Improving special motor vehicle internal combustion engines to raise environmental safety

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Abstract. The paper presents the results of theoretical and experimental studies of the environmental characteristics of internal combustion engines for commercial and public motor vehicles operating on the Diesel cycle using a hydrogen additive. An analysis of literary sources confirmed that there are different data on harmful emissions when using a hydrogen additive for internal combustion engines operating on the Diesel cycle. The results of theoretical and experimental studies of the environmental characteristics of internal combustion engines for commercial and public motor vehicles operating on the Diesel cycle using a hydrogen additive suggest the adequacy of the built model, since the error between the theoretical and experimental data did not exceed 14.5%. It was found that the concentration of NOx emissions in an internal combustion engine using a hydrogen additive operating on the Diesel cycle decreased by 52%. The above research results confirm the prospects for the use of hydrogen additive for internal combustion engines operating on the Diesel cycle, which was first used for commercial and municipal motor vehicles. It guarantees improved environmental safety in urban agglomerations.

1. Introduction
At the moment, in order to achieve environmental safety and ensure the conditions for ensuring the proper level of health of the population of the urban agglomeration, observing the normative quality of the environment and reducing harmful emissions, it is possible to use a hydrogen additive for ICE (internal combustion engine) operating according to the Diesel cycle [1-3]. The latter will help reducing harmful emissions of special motor vehicles with diesel ICE in urban agglomeration.

So in works [4, 5], hydrogen, from the point of view of environmental safety, is an ideal energy carrier, since when the hydrogen-air mixture is burned, nitrogen oxides can be the only toxic component.

Analysis of literary sources shows the existence of different data on harmful emissions when using a hydrogen additive for ICE operating on the Diesel cycle, especially nitrogen oxides NOx [6-7].

Thus, [8] states an increase in NOx emissions at higher loads of a compression ignition engine with hydrogen, and [9] states that the addition of hydrogen to diesel fuel reduces NOx emissions under low load conditions, but notes an increase at high load. Also, in works [8-9] results on high emissions of NOx using a hydrogen additive for ICE operating on the Diesel cycle are given, but it is concluded that all emissions are reduced using exhaust gas recirculation.

In the above results, for ICE operating on the Diesel cycle using a hydrogen additive [10], there was obtained a reduction in NOx emissions by 38.4%, CO2 by 27.4%, CO by 33.4%, from which it
was concluded that the combination of hydrogen addition and exhaust gas recirculation is beneficial for the overall reduction of emissions.

[11] notes the possibility of reducing NO\textsubscript{x} emissions in an engine with more than 90% hydrogen added while reducing carbon black emissions by increasing hydrogen added, notes a slight increase in NO\textsubscript{x} emissions and an increase in efficiency, all other harmful emissions have been drastically reduced. There is also a specific decrease in emissions of CO, CO\textsubscript{2} and smokiness with an increase in hydrogen addition.

2. Materials and Methods

The combustion efficiency of the fuel mixture increases with the addition of hydrogen due to excess air and, if there is no excess air, NO\textsubscript{x} emissions may decrease.

The results of experiments on the stand with Tector 4 and 6 engines (Iveco EuroCargo car) show that increasing the amount of hydrogen in the engine reduces the ignition delay, which also affects the main combustion phase. At the same time, the trend towards carbon black emissions steadily decreased with an increase in the amount of hydrogen.

To reduce NO\textsubscript{x} emissions, water can be injected into the combustion chamber, which helps prevent detonation and pre-ignition during hydrogen combustion. At the same time, water cools the charge and reduces the rate of combustion. However, the water injected into the intake manifold reduces the volumetric efficiency [12-16].

The load characteristic of the diesel engine and the environmental parameters characterizing the qualitative change of the working process of the diesel engine during its operation on mixed fuels, which includes hydrogen, in accordance with the load tests on the bench are presented on the graphs of Fig. 1, 2. From the above dependencies, it can be seen that the reduction of carbon black and nitrogen oxides in the exhaust gases is observed in the entire range of changes in the loading modes of the diesel engine. In a mode close to nominal ($P_e = 0.55$ MPa), the presence of hydrogen-containing methanol conversion products in mixed fuels helps to reduce the carbon black content in exhaust gases (EG) from 3.2 to 1.8 Bosch units, that is, by 45%, with a decrease in the concentration of nitrogen oxides in harmful emissions by 16%.

The change (increase) in CO concentration in the exhaust gas measured in front of the reactor was negligible. It should be noted that when using a modified version of the reactor, structurally combined with the catalytic oxidizer of the products of incomplete combustion of harmful substances, the presence of CO in the exhaust gases of the diesel engine was practically absent, according to the recorded indicators of the gas analysis register of the computer connected to the circuit.

Figure 3 shows a significant reduction in HC emissions for the 220 hp Iveco EuroCargo Tector 6 engine in no-load mode, starting with a crankshaft rotation speed of 1600 rpm for two methods of adding hydrogen to the gas diesel engine. Thus, for the case of adding 6 to 8% hydrogen to the intake manifold, the HC decreases by 1.05 to 1.29 times compared to the base model, and when 8 to 10% hydrogen is added to the Tector 6 engine intercooler, it decreases by 1.32 to 1.53 times.

Also, for the Tector 6 engine, with a capacity of 220 hp in load mode, the dependencies of the average HC emissions on the crankshaft rotation speed were obtained.

With the addition of 6 to 8% hydrogen to the intake manifold of the Tector 6 engine mounted on an Iveco EuroCargo, with a capacity of 220 hp under load, the average HC emissions (Figure 3) are 1.16 times lower than the base model. It should be noted, in this case there are points with similar emissions. When adding hydrogen 8 to 10% to the intercooler, HC emissions are also reduced by 1.05 to 1.40 times. This decrease is characteristic for the entire crankshaft speed range.

A graphical interpretation of the average SO\textsubscript{2} emissions for the 220 hp Iveco EuroCargo Tector 6 engine is shown in Figure 4.
Figure 1. Diesel engine load characteristic.

Figure 2. Environmental indices of diesel engine during its operation on regular and hydrogen-diesel mixed fuel by load characteristic with crankshaft rotation speed of 2000 min$^{-1}$. 
Figure 3. Dependencies of average HC emissions for Tector 6 engine installed on Iveco EuroCargo, 220 hp under load from the crankshaft rotation speed: 1 - base model; 2 - with addition of 6 to 8% hydrogen to the intake manifold; 3 - with addition of 8 to 10% hydrogen to the intercooler.

Figure 4. Dependencies of average values of SO$_2$ emissions for a Tector 6 engine installed on an Iveco EuroCargo car with a capacity of 220 hp without load on the crankshaft speed: 1 - base model; 2 - with addition of 6 to 8% hydrogen to the intake manifold; 3 - with addition of 8 to 10% hydrogen to the intercooler.

From the graphical interpretation given (Figure 4), it follows that the emissions of SO$_2$ for the base model of the Tector 6 engine, 220 hp in the no-load mode, are 1.12 to 1.43 times higher compared to the engine with the addition of 6 to 8% of hydrogen to the intake manifold depending on the rotation speed of the crankshaft and in 1.24 to 1.95 times higher than in an engine with the addition of hydrogen 8 to 10% to the intercooler.

Here, it can be noted that the reduced content of carbon black in the exhaust gases of a diesel engine operating on mixed hydrogen-diesel fuel determines the possibility of its forcing beyond the smoke line.
One of the very important factors that significantly affects the effectiveness of the use of hydrogen impurities is the very way they are supplied to ICE. Adding hydrogen at the ICE intake stroke is the easiest way to use it even in the early stages of implementation. But this method leads to a complication of the qualitative regulation of ICE, and is also not completely safe, due to the possibility of the formation of an explosive mixture in the intake duct of ICE and its ignition with subsequent explosion. Such phenomena were observed earlier, both in ICE operating on the Otto cycle, and in other diesel engines.

One possible way to solve the above problem is to supply small impurities of hydrogen by using a following solution. The main idea is to add hydrogen to the diesel fuel in the high-pressure line during low pressure formation by means of a special device. At this pressure, diesel fuel will be saturated with hydrogen and enter the nozzle, and then injection into the ICE cylinder takes place. After injection and pressure reduction in the cylinder, hydrogen is released from diesel fuel, contributes to further grinding of the droplets and quickly diffuses into the volume of the above-piston space. The amount of hydrogen that is required for the cycle supply of diesel fuel to the ICE is controlled by the hydrogen pressure at the intake to the device.

Using the above solution makes it possible not to make significant changes in the design of ICE or fuel equipment and to ensure a sufficiently high level of control quality and safety when using hydrogen impurities.

However, in the scientific literature not enough information has been found on the results of experimental studies of the addition of hydrogen to the main composition of ICE liquid fuel.

Thus, there are diverse opinions in the world about the use of hydrogen additive or hydrogen impurities for ICE operating on the Diesel cycle, which relate to harmful emissions in this case. Therefore, it is further relevant to conduct theoretical and experimental studies of the environmental safety of special motor vehicles when hydrogen impurities are used in ICE.

3. Results
The use of special motor vehicles in urban agglomerations also affects environmental safety. At the same time, an urgent task arises related to the reduction of harmful emissions of ICE special motor vehicles, which may include the preserving and development of an integrated system designed to protect the environment of urban agglomerations. The development of environmental safety in densely populated cities offers an opportunity to create conditions for ensuring a healthy environment, increasing the duration and quality of life of the population, which will contribute to the economic development of the entire region under consideration.

4. Discussion
At the moment, to ensure the necessary level of environmental safety and the health of the population of million-plus cities with a decrease in the impact of special motor vehicles on it, operational methods aimed at controlling and reducing the concentration of harmful (polluting) emissions should be applied. In this regard, the influence of emissions of special motor vehicles on environmental indicators was analyzed, using the example of Tector 4 and Tector 6 engines, which are installed on special vehicles (Iveco EuroCargo cars) operated in the city. The results have the following meanings depending on the crankshaft rotation speed:

- CO emissions are 0.2 to 0.9 g / min;
- NOx emissions are 0.05 to 0.17 g / min;
- HC emissions are 0.03 to 0.85 g / min;
- HC emissions are 0.035 to 0.095 g / min;
- SO2 emissions are 0.4 to 1.3 g / min;
- CO2 emissions are 200 to 1100 g / min;
- PM emissions are 0.01 to 0.06 g / min.
5. Conclusions
In order to achieve environmental safety and to ensure an adequate level of public health in urban agglomerations, it is possible to use a hydrogen additive or hydrogen impurities in the ICE of special motor vehicles, which will help reduce their harmful emissions. In this regard, it is relevant to conduct theoretical and experimental studies of the environmental safety of special motor vehicles when using hydrogen impurities in ICE. To do this, there is need to work out and manufacture a device for supplying hydrogen to the chassis of the car.

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