M. Chepyrniy, Cand. Sc. (Eng.), Assist. Prof.; N. Rezydent, Cand. Sc. (Eng.), T. Oleksyna

THERMOELECTRIC PLANTS ON THE BASE OF BACK-PRESSURE STEAM TURBINES AND TURBINES WITH LOW TEMPERATURE WORKING MEDIUM

Operating indexes of combined binary units on the base of back-pressure steam turbines and turbines, functioning with low temperature working medium have been determined.

Key words: *back - pressure turbine, binary cycle, thermoelectric plant, low temperature working medium, capacitor, equivalent fuel.*

Introduction

It is a well known fact, that more than 90% of the equipment, installed at thermoelectric plants depleted normative operation recourses and approximately 70% - depleted double operation resource. In accordance with development strategy of energy sector for the period till 2030, the generation of electric energy in the country must increase 2-2.5 times as compared with 2005 [1]. Increase of energy generating capacities as a result of reconstruction of existing generation facilities or putting into operation new generation units will require considerable investment, not available in Ukraine now. It should also be mentioned that as a result of gas supply decrease from Russia, heating and hot water supply in certain regions could be provided from boiler facilities, operating on electricity.

One of the priority guidelines of modernization of energy sector is considered to be the combined generation of electric energy and heat on the base of available low power equipment. There exist real possibilities for application of new efficient technologies for money of Ukrainian and not foreign investors. Among the above-mentioned new technologies the technology of binary cycles application , operating on low-temperature working media (LTM) [2 – 4] is very actual. In Ukraine many industrial low-power thermoelectric plants with back-pressure turbines operate, supplying water steam to industrial enterprises. However, nowadays as a result of reduction of industrial production or its reorientation the consumption of the steam of the set pressure decreased or suspended. First of all this concerns back-pressure turbines of 1.5 -1.8 MPa. Usage of such turbines for power-heat supply is not expedient due to considerable heat losses in the processes of throttling and steam cooling. In literature only separate general principles of binary cycles with LTM application are described, then, proceeding from the above- mentioned the task to determine operation indices of binary installations, created on the base of low power back-pressure turbines and attached steam turbines units (STU), operating on LTM.

Main results

Typical 1.5 MPa back-pressure turbines are chosen as basic ones. The calculation technique of thermal circuits of steam turbine installations is presented in [5]. The following parameters are taken for calculation: temperature of water steam before the turbines t_o=435 ºC; initial enthalpy of the steam h_o=3305 kJ/kg; temperature of reverse condensate t_{rc}=103 ºC; temperature of feed water t_{fw}=104,8 ºC; efficiency of steam boilers – 0.92. Certain indices of STU are presented in Table 1.

Table1

Certain characteristics and indices of basic STU operation

Indices	Turbine type / number of the variant			
	P-6-35/15	P-4-35/15	P-2,5-35/15	P-1,5-35/15
	1	2	3	4
Power of electric generator, MW	6	4	2,5	1,5
Steam temperature in backpressure, °C	335	338	342	345
Turbine steam losses, t/hr	123,5	85,4	56,3	35,5
Thermal capacity of industrial consumers, MW	89,21	61,81	40,90	25,87
Electric power of auxiliaries, kW	652	473	378	226
Equivalent fuel consumption, t/hr	13,272	9,178	6,052	3,815
Specific consumption of equivalent fuel for generation of electric and thermal energy, kg/GJ	38,72	38,73	38,735	38,74

Flow thermal diagram of binary unit based on typical STU and attached STU with low temperature cycle is shown in Fig. 1, where symbols of heat-transfer agents parameters are given: P – pressure; t – temperature; h – steam enthalpy; h′ – liquid enthalpy and also consumption of D and G in characteristic points of cycles. Benzene (C_6H_6) has been chosen as low – temperature working medium (LWM) because of the company, that designs and manufactures turbines, operating on benzene vapour [6].

Steam boiler 1 generates water steam with parameters P_o, t_o, h_o and consumption D_o. This steam enters backpressure (basic) turbine 2. Steam from the backpressure of the turbine may be supplied both to industrial consumers by the line 4 and to benzene boiler 9, that generates steam with parameters P_b, t_b, h_b and consumption D_b .

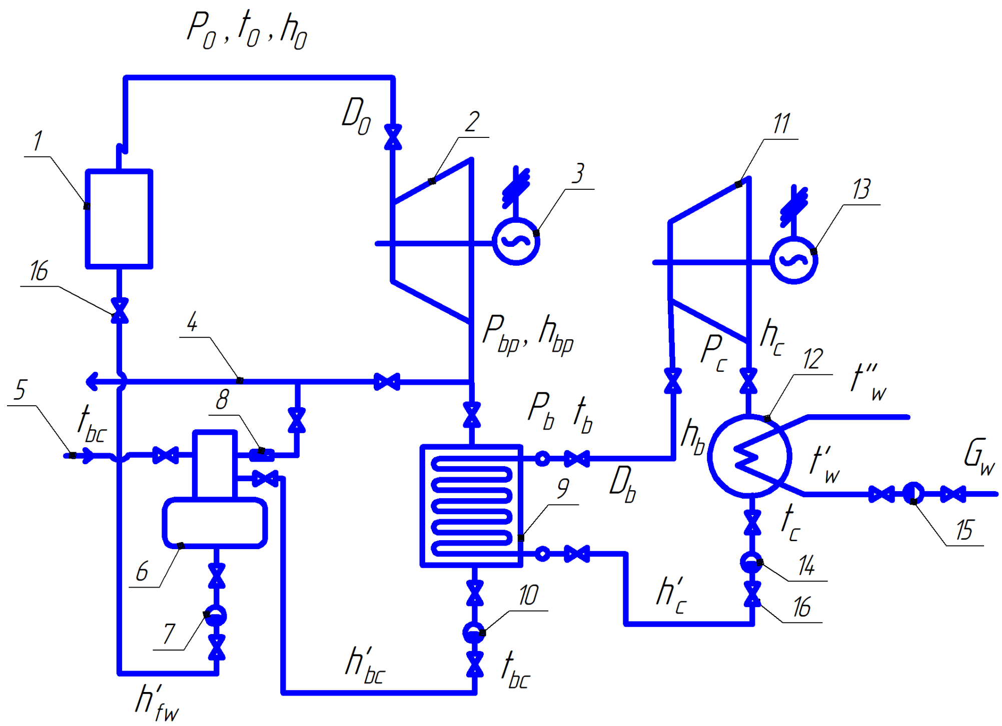

Fig. 1 – Flow thermal diagram of binary unit : 1 – steam boiler; 2 – backpressure turbine; 3 – electric generator; 4 – steam supply line to the consumers; 5 – condensate backflow line; 6 – deaerator; 7 – feed pump; 8 – pressure regulator; 9 – benzene vapour boiler; 10 –condensate backflow pump; 11 – benzene turbine; 12 – condenser; 13 –electric generator; 14 – condensate pump; 15 – circulating (networking) pump; 16 – shut-off valves.

If we denote by α the portion of steam, supplied to industrial consumers then the consumption of water steam, arrived to industrial consumers and in benzene boiler will equal correspondingly:

$$D_{cs} = \alpha \cdot D_0 \,;\; D_{bb} = (1-\alpha)\cdot D_0 \,, \tag{1}$$

Back flow condensate of water steam with the temperature t_{bc} returns along the pipeline 5 and pressure line of backflow condensate pump 10. Benzene vapour from the boiler 9 arrives to the turbine 11 and then to condenser 12. Cooled water is pumped by means of pump 15 across the condenser, this water is heated from the temperature t_w to temperature t''_w. Condensate of benzene vapour with the parameters t_c and h_c by means of pump 14 returns to the boiler 9. If benzene condensation is performed under the pressure $P_c \geq 0.2$ MPa, then the condensation temperature exceeds 100 ºC. In this case, the condenser may operate as the source of power-and heat supply, heating return water. Such combined installation will be called installation with binary power and heat supply cycle. Thus, we should distinguish two types of combined installations: 1) with completely condensate binary cycle: 2) with power and heat supply cycle.

Technique of binary cycles calculation is given in [7]. First, we will consider the characteristic operation features of binary units of the first type for the case when benzene STU generates only electric energy. For this purpose such parameters of benzene vapour have been chosen: $P_b = 0.6$ MPa; $t_b = 327$ ºC; $h_b = 656$ kJ/kg; $P_c = 0.0135$ MPa; $t_c = 25$ ºC; $h_c = 183$ kJ/kg [8]. Temperature difference in condenser is 12 ^{o}C. The results of the calculations of the first type units operation on condition that α = 0 (all the steam from backpressure of the basic turbine arrives to benzene boiler) are given in Table 2, where variants enumeration corresponds to enumeration of turbines variants in Table 1.

Table 2

Operation indices of the units with completely condensate binary cycle (α =0)

Indices	Variants			
	1	2	3	4
Benzene consumption, kg/s	98,83	68,47	45,31	28,86
Electric power of benzene STU, MW	43,11	29,81	19,75	12,49
Electric power of in-house load of benzene STU, kW	385	267	175	112
Electric power of binary unit auxiliaries, kW	1037,2	739,8	553	337,6
Total electric power, generated by binary unit, MW	49,1	33,8	22,25	13,995
Specific equivalent fuel consumption: kg/GJ;	75,07	75,42	75,55	75,74
kg/(kW·h)	0,2673	0,271	0,272	0,2725
Annual saving of equivalent fuel for electric energy generation, as compared with its generation in energy system, t/yr	31609	20996	11650	8954
Annual reduction of pollutant emissions, t/yr: CO;	3,87	2,484	1,378	1,11
CO_2;	6757	4378	2408	1915
nitrogen oxide	7,652	4,948	2,725	2,169

First of all we should pay attention to eightfold increase of electric power at the expense of binary cycle realization. At the same time, in case of absence of industrial consumers of the steam, specific equivalent fuel consumption per unit of the generated energy increases, although additional electric power is generated without additional fuel consumption.

But, if this additional power was generated at the power plants of energy system with the efficiency of 0.35, then specific consumption of equivalent fuel would be 97.6 kg/GJ or

0.3154kg/(kW·h). In this case, annual economy of equivalent fuel, as compared with electric energy generation in energy system must be, t/yr.

$$\Delta B = (0{,}3514 - b)\cdot N_b \cdot \tau_a, \quad (2)$$

where b – specific consumption of equivalent fuel at the combined binary unit, N_b – power of benzene SPU, MW; τ_a – annual amount of working hours.

According to this fuel saving harmful emissions in the atmosphere must have been reduced. On condition that working fuel is natural gas, having heat of combustion on dry mass 33.4 MJ/m^3 and theoretical volumes: air V^o=9.52 m^3/m^3 and gases V^o_g=10.6 m^3/m^3, values of these emissions were calculated according to the norms 34.02.305-2002 "Emissions of pollutant substances in the atmosphere from power units", and are also given in Table 2.

Operation of binary cycles according to considered variants at $\alpha = 0$ has the following drawbacks: large consumption of LTM, that stipulate cumbersome equipment of benzene STU, increase of energy consumption for in-house needs, decrease of operation efficiency as compared with the basic cycle.

These drawbacks can be eliminated to some extent, in case of loading industrial consumers of steam from the back pressure of basic turbine, i.e., on condition of $0 < \alpha < 1$ operation.

Fig. 2 contains the regularities of main parameters of binary unit with basic turbine P-4-35/15 (variant 2 in Table 1) change, depending on α values.

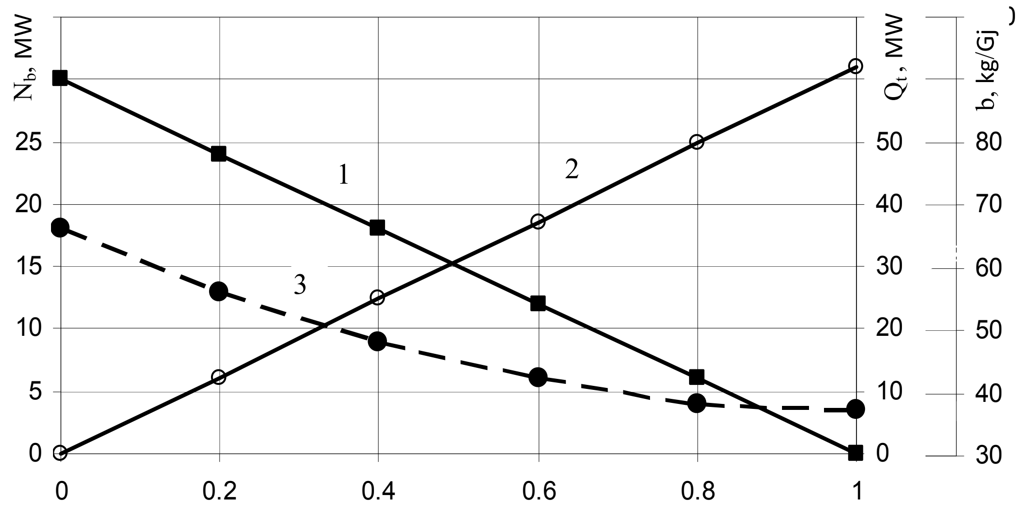

Fig. 2. Current values of: electric power of benzene STU - N_b (line 1); thermal capacity, supplied to industrial consumers – Q_t (line 2); specific consumption of equivalent fuel – b (line 3)

It is seen from Fig. 2, that with the increase of the share of steam, supplied to industrial consumers, electric power of benzene SPU linearly decreases and thermal capacity of binary unit linearly increases. Rate of Q_t increase leaves behind the rate of N_b decrease. As a result, total (thermal and electric) power, generated at thermal power plant with binary increase, thus, the efficiency of its operation increases too. On condition $\alpha = 0$ values of binary unit operation indices correspond to the values, given in Table 2, and on condition $\alpha = 1$ – to the values given in Table 1.

Analogous regularities of operation indices change of the units with binary condensate type are also observed for other variants with basic back-pressure turbines, given in the Table 1. Optimal operation modes of binary units is considered to be the mode, when $\alpha = 0.5 - 0.6$. In this case electric power increases 2 – 2.35 times , the cost of equipment of benzene – operated SPU and dimensions decrease 2 - 2.35 times.

Binary units operation efficiency, characterized by specific consumption of equivalent fuel increases 1.5 – 1.65 times.

Now we will consider characteristic features of operation of binary units with heat recovery cycle. For this case we will choose such parameters of benzene vapour: P_b = 1 MPa; t_b = 327ºC; h_b = 651.4 kJ/kg; P_c = 0.215 MPa; t_c = 117 ºC; h_c = 365 kJ/kg [8]. Cogeneration power of benzene STU will equal the condenser capacity, taking into account its efficiency. In the condenser return heating water of cogeneration system with the temperature 55 ºC is heated to the temperature of 110 ºC and is directed to hot water consumers. Table 3 contains the results of calculation of basic indices of binary units of the given type on condition that all the steam from the back pressure enters the benzene boiler.

Data, given in Table3 affirms that the application of cogeneration binary cycle improves the efficiency of thermal power plant (TPP) operation as a result of the increase of total thermal and electric power. We should note the increase of low-temperature working medium consumption and auxiliary power consumption. In this case the realization of this variant in practice becomes rather complicated. That is why, as in the first case we will consider the operation of cogeneration unit in the range of $0 < \alpha < 1$.

Table 3

Indices of binary unit with cogeneration cycle (α=0) operation

Indices	Number of the variant			
	1	2	3	4
Benzene consumption, kg/s	117,38	81,32	53,81	34,04
Electric power of benzene-operated STU, MW	31,45	21,79	14,42	9,12
Cogeneration capacity, MW	46,95	32,53	21,52	13,61
Auxiliary power of benzene-operated STU, kW	459	254	232	148
Auxiliary power of TPP, MW	1,111	0,827	0,610	0,374
Total power, generated by binary unit, MW	84,402	58,326	38,440	24,237
Specific consumption of equivalent fuel, kg/GJ	43,68	43,70	43,73	43,74

Calculated dependences of basic operation indices change of binary unit with cogeneration cycle on the base of basic turbine P-4-35/15 are constructed as an example in Fig.3 as in Fig.2.

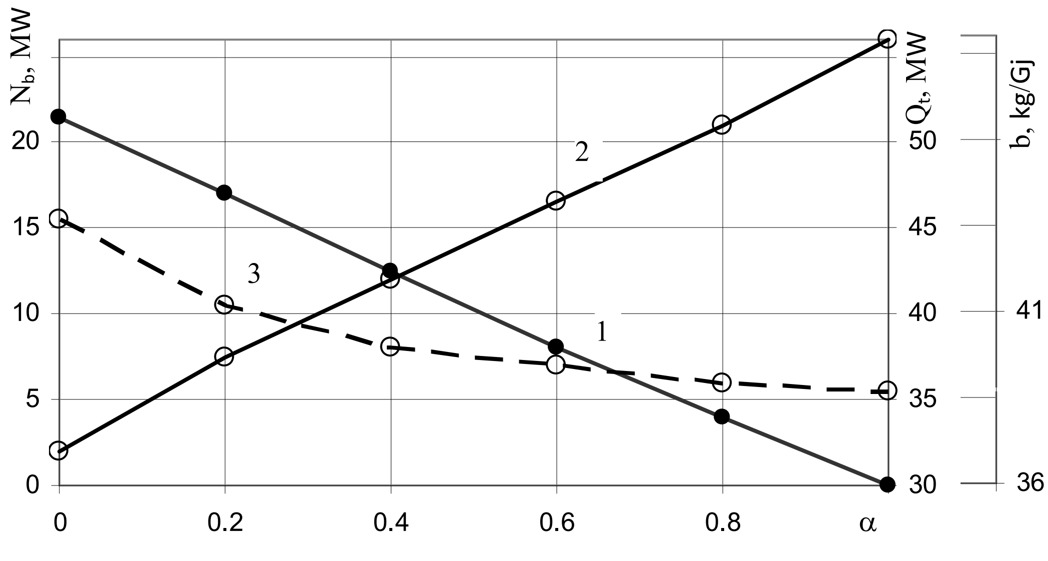

Fig.3. Values of basic operation indices of binary unit with cogeneration cycle (designations in Fig.2.)

Here, as before, values of operation indices, given in Table 3 and Table 1 correspond to limiting conditions of $\alpha = 0$ and $\alpha = 1$.

Analogous ratios are valid for other variants of binary units with basic back-pressure turbines. Operation efficiency of the units with cogeneration binary cycle is 20 – 25 % greater than the efficiency of the units with condensation cycle. Units with cogeneration binary cycle have disadvantages which were determined for the units with condensation cycle. Optimal operation modes of the studied units are considered to be modes with $\alpha = 0.6$.

It should be noted, that binary units, based on back-pressure turbines, having considerable consumption of water steam, cannot be realized in practice, on condition, that all the steam is spent for generation of low temperature working medium.

We would like to underline that binary cycles can be realized on the basis of back-pressure turbines with lower back-pressure (0.3 – 0.7 MPa) and less steam consumption. However, in this case there arises the need of the complete or partial superheat with back pressure up to temperatures 340 – 350 ^{o}C. These variants require separate study.

Conclusions

1. Application of binary units with LTM allows to increase considerably generation of electric energy without additional fuel burning.
2. Application of cogeneration binary cycles is 20 – 25 % more efficient than application of condensation cycles.
3. For the considered variants practical realization of binary cycles, on condition that all the steam from the backpressure of basic turbines, is spent for generation of LTM steam, is rather problematic.
4. The most efficient operation modes of the considered units are operation modes with α =0.6.
5. The results obtained are necessary precondition for the solution of the problem, dealing with the expediency of application of binary units with LTM on the base of back-pressure turbines with considerable steam pressure from the back-pressure.

REFERENCES

1. Стратегія розвитку паливно-енергетичного комплексу України до 2030 року. – К. : Вид-во Мін-ва палива та енергетики України, 2006. – 123 с.

2. A power generation system by low-temperature heat recovery // CADDET energy efficiency. Caddet Centre. September, 2002. – 42 p.

3. Сапожников М. Б. Электрические станции на низкотемпературных рабочих телах / М. Б. Сапожников, М. Н. Тимошенко // Теплоенергетика. – 2005. – N 3. – С.73 – 77.

4. Чепурний М. М. Теплоелектроцентралі на базі газотурбінних установок і парових турбін з низькотемпературним робочим тілом / М. М. Чепурний, С. Й. Ткаченко // Вісник Вінницького політехнічного інституту. – 2010. – N 4. – С. 21 – 25.

5. Чепурний М. М Розрахунки теплових схем ТЕЦ та ефективності при їх модернізації / М. М. Чепурний, С. Й. Ткаченко. – Вінниця: ВДТУ, 1997. – 61 с.

6. ORMAT ENERGY CONVERTER. Technical bulletin. ORMAT INK, 1990. –11 p.

7. Чепурний М. М. Енергозбережні технології в теплоенергетиці / М. М. Чепурний, С. Й. Ткаченко. – Вінниця: ВНТУ, 2009. – 114 с.

8. Варгафтик Н. Б. Справочник по теплофизическим свойствам газов и жидкостей / Н. Б. Варгафник. – М. : Наука, 1982. – 720 с.

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

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

Oleksyna Tetiana– Student, Institute of Civil Engineering, Heat and Power Engineering and Gas Supply.

Vinnytsia National Technical University.