Eletricity Generation Using Thermoelectric Generator – TEG

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ABSTRACT

Generating machines of electricity, using combustion engines and generate a great amount of residual thermal energy from the exhaust gases. This residual thermal energy can be converted into usable electricity using thermoelectric generator (TEG), which are manufactured cells with semiconductor materials employing the Seebeck effect. When recovering the waste heat in the exhaust ducts using TEG, increases the efficiency of electrical machines, because the same amount of fuel input generates more power or less intake of fuel, has the same amount the generated electric energy and thus less air pollution (as there will be less burning of fossil fuels) makes the system more sustainable. The purpose of this paper is present an electric generation plant using thermoelectric generator (TEG), which recover the thermal energy dissipated by combustion gases of an electric generator. The temperatures values are obtained through thermal imager and laser thermocouples type K. To improve the efficiency of generation is carried out the control and supervision of the temperature on the cold side of the TEG. The Supervisory System is responsible for data acquisition and generation of graphs and reports.

INTRODUCTION

Thermal energy that comes from exhaust gases from electrical generators can be used to generate electrical energy through thermoelectric generators – TEG, improving their efficiency [1]. Thermoelectric generators are made of p-type and n-type semiconducting materials that are called thermoelectric pairs. Each pair has two pins, where one of them is doped to be p-type and the other one is doped to be n-type. If several thermoelectric pairs are connected electrically in series and thermally in parallel, so that they are electrically isolated and thermally conducting, they form a module as shown in Fig. 1. If the module is subject to a heat source, an electrical power is generated and the module works as a TEG. On the other way, if the module is subject to an electrical current, the heat is absorbed by one of the sides of the module and rejected by the other, working as a refrigeration unit [1] and [2].

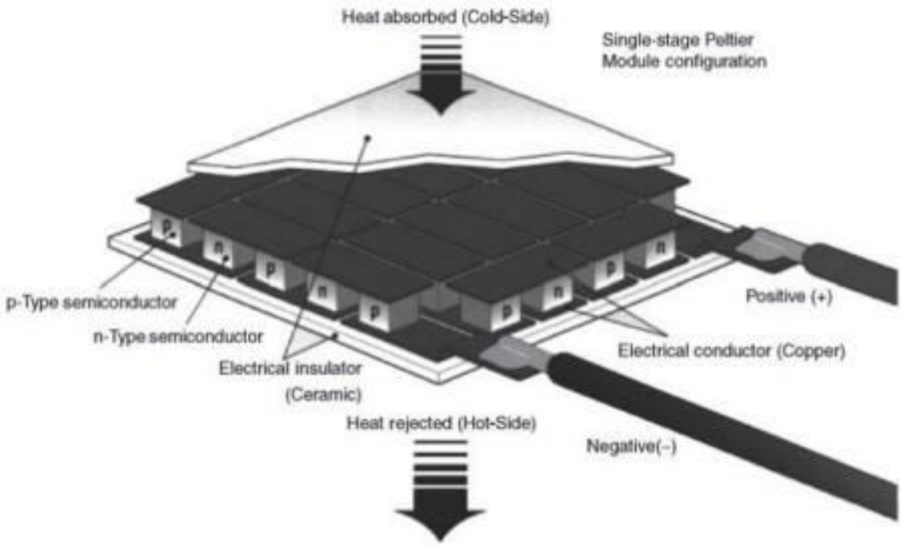

Fig. 1. P and N TEG junctions.

In the construction of a TEG are used thermoelectric materials (TE), solid semiconductors, responsible for producing electric current when joined and subjected to a temperature difference in the joints. This power generation using thermoelectric materials is known as the Seebeck effect [3]. One side of TEG receives heat rejected from the process, characterized, therefore, as the hot side "Th" (high temperature), while the other side has low temperature (cold side - "Tc"). This temperature difference allows the generation of electricity [1]. The open circuit voltage generated by TEG (V) is calculated (1) [4] and [5].

$$V = N.\alpha.\Delta T$$

Where: V is the open circuit voltage generated by TEG, in direct energy DC; N is the number of P / N pairs used in the construction of the module; _ is the Seebeck coefficient of the material used (V/K); and _T it is the temperature difference applied between the junctions (K).

The use of Seebeck Effect to generate energy is useful only for equipment that requires low power because the main disadvantage of this process is the low power generated (only a few Watts) even if millions of thermoelectric cells are associated. However, these modules are a source of renewable energy once they do not rely on fossil fuel, and they generate energy only when a difference of temperature is applied (even with a low difference in Celsius degrees), what makes this kind of process highly attractive. Because of that, this technology used to generate electrical energy is getting more and more applications, mainly when it is required high reliability, low maintenance cost, and the maximum energy recovery [1] and [6].

METHODOLOGY

For energy generation through thermoelectric generator is necessary to mount a thermoelectric generation plant consisting of: a technological apparatus, thermoelectric generator (TEG), cooling system on the cold side of TEG, control and monitoring system data and variable resistance load. The stainless steel apparatus with a 5 mm thickness and hexagon format was mounted in exhaust duct of the electric generator installed on Renewable Energy Sources Laboratory of the Federal Institute of Education, Science and Technology of Goiás (IFG), campus Goiania, as shown Fig. 2 and Fig. 3.

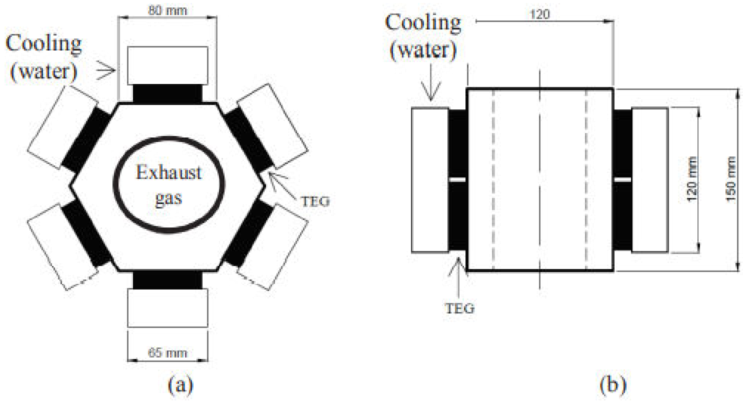

Fig. 2. (a) Top view of the assembly of the apparatus TEG; (b) Side view of the assembly of the apparatus TEG

Each apparatus side includes the installation of two (2) TEG, thus totaling a thermoelectric plant with twelve (12) TEG. The heat from the electric generator exhaust gases is transmitted by conduction to the hot side of the TEG, or Th. The cooling system of the TEG plant is comprised of: one (1) main reservoir (tank top);

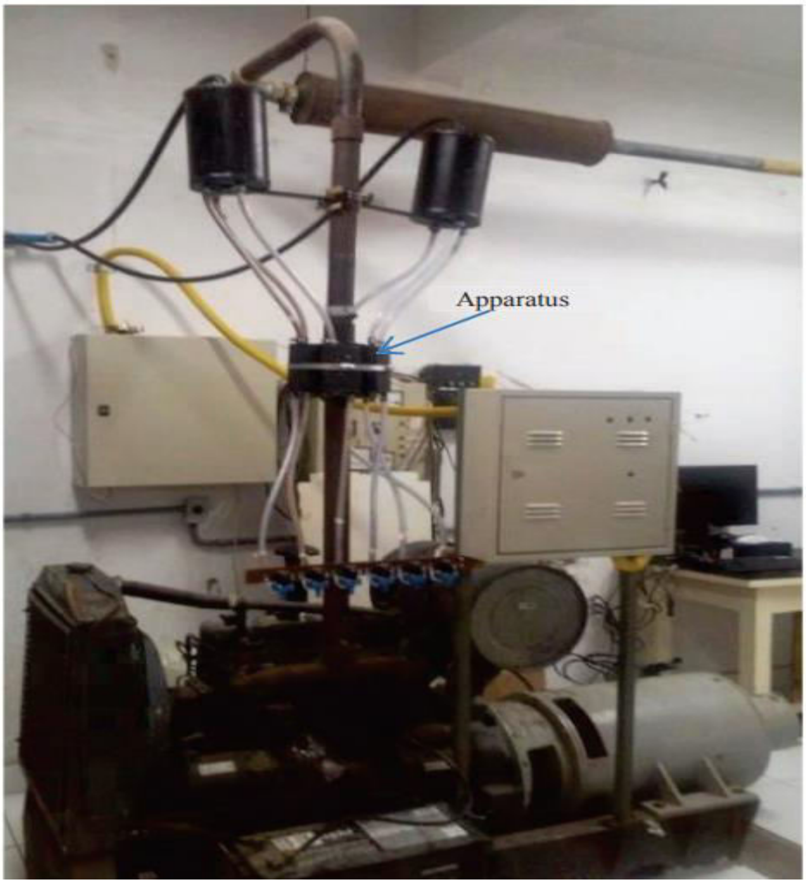

Fig. 3. Generator with technological apparatus

Two (2) tanks to stabilize the water flow; Six (6) stainless steel boxes, one for each side of the apparatus, these being in direct contact with the cold side of the TEG (Tc); One (1) secondary container (tank bottom) for storing water after passing through the enclosure; Six (6) onoff valves; hoses, connectors, among others. Process and Instrumentation Diagrams of the system is shown in Fig. 4.

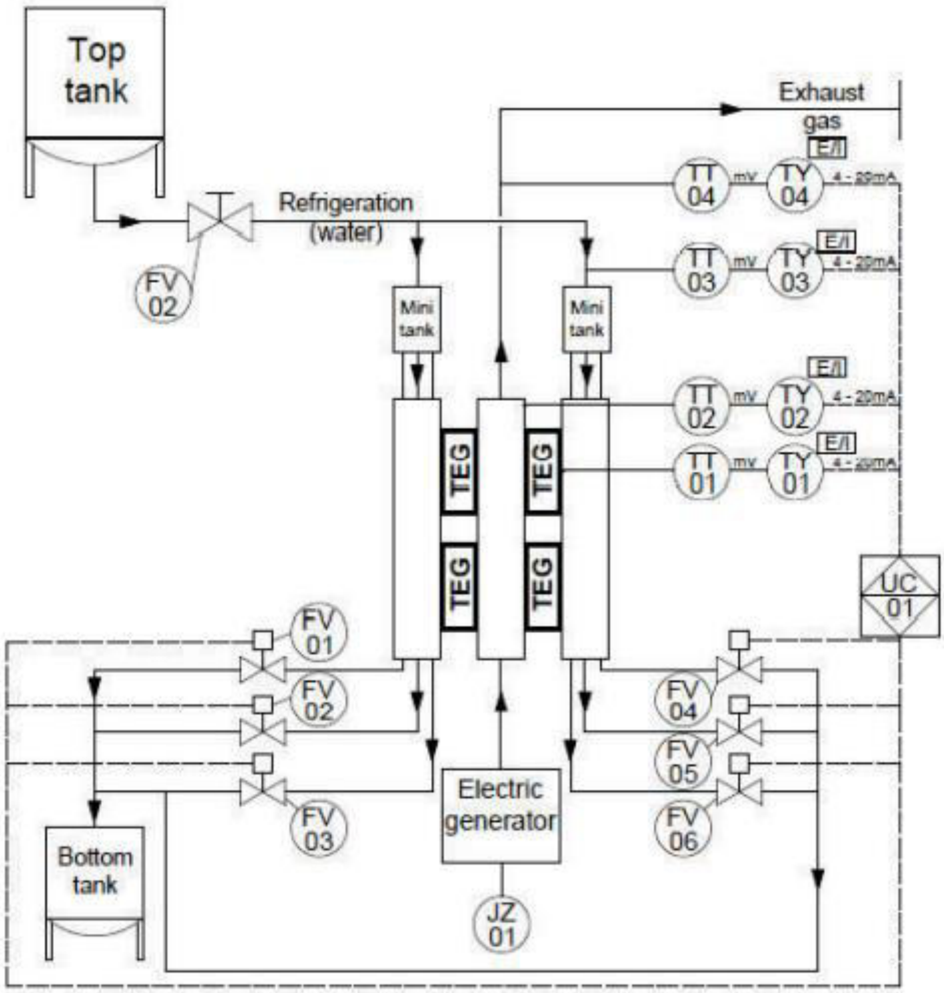

Fig. 4. Process and Instrumentation Diagrams of the technological apparatus

The TEG used in generating plant is the TELBP1-12656- 0.45 by Thermonamic manufacturer, as shown Fig. 5 and Table I. This module is built with a mixture of Bismuth telluride (Bi_2Te_3) and Lead telluride (PbTe) and can withstand a temperature range on the warm side of - 60 ° C to ± 360 ° C continuously, and a maximum of 400 ° C (intermittently). On the cold side, the range of temperature is - 60 ° C to ± 180 ° C continuously, and up to 200 ° C (intermittently) [7]. The hot and cold temperatures of the TEG sides are constantly read by a Programmable Logic Controller (PLC) and monitored by a Supervisory System that in addition to supervising the temperature variables, current and voltage of the TEG, generate alarms, graphs and reports the process. The screen of the Supervisory System is shown in Fig. 6 (the values shown in the displays are with the generator turned off). Only eight (8) temperature points are monitored because this is the maximum capacity of the acquired PLC model. The monitoring of the temperature of the hot side and cold of TEG is necessary to compare if the generated voltage and current values are equivalent to the TEG theory. The great advantage of reading the temperature values by a PLC and monitoring by a Supervisory System is able to store them in a database and generate reports for further analysis.

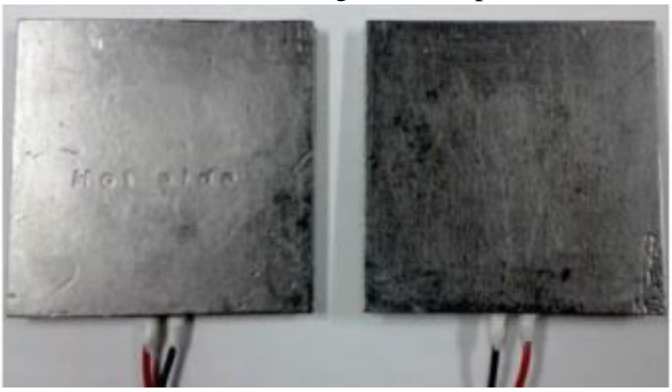

Fig. 5. TEG model TELBP1-12656-0.45

TABLE I. TEG TELBP1-12656-0.45 PARAMETERS

Hot Side Temperature - T_h (˚C)	350
Cold Side Temperature - T_c (˚C)	30
Open Circuit Voltage (V)	9.2
Matched Load Resistance (ohms)	0.97
Matched load output voltage (V)	4.6
Matched load output current (A)	4.7
Matched load output power (W)	21.7
Heat flow across the module (W)	≈ 247
Heat flow density ($W.cm^{-2}$)	≈7.9
AC Resistance (ohms) measured under 27 ˚C at 1000 Hz	0.42 ~ 0.52
Efficiency (%)	≈ 6.875
Seebeck coefficient ($volt.kelvin^{-1}$)	0.02875
Figure of merit	0.713875
Dimension (mm)	56 x 56 (± 0.5)

TEMPERATURE MEASUREMENT IN THE APPARATUS

Temperature measurements were made in the apparatus without the TEG generator for three different operating conditions: generator and unloaded with 20 minutes of operation; operating generator 2 minutes with 17 A load; operating the generator 5 minutes with a load of 47 A. The measurement points considered are shown in Fig. 7 and the values obtained are in Table II. The temperature measurement of the generator and unloaded is necessary to know what is the minimum possible temperature on the hot side of the TEG and the load with measuring (47 A) is to know which is the maximum, checking, so what would be the minimum and the maximum voltage generated by them.

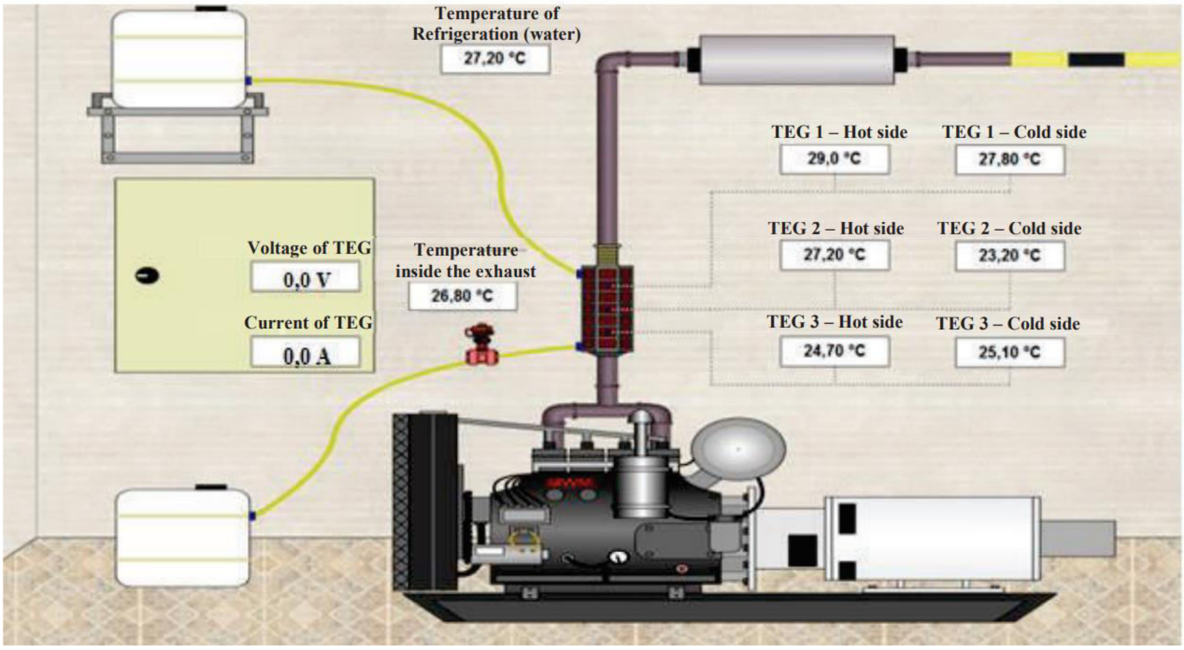

Fig. 6. Supervisory System – Monitoring screen of the process variables

In Table II and Fig. 7, T1, T2 and T3 values represent the temperature measurement directly from the exhaust gas (inside of the exhaust). T4 and T5 values represent of the temperature of the apparatus surface. So, it's possible verify that when the gas inside the exhaust is 313 ºC, the surface temperature is only 150 °C. This difference is because of the actual construction and equipment of the apparatus. In Fig. 7 (a) shows the image made by a thermal imager laser ITTMV Instrutemp-100 model. The measuring points T1, T2 and T3 were obtained from the model with thermocouples type K sheath placed inside the exhaust and the measuring points T4 and T5 by thermal imager.

POWER GENERATION OF THE THERMOELECTRIC PLANT

The thermoelectric power generating plant is composed of twelve (12) TEG with two (2) parallel branches, each branch contains six (6) TEG in series. Such a configuration is validated by the fact of raising plant pressure, while maintaining security of an operating system, where the lack of only one TEG a branch out of operation and the other will keep the load power. In Table III shows the technical characteristics of this plant. The amount of the hot side (Th) was taken from Table II (T5) which is the maximum temperature value of the generator with load (150 °C). The value of the cold side (Tc) is 30 °C because it's with this cooling value you get the maximum efficiency (according Table I). In Table III, the Voc value represents the open circuit voltage generated, Vmp is the maximum tension generated, Imp is the current, and Pmp is the power generated by the apparatus.

TABLE II. DATA TEMPERATURE APPARATUS WITHOUT TEG

Temperature T1 (ºC)	Temperature T2 (ºC)	Temperature T3 (ºC)	Temperature T4 (ºC)	Temperature T5 (ºC)	Load (A)
148	146	139	115	120	0
196	189	176	–	–	17
313	289	254	142	150	47

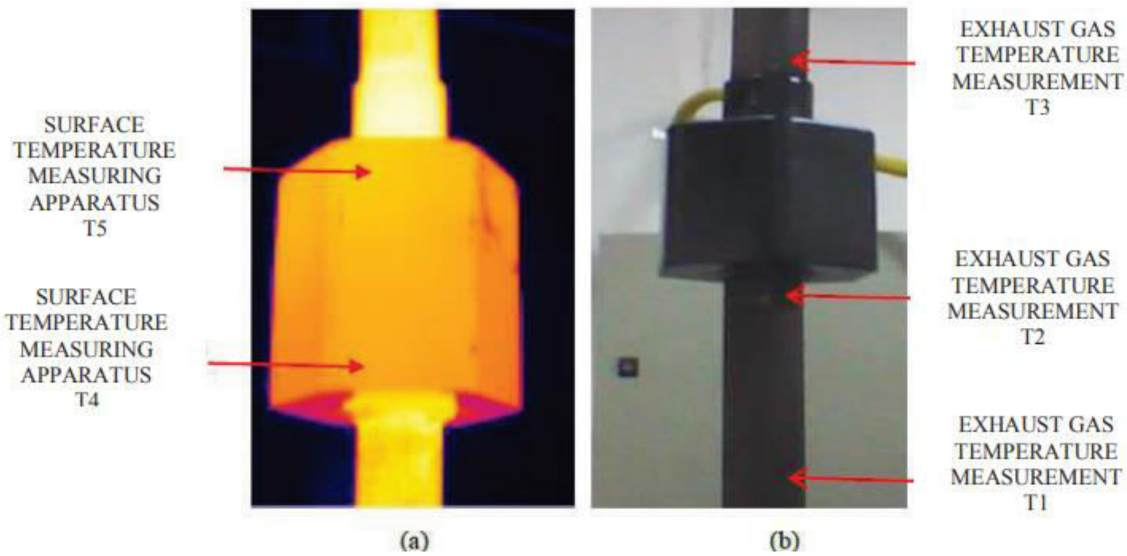

Fig. 7. (a) Thermal image of the apparatus without TEG; (b) Apparatus without TEG

TABLE III. TECHNICAL CHARACTERISTICS OF THE THERMOELECTRIC GENERATION PLANT

T_h (ºC)	T_c (ºC)	V_{oc} (V)	V_{mp} (V)	I_{mp} (A)	P_{mp} (W)
150	30	18	9,0	4,0	36,0

COOLING WATER VOLUME

As the cooling of the cold side of the TEG is done by water, it is necessary to calculate their consumption. For the TEG used, at a critical point (Th = 350 °C and Tc = 30 °C) has a heat flux (Φ) of approximately 247 W and an electric power output of 21.7 W. In this way, the flow of heat that must be dissipated from the cold surface of the TEG to the refrigeration box is 225.3 W or 225.3 J.s-1 or 53.82 cal.s-1 . Considering a time of 60 s, the specific heat of water 1 cal. g -1.K-1 and the initially cooling water temperature about 25 °C and increasing to 30 °C, then the mass of water needed for cooling for each TEG is shown in (2).

$$m = \frac{53,82\ x\ 60}{1\ x\ 5} = 654,84\ g = 0,654\ kg$$

Whereas the water density of 1000 kg.m-3, then is necessary to 0.654 liters of water to cool the cold side of each TEG (Tc) and keep it at 30 °C. For 12 TEG are required up to 7.848 l/min.

CONCLUSION

This paper presents results that contribute to the improvement of thermoelectric generation, brings temperature measurement using thermal imager and high-precision K-type thermocouple and performs control of the cold part of the TEG. It is noteworthy that with the effective control of process variables can obtain efficiency in the generation proposal. But more studies are necessary to confirm that the improvement in system efficiency using TEG, because the generator used in this work is the generation of low temperature, it is necessary to mount this apparatus on a generator reaches 350 °C.

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