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THERMOELECTRIC PLANTS ON THE BASE OF HEATING BOILER HOUSES AND GAS –TURBINE UNITS

Operation energy efficiency of water heating boiler houses and thermoelectric plants , created at the expense of gas-turbine superimposed units, has been analyzed.

Key words: *hot water boiler, gas turbine, gas turbine unit, waste heat boiler, chemical water treatment.*

Introduction

Efficiency of energy generation is an important characteristic of fuel-fired units and is estimated by the value of specific consumption of equivalent fuel per unit of generated power. As it is known ,cogeneration of thermal and electric energy is promising technology, enabling to solve , to great extent, problems of energy saving and the importance of this type of generation was noted on legislative level [1].In spite of this, centralized heat supply of a great number of consumers in Ukraine is realized not from thermoelectric plants(TEP) but from hot –water boiler houses.

Recent world trends in development of energy sector provide the creation of a large number of electric power plants of small capacity(distributed generation), including electric power plants for combined generation of thermal and electric energy, that allow to solve the problem of energy supply in each region .

Approximately 70% of generating capacities gain is planned to be realized at the expense of gas-turbine units(GTU) [2].Distributed generation of electric energy allows not only to improve the reliability of energy supply in the region but withdraw from the necessity to pay for the energy losses in transmission lines, if the energy is transported for long distances.

In regional and district centers of Ukraine a large number of hot –water(heating) boilers are still located within the limits of the town .In Ukraine material base of 6-160MW capacity GTU and efficiency of up to 0.37 is created. Construction of gas-turbine thermoelectric plants (GTU—TEP)on the base of heating boiler houses not only improves the reliability of energy supply but also promotes the reduction of stand-by capacities and increase of flexibility of energy system regulation .Self-contained GTUs are composed of separate modules of small size, the assembling of these modules is carried out without substantial financial and labour resources. In the majority of cases remote control and programming of GTU operation modes is provided.

Characteristic feature of energy cogeneration at GTU-TEP is that the thermal capacity generation Q depends on the production of electric power of GTU N. Operating conditions of hot water boiler houses are distinguished by disproportions of heat demand in the heating and non heating seasons. Capacity of hot water supply system is more or less stable. It is known that the most efficient GTU operation is achieved in case of its rated power [3,4], that is why, optimal operation mode of GTU-TEP is achieved when thermal capacity, produced as a result of utilization of combustion products heat of GTU (flue gases) in waste heat boiler, corresponds to operation mode of GTU with rated electric power . Hence, in heating season both hot water boilers and GTU with waste heat boiler must operate at GTU—TEP, and in non-heating period—only GTU with waste heat boiler.

Taking into account the above-mentioned, the attempt of comparative evaluation of main indices of operation efficiency of hot water boilers and GTU—TEP of the same thermal capacity is made.

Main results

For creation of GTU—TEP on the base of heating boiler houses a number of gas-turbine units with the efficiency factor not less than 0.32 is chosen. Characteristics of the selected GTU are given in Table.

Table 1

Main characteristics of GTU

Indices	Type of GTU or motor				
	GTU-9,5	GTU-16	ГТ-20	НК-37-1	ГТД-60
Electric power, MW	8,8	17	20	30	60
Temperature of gases before the turbine, °C	1120	1000	1133	1220	1170
Degree of pressure increase	21,7	17,8	17	23,4	15
Temperature of gases after the turbine, °C	480	420	520	455	500
Efficiency	0,32	0,35	0,36	0,37	0,35
Equivalent fuel consumption, kg/sec	0,938	1,657	1,896	2,767	5,85
Capacity of waste-heat boiler, MW	13,27	21,06	26,05	35,25	80,40

Heat diagram of GTU-TEP on the base of hot water boiler with two- pipes closed loop of heat supply is shown in Fig.1

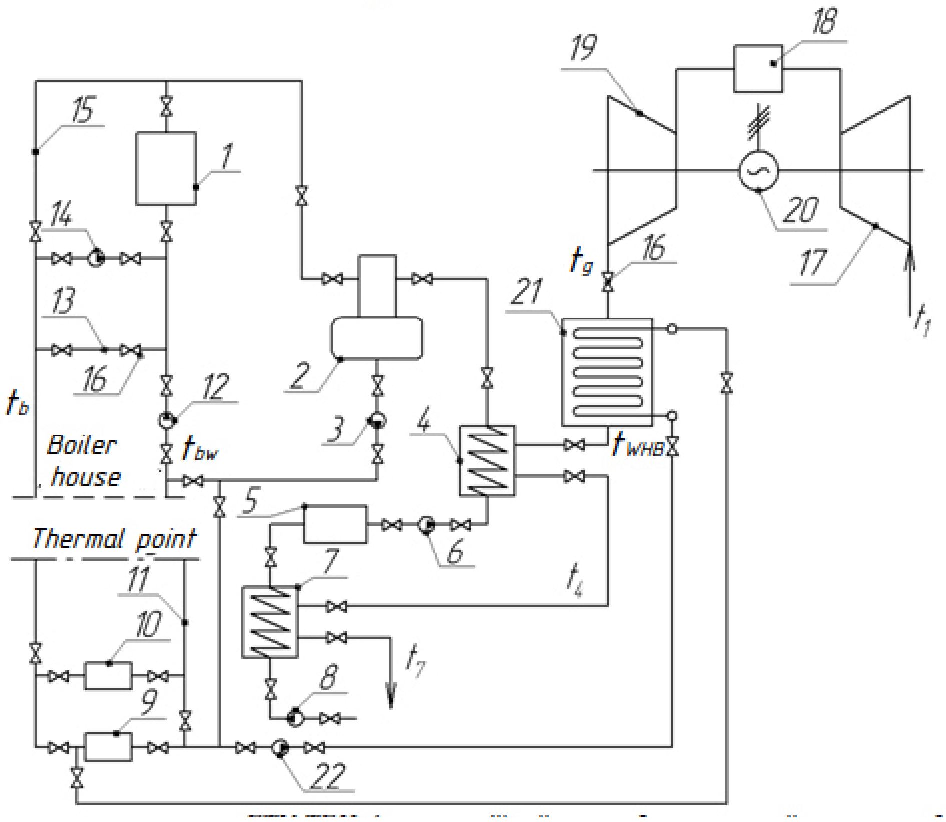

Fig 1 Heat diagram of GTU-TEP: 1 – hot water boiler; 2 – vacuum deaerator; 3 – deaerator pump(feed pump); 4 – heater of chemically purified water; 5 –chemical water treatment(CWT); 6 – pump of CWT ; 7 – heater of raw water ; 8 – raw water pump ; 9 – heater of the water for hot water supply; 10 – heater of heating water; 11 – pipe-line of return heating water; 12 – network pump; 13 – cross- over line; 14 –recirculation pump; 15 – boiler water pipe- line; 16 – stop- valves; 17 – GTU compressor; 18 – combustion chamber; 19 – gas turbine; 20 – electric generator; 21 – waste heat boiler; 22 – circulating pump; t_1 – temperature of the air at the inlet of GTU compressor; t_c – temperature of combustion products behind the turbine; t_{whb} – temperature of gases behind waste heat boiler; t_4 – temperature of gases behind the heater of chemically cleaned water; t_7 – temperature of gases behind the heater of raw water; t_b – temperature of boiler water; t_{rhw} – temperature of return network water

As compared with heat diagram of hot water boiler house, GTU(pos.17-20), waste heat boiler21 are added and water – to – water heaters4 and 7 , heated by boiler water from pipeline 15 are replaced by gas- to –water heaters as it is shown in the figure. They are heated by flue gases from waste heat boiler. Calculations of boiler houses operation indices were carried out according the technique, suggested in [4].In the calculations carried out , temperature mode of hot water boiler operation is chosen to be 130/70 °C, and of thermal point – 120/60 °C. In boiler house temperature of the water at the outlet of deaerator and water –to- water heaters 4 and 7 was 70°C. In case of GTU-TEP operation the temperature of water at the inlet of the deaerator was 65-67°C in heating season and 70°C in non-heating season. Losses of water in the circuit are chosen to be 2%. Power of hot water supply system was chosen to be equal almost the power of waste heat boiler in Table 1.

The temperature of unboiled water equals 5 °C, and temperature of the air at the inlet of GTU compressor t_1 is assumed to be equal 15°C, in accordance with international norms ISO 2314.Working fuel is natural gas, heat value on dry base being $Q^d{}_l$=33.4 MJ/m^3 and theoretical volumes: V^0 = 9.52 m^3/m^3; $V_g{}^0$ = 10.6 m^3/m^3. Temperature of gases behind the waste heat boiler is taken to be equal 150 – 160 °C, the efficiencies of hot water boilers were 0.92 and 0.9 for heating and non-heating seasons , correspondingly. Consumption of boiler water, additional water and raw water as well as consumption of working and equivalent fuel, electric power of pumps drives and forced ---draft installations were determined in the process of calculation of heat diagrams of boiler houses and GTU-TEP, applying the technique [5].

Thermal capacity of hot water boilers , as it is known, is determined by the formula, MW

$$Q_b = G_{bw} \cdot Cp_w(t_b - t_{rnw}), \qquad (1)$$

where G_{bw} – consumption of boiler water, determined from the calculations of heat diagram for the preset loading of boilers; Cp_w – mass heat capacity of water at constant pressure; t_b and t_{rnw} – temperature of boiler water and return network water.

This power(loading) of boilers corresponds to certain consumption of working, m^3/s and equivalent, kg/s , fuel

$$B_{ob} = Q_b(Q_l^d \cdot \eta_b); B_{whb} = Q_b/(Q_{eq} \cdot \eta_b), \qquad (2)$$

where η_b – efficiency of the boiler ; Q_{eq} = 29.3MJ/kg – heat of equivalent fuel combustion.

Consumption of equivalent fuel in GTU, kg/s

$$B_{gu} = N/(Q_{eq} \cdot \eta_g), \qquad (3)$$

where N – electric power of GTU,MW; η_g – efficiency of GTU.

Specific consumption of equivalent fuel in heating and non-heating periods of boiler house operation, kg/GJ

$$b^{ht}_{whb} = B^{ht}_{whb} \cdot 10^3/(Q_{ht} + Q_{hw}); b^{nht}_{whb} = B^{nht}_{whb} \cdot 10^3/Q_{hw}, \qquad (4)$$

where Q_{ht} and Q_{hw} – thermal power of heating and hot water supply, correspondingly, MW; B^{ht}_{whb} and B^{nht}_{whb} – consumption of equivalent fuel, kg/s, determined by the formulas (1) and (2) for the given periods.

Specific consumption of equivalent fuel at GTU—TEP at the same periods, kg/GJ

$$b^{ht}_{gu} = (B'^{ht}_{whb} + B_{gu}) \cdot 10^3/(Q_{ht} + Q_{hw} + N); b^{nht}_{gu} = B_{gu} \cdot 10^3/(Q_{hw} + N). \qquad (5)$$

Here B'^{ht}_{whb} – consumption of equivalent fuel per boiler in case of its incomplete loading in heating season of GTU-TEP operation, determined by (1) and (2).

Coefficient of fuel heat usage [3]

$$k_{fhu} = 34.13/b_{eq}, \qquad (6)$$

where b_{eq} – corresponding specific consumption of equivalent fuel.

Table2 contains calculated values of basic operation indices of boiler houses and GTU-TEP of the same thermal power. Energy efficiency of their operation was evaluated by means of k_{fhu}.

Table 2

Calculated values of basic operation indices of boiler houses and GTU-TEP

Indices	Boiler house, 55 MW	GTU-TEP-with GTU-9,5	Boiler house, 80 MW	GTU-TEP with GT-16	Boiler house 106 MW	GTU-TEP with GT20	Boiler house 140 MW	GTU-TEP with HK-37-1	Boiler house 320 MW	GTU_--TEP with GTU-60
Heating season										
Power of heating system, MW	42	42	60	60	80	80	105	150	240	240
Power of hot water supply system, MWM	13	13	20	20	26	26	35	35	80	80
Consumption of equiwalent fuel, t/yr	9,02	10,141	13,08	15,62	17,352	19,73	22,83	26,82	52,416	59,76
Electric power of auxiliaries, MW	0,569	0,448	0,826	0,735	1,06	0,943	1,395	1,235	3,233	2,725
Power, delivered into electric grid, MW	-	8,352	-	16,265	-	19,057	-	28,765	-	57,275
Specific consumption of equivalent fuel, kg/GJ	45,55	44,15	45,41	43,72	45,47	43,49	45,30	43,82	45,50	43,68
Coefficient of fuel heat usage	0,743	0,773	0,751	0,781	0,750	0,785	0,753	0,789	0,750	0,781
Non- heating season										
Consumption of equivalent fuel, t/yr	2,184	3,376	3,357	5,746	4,215	6,825	5,922	9,96	13,334	21,6
Electric power of auxiliaries, MW	0,133	0,075	0,214	0,119	0,268	0,153	0,392	0,211	0,882	0,475
Power, delivered into electric grid, MW	-	8,725	-	16,881	-	19,847	-	29,789	-	59,525
Specific consumption of equivalent fuel, kg/GJ	46,66	43,03	46,62	43,13	45,04	41,12	47	42,56	46,3	41,92
Coefficient of fuel heat usage	0,731	0,795	0,732	0,794	0,757	0,93	0,726	0,8	0,737	0,814

It is seen from Table 2 that energy efficiency of operation of all the variants of GTU-TEP, being considered is higher than the efficiency of boiler houses of the same thermal power, especially in non –heating period . GTU-TEP that have higher efficiency factor of gas turbines and higher temperature of gases behind the turbine operate most efficiently. It is easy to notice that at the same thermal power fuel consumption at GTU—TEP is higher than in boiler house. If we assume that this excessive consumption of fuel is spent for generation of electric power then specific consumption of equivalent fuel for such generation is two times less than in energy system. It should be noted also the drop of electric power for GTU—TEP auxiliaries due to the reduction of the power of forced –draft installations of boiler houses in heating period and their absence in non-heating period. Taking into account that the price of the unit of electric energy is at least, 1.5times higher than the price of the heat, the creation of GTU-TEP on the base of existing hot water boiler houses is expedient. Such TEP are able to cover both thermal and electric loads in every given case, increasing the reliability of power supply and improving regulation conditions of regional energy systems. Regarding the term of recoupment of gas turbine superimposed units, it depends, mainly, on fuel prices, electric energy and heat prices, in each given case it is determined on the base of technical –economic calculations.

Conclusions

1. Gas- turbine superimposed units on the base of existing hot water boiler houses allow to generate in cogeneration manner electric energy on heat supply and
reduce energy losses of auxiliary power.

2. Specific consumption of equivalent fuel at GTU-TEP is almost two times less than at electric power plants of energy system.

3. Application of GTU-TEP allows to improve energy supply in separate regions and prevent losses f energy in the process of its transmission from energy system.

4. Energy efficiency of GTU-TEP is higher as compared with distributed scheme of energy supply.

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