Development of technology for recovery of thermal energy of gases

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Abstract. The project aims to develop an energy saving method for conversion of thermal to electric energy. The review of engineering solutions in this area demonstrated the rationale for using thermoelectric generator (TEG) modules to produce energy for business use. As a part of the research, ANSYS models were developed and thermal fields of flue walls were studied at different flow speed rates and gas air environment temperatures. A design of the TEG unit consisting of 12 TEG modules, a cooling radiator and a switching unit was developed. A bench for studying the efficiency of converting thermal to electric energy was designed. Experiments using three types of TEG modules were carried out. Capacity values at different temperature gradients were determined. Pilot testing of a high performance thermo-electric generator was carried out within the temperature range under study. It was identified that by increasing the number of TEG units, it is possible to meet technological needs. A system consisting of single inline TEG units was developed. It was used for making circular cross sections in flues. The number of TEG units, the type of modules and the method for their connecting depend on capacity rates, temperature and flue dimensions. The authors filed a patent application. The possibility of research results commercialization in the oil and gas, metallurgy and chemical industries is being explored.

1. Introduction

Currently, demands on energy and resource saving technology are tougher due to increasing energy shortage. It stems from the fact that urbanization rates are rather high. Community, housing and production sectors are constantly developing. Studies on improvement of energy-saving methods which can increase manufacturing competitiveness are crucial due to the Russian legislative requirements.

In most Russian plants, the technological process is accompanied by high-temperature gas emissions into the environment. The review of engineering solutions in this area identified the rationale for using thermoelectric generation modules to generate energy for production use. The TEG module is a semiconductor oscillator generating current owing to different temperatures on the opposite module surfaces [1-4].

The authors developed a system consisting of single inline units of thermoelectric generators connected by a flexible high-temperature cable. The device is designed for making cross-sections of different diameters. The number of modules depends on output energy parameters, flue dimensions and operating and installation conditions [5-8].
Laboratory and pilot tests allowed for conclusion that thermal to electric energy conversion can generate energy for technological use, for example, for lighting of industrial sites. Besides, when cooling gases [9-10], their volume decreases which decreases gas-cleaning unit operation costs and helps solve the problem of released thermal energy utilization.

2. Description of the thermo-electric generator and the experimental unit
The TEG module is a semi-conductor oscillator generating current owing to different temperatures on opposite surfaces of the unit. The unit has no moving parts and is characterized by high reliability, ability to use heat from any thermal energy regardless of the space position. The analysis of technical and cost parameters showed that to solve this task, it is reasonable to use Bi2Te3-based modules. There is a wide range of these devices which are mass produced or designed for solving specific tasks.

Figure 1 shows a conventional thermoelectric module which was used for developing a TEG sample. The general view and components of the TEG unit which was designed as a part of the project are shown in Figure 2.

![Figure 1. The TEG module.](image1)

![Figure 2. The TEG unit.](image2)
The TEG unit consists of 12 thermoelectric modules which are installed on the heat-distribution plate and fixed by a fastening device to the cooling radiator using silicon-organic paste. The cooling radiator is made from steel. It ensures a required temperature difference. The switching unit is designed for accommodating connections of input contacts of the TEG modules and output terminals for powering up the devices or connecting with other TEG units.

Thermoelectric modules can be connected parallel, in series or in a combined way depending on the required capacity parameters.

To study thermoelectric conversion processes, a laboratory unit was designed. It consists of the following components:

- a flue in the form of a steel 50×50 mm pipe (700 mm in length, 3 mm in thickness);
- a heat air gun used for creating a flow rate at 660 °C;
- an air-flow meter;
- contact and immersion thermocouples;
- an eight-channel meter-regulator;
- a fixed digital multimeter;
and other auxiliary devices.

The hot air flow from the heat air gun was directed to the flue inlet. The temperature of the external surface of the flue was regulated by adjusting the supply air temperature and flow rate by means of an adjustable flap in the flue outlet.

Radiators were connected to the water supply system by means of sanitary fittings. Ball valves were installed for supplying / powering down the coolant. Thermoregulated radiator valves were used for adjusting the flow rate of the coolant.

To ensure a good contact of the thermoelectric module surfaces with the surfaces of the source, contact areas were covered with thermally conductive silicone paste.

Temperatures on the external surface of the flue and on the surface of the cooling radiator were measured using thermocouples. The temperatures were recorded using an eight-channel meter-regulator.

Output parameters of voltage and current were measured using stationary digital multimeters.

3. Laboratory testing of thermoelectric conversion

To assess efficiency of the thermal to electric energy conversion, three types of thermoelectric modules with different parameters were used: TGM 199-1.4-0.8; TGM 127-1.4-1.2 and TGM 127-1.4-2.5. As a result of the experiments, TEG module capacity values were determined at different temperatures (Table 1).

| Type of thermoelectric module | Flue wall surface temperature, °C | Radiator surface temperature, °C | Output capacity, W |
|------------------------------|-----------------------------------|----------------------------------|--------------------|
| TGM 199-1.4-0.8              | 40                                |                                  | 0.04               |
|                              | 60                                |                                  | 0.56               |
|                              | 80                                | 30                               | 0.9                |
|                              | 100                               |                                  | 1.12               |
| TGM 127-1.4-1.2              | 40                                |                                  | 0.08               |
|                              | 60                                | 30                               | 0.275              |
|                              | 80                                |                                  | 0.9                |
|                              | 100                               |                                  | 1.27               |
| TGM 127-1.4-2.5              | 40                                |                                  | 0.03               |
|                              | 60                                | 30                               | 0.125              |
|                              | 80                                |                                  | 0.45               |
|                              | 100                               |                                  | 0.84               |
Thermoelectric conversion processes were studied using an experimental unit in the following sequence:

- water supply to the cooling radiator;
- using a heat air gun feeding hot air;
- air flow aerodynamics control and gas temperature stabilization;
- water supply control and cooling radiator temperature stabilization;
- recording of thermoelectric conversion parameters.

It was identified that at temperatures under study, TGM 127-1.4-2.5 had the lowest performance rate. At 60 °C, TGM 199-1.4-0.8 had the best output values. Its capacity was 0.56 W. At 80 °C, TGM 199-1.4-0.8 and TGM 127-1.4-1.2 showed similar results. Their output capacity value was 0.9 W. At 100 °C, TGM 199-1.4-1.2 was the most effective module.

4. Pilot testing of the TEG unit

To prove the lab testing results, pilot tests on a circular flue 800 mm in diameter were conducted. A gas cooling unit consisting of 12 thermoelectric generation modules TGM-127-1.4-1.2 was used.

At the preliminary stage, the temperature of the external flue surface was measured using a thermal viewer, a digital pyrometer, and a contact thermocouple (Figure 3).

The external temperature of the flue walls was in the range of 74.8-84.6 °C. The TEG unit was installed at the site of the maximum temperature value. In addition, the temperature of gases inside the flue was 118 °C. The outside air temperature was 12 °C.

To fix the cooling radiator, a perforated fastening tape which can be tightened was used. Thermal paste KPT-8 was used as a heat-insulating layer between the radiator and thermoelectric modules.

A circulating pump and a 125 liter container were used to supply water to the cooler of the TEG unit. A 12-volt LED flashlight with a capacity of 15 W was used as a loading source.

Voltage and current values were recorded using digital multimeters; water temperatures were measured using a contact thermocouple.

Figure 3. Measurement of the flue wall temperature using a thermal viewer.

Figure 4 shows the general view of the gas cooling module using one TEG unit installed in the flue. The measurement results showed that when the temperature gradient is about 60 degrees (water temperature is 26 °C, and the flue wall temperature is 84.6 °C), the capacity of one TEG unit does not
exceed 12 W which is in compliance with the laboratory test results. The generated capacity was enough to supply the LED flashlight shown in Figure 5.

**Figure 4.** A general view of the gas cooling module using one TEG unit. **Figure 5.** The TEG unit-powered LED flashlight.

Based on the pilot testing results, the authors developed a system consisting of several TEG units (Figure 6).

**Figure 6.** The system consisting of four TEG units.

This solution combines TEG units forming a belt which can be installed in circular flues (Figure 7).

**Figure 7.** Variants of TEG units’ combinations in the circular flue.

The number of TEG units, the type of modules, the method used for connecting them depend on capacity parameters, temperature values and flue dimensions.

To install the system consisting of cooling modules, a perforated fastening tape was used. Figure 8 shows that the tape is tightened with bolts.
5. Conclusion

Thus, with a system consisting of 25 TEG units surrounding the flue circumference with a surface temperature of 90 °C and a diameter of 800 mm, the maximum generated capacity can be 300 W. When using LED lamps with a capacity of 15-20 W, heat energy recovery will provide technological needs for artificial illumination of the production site.

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