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MODERN TECHNOLOGIES FOR INCREASING THE ENERGY AND ENVIRONMENTAL EFFICIENCY OF ENERGY PRODUCTION

The problems of energy efficiency of energy production along with improving the environmental safety of enterprises are becoming increasingly relevant. One of the ways to solve these problems is the implemention of effective technologies, which include microflare incineration technology (MIT-technology) of gaseous fuels. The use of MIT- technology, in addition to a significant reduction in harmful emissions into the atmosphere, can simultaneously increase the energy efficiency of thermal power plants.

A significant positive effect can also be achieved by using contact energy exchange plants. A striking example of such a gas-steam plant "Aquarius" the operation of which exceeds the efficiency of gas turbine plants by 10-12% with a simultaneous significant decrease in the concentration of toxic nitrogen oxides NO_x and carbon monoxide CO in flue gases.

Keywords: *energy efficiency, environmental performance, microflare incineration technology, contact energy exchange.*

Introduction. The existence and development of human civilization is no longer conceivable without the production and efficient use of energy. The existence of the energy industry in each country ensures the functioning of all its industries and the economy as a whole. Energy industry is important, among other industries in each country. The energy industry of any country, its work and development is based on objective laws, axioms and principles, the implementation of which is designed to ensure the stable operation of all energy facilities. Recently, the tasks of ensuring the development of civilization without worsening the ecological conditions of the natural environment on the planet have become more and more urgent. Man has appeared and lives on planet Earth in a particular ecosystem. It is impossible to break the balance in its development and destroy this ecosystem. This can cause the death of not only all living things, but also the person himself.

1. Axioms and principles of power engineering functioning. The existence and development of power engineering in any country is based on objective laws, axioms and theorems [1].

Energy axiom 1 for any country: **"The energy sector must continuously supply all sectors and all spheres of the country's population with heat and electric energy in full"**. Violation of this axiom always leads to failures, emergencies, reduced productivity and can be the cause of crises and disasters.

Energy axiom 2: the energy sector of the economy of any state should be developed with constant consideration for **the need to ensure the energy balance between energy production and consumption,** as an invariable condition for strategic development. The energy produced cannot be stored and accumulated in the form of a strategic reserve, it cannot be destroyed or dumped without consequences. At the same time, its production cannot be instantly or in a short time significantly increased or fully used without a trace, just as it is impossible to break off the interconnected process of energy production and consumption. All energy production and its consumption at each moment of time must be balanced in full.

Energy axiom 3: "The growth rate of energy production in the energy sector should be ahead of the growth rate of energy consumption by all sectors of the country's economy combined" [2]. Violation of this axiom can lead to energy shortages, distortions and degradation in the development of individual sectors of the country's economy, and to a decrease in the production of Gross Domestic Product of the whole country.

The primary energy problem of the heat and power industry of any country is the need to constantly improve the energy efficiency of energy production, reduce costs, losses, unit fuel consumption and increase the profitability of energy facilities.

No less important and relevant at present is the problem of reducing the harmful negative impact of energy facilities on the environment: on the hydrosphere, on the atmosphere and on the lithosphere.

It is known that energy production at thermal power facilities (TPF) using fossil fuels is one of the main sources of environmental pollution that occurs in the form of thermal pollution, greenhouse gas emissions and toxic chemicals: CO, CO_2, NO, NO_2, SO_2, $C_{20}H_{12}$, dust and ash emissions.

Given the relevance of improving the environmental cleanliness of the TPF, it is necessary to make appropriate adjustments to the energy production management system. The new energy industry management system should provide improved environmental safety for energy production. This will succeed if the development of the energy industry is based on some energy principles that are based on the use of the energy axioms defined above.

The first energy principle of energy development – **is the principle of ecological balance of development** [3]**: "The growth rate of energy production (δN_i) should not exceed the growth rate of environmental safety (δg_i)"**. The basis of this principle is the need for the advancing development of technologies and the pace of improving environmental safety in comparison with the growth of energy production:

$$\delta N_i - g_{i-1} \leq 0$$

where $\delta N_i = \Delta N / N_i$ - growth rate of energy capacity,

$\Delta N = N_i - N_{i-1}$ - increase in energy capacity, $\delta g_i = \Delta g_i / g_{i-1}$ - rate of increase environmental safety, $\Delta g_i = g_{i-1} - g_i$ - increase in environmental safety.

Special attention should be paid to the scenarios, namely:

1st scenario: $\delta N - \delta g_i < 0$ - sustainable improvement of environmental safety of energy production,

2nd scenario: $\delta N - \delta g_i = 0$ – neutral level of environmental safety,

3rd scenario: $\delta N - \delta g_i > 0$ – high risk of environmental problems and natural disasters.

The second energy development principle relates to the sustainable development of the energy industry in any country in the world. It is advisable to take the well-known definition of sustainable development as the basis (UN Commission on Sustainable Development, 1996).

Sustainable development is the systematic coordination of economic, environmental and social development in such a way that the quality and safety of people's lives, environmental conditions do not decrease from one generation to another, and social progress takes into account the needs of each person [4]. This definition is taken as the basis for determining the second energy principle for the development of the energy industry.

Considering simultaneously the two energy principles of the development of the energy industry in any country, we come to the need to formulate a new energy-ecological paradigm for energy development in the world: "Sustainable development in harmony with nature!".

The new energy-ecological paradigm (NEEP) [5-6] opens up new horizons for the development and implementation of environmentally friendly energy technologies and deepens the understanding of the need to improve all energy production processes.

The relevance of the transition of the energy industry to a new energy-ecological paradigm is obvious in connection with the need for its subsequent development, which is objectively recorded in the energy axioms considered above.

Unfortunately, the current state and operation of energy facilities in many countries is characterized by low values of energy and environmental indicators for a set of objective and subjective reasons and factors, the main ones among them are [7]:

- thermal pollution of the environment;
- emissions of greenhouse gases and toxic chemicals: CO, CO_2, NO, NO_2, SO_2, $C_{20}H_{12}$, which significantly poison the environment and the world around us;
- dust emissions of ash;
- slag emissions;
- a long period of design, construction and commissioning of energy facilities (7 - 12 years), during which energy technologies become obsolete;
- planned operational period is 25 years. During this time (12 + 25 = 37 years), energy production technologies become obsolete and do not meet new requirements;
- systems for environmental cleaning of flue gases of power plants do not have time to reach new requirements for emissions into the atmosphere;
- significant capital investments are required for the construction of new power plants.

The main directions and tasks of increasing energy efficiency and environmental safety of power plants according to the new energy-ecological paradigm:

- improving the quality of fuel combustion in boilers;
- increasing the efficiency of heat transfer processes in boilers and other units;
- improving the quality of flue gas cleaning;
- improving the quality of staff training.

2. Possible solutions to problems in the heat power industry. It is very important to understand that improving the quality of work of existing thermal power facilities (TPF) is possible only in two ways:

Reconstruction - requires significant capital costs and time;

Modernization - is carried out quickly and does not require significant financial investments. With this method, in boilers, the following systems and parts can be upgraded to improve energy efficiency and environmental safety at the same time:

- burner system and combustion conditions (microflame incineration technology of combustion (MIT-technology) - developed at the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute") [8];

- flue gas cleaning systems (contact energy exchange technology - developed at the National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”).

3. Microflame incineration technology (MIT-technology) of combustion of gaseous fuels. This MIT-technology is based on the use of unique Bord nozzle effects and the successful implementation of a set of design features of burners with the implementation of classical methods for producing a homogeneous fuel-air mixture and reducing the emission of harmful substances of nitrogen and carbon oxides (NO_x, CO) in combustion products.

The features of this technology are as follows [9]:

- the unification of the technology is associated with the possibility of creating burner devices according to the same principle of forming their structure with achieving high efficiency and environmental friendliness in the process of burning gaseous fuels for a wide range of regulation and unit heat output of the unit (from 10 to 100%);

- the universality of the technology is emphasized by the possibility of using it with both high energy efficiency and environmental safety indicators for burning various types of gaseous fuels for different types of units: in boilers, contact heat generators and combustion chambers of gas pipe installations with a wide range of stepless power control and for various combustible gaseous media: natural gas, coke oven, blast furnace gas, associated petroleum gas, biogas, methane gas, hydrogen and their combinations in various concentrations;

- possibility of creating effective systems for burning heterogeneous gas mixtures in one burner and thermal incineration (neutralization) of aggressive and carcinogenic gas media.

Complex of positive effects when using MIT-technology [10]:

- continuous flow motion;
- effective combined mixing;
- the ability to burn highly thermal fuels (such as hydrogen H_2);
- continuous automatic self-regulation of combustion;
- internal recirculation of flows;
- low aerodynamic drag;
- temperature field uniformity.

MIT-technology has been successfully implemented in the following types of industrial plants:

-gas turbine units as a part of gas pumping units of types: GTU-10 (10 MW), GT-750-6 (6MW) at gas compressor stations of gas pipelines [11-13];

-steam and hot water boilers of type: DKVR 10/13, KVGM-10, KVGM-20, KVGM-100, PTVM-180 [13-17];

-heat generators of contact (KAOM-0,5 (0,5 MW); KAOM -1,0; KAOM -2,5) and surface (AOM-1,5 Mw; AOM-2,5) types for autonomous heating systems for residential buildings and workshops of industrial enterprises [18-20].

Results of modernization of burner systems on the basis on the basis of use MIT-technology:

1). saving natural gas: in boilers – 5 - 6,5%; in turbines – 10-15%,

2). decrease in concentration and gross toxic emissions into the atmosphere of pollutants in the composition of flue gases (Fig. 1):

-nitrogen oxides NO_x from 800 to 50 mg/m^3;

-carbon monoxide CO from 900 to 5 mg/m^3 (Fig. 1);

3). a wide range of turbine power regulation (from 10 to 100%) with high economic and environmental performance;

4). a high level of uniformity of the temperature field in the gas combustion zone and a reduction in vibration extend the life of the turbine and can increase the turbine power by 20% compared to the passport by reducing the temperature level and thermoelastic stresses in it;

5). the aerodynamic resistance of the burner system is reduced by 30-35%, which reduces energy costs for driving the fans of boilers and compressors in turbines;

6). the ability to perform upgrades in a short time from 1 to 3 days;

7). the estimated payback period for modernization costs while saving natural gas exceeds 10-15 months. Given the reduction in environmental charges and the increase in equipment life, the actual payback period will be significantly shorter;

8). there is no need to buy and install new turbines.

The combustion of gaseous fuels and the transfer of heat in the boiler furnaces and in the combustion chambers of gas turbines based on the use of the MIT-technology become much more efficient and environmentally friendly (Fig. 2, 3).

4. Contact energy exchange technology. The use of contact energy exchange technology allows to obtain a complex positive effect: simultaneously with the increase in energy efficiency (by reducing the temperature of the outgoing gases), an additional environmental effect is obtained – the purification of flue gases from toxic components due to direct contact between gas and water [21].

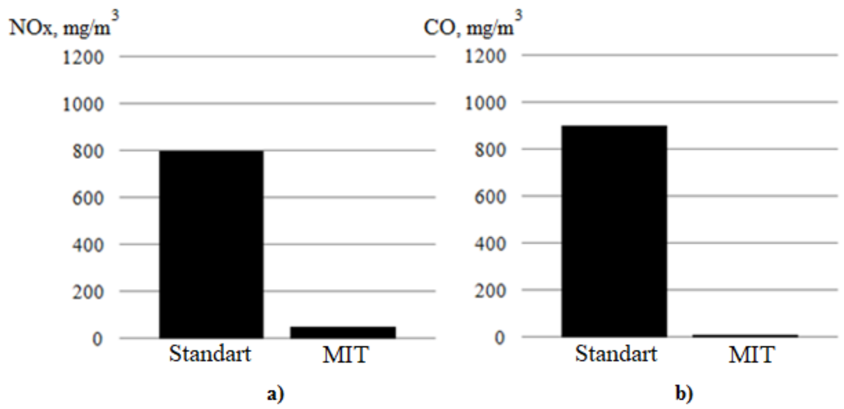
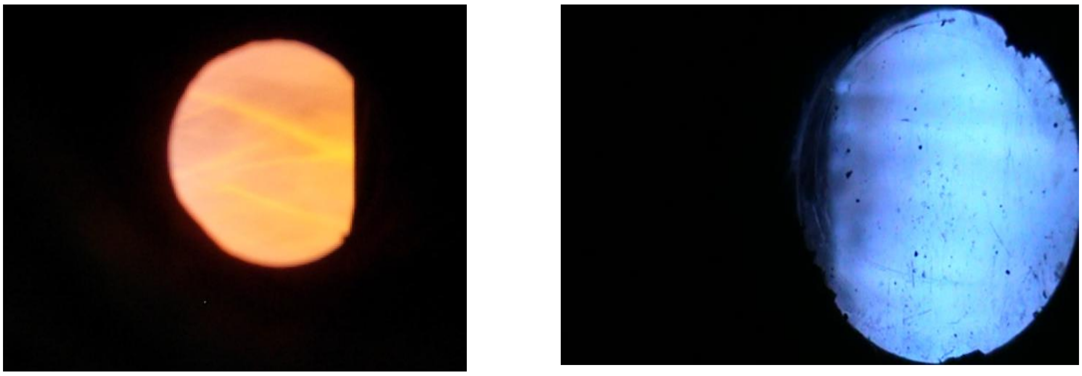


Figure 1 – Comparison of concentrations of harmful emissions into the atmosphere when using a standard register burner and an MIT-burner a) concentration of nitrogen oxides NO_x; b) Carbon monoxide CO

Figure 2 – View of the MIT burner in a boiler with a capacity of 10 MW and the nature of its flame



a) **b)**

Figure 3 – The nature of the flame during the combustion of natural gas in the turbine 10 MW: (a) for standard (register) technology, (b) for MIT-technology

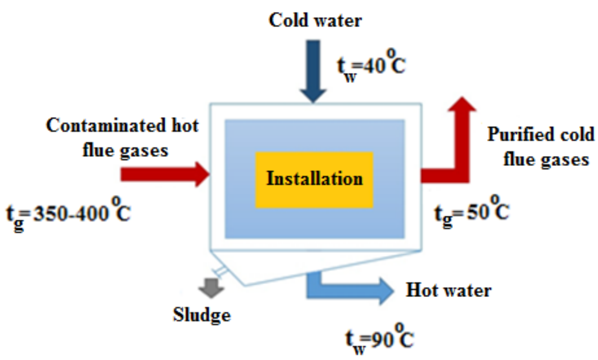


Figure 4 - Schematic diagram of the implementation of contact energy exchange

The implementation of such energy exchange has been studied in detail by the specialists of National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" and is successfully implemented in power plants.

The basic technological scheme of contact energy exchange with direct contact between gas and water for steam and hot water boilers is presented in Fig. 5.

Contact energy exchange technology can be implemented in existing boilers operating on any type of fuel by installing contact devices before the smoke stack (see Fig. 6).

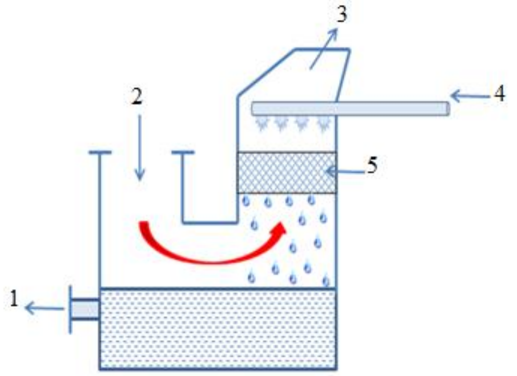


Figure 5 - Counterflow contact heat exchanger: 1- hot water (t_w=90°C); 2- hot flue gas (t_g=150-400°C); 3 - purified cold flue gases (t_g=50°C); 4- cold water (t_w=40°C); 5 – contact nozzle

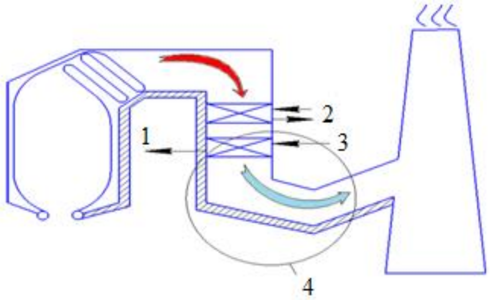


Figure 6 - Contact heat exchangers used before the smoke stack: 1- hot air; 2- water economizer; 3- cold air; 4- reconstruction area.

The implementation of contact energy exchange technology in coal-fired boilers is an especially urgent task in connection with the need to save fuel and ensure environmental cleanliness criteria for electricity production. The solution to the problem of increasing the efficiency of energy production in coal-fired boilers with a simultaneous increase in the environmental cleanliness of the power plant is possible with the implementation of contact technology for energy exchange at the outlet of the boiler. (Fig. 7).

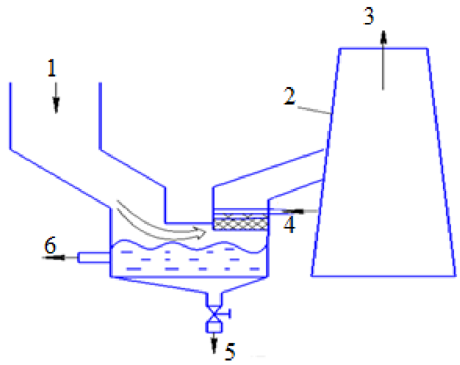


Figure 7 - Scheme of implementation of direct contact heat exchanger on coal-fired boilers: 1 – flue gas before cleaning, 2 – smoke stack, 3 – flue gas after cleaning, 4 – cold water, 5 – sludge, 6 – hot water

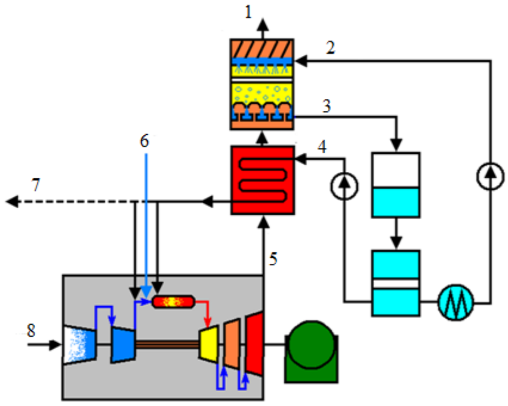


Figure 8 – Schematic diagram of the gas-steam plant "Aquarius": 1 - flue gases, 2 - cooling water, 3 - condensate, 4 - feed water, 5 - gas-steam mixture, 6 - fuel, 7 - steam generation, 8 – air

This technology was implemented in gas-steam plant GSP "Aquarius"contact unit, which has been successfully operating as a gas pumping unit at the gas compressor station of the main gas pipeline for 15 years [22]. In the GSP "Aquarius" (Fig. 8), energy exchange occurs using a capacitor with isothermal condensation, and another important process takes place in it. In the process of "wet" burning of natural gas, active hydrogen is released, which enters into a chemical reaction with atmospheric oxygen and forms H_2O. For example, the GSP "Aquarius" with a capacity of 16 MW generates about 30 tons of technically pure water per day, which can be used for various domestic and other purposes (irrigation on agricultural fields, plants) [22].

The gas-steam plant "Aquarius" can be used as an autonomous power station for generating electricity, as a heat-generating installation in cogeneration systems (generating electricity and hot water for heating and hot water supply systems), for driving various installations such as a gas pumping unit (for pumping natural gas through a gas pipeline) etc.

GSP "Aquarius" in comparison with conventional gas turbine units GTU with the same effective power has the following advantages (Table 1).

Table 1 – Comparison of characteristics of standard GTU and GSP “Aquarius” [22]

Main parameters	Standard GTU-16	GSP “Aquarius”	Parameter change, %
Power capacity, MW	16	16	0
Efficiency, %	30	42,16	+40%
Fuel consumption, kg/hour	3836	2700	-30%
Flue gas temperature, °C	450	45	10 times less
Content of CO_2, g/sec	2480	1920	-23%
Content of CO, g/sec	150	55	2,75 times less
Content of NO_x, g/sec	140	40	3,5 times less

Conclusions

The implementation of microflame incineration technology of combustion (MIT-technology) gaseous fuels and contact energy exchange technology leads to a comprehensive positive energy and environmental effect.

The concentration of harmful and greenhouse emissions (NO_x, CO) is reduced by 3-30 times.

The level of flue gas cleaning from ash and dust for coal-fired boilers can reach 99%.

Simplicity and low unit costs of implementation.

Short payback period (from 6 months (MIT-technology) to 3,5 years («Aquarius»)).

Increased efficiency (for power plants is 10-12%)

Possibility of obtaining additional technically pure H_2O water, which is especially important when the unit is located autonomously in separate, hard-to-reach and arid places and places (with a unit capacity of 16 MW GSP «Aquarius» produces an additional 20 tons of water).

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СУЧАСНІ ТЕХНОЛОГІЇ ПІДВИЩЕННЯ ЕНЕРГЕТИЧНОЇ ТА ЕКОЛОГІЧНОЇ ЕФЕКТИВНОСТІ ВИРОБНИЦТВА ЕНЕРГІЇ

Проблеми енергоефективності виробництва енергії поряд з підвищенням екологічної безпеки підприємств набувають все більшої актуальності. Одним із шляхів вирішення цих проблем є впровадження ефективних технологій, до яких відноситься мікрофакельна технологія спалювання (МТС-технологія) газоподібного палива. Застосування МТС-технології, крім значного зниження шкідливих викидів в атмосферу, може одночасно підвищити енергоефективність теплових електростанцій.

Значного позитивного ефекту можна також досягти за допомогою контактних енергообмінних установок. Яскравим прикладом такої установки є парогазова установка ПГУ «Водолій», робота якої перевищує ККД газотурбінних установок на 10-12% з одночасним значним зниженням концентрації токсичних оксидів азоту NOx і оксиду вуглецю CO у димових газах.

Ключові слова: *енергоефективність, екологічність, мікрофакельна технологія спалювання, контактний енергообмін.*

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