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THERMOELECTRIC PLANTS WITH BINARY CYCLE

Operation indices of binary thermal power units with low – temperature working medium created on the base of industrial thermoelectric plants with backpressure turbines have been determined.

Key words: *binary cycle, boiler, low temperature working medium, backpressure turbine, thermoelectric plant.*

Introduction

Efficiency of energy generation is important characteristic of fuel – operating installations. The efficiency is evaluated by means of utilization factor of fuel heat K_{hu}, that equals the ratio of net produced power to the capacity of burnt fuel. Cogeneration of heat and electric energy at thermoelectric plants (TEP) is very promising technology that, to great extent, allows to solve problems of energy saving. That is why, the given technology is considered to be one of the main directions of energy branch of Ukraine development and this is reflected on legislative level [1]. It is obvious, that normal operation of TEP can be provided if stable heat demand is available. However, nowadays, the situation is that as a result of the fall of industrial production or its reorientation, the consumption of technology steam has decreased and it became impossible to generate designed electric power at thermoelectric plants of industrial enterprises. But the forecast generation of electric energy by 2030 must increase 1.5 – 2 times, as compared with 2010 [2]. Besides, we must take into consideration the fact that as a result of energy fuel shortage hot water supply of numerous consumers is supposed to be performed from electric boilers.

One of the priority directions of modernization of Ukrainian heat and power engineering branch is the application of new, efficient technologies. Such technologies include usage of binary cycles, operating at low – temperature working media (LTM). Unfortunately, only general operation principles of binary installations with LTM are described in literature [3 - 5].

In this research, in connection with the above – mentioned an attempt is made to determine basic operation indices of binary cycles with LTM, created on the base of typical steam turbines with small back pressure.

Main results

Typical back – pressure turbines with 0.294 MPa back – pressure are taken as basic ones. Basic characteristics of these turbines are given in Table 1. Technique of thermal circuits of steam - turbine units (STU) calculation is presented in [6].

Table 1

Main characteristics of basic back-pressure turbines

Indices	Type of turbine / number of the variant				
	P-6-35/3	P-4-35/3	P-2,5-35/3	P-2,5-15/3	P-1,5-15/3
	1	2	3	4	5
Steam temperature before the turbine, ^{o}C	435	435	435	350	350
Steam pressure before the turbine, MPa	3,43	3,43	3,43	1,47	1,47
Steam temperature behind the turbine, ^{o}C	186	192	193	193	190
Steam consumption per turbine, t/hr	50,5	35,6	22,3	34,3	20,8
Equivalent fuel consumption, t/hr	5,357	3,784	2,367	3,445	2,088
Thermal capacity of steam consumers, Mw	32,91	23,36	14,63	22,40	13,60
Total net capacity, MW	38,91	27,36	17,13	24,96	15,1
Specific consumption of equivalent fuel, kg/Gj	38,25	38,4	38,4	38,3	38,4
Electric power of auxiliaries, MW	0,463	0,328	0,212	0,178	0,111
Specific heat, spent on overheat of the steam from the turbine to 350 ^{o}C, kJ/kg	335	323	306	321	327
Fuel heat utilization factor	0,892	0,888	0,888	0,89	0,888

While determining operating indices of back – pressure steam – turbine unit with the given type of turbines, we assume: the temperature of return condensate 104 ^{o}C; temperature of feed water 105 ^{o}C, efficiency factor of steam boilers 0.92. The scheme of binary unit, based on typical STU is shown in Fig. 1.

Benzene (C_6H_6) was chosen as LTM due to the company, designing and manufacturing turbines, that operate on benzene vapour [7]. The following symbols of heat carries parameters are given on the scheme: *P* – pressure; *t*- temperature; *h* – steam enthalpy; *h'* – liquid enthalpy and also consumptions; *D*- steam; *G* – liquid. The following initial parameters of benzene vapour at the inlet of the turbine are selected [8]: P_b = 0.6 MPa; $t_б$ = 327 ^{o}C; h_b = 656 kJ / kg. Steam parameters at the outlet of benzene turbine (at the input of the condenser) are assumed to be equal: P_c = 0,0135 MPa; t_c = 25 ^{o}C; h_c = 183 kJ / kg. As the temperature of water steam at the outlet of backpressure (basic) turbines is lower than the temperatures of benzene vapour at the inlet into benzene turbine, partial or complete overheat of this stem in steam boiler is suggested. Secondary overheat of water stem allows to decrease the temperature of flue gases from steam boiler and, respectively, increase its efficiency factor.

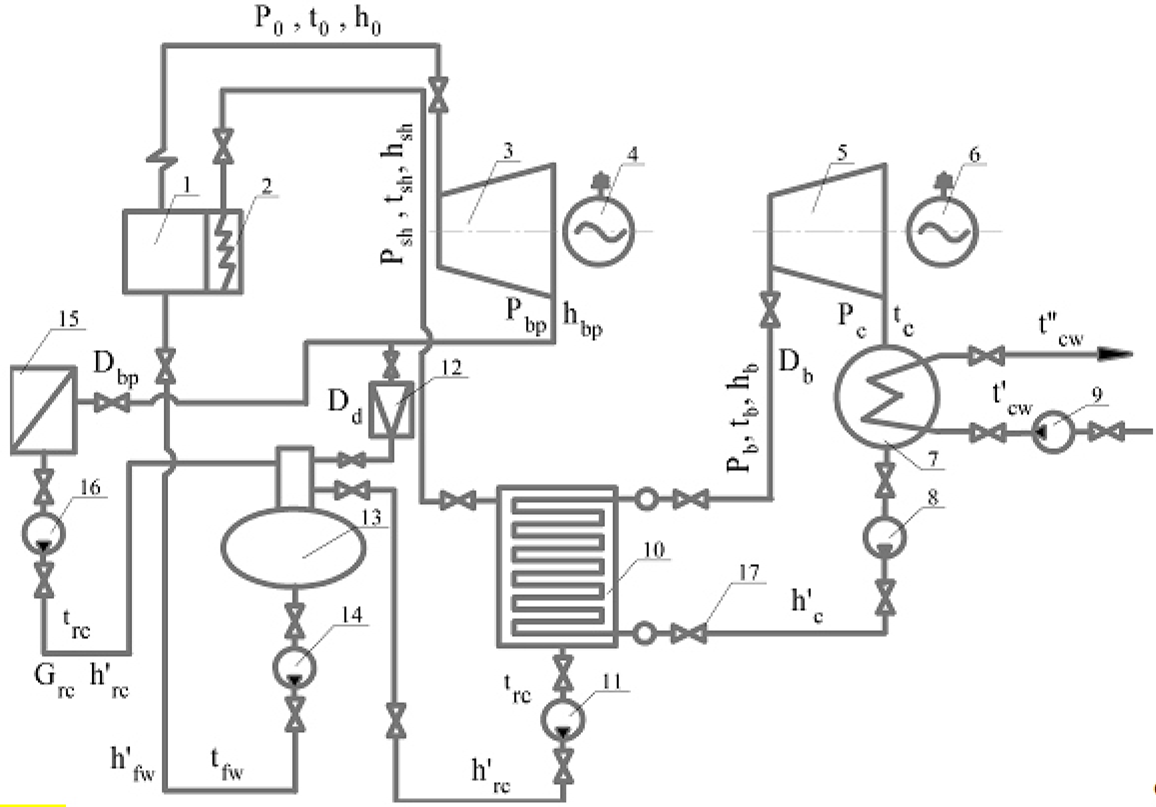

Fig. 1. Thermal flow diagram of binary unit: 1 – steam – water boiler; 2 – reheater; 3 – back pressure stem turbine; 4 – electric generator; 5 – benzene steam turbine; 6 – eelectric generator; 7 – condenser; 8 – condensate pump; 9 – circulating pump; 10 – benzene steam boiler; 11 – drain pump; 12 – steam pressure regulator; 13 –open deaerator; 14 – feed pump; 15 water steam consumer; 16 – return condensate pump; 17 – stop valves.

As a result of very small difference between the temperatures of the feed water and return condensate, steam consumption in deaerator with sufficient degree of accuracy may be neglected. If water steam consumption on the turbine is denoted buy $D_{o,}$ and the share of steam, supplied to industrial or heating consumer – by α, then steam consumption to consumers will be equal $\alpha\ D_o$, and steam consumption for reheating and benzene boiler will be equal $(1-\alpha)\ D_o$. It is clear, that at $\alpha = 0$ all the steam from back – pressure basic turbine is spent for generation of benzene steam, and at $\alpha = 1$ low – temperature cycle does not operate. Technique of calculation of thermal circuits of binary units is described [6]. The results of calculation of TEP operation with binary cycle for variants of basic turbines are given in Table 2.

Table 2

Main indices of units operation at $\alpha = 0$

Indices	Varinats				
	1	2	3	4	5
Benzene consumption, kg/s	36,51	25,92	16,23	24,91	15,09
Electric power of benzene – operated SPU, MW	15,5	11,01	6,89	10,59	6,40
Electric power of auxiliaries of benzene - operated SPU, MW	0,284	0,210	0,131	0,172	0,104
Additional consumption of equivalent fuel for superheat of back-pressure steam, kg/s	0,16	0,108	0,064	0,104	0,064
Total electric power of binary unit, MW	21,50	15,01	9,39	13,09	7,90
Total consumption of equivalent fuel in binary unit, kg/sec	1,648	1,160	0,722	1,061	0,644
Specific equivalent fuel consumption: kg/Gj,	76,65	77,28	76,89	81,05	81,51
kg/(kW·h)	0,276	0,278	0,277	0,292	0,293
Utilization factor of fuel heat	0,445	0,442	0,443	0,421	0,418
Annual saving of equivalent fuel for generation of electric energy as compared with its generation in energy system, t/yr	10238	7079	4490	5510	3274
Comparative decrease of harmful emissions in the atmosphere, t/yr: carbon monoxide	1,621	1,022	0,698	0,921	0,524
carbon dioxide	2870	2030	1180	1720	1030
nitrogen oxide	3,14	2,21	1,42	1,95	1,12

On condition α=0 binary unit generates only electric energy. It is seen from Table 2, that by means of binary cycle with LWB electric capacities of basic STU can be increase more than 3.5 times. In this case, fuel consumption, connected with secondary overheat of steam from backpressure turbines increases only 10 – 11 %. We should note the increase of electric power of auxiliaries. We cannot help paying attention to the fact, that zero power of thermal consumers general efficiency of binary unit operation decreases. However, if additional electric power had been generated at power stations of the unified energy system with the efficiency factor 0.35, then specific consumption of equivalent fuel would be 0.3514 kg (kW/h) that, on average, is 2.5 % higher, than in binary units. In this connection we can speak about comparative economy of fuel and, correspondingly, about reduction of harmful emissions in the atmosphere, values of these emissions are given in Table 2.

It is obvious that the efficiency of cogeneration units operation increases at loading of thermal consumers. If industrial or cogeneration consumers of steam with the share of loading α>0 are available, then fuel consumption for steam secondary overheat from back pressure basic turbine decreases and total delivered power increase. Tables 3 and 4 contain calculated values of basic indices of binary units operation within the range 0≤α≤1 with basic turbines P-6-35/3 and P-1,5-15/3, correspondingly.

Table 3

Operation indices of binary unit with basic turbine P-6-35 / 3

Indices	Values of α					
	0	0,2	0,4	0,6	0,8	1
Electric power of benzene STU, MW	15,50	12,41	9,30	6,20	3,11	0
Power thermal consumers, MW	0	6,58	13,16	19,76	26,32	32,91
Total delivered power, MW	21,50	24,99	28,47	31,95	35,43	38,91
Electric power of auxiliaries, MW	0,75	0,67	0,62	0,56	0,51	0,46
Equivalent fuel consumption for secondary overheat of the steam, kg/sec	0,16	0,128	0,095	0,064	0,032	0
Total consumption of equivalent fuel, kg/sec	1,648	1,616	1,584	1,552	1,520	1,488
Specific consumption of equivalent fuel, kg/Gj	76,65	64,66	55,61	48,57	42,9	38,25
Utilization factor of fuel heat	0,445	0,527	0,613	0,702	0,792	0,892

Table 4

Operation indices of binary unit with basic turbine P-1,5-15/3

Indices	Values of α					
	0	0,2	0,4	0,6	0,8	1
Electric power of benzene STU, MW	6,40	5,31	3,85	2,56	1,28	0
Power thermal consumers, MW	0	2,72	5,44	8,16	10,88	13,6
Total delivered power, MW	7,90	9,52	10,78	12,22	13,66	15,1
Electric power of auxiliaries, MW	0,152	0,131	0,112	0,101	0,090	0,085
Equivalent fuel consumption for secondary overheat of the steam, kg/sec	0,0644	0,0542	0,0386	0,0256	0,0128	0
Total consumption of equivalent fuel, kg/sec	0,644	0,634	0,618	0,605	0,593	0,580
Specific consumption of equivalent fuel, kg/Gj	81,51	66,59	57,28	49,53	43,39	38,4
Utilization factor of fuel heat	0,418	0,512	0,592	0,689	0,788	0,888

It is seen from these Tables that when thermal consumers are loaded from back – pressure of basic turbine the following parameters decrease: electric powers of benzene unit and auxiliaries, general specific consumption of equivalent fuel. At the same time the following parameters: total (thermal and electric) powers, generated at binary unit and utilization factors of fuel heat. Higher increment of electric power is observed in the units with lower parameters of the steam before basic turbines, that have higher fuel consumption for secondary of the steam from turbines back-pressure. Graphic interpretation of certain indices of combined units operation according to the data of Tables 3 and 4 are given in Fig 2 and 3, correspondingly.

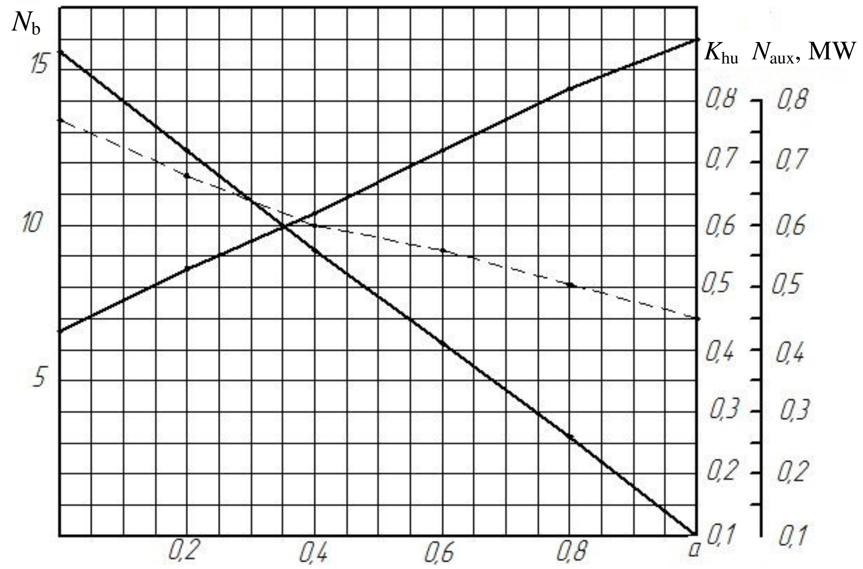

Fig. 2. Character of operation indices change of binary unit with basic turbine P-6-35 / 3: 1- power of benzene turbine N_b, MW; 2 – power of auxiliaries N_{aux}, MW; 3 – utilization factor of fuel heat K_{hu}.

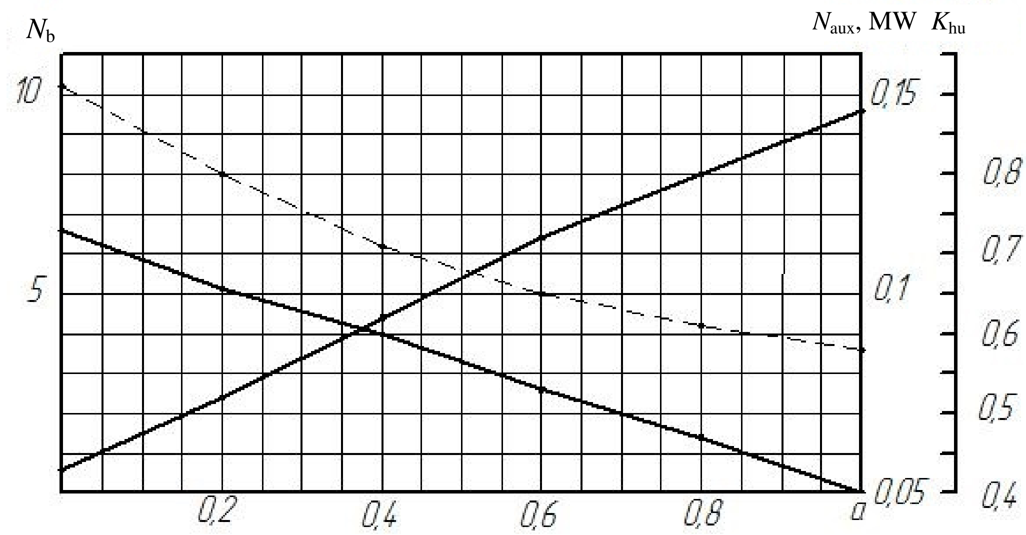

Fig. 3. Character of operation indices change of binary unit with basic turbine P-1,5-15 / 3: 1 – power of benzene turbine N_b, MW; 2 – power of auxiliaries N_{aux}, MW; 3 – utilization factor of fuel heat K_{hu}.

Regularities of basic parameters charge of binary units with LWT, operating with various parameters of water steam before basic back-pressure turbines are the same. Electric capacities of benzene turbogenerators increase linearly as the load of thermal consumers form back-pressure basic turbines decreases. In this case, coefficients K_{uf}, characterizing the efficiency of fuel usage in combined units increase almost linearly.

Conclusions

1. Application of binary cycles at TPP with back-pressure turbines, having not high pressure of water steam behind the turbine, allows to increase generation of electric energy more than 3 times.

2. Efficiency of electric energy generation at TPP of the given type is, on average, 25 % higher than at electric power stations of energy system, that allows to obtain fuel economy and reduction of harmful emissions in the atmosphere.

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