Results of development of the test prototype of a thermoelectric converter

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Abstract. Earlier studies have confirmed the reasonability of using thermoelectric converter (TEC) for heat recovery of electrolytic gases. The use of process flow diagram, which consists of a heat exchange unit along with thermoelectric converters is an innovative technology and will allow to increase the energy efficiency of production and achieve economic advantages of the aluminium production process.

1. Introduction

One of the ways to increase the energy efficiency of production is the recovery and return of thermal energy, carried away by process gases into the system of gas exhaust, into the technological process [1, 2, 3, 4].

So, for example, with anodic gases, removed to the system of gas cleaning plants (GCP), up to 12.5% of heat is carried away from electrolyzers with burned anodes [5].

Previous studies, presented in [6, 7, 8], confirmed the efficiency of using a shell-and-tube heat exchanger for cooling gases with a heat-transfer fluid.

As a result of working out the design features of the heat exchanger, it was determined that it is expedient to use a thermoelectric conversion device (TCD) to recover thermal energy. Herewith, the efficiency of the use of heat exchangers should be evaluated from the standpoint of capital and operating expenditure [9, 10].

2. Development of the thermoelectric converter

The developed thermoelectric converter (TEC) is a semiconductor oscillator that generates electric current due to the temperature difference on its opposite surfaces. The basis for the calculations was the calculated model for the distribution of temperatures on the surface of the adapter sleeve of the heat exchanger in the ANSYS application program package, developed by the specialists of the INRTU [1].

Inside the TEC, there is a number of thermoelectric modules, whose operation is based on the Seebeck effect, the essence of which is the appearance of an electromotive force due to the appearance of a potential difference in a chain of heterogeneous semiconductor materials when a temperature gradient is created.

One side of the TEC (heat sink) is made in the form of a flat heat-conducting surface, which is fixed on the hot plane of the system with a coolant (gas, liquid). The second side of the TEC (radiator) is a cooling module into which a cooling liquid is supplied under pressure.

General view of the thermoelectric converter is shown in figure 1.
Figure 1. General view of the TEC for the section of the gas inlet duct into the gas cooling system.

The structure of one TEC includes 12 thermoelectric modules, which are mounted on a heat-removable plate (heat sink) by fixing on the silicon-organic paste КПТ-8 and pressing the cooling radiator with a mounting corner with bolts that can monitor the tightening torque.

Electrical connection of thermoelectric modules to each other can be carried out in parallel, in series or in parallel-series in the switching unit, depending on the required output parameters.

The switching unit with overall dimensions: 250x20x40 mm is located on the lateral side of the cooling radiator and serves to accommodate the connections of the input contacts of thermoelectric modules and the output terminals to connect the power consumption devices, or for further connection with switching units of other TECs (in case the system consists of several TECs).

The switching unit has a removable cover on 4 bolted connections to protect from moisture ingress, short circuit, accidental mechanical damage of the contacts and the risk of electric shock.

To ensure the necessary temperature difference and heat removal from thermoelectric modules, a liquid cooling radiator was used. In case of heat exchange between a solid body and a liquid (gas), occurring when they are in contact and are simultaneously transferring heat by heat conduction and convection, convective heat exchange occurs.

An important factor which determines the choice of the module is its location. Since the sample of the thermoelectric converter will be located in close proximity to the source of water supply with a coolant temperature of 30 °C, it was decided to use a liquid cooling radiator.

In the initial structural modeling, aluminum and bimetallic liquid radiators with different heat transfer coefficients were used as the liquid cooling radiator. These liquid radiators, with the help of a
hardware connection, were attached to a steel gas pipe for surface matching of thermoelectric modules. Despite the good coefficient of heat conduction of aluminum (λ = 200 W/m * °C), compared to steel (λ = 55 W/m * °C), such radiators did not manage to cool the surface of thermoelectric modules to the required temperature. This is due to the fact that the surface of the radiator was being heated at the expense of thermal radiation from the steel pipe of the gas pipe and the small area of the heat transferring element (fin) of the radiator directly to the wall with the cooling liquid. It is possible that the material, from which the radiator is made, has a porous internal structure and the presence of a large amount of impurities in the composition, which could have a significant effect on the heat conduction coefficient.

In view of the fact that it was not possible to produce or purchase an aluminum radiator that would be suitable for solving this problem, it was decided to produce a steel cooling radiator where the cooled surface would directly contact with the wall surface with the cooling liquid. That is why, samples of steel water radiators were made, which, despite poor heat conduction compared to aluminum, provided cooling of the surfaces of the thermoelectric modules to the required temperature (figure 2).

![Figure 2. Steel water cooling radiator for the TEC.](image)

Connection of steel liquid radiators to the water supply system was carried out with the help of plumbing of the required length.

Thus, the main characteristics of the produced prototype of TEC:

- generated average power 24 W;
- maximum operating temperature 200 °C;
- recommended coolant temperature 30 °C;
- pressure in the cooling system is not more than 10 bar.

3. Conclusion

Previous studies have confirmed the reasonability of using TEC to recover heat of electrolytic gases. The main functions of the TEC are:

- reduction of the temperature and physical volume of the gases which are being cleaned at the gas inlet duct into the gas cooling system;
- conversion of the thermal energy of electrolytic gases into electrical energy;
- DC power supply of power consumption devices in the operational area and other technological needs.

The use of a process flow diagram which consists of a heat exchanger along with thermoelectric converters is an innovative technology, and will allow to increase the energy efficiency of production and achieve economic advantages of aluminum production technology.

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