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Eco-economic evaluation of emission treatment technologies efficiency at thermal power stations

The article substantiates the necessity of introducing the best available emission treatment technologies at thermal power plants. It studies in detail the available technologies of removing sulphur dioxide from thermal power stations' emissions. The article proposes a methodology for evaluating eco-economic efficiency of using the best available technology on the example of sulphur dioxide emissions treatment by thermal power stations.

Eco-economic evaluation of emission treatment technologies efficiency at thermal power stations, the best available technologies.

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Thermal power stations (TPS) and steam electric stations (SES) are among the major pollutants in Russia and abroad, because, in addition to the main combustion products, carbon and hydrogen, which are non-toxic, they emit sulphur dioxides (SO_2) into the atmosphere.

Modern TPS and SES with the capacity of 2.4 million kW emit about 50 tons of SO_2 per day. Scientists estimated that TPS and SES emit 46% of the total amount of sulphur dioxide and 25% of coal dust discharged into the atmosphere by industrial enterprises [1].

Sulphur dioxide is a colourless, non-flammable gas, which causes irritant toxic effects. SO_2 emissions cause great damage to flora and fauna. This gas destroys chlorophyll in plants, damages their leaves and needles. It is toxic for man and animals as well. Sulphur dioxide, entering their organism, combines with hemoglobin in the blood, which results in a lack of oxygen leading to various nervous system disorders. In addition, SO_2 can cause fatal allergic reactions in people suffering from asthma.

Sulphur dioxide spreads very well over wide areas and, naturally, there is a proportional decrease in its concentration when moving away from the source of pollution. In addition, once in the atmosphere, it transforms into a sulphurous anhydride, which is also a polluting and toxic gas.

Thus, reducing the amount of sulphur dioxide in gas emissions from TPS and SES has become an urgent task when introducing the best heat and power production technologies available.

The best available technology is a set of goods (products), performed works, rendered services at the facilities, affecting the environment, technological processes, equipment, methods, techniques and tools that are based on modern scientific and technological achievements combining to the greatest advantage the indicators of achieving environmental objectives and economic viability subject to the technical possibility of their application.

Currently, the following technologies are used for reducing sulphur oxides emissions from power plants, burning sulphur-containing fuel:

1) preliminary (pre-combustion) reduction of sulphur concentration in the original fuel;

2) removal of sulphur oxides from flue gases using special facilities;

3) the use of refuse-derived fuel as an alternative.

Desulphurization (removal of sulphur from the original fuel) is a promising method of reducing emissions from heat-and-power engineering enterprises, since it most comprehensively solves the task of eliminating the negative effects associated with the formation and movement of sulphur oxides in the boiler circuit. At the same time, there is no need to dispose of desulphurization products, which increases the combustion efficiency of such fuel. However, this process is technically sophisticated, and the introduction of such technology is costly [2].

The second method, consisting in removal of sulphur using sulphur capture installations, is more widespread.

At present there are more than 80 ways of removing SO_2 from flue gases. All of them can be divided into wet types and dry types, depending on the phase, in which the process of linking sulphur dioxide takes place.

Wet methods of flue gas desulphurization are used more widely owing to their greater economic and environmental efficiency. They use cheap consumables, such as lime, limestone and water. As a result, a marketable product (gypsum) is obtained. In addition, the use of these methods significantly reduces sulphur oxide emission, as well as expenditures connected with the introduction of this technology.

But at the same time, the available technologies have a number of drawbacks, such as the presence of wastewater requiring treatment, cumbersome equipment, the necessity of creating liquid irrigation systems, the presence of waste, high power consumption by technological processes [1].

The third option of reducing sulphur dioxide emission is the use of refuse-derived fuels (RDF). Refuse-derived fuel is obtained by the processing of waste, when non-combustible materials are removed and combustible components are retained and used for generating energy.

The USA and the UK have been processing waste into fuel pellets ‘Refuse Full’ since the 1970s. This fuel can be stored for a long time and transported over relatively large distances, and its environmental impact is significantly lower.

The advantage of using refuse-derived fuel, regarding its qualitative characteristics, consists in its high calorific value and low content of ash and carbon. Besides, it reduces the amount of unusable waste and its concentration in the environment.

The disadvantages of using refuse-derived fuel are caused by heterogeneous composition of waste, by the difficulties of complying with the requirements related to the burning of waste in different countries, by the necessity of a more comprehensive monitoring of combustion process and also by the necessity of re-equipment. The technology of deriving secondary fuel from waste is understudied; besides, its implementation in Russia would require significant investments [2].

The analysis, aimed at performing eco-economic evaluation of emission treatment technologies efficiency at thermal power stations, was carried out using the expert assessment method.

From all the available desulphurization technologies we can distinguish three most common ones and evaluate them according to three groups of indicators – environmental, economic and social. We can highlight several most important factors in each group [3].

The results of choosing the most efficient (best) available technology on the basis of the expert assessment method are presented in *table 1*.

The available technologies are marked as follows:

- technology 1 – preliminary desulphurization;
- technology 2 – absorption of SO_2 by using alkaline-earth compounds (60-fold reduction of SO_2);
- technology 3 – transition to the use of refuse-derived fuel.

Expert assessment was performed on a 5-point scale. The score of 1 point reflects the greatest environmental impact and the highest costs, the score of 5 points – the minimum impact and minimum costs, respectively. The rest of the scores (2, 3, 4 points) are intermediate. The following coefficients by the groups of indicators were introduced for

Table 1. Choosing the best available technology to reduce sulphur oxide emissions

Criterion	Technology 1	Technology 2	Technology 3
1. Ecological indicators (0.25)			
1.1. Impact on atmospheric air	3	4	3
1.2. Impact on water bodies	4	2	5
1.3. Impact on soil	3	3	4
1.4. Resource-saving	4	3	5
1.5. Use of waste as products	0	5	5
Sum	3.5	3.5	5.5
2. Economic indicators (0.5)			
2.1. Capital expenditure	1	3	2
2.2. Operating costs	2	3	1
2.3. Demand for the secondary product	0	5	3
Sum	1.5	5.5	3
3. Technological and social indicators (0.25)			
3.1. Personnel safety	4	3	5
3.2. Complexity of technological process	3	4	2
Sum	1.75	1.75	1.75
Total	6.75	10.75	10.25

objective evaluation: 0.25 for ecological and technological indicators, 0.5 for economic indicators, because, currently, this criterion is fundamental.

When conducting the environmental expert assessment of the available technologies, we also took into account the related possible emissions (discharges) of pollutants into the air (crit. 1 in tab. 1).

Desulphurization technologies and the use of refuse-derived fuel will have a negative impact on the atmospheric air (3 points), and the technology of sulphur dioxide absorption using alkaline-earth compounds is almost completely eco-friendly (4 points).

However, this technology, as a method of wet purification, requires large amounts of wastewater (2 points).

The impact of each method on the soil cannot be characterized as critical (3, 4 points). However, when using alkaline-earth sorbents, the deposition that forms on the walls of the device should be removed and disposed of.

From the resource saving viewpoint, the technologies of desulphurization and transition to the use of RDF are the most advantageous due to minimal consumption of resources (5 and 4 points). The absorption technology requires limestone and large amount of water (3 points).

When applying the absorption technology, the waste becomes a product (gypsum, used in construction), and the use of RDF implies the use of waste as fuel.

The expert assessment of economic efficiency of the existing available technology (crit. 2 tab. 1) shows that the technology of reducing sulphur concentration in the fuel (desulphurization) is the most unprofitable economically, since the capital expenditure and operating costs of the equipment and its maintenance are very high (1, 2 points). Waste treatment for using it as fuel also implies high expenditures, primarily capital.

The expert assessment of the existing available technology by the technical parameters (crit. 3 tab. 1) shows that RDF-based technology is the safest for personnel (5 points), but it is understudied and it is not used widely, which means that certain technological difficulties may emerge in its implementation (2 points). The presence of wastewater, the need for permanent heating of gas and removing depositions from the walls of the device make the absorption process unsafe (3 points), but this is compensated by the continuity and relative simplicity of the technological process (4 points).

Thus, using the expert assessment method, it is possible to identify the most efficient technologies and choose the most affordable one among them, which would satisfy the criteria of both the economic and commercial efficiency of an innovation project.

Judging by the expert estimates, the technology of preliminary desulphurization of fuel proved to be the most inefficient one according to the total score. This is explained by the fact that its implementation requires significant one-time expenses on equipment that are not always consistent with the available financial resources.

The latest RDF technology is promising, but costly; and it is not implemented in Russia due to the inaccessibility and scarcity of information and R&D in this sphere.

The expert estimates have proved that the best available technology in terms of eco-economic efficiency is the use of alkaline-earth compounds for absorption of SO_2.

Along with a significant environmental effect, the application of the best available technology enables third-party organizations to obtain additional economic effect from the sales of gypsum used in the technological process.

The quantitative assessment of commercial effectiveness of an innovation environmental project on the implementation of the best

Table 2. Calculation of capital investments

Fixed assets	Number, units	Cost of a unit, rubles	Total cost, rubles
Cost of absorption equipment, rubles	5	900 000	4 500 000
Cost of suspension-producing equipment, rubles	3	80 000	240 000
Cost of wastewater treatment equipment, rubles	2	100 000	200 000
Cost of treatment of absorber from depositions, rubles.	1	20 000	20 000
Total		4 780 000	

Table 3. Calculation of operating costs

Expenses	Costs, rubles/year
For water	87 600
For electric power	1 200 850
For purchase of lime	391 210
For purchase of fuel	735 000
Removal of waste	585 000
Payroll, including deductions to the Compulsory Medical Insurance Fund and the Pension Fund of Russia	1 220 000
Total	3 361 910

Table 4. Economic benefit calculation results

Indicator	Unit of measurement	Value
Net present value (NPV)	Ruble	1745
Payback period (P_{pb})	Year	4.6
Internal rate of return (IRR)	%	6.3
Profitability index (PI)	Unit	1.37

existing available technology of SO_2 absorption using alkaline-earth compounds was carried out using the Guidelines on assessing the efficiency of investment projects, approved by the Resolution of the Russian Federation State Committee for Construction, Architectural and Housing Policy (Gosstroy) dated June 21, 1999. No. VK 477 [4].

The lump sum capital investments *(tab. 2)* and operating costs *(tab. 3)* have been calculated on the example of a thermal power enterprise located in Perm Krai [5]. The capacity of the absorption unit is 1200 m^3/hour.

The calculation of current operating costs reflects the continuity of technological process, its high energy intensity and low cost of raw materials (tab. 3) [5].

Having implemented this technology, the company annually obtains additional economic benefit due to the reduction of environmental damage. The value of prevented environmental damage, calculated using the 'Temporal environmental impact assessment metho-dology', is used as the annual profit [6]:

$$I_{prr} = I_{spr} \cdot (M_1 - M_2) \cdot K_e \cdot J_d = 52.2 \cdot$$
$$\cdot 51560 \cdot 1.7 \cdot 1.06 = 4850 \text{ thousand rubles.}$$

Our calculations on the basis of the 'Methodology guidelines on assessing the efficiency of investment projects' [4] defined the main indicators of evaluating economic efficiency of the best available technology among those under our review *(tab. 4)*.

Thus, we can conclude that, since NPV = 1745 > 0, and PI = 1.37 > 1, the project is worth to be considered.

The payback period of the innovation environmental project under our review is 4.6 years and the profitability index is 1.37, this means that the project is quite attractive for potential investors and creditors.

Besides, in terms of socio-economic efficiency, the project is relevant and useful for ensuring the country's environmental security.

Speedy introduction of the best available technologies into innovation environmental projects requires, in our opinion, the attraction of own funds of enterprises and targeted credits at concessionary interest rate, domestic and foreign banks, as well as non-governmental and municipal environmental funds.

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