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## PROTECTION OF ATMOSPHERE FROM HARMFUL EMISSIONS OF STATIONARY FUELBURN INSTALLATIONS

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**Abstract:** The article analyzes domestic and foreign researches in the field of combustion gas cleaning from harmful matters. The drawbacks of the existing methods of cleaning emissions of small-capacity boilers are revealed. The results of the researches conducted by the authors are presented. Complex schemes of cleaning emissions of the industrial boilers of the DKVR series are considered. The results of the tests of afterburning devices installed in the industrial boilers are presented. The simplest design of an afterburning device by the example of an industrial boiler of the DKVR series is considered. It is shown that the application of the afterburning devices prevents emissions of the incomplete burning products (CO, carbon black, benzpyrene) and reduces the nitric oxide content by (50-80)%, depending on the scheme of cleaning. The usage of the afterburning devices improves boiler performance owing to the increase of the radiant component in a furnace chamber, reduction of heat losses, increase of efficiency.

**Key words:** fuel, burning, combustion products, cleaning

### Introduction

Protection of atmosphere is becoming a more and more urgent issue in the contemporary world. The increasing usage of organic fuel in the world increases considerably anthropogenic pollution of the atmosphere with harmful matters of fuel burning. Among them there are: carcinogenic benzpyrene C<sub>20</sub>H<sub>12</sub> (danger class 1), nitric dioxide N<sub>2</sub>O and sulphur dioxide SO<sub>2</sub> (danger class 3), carbon monoxide (danger class 4) detrimental to the population health, as well as harmful greenhouse gas.

The existing ecological situation requires immediate measures for reduction of air pollution. Therefore, it is important to have the approved complexes of

nature-conserving actions intended to protect atmospheric air from emissions of fuelburn installation. It relates especially to the stationary fuelburn installations that differentiate widely in design of boilers and furnaces, as well as in variable

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mode of operation). It is particularly important to ensure simultaneous elimination of the products of incomplete burning (carbon monoxide, carbon black, benzpyrene) and nitric oxides.

### **Methods of cleaning**

The analysis of foreign (Lebedeva & Loschilova, 2010, Ashworth, 2000) and domestic researches has revealed that the high efficiency of nitric oxide neutralization is achieved by the method of high-temperature homogenous recovery. However, the patented methods have a significant drawback. The recovery field lies in a narrow temperature range (950-970°C), which is hard to achieve during boiler operation under various loads.

Among the methods of cleaning combustion products from nitric oxides the so-called “technological methods” are widely used in the world. These methods – combustion gas recirculation without installation a special smoke exhauster, stepwise feeding of oxidizer, injection of water or steam in the burning zone – are quite promising as they are not capital-intensive.

Since the technological methods have been developed for power boilers, their direct use in industrial boilers creates some problems due to the features of construction of small-capacity boilers (Lebedeva, 1982, Lebedeva, Gordeev, Mochalina, 2005, Lebedeva, Gordeev, 2007).

One can reduce the content of incomplete-burning products (carbon monoxide, benzpyrene, carbon black) in a traditional way by creating high temperatures in a furnace and heat stress of furnace volume.

But in this case favourable conditions for formation of nitric oxides are created. And vice versa, the lowering of temperatures and heat stress in a furnace in order to reduce the nitric oxide content leads to the problem of incomplete-burning products and deterioration of boilers’ efficiency. It was proved by the normative methods of calculation of pollutant emission into the atmosphere, according to which the content of benzpyrene in the combustion gas increases in 1.8 times during recirculation and in 2.4 times during stepwise burning.

Thus, the issue of simultaneous cleaning of combustion products from nitric oxides NO<sub>x</sub> and incomplete-burning products, i.e. carbon monoxide, carbon black and benzpyrene has become urgent, especially with regard to the small-capacity boilers.

### Research results

To eliminate the above mentioned drawbacks and on the basis of the results of the theoretical and experimental researches (Lebedeva, 1982), a number of complex schemes of reduction of harmful emissions of industrial boilers has been developed. All schemes include a combination of the technological methods of pollutant reduction with the cleaning methods, but have different sets of nature preserving equipment. (Lebedeva, Gordeev, Mochalina, 2005).

Scheme No. 1 comprises the simplest method of simultaneous cleaning from emissions of NOX and incomplete-burning products (CO, carbon black, benzpyrene), which does not require radical reconstruction of furnace chambers (Lebedeva, Gordeev, Mochalina, 2005).

The method is based on the carrying out furnace processes under conditions of suppression of NOX formation with the subsequent combustion of the incompletely burned products in special afterburning devices. The scheme (Figure 1) consists of two blocks (1,2)

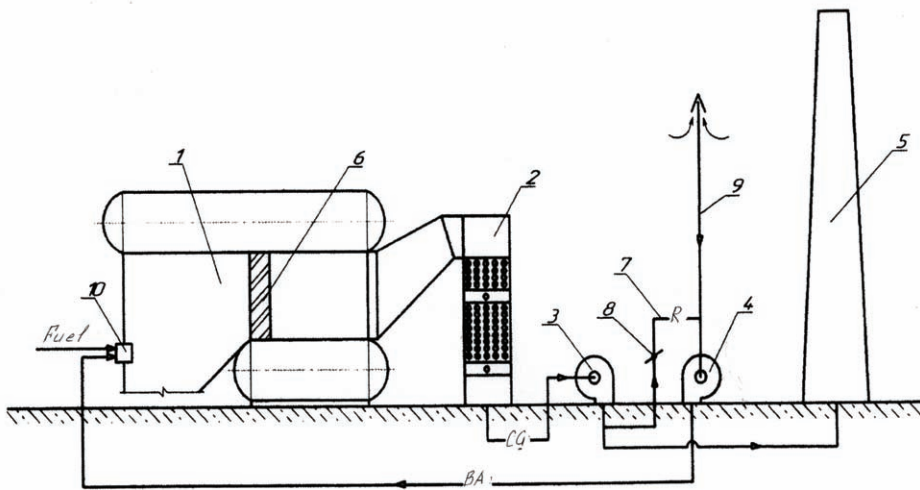


Figure 1. Complex scheme of combustion products cleaning (afterburning, recirculation): 1- boiler of DKVR series; 2 – economizer; 3 – smoke exhauster; 4 – blow fan; 5 – chimney; 6 – afterburning device; 7 – recirculation chimney; 8 – gate; 9 – air intake shaft; 10 – burner; BA – blow air; CG– combustion gas; R – recirculation products of combustion to boiler furnace

Block 1 is designed to reduce nitric oxides by means of technological methods, i.e. to suppress NOX formation during the process of burning. These methods allow cleaning the furnace gas from nitric oxide to (30-50)% after slight

reconstruction of the gas-air pipeline. Three types of technological methods can be used in block 1, either individually, or in complex: stepwise burning (block 1a); water injection into the furnace chamber (block 1b); recirculation of combustion gas into the furnace chamber (block 1c).

The carried out researches showed (Lebedeva, 1982), that the application of the NOX suppression methods in the boilers of the DKVR series causes occurrence of the incomplete burning products at the chimney outlet due to a small volume of the furnace chamber and insufficient time of the combustion gas presence in the high temperature section of the flame.

This drawback is overcome in the offered scheme by means of block 2 comprising an afterburning device that the author suggests (Lebedeva, 1982) for the elimination of the incomplete burning products and further cleaning of the combustion gas from the remaining nitric oxides.

The increased pollution of the atmosphere demands usage of more efficient methods of cleaning from nitric oxides, and the method of NOX high temperature recovery is one of them.

Previously this method was believed to have a significant drawback – the difficulty to maintain temperature in a narrow range (950-970°C) in the zone of introduction of the gas-regenerator under various heat loads of a boiler.

The developed afterburning device helped overcome this problem as well, i.e. keep the required temperature level under the variable operation conditions of a boiler. This method of combustion gas cleaning is protected by patent RU 2293254 C2 (Lebedeva, Gordeev, 2007). Based on the patent, an ecologically efficient complex scheme of fine cleaning of organic fuel burning products has been developed that allows reducing simultaneously emissions of nitric oxides and incomplete burning products, including carcinogenic benzpyrene, during natural gas burning in boilers.

The complex scheme (Figure 2) consists of 4 blocks: block 1a is the stepwise burning; block 2 is the afterburning device; block 3 is the complex of devices for ammonia preparation and its feeding to the high temperature section of the furnace chamber (the afterburning device).

This process uses ammonia as gas-regenerator, which acts selectively. The process runs at the temperature (930-970)°C. The afterburning device permits to maintain the required temperature level within the whole range of boiler heat

loads and eliminate entirely the products of incomplete burning – carbon monoxide, carbon black and benzpyrene.

The reduction of nitric oxide emissions takes place due to their recovery in a zone of red-hot refractory grates at the presence of ammonia during the two-stage fuel burning.

The results of these researches were presented at the 58th International fair for innovations, research and new technologies “Brussels Innova/Eurika 2009”, and they won a gold medal and a diploma of the Federal Service of Russia for intellectual property, patents and trade marks.

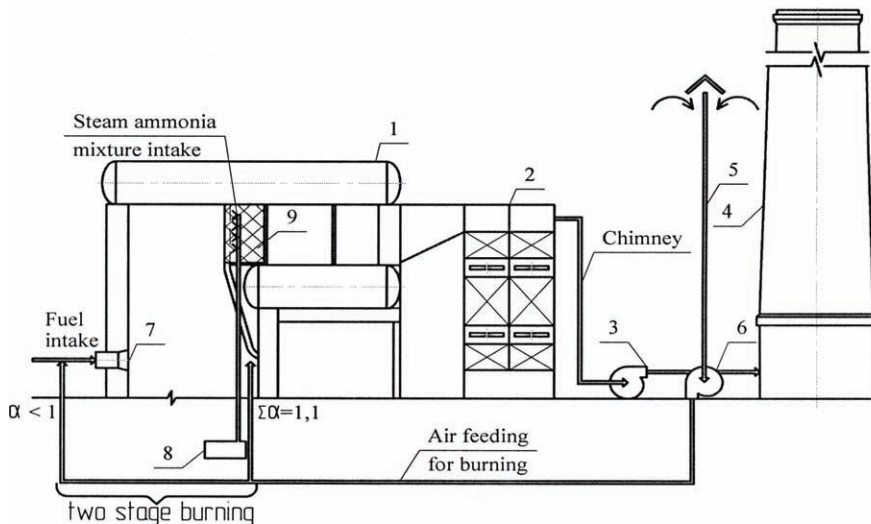


Figure 2. Complex scheme of cleaning natural gas burning products from nitric oxides and products of incomplete burning: 1 – boiler; 2 – water economizer; 3 – smoke exhauster; 4 – chimney; 5 – air intake shaft; 6 – blow fan; 7 – burner; 8 – equipment for preparation of ammonia mixture; 9 – afterburning device

The efficiency of the combustion gas cleaning from nitric oxides exceeds 80%, and carbon monoxide, carbon black and benzpyrene are not present in the exhaust gas.

The main feature of the offered complex schemes of the combustion gas cleaning is the use of an afterburning device. Most completely afterburning devices were approved in the industrial boilers of the DKVR series. The principle of operation of the afterburning devices and their effectiveness were described in detail in (Lebedeva, 1982, Lebedeva, Gordeev, Mochalina, 2005, Lebedeva, Gordeev, 2007).

The afterburning devices have been developed for the DKVR boilers of all standard sizes. An afterburning device consists of two refractory grates with a mixing chamber between them. Figure 3 shows the location of an afterburning device (rows 1 and 2) in a boiler of the DKVR-10 series.

The multiyear experiments (supervised by E.A. Lebedeva) have proved that the application of the afterburning devices gives considerable ecological and technological competitive advantages. From the ecological point of view, it is a possibility to reduce nitric oxide emissions by (60-90)% (depending on the used scheme of cleaning) and products of incomplete burning (carbon monoxide, benzpyrene, carbon black) – by (99-100)%.

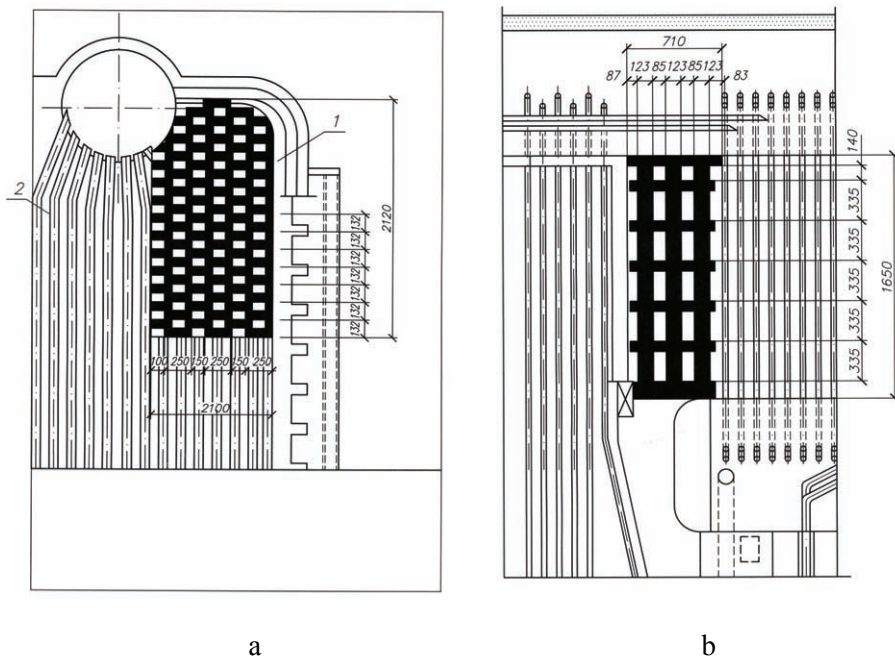


Figure 3. Cross-sections of a boiler of the DKVR-10-13 series with an installed afterburning device: a – the 1st row of the afterburning device; b – the 2nd row of the afterburning device, 1 – brickwork; 2 – screen pipes.

Figure 4 presents the results of the afterburning device testing in a boiler of the DKVR-10-13 series located in the boiler house of the artificial leather plant (the city of Bogorodsk of the Nizhny Novgorod region). Black oil, residual stock of oil refining, was used as fuel. A specific feature of black oil burning is formation of benzpyrene in quantity by order of magnitude higher than that of natural gas burning.

Analysis of the dependence of benzpyrene content in the boiler exhaust gas on the air excess coefficient before and after installation of an afterburning device has revealed that the presence of an afterburning device allows reaching black oil complete burning within the entire range of heat loads.

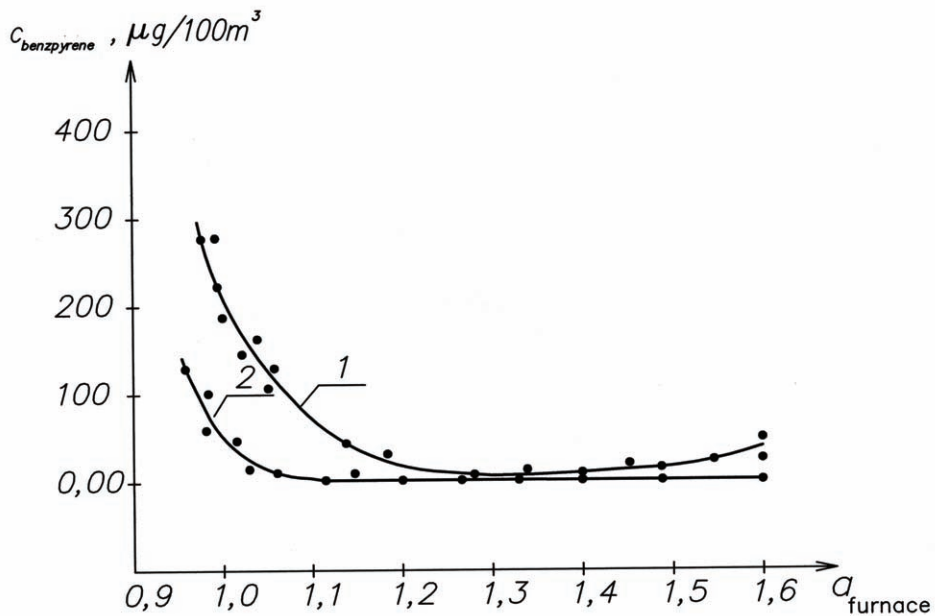


Figure 4. Benzpyrene content in the boiler exhaust gas before and after the afterburning device installation, depending on the air excess coefficient.

Besides, boilers equipped with afterburning devices have considerable technological advantages, too. Operation of industrial boilers with afterburning devices allows avoiding incomplete combustion ( $q_3=0$  and reduction of  $q_2$ ) at low air excess coefficients ( $\alpha_T = 1.03-1.05$ ). Without an afterburning device heat

losses due to the incomplete combustion  $q_3$  reach 5% to 7%. With the device, beside the increase of the performance coefficient the boiler capacity is increased by (5-8)% due to the increase of the radiative and convectional heat transfer in a furnace chamber (Lebedeva, E.A., Loschilova, E.V. 2010).

The role of the afterburning devices as heat energy accumulators should be underlined. Under increased heat loads the brickwork is heated up, and at a mode of minimal steam generation it gives heat to the combustion gas of temperature (700–800)°C, thus, contributing to the complete burning of toxic components and increase of the performance coefficient of a boiler and fuel utilization factor. The drag of the grates does not exceed (100-200) Pa.

The use of a cheap and widely available material, fire clay, in a 1000°C temperature zone is efficient and promising, because the fireclay refractory shows stable operation, and the brickwork strength is sufficient. Ash deposit is insignificant, the glazing and slagging of the refractory surfaces of the afterburning device have not been observed.

Thus, installation of an afterburning device does not require much investments and considerable reconstruction of the gas duct, it does not also influence negatively the boiler's operation.

Bellow the results obtained during exploitation of boiler No. 1 of the Vetluga plant "Metoksil", equipped with an afterburning device, are presented.

The necessity of installing an afterburning device on the boiler was explained as follows. The preliminary investigations performed by the JSC "Promenergogaz-2" on the level of the boiler's "photograph" showed that the characteristics of boiler No. 1 differed considerably from the normative parameters regarding the content of harmful matters in combustion gas.

Specialists of the JSC "Promenergogaz-2" did not manage to improve performance of boiler No. 1 during the operation-adjustment tests (see Table 1). Regardless the increased air excess, the flame was drawn into a convection chimney causing incomplete combustion and consequently increased emission of carbon monoxide CO (benzpyrene was not measured).

On the basis of that fact, the authors recommended to equip boiler No.2 of the DKVR-10-13 series at the Vetluga plant "Metoksil" with a modernized afterburning device. Its working drawings as well as mounting and operational specifications were handed over.



Tests of DKVR boiler No. 1 with an installed afterburning device fulfilled by the JSC “Promenergogaz-2” proved that the boiler’s reconstruction ensured complete fuel combustion in the entire range of heat loads. Table 2 presents a fragment of the operation chart developed during the testing of the boiler with an afterburning device.

Table1. Operation chart of DKVR-10-13 boiler No. 2 before afterburning

Ser. No.	Parameter	Unit of measure	Value				
1.	Steam-generating capacity	t/h	4.8	6.8	8.4	9.6	11.1
2.	Steam pressure in the boiler	kg/cm <sup>2</sup>	8 - 10				
3.	Number of burners	pcs.	2				
4.	Gas pressure at the burners	kPa	2.5	5.0	7.5	10.0	12.5
5.	Air pressure before the burners	kg/m <sup>2</sup>	15 - 20	35 - 40	50 - 55	70 - 75	80 - 85
6.	Exhaustion in the furnace	kg/m <sup>2</sup>	1.5 – 2.5				
7.	CO content in combustion gas	%	2.1	1.5	1.1	0.6	0.4
8.	NO <sub>x</sub> content in combustion gas	ppm	64	68	70	84	92
9.	NO <sub>x</sub> content in combustion gas adjusted to $\alpha = 1$	mg/m <sup>3</sup>	168	170	172	198	211

Along with the complete absence of carbon monoxide in the combustion gas a significant reduction of nitric oxides is noted. The comparison of Tables 1 and 2 shows that NO<sub>x</sub> emission from the boiler with an afterburning device has

Table 2. Operation chart of DKVR-10-13 boiler No. 2 with the afterburning device

Ser. No.	Parameter	Unit of measure	Value				
1.	Steam-generating capacity	t/h	4.8	6.8	8.4	9.6	11.1
2.	Steam pressure in the boiler	kg/cm <sup>2</sup>	8 - 10				
3.	Number of burners	pcs.	2				
4.	Gas pressure at the burners	kPa	2.5	5.0	7.5	10.0	12.5
5.	Air pressure before the burners	kg/m <sup>2</sup>	15 - 20	35 - 40	50 - 55	70 - 75	80 - 85
6.	Exhaustion in the furnace	kg/m <sup>2</sup>	1.5 – 2.5				
7.	CO content in combustion gas	%	Not present				
8.	NO <sub>x</sub> content in combustion gas	ppm	64	68	70	84	92
9.	NO <sub>x</sub> content in combustion gas adjusted to $\alpha = 1$	mg/m <sup>3</sup>	168	170	172	198	211

reduced by 20-30% under a small load (4.8 t/h) and by 35.5% under a high load (11.1 t/h). This fact can be explained by a partial recovery of nitric oxides in a high temperature zone of the refractory surfaces.

At present the complexes of nature conservation measures for industrial boilers are being further developed on the basis of the results of the previous theoretical

and experimental researches as well as available home and foreign experience. An optimal combination of the elements of the environment protection equipment is offered depending on the design and service life of boilers, as well as the required degree of cleaning of the combustion gas emitted into the atmosphere. To save energy resources, the developed schemes of cleaning comprise energy saving-equipment.

### **Conclusion**

Schemes of complex cleaning of the combustion products from nitrogen oxides and carbon black and benzpyrene were developed. Implementation of the methods considered in this paper allows along with a reduction in the concentration of harmful substances in emissions of industrial boilers to achieve increasing efficiency of boiler unit. Optimal combination of elements ecologically safe technology combined with energy-efficient equipment were proposed.

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