Increasing the efficiency of energy generation at Krasnoyarsk CHP-2 by utilization of waste heat

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Abstract. The relevance of the work is due to the implementation of the Federal law "on energy saving and energy efficiency and on amendments to certain legislative acts of the Russian Federation" and is aimed at reducing environmental pollution from the production of electricity and heat at the CHP. The aim of the work is to increase the energy efficiency of electric energy generation by upgrading the coal thermal power plant, reducing environmental pollution from the enterprise by reducing the amount of fuel burned at the same capacity. Research methods are Analysis of existing technologies for utilization of low-potential thermal energy in the energy sector; Thermal, technical and economic analysis of technologies that allow converting low potential thermal energy into electrical energy; Simulation of installation parameters based on the organic Rankine cycle using the Smoweb software package; Analysis of modern manufacturers of organic Rankine cycle technology in order to select the most suitable. Results are a comparative analysis of existing technologies for utilization of low-potential heat energy was carried out and the most effective option for energy efficiency was chosen. Heat and techno-economic analysis of the application of technologies to convert low-grade thermal energy into electrical energy was performed; modeling installation using the principle of organic Rankine cycle utilizing heat energy from the boiler BKZ-420-140-PT1 was designed

1. Choice of heat recovery technology

The rapid growth of electricity needs in the XXI century, the crisis state of the environment, technological problems that need to be addressed to meet these needs, based on modern criteria for a sharp increase in energy efficiency, reducing costs and minimizing the impact on the environment, require a significant expansion of research and development in the power industry. Research, design and development activities in the heat power industry should be aimed at the creation of highly efficient and environmentally friendly thermal power plants using advanced technologies and power equipment, providing solutions to the following tasks: improving the efficiency of energy supply by increasing its reliability and reducing the cost of electricity production; maximum reduction of harmful emissions of thermal power plants into the environment; increasing productivity and improving working conditions; reducing the cost of repair and restoration work.

At present, the issue of reducing environmental pollution from enterprises is acute in the city of Krasnoyarsk. The city is located in Siberia where the temperature varies from -40 °C to +40 °C, so the rejection of the existing source of generation of thermal power plants is impossible. Reduction of the environmental impact of CHP is possible by reducing the amount of fuel burned, by improving the efficiency of production of electricity and heat by the utilization of heat of the exhaust gases.
Currently, there are four widely distributed technologies to obtain electric energy from low-grade heat:

- Stirling engine
- Organic Rankine cycle
- Rankine Microcycle
- Thermoelectric converter

As noted in [1] (figure 1) Stirling Engine has a high efficiency and has found its application in industrial samples at temperatures 650-800 °C and above, but it is not applicable for such source of heat as mains water which temperature is about 95 °C. The Rankine microcycle is effective only in the joint production of heat and electricity, which is not required for this task. Thermoelectric converters have low efficiency below 5%.

![Figure 1. Analysis of technologies for converting thermal energy into low power electrical energy.](image)

As it is shown in figure 1 and noted by the authors [2-7] the most suitable and mature technology for the utilization of low-potential thermal energy is the organic Rankine cycle (ORC).

2. Inclusion of the installation of organic Rankine cycle in the technological scheme

Recycling the exhaust gases heat by lowering its temperature below the dew point temperature is called deep utilization. There are two types of ORC installations, the classical Rankine cycle and the regenerative one with the addition of a heat exchanger transferring heat from steam after the turbine to the condensate after the condenser. Given the above, there are four options for including the ORC installation for heat recovery of exhaust gases from the boiler and four options for including the ORC installation that converts low potential thermal energy from hot water (steam) into electricity:

- Deep utilization with ORC without regeneration
- Deep utilization with regenerative ORC
- Utilization with ORC without regeneration
- Utilization with regenerative ORC
- Conversion of thermal energy of mains water into electric ORC without regeneration
- Conversion of thermal energy of mains water into electrical energy with regenerative ORC
- Conversion of thermal energy of steam withdrawn from turbine into electrical energy without regeneration ORC
- Conversion of thermal energy of steam withdrawn from turbine into electrical energy with regenerative ORC
3. Assessment of the technical and economic effect of the implementation of recycling

The valuation of the main equipment is divided into:

- Assessment of the cost of heat exchanger for heat utilization (steel gas-air or glass gas-water exchangers)
- Evaluation of the cost of the heater (steel air-water in the schemes with the utilization of the heat of gases to a temperature above the dew point)
- Estimate cost of installation of the ORC with screw expander

Assessment of the cost of heat exchangers was taken from the online calculator of the cost of heat exchangers with a dollar exchange rate relevant for 2014.

Estimation of the cost of the ORC module was taken from the price list of the company “infinity turbine Ukraine”. The estimation of specific investments was carried out with the help of regressive analysis of cost, $ / kW:

Technical and economic analysis of the implementation of ORC units at the Krasnoyarsk CHP-2 is presented in table 1 and table 2

**Table 1.** The main technical and economic indicators of heat utilization of exhaust gases from the boiler of BKZ-420-140-PT1.

| Parameter                                      | Utilization with ORC without regeneration | Utilization with ORC with regenerative ORC | Deep utilization with ORC without regeneration | Deep utilization with ORC with regenerative ORC |
|------------------------------------------------|------------------------------------------|-------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Gas temperature, °C                            | 145                                      | 145                                       | 145                                           | 145                                           |
| The temperature of the cooled gases, °C        | 120                                      | 120                                       | 80                                            | 80                                            |
| Heat recovery, kW                              | 9000                                     | 9000                                      | 14000                                         | 14000                                         |
| Efficiency of ORC, %                           | 10,006                                   | 10,357                                    | 10,006                                        | 10,357                                        |
| ORC electric power, kW                         | 847,124                                  | 877,339                                   | 1372,08                                       | 1421,02                                       |
| The R142b flow rate, kg/s                      | 34,132                                   | 35,349                                    | 54,178                                        | 56,110                                        |
| The cost of the ORC, $                         | 1149013                                  | 1189444                                   | 1851459                                       | 1916946                                       |
| The price of the heat exchanger for utilization, $ | 126600                                  | 126600                                    | 510900                                        | 510900                                        |
| The price of the heater, $                      | 124300                                   | 124300                                    | 70872                                         | 72837                                         |
| Capital investments, mln. RUB.                 | 41,997                                   | 43,210                                    | 70,872                                        | 72,837                                        |
| Operating Costs, mln. RUB./year                | 13,199                                   | 13,442                                    | 18,974                                        | 19,367                                        |
| Cost of energy production, RUB/(kW·h)          | 1,94                                     | 1,94                                      | 1,94                                          | 1,94                                          |
| Income of electricity mln. RUB./year           | 5,572                                    | 5,999                                     | 8,025                                         | 8,025                                         |
| Payback period, years                          | 6                                       | 6                                        | 7                                             | 7                                             |
| Savings, t.t./year                             | 2371,94                                  | 2456,55                                   | 3411,54                                       | 3533,22                                       |

**Table 2.** The main technical and economic indicators of heat conversion of the steam withdrawn from T-110/120-130 turbine.

| Parameter                                      | Conversion of thermal energy of mains water into electric ORC without regeneration | Conversion of thermal energy of mains water into electrical energy with regenerative ORC | Conversion of thermal energy of steam withdrawn from turbine into electrical energy without regeneration ORC | Conversion of thermal energy of steam withdrawn from turbine into electrical energy with regenerative ORC |
|------------------------------------------------|---------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|
| Water (steam) inlet temperature, °C           | 120                                                                             | (140)                                                                   | (110)                                                                                                  | (110)                                                                                                  |
| Water (steam) temperature                     | 70                                                                              | 70                                                                     | (110)                                                                                                  | (110)                                                                                                 |


|                         | output, °C | Heat power, Gcal / kg | Efficiency of ORC, % | ORC electric power, kW | Capital investments, mln. RUB. | Operating Costs, mln. RUB. / year | Cost of energy production, RUB/(kW∙h) |
|-------------------------|------------|-----------------------|----------------------|------------------------|----------------------------------|-----------------------------------|--------------------------------------|
|                         | 750        | 750                   | 10,006               | 19946,6                | 801,182                          | 919,536                           | 7,53                                 |
|                         | 750        | 750                   | 10,3573              | 20658,1                | 828,744                          | 925,248                           | 7,31                                 |
|                         | 765        | 765                   | 11,4815              | 23336,7                | 943,502                          | 948,000                           | 6,63                                 |
|                         | 765        | 765                   | 11,9854              | 24393,3                | 985,917                          | 956,483                           | 6,41                                 |

4. Results

Deep utilization allows you to remove more heat from the exhaust gases due to condensation of water vapor, but at the same time there is a sulfur oxide in the outgoing gases which, when water vapor is being condensed, react with water forming sulfuric acid, which leads to sulfuric acid corrosion. This problem can be solved by using a glass heat exchanger. The scheme with gas-air utilization is devoid of this lack.

The addition of a regenerative heat exchanger increases the cost of installation, but allows increasing the efficiency of the ORC by reducing heat losses in the condenser. The efficiency of the regenerative heat exchanger depends on the freon used and the efficiency of the turbine.

The inclusion of an ORC using mains water as a heat source allows the production of electrical energy from heat. With this setup, the coefficient of use of thermal turbines increases, and as a result, the cost of production of electric energy is reduced and the reliability of operation is improved. The supply of steam withdrawn from turbine to the ORC as a source of heat will increase the degree of overheating of freon and energy unit efficiency, but will entail an increase in capital costs for individual heat exchangers and a system for regulating the distribution of steam between the network heaters and the ORC.

References

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