CONSTRUCTION OF A GAS THERMOELECTRIC MICROGENERATOR

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Abstract. *The energy extracted from the heat production in an infrared burner can be converted to electricity according to thermoelectric principles such as the Seebeck effect. When thermogenerators are exposed to a difference in temperature (thermal gradient), an electromotive force is generated inducing the appearance of an electric current in the circuit. Plates, known as thermoelectric chips, use the heater effect that can be provided by a high efficiency infrared furnace working on a set of multiple semiconductor chips (TEG's), which make the conversion of thermal energy into electricity. The semiconductor chips are formed by the p-types and n-types. These semiconductor elements are welded between two ceramic plates. Every system is solid, not containing any moving parts. This ensures their continuous operation and should be guaranteed a minimum thermal gradient. This work presents the construction and evaluation of a prototype, on a pilot scale, for energy generation to specific applications. The unit uses a fuel gas cylinder as a primary energy source. This prototype consists of an infrared burner, an adapter for the generator module, a number of semiconductor modules purchased from Hi-Z, Inc., to thermoelectric generation, a heat exchanger to be used as a cold source, and a cc-cc converter plate. It was built a test bench, using a system of temperature acquisition and a load module with lamps to vary the energy consumption and the system efficiency. The developed prototype and the adopted methodology met the test objectives, allowing to obtain conclusive results about the experiment.*

Keywords*: thermoelectric, termogenerators, conversion, energy*

1. INTRODUCTION

Over the past decades, the rational use of energy has become a key issue for policy development and maintenance of environmental sustainability. With the large hydroelectric potential has already explored the country to diversify its parent tends to increase the supply of energy and ensure the supply of its growing demand. The main alternatives are: thermoelectricity, small hydroelectric plants and solar and wind energy. Among them, the thermoelectricity has occupied a position of greater prominence, because of current policies adopted by the government and the discovery of new reserves in the national territory of the alternative fuel.

The increase in the supply of gas in the Brazilian energy market brings new opportunities for expansion of capacity to generate electricity in Brazil. According to Joseph (2004), currently the use of gas as fuel in place of almost all other fuels, especially for the ease of handling and the limited environmental effect of its burning is dominant. Among the main jobs are: generation of electricity, use in urban and remote areas.

According to Joseph (2004) the use of gas for generating electricity is growing in importance worldwide, and is considered the most appropriate fuel for use in the gas burners. It is used mainly in large power plants close to major centers of consumption. When there is possibility of adding these plants to large industrial users of such equipment, for use in cogeneration, the energy efficiency of the whole is even greater. Thus, the electricity is produced at low cost, which makes this type of application economically very interesting.

The thermogeneration is characterized as a solid conversion of thermal energy (heat) into electricity without the presence of moving parts. This gives a high degree of reliability to thermogenerators and low requirements for maintenance and replacement of parts.

The thermogenerator is an electric generator performs the same functions as an electric motor-generator powered by a fuel. Both produce electricity to power electrical loads.

The thermogenerator produces a certain amount of power from multiple thermocouples coupled in series. A difference in temperature is kept between the hot source and the cold source. Combinations of multiple thermogenerators can be made, in parallel or series, to meet higher power requirements.

As we will see below, the system showed a good performance in terms of electric generation of energy obtained in the laboratory of the Federal University of Rio Grande do Norte.

2. MATERIAL AND METHODS

2.1 Description of system

The unit of termogeneration uses a burner as a heat source. The power generating unit consists of 08 thermoeletric semiconductor modules of 2.5 W, model HZ-2 that converts the thermal gradient generated by burning gas in power. The necessary thermal gradient is maintained through a heat exchanger at the cold source, using water as refrigerant.

The heat source used in the proposed system is a type of infrared burner using a commercial cylinders of 13 kg of LPG as an energy source. The burner operates directly on the thermogenerator, which converts part of thermal energy (heat) into electricity (dc). The heat rejected during the generation of electricity is directed to the environment.

In the conversion of thermal energy into electricity from the temperature difference between hot and cold sources, using the thermoelectric module, HZ-2. This module provides the use of waste heat converting it into electrical energy, with maximum stress-load of 3.3 Volts. The basis of semiconductors with high relative efficiency as PbSnTe and Bite / SbTe, consists of 97 pairs of thermocouples as shown in Figure 1.

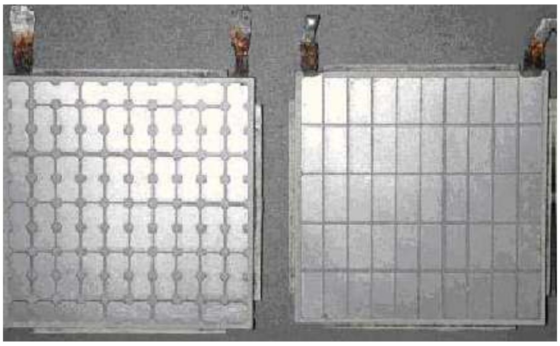

Figure 1. Thermoelectric module HZ-2 that shows the cold side (right); The hot side (left) presents the material points of the grid support. (LEAVITT, 2003)

The infrared burner of 2250 kcal/h offers an exchange of heat through infrared radiation associated with a substantial volume of heated gases. It is built on a base metal in which a ceramic bed is inserted in that space is where is the reaction of combustion. The radiation does not depend on the material means to transmit heat and the amount of energy carried by the waves is proportional to the fourth power of the temperature of the emitting surface. The infrared radiation does not require any means for transferring heat, and can even travel through the vacuum. (Natural Gas Engineers Handbook, 2005)

For the cold source, was designed a heat exchanger that was fixed to the head by means of screws and springs to ensure optimum compression of thermoelectric module. The heat exchanger was machined into a block of aluminum, to allow the movement of water through its input and output connections in order to keep the cold side of the module to lower temperature. To implement the cooling cold source was provided a tour of water, using plastic hose reinforced with nylon. The regulation of the flow was done manually using the drawer valvule, available at the point of a water supply.

The supply of gas to start and test the unit, was one of cylinders of 13 Kg, installed on the outside of the laboratory, consisting of pressure-regulating valve for gas, an indicator of gas pressure and check valve for gas. Connected to the infrared burner, by means of rubber hose, 3/8", specified to withstand pressure of 500 PSI (3.447 MPa).

The modulation of the flame to avoid high temperature, is performed by monitoring the temperature of the hot surface by a thermocouple, which sends the signal to a controller which in turn triggers a valve controller of two routes, one for high flow and one for low flow of gas.

System for monitoring temperatures

The analysis of energy efficiency of thermogenerator is obtained from the calculations of conversion of energy. To obtain information about the flow of heat unit, were used temperature sensors, thermocouple type "K", installed on 4 points of the unit (temperature of the hot source, the source cold temperature, temperature of water entering and leaving water temperature).

To the acquisition of temperatures, thermocouples were connected to their number of channels 1 to 4 in VI Logger® software, which is connected to CPU.

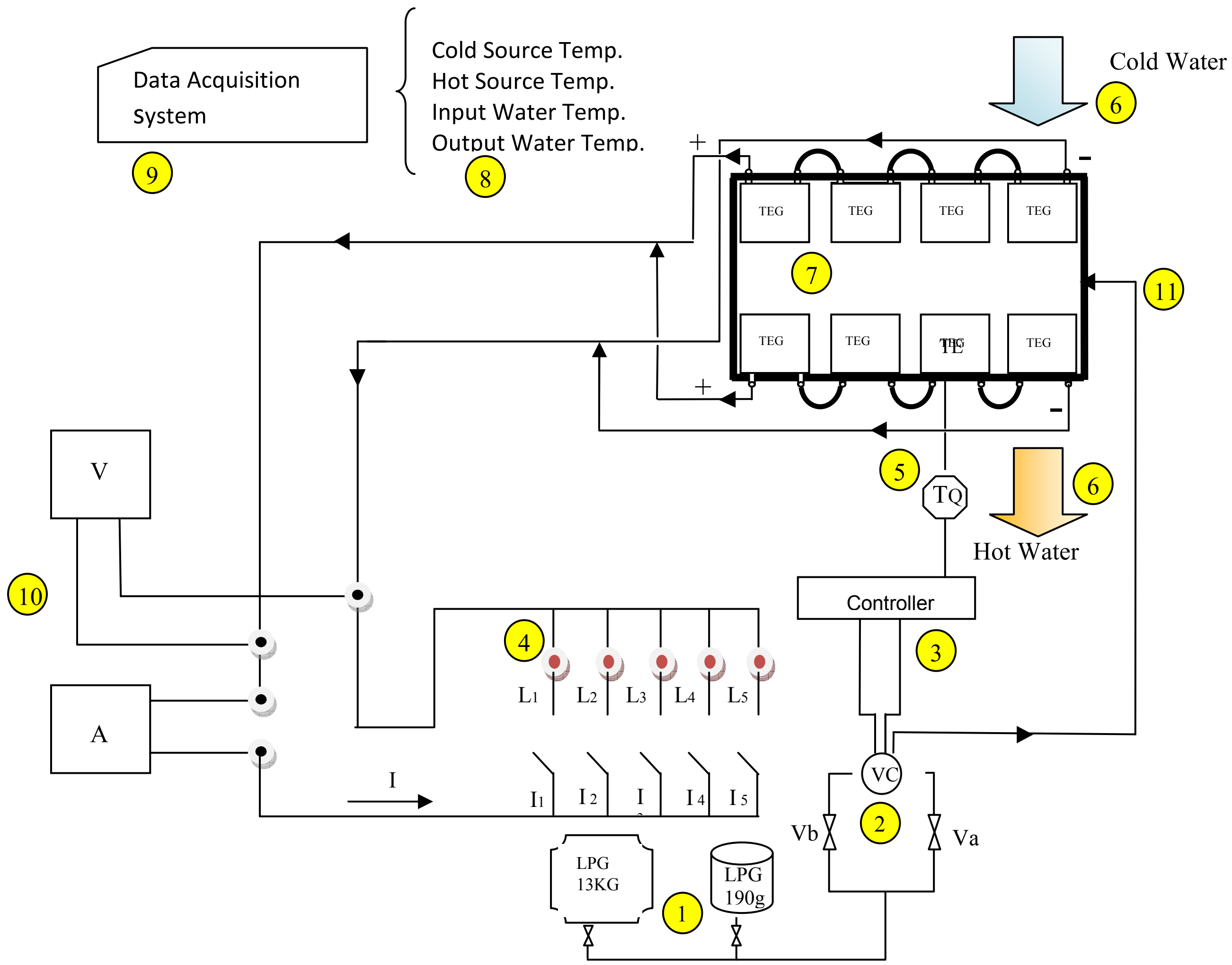

Figure 2. Illustrates the components of the generating unit of electrical energy. Below the description of the components

where:

1. Heat source - (commercial LPG gas cylinder).

2. Control system of the burner flame
   Va - needle valve for high-fire (high flow)
   Vb - needle valve for low fire (low flow)
   Vc - throttle (on-off)
3. Controller.
4. Loads (05 lamps of 5 watts)
5. TQ - thermocouple hot source
6. Heat exchanger (cold source) - machined aluminum block.
7. Source hot - plate of aluminum.
8. Semiconductor Module - model HZ -2
9. Data Acquisition System
10. Multimeters
11. Infrared burner

2.2 Testing Procedures

After completion of assembling the unit, installation of the gas system, cooling system and thermocouples to measure temperature of the unit of thermoeletric generation was subjected to observation and testing of a gas leak, and then start the test to evaluate the heating performance. The temperature of the module, the temperature of combustion gases, water temperature and output voltage generated by the module were evaluated during the test.

The pressure of gas leaving the cylinders was controlled at 2 bar (200 kPa) through the pressure-regulating valve installed in the LPG cylinder.

The circuit was composed of a multimeter connected in series, in light of ammeter, and another connected in parallel with the function of a voltmeter. We made simultaneous readings of current and voltage to allow the calculation of the power supplied by the thermoelectric module.

One of the most important quantities for determining the thermal energy involved in thermal systems is temperature. It was installed a system of simultaneous acquisition, for the entry and exit of each important element in the balance of this study.

The test was started linking up the infrared burner via a spark at the tip of the fuel gas entry. Now has begun to collect data through the acquisition VI Logger software, which recorded the temperature every second.

After the pre-operation the system was shut down for cooling, and replacing the source of gas. An alternative system of feeding gas was used. This system consisted of a disposable gas cartridge of 190g which was connected to thermogenerator energy through a connection of rubber hoses and have the 3/8", specified to withstand pressure of around 300 PSI (2.068 MPa).

When the temperature stabilized at the level of up to 200°C, entering in the steady, it started the measurements of: fuel consumption (kg/s), discharge of cooling water (m^3/s), current (A) and voltage of the module thermoelectric (V).

The system was subjected to resistive loads (five lamps of 5 watts); 0 to 100% usage in order to collect the changes in voltage and current.

Flow of water (q_n)

To determine the flow of water for cooling, it was calculated the arithmetic mean of three measurements performed in a becker with volume calibrated. The flow time of water was measured with a stopwatch precision. The flow of water was obtained by calculating the flow rate is initially collected for each sample, using Equation 1.

$$q_n = \frac{v}{t} \tag{1}$$

where:

q_n = volumetric flow for the samples of 1 to 3 [mL/min]

v = volume of water [mL]
t = time [min]

Thermoelectric module power (Pm)

The calculation of the thermoelectric power module was obtained by Equation 2.

$$P_m = V.I \tag{2}$$

where:

P_m = net provided by the thermoelectric module [Watts]
V = voltage generated by the thermoelectric module [Volts]
I = electric current generated by the module [Ampére]

Electrical efficiency (η_e)

The calculation of the electrical efficiency of thermoelectric module was obtained by Equation 3.

$$\eta_e = \frac{VI}{M_c \,.\, PCI} \tag{3}$$

where:

η_e = electric efficiency [%]
VI = infrared burner power [Kcal/h]
M_c = mass flow rate [Kg/s]
PCI = calorific value of LPG [Kcal/Kg]

Thermal efficiency (η_t)

The calculation of the thermal efficiency of the thermoelectric microgenerator was obtained by Equation 4.

$$\eta_t = P_t / P_c \tag{4}$$

Where:
η_t = thermal efficiency (%)
Pt = thermal power [W]
Pc = power of fuel [W]

Data processing

For completion of data processing and removal of graphics, we used the MS. Excel® software in order to expedite the calculations, organize data and automate the process of implementation.

2.3 Results and discussions

Table 1 shows the data for three maximum temperatures reached on a permanent basis (167°C, 190°C and 200°C). The power was calculated based on the values of loads from 0 to 100%.

Table 1. Experimental data obtained from the tests.

Parameter	Test 1 167°C ΔT=117ºC	Test 2 190°C ΔT=138ºC	Test 3 200°C ΔT=148ºC
Flow gas (kg/s)	0,000107	0,000105	0,000101
Flow water (kg/s)	0,063	0,082	0,068
Flow fuel gas (kg/s)	0,000116	0,000120	0,000123
Enviroment temperature (°C)	28,0	28,0	28,0
LPG pressure (KPa)	200,0	200,0	200,0
Pressure of fuel gas (KPa)	2,8	2,8	2,8
Hot source temperature (°C)	167,0	190,0	200,0
Cold source temperature (°C)	49,2	51,7	52,2
Inside water temperature (°C)	29,2	29,0	29,7
Outside water temperature (°C)	33,7	33,4	35,1

Table 2 shows the values of electrical efficiency and load measured for levels of maximum temperature of 167°C, 190°C and 200°C in a stable regime. The electrical efficiency was calculated based on the values of loads from 0 to 100%. The performance of thermoelectric thermogenerator is shown in the graph of Figure 2.

Table 2. Performance of thermoelectric module

Main results	T=167ºC	T=190ºC	T=200ºC
Voltage module without load (V)	9,10	11,18	11,69
Average voltage of the module loaded 100% (V)	1,30	1,83	2,02
Average current of the module loaded 100% (A)	1,12	1,23	1,43
Maximum electric Power in the module (W)	9,70	12,70	14,70
Electric efficiency (%)	0,19	0,26	0,31
Thermal efficiency (%)	23,80	30,90	33,20
Global efficiency (%)	23,99	31,16	33,51

The value of the maximum power obtained was 11.69 W, corresponding to a maximum electrical efficiency of 0.31% for a load of 20%. It was observed that both efficiencies (thermal and electrical) increased with the increase of thermal gradient (Figures 3 and 4). We observed the relationship of the efficiency of the system with the temperature difference between hot and cold surfaces.

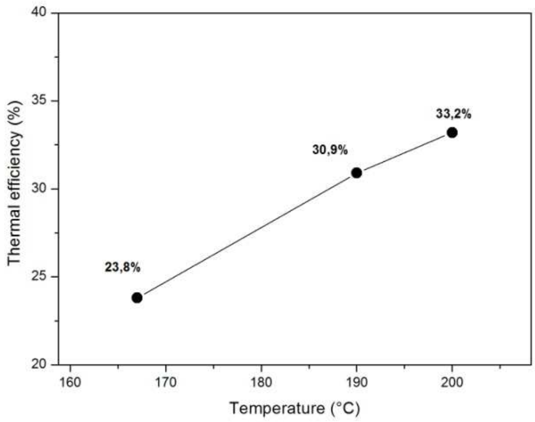

Figure 3. Thermal efficiency

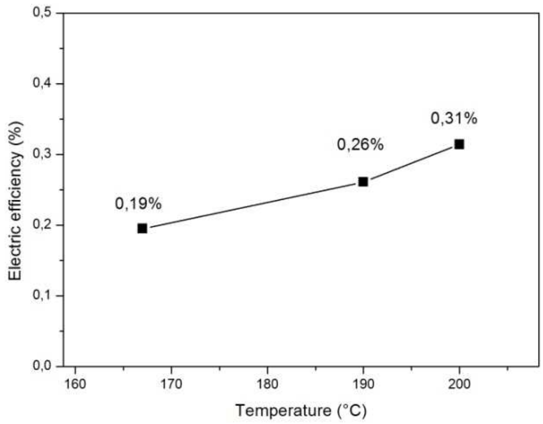

Figure 4. Electric efficiency

2.4 Conclusions

The prototype developed, as well as the test methodology used, satisfactorily met the objectives, allowing to obtain conclusive results about the performance of the experiment.

The results are consistent with those presented in literature and manufacturer of modules semi-conductive.

The overall efficiency of the system could be increased by improving the thermal insulation of the prototype and reducing the resistance of the conductive plate of radiant heating by reducing the thickness in the area of contact with the thermoelectric modules.

The results show that energy efficiency increases with increasing temperature of the hot source of the thermoelectric module, since the heat capacity of fuel is best exploited by the scheme, allowing greater generation of electric power.

The cost of the prototype is obtained with the adjustment of the air / fuel in high levels of fire and fire down the controller, the source temperature hot. The proportional control strategy adopted was satisfactory for regulating the temperature of the hot source through the infrared oven.

The effective area of heat recovery was not used in its entirety, resulting in a lower generation of electric power, ie the number of modules could be folded into the heated area.

3. ACKNOWLEDGEMENTS

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