Effects of 8Ч12/12 catalytic converter prestarting on harmful emissions at negative ambient temperatures

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Abstract. We consider the possibility of reducing the harmful emissions of diesel engines at negative ambient temperatures by using preheater exhaust gas heat recovery to sustain the thermal parameters of gas cleaning in the catalytic converter. At starting, idling, or low loads, the unheated neutralizer is inefficient, which is why the catalytic-converter bricks have to be preheated during prestarting from the ambient temperature to its optimal operating temperature for efficient gas cleaning. It has been revealed that the composition of exhaust gases of a diesel engine depends on the ambient-air temperature. We have estimated the harmful emissions of nitrogen oxides, hydrocarbons, carbon monoxide, and particulates at 241…248…264…273…298 K and compared them to such standards as UN ECE EURO-3, EURO-4, and EURO-5. Studying of the changes in the emissions resultant from the exhaust of a 8Ч12/12 diesel engine has revealed that reducing the ambient temperature from 298 K to 241 K increases the emission of nitrogen oxides 1.07 times, while also reduce the carbon monoxide emission 1.59 times, the total hydrocarbon emissions 2.46 times, and particulate emissions 1.57 times. During preheating, as the catalytic-converter bricks are heated from 250 K to 833 K, the converter reduces the emissions of nitrogen oxides 3.73 times, the emissions of hydrocarbons 12.75 times, the carbon monoxide emissions 2.5 times, and particulate emissions 3 times. Heating the bricks to 833 K while starting the diesel engine reduces its harmful emissions by 52% in terms of nitrogen oxides, by 86% in terms of carbon monoxide, by 67% in terms of hydrocarbons, and by 85% in terms of particulate matter.

1. Introduction
One of the promising methods of reducing the harmful emissions of diesel engines during winter consists in recovering the heat of preheater exhaust gases to sustain the thermal parameters of gas cleaning in catalytic converters. During pre-starting, the catalytic-converter bricks have to be heated up from the ambient temperature to the operating temperature for efficient gas cleaning.

For preheater-equipped diesel engines operated at negative ambient temperatures and parked outdoors, preheating time and harmful preheater emissions are two relevant problems [2–9].

Given that, for instance, diesel engines that utilize film atomization of fuel are not heated to the nominal temperatures of the coolant and oil in winter, combustion is incomplete to a significant extent, with specific harmful emission content in exhaust gases reaching the following levels at full load: 10...14 g of CO per kW·h, 2.3...2.7 g of SO₂ per kW·h, 0.15...0.25 g of aldehydes per kW·h, 6.00...8.5 g of hydrocarbons (C₅H₉) total per kW·h, 2.3·10⁶ g benzo-α-pyrene per kW·h, 15...20 g of nitrogen oxides per kW·h, and 1.8...2.2 g of particulate matter per kW·h [1,2,3,4,7].
For most converters, the lowest operating temperature is in the range of 420...520 K. Such catalytic-converter temperatures cannot be reached without long preheating by exhaust gases, especially if the diesel engine is operated at negative temperatures. At starting, idling, or low-loads, an unheated converter is inefficient [5-7].

Placing a catalytic converter next to the engine is a common approach, since it reduces the time to heat the converter at cold start. However, such placement does increase the exhaust-gas pulsation, which may reducing the gas cleaning effectiveness by as much as 30% [5].

Meanwhile, Boysen has designed an exhaust-gas cleaning system for the BMW NG-R6 family, which implies near-engine placement of catalytic converters and using a set of short interconnecting pipes of various shape. Komatsy Ltd, Japan, has created and patented in the U.S. a diesel engine with fast cold-start heating [12]. There is a system for heating three-way catalytic converters and nitrogen-oxide absorbers placed consecutively in the exhaust system. Toyota, Japan, has created a device for ICEs running on lean air-fuel mixture and containing the starting catalytic NOx absorber and the primary one, placed consecutively [1,6,8]. Volkswagen, Germany, has proposed faster cold-start converter heating by letting the exhaust gases through the inner pipe only to reduce heat loss. General Motors Corporation, United States, has created an electronic system that speeds up the catalytic converter heating after starting an ICE; the system is efficient at -20°C or higher [10,11]. V.S. Kukis and T.F. Sultanov have demonstrated the efficiency of using heat accumulators to stabilize the temperature before the catalytic converter [5].

2. Research Goal
The goal of this research is to improve the efficiency of cleaning performed by a catalytic converter contained in the exhaust system of the diesel-engine preheater while operating at negative temperatures, this helps to decrease the harmful emissions carried with exhaust gases.

3. Materials and Methods
In order to study the effects of ambient temperature on the 8112/12 diesel engine exhaust gases and to find the catalytic conversion efficiency, we carried out tests in a wintertime setting at the ambient temperature $T_o = 241...264$ K, pressure $P_o = 758...762$ mmHg, humidity $W_o = 75...85\%$, and windspeed $V_w = 10...12$ m/s.

One important feature of these experiments is that some of the measurements (load and speed measurements) were done on different days under different atmospheric conditions, with the results being normalized per GOST.

We have estimated the harmful emissions of nitrogen oxides, hydrocarbons, carbon monoxide, and particulates at $241...248...264...273...298$ K and compared them against such standards as UN ECE EURO-3, EURO-4, and EURO-5.

Prior to the experiment, the diesel engine had been preheated to the coolant temperature $T_{cool} = 363$ K and to the oil temperature $T_{oil} = 358$ K.

Diesel preheating makes it difficult to study the effects of catalytic-converter bricks produced by self-propagating high-temperature synthesis (SHS). Therefore, the temperature of SHS converters was simulated and sustained by applying air from the preheater to the converter inlet.

Experiment was carried out in 24 hours at $T_o = 250...234$ K, $P_o = 738$ mmHg, $W_o = 60\%$, and $V_w = 15$ m/s. After carrying out a series of experiments, the diesel unit was poured with cold tosol from a spare tank to quickly stabilize the temperature. Preheating took 25 minutes. Over that time, the sump oil temperature rose to 260 K, the coolant temperature at the unit outlet rose to 300 K. The catalytic-converter brick temperature rose to 880 K.

Exhaust-gas composition was analyzed per GOST 10448-80, GOST R 41.24-2003, GOST R 51249-99.
4. Results and Discussion
Figures 1 and 2 present the results of studying the effects of ambient temperatures on the composition of the 8I12/12 diesel engine exhaust gases. Figure 1 presents by-load curves of emissions produced by the 8I12/12 diesel engine at 2600 min\(^{-1}\). Increase in the nitrogen oxides emission by load can be explained by the fill factor \(\eta_v\) being increased due to a fresh cylinder charge as well as by the increased air-fuel ratio provided consistent cyclic flow. This facilitates nitrogen oxidation in the diesel engine cylinder.

Lower levels of particulate matter (PM), hydrocarbons \(\text{C}_x\text{H}_y\) (CH), and carbon monoxide (CO) – are resultant from increasing the air-fuel ratio as the air mass charge in the cylinder is greater.

Tests by external speed (see Figure 2) show that changing the ambient temperature from 298 K to 241 K at 1000...2600 min\(^{-1}\) at full fuel flow reduces the emissions of hydrocarbons, carbon monoxide, and particulate matter, while also increasing the content of nitrogen oxides carried with exhaust gases.

![Figure 1](image1.png)
**Figure 1.** By-load changes in 8I12/12 diesel-engine exhaust-gas emissions at 2600 min\(^{-1}\) at: ● - 298 K; ○ - 241 K

![Figure 2](image2.png)
**Figure 2.** By-speed changes in 87I12/12 diesel-engine exhaust-gas emissions at: ● - 298 K; ○ - 241 K
Table 2 presents the effects of ambient temperature (adjusted for wind speed) on the specific estimates of harmful emissions, a summary for \( T_0 = 241 \ldots 264 \ldots 273 \ldots 298 \) K.

**Table 1.** How ambient temperature affects the 8Ч12/12 diesel-engine emission estimates

| Emission estimate | Value, g/(kW·h) | Exceedance degree, times | EURO-3 | EURO-4 | EURO-5 | Permissible levels | Harmful emissions at | EURO-3 | EURO-4 | EURO-5 |
|-------------------|------------------|-------------------------|--------|--------|--------|-------------------|---------------------|--------|--------|--------|
|                   |                  | at \( T_0 = 241 \) K    | 241 K  | 264 K  | 273 K  | 298 K            |                     | 264 K  | 273 K  | 298 K  |
| \( q_{\text{NOX}} \) | 5.00             | 3.500                   | 2.00   | 9.24   | 8.98   | 8.77             | 8.63               | 1.85   | 2.64   | 4.62   |
| \( q_{\text{CO}}  \) | 2.10             | 1.50                    | 1.50   | 2.04   | 1.60   | 2.01             | 2.45               | 0.73   | 1.03   | 1.03   |
| \( q_{\text{CH}}  \) | 0.60             | 0.46                    | 0.25   | 0.34   | 0.52   | 0.69             | 0.69               | 0.47   | 0.61   | 1.12   |
| \( q_{\text{PM}}  \) | 0.10             | 0.02                    | 0.02   | 0.14   | 0.19   | 0.20             | 0.22               | 0.14   | 0.70   | 0.70   |

The data obtained suggests that without a catalytic converter, none of the EURO standards above can be complied with in terms of emissions carried with exhaust gases. Noteworthy is the degree, to which the nitrogen-oxide and particulate-matter emission norms are exceeded. EURO-3 standard for carbon monoxide and hydrocarbon emissions is complied with at \( T_0 = 241 \) K However, the nitrogen-oxide and particulate-matter norms are exceeded.

In accordance with the goals of this research, we have carried out a series of experiments to find the effects of PHD-30 preheater exhaust-gas flow and catalytic-converter brick temperature on the efficiency of cleaning. Table 2 presents the research results.

**Table 2.** Effects of PZhD-30 preheater exhaust-gas flow and catalytic-converter brick temperature on the efficiency of cleaning at \( G_{FL} = 6.49 \) kg/h

| Gas flow, m\(^3\)/kg of fuel | Harmful substance | Emission reduction, %, as a function of catalyst brick heating, K |
|------------------------------|-------------------|----------------------------------------------------------|
| 13.45                        | Nitrogen oxides   | 27 61 82 83 80 77 72                                    |
|                              | Hydrocarbons      | 19 50 70 76 77 76 75                                    |
|                              | Carbon monoxide   | 16 45 64 74 80 84 86                                    |
|                              | Particulate matter| 0 4 8 14 23 36 87                                    |
|                              | Nitrogen oxides   | 25 58 77 78 77 74 70                                    |
|                              | Hydrocarbons      | 14 40 60 71 72 72 71                                    |
| 14.57                        | Carbon monoxide   | 15 42 60 70 77 81 82                                    |
|                              | Particulate matter| 0 2 7 12 21 34 65                                    |
|                              | Nitrogen oxides   | 20 55 75 75 72 70 65                                    |
|                              | Hydrocarbons      | 10 33 51 63 66 66 65                                    |
| 15.69                        | Carbon monoxide   | 10 40 55 65 72 76 78                                    |
|                              | Particulate matter| 0 1 6 10 20 30 56                                    |
|                              | Nitrogen oxides   | 18 53 68 68 65 63 56                                    |
|                              | Hydrocarbons      | 8 28 44 54 54 55 54                                    |
| 16.82                        | Carbon monoxide   | 9 35 50 60 67 71 73                                    |
|                              | Particulate matter| 0 1 5 9 18 29 50                                    |
|                              | Nitrogen oxides   | 15 43 61 60 57 54 48                                    |
|                              | Hydrocarbons      | 6 20 33 38 37 36 36                                    |
| 17.94                        | Carbon monoxide   | 8 29 43 52 59 63 65                                    |
|                              | Particulate matter| 0 1 4 8 15 28 48                                    |
It has been found out that at an air-fuel ratio of $\alpha_{PH} = 1.18$, the rising gas temperature at the start heats the catalytic-converter bricks to 880 K. The efficiency of cleaning $\delta_{NO}$, $\delta_{CH}$, $\delta_{CO}$ and $\delta_{PM}$ begins to manifest at about 300 K and increases significantly while heating to 880 K. Increasing the gas flow by means of increased air-fuel ratio results in less efficient gas cleaning in terms of all primary components (carbon monoxide, nitrogen oxides, hydrocarbons, and particulate matter).

Figure 3 shows the dynamics of efficiency of cleaning PHD-30 exhaust gases in a catalytic converter which uses porous bricks produced by self-propagating high-temperature synthesis (SHS). As can be seen in the graph, intensive-cleaning temperature is component-specific. Thus, hydrocarbons are cleaned at 630–340 K or above, while carbon monoxide is cleaned at 530–540 K or above; particulate matter is filtered to 50% at up to 735 K, then to 89% by catalytic burning at higher temperatures. Nitrogen oxides are cleaned at 425 K or above, with the cleaning being intensified while increasing the temperature to 635 K and stabilizing at $\delta_{NOx}=73$-89 at 880 K.

![Figure 3](image)

**Figure 3.** Effects of heating the catalytic-converter bricks on the efficiency of cleaning the PHD - 30 exhaust gases

5. **Conclusions and recommendations**
5.1 The composition of diesel-engine exhaust gases depends on the ambient temperature (adjusted for wind speed). Reducing the ambient temperature from 241 K to 298 K increases the emission of
nitrogen oxides 1.07 times, while also reducing the carbon oxide emission 1.59 times, the total hydrocarbon emissions 2.46 times, and particulate emissions 1.57 times;

5.2 During preheating at $\alpha_{ph} = 1.3$, as the catalytic-converter bricks are heated from 250 K to 833 K, the converter reduces the nitrogen oxide emissions 3.73 times; the reduction in hydrocarbon emissions is 12.75 times; in carbon monoxide, 2.5 times; in particulate matter, 3 times;

5.3 Heating the catalytic-converter bricks to 833 K while starting the diesel engine reduces its harmful emissions of nitrogen oxides by 52%, those of carbon monoxide by 86%, those of hydrocarbons by 67%, and particulate-matter emissions by 85%.

5.4 Increasing the gas flow by increasing the air-fuel ratio results in less efficient gas cleaning in terms of all primary components: carbon monoxide, nitrogen oxides, hydrocarbons, and particulate matter.

5.5 To ensure efficient cleaning of exhaust gases in the catalytic converter, we recommend adjusting the preheater by $\alpha_{ph} = 1.18…1.2$.

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