Modernization of technological equipment in the waste water purification process behind the coke oven using the organic Rankine cycle

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Abstract. The authors analyzed the state of the process scheme, which is a structural part of the water supply treatment facilities. The research results can be applied in oil and gas, chemical, metallurgical and energy industries. In particular, the authors for the first time propose an efficient scheme for the reuse of heat to obtain purified water. Currently, a way to reduce energy consumption by introducing a plant based on an organic Rankine cycle has been considered. The metallurgical production has such equipment as converters, coke ovens, scrubbers, gas ducts, cooling boilers, waste heat boilers. The heat recovery schemes developed by the authors increase the efficiency of the process equipment in the metallurgical industry. In the work of enterprises, low-potential heat of soil, water, air is increasingly used. One of the main directions of energy saving to increase the energy efficiency of the boiler house is to increase the heat utilization rate of the fuel at power plants. Boiler houses that run on gas lose at least 13-18% of heat with flue gases. In the article, the authors propose to combine the methods of heat utilization. Namely, a contact heat exchanger and an organic Rankine cycle are used. The water temperature is significantly reduced due to the fact that the collectors are designed to transport water. In this regard, experts consider it expedient to utilize the heat of wastewater not only at treatment plants, but also directly in the building itself. Prospects for the use of the authors' developments are associated with their further implementation at industrial enterprises of the metallurgical industry.

1. Introduction

The amount of sewage produced in huge quantities by large cities remains virtually unchanged throughout the year. The wastewater temperature is lower than the outdoor temperature in summer and higher in winter. This makes them an ideal source of low grade heat for use in heat pumps. Various devices for the utilization of waste water heat have been developed and used for about 30 years [1, 2]. The most common system is the use of heat pumps installed in waste water treatment plants. Such systems centrally collect waste water heat, which saves a lot of energy. At the same time, energy efficiency experts say that a significant amount of wastewater heat energy literally goes into the ground. Thus, the authors will need to develop methodological approaches to carry out the exergy method of thermodynamic analysis based on new methods for approximating piecewise linear functions. In addition, it is proposed to use this method not only to optimize exergy losses, but also to analyze the
flow energy, since any type of energy, according to the fundamental foundations of physics, consists of exergy and anergy.

2. Materials and methods
The top-level program with elements of artificial intelligence incorporated into the control system to optimize the operation of the power plant is adaptive and trainable. When first switched on, the program must test the sensor system of the power plant. After stabilization of the power plant operating mode, the self-learning system records the sensor readings. This procedure must subsequently be repeated under different operating conditions to build the power curve. Moreover, between these measurements, the installation can already operate in a certain safe test mode, but not with full power. During operation, the parameters of the power plant may change slightly, therefore, the described iterations for adjusting the characteristics can be repeated periodically. As a result of constructing the desired graph, the control system has all the data and, taking this into account, builds the load characteristics of the generator. These dependencies will be studied in detail during the project. An alternative to calculating the graph in this way can be the manufacturer's standard load curves. In order to reduce the cost of electricity and heat energy, much attention is paid to inexpensive, low-cost technologies that can be put into operation in a short time. Basically that means technologies for increasing the efficiency of boiler plants using secondary energy resources [3, 4]. The overwhelming majority of treatment facilities are in need of reconstruction or repair. At the same time, it is impossible to use standard solutions that are implemented during design. Reconstruction is a process that requires atypical tasks to improve the energy and economic performance of sewerage systems [5, 6]. The balance of the enterprise may include about 400 pumping stations, more than 3000 km of water supply networks. In addition, control over water quality is carried out by specialists in laboratories. Several thousand people work around the clock so that the inhabitants of megacities receive high-quality water. Mechanical treatment facilities do not meet the requirements for such facilities at the present time [7, 8]. Due to the wear of the mechanical cleaning grate and the sand catcher, the quality of water treatment is not ensured. It should be noted that it is often necessary to replace the system for removing sediment accumulating at the bottom of the plant. Compaction and flushing of the waste can seldom be missing. Biological treatment facilities may not have equipment to remove phosphorus and nitrogen compounds from wastewater. Thus, the goal of the modernization of treatment facilities is not only to improve the quality of water purification to standardized requirements, but also to reduce energy consumption [9, 10].

3. Results
The tasks of efficient use of energy resources, reduction of heat losses in industrial and domestic economy are becoming more and more urgent. The rise in prices for energy resources is forcing the use of low-potential energy sources, the heat of which is emitted into the environment. Domestic waste water is one such source. After passing through the purification system, the water is discharged back into the purified water channel and the cycle is closed. Waste heat from water treatment plants is low-grade. Utilization of this heat into useful work is necessary to improve the energy efficiency of the treatment facilities. The solution to this problem contributes to the development of decentralized energy. There are various thermodynamic cycles for converting low grade thermal energy. Increasingly, the organic Rankine cycle is used using an alternative working fluid, the boiling point of which is significantly lower than the boiling point of water. In the installation scheme, based on the organic Rankine cycle, sewage purified water is used as a low-grade heat source (figure 2). In a heat exchanger, water transfers its heat to the working fluid. Reaching the saturation temperature, the refrigerant boils and in a state of vapor enters the piston expander, where in the cylinder when the piston moves, it expands, and the thermal energy goes into the mechanical work of the rotation of the rotor of the electric generator. After the expander, the working fluid is fed into the condenser, where it is cooled by the flow water and condenses. In the liquefied state, the refrigerant is fed back to the heat exchanger by pump, driven by the engine. The electricity generated by the rotation of the rotor of an
electric generator can be used for the company’s own needs. Heaters made in the form of perforated rings can be installed in fuel oil tanks in the area where the suction pipes of fuel pumps are connected to them. Calculations and accumulated operational experience show that with the correct application of the technology under consideration, the possibility of excessive watering of fuel oil or accumulation of water in fuel oil tanks is excluded. This solution is much easier to implement in boiler plants, however, the economic and environmental effect of its use is practically the same as when using the previous method. The most effective technology provides for the use of blow down water simultaneously for heating and transporting fuel oil from the fuel oil facility to the boiler using jet pumps. It is recommended to use blow down water, which ensures complete utilization of its heat and mass. This invention provides for the complete mixing of blow down water with steam used in production processes, which include steaming of reinforced concrete products, contact heating of raw materials, fuel, that is, processes for which the presence of a certain amount of mineral salts in the steam is not essential. In low pressure boilers with steam superheating, blow down water can be supplied to the live steam pipeline supplied to the consumer. In boilers of medium and high pressure, it is advisable to introduce the blow down water into the bleed-off steam pipeline of the turbines or use it as a cooling medium in reduction-cooling plants.

Figure 1. The process scheme using the conacting heat exchanger: 1 – gases; 2 – gas fan; 3 – electric drive; 4 – valve; 5 – gas duct; 6 – water tank; 7 – water input; 8 – gas out

Figure 2. The process scheme using ORC: 1 – electric drive; 2 – pump; 3 – detander; 4 – electric generator; 5 – electric cable; 6 – heat exchanger; 7 – water line

The advantage of the Rankine cycle over the Sterling, Brighton and Kalina cycles is the ability to adapt to various sources of thermal energy, low cost equipment and ease of implementation. In addition, this system can operate in a binary cycle in both high-temperature and low-temperature areas. Industrial plants release a large amount of thermal energy into the environment along with the flow of combustion products and heat carrier at a relatively low temperature. This circumstance often has an extremely adverse effect on the environment, polluting it and leading to climate change. In addition, the cost of the energy released is ultimately determined by the cost of production. Accordingly, the proposed method can be adapted for any control system of a power plant of any capacity, with any generator, with any control system. Moreover, the algorithm can also work with the corresponding power take-off control, which also has to be simulated in the project and tested on real
power plants. Thus, the proposed methods and approaches make it possible to successfully solve the assigned tasks and carry out the project at a level significantly exceeding the world level.

4. Discussion

Similar methods of heat recovery were used for the prospect of further increasing the energy efficiency of a thermal power plant based on a contact heat exchanger with an active packing. This heat exchanger is planned to be installed behind the KVG-58.2-150 hot water boiler. This will allow reducing the cost of heat production. The use of contact heat exchangers is one of the most effective ways to save metals and other scarce materials, reduce capital and operating costs, and improve equipment reliability [11, 12]. Water heated to 40 degrees Celsius in a contact heat exchanger can be used for hot water supply in a private school. Here, with the help of heating elements, the water will be heated to 65-70 degrees Celsius. The school also plans to build a swimming pool. The heated water in heat exchanger can be used in this case as well. It should be noted that the school is located at a short distance from the boiler room, which is one of the conditions for using a contact heat exchanger. A contact heat exchanger with an active nozzle is a recuperative-mixing type device, it is designed to utilize the heat of flue gases and to heat water for various needs in the temperature range from 5 to 50 degrees Celsius [13, 14]. It consists of a body made of sheet steel, forming a chamber with an irrigation system, an active nozzle made in the form of a bundle of pipes with a coolant circulating in them, and a separation device. Simultaneously with the heat exchange processes in heat exchanger, figure 1, the utilized gases are cleaned from mechanical impurities of incomplete fuel combustion. Mechanical impurities are captured by the scrubbing liquid [15, 16]. Selective purification from gaseous components can be carried out depending on the composition of the scrubbing liquid [17, 18].

5. Conclusion

As noted in [12], if a CHP plant uses only 37% of the fuel energy, this means that 63% of this energy is lost forever. Therefore, in recent years, great efforts have been made to utilize thermal waste from industrial enterprises with the possibility of generating electricity. Numerous studies show that there are quite a few industrial enterprises with unused reserves of thermal energy. For example, cement production is very energy intensive. This sector of the economy accounts for 12-15% of the total energy consumed by industry, while up to 15% of fuel energy is dissipated into the environment. The temperature of the combustion products at the outlet of a gas turbine usually exceeds 400 °C, the petrochemical industry emits gases with a temperature of 150-300 °C. In this case, the ORC unit also provides the opportunity to use the remaining thermal energy, however, disposal of these reserves, as a rule, is a challenging task [19, 20]. The planned result is new knowledge about the formation of an exergy method for analyzing economic analysis in order to optimize the operation of a power plant for desalination of water based on the study of applicable hydrodynamic, mechanical, heat and mass transfer and management laws. Scientific significance lies in obtaining new knowledge that is essential and important for world science [21, 22]. The applied significance lies in the use of this knowledge to create a computer model of a power plant.

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