RESEARCH REGARDING THE IMPROVEMENT OF THE PERFORMANCES OF THE POWER GENERATION BY POWDERED COAL COMBUSTION

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Abstract. The work presents some conclusions of the author's research carried out with the aim of increasing the energetic efficiency of the steam generators with natural circulation, running on coal in powdered state in thermal power plants.
The exergetic analysis of the thermodynamic processes, which take place in these thermal installations, made possible the identification of an optimal operating range, characterised by an increased overall efficiency and lower fuel consumption. An optimal range of the delivered steam flow and of the consumed fuel was established, while maximum values of exergetic efficiency are registered.

Keywords : powdered coal combustion, high exergetic efficiency, low consumed fuel.

1. INTRODUCTION

An important part of the energetic processes in the thermal cycle of the power plants are achieved inside the equipment of the steam generators, when there occurs a conversion of the chemical energy of the fuels in thermal energy contained in the live steam produced by the installation.
At present, the energetic steam generators working with coal pulverisation have a low overall efficiency due to the important thermal losses that are registered in the actual stage of development of these installations. Therefore, the increase of the overall performances of this type of installations during operation became a requirement in order to diminish the fuel consumption, to reduce the costs of generating electricity and heat, to protect de primary sources of energy of the country.
The qualitative analysis of the thermodynamic processes developed in the energetic steam boilers with natural circulation running on pulverised coal, through an exergetic efficiency, made it possible to identify the optimal ranges of the operating parameters, inside which the global efficiency reaches maximum values, [1], [2]. The exergy represents the maximum useable fraction of an energy form, which could be obtained by a reversible transformation in another energy form, taking into consideration the state of the ambient.

2. EXPERIMENTAL RESEARCH

The experimental research has been achieved in the installation of a steam generator with natural circulation delivering 400 ton/hour (111.1 kg/s). The furnace is fully screened with membrane walls consisting of tubes of low diameters having 60x5 mm. The main technical characteristics of the experimental steam generator at nominal load are: steam flow $D_n = 111.1\ kg/s$; thermal capacity $P_{tn} = 340\ MW_t$; superheated steam temperature $T_n = 823\ K$; steam pressure $p_n = 13.7\ MPa$; feed water temperature $T_{aa} = 503\ K$; combustion air temperature $T_{ac} = 513\ K$; flue gases temperature after heater $T_{gev} = 413\ K$, [2]. The processes of preparing and burning coal powder achieved in the thermal power plants are indicated in figure 1.

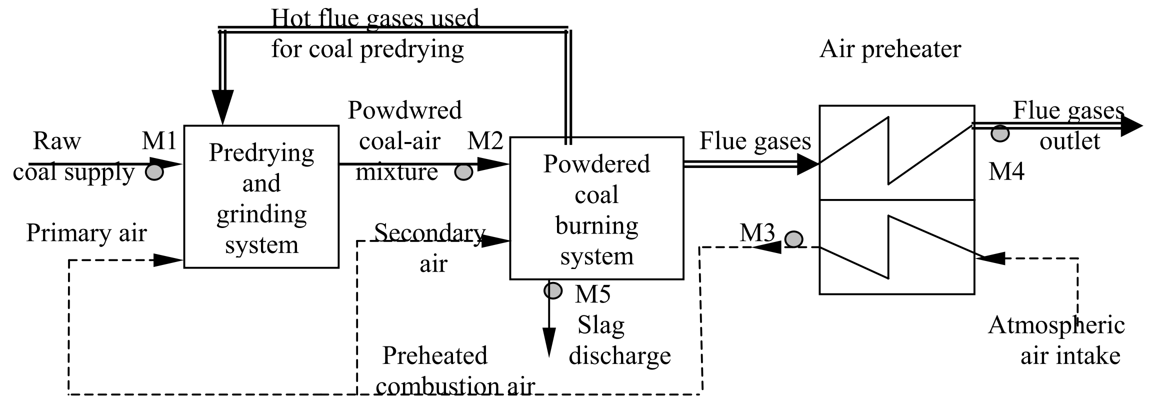

Fig. 1. Powdered coal preparation and combustion system used in the thermal power plants.

The coal grinding equipment is composed of 6 fan-like mills having 30 ton/hour, of which 4 – 5 mills were maintained in operating state in order to assure the thermal load of the steam generator, required inside the power plant at a certain point. The powdered coal fineness was in range of $R_{0.09} = 40 - 60\ \%$, in accordance with the fan mills grinding elements wear cycle. Coal pre-drying is achieved using hot flue gases, extracted from the final part of the furnace at a temperature of 950ºC. The air for the process of combustion was preheated at 190 – 220ºC in a regenerative equipment using the recovered heat of the outlet flue gases. For the burning of powdered coal a technology of preparation with coal dust concentrator and direct blowing sketch in furnace of the flow mixture of air – coal has been used, [2].

The values of the sizes of the fuel supply, the combustion air, the flue gases, the slag and ash discharge circuits used in the exergetic analysis have been measured in the following points, indicated in figure 1: M1-flow and characteristics of the consumed coal; M2- primary air-coal dust mixture parameters; M3-preheated air combustion temperature; M4-flue gases outlet temperature; M5-incompletely burnt content from slag and ash.

The chemical and energetic properties of the coal are variable in a wide range during the operation of the steam generator. For this reason it was necessary to define a fuel having middle properties. The average properties of the equivalent burnt fuel, which is a mixture between coal and oil, are indicated in table 1, [2].

The main fuel used for the steam generator running was low-grade coal, characterised by high humidity and ash content, having a reduced heating power. The flame support of the powdered coal burner was assured by using oil with low sulphur content.

Table 1- Average characteristics of the equivalent fuel

Chemical elementary analysis al initial state	Symbol	Unit	Average values
Carbon	$C^i_{m,e}$	%	23.74
Hydrogen	$H^i_{m,e}$	%	1.86
Sulphur (combustible)	$S^i_{cm,e}$	%	1.16
Nitrogen	$N^i_{m,e}$	%	0.61
Oxygen	$O^i_{m,e}$	%	9.22
Total humidity	$W^i_{tm,e}$	%	34.24
Ash	$A^i_{m,e}$	%	29.17
Low heating value at initial state	$Q^i_{im,e}$	kJ/kg	8 140
High heating value at combustion state	$Q^{mc}_{sm,e}$	kJ/kg	23 421

3. MATHEMATICAL EQUATIONS OF THE EXERGETIC ANALYSIS

The exergetic efficiency of the steam generator η_e can be expressed in the following form [1], [2] :

$$\eta_e = \frac{E_u}{E_t} \cdot 100 \quad [\%] \tag{1}$$

where : E_u [kW] - useful exergy output flow produced by steam generator,
E_t [kW] - total exergy input flow of the analysed thermal system.
Total exergy input flow results from the balanced equation :

$$E_t = E_{ch} + E_{fcb} + E_{fa} + E_{aa}, \ [\text{kW}] \tag{2}$$

in which :
E_{ch} [kW] - chemical exergy input flow of the equivalent fuel,
E_{fcb}, E_{fa}, E_{aa} [kW] - physical exergy of the equivalent fuel, combustion air and feed water input flows.
The components of the total exergetic input flow E_t, are defined as follows, [2], [3]:

$$E_{ch} = B_e \cdot e_{ne}, \ [\text{kW}] \tag{3}$$

$$E_{fc} = \left(1 - \frac{T_o}{T_{ce}}\right) \cdot B_e \cdot c_{pe} \cdot t_{ce}, \ [\text{kW}] \tag{4}$$

$$E_{fa} = \left(1 - \frac{T_o}{T_{aci}}\right) \cdot B_e \cdot \lambda_f \cdot V_{ae}^o \cdot i_{aci}, \ [\text{kW}] \tag{5}$$

$$E_{aa} = \left(1 - \frac{T_o}{T_{aai}}\right) \cdot D_{aai} \cdot i_{aai}, \ [\text{kW}] \tag{6}$$

The useful exergy output flow E_u is defined by equation :

$$E_u = \left[D_{ab} \cdot e_{ab} - D_{aai} \cdot e_{aai}\right] + B_e \cdot \lambda_f \cdot V_{ae}^o \cdot \left[\left(1 - \frac{T_o}{T_{ace}}\right) \cdot i_{ace} - \left(1 - \frac{T_o}{T_{aci}}\right) \cdot i_{aci}\right], \ [\text{kW}] \tag{7}$$

The sizes mentioned in the relations (3) – (7) represent: $B_e [kg/s]$ -equivalent fuel flow; $e_{ne} [kJ/kg]$ -specific exergy of the equivalent fuel; c_{pe} -specific heat at constant pressure of the equivalent fuel; λ_f -air ratio of the furnace; $V_{ae}^o [m_N^3/kg]$ -theoretical air volume for the equivalent fuel burning; $t_{ae} [°C]$ -equivalent fuel temperature; $i_{aci}, i_{ace} [kJ/kg]$ -specific enthalpie of combustion air before and after pre-heater; $T_{aci}, T_{ace} [K]$ - temperature of combustion air before and after preheater; $D_{aai}, D_{ab} [kg/s]$ -feed water input flow, delivered steam flow ; $T_{aai} [K], i_{aai} [kJ/kg]$ -feed water input temperature and specific enthalpie; $e_{aai}, e_{ab} [kg/s]$ - feed water input and delivered steam specific exergy;

4. RESULTS AND CONCLUSIONS

The behaviour of the steam generator working with coal in pulverised state was analysed in 6 operating regimes characterised by delivered steam flow inside the range of 66.1 kg steam/s – 108.6 kg steam/s (238 ton steam/hour – 391 ton steam/hour). Based on experimental measures, the calculations achieved according to the relations (1) – (7) indicated in chapter 3, have permitted to establish the total exergy input flow E_t, the useful exergy output flow E_u and, finally, the values of the exergetic efficiency η_e of the analysed steam generator.

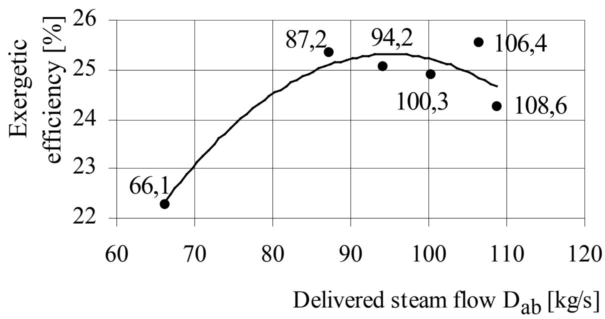

Fig. 2. Exergetic effiency of the steam generator depending on the steam flow outlet

The graphic correlation established by experimental research, based on exergetic analysis, between the operating parameters measured in coal preparation and flue gases circuits, on the one hand, and the exergetic output, on the other hand, takes into evidence optimal ranges of the steam generator running on coal pulverisation, characterised by maximum efficiency and lower fuel consumption.

The exergetic efficiency of this thermal equipment has maximum values in the load range of 0.80 % – 0.85 % from nominal steam flow. For the studied steam generator with natural circulation, on coal burnt in pulverised state, operating at $D_{ab} = 92 - 98$ kg steam/s, the highest values of the exergetic output between $\eta_e = 25.3 - 25.4$ % are registered, [2], (figure 2).
The admission of air-powdered coal mixture in the burning space at optimal temperatures, which results from the proper increase of the preheated combustion air temperature, led to the improved ignition and burning conditions of coal particles, due to the higher level of the combustion temperature achieved inside the furnace. The high intensity of the abstracted heat in the combustion space was obtained through a good carbon oxidation. At the same time, the process of heat transfer to the screened walls placed in the radiation zone becomes stronger due to the uniform thermal load of the furnace. All these thermal processes have a remarkable contribution to the decrease of the exergy losses from the steam generator furnace and, finally, to the rising of the exergy efficiency in the whole installation. By increasing the heat flow delivered to the combustion air in the pre-heater, the temperature of the flue gases was reduced after this thermal installation and, in this way, an important diminishing of the exergy losses by the flue gasses exhausted from the installation was achieved.

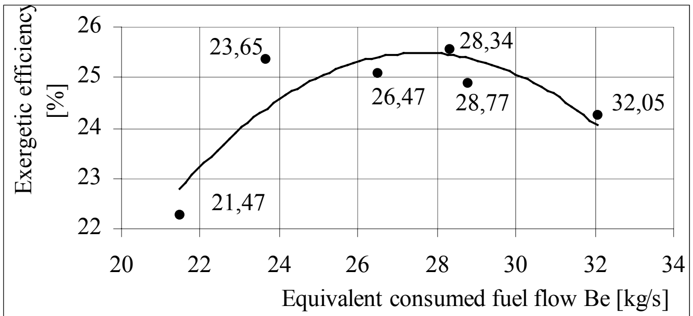

Fig. 3. Maximum exergy efficiency of the steam generator defined by an optimal fuel consumption

The increase of the efficiency of the steam generators, by operating in an optimal range of the technological parameters, had an important effect on the reducing of the consumed fuel flow. The correlation between the equivalent fuel flow consumption and the exergetic output is shown in figure 3. In a range of the burnt fuel, maximum values of the exergetic efficiency can be observed. In the case of the analysed steam generator between $B_e = 27 - 28$ kg coal/s, the highest values of the exergetic output $\eta_e = 25.5$ % are obtained, [2]. This experimental research has a practical importance for the specialists in the field of thermoenergetics working in the power plants equipped with steam generators burning pulverised coal, in order to define the fuel consumption required for running with high performances.

REFERENCES

1. Mădărăşan, T. *Bazele termotehnicii*, Editura Sincron, Cluj-Napoca, 1998.
2.Vasiu, I. *Performanțele generatoarelor de abur energetice pe cărbune pulverizat*, Editura Universității din Oradea, 2003.
3. Bejan, A. *Thermal design and optimization*, Ed. Wiley – Interscience, New – York, 1996.