The blast air preheating of an power boiler CHP ZIGM

S K Ziganshina and A A Kudinov
Samara State Technical University, ul. Molodogvardeiskaya 244, Samara, 443100, Russian Federation

E-mail: svet.zig@yandex.ru

Abstract. To improve the efficiency of the steam-turbine thermal power plant by reducing heat loss in a cold source by regenerating part of the heat of condensation of steam exhaust in the turbine, it is proposed to preheat the boiler blast air in a heat exchanger with circulating water heated in a steam turbine condenser. Saving of heat energy in monetary terms due to the use of part of the heat of condensation of steam in the turbine during preheating of the blast air of the energy boiler BKZ-420-140 NGM of the Samara Thermal Power Plant to 20 °C is 13.244 mln rub/year. The design of an air-preheating unit for preheating the blast air of the power boiler BKZ-420-140 NGM has been developed, in which the heating coolant is circulating water heated in a steam turbine condenser. Variant calculations were carried out, as a result of which the main thermal performance parameters of the installation were determined at different boiler loads and outdoor temperatures.

1. Introduction
The steam power plant (SPP) efficiency depends on the configuration of the thermodynamic cycle, the parameters of water vapor and the quality of fabrication of each thermal power unit. The Rankine SPP has a low thermal efficiency, owing to the significant heat losses in a cold source, the condenser of the steam turbine in which the exhaust turbine steam is consumed for heating the circulating water and is not used usefully. The resources of this part of heat in steam turbine thermal power plants are significant, they are considered as secondary [1, 2, 6].

To increase the efficiency of a steam turbine thermal power plant, it is proposed to use part of the condensation heat of the spent vapour in turbine for preheating the boiler's blast air, that is, regenerative heating of the blast air is carried out by the heat of the spent vapour in turbine [3, 6]. Increasing the efficiency of the Rankine cycle of a steam power plant in this case is achieved by reducing heat losses in the cold source. In this case, water vapor makes work in the entire wheel space of the turbine. Here, this effect of regeneration is much higher than that of the regenerative feedwater heating since there is not the decrease in the generation of electric energy by the electricity generator of turbine unit.

2. Experimental
It is proposed to install an air heating unit in the circulating water system of a thermal power plant for preheating the boiler's blast air. Heating is carried out by circulating water heated in a steam turbine condenser. The proposed method is considered on the example of the Samara CHP, which has five power boilers BKZ-420-140 NGM and four steam extraction turbines (three T-100/120-130-3 and one PT-60-130/13). The station has two cooling towers of the BG-2600-70 type for cooling the circulating water heated in the condensers of steam turbines. The unit for the blast air preheating of the power
boiler of the Samara CHP consists of 18 sections of SO-110 type heaters, which are located in two parallel pressure air line. In this case, the network water is a heating medium.

The results of calculations of the air heating unit heat output $Q_{air}$, the circulating water flow rate $G_w$ and economic efficiency $E_{day}$ for the boiler BKZ-420-140 NGM at different values of the outdoor air temperature $t_{out,air}$ are shown in Table 1. It was found that at an average annual outdoor air temperature of $+3.8 \, ^\circ C$ (for the city of Samara), the use of secondary energy resources in the process of the blast air preheating of one boiler BKZ-420-140 NGM can reduce the heat consumption connected to heating the blast air by 13644 MWt·h/year (at $t_{air}=15 \, ^\circ C$) and by 19735 MWt·h/year (at $t_{air}=20 \, ^\circ C$). Thermal energy savings in monetary terms will amount to 9.156 mln rub/year ($t_{air}=15 \, ^\circ C$) and 13.244 mln rub/year ($t_{air}=20 \, ^\circ C$) through the utilization of part of the condensation heat of the spent vapour in turbine.

Table 1. Results of calculations of economic efficiency due to the blast air preheating of the boiler BKZ-420-140 NGM in an air heating unit using circulating water.

| $t_{out,air}$, $t_{air,av.}$, $V_{air}$, $Q_{air}$, $G_w$, $E_{day}$, $t_{air,av.}$, $V_{air}$, $Q_{air}$, $G_w$, $E_{day}$, $t_{air,av.}$, $V_{air}$, $Q_{air}$, $G_w$, $E_{day}$, | $t_{air}''=15 \, ^\circ C$ | $t_{air}''=20 \, ^\circ C$ |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| $t_{out,air}$, $^\circ C$ | $t_{air,av.}$, $^\circ C$ | $V_{air}$, m$^3$/s | $Q_{air}$, kWt | $G_w$, kg/s | $E_{day}$, ths.rub/day | $t_{air,av.}$, $^\circ C$ | $V_{air}$, m$^3$/s | $Q_{air}$, kWt | $G_w$, kg/s | $E_{day}$, ths.rub/day | $t_{air,av.}$, $^\circ C$ | $V_{air}$, m$^3$/s | $Q_{air}$, kWt | $G_w$, kg/s | $E_{day}$, ths.rub/day |
| -25 | -5 | 105.06 | 5573.3 | 90.7 | 89.763 | -2.5 | 106.04 | 6264.56 | 101.95 | 100.896 |
| -20 | -2.5 | 106.04 | 4872.44 | 79.3 | 78.475 | 0 | 107.02 | 5562.75 | 90.53 | 89.593 |
| -15 | 0 | 107.02 | 4172.06 | 67.9 | 67.195 | 2.5 | 108 | 4866.39 | 79.2 | 78.377 |
| -5 | 5 | 108.98 | 2781.93 | 45.27 | 44.805 | 7.5 | 109.96 | 3475.53 | 56.56 | 55.976 |
| 0 | 7.5 | 109.96 | 2085.32 | 33.94 | 33.586 | 10 | 110.94 | 2780.68 | 45.25 | 44.785 |
| 3.8 | 9.4 | 110.7 | 1557.55 | 25.35 | 25.086 | 11.9 | 111.68 | 2252.83 | 36.66 | 36.284 |
| 8 | 11.5 | 111.53 | 973.71 | 15.85 | 15.682 | 14 | 112.51 | 1668.95 | 27.16 | 26.88 |

Thermal calculation of the air heating unit for the boiler BKZ-420-140 NGM was performed. The unit consists of two blocks. Each block is made of VNV type air heaters of the Kostroma heating plant.

Mass flux of gas or air $V$, kg/(m$^2$·s), is given by the formula:

$$V = G_{air} / (n_1 f_{air})$$

where $G_{air}$ – mass air flow rate, kg/s; $f_{air}$ – useful air flow area of one air heater, m$^2$; $n_1$ – the transverse number of air heaters relative to the air flow.

Air velocity $v_{air}$, m/s:

$$v_{air} = V / p_{air}$$
Water velocity in the heat exchanger tubes \( v_w \), m/s:

\[
v_w = \frac{G_w}{(\rho_w n_w f_w)},
\]

where \( \rho_w \) – the water density, kg/m\(^3\); \( n_w \) – the number of air heaters that receive circulating water after the steam turbine condenser; \( f_w \) – the cross-sectional area for the passage of water from one air heater, m\(^2\).

The heat transfer coefficient \( k \), Wt/(m\(^2\)·K), and aerodynamic resistance \( \Delta p_{air} \), Pa, of VNV type air heater:

\[
k = A \cdot V^n \cdot v_w^r.
\]
\[
\Delta p_{air} = B \cdot V^m.
\]

The values of coefficients \( A \) and \( B \), indicators of degrees \( n \), \( r \) and \( m \) are accepted according to the tables given in the materials for selecting air heaters and heat exchangers of the Kostroma heating plant.

The radiation surface \( F \), m\(^2\), of the unit:

\[
F = \frac{Q_{air}}{(k \Delta t_{av})},
\]

where \( \Delta t_{av} \) – the average temperature drop, °C, [7].

According to the results of variant calculations, it is found that it is advisable to perform an air heating installation from two blocks: each block consists of 12 air heaters of the VNV123-412-01ATZ type and has the following dimensions 3.5×4.73×0.36 m. The overall heat exchange surface of the unit – 4149.6 m\(^2\). The supporting pipe of the specified type air heater are made of corrosion-resistant steel. The heat carrier moves in the installation according to a cross-flow counter-flow scheme: the air flow is single-pass, the heating carrier is multi-pass (see figure 1).

![Figure 1. Scheme of the air heating unit.](image)

The heated air passes sequentially in the inter-tube space of two air heaters, and the circulating water with temperature \( t''_w \) enters the tubes of one of these air heaters, exits it and enters the second air heater, from which it exits with temperature \( t'_w \).

The hydraulic resistance \( \Delta p_w \), Pa, of the air heater:

\[
\Delta p_w = \frac{\rho_w v_w^2}{2} \left[ 2.7 \left( \frac{f_w}{f_b} \right)^2 + 6.7(n_s - 1) \left( \frac{f_w}{f_c} \right)^2 + 0.0121 \frac{n_s L}{d_{1.266}} + 0.6 n_s + 3.9 \right],
\]
where \( f_w, f_b, f_c \) – the cross-section area of one stroke, branch pipe and collector, respectively, \( m^2 \); \( n_s \) – the number of strokes of water; \( d \) – the inner diameter of the heat-liberating tube, \( m \); \( L \) – the length of the tube, \( m \).

For the VNV123-412-01ATZ type air heater: \( f_{air}=2.488 \, m^2 \); \( F_c=172.9 \, m^2 \); \( f_b=0.00546 \, m^2 \); \( f_b=0.00221 \, m^2 \); \( f_b=0.0022 \, m^2 \); \( L=1.655 \, m \); \( n_s=4 \); \( d=0.014 \, m \); \( A=25.5 \); \( n=0.496 \), \( r=0.16 \); \( B=8.63 \), \( m=1.833 \).

Increasing the power, \( \Delta N_{fan} \), kWt, of the blast fan:

\[
\Delta N_{fan} = 2\Delta p_{air} \frac{V_{air} \eta_{fan}}{1000},
\]

where \( \eta_{fan} \) – the fan efficiency; \( \eta_{fan} = 0.8 \).

The power of the additionally installed pump \( N_p \), kWt, for supplying circulating water to the air heating unit:

\[
N_p = 2\Delta p_w \frac{G_w}{1000\rho_w \eta_p},
\]

where \( \eta_p \) – the pump efficiency; \( \eta_p=0.85 \).

The results of calculations of the air heating unit at different loads of the steam boiler and at the temperature \( t_{out,air} \) equal to -25 °C, 0 °C and +3.8 °C are presented in Table 2.

### Table 2. Results of calculations of the air heating unit.

| Name of parameter | 210 (50%) | 252 (60%) | 336 (80%) | 420 (100%) |
|------------------|-----------|-----------|-----------|------------|
| Air flow rate \( G_{air} \), kg/s | 34.6 | 41.51 | 55.35 | 69.19 | 69.19 |
| Air flow rate \( V_{air} \), m³/s | 26.51 | 31.81 | 42.42 | 53.02 | 55.47 | 55.84 |
| Water flow rate \( G_w \), kg/s | 25.49 | 30.58 | 40.78 | 50.98 | 22.63 | 18.33 |
| Air temperature \( t_{out,air} \), °C | -25/20 | -25/20 | -25/20 | -25/20 | 0/20 | 3.8/20 |
| Water temperature \( t_w \), °C | 32.6/17.6 |
| Heat output, \( Q_{air} \), kWt | 1566.1 | 1879.3 | 2506.1 | 3132.3 | 1390.3 | 1126.4 |
| Air velocity \( u_{air} \), m/s | 1.78 | 2.13 | 2.84 | 3.55 | 3.71 | 3.74 |
| Water velocity \( u_w \), m/s | 0.781 | 0.936 | 1.249 | 1.561 | 0.693 | 0.561 |
| Mass flux of gas or air \( V \), kg/(m²·s) | 2.32 | 2.78 | 3.71 | 4.63 | 4.63 | 4.63 |
| Heat transfer coefficient \( k \), W/(m²·K) | 37.21 | 41.9 | 50.63 | 58.56 | 51.43 | 49.72 |
| Average temperature drop \( \Delta t_{air} \), °C | 23.89 | 23.89 | 23.89 | 23.89 | 14.15 | 12.8 |
| Air resistance \( \Delta p_{air} \), Pa | 80.72 | 112.45 | 190.85 | 286.45 | 286.45 | 286.45 |
| Hydraulic resistance \( \Delta p_w \), MPa | 0.1 | 0.144 | 0.256 | 0.399 | 0.079 | 0.052 |
| Increase fan power \( \Delta N_{fan} \), kWt | 2.675 | 4.471 | 10.12 | 18.984 | 19.862 | 19.994 |
| Pump power \( N_p \) kWt | 3.007 | 5.182 | 12.304 | 24.025 | 2.102 | 1.116 |

Analysis of the calculation results (see Table 2) shows that the following parameters decrease when the boiler load is reduced by 20% (\( t_{out,air} / t_{air}^{*} =-25/20 \, °C \)): \( \Delta p_{air} \) by 33.4% (from 286.45 to 190.85 Pa), \( \Delta p_w \) by 35.8% (from 0.399 to 0.256 MPa), \( \Delta N_{fan} \) by 46.7% (from 18.984 to 10.12 kWt), \( N_p \) by 48.8% (from 48.05 to 24.608 kWt). When the boiler load is reduced by 50%, the same unit parameters are reduced by 71.8% (from 286.45 to 80.72 Pa), 74.9% (from 0.399 to 0.1 MPa), 85.9% (from 18.984 to 2.675 kWt) and 87.5% (from 48.05 to 6.014 kWt), respectively. In addition, when the \( t_{out,air} \) increases, the hydraulic resistance of the unit decreases due to a decrease in the flow of heat carrier. For example, when the rated load of the boiler increases the temperature from -25 °C to + 3.8 °C leads to a decrease in: \( Q_{air} \) by 64% (from 6264.6 to 2252.82 kWt), \( \Delta p_w \) by 87% (from 0.399 to 0.052 MPa) and \( N_p \) by 95.4% (from 48.05 to 2.232 kWt).

Power consumed by the electric motor from the network:

\[
N_n = k_N / \eta_c.
\]
Where $k_s$ – safety factor, $k_s=1.1$ [8]; $\eta_e$ – the efficiency of the motor, $\eta_e=0.9$ [4].

3. Results and Discussions

Thus, the total power consumed by the electric motors of the blast fans and the pump at $t_{\text{out,air}}=+3.8^\circ\text{C}$ is $42.22\cdot 1.1/0.9 = 51.6$ kWt. Therefore, the annual cost of additional electricity consumption at its cost of 1.8 rub/(kWt·h) is on average equal to 813.628 ths.rub/year. The cost of one VNV123-412-01ATZ type heater is 118000 rubles with VAT without transport costs. Therefore, the cost of 24 air heaters is equal to 2 mln 832 ths.rub. The cost of delivery and installation work of heat exchangers will take 60% of their cost. In this case, the total capital investment will amount to 4 mln 531.2 ths.rub.

Considering that the economic efficiency is equal to 13.244 mln rub/year due to the boiler's blast air preheating to 20 °C using circulating water, the payback period for these costs will be less than one year.

4. Conclusions

1. Economic efficiency due to preheating of the blast air of one boiler BKZ-420-140 NGM of the Samara CHP with circulating water heated in the steam turbine condenser will average 9.156 mln rub/year and 13.244 mln rub/year, respectively, when the blast air is heated to 15 °C and up to 20 °C.

2. Verification and constructive thermal calculations of the installation for preheating the blast air of the BKZ-420-140 NGM steam boiler were performed, in which circulating water heated in the steam turbine condenser is the heating coolant. The main thermotechnical indicators of the operation of the installation are determined at different boiler loads and outdoor temperatures. It has been established that the payback period for the costs of its implementation is less than one year.

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