The influence of thermal pressure on the catalytic properties of SHS converter blocks during pre-start preparation of a diesel engine

Alla Melbert[1*], *Alexander* Mashensky[1], *Alexander* Scherbakov[2], *Ilgiz* Razetdinov[3], and *Airat* Safin[3]

[1]Polzunov Altai State Technical University, Barnaul, 656038, Russia
[2]Saint Petersburg State University of Architecture and Civil Engineering, Saint Petersburg, 190005, Russia
[3]Kazan Federal University, Kazan, 420008, Russia

Abstract. The study is aimed at solving the important environmental problem of reducing harmful exhaust gas emissions from diesel engines with pre-heaters when operating at subzero ambient temperatures. The issue of cleaning the exhaust gases of the pre-heater in the catalytic converter during the heating of the catalytic units during the pre-start preparation period of the 8Ch12/12 diesel engine is considered. It was found that an increase in the specific heat flow and volumetric thermal gas pressure on the porous SHS catalytic material leads to an improvement in catalytic properties in exhaust gas purification processes. An increase in heat flow from 1589 to 3807 mJ/(m^3×h) led to a decrease in the estimated values of harmful emissions: nitrogen oxides – by 1.6 times; carbon monoxide – 1.9 times; hydrocarbons – 1.23 times; solid particles - 2.1 times. It was revealed that when the exhaust gas temperature changed from 650 to 810 K, the efficiency of cleaning from solid particles increased from 50 to 75%, from nitrogen oxides - from 20 to 83%, and carbon monoxide - from 53 to 75%. An increase in the quality of hydrocarbon purification is noted up to 790 K; the quality of purification changes from 32 to 47%.

1 Introduction

Environmental pollution is caused by many factors of human activity, however, one of the main ones is internal combustion engines and, in particular, diesel engines. Internal combustion engines, including diesel engines, emitting large amounts of harmful substances, create a major economic problem and have a harmful effect on living organisms and the general state of the natural environment [1,2,3,4].

The relevance of this study is to solve the important environmental problem of reducing harmful emissions from exhaust gases during the pre-start preparation of diesel engines at subzero ambient temperatures.

*Correspondingauthor: aamelbert@mail.ru

The use of catalytic converters simultaneously from diesel engines and preheaters in exhaust systems is not sufficiently described in published sources and requires detailed consideration [4].

During the pre-starting period, the catalytic units of the converters must be heated from ambient temperature to operating temperatures in order to ensure the efficiency of gas purification.

When operating diesel engines at subzero ambient temperatures, it is necessary to keep in mind that in some cases it is possible that pre-start heaters may also be involved during the period of post-start warming up of diesel engines. It is then necessary to consider emissions from diesel engines and preheaters simultaneously. Therefore, there is a need to consider the issue of cleaning the exhaust gases of the pre-heater in the catalytic converter during the heating of the catalytic units during the entire period of pre-start preparation [2,3,4,6-8].

Directing the exhaust gases of the preheater into the catalytic converter serves to perform two tasks simultaneously: cleaning them from products of incomplete combustion and nitrogen oxides and using their heat for preheating the catalytic units [4]. During the pre-start period, the catalytic units of the converters must be warmed up to operating temperatures to ensure efficient exhaust gas cleaning. It should be borne in mind that for most converters the operating temperatures are in the range of 420...520 K. Such temperatures of the catalytic units without preheating the converters, especially under conditions of diesel engine starts at subzero temperatures, are achievable only after long-term post-start warming up with diesel exhaust gases. At start-up, idle and light load modes, a thermally unprepared converter operates ineffectively [2,3,4,6,8].

2 Materials and methods

According to previously conducted studies, the 8Ch12/12 diesel engine (α = 1.7; G_T = 53 kg/h; T_K = 360 K; P_K = 0.17 MPa) emits up to 850 m^3/h of exhaust gases. Considering that the exhaust gas converter was designed for use both for naturally aspirated and supercharged diesel engines, assuming that exhaust gases were directed to the converter from the preheater, the gas flow rate was set at 950 m^3/h.

To study the effect of thermal pressure on catalytic units and the quality of exhaust gas purification, tests were carried out on a stationary stand equipped in accordance with GOST. It is difficult to study the influence of the temperature of SHS-catalytic porous permeable blocks of converters during the pre-heating of a diesel engine. Therefore, the temperature of the SHS catalytic units was simulated and maintained by supplying air to the inlet of the converter from the preheater during the post-start period.

An experimental study to determine the influence of thermal pressure on catalytic blocks manufactured using self-propagating high-temperature synthesis (SHS blocks) on the quality of purification of exhaust gases of an 8Ch12/12 diesel engine in a catalytic converter was carried out during winter operation at an ambient temperature T_o = 248...250 K, pressure P_o = 758 mm Hg. Art., relative air humidity W_o = 76%, air speed V_v = 5 m/s.

The experiment was carried out over one day, pre-heating was 24...25 minutes and the temperature of the oil in the sump during this time was 263 K, the temperature of the coolant at the outlet of the block was 300 K, the temperature of the catalytic blocks was 593 K.

To conduct the experiment, the following retrofitting of the stationary stand was carried out:

- Installation of pre-start liquid heater PZD-30;
- Installation of a gas exhaust tray under the oil sump;
- Equipping the engine with a gas outlet route from the tray to the gas distributor of the catalytic converter;

– Installation of thermocouples on the catalytic converter on the external surfaces on the gas inlet side.

3 Research results and their discussion

The reaction rates in the processes of catalytic purification of exhaust gases of internal combustion engines are determined largely by the thermal pressure on the surface of the catalytic materials of the converters. Previously, the authors determined the specific surface areas of catalytic materials of SHS blocks with different porosities. For such a material with a porosity of 40% and a specific gravity of 1600 kg/m^3, the specific surface area was $110 \cdot 10^3$ m^2/kg.

Therefore, the thermal pressure on the surface of the catalytic block was determined taking into account its specific surface area. In order to determine the influence of heat flow and heat pressure in catalytic blocks on the quality of diesel exhaust gas purification, a study was carried out on blocks with a total material surface area of $374 \cdot 10^3$ m^2. The optimal mass of the catalytic material was previously selected as a result of modeling and experimentation [2-4].

As a result of experimental studies of blocks with a volume of 0.00107 m^3, it was found that, depending on the temperature of the exhaust gases and changes in their flow rate along the load characteristic at 2200 min^{-1}, the specific heat flux changes from 449.764 to 1077.512 mJ/h, and the thermal pressure on the surface from 1589 to 3807 mJ/(m^3×h) (Table 1).

Table 1. Change in the specific heat flow of gases to a porous SHS block.

Exhaust gas temperature T_{OG}, K	Exhaust gas consumption V_{OG}, m^3/h	Exhaust gas density ρ, kg/m^3	Exhaust gas mass flow, G_{OG}, kg/h	Heat capacity Cv, kJ/kg×deg	Exhaust gas heat flow Q_{OG}, mJ/h	Volumetric specific thermal pressure of exhaust gases σ_{OG}, mJ/(m^3×h)
532	622	0.678	422	30.97	449.764	1589
633	656	0.561	368	32.31	598.967	2116
683	688	0.519	358	32.85	689.122	2435
773	724	0.459	332	34.25	855.718	3024
880	764	0.403	308	35.90	1077.512	3807

With an increase in the specific heat flow, the manifestation of the catalytic properties of the SHS material was observed.

Table 2 shows data on the influence of the specific thermal pressure on the catalytic units and on the specific indicators of harmful emissions of the 8Ch12/12 diesel engine with a heated catalyst and compares them with EURO standards.

From the data in Table 2 it follows that an increase in the thermal pressure on the catalytic units from 1589 to 3807 mJ/(m^3×h) leads to a decrease in the values of the estimated indicators of harmful emissions: nitrogen oxides - 1.6 times; carbon monoxide – 1.9 times; hydrocarbons – 1.23 times; solid particles - 2.1 times.

The heating capacity with exhaust gases of the 8Ch12/12 diesel engine is 1077 mJ/h at full power, and of the PZD-30 preheater is 157 mJ/h. However, taking into account the losses and operating time of the latter up to 25 minutes. pre-heating of the catalytic units can be carried out [5].

Table 2. The influence of specific thermal pressure on catalytic units and specific indicators of harmful emissions of 8Ch12/12 diesel engine with a heated catalyst.

Estimatedemissions	Values of estimated indicators, g/(kWh)									Multiplicity of excess of permissible estimated emissions according to EURO and RF standards At σ_{OG}=3807mJ/(m³×h) EUROIII/IV/V//VI/RF
	Acceptable levels					Emission levels				
							σ_{OG}, mJ/(m³×h)			
	EURO III	EURO IV	EURO V	EURO VI	for Russia (from 2021)	Without CC	1589	2435	3807	
$q_E NO_x$	5.00	3.50	2.00	0.40	6.00	8.86	6.38	4.43	3.99	0.8/1.14/1.99/9.98
q_E CO	2.10	1.50	1.50	1.50	3.50	4.93	2.37	2.22	1.23	0.59/0.82/0.82/0.82/0.35
q_E CH	0.60	0.46	0.25	0.13	0.40	1.23	0.80	0.70	0.65	1.08/1.42/2.61/5/1.63
q_E HP	0.10	0.02	0.02	0.01	0.10	0.40	0.19	0.16	0.09	0.9/4.5/4.5/9/0.9

The graphs in Figure 1 show the influence of the heating temperature of the catalytic SHS blocks on the efficiency of cleaning the exhaust gases of the PZD-30 pre-heater from harmful emissions in the catalytic converter.

It was revealed that for each of the components intensive cleaning begins at different heating temperatures. Thus, purification from hydrocarbons begins from 630-640 K, from carbon monoxide - from 530-540 K. The reduction in the content of solid particles occurs up to a temperature of 735 K to 50% due to filtration and up to 89% due to catalytic burnout. Purification of gases from nitrogen oxides was observed from a temperature of 425 K, then sharply increased with increasing block temperature to 635 K and then stabilized with an increase in temperature to 880 K to δ_{NOx} = 73-89% [2].

4 Conclusion

An increase in the specific heat flow and volumetric thermal gas pressure on the porous SHS catalytic material leads to a significant pronounced manifestation of catalytic properties in exhaust gas purification processes and an improvement in the quality of purification.

When the exhaust gas temperatures changed from 650 to 810 K, the efficiency of cleaning from solid particles increased from 50 to 75%, from nitrogen oxides - from 20 to 83%, and from carbon monoxide - from 53 to 75%. An increase in the quality of hydrocarbon purification is noted up to 790 K; the quality of purification changes from 32 to 47%.

The catalytic converter in the preheater exhaust system significantly reduces harmful emissions into the environment [9].

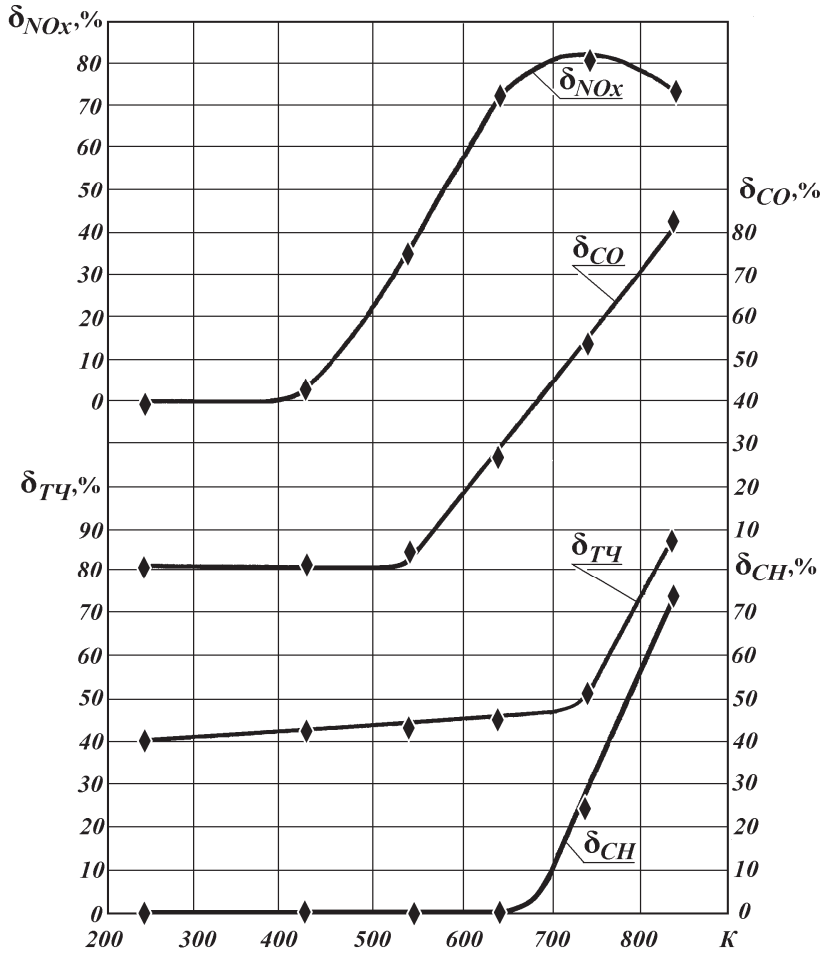

Fig. 1. Influence of heating temperature of catalytic units on the efficiency of purification of PZD-30 exhaust gases from harmful emissions.

An increase in the thermal pressure on the catalytic units from 1589 to 3807 mJ/(m^3×h) leads to a decrease in the estimated values of harmful emissions: nitrogen oxides – by 1.6 times; carbon monoxide – 1.9 times; hydrocarbons – 1.23 times; solid particles - 2.1 times.

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