Improving the tests of catalytic converters accounting for the relationship between the composition of the working mixture entering the engine combustion chamber and CO and CH in exhaust gases

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Abstract. The article presents results of the study aimed to establish the relationship between the working mixture entering the engine combustion chamber and CO and CH in the exhaust gases. On the basis of the theory of fuel combustion in the engine chamber and the systematic approach, and using the mathematical methods, the fuel combustion in the combustion chamber is analyzed at low ambient temperatures to decrease emissions of carbon monoxide and hydrocarbons. The criterion for optimizing the tests of catalytic converters is substantiated for low temperatures - temperatures of the heat flow of the mixture at the exit from the combustion chambers of the engine cylinder. The limitation is the warm-up time of the catalytic converter when testing it on vehicles operating at low temperatures and the standards for the content of CO and CH in the exhaust gases of a passenger car engine. The application of the methods and the mathematical model can be the basis for supplementing UNECE Regulation No. 83-06 and improving the VI type test method for vehicles operating at low ambient temperatures.

1. Introduction

The relevance of theoretical and methodological approaches to improving the tests of catalytic converters taking into account the operation of cars at low temperatures is due to the fact that the issue of impacts of transport on the environment is crucial. The main documents containing answers to these impacts are part of the projects of residential developments in large cities.

Test methods are proposed in UNECE Regulation No. 83-06. Particular attention is paid to the VI type test method, as the test ambient temperature should be 266 K (−7 °C) ± 3 K, which is significantly different from the operating conditions.

In Russia, the Federal Project "Clean Air" has been developed as part of the national project "Ecology", aimed to reduce the level of air pollution in large industrial centers. Reducing the volume of emissions by 20% can help to prevent diseases [1].

UK scientists argue that increased emissions from the cold start increase the health burden associated with exposure to NO2. The assessment should take into account the influence of weather conditions on car engines [2].
The generation of carbon monoxide from the decomposition of CO\textsubscript{2} is now more important than ever before due to the continuous increase in its level [3]. Existing and legally approved methods are aimed at conducting tests in laboratory conditions, which differ from the operating ones. It is necessary to develop a new approach to amend UNECE Regulation No. 83-06 and improve the VI type test method.

2. Materials and Methods
The review of works on the use of catalytic converters showed that the studies deal with the effectiveness of catalysts.

To improve the efficiency of the catalytic converter under cold start conditions, Massaguerb, Pujola, Comamalaa, and Massaguera [4, 5] suggested using a thermoelectric generator, connected to an exhaust gas heater. Hamedi, Doustdar, Tsolakis, and Hartland [6] developed a thermal energy storage system used in combination with the exhaust gas aftertreatment system.

The review showed that studies on the composition of the working mixture entering the combustion chamber of a passenger car engine and CO and CH describe
- modified polymer sulfonic cation exchangers and their use with the aim to improve the efficiency of systems for cleaning exhaust gases from nitrogen oxides [7];
- the use of hydrogen-containing mixtures [8, 9];
- replacement of traditional hydrocarbon fuel with cryogenic liquids or cryogenic liquids [10];
- methods for timely diagnostics of engines to ensure the required environmental parameters in exhaust gases [11].

Gritsenko, Almetova, Anoshina, and Lykov [12] suggested using portable gas analyzers built into the exhaust system to monitor changes in the amount of CO, CH in engine exhaust gases.

It is suggested using a tool for providing test modes of diagnostics - an additional loader for gasoline engines DBD-4 [13].

Studies on the optimization of mathematical models to ensure the required environmental parameters in the exhaust gases of cars use various efficiency indicators.

Gritsenko, Glemba, and Salimonenko [14] recommend using technical, technological and economic parameters to assess the reduction of exhaust gas toxicity. The method aimed to regulate the engine displacement at partial loads was evaluated in terms of fuel economy and costs [14].

Chenga, Jianga, Wua, Lia, Xua, Dengaa, and Lib [15] suggested using the performance of various systems as an optimization criterion. The optimization process is based on the improved algorithm for optimizing genetic particles, the comparison was conducted by technical and exergoeconomic indicators.

To calculate the completeness of fuel combustion, Shaikin and Galiev [16] developed a formula that takes into account the state and equality of pressures in the burned and unburned areas of the combustion chamber.

Abbasov [17] suggested using the volume of emissions of harmful substances to assess the toxicity of the Volkswagen Passat car.

S. Sabatini, S. Gelmini, M.A. Hoffman, and S. Onori [18] developed a model of oxygen accumulation for the three-pass catalyst, which makes it possible to determine its efficiency taking into account the influence of the time factor on oxygen accumulation.

S. Kannepalli, A. Gremminger, and S. Tischer [19] improved the spatial distribution of the load for a fixed amount of precious metal in order to maximize the efficiency of chemical conversion during the transient operating mode of the catalytic converter.

A variety of theoretical and methodological approaches to the development of the theory of fuel combustion in the car engine chamber speak for the relevance of the present study, and allow us to supplement the existing approaches with our own one taking into account the operation of vehicles at low temperatures.

3. Results and discussion
The theoretical significance is due to an attempt to improve tests of catalytic converters, taking into account the relationship between the working mixture entering the combustion chamber of the car engine and CO,
CH in the exhaust gases. When testing catalytic converters in real operating conditions, it is necessary to take into account the composition of the working mixture and values of CO, CH in the exhaust gases (Fig. 1).

Figure 1. The relationship between the composition of the working mixture entering the combustion chamber of a car engine and CO, CH indicators in the exhaust gases

This work uses the methods of the theory of fuel combustion and the systematic approach to determine the temperature of the heat flow of the mixture at the exit from the combustion chambers and to ensure the required environmental performance when testing catalytic converters (formulas (1), (2)).

\[ E = \sum_{i=1}^{I} HFT_i \rightarrow \text{max}, \]

where \( HFT_i \) – temperature of the heat flow of the mixture at the exit from the combustion chamber of the \( n \)-th cylinder, °C; \( i \) is the number of the cylinder; \( I \) is the amount of cylinders of the car engine.

\[ HFT_i = \frac{Q_{sl} / \dot{m}}{C_v \cdot G_v}, \]

where \( Q_{sl} \) – heat flow leaving the combustion chamber of the \( n \)-th cylinder at the \( j \)-th time, W; \( C_v \) – specific heat capacity of exhaust gases, J/(kg·K); \( G_v \) – mass flow rate of exhaust gases, kg/s; \( j \) – time to reach the average level of CO and CH according to the current requirements in exhaust gas emissions after starting the cold engine, s; \( j = 1/c \).
where $Q_{\text{enter}}^{EGL_J}$ – heat flow from the i-th cylinder brought with the exhaust gases into the catalytic converter at the j-th time, W; $Q_{\text{CAT}}^{J}$ – heat flow released in the catalytic converter reactor as a result of the exothermic reaction of oxidative catalysis at the j-th time, W; $Q_{\text{exit}}^{EGL_J}$ – heat flow carried away from the neutralizer with exhaust gases at the j-th time, W; $Q_{\text{ENV P}}^{J}$ – heat flow transferred to the environment through the neutralizer body at the j-th time, W; $Q_{\text{heat J}}$ – heat flux from the i-th cylinder spent on heating the structure of the catalytic converter at the j-th time, W.

$$m_{\text{mat}} C_{\text{mat}} \frac{dT}{dz} = \alpha_{EGL_J} F_{\text{wails}} (T_{\text{wails}} - T_C);$$  

$$j_z = - \frac{m_{\text{mat}} C_{\text{mat}} \ln \theta_z}{F_{\text{wails}}};$$  

$$j_{\text{heat}} = \sum_{z=1}^{Z} j_z;$$

where $m_{\text{mat}}$ – mass of the material of the walls of the catalytic block, kg; $C_{\text{mat}}$ – specific heat of the material of the walls of the catalytic block, J / (kg · K); $\alpha_{EGL_J}$ – temperature coefficient in the z-th elementary section of the catalytic converter; $T_C$ – current value of the catalyst wall temperature, K; $T_{\text{wails}}$ – catalytic converter warm-up time, s; $T_{\text{wails}}$ – warm-up time of the z-th elementary section of the catalytic converter, s; $Z$ - number of elementary sections of the catalytic converter.

When testing catalytic converters, it is necessary to take into account the fuel consumption when the car engine is running, the composition of the working mixture entering the combustion chamber of the car engine and CO, CH indicators in the exhaust gases (Fig. 1). Fuel consumption per hour (kg / h) is determined by formula:

$$G_T = N_e \frac{3600}{H_u \eta_e}$$

where $N_e$ – idle engine power, kW; $H_u$ – lower heat of combustion of fuel, MJ/kg. For automobile gasoline $H_u = 43,93$ MJ / kg; $\eta_e$ – effective engine efficiency.

In [20], it was proved that the impact of temperatures of open storage of cars on the heating time of the catalytic converter, taking into account the current standards for the content of CO and CH in the exhaust gases can be determined experimentally.

Using the developed mathematical model, tests were conducted on LADA VESTA (VAZ-21129 engine). They established that at -30 °C, the heating time for the catalytic converter to the temperature at which CO and CH afterburning is 385 seconds; the average consumption fuel amounted to 1.48 l / h.

4. Conclusions

The article described the approach whose application can improve the testing of catalytic converters, taking into account the relationship between the composition of the working mixture entering the combustion chamber of a car engine and CO, CH indicators in the exhaust gases.

The novelty of the research is due to the following findings:

- the average fuel consumption when the engine is idling and its value in real testing conditions were determined;
- the mathematical model for testing catalytic converters, taking into account the relationship between the composition of the working mixture entering the combustion chamber and CO, CH indicators was developed.
The practical significance of the research results is due to the application of the approach for supplementing UNECE Regulations No. 83-06 and improving the VI type test method under open storage of cars in terms of determining fuel consumption when the ambient temperature changes to the temperature of CO and CH afterburning.

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