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The thermoelectric generators use for waste heat utilization from conventional power plant

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Abstract. On the base of available data, it is estimated that the industrial approx. 20-50% of the energy is removed into the atmosphere as waste heat include in the form of hot flue gases, cooling water, the heat losses from the equipment hot surfaces or heated products. However, according to the data from the US market in 2010, in the form of waste heat is emitted more than 96 · 106 TJ annually (2.7 · 1010 MWh), means more than 57% of the produced energy. According to statistics, currently the energy production in the US amounts to approx. 26% of the world's energy production. Assuming the same indicators, the total annual amount of waste heat in the scale of the world equals 370 · 106 TJ (10.4 · 1010 MWh). One of the ways to increase the energy efficiency of manufacturing processes and reducing energy consumption and negative impacts to the environment is the use of waste energy [1,2,3] In this work it was investigated the possibilities of the waste heat utilization from conventional thermal power plant using thermoelectric generators, the operation of which is based on the Seebeck effect.

1 Introduction

Nowadays, one of the major economic problems is the increasing energy consumption. This results in a rapid depletion of fossil fuel resources. To reduce the consumption level of these resources, a lot of investment in renewable energy and development investment in these sources. However, there is also the possibility of improving the efficiency of energy production from non-renewable sources. Energy production often involves the formation of by-product which is waste heat. However the waste heat is a certain volume of energy carrier which can still be utilized. One of the equipment processing heat into electricity is a thermoelectric generator. Its operation is based on the principle of thermoelectric phenomenon, which is known as a Seebeck phenomenon. The simplicity of thermoelectric phenomena allows its use in various industries, in which the main waste product is in the form of heat with the temperature of several hundred degrees. The most beneficial seemingly waste heat with the highest temperature. Thermoelectricity was discovered in the nineteenth century. The phenomenon of heat conversion into electricity and vice versa are called

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thermoelectric effects. Distinguishes the 3 main types of these phenomena: Seebecka; Peltiera; Thomson [1, 2, 3]. Thermoelectric effect in the 20th century was used in various fields, eg. power the spacecraft, drawing heat for the heating of a single connector on the nuclear reactions. Thermoelectric materials were also used to power the pacemaker. Thermoelectric generator can also be used in the exhaust systems of cars. According to estimates, in modern engines with spark ignition and compression ignition heat contained in the exhaust gases is approx. 30% of the total heat from burning fuel. This heat instead of giving ineffectively to the environment, can be though to some extent re-use. This will increase the efficiency of the drive system. The use of thermoelectric generators to convert about 6% derived waste heat will reduce fuel consumption by up to 10%.

1.1 Construction and operation of thermoelectric generator

Thermoelectric generators are built of thermoelectric modules. A single module is made with a thermocouple. A single thermocouple generates a small thermoelectric force, and therefore to the formation of one module is used even hundreds of thermocouples. The module is encased ceramic layer which also acts as a housing and the insulator. Under the housing elements are arranged semiconductor . The thermal energy is supplied to the heat exchanger. Then, the heat is directed to the thermoelectric modules in which a partial conversion of thermal energy into electricity. The rest of the heat is discharged to the cooler. The process of Thermoelectric (Figure 1) begins at the start of one side of the generator heating. Absorption of a certain amount of heat causes diffusion of the mobile charge carriers along the temperature gradient. Negative particles flow to the "cold" side by an semiconductor n- type, and the particles of the positive p-type semiconductor. As a result, between the two parties to the generator potential difference is formed [2, 3].

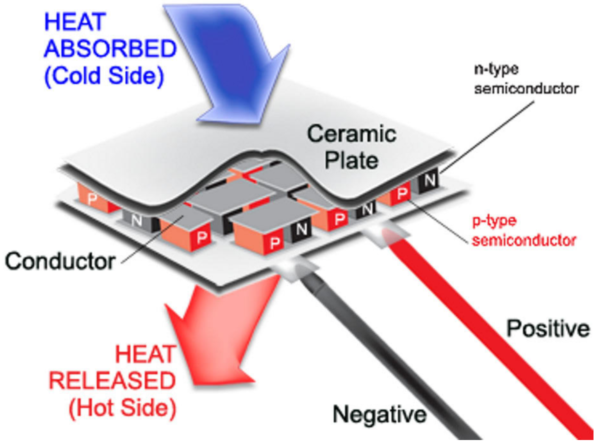

Fig.1. Scheme and operation of thermoelectric module [3]

The benefit would be getting the greatest power in the process. It is possible to increase the value of received power. For this purpose semiconductors are connected in the cell. This increases the voltage of the cell, and thus also the power.

1.2 The use of thermoelectric systems

Practical use of thermoelectricity phenomenon began in the twentieth century. The beginnings of this field is inter alia powering radio or creation of the first thermoelectric generator with an efficiency of 5% in the first half of the twentieth century. Later, one of the most significant initiatives was the American SNAP project, which was used by NASA when

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powering space probes, including expeditions to the moon. These facilities have used radioactive reactions as a heat source. Also, Voyager 1 space probe (sent into space in 1977), now the farthest located object sent by man, is powered by thermoelectric generators. The universality of such systems application due especially to the lack of moving parts and the possibility of long-term work. The success of the project on the Voyager probes led to further projects the power of objects sent into space by utilizing the thermoelectricity phenomenon. General-Purpose Heat Source Radioisotope Thermoelectric Generator (GPHS-RTG) was designed. These generators used as power of Cassini probes, which has been sent to Saturn, New Horizons was sent on Pluto, Galileo was directed to Jupiter and Ulysses investigating regions of the sun. In France Thermoelectricity used to power a pacemaker, and in the 90s the company producing watches named Seiko has introduced a thermal watch, which used the heat of the human body. In recent years, a pioneer in the use of thermoelectricity in the industry is an American company Alphabet Energy [6].

Research in this area is also GMZ Energy cooperating inter alia with the company car Honda. The company has developed an advanced generator for Honda Accord. There has generator power at 1 kW. This result was achieved through a combination of five generators with a capacity of 200 W. The electrical energy will support the operation of the automotive alternator. The company's activities are co-financed by the US army. Tests were also conducted for the possibility of generator using by the military. GMZ used to this materials of half-HEUSLER type. By using nanostructures have improved mechanical integrity or stability in areas of high temperatures . Also, the Fiat Group in collaboration with companies trying to develop the technology and bring it to their vehicles. Model, for which the study was conducted was the Fiat Iveco Daily fitted with a diesel engine with a capacity of 2.3 liters. As the thermoelectric material bismuth telluride Bi_2Te_3 was used (exhaust gas temperature of 450 °C, gas flow of 70 g/s (at maximum load), 140 g/s (at full load) and the parameters of the coolant temperature of 60 °C, flow rate 0.33 l/s). Reached limit the amount of consumed fuel by 4%. Tests have shown that the thermoelectric materials allowed to work at a maximum temperature of 270 °C, so it is necessary to use materials for higher temperature ranges. [8] In Poland, research on thermoelectric generator installed in the exhaust system of the ignition engine 1.3 JTD (Figure 2) were conducted. They were conducted at the AGH University of Science and Technology under the direction of Professor Krzysztof Wojciechowski. Due to the use of thermoelectric modules built on the compounds of tellurium, bismuth and antimony generator provided at the place where the temperature of exhaust gas is about 300 ° C to ensure the best use of them. The tested system in optimal conditions generate a power of 200 W, acting with efficiency in the range of 1.1-1.9%. Maximum efficiency of thermoelectric modules amounted to 3% and has been achieved for temperatures: the cold side Tc = 25 °C, the hot side Th = 200 °C [2,8, 4].

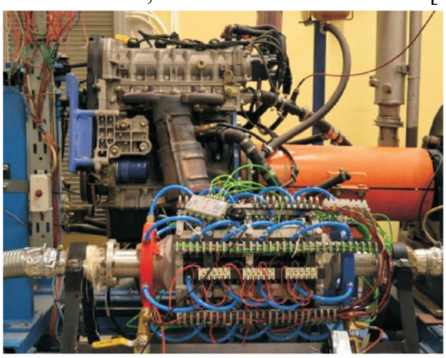

Fig. 2. Picture of the tested at the AGH University of Science and Technology thermoelectric generator [8]

Thermoelectric Laboratory at AGH developed modules that can be used at higher temperatures. Their highest possible efficiency is 9%. Thanks to their use the electric power of the thermoelectric generator can be increased to 1 kW [8].

2 Thermoelectric generator use in conventional thermoelectric power station

The electric power installed in Polish power plants in 2015 was 40.45 GW . 82% of the power was supplied by the combined heating plants - CHP (ie. producing energy for distribution and sale in the domestic energy system), use of traditional fuels (coal: 54.5%, lignite: 25.2%, gas 2.3 %). Another 6.3% provide wind turbines. As a result of the manufacturing process, the release of huge amounts of waste heat, which is not in any way disposed of and used further for energy purposes. One way to use waste heat of a sufficiently high temperature is to use thermoelectric generators which on the one hand, will produce electricity on the other hand will heat the cooling medium of thermoelectric generator, which can later be used for other industrial processes. Thermoelectric generator is possible for an application in any installation emits waste heat. The problem of waste heat is not limited only to the extraction and processing. It also causes huge losses, estimated at 20-50% of total energy consumption in the industry [Energetics, Energy Use, Loss, and Opportunities Analysis: U.S. Manufacturing & Mining, p. 17, 2004]. Almost 15 GW is lost in the US manufacturing sector. Also transport generates huge amounts of waste heat. Approximately 33% of the fuel energy is wasted in the exhaust system of the vehicle, a 29% loss in the cooling system [Steven Chu & Arun Majumdar, Opportunities and challenges for a sustainable energy future, Nature vol 488]. According to data from the US market in 2010, in the form of waste heat emitted annually is more than $96 \cdot 10^6$ TJ ($2.7 \cdot 10^{10}$ MWh), or more than 57% of the produced.energy According to statistics, currently the production of energy in the US amounts to approx. 26% of the world's energy. Assuming the same indicators, the total annual amount of waste heat in the scale of the World is amounted of $370 \cdot 10^6$ TJ ($10.4 \cdot 10^{10}$ MWh). If the heat will be converted using thermoelectric generators with an average efficiency of 5%, you can get $5.2 \cdot 10^9$ MWh of electricity, which (with the price of energy 165 PLN/MWh), would annually generate electricity worth 865 billion PLN [3, 5.6]. Conventional steam power plants use the chemical energy of fuel to produce electricity. Electricity can be produced in power plants or in combined heat and power plants CHP (combined with thermal energy). The combustion of fuel in the boiler generates heat, which is transmitted working medium - water, which evaporates. The steam drives a turbine blade, allowing it to work, produced power is transmitted to the electrical generator that produces electricity. This paper is focused on analyzing the possibilities of waste heat utilization for a small industrial power plants which are in Poland a dozen and the most popular boiler used in the steam production is OR-32/2 boiler . In combined heat and power plants one of the used boilers types are pulverized coal and grate boilers tab.1.

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Table.1. Main parameters of power plant installation

Electrical power P_G	1,5	MW
Steam pressure	36	bar
Steam temperature	425	°C
Steam mass flow	32	t/h
Total efficiency of cycle	37	%
Boiler efficiency	76	%
The temperature of the boiler feed water	105	°C
Flue gas mas flow	56900	m^3/h

The calculations take into account the parameters of one such OR-32 boiler. Temperature of water supplied the boiler is 105 °C. After leaving of this boiler type the steam parameters are as follows: pressure 3.6 MPa, temperature of 425 °C, maximum continued capacity 32 t/h, rated thermal output approx. 25.2 MW and a guaranteed efficiency of 72%. The boiler is supplied with coal. Flue gas parameters relevant for the thermoelectric generators application, which is temperature of the air preheater outlet and a stream at the boiler outlet are respectively 200 °C and 56900 m^3/h . Achievable power depends on whether the steam from the boiler is used for other processes of plant or also a whole may be directed to the turbine. Below is a sample steam – water cycle of combined heat and power plant (Fig.3).

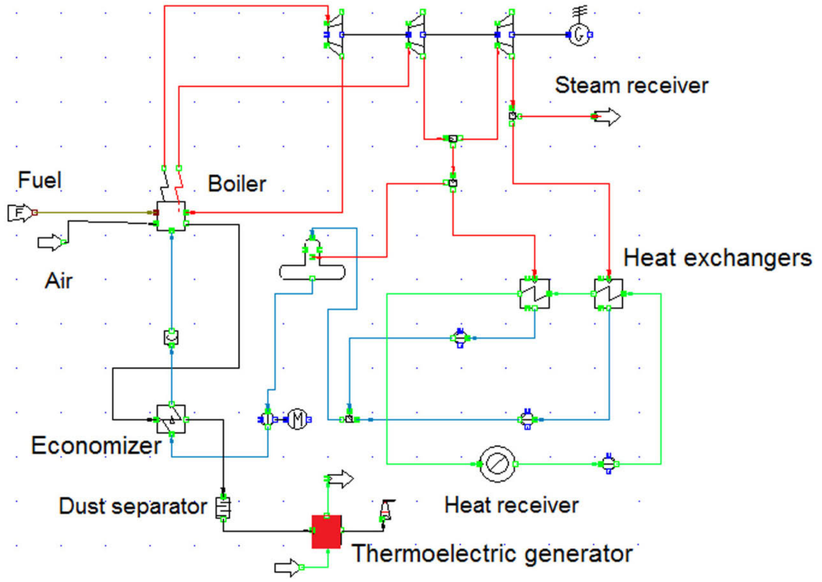

Fig.3. IPSE pro Scheme the cogeneration installation with OR-32 boiler

After analyzing the steam – water cycle of small heat and power plant for potential local use of waste heat by thermoelectric generators. The case analysis shows that from the operating of heat and power plants point of view is important to thermoelectric generator the least interfered with the structure of the plant's water steam power cycle because any change could result in unplanned downtime and additional costs of installation. Therefore it determined

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that the best place for the waste heat utilization from combined heat and power plants is flue gas duct after the flue gas cleaning system where the flue gas reaches a temperature of about 200 °C. In the flue gas duct thermoelectric genrators are arranged in such a way as not to affect the flow of flue gas through the electrostatic precipitator or other flue gas cleaning equipment . In most cases, for the flue gas cleaning process at low gas flow used are small-sized electrostatic precipitators. Small-sized electrostatic precipitators are used for extraction of gas from boilers with power being in the range of 5-50 MW coal-fired or biomass. These are called. "Small sources of dust." They clean gases from water grate and steam boilers. Small-sized electrostatic precipitators produced by Elwo allow for flue gas cleaning which flow rate is in the range of 10000 to 65000 Nm^3/h and the concentration of flue gas dust is from 1 to 10 g/Nm^3. On the basis of the manufacturer's data specified that the drop of flue gas temperature in the flue gas cleaning unit is approx. 5 °C, so when the enter flue gas temperature of 200 °C will be the cooling to the temperature of approx. 195 °C [9,10,11,12].

3 Results of analysis

The calculation considers the energy conversion for the three cases. They differ in the temperature to which the flue gases are cooled (respectively 150, 145 and 130°C). The flue gas temperature after extraction before the process of energy conversion is 195 °C. The valuesof the flue gas stream is contemplated in the range of from 30000 to 80000 m^3/h by adjusting its value at 5000 m^3/h. Adopted cooling temperatures of the flue gas are selected on the basis of a graph representing the content of sulfur in the operational state coal. The content of this element in the fuel affects the dew point of the flue gas. Low sulfur content results in a lower dew point temperature, which makes it possible to cool the flue gas to a lower temperature. Considered the grate furnace due to the characteristics of the OR-32 boiler.

For the simulation calculations in IpsePro software adopted the following chemical composition of flue gases: [15] –CO_2 0.18659 kg/kg; - H_2O 0.18044 kg; - N_2 0.62693 kg; 0.00016641 kg O_2/kg - SO_2 0.0058755 kg/kg. Considered the use of thermoelectric generators studied at the AGH University of Science and Technology [3,8]. Maximum generators efficiency investigated at the AGH University of Science and Technology was 1.9%. Calculations of realizable power were also conducted for generators wit efficiencies of 3 and 7%.

Table. 2. Production of electricity by thermoelectric generators with the efficiency of 7%

Exhaust gas flow [m^3/h]	Exhaust gas temperature Flow out from of TGE		
	150°C	145°C	130°C
30000	15.32	17.19	23.04
40000	20.43	22.92	30.72
50000	25.54	28.65	38.41
60000	30.65	34.39	46.09
70000	35.76	40.12	53.77
80000	40.87	45.85	`61.45

Table. 3. Production of electricity by thermoelectric generators with the efficiency of 3%

Exhaust gas flow [m^3/h]	Exhaust gas temperature Flow out from of TGE		
	150°C	145°C	130°C
30000	6.56	7.36	9.87
40000	8.75	9.82	13.16
50000	10.94	12.28	16.46
60000	13.13	14.73	19.75
70000	15.32	17.19	23.04
80000	17.51	19.65	26.33

Table. 4. Production of electric energy by thermoelectric generators with the efficiency of 1.9 %

Exhaust gas flow [m^3/h]	Exhaust gas temperature Flow out from of TGE		
	150°C	145°C	130°C
30000	4.16	4.66	6.25
40000	5.54	6.22	8.34
50000	6.93	7.77	10.42
60000	8.32	9.33	12.51
70000	9.70	10.89	14.59
80000	11.09	12.44	16.68

For the flue gas flow of 60,000 m^3/h can be achieved up to 45 kWe for AGH modules (efficiency 7%) and 12 kWe of electricity with the use of commercial embedded thermocouples in the flue gas duct for which efficiency is at least 1.9%, assuming that the drop in temperature is 650 °C.
Application of this case involves the reconstruction of the flue gas duct and flue gas cleaning installation. Such a solution would be the most beneficial for combination of flue gas cleaning system with the fabric filter, where the temperature reduction is indicated for technological and safety reasons where local flue gas temperature is much higher.

4 Conclusions

The aim of the study was to analyze the possibility of the thermo elements use to convert waste heat into electricity. Simulations were performed using the IPSEpro software. It allows to simulate all kinds of thermal cycles, power units and cooling cycles. The study analyzes the possibility of the thermoelectric generators use in a steam, OR-32 grate boiler, behind which is placed the small electrostatic precipitator for flue gas cleaning. Considering the obtained results, for systems with thermoelectric efficiency of 1.9%, or such as that achieved at the AGH University of Science and Technology it is noted that the parameters characterizing the OR-32 boiler (flue gas stream of 56900 m^3/h) electric power will be from about 7 to about 13 kW, depending on the temperature to which the flue gas are cooled. For generators with an efficiency of 3% can be achieved several kilowatts of electric power. Using the thermoelectric chips on the efficiency of 7% can be obtained the power of 30 kW, and the temperature was reduced to 130°C even at the level of 40 kW. Increased value of the flue gas stream would result in higher values obtained power. They are not too high value as compared with the losses in the boiler, due to the relatively low values of thermoelectric generators, but the resulting power may be useful as a partial meet the needs of their own power. Examples of auxiliary OR-32 boiler, such as primary and secondary air fans show demand for power respectively 22 and 7.5 kW (based on the technical documentation of Fakop), these are values that can be covered with energy obtained as a result of thermoelectric systems use behind the electrostatic precipitator. In the next stages of work out economic analysis allows to determine the payback period for the construction of thermoelectric generator will be carried. The use of thermocouples which is a very innovative solution possible to implement not only in the power systems but also in other installations where there is a problem with the waste heat utilization and switch it to a useful product.

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