

The assessment of technical and economic indicators of gas cleaning systems working on various types of coal

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Abstract. The object of the study is a set of activities to reduce the concentration of sulfur and nitrogen oxides in the combustion products of boiler units, by equipping them with a gas purification system. Improving the environmental parameters of the power facility is achieved through the installation of devices for cleaning combustion products: an absorber for cleaning sulfur oxides and a neutralizer for cleaning combustion products from nitrogen oxides. In this work the definition of technical and economic indicators is carried out and a comparative analysis of various types of fuels in order to increase the economic and environmental parameters of the installation are presented. The technical and economic indicators for each type of the fuel are determined.

Key-words: ash cleaning, nitrogen purification, desulfurization, maximum permissible concentration.

1. Introduction

The basis of the modern energy is a various types of power plants. The technology of production electric energy at thermal power plants is associated with a large amount of waste which released into the environment. The problem associated with the impact of energy on the environmental situation is becoming especially relevant because the pollution of the environment, atmosphere and hydrosphere is increasing every year. If we take into account that the scale of energy consumption is constantly increasing, then the negative impact of energy on nature will increase accordingly.

Nowadays a number of requirements for the gas cleaning systems are increasing. This causes the relevant of the problems of cleaning flue gases from harmful impurities.

The environment deterioration in Russia and in the world contributes to attracting investment in the construction of treatment facilities and units.

When burning solid fuel, substances such as sulfur and nitrogen oxides, ash particles are emitted into the atmosphere. An increase in the level of pollution leads to the achievement of the maximum permissible concentration (MPC).

The main objective of control system of environmentally friendly power station is to obtain an optimal operating mode with a minimum output of air polluting substances.



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In the fig. 1 the impact of the interaction of thermal power plants on the environment is shown [1, 2]. In order to avoid the further deterioration of the pollution of the atmosphere, lithosphere, and hydrosphere need to pay attention to the indicators of flue gas purification from SO_x and NO_x .

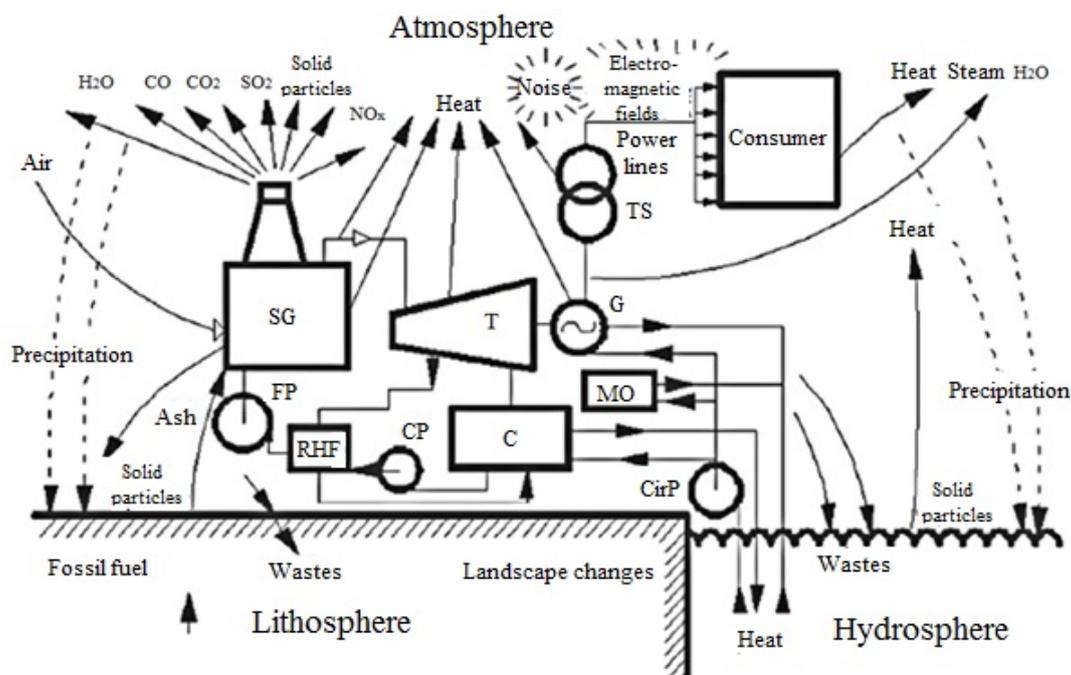


Figure 1. The scheme of interaction of thermal power plants with the environment:

SG –steam generator; T – turbine; C– capacitor; FP –feed pump, CP –condensate pump, CirP –circulation pump;

RHF –regenerative heating of feed water; G–electric current generator; MO –mass cooler;

TS –transformer substation; PL –power line

In recent years the intensive work has been carried out to improve the direction associated with a reduction in the formation of nitrogen oxides in the process of burning fuels. Low-toxic burners and multi-stage fuel combustion technologies are actively introduced at existing pulverized coal and fuel oil boilers, and new gas turbine plants are equipped with low-toxic combustion chambers, which provide a significant reduction in the concentration of NO_x . For example, more than 80 modifications of methods for removing SO_x from flue gases are currently known [3, 4].

2. Problem statement

As a result of the literature and patent search [2, 5, 6, 7, 8] and a detailed review of the analogues of installations for cleaning SO_x and NO_x , and also taking into account the advantages and disadvantages of the existing schemes, the following schematic diagram of the installation was chosen (Fig. 2).

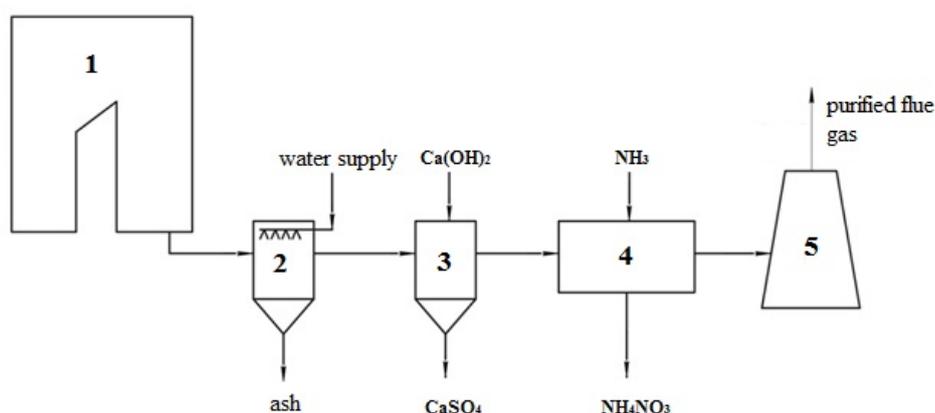


Figure 2. Technological scheme:

1 – boiler unit, 2 – scrubber, 3 – absorber, 4 – irradiator, 5 – chimney

After fuel is burned in boiler unit 1 flue gases containing ash particles, as well as sulfur and nitrogen oxides, are sent to the scrubber 2. The Ventury scrubber works with high efficiency when cleaning flue gases from dust with an average particle size of 1–2 microns and capture fine dust particles with a concentration of from 0.05 to 100 g / m³. The Ventury scrubber provides highly dispersive dust and gas cleaning from dust particles of almost any dispersed composition. A high degree of dust extraction from gas is achieved by wet cleaning. In the process of cooling a wet gas, water vapor condenses on dust particles. Thus, the weight of dust particles increases, and they are easily separated from the gas under the action of gravity or inertia.

After the scrubber the gases enter the absorber 3 where they are purified from sulfur oxides using the reagent $\text{Ca}(\text{OH})_2$, and the final product of this method, as a rule, is calcium sulfate (gypsum), suitable for further use; which moves counter currently to the movement of gases.

Then the gases enter the irradiator 4, in which the final stage of purification of the exhaust gases is passed and where gases are irradiated by a beam of accelerated electrons with energy of about 1 MeV. As a result of such irradiation, radicals, ions, excited molecules are formed that interact with SO_2 , NO_x , and form as a result pairs of sulfuric and nitric acids, respectively. Before the irradiator, ammonia is introduced in the form of solution drops or in gaseous form. Ammonia interacts with fumes of nitric and sulfuric acids to form sulfates.

Accelerators of the ELV series for purification of exhaust gases of thermal stations from sulfur and nitrogen oxides are direct current accelerators. The accelerator tube is powered by a high voltage source. The electrons emitted by the cathode located on the upper high-voltage end of the accelerator tube have a total energy equal to the value of the accelerating voltage at the exit of the accelerator tube.

Accelerated electrons are released into the atmosphere through a window of thin titanium foil. A uniform current distribution over the surface of the foil is achieved by scanning the electron beam in two mutually perpendicular directions using electromagnetic deflecting systems. The irradiated gases move under the exhaust window in the transverse direction. The finished product is a chemical compound: ammonium nitrate NH_4NO_3 . Purified gases are removed through the chimney 5 into the atmosphere.

The advantage of the technological scheme is the possibility of complex purification of flue gases from ash particles, sulfur and nitrogen oxides [9, 10, 11]. The application of this scheme allows the purification of harmful impurities SO_x and NO_x of approximately 99 %.

3. Theory

The methodology for calculating technical and economic indicators is to determine operating costs in the systems for cleaning exhaust gases from harmful emissions [10, 12, 13] and is determined by the formula, dollar / year:

$$E = E_m + E_s + E_{sn} + E_{am} + E_{other}.$$

Material costs, dollar / year:

$$E_m = E_f + E_r + E_{mat,prod}.$$

Costs of repair, dollar / year:

$$E_r = K \cdot \alpha_{rep},$$

where $\alpha_{rep} = 0.02$ is the coefficient of repair deductions, 1 / year.

Costs for the purchase of ammonia, dollar / year:

$$E_{NH_3} = V_{NH_3} \cdot C_{NH_3}.$$

Labor costs are determined by the formula, dollar / year:

$$E_s = P \cdot F_s.$$

Deductions for social needs, dollar / year:

$$E_{sn} = E_s \cdot H_d,$$

where $H_d = 0.3$ is the coefficient of deduction ratio, 1 / year.

Amortization deductions, dollar / year:

$$E_{am} = K \cdot \alpha_{am},$$

where $\alpha_{am} = 0.02$ is the coefficient of depreciation rate, 1 / year.

Net present value (NPV) is the excess of the integrated (i.e., total for the entire billing period) results over the integrated costs. The NPV value is calculated by the formula:

$$NPV = \sum_{t=0}^T (R_t - P_t) \cdot \alpha_t - \sum_{t=0}^T K_t \cdot \alpha_t,$$

where $\alpha_t = \frac{1}{(1+E)^{t-t_0}}$ is the discount coefficient, 1 / year; E is the discount rate; R_t is the result achieved at the time step t , million dollar; K_t is the investment at step t of the billing period, million dollar, P_t is the production cost (with the exception of amortization), million dollar / year.

Profitability index (PI) is the ratio of payoff to investment of a proposed project. [13]:

$$PI = \frac{\sum_{t=0}^T (R_t - P_t) \cdot \alpha_t}{\sum_{t=0}^T K_t \cdot \alpha_t}.$$

If $PI > 1$, so the investment in the project is expedient.

The composition of the fuel is the most important characteristic. The operation of treatment devices, such as: a scrubber, an absorber and an irradiator, will depend on the content of various components in it.

We will consider the dependence of some characteristic parameters on the initial fuel composition.

In the table 1 the types of fuels are presented.

Table 1. Indicators of fuels

Fuel	Fuel composition, %							Ash melting temperature, K
	C _w	N _w	H _w	O _w	S _w	A _w	W _w	
Kuznetsky, D	58.7	1.9	4.2	9.7	0.3	13.2	12	1533
Ekibastuzsky, CC	44.8	0.8	3.0	7.3	0.7	36.9	6.5	1500
Berezovsky, 2BR	44.2	0.4	3.1	14.4	0.2	4.7	33	1290
Chelyabinsky, BZ	71.5	1.7	5.2	18.9	2.7	34	17	1493

By varying the composition of the fuel let us see how this will effect on some parameters of the operation of the boiler unit. The initial data for technical calculations were the characteristics of the boiler unit, summarized in table. 2.

Table 2. The technical characteristics of the boiler unit BKZ-320

Nominal performance, D_r , t/h	Steam pressure at the outlet of the reheater P_r , MPa	Superheated steam temperature at the outlet t_r , °C	Feed water temperature t_{fw} , °C	Purge value P_p , %
320	12	560	220	4

We accept the standard characteristics and operating parameters of the BKZ-320 boiler unit. Then the maximum fuel consumption can be determined by the formula:

$$B = \frac{D \cdot (h'' - h_{fw}) + D_{bw} \cdot (h' - h_{fw})}{Q_l^w \cdot \eta}$$

where D and D_{bw} are the flow rate of steam and blowdown water, respectively, kg / h, ($D_{bw}=0,1 \cdot D$); Q_l^w is the calorific value of fuel kJ / kg; η is the efficiency of the boiler; h'' , h' , and h_{fw} are the enthalpy of steam, boiling water, feed water, respectively, kJ / kg.

Further some of the most important characteristics are considered - the consumption of fuel with constant characteristics of the boiler, and the effect of combustion products on the environment.

Sulfur is a harmful component of coal both in terms of environmental impact and technologically. Coals are natural sulfur concentrators. In fossil coals and rocks of coal-bearing strata, sulfur is contained in the form of sulfides, sulfates, organic compounds and elemental sulfur.

In most cases the sulfur content in coals depends on the possibility of their use in power plants because all types of sulfur, except sulfate, are converted to SO_2 , which is removed with flue gases, which causes wear of chimneys, boilers and equipment, and also leads to adverse environmental the consequences.

Taking into account the Decree of the Government of the Russian Federation of September 13, 2016 №. 913 (with changes of June 29, 2018) «On the rates of fees for negative environmental impact and additional factors», the rates of fees for 1 ton of pollutants (waste generated by operation and consumption) for 2018 are as follows (ruble):

- hydrogen sulfide – 686.2;
- carbon disulfide – 1094.7;
- sulfuric acid – 45.4;
- sulfur dioxide – 45.4.

At present time the burning of coal produces at least 80 million tons / year of sulfur dioxide, which is comparable with the production of sulfur compounds in chemical plants.

In this regard the demand and prices for high-sulfur coals are usually lower than that of low-sulfur coals. Despite the fact that sulfur is one of the combustible elements of solid fuel, 9.04 MJ of heat is released when it is burned. Consider the graph of the effect of the presence of sulfur in the fuel on the efficiency of the boiler.

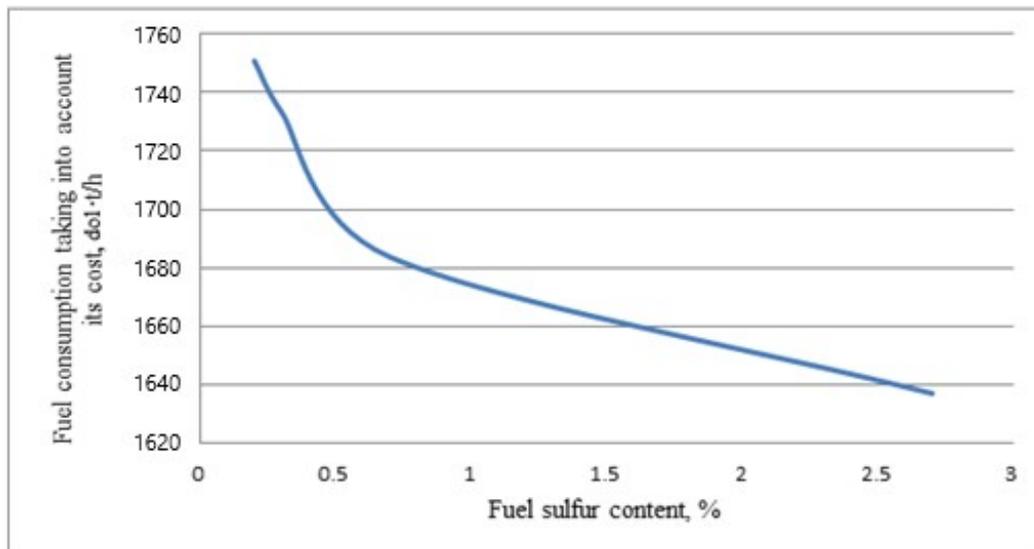


Figure 3. The dependence of the consumption of fuel taking into account its cost from sulfur content

The graph shows that with an increase in sulfur content from 0.2 % to 2.7 %, fuel costs decrease by about 5 %. But this increases the concentration of sulfur oxides. Below is a graph of the total amount of absorbed sulfur oxides on the sulfur content of the fuel.

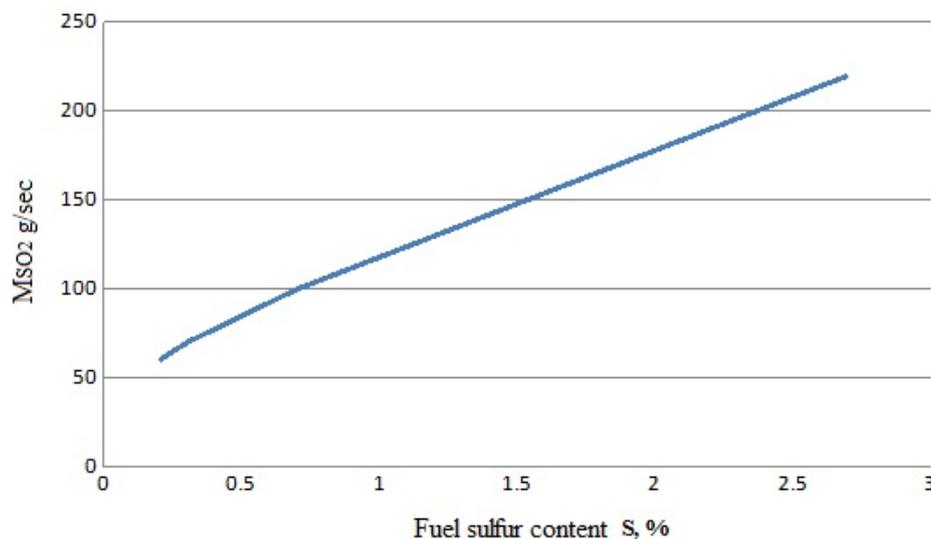


Figure 4. The dependence of the gross emission of sulfur oxides from fuel sulfur content

This dependence is due to an increase in sulfur oxide emissions with an increase in their amount in fuel. Thus, an increase in sulfur content leads to an increase in the total emission of sulfur oxides by approximately 165 g / sec.

The following general conclusions we can be made from the calculation results. With an increase in the sulfur content in the fuel from 0.2 % to 2.7 %, the following parameters change:

- fuel costs are reduced by about 5 % (this is explained by the fact that high-sulfur fuels are usually more expensive than low-sulfur, but at the same time, with an increase in sulfur content, fuel calories also increase; when burning sulfur, 9.04 MJ of heat is released);

- the total amount of sulfur emitted into the atmosphere increases by more than 3.7 times, but the use of this flue gas treatment scheme allows to reduce emissions by almost 99 %.

With this in mind we can argue that with the high-quality cleaning of flue gases from sulfur oxides, we can use fuel with a higher sulfur content, which will reduce fuel consumption.

4. Numerical experiments results

To calculate the expected technical and economic indicators the values of capital costs and operating costs for each of the considered types of fuels will be required. In the table 2 summarizes the results of calculating the capital costs and the costs of building and maintaining the apparatus during the operation of the thermal power station on base fuel (Kuznetsky coal, D). The results are based on the following initial data: discount rate $E = 9.65\%$, number of staff $P = 200$ people, investment period $t = 3$ years, estimated period of operation $t_{op} = 20$ years.

Table 3. The results of calculation

Indicators, units	Formula	Value
Total capital investments, mil. dol.	$C = \kappa \cdot N_{TPS}$	77.17
Annual capital investments, mil. dol.	$C_t = K/t_{constr}$	25.72
Costs of fuel, mil. dol.	$E_f = B_f \cdot C_f$	4.33
Costs of repair, mil. dol.	$E_r = K \cdot \alpha_{rep}$	1.54
Other material costs, mil. dol.	$E_{m.other} = (E_f + E_r) \cdot \alpha_{m.other}$	1.06
Material costs, mil. dol.	$E_m = E_f + E_r + E_{mat.prod}$	6.93
Labor costs, mil. dol.	$E_s = P \cdot F_s$	0.78
Deductions for social needs, mil. dol.	$E_{sn} = E_s \cdot H_d$	0.24
Amortization deductions, mil. dol.	$E_{am} = K \cdot \alpha_{am}$	1.54
Property tax, mil. dol.	$E_p = F \cdot H_p$	1.13
Costs for communication services, mil. dol.	$E_{other1} = (E_s + E_{sn} + E_{am}) \alpha_{other}$	0.21
Land tax, mil. dol.	$E_l = S_l \cdot \kappa_l \cdot H_l$	0.01
Water tax, thous. dol.	$E_w = V_w \cdot H_w$	0.47
Other costs, mil. dol.	$E_{other} = E_p + E_{other1} + E_l + E_w$	1.35
The total cost of electrical energy, mil. dol.	$E = E_m + E_s + E_{sn} + E_{am} + E_{other}$	10.83

In the table 4 the results of calculating the economic indicators of the gas treatment system for each type of fuel are shown.

Table 4. The results of calculation

Indicator, units	Fuel			
	Kuznetsky, D	Ekibastuzsky, CC	Berezovsky, 2BR	Chelyabinsky, BZ
Payback period, years	10.2	9.3	10.7	9.7
NPV, mil. dol	30.47	27.88	32.96	26.64
PI	1.56	1.64	1.48	1.69

From the analysis of the obtained results the following conclusions can be made: with an increase in sulfur content from 0.2 % to 2.7 % in fuel the payback period decreases. At the same time, the application of the proposed scheme for gas purification from sulfur oxide and nitrogen oxide leads to high-quality purification of flue gases and does not worsen the environmental performance of the boiler unit.

5. Conclusions

As a result of calculation the technical and economic indicators for each of the fuels are determined. So NPV for each of the fuels was: Kuznetsky coal, D – 30.47 million dollar, Ekibastuzsky coal, CC – 27.88 million dollar, Berezovsky coal, 2BR – 32.96 million dollar, Chelyabinsky, BZ – 26.64 million dollar. And PI for each of the fuels: Kuznetsky, D – 1.56, Ekibastuzsky, SS – 1.64, Berezovsky, 2BR – 1.48; Chelyabinsky BZ – 1.69.

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