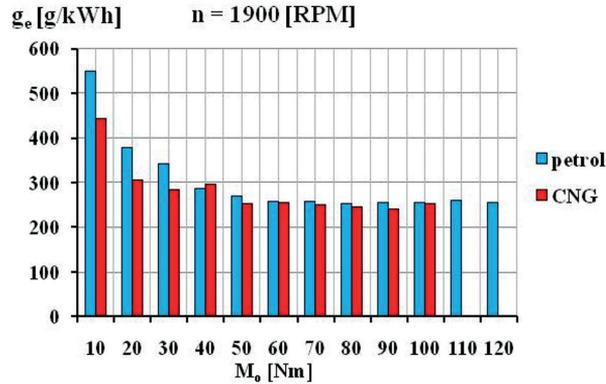


Fig. 5. Specific fuel consumption of the Fiat 0.9 TwinAir engine operating according to the load characteristics for a crankshaft speed of 1900 rpm and supplied with the tested fuels

The highest value of the concentration of carbon monoxide CO in the exhaust gases was obtained during the operation of the engine with a load of 10 Nm and with petrol supply. In the average engine load range, higher values of carbon monoxide concentration in exhaust gases were obtained when the engine was powered with natural gas. Values of carbon monoxide concentration in the exhaust gas of Fiat 0.9 TwinAir engine working according to load characteristics and fuelled with CNG and, for the purpose of comparison, with unleaded petrol of octane number 95 are presented in Figure 6.

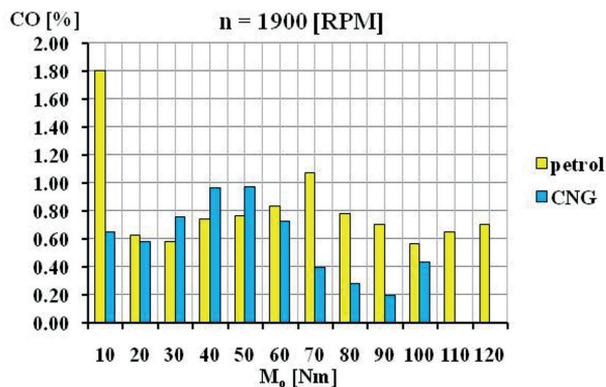


Fig. 6. Carbon monoxide concentration in the exhaust gas of the Fiat 0.9 TwinAir engine operating according to the load characteristics for a crankshaft speed of 1900 rpm and supplied with the tested fuels

In the high load range, the natural gas supply to the engine had a positive effect on the obtained carbon monoxide concentration values. In the case of CNG engine operation in the load range from 70 Nm to 90 Nm, an average decrease of this component by around 56% was obtained in comparison to values obtained in conventional operation.

The values of carbon dioxide concentrations in the exhaust gas are shown in Figure 7. When the engine was running on petrol, similar values of this component were obtained in the exhaust gas at the level of 14% over the entire load range. When the engine was powered with compressed natural gas, the concentration of carbon dioxide in the exhaust gas was significantly lower in comparison to the values of this component obtained when the engine was running on petrol. No significant effect of engine load on the obtained values of carbon dioxide concentration in the exhaust gases has been identified.

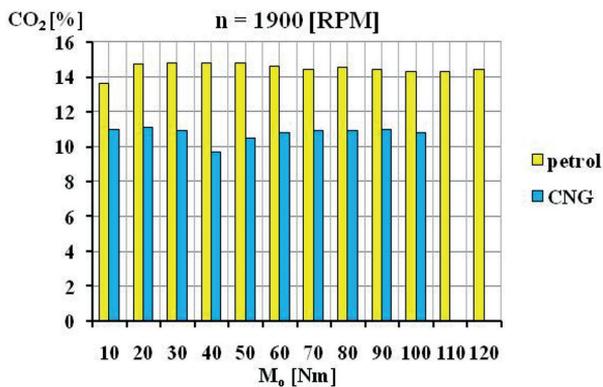


Fig. 7. Carbon dioxide concentration in the exhaust gas of the Fiat 0.9 TwinAir engine operating according to load characteristics for a crankshaft speed of 1900 rpm and supplied with the tested fuels

Figure 8 shows the correlation between the results obtained when fuelling the engine with petrol and CNG with regard to hydrocarbon concentrations in the exhaust gas. An increase in load starting from 10 Nm resulted in a slight decrease in hydrocarbon concentration values for both petrol and gaseous fuels. The lowest concentration of this component in the exhaust gas for running the engine on petrol was obtained at a load of 50 Nm. A further increase in engine load caused a sharp increase in hydrocarbon concentrations in the fumes. The maximum value of the concentration of this component in the exhaust gas was obtained at the maximum load of the engine and when it was fuelled with petrol. Considering the hydrocarbons concentration in the exhaust gases, powering the engine with compressed natural gas was beneficial. The lowest value of the concentration of this component was obtained at a load of 30 Nm and with the engine powered with CNG. The load increase in the average and high load range, as in the case of petrol operation, resulted in an increase in hydrocarbon concentration in the exhaust gases.

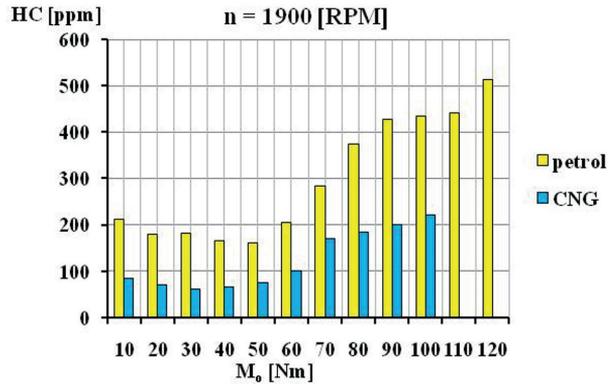


Fig. 8. Hydrocarbon concentration in the exhaust gas of the Fiat 0.9 TwinAir engine operating according to load characteristics for a crankshaft speed of 1900 rpm and supplied with the tested fuels

The CNG supply to the engine has also contributed to the benefit of reducing the concentrations of nitrogen oxides in the exhaust gas, as shown in Figure 9. The concentration value of nitrogen oxides in the exhaust of the Fiat 0.9 TwinAir engine was strongly influenced by its load. The concentration of this component was low with a low engine load of 10 Nm. At such a load, when the engine was powered with petrol, its value reached 139 ppm and only 76 ppm when powered with compressed natural gas. The increase in load caused a significant increase in the concentration of nitrogen oxides in the exhaust gases not only when the engine was powered with CNG but also when the engine was powered with petrol. The maximum concentration values of this exhaust gas component were 2448 ppm for a 90 Nm load when the engine was powered with gaseous fuel and 3487 ppm when the engine was powered with 100 Nm torque and petrol.

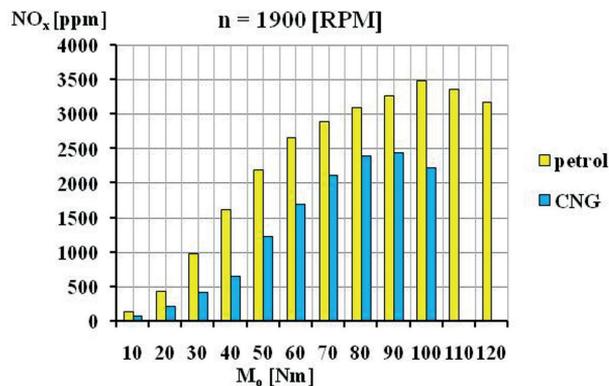


Fig. 9. The concentration of nitrogen oxides in the exhaust gas of the Fiat 0.9 TwinAir engine operating according to load characteristics for a crankshaft speed of 1900 rpm and supplied with the tested fuels

The composition of the flammable mixture was evaluated on the basis of the obtained values of the lambda  $\lambda$  air excess coefficient shown in Figure 10. When the engine is powered with CNG, the prevailing number of points determining the composition of the mixture falls within the range of 1.008 to 1.043. This shows that the engine operates on lean mixtures. The operation of the engine according to the load characteristic and being fueled with unleaded petrol was characterized in most cases by the combustion of rich mixtures. The course of the air excess coefficient value was stochastic and it is difficult to clearly determine the effect of engine load on the obtained values. These values may indicate the need to improve the regulation of the engine while running on compressed natural gas CNG.

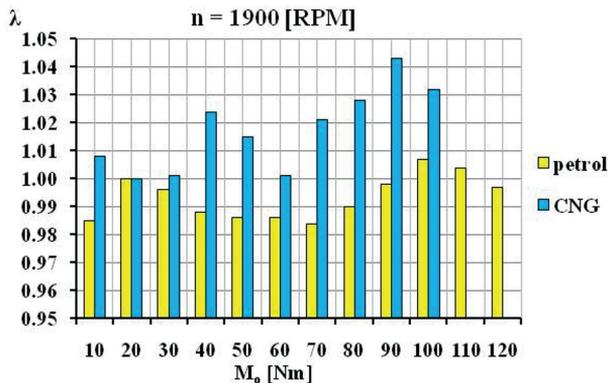


Fig. 10. Values of the Fiat 0.9 TwinAir engine excess air ratio operating according to load characteristics with a crankshaft speed of 1900 rpm and supplied with the tested fuels

## 7. Conclusions

Taking into account the modern technologies of fuel injection and the control of gas supply systems, the possibility of using natural gas offers a solution to the problem of maintaining the use of a very large fleet of cars equipped with piston internal combustion engines. The analysis of the engine exhaust gases when running on natural gas has shown significant benefits in the obtained values of ecological indicators. The combustion of lean mixture resulted in lower concentrations of carbon monoxide, hydrocarbons and nitrogen oxides in the exhaust gases. A reduction in the concentration of carbon dioxide of around 25% and a near 75% reduction in the concentration of HC hydrocarbons was obtained in comparison to the values of these components obtained when fuelling an engine with petrol. The engine was also supplied with compressed CNG gas and this significantly contributed to the reduction in the concentration of nitrogen oxides in exhaust gases. Only at three out of ten operating points of the engine fuelled with CNG was a slight increase in the concentration of carbon monoxide in the exhaust gas achieved. The article also shows the influence of self-regulation of the CNG engine supply system to the intake manifold on the values of air excess coefficient  $\lambda$ . Its evaluation reveals the need to improve the process of preparation

of the flammable mixture by changing the opening time of injectors when supplying the engine with gaseous fuel.

From the point of view of users of vehicles fuelled with CNG, economic considerations are an important aspect of powering the engine with this fuel. The current price of natural gas as vehicle fuel is favorable in comparison to alternative fuels. The barrier to greater interest in this fuel for vehicle users is undoubtedly the small number of CNG gas filling stations. Reducing the harmful impact of vehicles on the natural environment in the era of the current standards of gas emissions in individual member states of the European Union by increasing the number of vehicles powered with compressed natural gas has a legitimate basis, as confirmed by numerous studies and scientific works. The transition period for the transformation of the drive sources in the means of transport to their electric power supply can be significantly filled by powering the previously used heat engines with compressed natural gas. Such a method of powering seems to be a rational alternative for countries where the infrastructure for charging electric cars has not yet been developed and for countries where electrical energy is obtained using traditional technology of burning fossil fuels, mainly hard coal.

## 8. Nomenclature

Gh	hourly fuel consumption
ge	specific fuel consumption
CO	carbon monoxide
CO <sub>2</sub>	carbon dioxide
HC	hydrocarbons
NOx	nitrogen oxides
λ	air excess coefficient

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