M. Chepyrniy, Cand. Sc. (Eng.), Assist. Prof.; N. Rezydent, Cand. Sc. (Eng.); Y. Vozijan

GAS –TURBINE SUPERPOSED PLANTS ON THERMOELECTRIC PLANTS WITH EXTRACTION TURBINES

Calculation technique of basic operation indices of thermoelectric plants with gas-turbine superposed plants is suggested. Nomograph for determination of specific consumption of equivalent fuel at GTP-TEP is constructed.

Key words: *thermoelectric plant, extraction plant, gas-turbine installation, equivalent fuel, waste heat boiler.*

State of the problem

The forecast consumption of electric energy in Ukraine up to 2030 has to increase 2.5 times as compared with 2005 [1]. However, wear level of energy-generating equipment is more than 90 %. The majority of generating units at thermal power stations of Ukraine exceeded 2 times normative term of operation and are characterized by increased accident rate and low efficiency, that is why, they must be put out of service. Total expenditures for reconstruction or introduction of new generating units of 200 – 300 MW will be not less than 8.5 billion USD during 10 – 15 years [2].

There appeared a trend in a world power engineering, aimed at decreasing of unit power of energy sources (distributed generation) that provides the creation of numerous electric stations of small power. Such power stations must provide reliable electric supply in every region and improve the flexibility of electric system regulation. It is considered that 70 % of generating power will increase at the expense of putting into operation gas turbine plants (GTP).

One of priority directions of Ukrainian power engineering development is considered to be the increase of energy generation at the existing equipment. Introduction of GTP with waste-heat boilers, where heat of flue gases is used is a pressing issue nowadays. Real possibilities of using efficient technologies at the expense of the domestic but not foreign investors exist in the sphere of heat power engineering. Usage of gas-turbine superposed plants allows to decrease the specific fuel consumption for generation of electric energy and it is the simplest method to retrofit energy sector at the given stage [3 – 5].

In Ukraine, the necessary facilities of GTP with power of 6 – 160 MW and efficiency of 0.36 are created. Construction of gas-turbine thermoelectric plants (GTU–TEP) on the base of available heat-producing thermoelectric plants of small power not only promotes the increase of reliability and efficiency of operation and deprives of the necessity to pay losses of electric energy in transmission lines in the process of electric energy transportation over long distances.

Taking into account the above-mentioned, the problem of determination of combined gas-steam plants operation indices, created at the expense of gas turbine superposed plants of steam heat producing turbines at municipal heating thermoelectric plants, was put forward.

Main results

Principal heat balance diagram of GSP created on the base of GTP with waste heat boiler and cogeneration steam turbine is shown in Fig. 1, where pressures (*P*), temperatures (*t*) and gas or steam flow rates (*G*, *D*) in characteristic points of gas and steam cycles are indicated. Parameters of ambient air are marked by index «1» (according to international standards: P_1 = 101.3 kPa, t_1 = $15\,°C$). Fuel flow is marked by the letter «B».

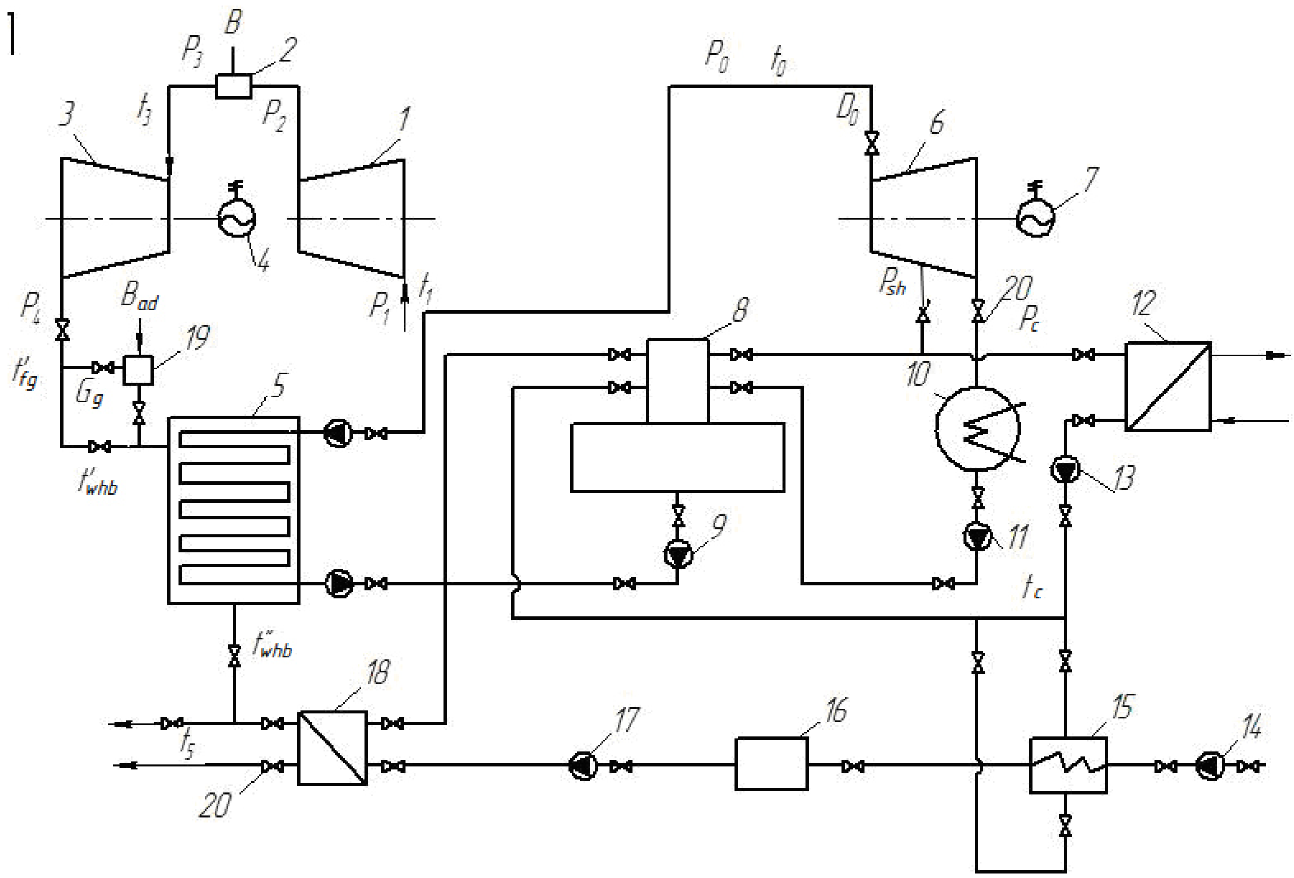

Fig. 1. Principal heat balance diagram of gas-steam plant with cogeneration steam turbine: 1 – compressor; 2 – combustion chamber; 3 – gas turbine; 4 – electric generator of GTP; 5 – waste–heat boiler; 6 – cogeneration steam turbine; 7 – electric generator of STP; 8 – deaerator; 9 – feed pump; 10 – condenser; 11 – condensate pump; 12 – heater of hot water supply system; 13 – drain pump; 14 – raw water; 15 – raw water heater; 16 – chemical treatment of water (CTW); 17 – pump of chemical treatment of water; 18 – feed water heater; 19 – chamber of additional burning of fuel; 20 – shut-off valves

Steam turbine has heat extraction of the steam with the pressure P_{HE}, that supply deaerator 8 and heater of heating water 12with power Q_{HE}. Condensate of heating steam from the heater 12 arrives at the heater of raw water 15, where coaling by 10 ^{0}C, heats the water before water treatment plant 16. Main condensate from turbine condenser 10 by means of condensate pump 11 is transferred into deaerator. Water from deaerator by means of feed pump 9 enters waste heat boiler 5, where steam at pressure P_0, temperature t_0 and steam rate D_0 is generated. This steam is directed to steam turbine 6. Waste gases of GTP, if needed, may be heated to the required temperature at the expense of additional fuel consumption B_{ad}, that is burnt in the chamber of additional burning (CAB). Burning is carried out without additional supply of air because burning products of GTP contain 13 – 16% of oxygen. At the outlet of waste-heat boiler gases, having the temperature $t''_{whh,}$ are additionally cooled to the temperature t_5 in feed water heater 18, where they heat it prior to supply to deaerator by the pump 17. According to the suggested circuit, steam boiler of steam turbine plant does not work, and generation of thermal and electric energy is performed at the expense of the fuel, burnt in GTP.

As it is known, consumption of the equivalent fuel in GTP is defined by the formula [7], кg/s

$$B_g = N_g / \left(Q_{eq} \cdot \eta_g \right) = N_g /(29{,}3 \cdot \eta_g) = 0{,}03413 N_g / \eta_g , \qquad (1)$$

where N_g – is electric power of GTP, MW; η_g – is efficiency of GTP; Q_{eq} =29.3 MJ/кg– is heat of combustion of equivalent fuel.

Power of flue gases in GTP, MW

$$Q_{fg} = G_g\left(C_{pg}t_{fg} - C_{pg}t_1\right) = N_g(1-\eta_g)/\eta_g = B_g \cdot Q_{eq} - N_g \ , \tag{2}$$

where G_g – is mass consumption of combustion products at the outlet of GTP, kg/s; C_{pg} – is isobaric mass heat capacity of gases for corresponding temperature; t_{og} – temperature gases at the outlet from gas turbine, °C.

Coefficient of heat recovery of GTP flue gases in waste-heat-boiler, correspondingly.

$$\psi = (t'_{whb} - t''_{whb})/(t'_{whb} - t_1) \ , \tag{3}$$

where t'_{whb} and t''_{whb} – is the temperature of gases at the inlet into waste-heat boiler and at its outlet, correspondingly.

It is clear, that in case of absence of additional burning of fuel in CAB.

$$t'_{whb} = t_{fg} \ .$$

Thermal capacity of waste-heat-boiler, MW

$$Q_{whb} = Q_{fg} \cdot \psi = N_g(1-\eta_g) \cdot \psi/\eta_g = N_g \cdot \varphi \tag{4}$$

Thermal capacity of waste-heat-boiler must be equal thermal capacity of STP, i. e.

$$Q_{whb} \geq N_p + Q_{sh} + Q_c = Q_{STP} \ , \tag{5}$$

where N_p – is electric power of STP; Q_{sh} – is the power of steam heat extraction; Q_c – is the power of heat losses in turbine condenser.

Taking into account (4) the last solution will have the form

$$\varphi \cdot N_g(1-\alpha_c) = N_S(1+\varepsilon)/\varepsilon = N_S \cdot \beta \ , \tag{6}$$

where $\alpha_c = Q_c/Q_{STP}$ – is the portion of heat losses in the condenser; $\varepsilon = N_S/Q_{sh}$ – is the portion of electric energy generation on heat supply.

In case of gas-turbine superposed plant, the formula (6) is necessary for correct choice of GTP electric power

$$N_G \geq N_S\beta/(\varphi \cdot (1-\alpha_c)) \tag{7}$$

Characteristics of certain types of heat extraction STP of small power are given in Table 1, the Table also contains the values of total and specific consumption of equivalent fuel on condition of separate operation of STP with steam boiler.

Table 1

Characteristics of cogeneration turbines and STP operation indices

Indices	Type of the turbine / number of the variant			
	T-4-35	T-6-35	T-12-35	T-25-90
	1	2	3	4
Electric power, MW	4	6	12	25
Turbine pressure before the turbine, MPa	3.43	3.43	3.43	8.82
Steam temperature before the turbine , ^{0}C	435	435	435	500
Turbine flow, t/hr	24.8	42.3	81.5	135
Cogeneration steam flow, t/hr	22	35	65	100
Cogeneration power, MW	14.6	21.9	43	78.41
Total power of STP, MW	22.60	33.67	64.88	116.21
Portion of power, lost in the condenser	0.334	0.349	0.337	0.302
Portion of energy generation on heat supply	0.274	0.275	0.279	0.337
Equivalent fuel consumption for STP, t/yr	3.051	4.546	8.764	16.164
Specific equivalent fuel consumption, kg/GJ	45.57	45.26	44.24	43.62

It is seen from Table 1, that the temperature of superheated vapor before the turbines t_0 is either 435 or 500 ˚C. To reach this temperature at the outlet of waste heat boiler, it is necessary that the difference between the temperatures of gas and steam be not less than 100 ˚C, i. e. $t'_{whb} = t_0 + 100\,^{\circ}$C. Analysis of the characteristics of domestic GTP showed that the temperature of gases behind gas turbines does not exceed $520\,°C$.

It means, that the creation of gas-turbine superposed plants according the suggested scheme can be realized on condition of additional burning of fuel in CAB. Additional consumption of equivalent fuel (B_{ad}) is easy to determine by the equation of additional combustion chamber thermal balance, kg/s

$$G_g C_{pg} t_{fg} + B_{ad} \cdot Q_{eq} = (G_g + B_{ad}) C_{pg} t'_{whb} \ , \tag{8}$$

where mass consumption of gases G_g is determined by (2).

Total consumption of equivalent fuel by GTP, kg/s

$$B_t = B_g + B_{ad} = B_g (1+\delta) \ , \tag{9}$$

where $\delta = B_{ad}/B_g$ – is the portion of additionally burnt fuel.

Useful power of GTP-TEP with heat generating steam turbines, MW

$$Q_{TEP} = N_g + N_p + Q_{sh} = N_g (1 + \varphi(1-\alpha_c)) \tag{10}$$

Specific consumption of equivalent fuel in GTP-TEP, kg/GJ

$$b = B_t \cdot 10^3 / Q_{TEP} = \frac{34,13(1+\delta)}{\eta_g (1+\varphi\cdot(1-\alpha_c))} = b_0 (1+\delta) \tag{11}$$

Heat availability factor at GTP-TPP

$$K_{TPP} = 34,13 / b = (1+\varphi(1-\alpha_c)) / (1+\delta) \tag{12}$$

Thus, simple and convenient for engineering calculations relations for determination of GTP-TEP operation indices, created on the base of gas-turbine superposed plants of existing TEP with heat extraction steam turbines are obtained. It should be noted, that the given technique is suitable for determination of operation indices of GTP-TEP, created on the base of industrial TEP with turbines, having industrial steam extraction.

Table 2 contains types of GTP, chosen for gas-turbine superposed plants of heat extraction turbines according to the variants of the Table 1. Besides, Table 2 contains main operating indices of GTP-TEP. As operation indices of STP, functioning in GTP-TEP block remain unchanged, then the increase of fuel consumption at the expense of gas-turbine superposed plants can be referred to additional generation of electric power that equals the power of GTP.

To simplify the calculations, b_0 value can be determined by means of the nomograph, shown in Fig. 2.

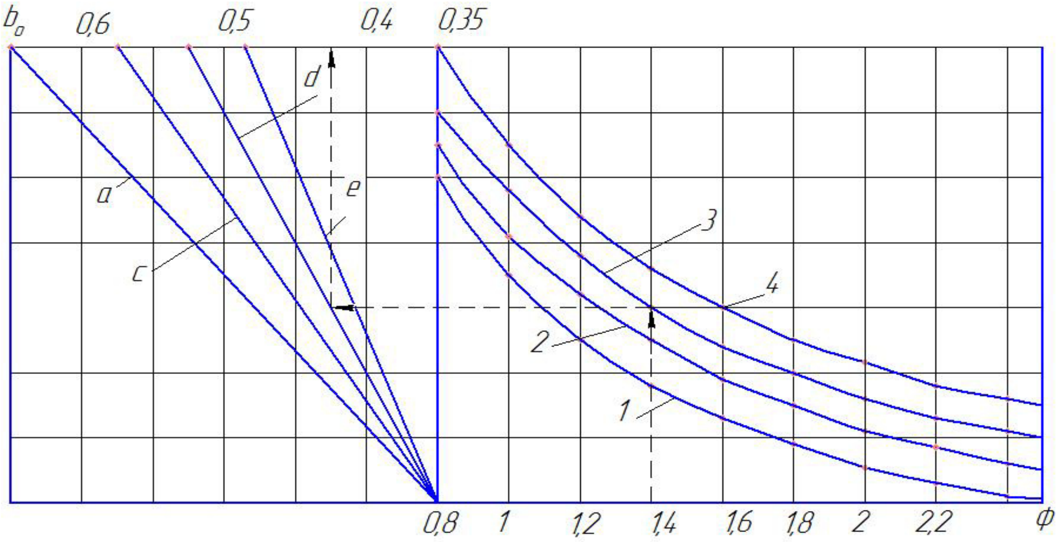

Fig. 2. Nomograph for b_0 determination, kg/GJ: $1-\alpha_c=0,1;$ 2 – 0,2; 3 – 0,3; 4 – 0,4; $a-\eta_g=0,32;$ c – 0,36; d – 0,4; e – 0,44

Table 2

Characteristics of GTP and main indices of GTP – TEP operation

Indices	Number of the variant			
	1	2	3	4
Type of gas turbine plant	ГТ-20	ГТД-25	ГТД-50	ГТГ-100
Electric power of GTP, MW	20	25	50	100
Gas temperature behind the turbine, ^{0}C	520	490	490	517
Efficiency	0.36	0.36	0.35	0.36
Coefficient φ	1.303	1.273	1.329	1.299
Gas temperature after CAB ^{0}C	585	535	535	600
Gas temperature behind waste heat boiler, ^{0}C	150	150	150	160
Required electric power of GTP, MW	17.41	23.62	48.31	92.01
Equivalent fuel consumption on GTP, t/hr	5.932	8.060	16.959	31.402
Additional consumption of equivalent fuel, t/yr	0.139	0.579	0.749	2.291
Portion of additional fuel consumption	0.0234	0.0718	0.0437	0.0729
Specific consumption of equivalent fuel on GTP – TEP, kg/GJ	46.85	46.58	47.3	47.89
Specific consumption of equivalent fuel in case of separate operation of GTP, kg/GJ	94.7	94.68	97.5	94.8

It is seen from Table 2, that operation efficiency of GTP-TEP is lower than that of STP at the expense of additional burning of fuel. However, if electric power of GTP was generated in energy system or separately at GTP, then the efficiency of electric energy generation would decrease almost two times. In the connection with the above-mentioned, we may assume that the creation of gas-turbine superposed plants at the existing steam-turbine TEP is expedient because it allows to increase five times the generation of electric energy without considerable capital investments.

Conclusions

1. The results obtained allow to select correctly the electric power of GTP for gas-turbine superposed plants at steam-turbine TEP and evaluate the operation efficiency of the created GTP-TEP.
2. Generation of electric energy at GTP-TEP is two times more efficient than in energy system.
3. GTP-TEP, having higher GTP efficiency and smaller portion of additional burning of fuel, operate most efficiently.

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Chepurnyi Mark – Cand. Sc. (Eng.), Professor with the Department of Heat and Power Engineering.

Rezident Nataliia – Cand. Sc. (Eng.), Assistant Professor with the Department for Heat and Power Engineering.

Vozijan Yulia – Student, Institute of Civil Engineering, Heat and Power Engineering and Gas Supply.

Vinnytsia National Technical University.