UDC 681 5 9 7558

DEVELOPMENT OF AN OPTIMAL ALGORITHM FOR CONTROLLING THE STEAM GENERATION PROCESS

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Abstract: In this work, an algorithm for optimal control of a steam boiler is developed to minimize fuel consumption per unit of steam generated and given to consumers, when operating in a certain mode and control restrictions. Taking into account the nature of the steam generation process, where the control of some technological parameters and the output of control actions on the object is performed discretely, the simplex method was chosen as a mathematical tool for the optimal control algorithm.

Keywords: steam boiler, multi-connected object, multi-criteria optimization, fuel consumption, steam consumption, oxygen content.

The main equipment that generates heat energy in industrial and heating boilers are steam hot water boilers, and one of the main tasks in the production of heat energy is to save all types of fuel.

Rational and safe combustion of fuel in boilers, first of all, depends on the professional knowledge of the service personnel, on the competent and safe exploitation of boilers and boiler equipment.

With proper exploitation of boiler installations, it is possible to ensure uninterrupted and economical operation of boilers and equipment, reduce the cost of their repair, and save fuel [1,2]. To produce steam, used special devices are - steam boilers. A steam boiler is a system consisting of heating surfaces, auxiliary devices, fittings, organs and equipment of the control system (Pic. 1). One of the main devices included in the combined concept of a boiler is a boiler unit (BU) [3].

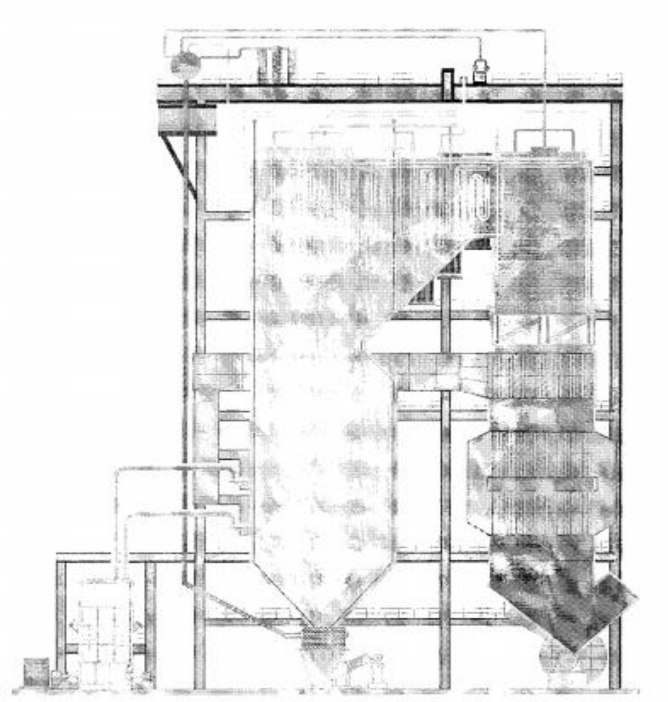
The boiler unit BKZ-320-140 PT is single - drum, vertical-water-tube with natural circulation designed for coal combustion. The layout of the boiler is made according to the P-shaped scheme. The combustion chamber is located in the first (ascending) flue. In the upper (rotary) flue there is a superheater, in the second (descending) flue there is a water economizer and an air heater.

The boiler is a complex multi-connected object, the processes of which are characterized by many technological variables. Among the many steam generation processes are considered, the fuel consumption, the excess oxygen content behind the superheater, the amount of steam generated, the temperature of the superheated steam, and the metal temperature of the superheater [3].

The relatively large inertia of the change in the parameters of the technological state of the steam boiler, when operating in stationary mode, allows us to consider the object in a certain period of time as linear and stationary. The above allows us to search for the optimal solution by the considered methods of linear programming (simplex method).

The economic profitability of steam generation by a drum boiler is improved by minimizing fuel consumption, minimizing the excess of the optimal excess oxygen behind the superheater, and minimizing the excess steam generated, while still ensuring the required amount and temperature of steam. If you manage by one of these criteria, the other two criteria will not be met. Therefore, it is necessary to develop the law of optimal control according to three criteria. Therefore, the task of controlling a steam boiler should be considered as a multi-criterial.

Using the topological method of C-graphs [4,5], we can find the functional dependence of fuel consumption, oxygen content and the amount of steam produced on certain technological parameters



Picture 1- Boiler unit BKZ -320-140 PT

$$B_{f.c} = f\,(G_{a.c}, P_{h.s.p.MSL}, D_{h.c}, O_2)$$
$$O_2 = f\,(G_{a.c}, B_{f.c}, P_{h.s.p.MSL}, D_{h.c}) \qquad (1)$$
$$D_{h.c} = f\,(G_{w.c}, B_{f.c}, G_{a.c}, T_{w.t}, P_{w.p}, D_{c.v})$$

where $P_{h.s.p.MSL}$ – heated steam pressure in the main steam line; O_2–oxygen size after the superheater; $D_{h.c}$ – consumption of heated steam; $P_{w.p}$, – feed water pressure; $T_{w.t}$ – feed water temperature.

Managed parameters: $B_{f.c}$ – fuel consumption; $G_{a.c}$– air consumption; $G_{w.c}$ – feed water consumption; $D_{c.v}$ – steam consumption for continuous ventilation.

The steam boiler is a multi-connected object [5] and, as follows from equation (1), the technological parameters that determine the fuel consumption function are among the ones that determine the oxygen content behind the superheater and the amount of steam produced. This dependence allows us to develop an optimal control algorithm based on three criteria:

1. The main criterion of optimality is the minimization of fuel consumption. It is necessary to search, using the Simplex method, for the optimal values of the technological parameters

($G_{a.c}$, $G_{w.c}$, $D_{c.v}$, $B_{f.c}$) at which the minimum fuel consumption will be provided, while some parameters are subject to technological restrictions.

2. We find the minimum content of the optimal excess of oxygen content behind the superheater using the Simplex method, and the value of the $B_{f.c}$ parameter found in the first step is used as a constraint. The remaining technological parameters are subject to limitations due to the steam generation technology.

3. We find the minimum produced steam, taking into account the balance between the produced and consumed steam, using the Simplex method, while the parameter values $B_{f.c}$ and $G_{w.c}$ found in the first step are used as constraints. The remaining technological parameters are subject to limitations due to the steam generation technology.

We obtain the optimal control solution in the form:

$$\left.\begin{array}{l} B_{f.c} \rightarrow \text{min} \\ O_2 \rightarrow (O_2 \text{ optimal+ min}) \\ D_{h.c} \rightarrow (D_{h.c} \text{ consumable + min}) \end{array}\right\} \quad (G_{a.c}, G_{w.c}, D_{c.v}, B_{f.c})$$

The mathematical formulation of the optimal control algorithm according to three criteria for the steam generation process is carried out in several stages [6,7].

The entire calculation path for optimization based on one of the criteria is shown in Table 1, obtained using Excel from the Microsoft Office software package

Table 1- Optimization results

Initial values											
$B_{f.c}$	O_2	$D_{h.s}$	$T_{w.t}$	O_2(c)	O_2(o)	$P_{h.s.p.MS}$	$G_{a.c}$	$G_{w.c}$	$T_{w.c}$	$P_{w.p}$	$D_{c.v}$
43.566	6.1	260	547	5.2	7	135	192900.5	260	251	196	2
Values after minimizing fuel consumption											
$B_{f.c}$	O_2	$D_{h.s}$	$T_{w.t}$	O_2(c)	O_2(o)	$P_{h.s.p.MS}$	$G_{a.c}$	$G_{w.c}$	$T_{w.c}$	$P_{w.p}$	$D_{c.v}$
43.271	5.79	260.1	554.95	5.2	7	135	193003	255.9	251	196	2
Values after minimizing excess oxygen behind the superheater											
$B_{f.c}$	O_2	$D_{h.s}$	$T_{w.t}$	O_2(c)	O_2(o)	$P_{h.s.p.MS}$	$G_{a.c}$	$G_{w.c}$	$T_{w.c}$	$P_{w.p}$	$D_{c.v}$
43.271	5.78	260.1	554.95	5.2	7	135	193002	255.9	251	196	2
Values after minimizing the excess steam generated											
$B_{f.c}$	O_2	$D_{h.s}$	$T_{w.t}$	O_2(c)	O_2(o)	$P_{h.s.p.MS}$	$G_{a.c}$	$G_{w.c}$	$T_{w.c}$	$P_{w.p}$	$D_{c.v}$
43.271	5.78	260.0	554.72	5.2	7	135	193001	263.6	251	196	2

According to a preliminary assessment of the results of calculations, it turns out that fuel consumption, in the current mode, can be reduced by 43.566-43.271=0.295 t / hour, based on the cost of coal equal to about 12000 tenge per ton, a savings of about 3540 tenge per hour is obtained, which means that if this level is within one year, the savings will be about 31 million tenge. All this can be implemented on existing equipment without additional automation costs.

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