Scheme of joint operation of an absorption heat pump and combined-cycle plant

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Annotation. In this paper, we propose and consider a scheme for the combined operation of an absorption heat pump and a combined-cycle plant. A computational study was carried out and the results confirming the effectiveness of the scheme were obtained. The heat power of the gas heater of the network water due to the inclusion of an absorption heat pump is increased by 12-14% from its previous value.

1. Description of the object and method of investigation

The scheme of a combined-cycle plant without an absorption heat pump is shown in Fig.1 [1-3]. The main elements of the combined-cycle plant are: gas turbine unit 1, waste heat boiler 2 and steam turbine 3. The waste heat boiler has five heat exchange surfaces: superheater a2, evaporator b2, economizer c2, gas heater of the condensate d2 and gas heater of the network water e2. To simulate the heat consumer after gas heater of the network water, the scheme includes a water-to-water heat exchanger i2. In the scheme also identifies and numbered: deaerator 4, condenser of steam turbine 5, drum of waste heat boiler f2, cooling tower of circulating water supply 6.

The combined scheme of a combined-cycle plant and the absorption heat pump is shown in Fig.2. Absorption H2O-LiBr heat pump consists of five main elements: generator c7, condenser a7, evaporator b7, absorber d7 and heat exchanger of the solutions e7 [4-7]. The heat conversion coefficient achievable in a heat pump depends on the parameters of the heating source, on the thermodynamic cycle being realized, and on the properties of the H2O-LiBr solution [8-10]. Principal difference of the combined scheme (see Fig.2) from the scheme of a combined-cycle plant without a heat pump (see Fig.1) are the consist in the installation of an additional heating surface in the waste heat boiler and the use of heat of the circulating water for heating the heat pump evaporator. In Fig.1, before being fed into the deaerator, the condensate is heated in the gas condensate heater. In Fig.2, before being fed into the deaerator, the condensate passes successively through the absorber and the heat pump condenser and the gas water heater. Heating of the heat pump generator is carried out by means of water of the intermediate circuit from the gas water heater.

The advantage of the combined scheme is an increase in the heat capacity of the gas heater of the network water as a result of the reduction of the heat load of the heat recovery boiler by heating the condensate. The disadvantage is the complexity of the scheme and the additional costs of acquiring and commissioning new equipment.
Fig. 1. Scheme of combined-cycle plant without heat pump:
1 - gas turbine plant; 2 - waste heat boiler; 3 - steam turbine; 4 - deaerator; 5 - steam turbine condenser; 6 - cooling tower; a1 - combustion chamber; b1 - air compressor; c1 - gas turbine; d1 - gas turbine generator; a3 - steam turbine generator; a2 - superheater; b2 - evaporator; e2 - economizer; d2 - gas heater of the condensate; e2 - gas heater of the network water; f2 - drum; i2 - water-to-water heat exchanger. The decoding of the flow temperatures is given in Table 1.

Fig. 2. Combined scheme of the combined-cycle plant and the absorption heat pump:
7 - absorption heat pump; j2 - gas heater of the water; c7 - the generator; b7 - evaporator; a7 is the condenser; d7 - absorber; c7 - heat exchanger of the solutions. The remaining symbols are the same as in Fig.1.
To evaluate the efficiency, the initial data were determined and the following were performed: 1) calculation of the combined-cycle plant scheme without an absorption heat pump; 2) calculation of the combined scheme of a combined-cycle plant and of an absorption heat pump; 3) a comparative assessment of the efficiency of the inclusion of an absorption heat pump in the scheme of a combined-cycle plant.

| № | Decoding of symbols and dimensions | Symbol | Fig.1 | Fig.2 | Fig.1 | Fig.2 | Fig.1 | Fig.2 | Fig.1 | Fig.2 |
|---|----------------------------------|--------|-------|-------|-------|-------|-------|-------|-------|-------|
| 1 | Outdoor temperature, °C | t_{d} | -32,0 | -32,0 | -18,0 | -18,0 | -5,2 | -5,2 | 8,0 | 8,0 |
| 2 | Temperature combustion gas behind c1, °C | t_{c1} | 518,7 | 518,7 | 526,4 | 526,4 | 532,7 | 532,7 | 538,8 | 538,8 |
| 3 | Temperature combustion gas behind a2, °C | t_{a2} | 454,0 | 454,0 | 458,4 | 458,4 | 462,0 | 462,0 | 465,4 | 465,4 |
| 4 | Temperature combustion gas behind b2, °C | t_{b2} | 255,4 | 255,4 | 255,4 | 255,4 | 255,4 | 255,4 | 255,4 | 255,4 |
| 5 | Temperature combustion gas behind c2, °C | t_{c2} | 215,7 | 215,7 | 218,4 | 218,4 | 214,0 | 214,0 | 213,3 | 213,3 |
| 6 | Temperature combustion gas behind d2, °C | t_{d2} | 166,4 | 183,3 | 164,4 | 181,6 | 162,7 | 180,3 | 161,1 | 179,0 |
| 7 | Temperature combustion gas behind j2, °C | t_{j2} | - | 173,4 | - | 171,5 | - | 169,9 | - | 168,5 |
| 8 | Temperature combustion gas behind e2, °C | t_{e2} | 110,0 | 110,0 | 110,0 | 110,0 | 110,0 | 110,0 | 110,0 | 110,0 |
| 9 | Temperature steam outlet of a2, °C | t_{a2out} | 478,7 | 478,7 | 486,4 | 486,4 | 492,7 | 492,7 | 498,8 | 498,8 |
| 10 | Temperature steam at the input in a2, °C | t_{a2in} | 245,4 | 245,4 | 245,4 | 245,4 | 245,4 | 245,4 | 245,4 | 245,4 |
| 11 | Temperature condensate and steam in b2, °C | t_{b2} | 254,5 | 254,5 | 254,5 | 254,5 | 254,5 | 254,5 | 254,5 | 254,5 |
| 12 | Temperature condensate outlet of c2, °C | t_{c2out} | 235,4 | 235,4 | 235,4 | 235,4 | 235,4 | 235,4 | 235,4 | 235,4 |
| 13 | Temperature condensate at the input in c2, °C | t_{c2in} | 159,4 | 159,4 | 159,4 | 159,4 | 159,4 | 159,4 | 159,4 | 159,4 |
| 14 | Temperature condensate outlet of d2, °C | t_{d2out} | 143,8 | 143,8 | 143,8 | 143,8 | 143,8 | 143,8 | 143,8 | 143,8 |
| 15 | Temperature condensate at the input in d2, °C | t_{d2in} | 60,0 | 75 | 60,0 | 75 | 60,0 | 75 | 60,0 | 75 |
| 16 | Water temperature outlet of j2, °C | t_{j2out} | - | 160 | - | 160 | - | 160 | - | 160 |
| 17 | Water temperature at the input in j2, °C | t_{j2in} | - | 130 | - | 130 | - | 130 | - | 130 |
| 18 | Temperature water outlet of c2, °C | t_{c2out} | 140,0 | 140,0 | 140,0 | 140,0 | 140,0 | 140,0 | 140,0 | 140,0 |
| 19 | Temperature water at the input in c2, °C | t_{c2in} | 80,0 | 80,0 | 65,0 | 65,0 | 60,0 | 60,0 | 60,0 | 60,0 |
| 20 | Heating capacity e2, MW | Q_{e2} | 8,77 | 9,85 | 8,25 | 9,33 | 7,73 | 8,79 | 7,21 | 8,20 |
| 21 | Consumption combustion gas behind c1, kg/s | G_{c1} | 146,0 | 146,0 | 142,6 | 142,6 | 138,0 | 138,0 | 132,7 | 132,7 |
| 22 | Consumption steam through a2, kg/s | G_{a2} | 18,10 | 15,07 | 18,07 | 18,07 | 17,80 | 17,80 | 17,40 | 17,40 |
| 23 | Condensate consumption in b2, kg/s | G_{b2} | 18,10 | 18,10 | 18,07 | 18,07 | 17,80 | 17,80 | 17,40 | 17,40 |
| 24 | Consumption condensate through c2, kg/s | G_{c2} | 18,47 | 18,47 | 18,44 | 18,44 | 18,16 | 18,16 | 17,75 | 17,75 |
| 25 | Consumption condensate through d2, kg/s | G_{d2} | 21,83 | 17,49 | 21,80 | 17,47 | 21,47 | 17,21 | 20,99 | 16,82 |
| 26 | Consumption waters through j2, kg/s | G_{j2} | - | 12,01 | - | 12 | - | 11,89 | - | 11,56 |
| 27 | Consumption waters through e2, kg/s | G_{e2} | 34,59 | 38,87 | 26,08 | 29,51 | 22,94 | 26,08 | 21,38 | 24,48 |
| 28 | Heat load c7, kW | Q_{c7} | - | 1550 | - | 1550 | - | 1530 | - | 1495 |
| 29 | Heat load b7, kW | Q_{b7} | - | 1088 | - | 1087 | - | 1072 | - | 1047 |
| 30 | Heat load a7, kW | Q_{a7} | - | 1153 | - | 1152 | - | 1135 | - | 1109 |
| 31 | Heat load d7, kW | Q_{d7} | - | 1490 | - | 1489 | - | 1466 | - | 1433 |
| 32 | Heat load c7, kW | Q_{c7} | - | 1810 | - | 1807 | - | 1780 | - | 1740 |
| 33 | Temperature waters at the input in c7, °C | t_{c7in} | - | 160 | - | 160 | - | 160 | - | 160 |
| 34 | Temperature waters outlet of c7, °C | t_{c7out} | - | 130 | - | 130 | - | 130 | - | 130 |
| 35 | Temperature water at the input in b7, °C | t_{b7in} | - | 35 | - | 35 | - | 35 | - | 35 |
| 36 | Temperature water outlet of b7, °C | t_{b7out} | - | 20 | - | 20 | - | 20 | - | 20 |
| 37 | Temperature condensate at the input in d7, °C | t_{d7} | - | 39 | - | 39 | - | 39 | - | 39 |
| 38 | Temperature condensate outlet of d7, °C | t_{d7} | - | 75 | - | 75 | - | 75 | - | 75 |
| 39 | Consumption waters through c7, kg/s | G_{c7} | - | 12,01 | - | 12 | - | 11,89 | - | 11,56 |
| 40 | Consumption condensate through d7 and a7, kg/s | G_{d7a7} | - | 17,49 | - | 17,47 | - | 17,21 | - | 16,82 |
| 41 | Consumption water through b7, kg/s | G_{b7} | - | 17,27 | - | 17,26 | - | 17 | - | 16,62 |
The scheme of the combined-cycle plant was calculated in a computer program designed for calculating the heat schemes of combined-cycle plants with waste heat boilers. The working algorithm of the program is based on the generally accepted methods for calculating the heat schemes of combined-cycle plants [1]. Calculation of the absorption heat pump was carried out separately from the calculation of the heat scheme of the combined-cycle plant according to the generally accepted calculation methods [5,6]. The heat load of the generator, absorber, evaporator, condenser and intermediate heat exchanger of the absorption heat pump was determined by the condensate flow rate to the deaerator. The comparability of the results was ensured by the condition that the electric power and efficiency of the gas and steam turbines, the parameters and the flow rate of the superheated steam, the temperature of the flue gases before and after the recovery boiler were adopted the same for the compared schemes and determined for four temperature values outdoor air.

2. The results of the study and their discussion

The results of interest for evaluating the effectiveness of the compared schemes are given in Table 1 and in Figures 3 and 4.

| Heat exchange surfaces of the heat recovery boiler | Scheme without heat pump | Combined scheme |
|--------------------------------------------------|--------------------------|-----------------|
| a1                                               | 64.7                      | 64.7            |
| b1                                               | 198.6                     | 198.6           |
| c1                                               | 39.7                      | 39.7            |
| d1                                               | 49.3                      | 32.4            |
| j1                                               | 0                         | 9               |
| e1                                               | 56.4                      | 63.4            |

Fig.3. Change of flue gas temperature in waste heat boiler:
a2 – superheater; b2 – evaporator; c2 – economizer; d2 – gas heater of the condensate; j2 – gas heater of the water; e2 – gas heater of the network water.

Fig.4. Heat power of the gas heater of the network water depending on the outside temperature
The histogram in Fig.3 is constructed for climatic conditions with an average outside air temperature for a heating period of -5.2 °C. It can be seen from the histogram in Fig.3 due to the preheating of the condensate in the absorber and the condenser of the heat pump, the temperature of the flue gases in the gas heater of the network water in the combined scheme changes more than in the scheme without the heat pump.

Figure 4 shows the graph of the change in the heat power in the gas heater of the network water depending on the temperature of the outside air. From the graph it follows that in the combined version of the circuit the heat power of the gas heater of the network water in the considered range of outside temperatures, with other things being equal, can be increased by 0.99 MW at the ambient temperature +8 °C, by 1.06 MW at an ambient temperature of -5.2 °C; by 1.08 MW at outdoor temperatures of -18 °C and -32 °C.

The increase in the heat power of the gas heater of the network water, other things being equal, allows to obtain additional income from the sale of heat energy, which can be estimated approximately by the formula, rubles/year:

\[ \Delta D = \frac{\Delta Q \cdot t \cdot S \cdot \eta}{1,163} \]  

where: \( \Delta D \) - income from the sale of additional heat power, rubles/year; 1,163 - conversion factor of MW to Gcal/h; \( \Delta Q \) - additional realizable heat power, MW; \( t \) - the number of hours in the year during which the additional heat power is realized, h/year; \( S \) - selling price 1 Gcal of heat energy, rub/Gcal; \( \eta \) - efficiency coefficient of the tariff, taking into account all the additional costs and losses not included in the tariff and losses in the process of production, transportation, distribution and sale of additional heat power.

Thus, for example, with increasing heat supply to consumers from a gas heater for network water at \( \Delta Q = 1 \) MW, provided that heat energy is realized during a heat energy consumption of 8400 hours/year and the cost of heat energy, \( S = 1626 \) rubles/Gcal, with an efficiency coefficient of the tariff \( \eta = 0.5 \), the additional annual income will be:

\[ \frac{1}{1,163} \cdot 8400 \cdot 1626 \cdot 0.5 = 5872055 \text{ rubles/year}. \]

Conclusions

1. A combined scheme of a combined-cycle plant and an absorption heat pump is proposed and considered.
2. The calculation study was carried out and the results confirming the efficiency of the combined scheme in comparison with the scheme of a combined-cycle plant without a heat pump were obtained.
3. In a given temperature range of outside air, the heat power of the gas heater of the network water can be increased by 12-14% from its previous value due to the installation of the heat pump. The increase in the heat capacity of the gas heater of the network water, other things being equal, allows to obtain additional income from the sale of heat energy.

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