UDC 629.123: 665.61

A METHOD OF REDUCING EMISSIONS OF HARMFUL SUBSTANCES INTO THE ATMOSPHERE BY BOILER PLANTS

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The article deals with harmful substances which are formed during boiler operation and their influence on people. An estimation of the dynamics of the change in the environmental tax on the emission of pollutants into the atmospheric air over the last ten years is given. The mechanism of formation of nitrogen oxides is considered. Recommendations are given on possible ways to reduce emissions of nitrogen oxides to the atmosphere that form during the operation of boiler houses. It is noted that using emulsions based on oily waste as an additive to the main fuel of boiler plants will allow not only to dispose of these substances, but will reduce emissions of nitrogen oxides into the atmosphere and consumption of the main fuel.

Introduction. At present, the problem of protecting the environment from harmful emissions from the use of fossil fuels, including natural gas, attracts the attention not only of scientists but of the entire world community. Acad. M.A. Strykovich notes [1] that in recent years, the anthropogenic impact of boiler plants on the atmosphere has become especially dangerous, the number of which increases every year. The annual emissions of the main toxic substances are: 150 million tons of sulphur dioxide, 300 million tons of carbon monoxide, 50 million tons of nitrogen oxides.

According to the data of prof. I. J. Sigala [2], Table 1 shows the effects of some toxic substances on the human body, confirming the relevance of work to reduce the hazards in combustion products of fuel.

Table 1. – Characteristics of exposure to harmful substances per person

Duration and nature of human exposure	Content in air,%		
	CO	NO_x	SO_2
A few hours without noticeable action	0,01	0,0008	0,0025
Signs of easy poisoning	0,01–0,05	0,001	0,005
Serious poisoning is possible in 30 minutes	0,05–0,30	0,005	0,008–0,015
Danger of life if exposed for short periods of time	0,50–0,80	0,015	0,060

Objective – Having considered the mechanism of formation of nitrogen oxides, we propose ways to reduce emissions of nitrogen oxides into the atmosphere by boiler plants.

Results and discussion. Boiler installations, which many enterprises have, are both large consumers of fuel and energy resources and large sources of pollutant emissions [1, 2]. The pollutants formed during the operation of the boiler plants are classified in the following hazard classes: nitrogen (II) oxide (nitrogen oxide) – 3; nitrogen (IV) oxide (nitrogen dioxide) – 2; sulfur dioxide (sulfurous anhydride, sulfur (IV) oxide, sulphur gas) – 3; solid particles (undifferentiated by composition dust / aerosol) – 3; aromatic hydrocarbons – 2; aliphatic hydrocarbons C_1–C_{10} – 4; aliphatic hydrocarbons C_{11}–C_{19} – 4; carbon black (Soot) – 3; carbon oxide (carbon monoxide) – 4.

A company pays an environmental tax for these emissions. According to the Tax Code of the Republic of Belarus (Special part) of December 29, 2009 No. 71-3 (including changes and amendments, including the Law of the Republic of Belarus of January 9, 2017 No. 15-3), the environmental tax rate (rub) for emissions of pollutants into the air, in total for 1 ton substances currently constitute: the second hazard class – 769.97; third hazard class – 254.54; fourth hazard class – 126.48. Figure 1 shows the change in the environmental tax on the emission of pollutants of various hazard classes into the ambient air annually since 2008.

The dynamics of the growth of the ecological tax is vivid. Figure 2 shows the change in the ratio of the environmental tax rate for the emission of pollutants into the ambient air over the years to the rate applicable in 2008 for the second hazard class (for other hazard classes the ratio is almost the same). During 10 years the rate has increased almost 6 times. This should motivate enterprises to reduce emissions of pollutants into the air.

For many enterprises, paying an environmental tax for emissions of pollutants into the atmosphere is an important expense item and one of the reasons for switching boiler plants from fuel oil to natural gas. The use of natural gas as fuel in boiler plants excludes atmospheric pollution by sulfur dioxide and solid particles. At the same time there is a continuous pollution of the atmosphere by combustion products of gaseous fuel (mainly nitrogen dioxide) [2].

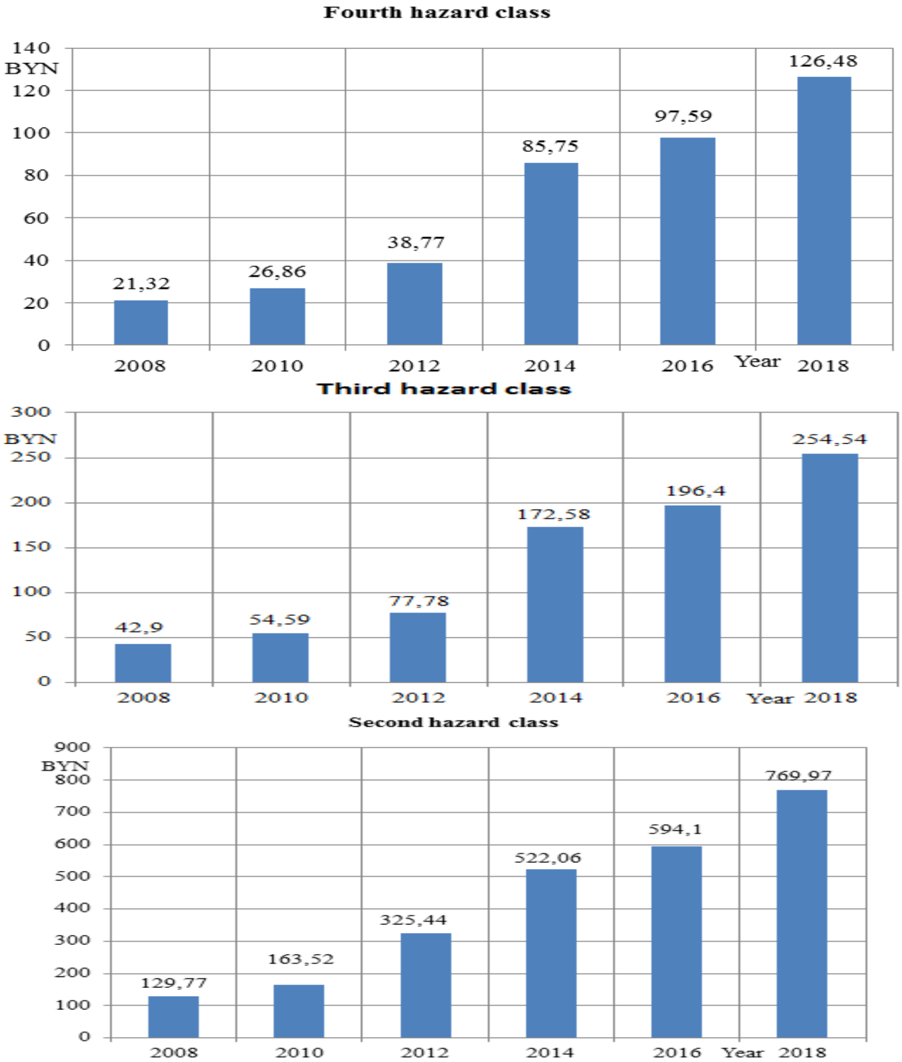

Fig. 1. Change in environmental tax on pollutant emissions
of different hazard classes in the atmospheric air annually

Formation of nitrogen oxides. Nitrogen oxides at high temperature form a number of thermodynamic stability: NO, N_2O, NO_2, N_2O_3, N_2O_4 [2]. Both nitrogen from the air and organic compounds of nitrogen with fuel take part in the formation of oxides [3]. The formation of nitrogen oxides is affected by catalysts - various compounds of mineral or mineral-organic constituents of fuel [2, 3]. Both the increase in the power of the burners and the boiler load, and the increase in the temperature of the medium in the furnace contribute to the increase of NO_x formation [2].

Nitric oxide is about 95% of the sum of all nitric oxides [2]. NO formation under high temperature oxidation of atmospheric nitrogen occurs by a radical chain mechanism with N and O atoms. The gross reaction of NO formation [3] can be expressed in the following form:

$$N_2 + O_2 \leftrightarrow 2NO - 180{,}2 \text{ kJ/ mol},$$

the complete chain diagram of this reaction is as follows:

initiation:

$$O_2 + M \leftrightarrow O + O + M - 494{,}4 \text{ kJ/ mol};$$

chains:

$$O + N_2 \leftrightarrow NO + N - 314{,}2\ kJ/mol$$

$$N + O_2 \leftrightarrow NO + O + 134{,}0\ kJ/mol;$$

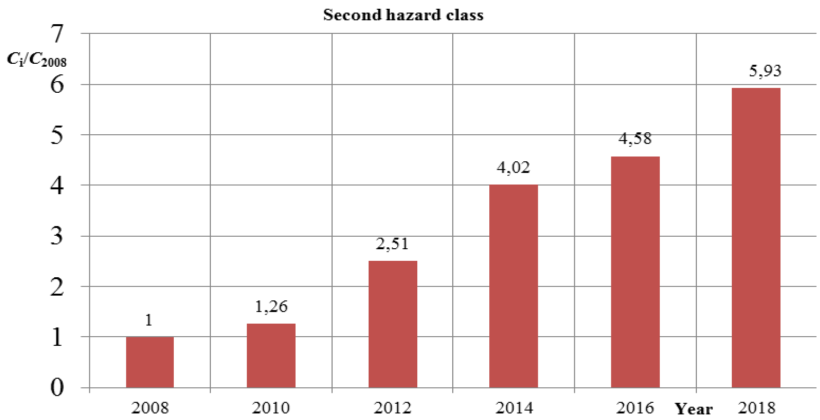

Fig. 2. Change in the ratio of the rate of environmental tax on the emission of pollutants into the air of the *i-th* year to the rate of 2008

chain termination:

$$O + O + M \leftrightarrow O_2 + M + 494{,}4\ kJ/mol.$$

Coming with flue gases to the atmosphere, NO is oxidized to nitrogen dioxide NO_2, reacts with atmospheric moisture and falls out with precipitation as a weak solution of nitric acid HNO_3, dissolving in water bodies. The formation of NO_2 at an excess air-content ratio of 1.1 and a flue gas temperature of 200 ° C requires 35 minutes, so it is practically not formed in the gas path of the boiler. N_2O heminoxides are thermally unstable, and the proportions of the dimer of N_2O_4 dioxide and N_2O_3 trioxide are very small to take into account when studying toxic emissions of boilers [2].

The share of harmful emissions in the flue gas composition also includes nitrogen oxides formed from chemically bound nitrogen of the fuel. Fuel nitrogen through the radicals is partially oxidized to nitrogen oxides. The separation of nitrogen atoms from fuel elements consumes 1.5-4.0 times less energy than the dissociation of the nitrogen molecule from the air. The major part of the nitrogen oxides formed in the furnace of the boiler is due to the high temperature of the medium in the combustion zone and the presence of an oxidizer.

Oxides and nitrogen dioxide are formed by burning fuel in high temperature zones. Studies conducted under the supervision of Acad. J.B. Zeldovich [3] showed that reducing the burnup time of fuel droplets by two times leads to a decrease in NO_x concentration by 22% (Figure 3). Thus, the reduction in the residence time of the combustion products in the high-temperature zone of the boiler furnace leads to a decrease in the concentration of nitrogen oxides.

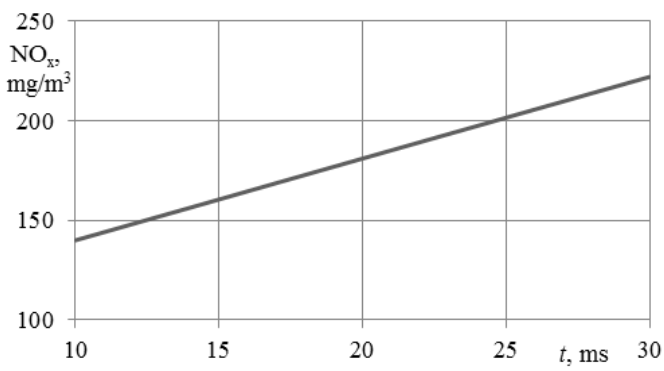

Fig. 3. Dependence of nitrogen oxides NO_x in flue gases (from burning oily emulsion) on the burnout time t in the boiler flare

To improve the environmental situation in the area of operation of boiler plants, it is necessary to strive not only to suppress the formed harmful substances, but also to a greater extent to the localization of their appearance [1-3]. One way to reduce the formation of harmful substances (oxides and nitrogen dioxide and carbon monoxide (II)) during the combustion of gaseous fuels is the injection of water or steam into the combustion chamber [2-5]. In prof. I.J. Sigala's opinion [2], the introduction of water or steam into the fuel-air mixture affects the combustion and formation of NO_x no less than the introduction of a similar volume of recirculating gases. Water vapour has a strong inhibitory effect on the synthesis of nitrogen oxides due to the effect of water vapour on the kinetics of NO_x formation. The prerequisite for this is the fact that water vapour affects the flame propagation velocity, and therefore the introduction of even a small amount of water vapour into the core of the combustion zone significantly affects the yield of nitrogen oxides.

However, on an industrial scale, this method is practically not used. It is due to the fact that, according to Acad. J.B. Zeldovich [3] and prof. I.J. Sigala [2], when the temperature of the flare decreases, the efficiency of the boiler decreases, which means that an additional volume of fuel is needed.

Polotsk State University is carrying out research to develop a technology for the preparation of emulsions based on oily waste [6-8]. Its use will allow enterprises to significantly reduce the capital and current costs for the separation of oily waste into petroleum products and water, since the emulsion includes water. One way to use such an emulsion is to use it as an additive to the main fuel of boiler plants [4, 5, 9].

Conclusion. Experimental studies have shown that burning emulsions based on oily waste (10-20% of water) with the main fuel with a uniform distribution of water throughout the volume of the material in the furnace of the steam boiler provides a reduction in emissions of harmful substances in the atmosphere compared to their quantity when burning dehydrated fuel. The reduction of carbon monoxide (II) by 43-59% and nitrogen oxides by 28-45% has been achieved. Using an emulsion based on OCW as an additive to fuel can reduce the consumption of the main boiler fuel by 3-5% [4, 5, 9].

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