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CALCULATED EVALUATION OF QUANTITATIVE INDICATORS OF NITROGEN OXIDES WHEN USED AT DIFFERENT ENERGY INSTALLATIONS

Energy consumption is closely linked to all human activities. Today, emissions from thermal power plants in Ukraine are 5–30 times higher than the established standards of the European Union and are the main air pollutant in the country. Although solid fuels are being replaced by other energy sources (such as natural gas and oil), over the last century, approximately 3 billion people worldwide still rely on solid fuels burned in traditional furnaces or on open fires for cooking or heating. This traditional incineration equipment emits large amounts of pollutants, leading to 4 million premature deaths worldwide each year and serious regional air pollution. The negative impact of harmful components, such as nitrogen oxides, on human health, flora and fauna, buildings and structures is not limited to the area adjacent to the emission sources, but extends to hundreds and thousands of kilometers. Emissions of nitrogen oxides should be controlled, as they are strictly regulated by current legislation. First of all, the production of exhaust gases should be minimized. The following anthracite-type combustion plants in order to reduce the emission of nitrogen oxides are considered: boilers with circulating fluidized bed and fixed bed, as well as boiler plants with liquid slag removal and solid slag removal. Therefore, currently environmental pollution is becoming global in nature, and the cost of its protection has become commensurate with the magnitude of environmental damage. The main purpose of this article is to conduct a calculated study of the level of nitrogen oxide emissions during the combustion of anthracite-type at various power plants. A comparative analysis of the level of emission of nitrogen oxides during the combustion of anthracite in the above equipment. It is established that the most optimal installation from the point of view of environmental friendliness is the circulating fluidized bed, the worst – the installation with liquid slag removal at flaring. It is established that the most optimal installation from the point of view of environmental friendliness is the circulating fluidized bed, the worst – the installation with liquid slag removal at flaring. Also, measures to reduce emissions of nitrogen oxides used in boilers with solid and liquid slag removal are considered.

Key words: *nitrogen oxides, emission index, ecological status, circulating fluidized bed, fixed bed, liquid slag removal, solid slag removal.*

Formulation of the problem. Environmental pollution in the most developed countries of the world is one of the most important and urgent issues of our time and it really needs a lot of attention from both the community and government agencies, in particular, much attention is paid to studying the environmental impact of energy production. Energy consumption is closely linked to all human activities, such as: home heating, cooking, vehicle traffic, agricultural production, etc. Solid fuels (eg coal, wood, crop residues, etc.) play an important role in energy for everyday human life and production. Although solid fuels are being replaced by other energy sources (such as natural gas and oil), over the last century, approximately 3 billion people worldwide still rely on solid fuels burned in traditional furnaces or on open fires for cooking or heating. This traditional incineration equipment emits large amounts of pollutants, leading to 4 million premature deaths worldwide each year and serious regional air pollution.

Analysis of recent research and publications. Consider a number of works on the above issues, among which we should pay attention to [2–11].

At the same time, fossil fuels are gradually depleted every year, and environmental damage such as global warming, acid rain and urban smog due to emissions are forcing the world to reduce pollutant emissions. According to the EU Directive [1], it is necessary to provide 30% of renewable energy sources in final energy consumption by 2030 in order to reduce harmful emissions. But in Ukraine, compared to other countries, the situation is the opposite. While all countries of the world are trying to reduce the number of thermal power plants, Ukraine, on the contrary, is increasing the purchase of coal for thermal power plants. Combustion of solid and liquid fuels is accompanied by the release of sulfur, carbon dioxide and carbon monoxide, as well as oxides of nitrogen, dust, soot and other pollutants and hazardous substances [2]. Inefficient combustion also leads to greenhouse gas emissions and exacerbates global warming. Today, emissions from thermal power plants in Ukraine are 5–30 times higher than the established standards of the European Union and are the main air pollutants in the country. Therefore, the provision of favorable living conditions for the inhabitants of the cities of our country is the main pressing issue, which requires a clear analysis of the impact of harmful emissions of thermal power plants on the environment and the adoption of ways to solve this environmental problem. Among the harmful emissions, nitric oxide (NOx) attracts a lot of attention. Although nitrogen oxides are not the only pollutants, they make a significant contribution to air pollution. Industrial processes, which are mainly related to energy production, combustion of coal, oil and natural gas, as well as galvanic processes, are largely responsible for the production of the largest amount of NO_X. Various scientists deal with the problem of nitrogen oxides. J.S. Mysak studied the combustion of fuel in pulverized coal boilers while maintaining the reliability of the equipment, improving environmental performance and reducing harmful emissions into the environment of thermal power plants [3]. F. Shiro and others. [7] analyzed the properties of natural gas enriched with hydrogen and its combustion products, taking into account the current European standards for gas boilers. Scientists around the world are trying to reduce emissions into the environment, there are many ways to do this. One such way is to choose the combustion process. First of all, it is important to minimize the formation of emissions, and then remove those nitrogen oxides, the formation of which is unavoidable. Minimizing their formation can be achieved through strategies such as lowering the operating temperature, reducing the residence time of gases in the combustion zone and reducing the oxygen / fuel ratio while reducing excess air. Reduction of NOx formation is achieved mainly by influencing the maximum combustion temperature provided by the introduction of recirculation gases, water or steam into the combustion zone or into the blast air, as well as two- and three-stage fuel combustion, which reduces the maximum temperature and oxygen content in the maximum temperature zone. During the last decades, engineers have developed and implemented various advanced furnaces. However, it is not possible to completely prevent the formation of nitrogen oxides, it is necessary to use methods that allow the removal of NO_X formed to comply with increasingly demanding legislation in this area. Absorption by chemical reaction, selective non-catalytic reduction and selective catalytic reduction by chemical reaction are the most commonly used measures to remove nitrogen oxides. And the latter is more suitable for powerful boilers. The reduction method in a selective catalytic chemical reaction is based on a catalytic process in which nitrogen oxides are selectively reduced in the presence of a catalyst and the reducing agent is oxidized to nitrogen gas. The main advantages of this technology are the very high yield of NOx during removal and the fact that NO_X is converted to nitrogen gas without additional by-products or residues. Many studies have been conducted on this topic, but in the literature there is no data on a comparative analysis of the characteristics of anthracite-type combustion at different fuel combustion plants in terms of determining the level of nitrogen oxide emissions.

Setting objectives. The main purpose of this article is to conduct a calculated study of the level of nitrogen oxide emissions during the combustion of anthracite-type at various power plants. Such installations are: boilers with circulating fluidized bed and fixed bed, as well as boiler plants with liquid and solid slag removal.

Presentation of the main research material. Consider in more detail the above settings. A fluidized bed is a two- or three-phase system that is created by bringing particles of a solid phase to a suspended state by dynamically influencing them with an upward flow of liquid or gas (air). In fireboxes with a fluidized bed, the lifting force of the gas-air flow balances the weight of the particles, due to which there is a pseudo-liquefaction - intense heat and mass transfer in height and cross section of the layer. In the superlayer space, the living cross-sectional area is larger, and, consequently, the gas velocity is smaller (up to 1.0–2.5 m / s), and most of the particles removed from the layer fall back into the layer. Due to the fact that the combustion particles, the proportion of which in the layer is small, are surrounded by inert gases, they do not overheat, and the average temperature of the layer does not exceed 950°C. Under these conditions, the generation of nitrogen oxides is low. Relatively low specific burning rates of carbon and its concentration in the layer are compensated by the relatively large mass and height of the layer (up to 1.0–1.2 m), and deep firing of most particles is achieved due to a sufficiently long time in the furnace. The fluidized bed is undemanding to the quality of fuel: it is quite successful in burning coal and carbonaceous waste with an ash content of up to 70% and relatively low-ash with a moisture content of up to 60% [8].

A firebox with a fixed layer is a type of fuel combustion that originates from the development of fire by ancient people in the form of a fire. Fuel can be loaded manually, through the door, or mechanically, from the hopper. Before feeding into the fuel hopper, the required fraction is provided by crushing on a crusher, or, conversely, the formation of fuel pellets (pellets). In furnaces with a fixed layer, the fuel lying freely on the grates is blown from below by air. Due to this, there are zones of oxidant leakage in the layer and, as a consequence, zones of uneven combustion – cooling (resulting in local afterburning and CO emissions with flue gases), as well as zones of overheating (result – accelerated destruction of the lattice) [9].

With liquid slag removal furnaces are of different types. Much more favorable working conditions of a semi-open single-chamber furnace with liquid slag removal. Here the melting zone and the cooling zone are largely separated. In the combustion chamber, the screen pipes are studded and covered with refractory coating. The process of fuel combustion is almost completely completed in this chamber, and its volume is relatively limited, in connection with which the intensity of heat release here is 0.5–0.8 MW / m^3, and the temperature is 1700–1800°C. 20–40% of fuel ash is captured in the chamber, which is removed in a liquid state through the fly. In the upper part of the furnace there are open screen surfaces, which provide gas cooling and removal.

In a two-chamber furnace with liquid slag removal, the combustion chamber with liquid slag and the cooling chamber are separated by slag-separating gratings, which are made of diluted studded screen tubes having a refractory coating. The main amount of molten slag is captured in the combustion chamber. Additionally, the trapped slag flows to the bottom of the furnace, from where it enters the water bath for granulation through the fly. Up to 70% of all ash is captured in a two-chamber furnace [10].

To determine the most efficient technological method of burning anthracite, among those discussed above, it is necessary to calculate the level of nitrogen oxides.

The calculations were performed in accordance with [11] by the formula:

$$k_{NOx} = (k_{NOx})_0\, f_H\,(1-\eta_I)(1-\eta_{II}\beta)\text{, g / GJ} \qquad (1)$$

where $(k_{NOx})_0$ – emission index of nitrogen oxides without taking into account emission reduction measures, g / GJ;

$f_н$ – the degree of reduction of NOx emissions when working at low load;

η_I – the effectiveness of primary (regime-technological) measures to reduce emissions;

η_{II} – efficiency of secondary measures (nitrogen treatment plant);

β – the efficiency of the nitrogen treatment plant.

According to the calculations obtained the following data, which are listed in table 1.

Table 1

The emission of nitrogen oxides when using different technological methods of combustion of anthracite

Installation for burning of ASh	Nitrogen oxide emission index, g / Gcal
With a circulating fluidized bed	32
With a fixed layer	49
With solid slag removal	105
With liquid slag removal	190

Figure 1 shows the dependence of the emission of nitrogen oxides during the combustion of coal in a circulating fluidized bed, with liquid and solid slag removal during flare combustion and in a fixed bed.

The graph (Fig. 1) shows that the best setting in terms of environmental friendliness is a circulating fluidized bed, the worst – a plant with liquid slag removal during flaring.

To improve the environmental conditions and solve the problems of plants with a high concentration of nitrogen oxides, measures have been developed and implemented to help reduce NOx emissions at stations with boilers with liquid and solid slag removal.

The reduction of NOx formation is achieved by influencing the maximum combustion temperature provided by the introduction of recirculation gases, water or steam into the combustion zone or into the blast air, as well as by multi-stage fuel combustion.

The introduction of flue gas recirculation became widespread in the late 70's of the twentieth century. and has since been widely used in boiler technology. Flue gases with a temperature of up to 400°C are taken in front of the air heater and a special recirculation flue is fed to the combustion chamber. It is technically possible to provide recirculation without a special recirculation flue. To do this, a special tongue damper is installed in the chimney of the boiler near the smoke extractor, which allows you to regularly select about 20% of the flue gases and direct them to the inlet of the blast fan. As a result, the maximum temperature in the furnace is reduced and, in addition, the concentration of oxygen in the combustion zone is reduced, which also reduces the formation of NOx. The supply of recirculating gases with fuel reduces the yield of nitrogen oxides more effectively than mixing them into the blast air. It should be borne in mind that the use of recirculation leads to a decrease in the efficiency of boilers in proportion to the amount of recirculation gases supplied. Thus, with increasing the degree of recirculation from 20 to 30%, the efficiency of the boiler decreases by 0.5 and 0.75%, respectively. Currently, gas recirculation is used in powerful boilers of power units running on coal dust, fuel oil and natural gas.

The introduction of water or steam into the combustion zone suppresses the formation of nitrogen oxides no less effectively, and it should be noted the relative simplicity of this method, deeper combustion of carbon monoxide and benzopyrene, as well as the possibility of using solid fuels. The introduction of water or steam in an amount of more than 5–6% of the mass of air supplied to the burners can adversely affect the completeness of combustion and reduce efficiency by 4–5% due to a significant decrease in temperature.

The essence of staged fuel combustion is that less air is supplied to the primary combustion zone than theoretically required (α = 0.70–0.95), the remaining air required for complete fuel combustion is supplied further at one or more levels along the length torch, resulting in a decrease in the maximum temperature in the combustion zone, the oxygen content in the core of the torch, decreases the reaction rate of nitric oxide formation, increases the length and luminosity of the torch. Structurally staged combustion is used in boiler units with a multi-tiered arrangement of burners, which allows you to adjust the fuel-air ratio along the length of the torch. Lower tier burners operate with a lack of air, the rest of the air is supplied through air blast lances or upper row burners where fuel is supplied little or not at all. The most important feature of step combustion is the presence of a recovery zone, where due to lack of air there are products of incomplete combustion of CO and H_2, and nitric oxide is not formed.

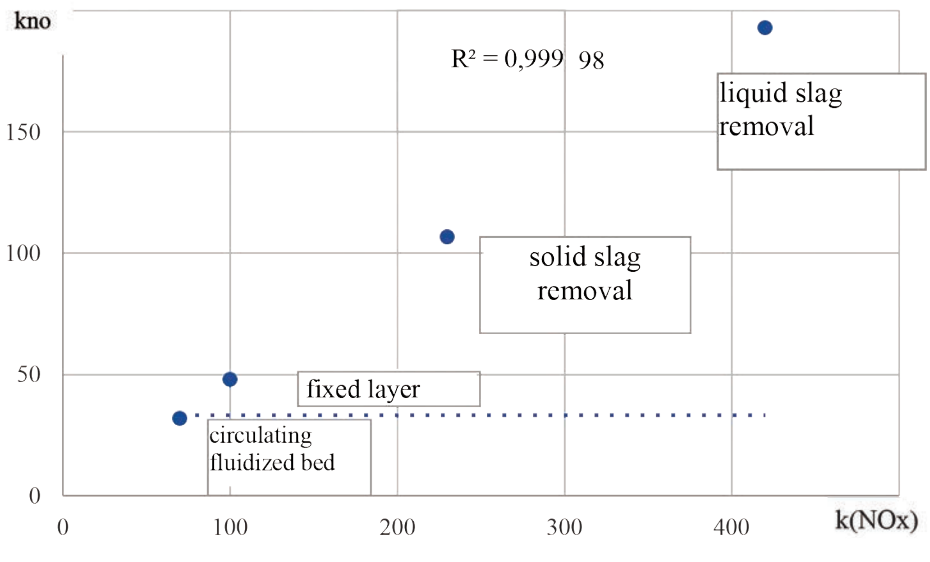

Figure 1. "Dependence of emission of nitrogen oxides during combustion of coal in a circulating fluidized bed, with liquid and solid slag removal during flare combustion and in a fixed bed"

Conclusions. Emissions of nitrogen oxides should be controlled, as they are strictly regulated by current legislation. First of all, the production of exhaust gases should be minimized. The following anthracite-type combustion plants in order to reduce the emission of nitrogen oxides are considered: boilers with circulating fluidized bed and fixed bed, as well as boiler plants with liquid slag removal and solid slag removal. A comparative analysis of the level of nitrogen oxides emission during the combustion of anthracite was performed using different technological methods.

It is established that the most optimal installation from the point of view of environmental friendliness is the circulating fluidized bed, the worst – the installation with liquid slag removal at flaring. Also, measures to reduce emissions of nitrogen oxides used in boilers with solid and liquid slag removal are considered.

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РОЗРАХУНКОВА ОЦІНКА КІЛЬКІСНИХ ПОКАЗНИКІВ ЗАКИСІВ АЗОТУ ПРИ ВИКОРИСТАННІ НА РІЗНИХ ЕНЕРГЕТИЧНИХ УСТАНОВКАХ

Споживання енергії тісно пов'язане з усіма видами людської діяльності. Сьогодні викиди від теплових електростанцій в Україні у 5–30 разів перевищують встановлені стандарти Європейського Союзу та є основним забруднювачем атмосферного повітря у країні. Негативний вплив шкідливих компонентів, таких як оксиди азоту, на здоров'я населення, флору і фауну, будівельні об'єкти і споруди не обмежується територією, що прилягає до джерел викидів, а поширюється на сотні й тисячі кілометрів. Хоча тверде паливо замінюється іншими джерелами енергії (наприклад, природним газом і нафтою), протягом останнього століття приблизно 3 мільярди людей у всьому світі все ще покладаються на тверде паливо, що спалюється у традиційних печах для приготування їжі або опалення. Це традиційне обладнання для спалювання виділяє велику кількість забруднюючих речовин, що призводить до 4 мільйонів передчасних смертей у всьому світі щороку та серйозного регіонального забруднення повітря. Необхідно контролювати викиди оксидів азоту, оскільки вони суворо регламентуються чинним законодавством. Насамперед слід звести до мінімуму утворення вихлопних газів. Для зменшення викидів оксидів азоту розглядаються такі спалювальні установки антрацитового типу: котли з циркуляційним киплячим шаром і нерухомим шаром, а також котельні *з видаленням рідкого шлаку та видаленням твердого шлаку. Тому нині забруднення довкілля набуває глобального характеру, а витрати на його охорону стали сумірні з величиною екологічного збитку. Головною метою цієї статті є провести розрахункове дослідження рівня емісії оксидів азоту при спалюванні антрацитового штибу на різних енергетичних установках. Проведено порівняльний аналіз рівня емісії оксидів азоту при спалюванні антрацитового штибу у вищезазначеному обладнанні. Встановлено, що найоптимальнішою установкою з погляду екологічності є циркулюючий киплячий шар, найгіршою – установка з рідким шлаковидаленням при факельному спалюванні. Також розглянуто заходи щодо зниження викидів оксидів азоту, що використовуються у котлах із видаленням твердого та рідкого шлаку.*

Ключові слова: *оксиди азоту, показник емісії, екологічний стан, циркулюючий киплячий шар, нерухомий шар, рідке шлаковидалення, тверде шлаковидалення.*