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INFLUENCE OF THE MIXTURE COMPOSITION ON THE CONVERSION DEGREE OF CATALYTIC CONVERTER DURING POWER SUPPLY OF THE ENGINE WITH NATURAL GAS

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Abstract

The article tackles with a topic of emission of hazardous components of exhaust gases into the atmosphere and a conversion degree of catalytic converter while supplying the combustion engine with natural gas. The natural gas is an example of alternative fuel for fossil fuel characterized by low weight carbon participation. The supply of combustion engines with gas fuel is realized in one- or two-fuel systems. The results of measurements were presented performed on the post of engine braking stand, in the conditions for preparing loading characteristics for the engine with spark ignition. The parameter which was changed, was the composition of the combustible mixture. On the basis of the measurements, the analysis of influence of combustible mixture was presented onto the contents of hazardous components in exhaust gases as well as efficiency of catalytic operation.

Keywords*: alternative fuel, air excess coefficient, air – fuel mixture, catalytic converter, emission*

1. Introduction

Fast development taking place in many fields of a human being's activity connected with highly advanced technology on one hand facilitates everyday functioning, but, on the other hand, it causes significant degradation of the environment. It affects deterioration of living conditions of all living organisms. Therefore, more and more commonly limitations are introduced concerning negative impact of a human being's operation on the surrounding environment. Among the fields which are subject to the strictest restrictions there is automobile industry, where subsequent standards to limit emission of hazardous substances into the atmosphere are systematically introduced. It forces the necessity to implement far-reaching changes in construction and equipment of the engine in order to reduce the fuel consumption as well as the improvement of the creation process of combustible mixture so as to obtain combustion process parameters as close to complete and total combustion as possible. In addition, also non-engine limitation methods of hazardous substances into the atmosphere are used, mainly by means of purifying exhaust gases discharged from the engine. However, they are not sufficient ones, therefore, alternative motorization energy sources for fossil fuel are introduced. In order to obtain a positive effect in the form of reducing emission of hazardous substances into the environment, this fuel should be taken into account which is characterized by low weight carbon participation [3, 12]. The natural gas is an example of such a fuel, characterized by high energetic value and octane number, however lower density than petrol or diesel fuel.

The supply of combustion engines with gas fuel is realized in one- or two-fuel systems. The one-fuel system will be adjusted much better to combust gas fuel, as there will be no necessity to obtain a compromise between combustion process parameters optimum for the liquid fuel and for the gas fuel, the physical-chemical properties are different. However, factory-mounted systems should be differentiated, which more and more frequently appear in the offer of automobile companies, from so called cover installations which dominate on the personal cars market. The introduction of a version with two-fuel supplied engine by the manufacturer onto the market is a consequence of parameters' optimalization of the engine's operation resulting from the research conducted [11]. In case of cover installations used for many engines which differ in technical solutions and working parameters, it is hard to speak about optimum work of the system, and only about better or worse adjustment thereof. Even more, that the user is interested, to a large extent, in the best exploitation parameters and low costs of the vehicle's usage. As a result, the usage of the fuel, the chemical composition of which is beneficial from the ecological point of view, may not give a positive effect due to improper adjustment of engine's operation parameters to the fuel.

The supply of the engine with natural gas limits the emission of carbon dioxide into the atmosphere due to low contents of carbon therein. Simultaneously, the emission of methane is significantly higher and constitutes about 70 – 80 % hydrocarbons emitted in exhaust gases while during supplying the engine with petrol, it does not exceed 10 %. Methane, the same as carbon dioxide is included into the gases which contribute to the greenhouse effect to occur [7,8,11,12]. Additionally, conversion degree of methane in catalytic converters is low, significantly deviating from oxidation of higher hydrocarbons [4].

While supplying the engine with natural gas, stechiometric composition or poor mixtures are used [6]. Therefore, results of measurements and analyses were presented concerning the influence of the composition of the mixture onto the contents of hazardous substances in the exhaust gases and onto the conversion degree in catalytic converter.

2. Measurement stand

The measurements were performed on the test stand in the laboratory of combustion engines at University of Science and Technology. The stand is equipped with torque dynamometer of Schenck W130 type. A four-cylinder combustion engine was used for conducting the measurements with sparkle ignition Fiat 170A1.00 with stroke capacity of 900 cm^3. The engine is equipped with standard petrol supply system and in the system which enables to supply with natural gas. The amount of the natural gas provided to the engine is steered by means of the gas supply regulator, which allows for changing the composition of the mixture while supplying with natural gas. In the inlet system of the engine, the airflow meter and thermocouple were mounted. The thermocouples were placed also in the engine's cooling system and in the exhaust system – in exhaust manifold and behind catalytic converter. In addition, the stand is equipped with a system for volumetric measurement of liquid fuel consumption, flow system of gas fuel consumption and analyser of exhaust gases of Capelec CAP 3201 type (Fig.1).

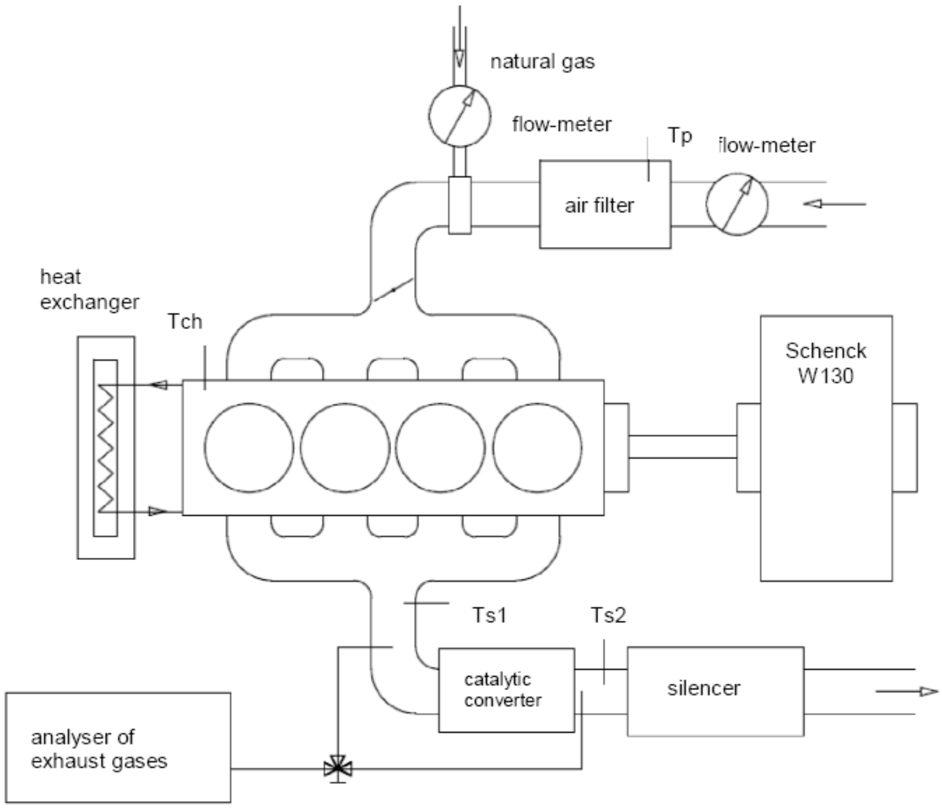

Fig. 1. Schema of the test stand.

3. Methodology of conducted measurements

The assumed methodology of measurements included registration of parameters of the natural gas-supplied engine with a constant working speed of 3000 1/min and constant loading of the engine. The parameter which was changed, was the composition of the combustible mixture, which was obtained while steering the location of the step engine placed in the natural gas supply system. The regulation of the mixture composition required to have the lambda probe disconnected. In each measuring point, the consumption of fuel, air mass stream, composition of fuel and temperature in the inlet, outlet and cooling system were measured. The measurements were conducted by means of making registration of volumetric concentration of exhaust gases' components in front of the catalytic converter and then behind it.

On the basis of the results of the measurements, the analysis was conducted on the influence of mixture's composition on the composition of exhaust gases of the engine supplies with natural gas as well as on the efficiency of catalytic converter operation.

4. Analysis of measurements' results

The usage of the exhaust gases' analyser Capelec CAP3201 allowed to register the volumetric concentration of particular components of exhaust gases, which referred to the volume of dry exhaust gases. Therefore, in order to calculate the emission of particular exhaust gases' components, the volume of dry exhaust gases should have been calculated [1,2,9].

As the high-methane natural gas with methane concentration amounting 96-98 % is the gas used, it was assumed for the calculations that its composition constitutes 100 % of methane.

On the basis of volumetric values of dry exhaust gases (V_{sps}) calculated for each measuring point and measured volumetric fuel consumption ($\dot{V}_e$) and volumetric concentration of particular components of the exhaust gases, the volumetric, and then weight shares were obtained of particular exhaust gases' components, which were referred to the engine power obtained during measurements [2,10,12].

The results of the measurements and calculations were presented in the form of diagrams. The works conducted aimed at analyzing the composition of the combustible mixture with supplying the engine with natural gas onto the emission of hazardous components in the exhaust gases, as a result, the data on the diagrams is presented as a function of air excess coefficient λ.

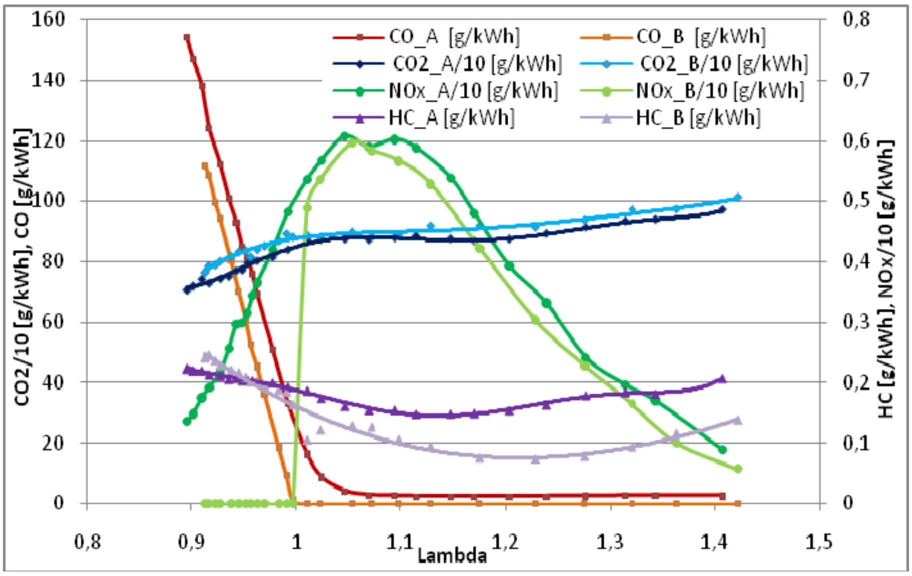

Fig. 2. Emission of carbon oxide (CO), carbon dioxide (CO_2), hydrocarbons (HC) nitric oxides (NO_x) in the function of air excess coefficient (λ) with the engine supplied with natural gas, measured before the catalytic converter (A) and behind catalytic converter (B).

On the figure 2, the emission of carbon dioxide, carbon oxide, hydrocarbons and nitric oxides were presented before and behind catalytic converter. In the scope of air excess coefficient (λ) from 0,9 to 0,95, emission of CO behind the converter is lower by 15 – 20 %, however, both before and behind the converter, it is very high. From the value λ = 0,95 the difference increases until the full conversion of CO in the converter with λ = 1. Simultaneously, the value of CO emission measured before the converter decreases in the scope 8 times and in the range of the λ coefficient from 1,1 to 1,4 has a constant value, which does not exceed 2,8 g/kWh. The emission of CO_2 behind the converter in the whole scope of the air excess coefficient is higher by about 1 to 8 %, which results from the oxidation of CO in catalytic converter. The emission of HC in the whole scope of air excess coefficient does not exceed the value of 0,22 g/kWh. The exception is, in the narrow scope of the λ coefficient (0,9 – 0,93), the emission behind the converter, which slightly exceeds the value and the emission value before the converter reaching up to 0,24 g/kWh. An increase of the HC emission value, both before the converter and behind it, with λ higher from 1,2 results from reducing the speed at which the combustion reaction takes place caused by a significant excess of the air in the combustion chamber. The emission of nitric oxides changes in the wide scope of values depending on the air excess coefficient. Full conversion takes place only in the range λ from 0,9 to 0,99, after which a rapid increase of emission takes place to the maximum value of about 6,0 g/kWh with λ = 1,07. With the air excess coefficient value λ = 0,95 in the engine's exhaust system, the exhaust gases' temperature starts to raise (Fig. 3). In the exhaust manifold, the exhaust gases; temperature changes from the value 690 ^{0}C to 715 ^{0}C with λ from 0,99 to 1,04, and then it reduces its value down to 700 ^{0}C with λ = 1,1, reaching in a further range the value of about 690 ^{0}C. As a result of the combustion temperature's increase, the emission of NO_x goes up, to reach values above 5,0 g/kWh in the scope of the air excess coefficient λ from 1,0 to 1,15, whereas, maximum value is about 6,1 g/kWh. From obtaining the stechiometric mixture, the difference in emission of NO_x before and behind catalytic converter amounts to about 5 – 10 %.

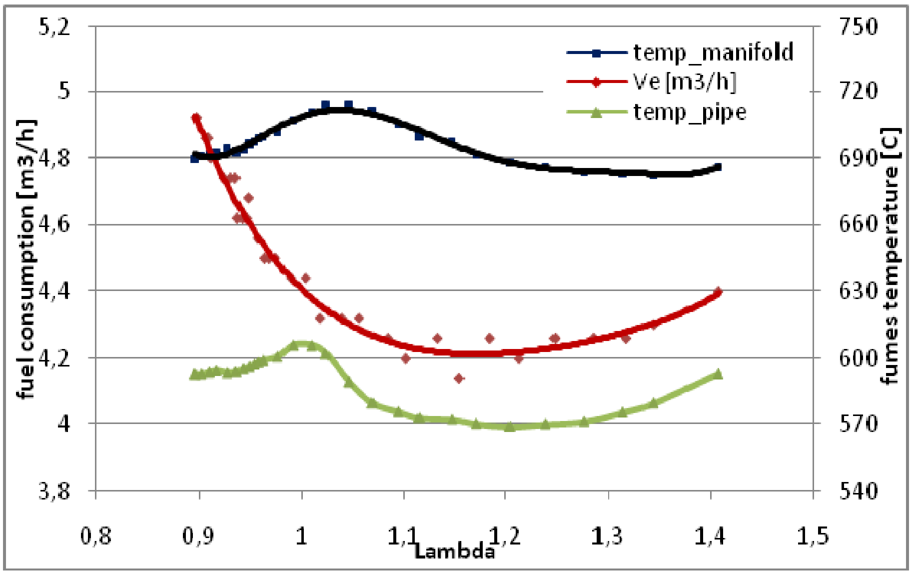

Fig. 3. Consumption of natural gas and exhaust gases' temperature in exhaust manifold and behind catalytic converter in the function of the air excess coefficient function (λ).

On the measurement position, a three-way catalytic converter is mounted, which is characterized by the best operation with the stechiometric composition of the mixture, as there is no competition between NO_x and O_2 then for oxidation of carbon oxides and hydrocarbons. When the mixture is poor in contents, there drop of efficiency takes place in nitric oxides' reduction, whereas when the mixture is rich, it causes a drop of hydrocarbons and carbon oxides' oxidation [4]. The conversion degree of toxic components of exhaust gases is influenced also by exhaust gases' temperature [4,5]. The measurements were performed in stabilized working conditions, therefore, the temperature in the exhaust manifold was in the range from 680 to 715 ^{0}C, whereas behind the catalytic converter between 570 and 610 ^{0}C (Fig. 3). It means that catalytic converter worked in temperatures' range which was optimum for the conversion process.

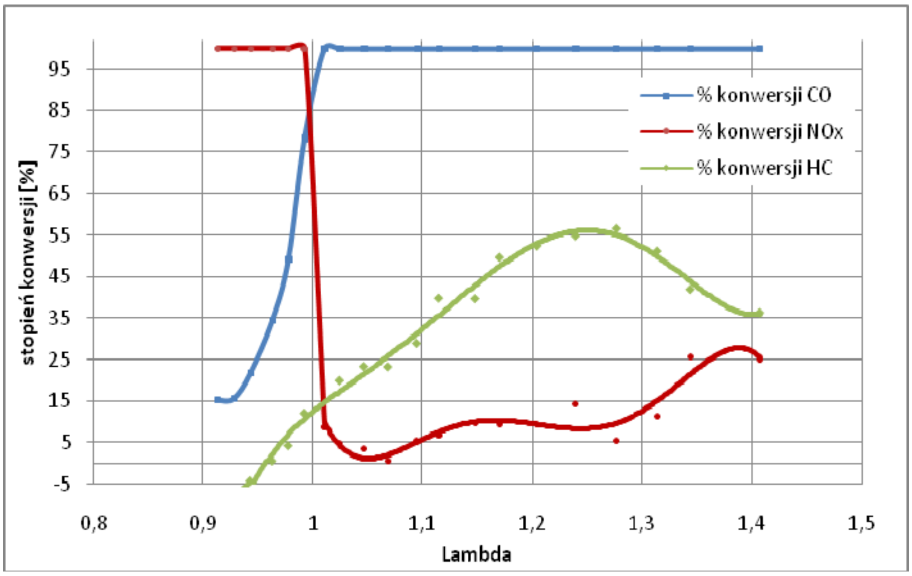

Fig. 4. Conversion degree of toxic components of exhaust gases in catalytic converter in the air excess coefficient function (λ).

Conversion degree of toxic components of exhaust gases in catalytic converter was presented in the figure 4. For stechiometric mixture (λ = 1), conversion degree of carbon oxides amounts to 89 %, nitric oxides 61 %, and hydrocarbons 14 %. Conversion of CO equal to 100 % takes place from the value of λ = 1,01, whereas for NO_x up to the value of λ = 0,99. In case of HC, maximum of conversion degree amounts to 57% and is obtained with λ = 1,27.

5. Summary

The manufacturers of vehicles, more and more often decide to place vehicles with two-fuel supplied engine – petrol and natural gas or only with natural gas, among versions of a given model. It results from the necessity to reduce unfavorable impact of automobile industry on the environment and the economic needs of vehicles' exploitation, which is expected by the users. Brand new mounted system is characterized by precisely adjusted working parameters of the engine to the fuel used, which in case of so called cover systems of gas supply is difficult to obtain, as a result, not necessarily it will give a positive ecological effect.

On the post of engine brake stand the emission measurements of harmful components of exhaust gases were conducted depending on the air excess coefficient being the representative of the older generation of construction solutions, to which natural gas supply system was adjusted.

The emission of carbon dioxide in the analysed period of air excess coefficient was very high, however the same engine supplied with petrol showed even higher emission of carbon dioxide which results from significantly lower contents of coal in natural gas.

There was a similar situation in case of emission of nitric oxides, which was also high in the whole period tested and simultaneously lower than with supply with petrol, which is also the consequence of the fuel's chemical composition. An increase of temperature in the combustion chamber with air excess coefficient about 0,95 caused a rapid increase of contents of NO_x in exhaust gases caused with achieving a thermal-dynamic balance of the component. Simultaneously, a conversion degree with poor mixture is very low. The reasons are thermal conditions, low contents of CO and HC in fumes resulting from chemical composition of fuel and presence of oxygen in exhaust gases, which comes in reaction easier with CO and HC than oxygen created from NO dissociation. Obtaining lower emission value of these components required optimalization of combustion process and increase in compression degree during supplying engine with natural gas.

Volumetric concentration of carbon oxide in raw exhaust gases, in the supply range of the engine with poor mixture, from the air excess coefficient 1,1 was very low. Whereas, in the range from the stechiometric mixture to rich one, emission of carbon oxide grew very rapidly to obtain 8-times higher value. A low conversion degree of CO for rich mixtures results from shortage of oxidizer in exhaust gases.

As the main component of natural gas is methane, variety of hydrocarbons included in exhaust gases is significantly limited with reference to liquid fossil fuels. Also, the number of hydrocarbons in exhaust gases is lower, which is a favorable phenomenon, as they constitute the most difficult component of exhaust gases to remove [4]. Emission of hydrocarbons in the whole range of measurements was very low, but also conversion degree of the component in catalytic converter was not high. It proves high contents of methane in exhaust gases, being the hydrocarbon which oxidized most difficult [4]. In addition, methane, similarly as CO_2, belongs to a group of greenhouse gases, the emission of which is also limited.

From the point of view of emission of particular components of exhaust gases in raw ones, as well as from the point of view of engine's efficiency, its supply with poor mixture of natural gas with air with air excess coefficient of 1,2 seems to be most favorable. However, it would require to replace three-way catalytic converter of TWC type into three-way one – a trap of nitric oxides (LNT) [5]. In order to make a full analysis of influence of composition of combustible mixture onto the composition of exhaust gases, in order to select an optimum scope of air excess coefficient, the measurements for other points of the engine's operation should be conducted.

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