ENERGY CHARACTERISTICS OF Pp-330/140-P55 STEAM BOILER

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Abstract: Energy characteristic of a boiler represents the fuel consumption depending on boiler load. After a long-time operation energy characteristic can change as a result of wear and maintenance. In this paper energy characteristic of Pp-330/140-P55 steam boiler is established by measurements carried out at different loads.

Key words: steam boiler, energy characteristic, fuel consumption.

1. INTRODUCTION

Large combustion boilers are used to generate steam for power generation. Energy efficiency is an important aspect of modern economy, therefore predicting energy consumption depending on load can be useful for determining fuel requirements in order to keep stocks low.

Keeping coal stocks low is important not only from economic point of view, but also large stockpiles of coal can self-ignite, producing disruption in normal power plant operation.

Saving 20% of EU's primary energy consumption by 2020 as stated in Directive 2012/27/EU on energy efficiency [1], can be achieved only by increasing energy efficiency. By increasing efficiency, less fuel is required to generate same amount of steam, and more fuel supply will be available.

Energy characteristic for a steam boiler can be useful in many ways: the appropriate functioning of the boiler can be monitored, and at the same time fuel supplies can be kept at optimal levels.

Any change in time of the energy characteristic of steam boiler can be a sing that maintenance must be carried out or that the maintenance activities are poor and additional measures must be taken into account.

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2. A BRIEF PRESENTATION OF STEAM GENERATOR

Built in 1968 in the USSR the Pp-330/140-P55 [2] steam generator is a once-through coal-fired boiler.

Its construction is carried out in two distinct bodies, symmetrical with the axis of the group, and can be operated in parallel to steam turbine, but they can work independently with the turbine as they are equipped with adequate valves to be isolated. Steam output for one body is 330 $t \cdot h^{-1}$, at a pressure of 140 bar and 550 °C for live steam and 24.4 bar at 550 ºC temperature for reheat steam. Each steam generator body (Fig. 1) is designed with two flue gas paths - in the shape of Π - one ascending and one descending, tied together with a reverse room.

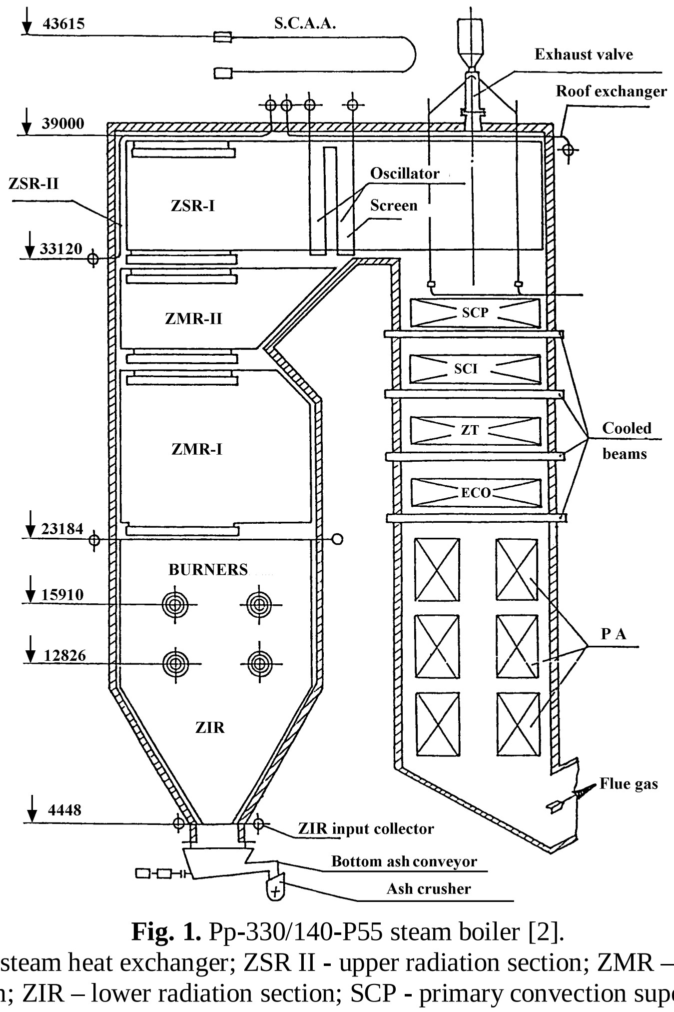

Fig. 1. Pp-330/140-P55 steam boiler [2].
SCAA - steam-steam heat exchanger; ZSR II - upper radiation section; ZMR – median radiation section; ZIR – lower radiation section; SCP - primary convection superheater; SCI - intermediate convection superheater; ZT – transition section; ECO – economizer; PA – regenerative air heater (SCAA and SCI are part of the reheater circuit).

The ascending path is the furnace chamber area, where the radiation heat exchangers are located and the descending path consists in the convection heat exchange surfaces.

Combustion air and the air used for the transport of pulverized coal are blown by a centrifugal air fan.

The basic fuel is crushed coal, obtained in 4 hammer mills for each body of the steam generator. To start and support the flame, auxiliary fuel is used (natural gas).

One mill, delivers crushed coal for two burners placed in cross on each side of the furnace chamber.

Flow of coal in grinding mill is provided by the raw coal feeder (with scraper band) whose speed can be adjusted remotely by the voltage applied to the DC drive motor.

Boiler efficiency at rated load reaches 90,07% (by project) especially by placing particular areas of regenerative convection heat exchangers (economizer and air preheater), leading to lower flue gas temperature to a value of 151 °C, when operating exclusively on pulverized coal.

Supply water parameters at steam generator rated load are: pressure 188 bar, temperature 242 °C.

3. ENERGY CHARACTHERISTICS OF STEAM GENERATORS

Energy characteristic of a boiler represents the fuel consumption (denoted with B) depending on boiler load.

Depending on load and how the fuel consumption is calculated, energy characteristics can be:

- gross energy characteristic $B=f(Q_u)$ of $B=f(D)$ where Q_u is the useful heat of steam or hot water supplied by the boiler and D is the steam flow rate provided by the steam generator.
- net energy characteristic, $B_{net}=f(Q_u)$ of $B_{net}=f(D)$ where B_{net} contains the fuel equivalents of supplemental energy consumption of blowers and other equipment needed for proper boiler functioning.

The gross energy characteristic is the most commonly used for characterizing the operational level of the boiler.

Forms of energy characteristic equations are [3]:

$$\begin{gathered} B = a + b \cdot D + c \cdot D^2 \\ B = a' + b' \cdot Q + c' \cdot Q^2 \end{gathered} \tag{1}$$

depending on what form we would like to use, the steam flow rate provided by the steam generator D or the useful heat of steam or hot water supplied by the boiler Q.

In order to establish the actual characteristic of steam boiler at a given moment coefficients a, b, and c or a', b' and c' must be evaluated.

Measurements can be carried out for this purpose or data obtained when energy balance measurement are done, can be used.

A minimum of three measurements must be carried out same as regulations for energy balance states [4], [5], [6].

Based on measured data energy balance is calculated and values for *D* and *B* are determined.

Base on values D_i and B_i, where i=1…n stands for number of measurements performed, coefficients *a*, *b* and *c* can be calculated as follows:

$$c = \frac{K_2 \cdot K_3 - K_1 \cdot K_5}{K_2^2 - K_1 \cdot K_4} \tag{2}$$

$$b = \frac{K_2 \cdot K_5 - K_4 \cdot K_3}{K_2^2 - K_1 \cdot K_4} \tag{3}$$

$$a = \frac{\sum_{i=1}^{n} B_i - b \cdot \sum_{i=1}^{n} D_i - c \cdot \sum_{i=1}^{n} D_i^2}{n} \tag{4}$$

where:

$$K_1 = \sum_{i=1}^{n} D_i^2 - \frac{\left(\sum_{i=1}^{n} D_i\right)^2}{n} \tag{5}$$

$$K_2 = \sum_{i=1}^{n} D_i^3 - \frac{\sum_{i=1}^{n} D_i \cdot \sum_{i=1}^{n} D_i^2}{n} \tag{6}$$

$$K_3 = \sum_{i=1}^{n} B_i \cdot D_i - \frac{\sum_{i=1}^{n} B_i \cdot \sum_{i=1}^{n} D_i}{n} \tag{7}$$

$$K_4 = \sum_{i=1}^{n} D_i^4 - \frac{\left(\sum_{i=1}^{n} D_i^2\right)^2}{n} \tag{8}$$

$$K_5 = \sum_{i=1}^{n} B_i \cdot D_i^2 - \frac{\sum_{i=1}^{n} B_i \cdot \sum_{i=1}^{n} D_i^2}{n} \tag{9}$$

where B_i stands for the fuel consumption for measurement "*i*" and D_i for steam output for the same measurement.

Relations (2) – (9) can be used for the second form of energy characteristic, replacing D_i with Q_i.

The method used for calculating the coefficients in equations (2) - (9) is "the method of the smallest squares", as values D_i and B_i are not accurate values in order to corroborate the energy characteristic curve, but close values, since measurement errors occur.

4. MEASUREMENTS AND RESULTS

Data for analysis was provided by the Distributed Control System (DCS) of unit. As required, measurements must be carried out for least 3 different loads. The loads were fixed to 460 $t \cdot h^{-1}$ - 70%, 560 $t \cdot h^{-1}$ – 85% and 620 $t \cdot h^{-1}$ - 94% of rated steam flow rate D_0 = 660 $t \cdot h^{-1}$. Since measured parameters vary around the values set above, in the end a number of 363 unique data sets were acquired. Analyzing obtained data a major variation in natural gas flow rate between 1626 to 9022 $m^3_N \cdot h^{-1}$ (used for flame support) can be observed. Coal quality and flow rate also varies; as a result the lower heating value of coal-methane gas mixture varies too. This creates a problem when energy characteristics for the same boiler were established using fuel having different lower heating values, and then they need to be compared. Solution to this problem is to express the fuel consumption B relative to a standard quality coal lets say a coal having lower heating value 7,000.0 $kcal \cdot kg^{-1}$.

Another specific feature that must be considered is that part of the steam supplied to the turbine, is recycled and reheated in the boiler so that only second form of equation (1) can be used, the one that is considering the useful heat Q_u.

The useful heat Q_u is the sum of the heat of steam supplied to the turbine and the heat supplied to the steam at reheat.

Results obtained are presented in Table 1.

Table 1. **Coefficients of energy characteristic equation**

Coefficient	Boiler Body A	Boiler Body B
a	-10,620.4862096553	-14.106,5247583548
b	2.18288425541375E-01	2,23162142398240E-01
c	-2.48908875542627E-07	-2,22260213610817E-07

Data in Table 1 shows that coefficient values for the energy characteristic equation for Body A and B are very close except coefficient *a*.

In Figure 2 the polynomial equations are graphically represented in order to view how close the two characteristic curves are one to another.

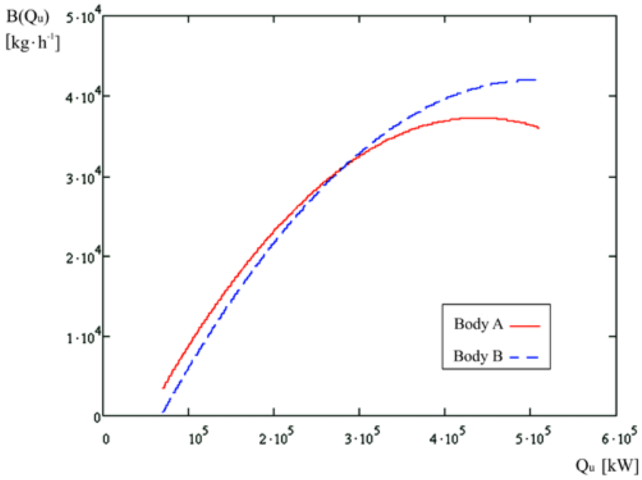

Fig. 2. Energy characteristics for body A and B of Pp-330/140-P55 steam boiler

5. CONCLUSION

Comparison of energy characteristic for body A and B of Pp-330/140-P55 steam boiler show that although working in similar conditions, energy characteristic curves are close to but do not overlap. This is due to the fact that there are a lot of variables that influence fuel consumption and useful heat output.

Their interactions are difficult to predict, and adjusting parameters that influences the operation of the boiler at a fixed load for a long time isn't possible, rather it will work around the desired load value.In order to develop an energy characteristic curve for the steam boiler more data must be acquired.

Using additional data, analysis can be performed in order to discover if a relationship can be found, sufficiently precise to describe the energy characteristic for Pp-330/140-P55 steam boiler, so that this characteristic can be used to predict accurately fuel consumption for a planned operating regime.

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