Increase of efficiency of heat sources work due to application of condensation economizers on an example of a boiler PTVM-180

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Abstract. In this article, a method is considered to increase the efficiency of boiler room operation with PTVM-180 boilers by the use of a flue gas flue in a condensing economizer. The efficiency evaluation of the utilization of the heat exchanger in accordance with the operating mode of the boiler house was evaluated, and the technical and economic parameters of the project were assessed, depending on the unplanned changes in such key factors as capital costs, operating time, operating mode.

The economy of fuel burned in boiler units is an urgent task when solving the problem of reducing the cost of produced heat energy.

At present, one of the ways to increase the efficiency of boiler houses is the use of deep utilization of the heat of flue gases using condensing economizers.

As an object for the introduction of condensation technology, the boiler house of Kazan is being considered. On the boiler-house are installed water-heating boilers of the type PTVM-180 in the amount of 2 pcs. In the summer period the boiler-house does not work.

The main indicators of the boiler house are presented in Table. 1.

| Table 1 Main indicators of boiler plant operation. |
|-----------------------------------------------|
| Indicator | Output, Gcal | Operating time, h | Average load, Gcal/h | Excess air, α | Number of combustion air for α> 1, nm³/h | Gas consumption, nm³/h | General |
|-----------|--------------|-----------------|-------------------|-------------|---------------------------------|------------------|---------|
|           | BK-1 | BK-2 | BK-1 | BK-2 | BK-1 | BK-2 | BK-1 | BK-2 | BK-1 | BK-2 | BK-1 | BK-2 | Gene  |
| January   |     94  | 79   | 542  |    728 | 740 | 129,2 | 107,4 |  9 | 1,24 | 1,14 | 154  | 119701 | 12 | 10 | 22 | 920 |
| February  |     90  | 71   | 188  |    672 | 672 | 135,0 | 105,9 |  3 | 1,23 | 1,14 | 144  | 105216 | 11 | 769 | 20 | 998 |
| March     |     80  | 60   | 969  |    744 | 744 | 108,7 | 81,95 |  6 | 1,27 | 1,18 | 130  | 91536  | 10 | 296 | 18 | 053 |
| April     |     65  | 60   | 490  |    704 | 720 | 92,52 | 84,01 |  9 | 1,28 | 1,17 | 103  | 88203  | 8  | 117 | 7  | 538 |

The value of the capital cost was 129,2 Gcal. The operating time is 728 h. The average load is 129.2 Gcal/h. The excess air is 1.24. The number of combustion air for excess air α> 1 is 154 nm³/h. The gas consumption is 119701 nm³/h.

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| Indicator | Output, Gcal | Operating time, h | Average load, Gcal / h | Excess air, α | Number of combustion air for α > 1, nm³/h | Gas consumption, nm³/h |
|-----------|--------------|-----------------|------------------------|--------------|------------------------------------------|-----------------------|
|           | BK-1         | BK-2            | BK-1                   | BK-2         | BK-1                                     | BK-2                  |
| May       | -            | 14 671          | 106                    | 138.4 1      | -                                        | 18 995               | - 1 681               | 1 681                 |
| Jun       | -            | -               | -                      | -            | -                                        | -                    | -                    | -                     |
| Jul       | -            | -               | -                      | -            | -                                        | -                    | -                    | -                     |
| Aug       | -            | -               | -                      | -            | -                                        | -                    | -                    | -                     |
| Sept      | -            | 21 133          | - 263                  | 80.35        | - 1.19                                   | - 180 92.8           | - 15 204             | 15 204                |
| Octr      | 43 446       | 76 591          | 443                    | 745          | 98.07                                    | 102.8 1              | 1.18                 | 1.16                  |
| Nov       | 70 093       | 76 294          | 220                    | 720          | 97.35                                    | 105.9 6              | 1.18                 | 1.16                  |
| Dec       | 79 631       | 87 320          | 744                    | 744          | 107.0 3                                  | 117.3 7              | 1.18                 | 1.15                  |

The installation of condensing economizers on boilers allows to solve such tasks as deep cooling of exhaust gases, thereby reducing thermal pollution of the environment, and also to increase fuel efficiency. The utilized heat energy can be used to heat raw water, preheat the return network water before entering the hot water boiler.

In the condensation economizer, the combustion products are deeply cooled to a temperature at which the maximum possible part of the water vapor contained in the gases can be condensed and the latent heat of condensation can be used. In addition, deep cooling of gases allows fuller use of their physical heat [1].

The heat exchanger is installed behind the smoke exhausters of the PTVM-180 boilers through new flues, some gases (about 25%) are taken from the common flue, pass through the heat exchanger, cool and return to the common flue.

Smoke gases after the heat exchanger have a temperature of 50°C and, when mixed with the main stream, are heated, thereby preventing the condensation of water vapor in the common flue. The heat exchanger and part of the flue after it are made of stainless steel to prevent low-temperature corrosion. The newly installed equipment will create additional aerodynamic resistance. The increase in resistance in the heat exchanger is partially compensated by the decrease in the volume of flue gases after the heat exchanger, which occurs due to a decrease in their temperature, condensation and removal of a part of the water vapor, which will eliminate the need to replace the operating smoke exhausters.

The condensate formed in the body of the utilizor is desalted water. The presence of weakly basic carbonic acid in the condensate (CO₂ binding with water) gives pH- 3.5. Condensate is removed from the body of the utilizor by gravity into a special tank through the body of the heat exchanger, equipped with a hydraulic seal. Further from the tank through the calciner the condensate pump is fed to the chemical water treatment.

The value of "dewpoint" of combustion products depends on the amount of excess air, which can be determined from the graph shown in Fig. 1.
The amount of moisture condensing during the cooling of flue gases also depends on the value of the excess air factor and can be determined from the graph shown in Fig. 2.

![Fig. 1 Dependence of the "dew point" of natural gas combustion products on the excess air factor](image1)

**Fig. 1.** Dependence of the "dew point" of natural gas combustion products on the excess air factor

The amount of heat that is utilized in the condensation economizer is the sum of the physical heat of the flue gases and the latent heat of condensation of the water vapor. The amount of heat can be determined from equation (1).

\[
0.9 \cdot \Sigma Q_{ke} = (G_{dg} \cdot c_p \cdot (t_{dg1} - t_{dg2}) + (G_{vp} \cdot r_{vp})/4186) \text{ Gcal/h}
\]  

(1)

Where \(G_{dg}\) – flue gas consumption, nm³/h; \(c_p\) – averaged heat capacity of flue gases, kJ/kg•°C; \(t_{dg1}\) – flue gas temperature at the condenser economizer inlet, °C; \(t_{dg2}\) – flue gas temperature at the outlet of the condensing economizer, °C; \(G_{vp}\) – the amount of condensing water vapor in the economizer, kg/h; \(r_{vp}\) – latent heat of condensation of water vapor, kJ/kg; 0.9 – efficiency of condensing economizer; 4,186 – the conversion factor from kJ to kcal.

It is proposed to use a condensation economizer to preheat make-up water [3].

The make-up temperature is assumed at 40 °C in connection with the technological requirements of HVO. The heating temperature of the feed in the heat exchanger is regulated by the flow rate of the flue gases.

The amount of condensate formed during the operation of the utilizor for the period October-April is determined by the expression (2):
The amount of thermal energy contained in the resulting condensate formed when the part of the boiler gas is cooled is determined by the formula (3):

\[ Q_{km}^{\text{un}} = \left( (t_g - t_{\text{vl}}) \cdot G_{\text{vp}} \cdot 1000 \right) \cdot \tau \]  

(3)

The results of the calculation are given in Table 3.

The consumption of flue gases is determined by formula (4):

\[ G_{dg} = B \cdot K_1 + K_2 \cdot Q_i + ( -1 ) \cdot ( k_3 + K_4 \cdot Q_i ) \cdot ( 273 + t_p ) / 273 \]  

(4)

where

- \( B \) – second consumption of natural fuel, kg/s (nm\(^3\)/s);
- \( K_1, K_2, K_3, K_4 \) – numerical coefficients selected for each type of fuel by the least squares method; \( K_1 = -0.739 \) for natural gas; \( K_2 = 0.278 \) for natural gas; \( K_3 = 0.0864 \) for natural gas; \( K_4 = 0.267 \) for natural gas;
- \( Q_i \) – lower heat of combustion of fuel MJ / nm\(^3\);
- \( \alpha \) - coefficient of excess air;
- \( t_p \) – flue gas temperature.

The amount of moisture formed during condensation is determined by formula (5) and nomogram (Fig. 2).

\[ G_{\text{vp}} = \frac{d_{\text{vp}} \cdot \rho_{dg} \cdot G_{dg}}{1000} \text{ kg/h} \]  

(5)

where

- \( d_{\text{vp}} \) – moisture content of flue gases (determined from the nomogram of Fig. 2), g / kg;
- \( \rho_{dg} \) – averaged density of flue gases (in the temperature range 50-145 \(^\circ\)C), kg / m\(^3\);

It is intended to use a condensing economizer to preheat the return network water before feeding it to the hot water boiler.

The temperature of the return network water at the outlet of the condensing economizer is determined by formula (6).

\[ t_{2a} = t_{1a} + \frac{\sum Q_o}{( G_{2a} - G_{2a} \cdot 1000 ) / 1000000} \]  

(6)

where

- \( t_{1a} \) – return water temperature at the condenser economizer inlet, \(^\circ\)C;
- \( G_a \) – return water flow rate, t / h;
- \( c_w \) – heat capacity of water, kcal / kg \(^\circ\)C;
- \( 1000 \) – density of water, kg / m\(^3\);
- \( 1000000 \) – transfer to Gcal.

The amount of heat received in the economizer is determined by the equation (7):

\[ Q_{\tau} = \frac{G_{2a} \cdot ( t_{2a} - t_{1a} ) \cdot \tau}{1000} \text{ Gcal} \]  

(7)

where \( \tau \) - operating time of the boiler within a month, hour.

Further, an increase in the production of thermal energy is determined, the values of which are given in Table 2.

**Table 2.** The results of calculating the amount of thermal energy that is utilized in the condensation economizer [2].

| Period   | Water temperature at the heat recovery, \(^\circ\)C | The water temperature at the output of the heat recovery boiler, \(^\circ\)C | Amount of heat, Gcal | Increase in output, % |
|----------|-----------------------------------------------|-------------------------------------------------|---------------------|----------------------|
| October  | 50                                            | 40                                              | 295.65              | 0.29                 |
| Period  | Water temperature at the heat recovery, °C | The water temperature at the output of the heat recovery boiler, °C | Amount of heat, Gcal | Increase in output, % |
|---------|--------------------------------------------|---------------------------------------------------------------|----------------------|-----------------------|
| November| 48,41                                      | 40                                                           | 1 066,69             | 0,74                  |
| December| 50,81                                      | 40                                                           | 1 169,47             | 0,65                  |
| January | 48,57                                      | 40                                                           | 1 175,58             | 1,33                  |
| February| 44,34                                      | 40                                                           | 1 102,59             | 0,84                  |
| March   | 39,8                                       | 40                                                           | 1 181,69             | 0,9                   |
| April   | 40,63                                      | 40                                                           | 892,89               | 1,14                  |
| Total   |                                            |                                                               | 6884,55              | 0,84 (average.)       |

Table 3. The results of calculating the thermal energy of the condensate formed in the utilizer.

| Period  | Amount of heat, Gcal |
|---------|----------------------|
| October | 27,30                |
| November| 90,68                |
| December| 97,73                |
| January | 98,95                |
| February| 92,73                |
| March   | 95,45                |
| April   | 72,94                |
| Total   | 575,78               |

To assess the natural draft of the chimney in the conditions of reducing the temperature of the flue gases, an aerodynamic calculation of the chimney was performed, taking into account the work of the condensing heat exchanger. Calculations showed that with the introduction of heat recovery, the natural draft of the existing chimney will have a reserve of 7.29 mm.vod.st.

**Conclusion**

As a result of the conducted studies, the introduction of a condensing heat recovery unit for flue gas at the boiler house with PTVM-180 boilers will reduce the cost of heating raw water, as well as reduce the amount of feed-through due to the beneficial use of condensate formed during deep cooling of a part of the flue gases. A simple payback period for the introduction of a condensing economizer will be 5.76 years with a capital expenditure of 17,849,724 rubles. The economic effect will amount to 3,096,651 rubles.

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