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EFFICIENCY INDEXES OF COGENERATION UNITS OPERATION, INTENDED FOR GENERATION OF THERMAL AND ELECTRIC ENERGY

The influence of operational factors on the efficiency of power plants of various types, intended for combined generation of electric and thermal energy is analyzed.

Keywords: *steam generator, steam turbine, gas turbine, conventional fuel, specific consumption.*

Introduction

It is well known that the combined generation of electric and thermal energy is a promising technology, that solves the problem of energy saving and it is paid attention to at the legislative level [1]. The use of thermal power plants for combined generation of energy results in considerable saving of fuel in energy system. Regarding the evaluation of the volume of economy, different methods for its determination are offered [2 – 7]. In many cases, evaluation of efficiency of combined heat and power (CHP) plants operation is suggested to perform calculating the specific cost of conventional fuel required for generation of electric and thermal energy. Analysis of the methods of evaluation of combined plants operation efficiency is carried out in [8], where the inadequacy of such methods application is proved, since it is not possible to define exactly the share of fuel in total expenses for generation of electric and thermal energy. In [3, 5] it was emphasized that the main efficiency index of combined units operation is the value (coefficient) of electric energy generation for heat demand, i.e.

$$E = N/Q, \tag{1}$$

where N and Q – electric and heat output, generated, respectively, by combined installation.

In the above-mentioned papers it was outlined that the higher value of E, the more efficiently thermal power plant will operate , the efficiency of the plant was suggested to evaluate by the value of conventional fuel saving as compared with distributed scheme of power supply. However, regularities of E influence on the value of fuel saving were not revealed.

Meanwhile, in [8] it was found that, besides E, efficiency index of combined installation operation is the value which characterizes the proportion heat output of fuel burnt Qf, which is spent on heat generation, i.e.

$$\alpha_{T} = \frac{Q}{Q_F} = \frac{Q}{B \cdot Q_L^p}, \tag{2}$$

Where B – fuel expenditure; Q_L^p – lowest temperature of fuel burning.

In [8] it is also determined that all efficiency factors, used to assess the efficiency of TPP and cogeneration units are the function of E and α_T variables. But precise influence of E and α_T on the efficiency of combined units operation was not determined.

However, the problem to suggest the efficiency factor of steam –turbine and gas-turbine units operating at thermal power plants, and define its dependence on E and α_T coefficients was put forward.

Main results

Unlike [2, 4 – 6], as efficiency factor of combined and cogeneration plants we suggest to apply fuel rate index for evaluation of cogeneration of electric and heat energy - b, kg / MJ.

To study the influence of coefficients E and α_T, which are operation characteristics, on this index, we performed calculations of commercial steam turbines and gas turbines units , which can operate at TPP. The calculations assumed that combined heat and power installations operated with rated power.

Regarding heat output of the units, it varies according to the peculiarities of operating of a particular unit. The calculation procedure of combined units of various types is described in [9]. The results of calculations of some units are given below.

Gas turbine unit with heat recovery boiler. Installation of CCD-25000 type is selected , with basic characteristics: electric power N = 25 MW; efficiency factor- η = 0.36; level of presser increase- λ = 21.8; - C, the temperature of gases at °turbine inlet 1250; temperature of gases at turbine outlet C°= 490 C.°

Exhaust gases of the turbine enter heat recovery boiler (HRB), where return heating water of district heating system is heated from 60 to 120 It is clear, that the production of thermal power in the boiler depends on the temperature of gases after heat recovery boiler t_{rb}. Thus, heat capacity of HRB is directly proportional to the difference of temperatures (t_g - t_{rb}), on condition that N = const and G = const, where G – discharge of combustion products (flue gases). The results of calculations of basic indexes of gas turbine unit with heat recovery boiler are shown in Table 1.

Table 1

Main indexes of gas-turbine unit –TPP operation

Denomination	Temperature after heat recovery boiler				
	120	140	160	180	200
Fuel rate, kg/s	2,37	2,37	2,37	2,37	2,37
Heat output, MW	34,602	32,746	30,870	29,011	27,112
Share of fuel heat, spent for heat generation ($\alpha_т$)	0,498	0,417	0,444	0,417	0,391
Energy generation factor on heat demand (E)	0,722	0,760	0,811	0,862	0,922
Gross fuel rate for cogeneration of energy, kg/MJ	0,0397	0,0411	0,0422	0,0438	0,0455

Table 1 shows that the least amount of fuel rate for heat and electric energy generation is observed at the highest values of a_T and smallest values of E. Consequently, the statement [3, 5] that the efficiency of the combined plants should increase with increase of E for gas turbine -TPP is not proved. On condition of simultaneous decrease of $\alpha_т$ and increase of E, efficiency reduces.

Steam-turbine TPP with backpressure turbine. This unit includes steam generator, steam turbine, generator, industrial consumers of steam, deaerator, feed pump, pump of return condensate [9]. Steam after the turbine (from backpressure) is directed to industrial consumers, and the return condensate is pumped back to the deaerator. Dearator of atmospheric pressure (APD) is supplied with steam from the backpressure turbine by means of throttle device. As an example, the results of calculations of main operation indexes of STU(steam turbine unit) with backpressure turbine P-6-35 / 6 with characteristics: Nominal power – N = 6 MW, temperature and pressure at turbine inlet – P_0 = 3.5 MPa; t_0 = 435°C, temperature and pressure of steam at turbine outlet (in back-pressure) P_s = 0.6 MPa; t_s = 250°C. Steam pressure after the turbine is adjustable and can vary from 0,4 MPa to 0,7 MPa. It is clear that if N = const increase of pressure after the turbine causes an increase steam flow to the turbine due to reduction of operation heat drop (specific work) in the turbine. Increase of steam rate to the turbine causes , in its turn, increase of heat power of exhaust steam in the turbine, which is directed to industrial consumers. Therefore, the calculations of STU operating indexes were carried out for different values of the steam after the turbine. The temperature of return condensate was 100°C, the temperature of feed water was – 104 °C, the efficiency of the steam generator – 0.91. The results of calculations are given in Table. 2.

Table 2

Basic indexes of steam turbine unit with backpressure turbine operation

Denomination	Steam pressure at turbine outlet, MPa			
	0,4	0,5	0,6	0,7
Power supplied to industrial consumers, MW	34,808	41,112	45,212	47,408
Fuel rate, kg/s	1,575	1,805	1,935	2,078
Share of fuel heat, spent for heat generation ($\alpha_т$)	0,7539	0,7652	0,7971	0,804
Energy generation factor on heat demand (E)	0,172	0,151	0,133	0,124
Gross fuel rate for cogeneration of energy, kg/MJ	0,040	0,0404	0,0411	0,0414

In this case, the most efficient operation modes of combined installation are typical for higher values of E and lower values of α_T, i. e. quite differently than for gas turbines. Within the limits of possible operational changes of steam pressure at the outlet of the turbine, the efficiency of steam turbine unit varies slightly (by 3,5%). Calculations showed that similar character of changes inoperation is characteristic for turbines with industrial steam extraction. The latter, however, operate with higher fuel rate due to energy losses in the capacitor.

Steam-turbine TPP with heat power extraction turbine. Such TPP comprises steam generator, heat power extraction steam turbines of type T; generator; condenser; network heater of district heating system water; regenerative feed water heater, deaerator; condensation, circulation, drainage pumps; feed water pump [9].

The turbine has heat power extraction steam with a pressure of 0.12 MPa, which feeds: network water heater, regenerative heater and deaerator. Table. 3 contains the results of calculations of the basic indexes of STU, equipped with T-6-35 turbine operation, which has the following characteristics: nominal power – N = 6 MW; pressure and temperature of steam at the inlet of the turbine – P_0 = 3.5 MPa; t_0 = 435^{0}C ; steam pressure in the condenser 5 kPa, internal relative efficiency factor of the turbine 0.82. As in the previous case, it was believed that the temperature of feed water 104^0 C, efficiency factor of steam generator is 0.91. The calculations were performed under the condition of N = const, the share of steam extracted from the turbine β which supplied water heater of district heating system varied, i.e. steam flow on the turbine changed.

Table 3

Basic indexes of steam turbine unit **with extraction turbine**

Denomination	Value β			
	0,2	0,4	0,6	0,8
Power and heat –supply consumers MW	3,468	7,091	11,663	17,195
Fuel rate, kg/s	0,8195	0,8377	0,9182	1,0151
Share of fuel heat, spent for heat generation (α_T)	0,144	0,288	0,434	0,578
Energy generation factor on heat demand (E)	1,731	0,857	0,514	0,348
Gross fuel rate for cogeneration of energy, kg/MJ	0,0865	0,0641	0,0522	0,0455

Here, as in the first version with the GTU-TPP more efficient modes are observed in case of maximum values of α_T and minimum values of E. Similar results are typical for more powerful cogeneration turbines. Note that the operation of STU with cogeneration turbine is characterized by higher value of fuel rate (less efficient), that can be explained by heat losses in the capacitor.

In addition to the above-mentioned options, calculations of the combined plants of binary type operation are performed: on the base of gas turbine units with backpressure steam turbines; on the base of gas turbine units with heat power extraction turbines that operate at low-temperature working bodies. In both cases, the reduction of fuel rate for cogeneration of electricity and heat was observed while simultaneous increase of E and insignificant decrease of α_T .

Proceeding from these results we can state that neither the indexes of E in [3], nor index a_T introduced by us, can characterize separately the efficiency of combined heat and power plants operation . Generalization of calculated data for different types of combined systems is shown in Fig. 1. These dependences are approximated by a simple and convenient for engineering calculations formula used for determination of fuel rate:

$$b = \frac{0{,}03413}{\alpha_T (1 + E)}. \tag{3}$$

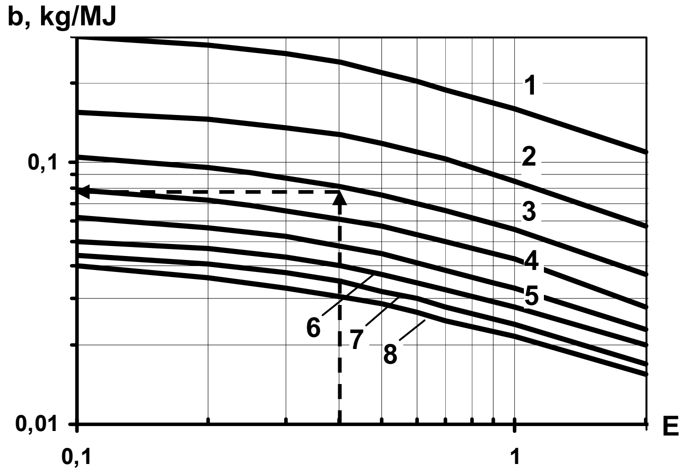

Fig. 1.Value of gross fuel rate at combined units: 1 – $\alpha_т$=0,1; 2 – 0,2; 3 – 0,3; 4 – 0,4; 5 – 0,5; 6 – 0,6; 7 – 0,7; 8 – 0,8

Ratio (3) enables to perform express assessment of the efficiency of existing and designed combined plants, depending on operational characteristics .

Conclusions

1. The suggested value of fuel rate required for cogeneration of heat and electrical energy characterizes operation efficiency of combined units of various types.
2. Coefficients У and a_T taken separately, can not evaluate operation efficiency of combined plants.

Therefore, existing methods for evaluation of their efficiency can not be considered as satisfactory.

3. The results obtained are necessary prerequisite for evaluation of operation efficiency of existing and designed combined plants.

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