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Reduction of Harmful Emissions at Power Plants by Controlling Optimal Fuel Flow Rate for Boiler Burners Ignition

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Abstract

This research work focuses on the study of the issue of the effective use of natural gas and fuel oil for the ignition of pulverized coal torches of boilers at thermal power plants. The main goal of this work is to conduct an analysis of experimental studies and identify the optimal flow rate of natural gas and fuel oil, which ensure the most effective and economical ignition of a pulverized coal torch. Namely, the test results of TPP–210A boiler when burning coal with natural gas ignition at the flow rate of 6,000 m^3/h, 10,000 m^3/h, 14,000 m^3/h or 12%, 21%, 30% by heat were given and analyzed. The influence of operating mode factors on the economic indicators of the boiler and the output of liquid slag has been demonstrated, and their optimal values have been determined. With the optimal values of the mode factors, the economic and ecological indicators of the boiler have the following values: gas flow rate for ignition is 6,000 m^3/h – 10,000 m^3/h; content of combustibles in the take away ashes is 21% – 16%; boiler efficiency is 84.52% – 86.73%; amount of NO_x emission is 665 mg/m^3 – 740 mg/m^3. It has been experimentally proven that the minimum gas flow rate at which optimal boiler operation conditions are ensured in terms of efficiency and liquid slag output is 10,000 m^3/h, under the condition of uniform distribution of gas to all burners.

Keywords: pulverized coal boiler; torch ignition; coefficient of excess air; burner.

1. Statement of problem

In connection with marital war and the hostilities on the territory of our state, the importance of energy efficiency and environmental safety in the energy industry is increasing. Boilers of the TPP–210A type, which use pulverized coal fuel, are the most common in thermal power plants of Ukraine. However, the process of igniting the pulverized coal torch of boilers is quite energy-consuming and expensive, which makes it necessary to investigate and optimize this process [1].

The purpose of this article is to determine the optimal flow rate of natural gas and fuel oil for lighting the pulverized coal torch of TPP–210A boilers to reduce fuel flow rate and improve the efficiency of the combustion process. The research is aimed at establishing optimal parameters of fuel lighting, which ensure stable and trouble-free operation of boilers, avoiding misfires, as well as reducing emissions of harmful substances into the atmosphere. To achieve the task, experimental research methods will be used, as will their analysis.

It is expected that the results of this study will help optimize the flow rate of natural gas and fuel oil, ensuring the economic and environmental efficiency of the TPP–210A boilers. The data of the study can be useful for energy enterprises that use pulverized coal boilers, as well as for scientists and engineers working in the industry of thermal energy and energy saving. The research will contribute to improving the efficiency and sustainability of energy systems, helping to reduce the impact on the environment and reduce the consumption of natural resources.

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2. Literature review

The rational use of natural gas and fuel oil allows you to significantly reduce fuel costs during the operation of thermal power plants and other thermal facilities, this is an important aspect of reducing the cost of products and increasing the profitability of enterprises, as well as reducing emissions into the environment. According to [5], it is important to have automated control systems that can accurately regulate the supply of gas or fuel oil to the pulverized coal flare, this allows for accurate control and optimization of fuel flow rate depending on various factors, such as load, temperature, and fuel composition. However, referring to [6], we can argue that the use of advanced combustion technologies, such as highly efficient burners and control systems, can help reduce fuel consumption and improve flare efficiency. It is important to provide effective and reliable torch ignition to avoid accidents and potentially dangerous situations related to insufficient heating or other problems. According to [7], we can assume that by setting the optimal flow rate of natural gas, during the operation of the TPP–210A boiler, we will ensure effective and economical ignition of the pulverized coal torch, as well as economical operation of the boiler unit.

Having analyzed [8], we also note that fuel moisture affects the heat output and combustion efficiency. Fuel that is too wet can reduce heat transfer, increase fuel flow rate, and slag emissions. We can also state that the overall impact on economic and environmental indicators depends on many factors, including the technical characteristics of the boiler, fuel properties, and regulatory systems [9]. Optimizing the operation of the boiler taking into account these indicators will improve efficiency and reduce the negative impact on the environment.

We assume that the gas flow rate, at which optimal boiler operation conditions are ensured in terms of efficiency and liquid slag output, is the gas flow rate that is evenly distributed to all burners, which means that such gas flow rate gives the best balance between combustion efficiency and minimization of liquid slag output in specific operating conditions of a specific boiler [10].

Different types of boilers are used in thermal power plants of Ukraine for electricity production, but TPP-210A boilers are among the most common, due to the presence of large reserves of fuel and infrastructure for working with coal. Currently, the energy sector in many countries, including Ukraine, is also actively working on modernization and transition to more environmentally friendly energy sources and technologies to reduce the negative impact on the environment.

This may include measures to improve boiler efficiency, the use of coal gasification, and other initiatives to reduce emissions and improve air quality. This is an important direction for ensuring a stable and reliable energy supply and reducing the negative impact on the environment.

3. Methodology of research

The main measurements during boiler tests of the 2nd complexity category were performed taking into account the recommendations [2]. Measurement of the temperatures of steam, water, air, and flue gases was carried out mainly with standard devices. In addition, the temperature of the gases was measured through the corner hatches. Measurements were made using a visual pyrometer of the “BENETECH GT950” type. Ash samples were taken with the help of cyclones of the operational installation.

The content of oxygen and nitrogen oxides in the flue gases at the operating point (behind the superheater) as well as in the flue gas was measured using a TESTO 340-type gas analyzer. In addition, the content of oxygen and nitrogen oxides in the regime point was monitored using standard devices [3].

The flow rate of natural gas, which was less than one-third of the scale of the flow meter, was estimated according to the formula:

$$V_g = \left(P_g/0.184\right)^{0.5} \cdot 27000 \,, \quad (1)$$

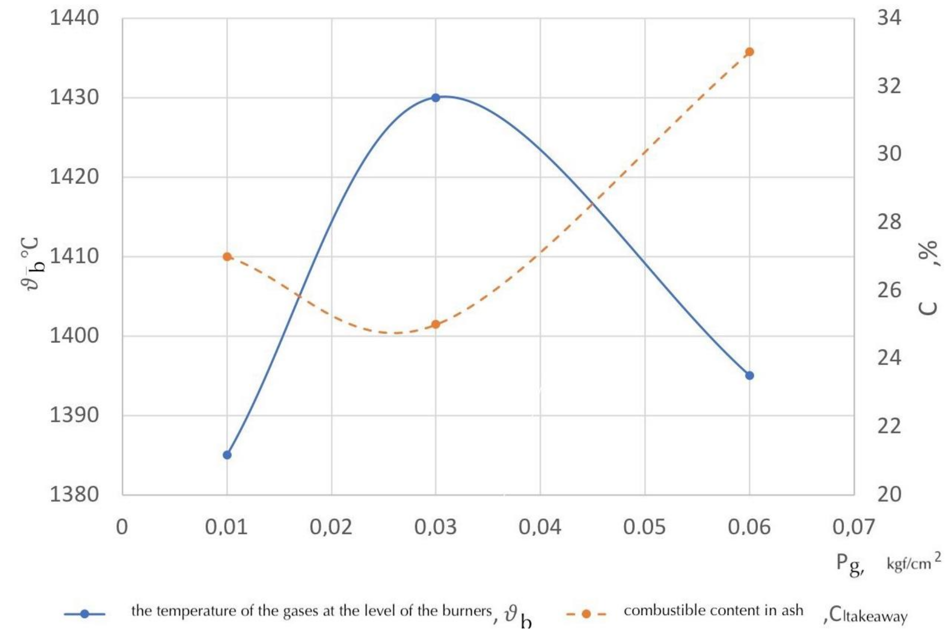
where P_g is the average value of the gas pressure in front of the burners during the experiment, kgf/cm^2; 27000 is gas flow rate, which corresponds to approximately half of the scales of the secondary device, m^3/h; 0.184 is the average gas pressure in front of the burners, which corresponds to the indicated flow rate, kgf/cm^2.

4. Research results

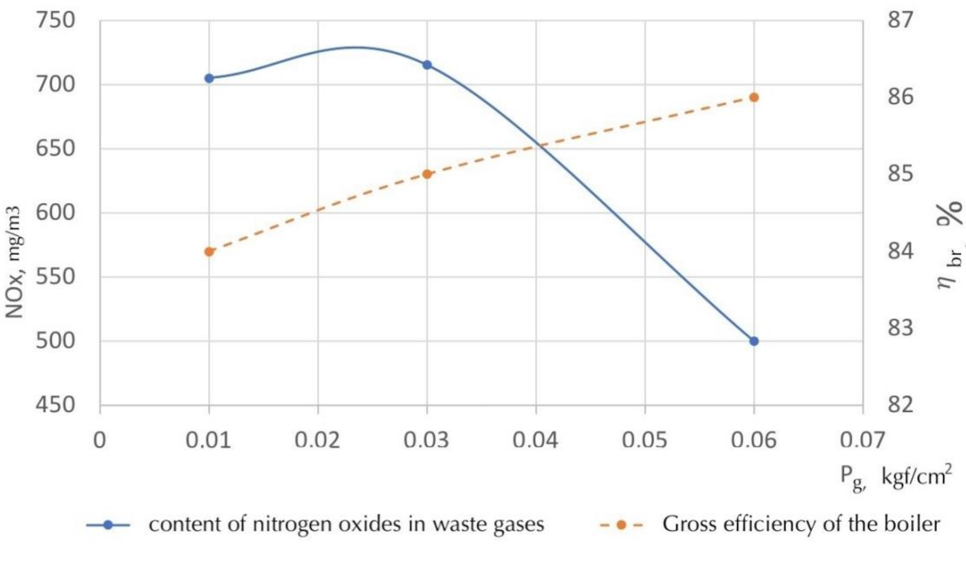
During the analysis of the condition of the equipment, the equipment showed acceptable values for all key parameters. During the experiments, the lower heat of combustion of natural gas was 8000 kcal/m^3 (at standard conditions). The coal was burned with the following characteristics: lower heat of combustion was 5168 kcal/kg; working ash content was 22.3%.

The key task of the research was, however, to determine how natural gas flow rate affects the boiler performance indicators. Therefore, during the experiment, gas flow rates of 6,000 m^3/h, 10,000 m^3/h, and 14,000 m^3/h were investigated, corresponding to gas pressures in front of the burners of 0.01 kgf/cm^2, 0.03 kgf/cm^2, and 0.06 kgf/cm^2, respectively. At the nominal load, the share of gas in terms of heat was 12%, 21%, and 30%.

The dependence of the content of combustibles in ash, the gross boiler efficiency, the gas temperature in the combustion chamber, and the nitrogen oxide content in the exhaust gases on the gas pressure in front of the burners at the nominal load is shown in Fig.1. (The points on the graph represent the average values of the respective parameters for all experiments).



a)



b)

Fig.1. a) Dependence of the gas temperature at the level of the burners and the content of combustibles in the ash, on the pressure in front of the burners. b) Dependence of the content of nitrogen oxides in waste gases and boiler gross efficiency on the pressure in front of the burners.

As it is shown in Fig.1, the best results in terms of coal combustion completeness are achieved when the gas fraction is at 21% in terms of heat. This regime is characterized by the highest temperature in the combustion chamber and, correspondingly, NO_x emissions.

It is also important to note that the curves in Fig.1 do not correspond to optimal values of the parameters. They provide only a qualitative representation of the relationship between the content of combustibles in the take away ashes (C_{ta}) and the boiler gross efficiency concerning gas flow rate for ignition.

In separate experiments, the mentioned values deviate from the averages shown in Fig.1. This can be explained by the influence of the following operational factors [4]:

- the degree of peripheral air closure;
- the operation mode of overfire air burners;
- non-uniform fuel flow rate in the pulverized fuel conduits;
- the excess air coefficient in the combustion chamber.

Below, we will analyze how the factors listed above affect the combustibles content in ash (C_{ta}).

4.1. Influence of the degree of closure of peripheral air

According to the current operating chart, the damper for peripheral air is fully open, so the impact of its opening/closing on C_{ta} was investigated.

Closing the peripheral air at nominal load with a gas pressure in front of the burner of 0.01 kgf/cm^2 to the level of 40% of the peripheral air damper (PAD) position results in a clear reduction in combustibles in the ash (Fig.2). At a gas pressure in front of the burner of 0.03 kgf/cm^2 and 0.06 kgf/cm^2, two modes were investigated: a mode with fully open peripheral air and a mode with fully closed peripheral air.

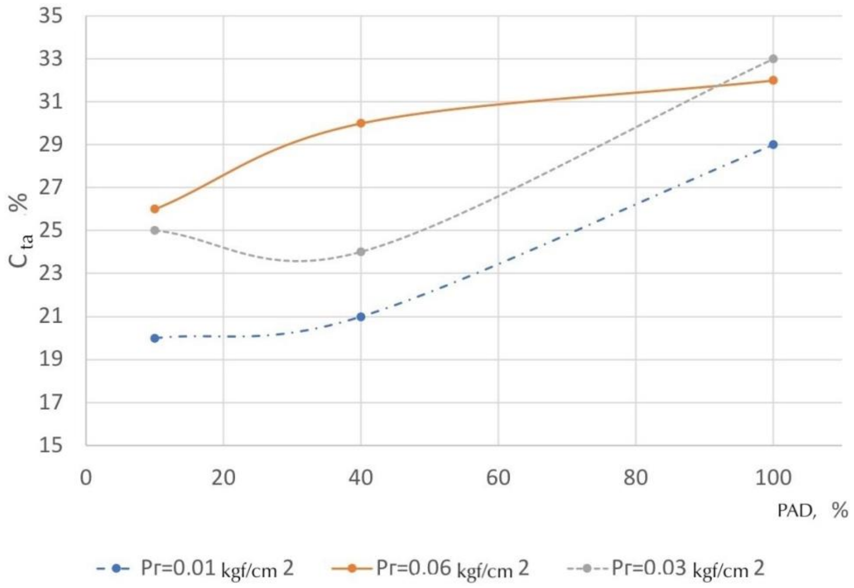


Fig.2. Dependence of combustibles content in ash on the degree of peripheral air closure.

Summarizing the above, it can be concluded that regardless of the gas pressure in front of the burners, changing the position of the damper from fully open to fully closed leads to a reduction in C_{ta} by 7–10%. However, closing the peripheral air beyond 60% to 40% opening is not advisable. The positive effect of closing the peripheral air on the combustion regime can be explained by improving the fuel and air mixing through changes in the ratio of primary and secondary air velocities in the burner throat toward its optimal value.

4.2. Influence of overfire air burner operation

The gas flow rate to the overfire air burners was not precisely determined. An approximate estimate suggests that at a gas pressure in front of the overfire air burners of 0.25 kgf/cm^2, the gas flow rate for one burner is around 400–500 m^3/h. The activation of overfire air burners has an ambiguous impact on the coal combustion quality.

Interestingly, at a gas pressure of 0.01 kgf/cm^2, the activation of overfire air burners deteriorates the combustion regime (Fig.3,a and Fig.3,c), while at a gas pressure in front of the burners of 0.03 kgf/cm^2, it conversely improves the coal combustion regime (Fig.3,b and Fig.3,d).

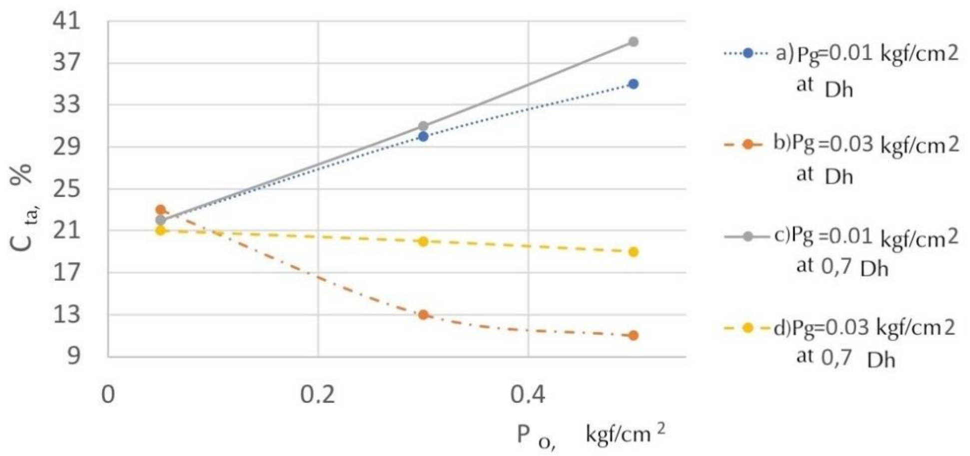


Fig.3. Dependence of combustibles content in ash on the gas pressure in front of the overfire air burners.

4.3. Influence of excess air in the combustion chamber

Fig. 4 illustrates the relationship between the combustibles content in ash and the excess air coefficient (α_{ac}) at the operating point for various values of gas pressure in front of the burners. As shown in Fig.4, at a gas pressure of 0.03 kgf/cm^2, the optimal excess air coefficient is 1.27. At a gas pressure of 0.01 kgf/cm^2, the optimal excess air coefficient is 1.29, and at a gas pressure of 0.06 kgf/cm^2, the optimal excess air coefficient is 1.38.

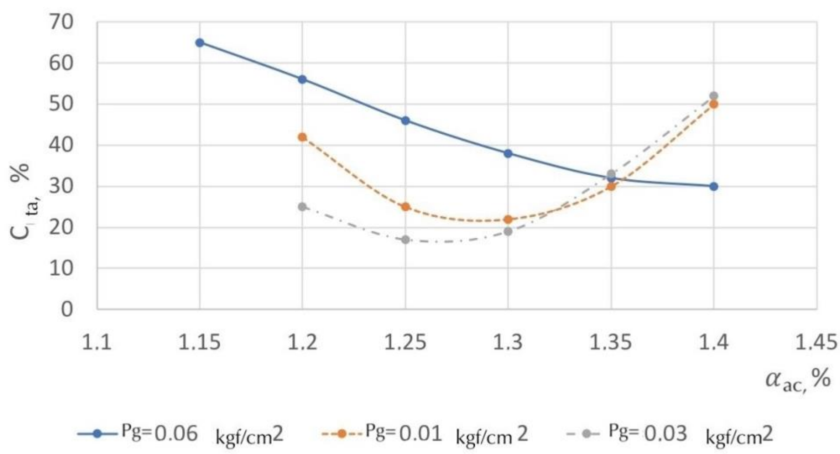


Fig.4. Dependence of the content of combustibles in fly ash on the coefficient of excess air in the furnace.

4.4. Minimum gas flow rate for burner ignition under boiler efficiency conditions

Based on the conducted research, we can conclude that the best conditions for boiler efficiency and liquid slag output are achieved when the gas flow rate to the boiler is 10,000 m^3/h, corresponding to a gas pressure in front of the burners of 0.03 kgf/cm^2, without accounting for the gas flow rate for overfire air burners.

This conclusion regarding boiler efficiency is made based on the presented results of boiler efficiency calculations under optimal operating conditions (Table 1).

Table 1. Test results of the TPP-210A boiler

Variable Name	Value		
Gas pressure in front of burners, kgf/cm^2	0.01	0.03	0.06
Gas flow rate, m^3/h	6000	10000	14000
Gas fraction in mixture, %	12	20	30
Fuel ash content, %	22	22	22
Lower heating value of coal, kcal/kg	5100	5100	5100
Air temperature in front of overfire air burners, °C	30	30	30
Optimal excess air coefficient at operating point	1.29	1.27	1.378
Excess air coefficient by design	1.694	1.674	1.782
Heat loss with flue gases, %	7.52	7.47	8.12
Combustibles content in ash at optimal excess air, %	21	16	31
Heat loss due to mechanical incomplete combustion, %	7.6	5.44	12.95
Heat loss to the environment, %	0.36	0.36	0.36
Boiler gross efficiency, %	84.82	86.73	78.67

4.5. Environmental Performance of the Boiler

The relationship between the nitrogen oxides (NO_x) content (normalized to α=1.4) and the excess air coefficient at the operating point for gas flow rates of 6000 m^3/h, 10000 m^3/h, and 14000 m^3/h is shown in Fig.5.

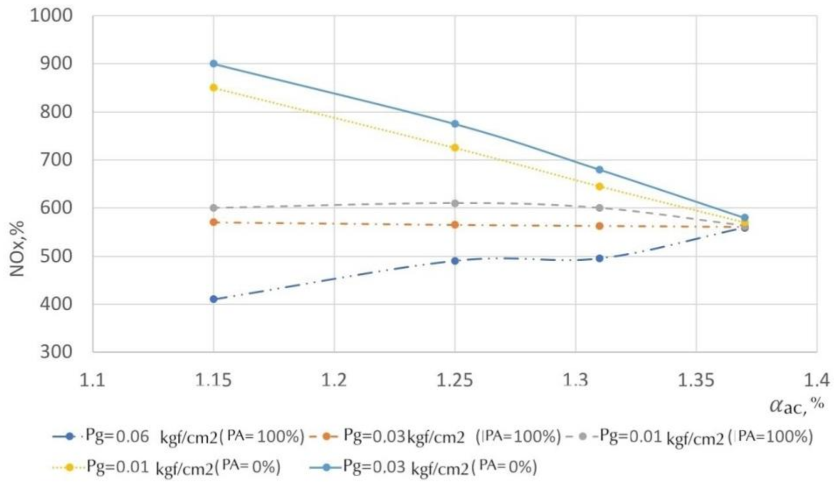


Fig.5. Dependence of nitrogen oxides content on the excess air coefficient in the combustion chamber.

It is evident from this figure, that the highest NO_x emissions occur at a gas flow rate of 10,000 m^3/h. This data was obtained with the peripheral air closed. When the peripheral air is open, NO_x emissions remain at a level of 570 mg/m^3 regardless of the gas flow rate to the boiler.

5. Conclusion

This article is dedicated to determining the optimal gas ignition for coal-dust burners in a boiler, highlighting the importance of this aspect in ensuring efficient and environmentally safe fuel combustion at thermal power plants. Optimal gas ignition for coal-dust burners is crucial for maintaining combustion stability and minimizing emissions of harmful substances.

The research presented in this article examines the combustion regimes of low-calorific coal with an average calorific value of 5,180 kcal/kg and an ash content of 22.3%, ignited by natural gas at flow rates of 6,000 m^3/h, 10,000 m^3/h, and 14,000 m^3/h uniformly across all burners. An analysis of the influence of key technical parameters on boiler operation has been conducted.

It has been determined that the best conditions for boiler efficiency are achieved with a gas flow rate to the boiler of 10,000 m^3/h, corresponding to a gas pressure in front of the burners of 0.03 kgf/cm^2, without accounting for the gas flow rate of overfire air burners.

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Зменшення шкідливих викидів на електростанціях шляхом контролю оптимальної витрати палива на підсвічування пальників котла

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Анотація

Ця дослідницька робота присвячена вивченню питання ефективного використання природного газу та мазуту для підсвічування пиловугільних факелів котлів на теплових електростанціях. Основною метою цієї роботи є проведення аналізу експериментальних досліджень та визначення оптимальної витрати природного газу та мазуту, що забезпечує найбільш ефективне та економічне підсвічування пиловугільного факела. А саме, було приведено та проаналізовано результати випробування котла ТПП – 210А при спалюванні вугілля з підсвічуванням природним газом з витратою 6000 $м^3$/год, 10000 $м^3$/год, 14000 $м^3$/год або 12%, 21%, 30% по теплу. Показано вплив режимних факторів роботи на економічні показники котла і вихід рідкого шлаку та визначено їх оптимальні значення. При оптимальних значеннях режимних факторів економічні і екологічні показники роботи котла мають такі значення: витрата газу на підсвічування становить 6000 $м^3$/год – 10000 $м^3$/год; вміст горючих у золі виносу складає 21% – 16%; ККД котла становить 84,52% – 86,73%; обсяг викидів NO_x складає 665 мг/$м^3$ – 740 мг/$м^3$. Експериментально доведено, що мінімальною витратою газу, при якій забезпечуються оптимальні умови роботи котла щодо економічності та виходу рідкого шлаку є витрата 10000 $м^3$/год, при умові рівномірного розподілу газу на всі пальники.

Ключові слова: пиловугільний котел; підсвічування факела; коефіцієнт надлишку повітря; пальник.