Analyze the Potential of Use Thermoelectric Materials for Power Cogeneration by Energy Harvesting - Brazil

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Abstract

Thermoelectric materials have a physical behavior that enables the generation of energy. Therefore this research aims at the formation and consolidation of knowledge about thermoelectric materials and their use to energy harvesting for cogeneration. In order to demonstrate the potential of this source of energy cogeneration, there were two laboratory experiments. First simulating the application of thermoelectric module in high temperature gradients and second experiment applying the thermoelectric module in a processor in its operation. The application processor provides unsatisfactory results due to the low temperature gradient. While the laboratory simulation, that due to the high temperature gradient, provides satisfactory results for use in energy harvesting of the industrial processes. Finish up featuring the Brazilian Potential for cogeneration of electricity, showing how Brazil consumes electricity in a year and how much would be possible to save if the thermoelectric modules were used in the ceramics industry, new cars and airplanes. The end result is extremely promising, much of which comes from the potential vehicles combustion. Furthermore, the cogeneration using thermoelectric modules is totally clean, avoiding the emission of carbon to the environment.

Keywords

Energy Harvesting, Thermoelectric Module, Source Energy and Green Energy.

Introduction

The proposed research is to verify the behavior of thermoelectric modules for development of a system for energy harvesting. Thermoelectric materials are materials capable of converting temperature gradient directly into electricity through the Seebeck effect known as. Among the various possibilities of harvesting energy, we highlight the use of thermoelectric materials, because the modules requiring a small footprint, and have no vibration or noise during operation. Since recent studies using rare earth development of new materials show that the thermoelectric modules can reach yields close to 20% [1].

Thermoeletric Materials

The thermoelectricity is the relationship between temperature and electricity. The Seebeck effect, discovered by Thomas Seebeck Johann, this is generating a potential difference between two bimetallic joints when they are at different temperatures [2].
Some years later a physicist named Jean Charles Athanase Peltier discovered that a metal junction can produce heat or cold, the reverse process of Seebeck.
Thermoelectric materials are formed from semiconductors, for a higher current density and therefore the power, due to their proportionality. The semiconductor materials most used are: tellurium, antimony, germanium and silver, highly doped semiconductors to create n-type and p-type grouped

as pairs, which act as dissimilar conductors.

Thermoeletric Modules

Conventional thermoelectric modules have various specifications according to the application. Its dimensions are varied and its tracks to the heat rate may vary from 1 Watt to 125 Watts, with studies underway that may increase this range. The temperature gradient between the hot side and the cold side can reach up to 200 °C. Mostly comprise of 3 to 127 thermocouples. These thermocouples are distributed in some applications in series, operating in cascade in order to obtain differentials higher temperatures, which can reach about 250 °C. Temperatures reached can also be negative, which could arrive experimentally at -100 °C. [3]

Power Generation

Among applications on an industrial scale stands for use by NASA of a micro thermoelectric material in space, the spacecraft like Voyager, Pioneer, Galileo, Cassini, and Viking [1].

FIG. 1 SATELITE VOYAGER [5]

The use of these space occurs due to the energy requirement, thus simply and lightweight, and significantly exceed inefficiency losses in [1].

Presently there are studies using thermoelectric modules in cars whose combustion engines have a maximum yield of 33%, their thermal losses (heat dissipation and exhaust gases) are at least 57% [6].

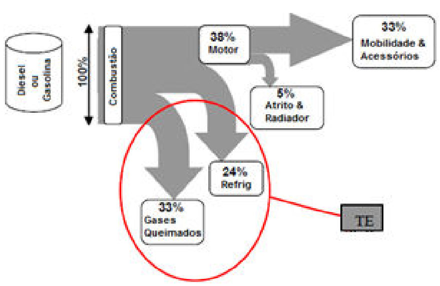

FIG. 2 USING THERMOELECTRIC MODULES IN CARS [6]

Given that only 33% of combustion is converted into work, or 57% will be lost (33% burned gases and 24% of the losses are cooling). Given the temperature gradient, it is possible to grasp about 5% (yield of the module), an increase in the yield of 8.67% in the automobile.

MATHEMATICAL MODELING

Mathematical modeling is the representation of heat transfer from the module that is flowing to the environment, characterizing each step of this transfer. Models of heat transfer occur simultaneously, being these models, conduction, convection and radiation, may examine each of these separately.

The heat conduction is the phenomenon that occurs between solids that present themselves to different temperatures and in contact one to another. Equation (4) describes what is used as the Fourier fundamental equation when studying their analytical theory of heat, with the rate of heat transfer by conduction. It is important to remember that radiation also occurs between solids, but it is very difficult to separate them from driving into the pores of the solid [3].

$$Qcond = kA.\frac{\Delta T}{L} \text{ [cal]} \quad (4)$$

Where:

k: thermal conductivity of the material

A [M²]: Contact area

$\frac{\Delta T}{L}$ [°C/M]: Temperature distribution

The exchange of heat with the surroundings takes place through conduction and convection models and also in a way inferior to the other occurs by radiation. Not being considered possible heat exchange with fans that refrigerariam the thermoelectric module. The heat exchange by convection occurs based on Newton's Law of Cooling, known by (5) below.

$$Qconv = hA(Ts - T\infty) \text{ [cal]} \quad (5)$$

Where:

h [W/M²K]: Convection coefficient

Ts [K]: Surface temperature

T ∞ [K]: Ambient temperature

Energy balance for thermoelectric module

The energy balance is related to the rate of heat absorbed, with the input power and the amount of heat dissipated [3]. Therefore, the amount of heat dissipated is:

$$Qh = Qc + Pin \text{ [cal]} \quad (6)$$

Where:
Qh [cal]: Heat dissipated
Qc [cal]: Heat absorbed
P*in* [W]: Power input

Given that the process is related to thermoelectric effect, requires the inclusion of the thermoelectric effect on energy balance Qc, considering that the material properties are independent of temperature, and half of the heat is generated by Joule effect.

According Moretto, to the Joule effect for best performance of the module occurs in each plate form equal to half the total effect of the module, and also to transfer heat that is induced by temperature gradient appears between plates [3]. Thus it appears to (7).

$$Qc = 2N.\left(\alpha ITc - I^2\frac{R}{2}\right) - k(Th - Tc) \text{ [cal]} \qquad (7)$$

Where:
N: Number of thermocouples module
α : Seebeck coefficient of the material
k: Conductivity of the material
T*h* [°C]: Hot side temperature
Tc [°C]: Cold side temperature

By comparing (10) to (11), one can verify the possibility of expanding pin being expressed in (8).

$$RI^2real = \frac{RI^2otm}{\eta} \quad \text{[W]} \qquad (11)$$

Simplifying, can describe (12).

$$Ireal = \frac{Iotm}{\sqrt{\eta}} \quad \text{[A]} \qquad (12)$$

The amount of cooling coefficient of performance, or COP value is demonstrated in (9), this value means how many times the amount of cooling that is greater heat absorption by the cold side, desiring to increase the value of the COP maximum. [3]

Calculation of Efficiency

To analyze the behavior of the yield of a thermoelectric module there are some steps to follow. The calculation procedure for said work being based on the Seebeck technology from a thermal load and a temperature gradient, determining satisfactory operation points, and estimating the performance for the system, since this presents no linear behavior. [2]

The electrical and thermal characteristics by graphic analysis of the performance of thermoelectric materials to be used are extracted from the datasheet model TEHP1-1.2-24156 available from the manufacturer and shown in Figure 7 with the intention to exemplify the calculations. It is noteworthy that for each application should be analyzed various types and combinations of modules in order to obtain the best result for the system.

Together with the data from the module working temperature, determine the thermal load of the system, and may be of two designs. The active thermal load is to the thermal energy dissipated by the device. And the passive heat load is derived from the radiation, convection or conduction, or a combination of the last two. [3]

To estimate the performance of the module, using the relation Dt / ΔTmax, expressed below:

$$\frac{\Delta T}{\Delta T\,\mathrm{max}} \qquad (13)$$

We analyze the technical data of the thermoelectric material relationship with the current temperature gradient, finding the ratio I / Imax. With the current value of the ratio by the maximum current allowed by the material, is the operating current of the module.

$$\frac{I}{\mathrm{Im}ax} = X \qquad (14)$$

Where, X: Value extracted graphically.

With the current value of the ratio by the maximum current allowed by the material, is the operating current of the module. The voltage limit specifications for the thermal load are obtained by I x V curve of the device, by using the current value found previously. With the results of operating voltage and operating current, provides the calculation of power generated.

$$P = V \cdot I \quad \text{[W]} \qquad (15)$$

Therefore, there has knowledge of the theoretical values required for analysis of the behavior of thermoelectric material. [3]

Correspondent Electric of Generation Thermoelectric

Only the use of the thermoelectric module for converting energy becomes a form of power generation uncontrolled, not being thus possible to measure all that energy from the waste heat and thus obtain maximum energy transfer.

Thus, an efficient cogeneration system consists of various auxiliary equipment. The main components that make up the thermal cogeneration system are:

- Hot Source: Source of waste heat.
- Thermoelectric Module
- Cold Source.

- DC Converter - DC: Filter level.
- Charge Controller: Adjusts load protecting against overloads.

It appears that the use of thermoelectric modules for power generation is not only limited to the module, but a set of electrical equipment that make a structure to a single result. [7]

EXPERIMENTAL ANALYSIS

Theoretical Analysis of Thermoelectric Modules

A thermoelectric module is used INBC1-127.0HTS manufacturer WAtronix Inc., whose dimensions are shown in Fig 3. [8]

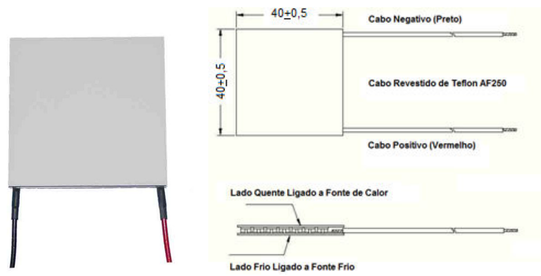

FIG. 3 THERMOELETRIC MODULE MODEL INBC1-127.0HTS [8]

The behavior of the thermoelectric module is shown in the graph of Figure 4, it is possible to analyze which values of power, voltage and current in relation to temperature gradient

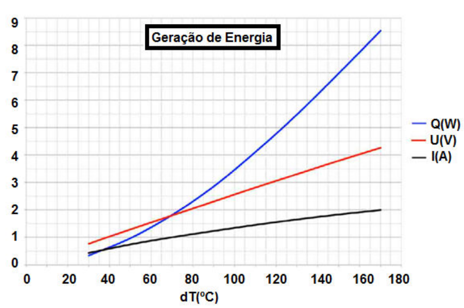

FIG. 4 CURVE OF THE PERFORMANCES INBC1-127.0HTS [8]

We also used to perform analysis of the experimental model thermoelectric module TEHP1-24156-1.2 manufacturer Thermonamic Module (Fig. 5). The module uses like Bismuth and Tellurium thermoelectric material (Bi-Te) and can work at elevated temperatures of up to 330 ◦ C. This module is coated with graphite sheet of high thermal conductivity, not requiring application of thermal greases [9]. Based on the theoretical study makes up the experiment in order to simulate the temperature gradient in order to analyze the behavior of thermoelectric modules. To perform the experiment are used two models, INBC1-127.0HTS and TEHP1-24156-1.2, the tests being conducted on both separately.

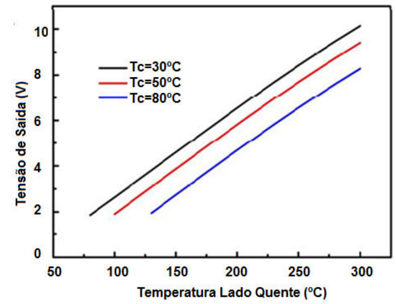

FIG. 5 CURVE OF THE PERFORMANCES TEHP1-24156-1.2 [9]

Initially perform the calculations to analyze the performance of thermoelectric modules. Followed by calculation of income shown in mathematical modelling to the module INBC1-127.0HTS have the values: R = 2Ω and P = 16W. As for the thermoelectric module model TEHP1-24156-1.2, resulting in: I = A and P = 11.6 W. 60.32

Knowing thus the theoretical values for analyzing the behavior of a thermoelectric module of each of the two available models to be applied, it being possible to consider such values are higher than shown in the manufacturer's data sheets, with a maximum output of 8.5 watts for model INBC1-127.0HTS and 20 watts TEHP1-24156-1.2. The theoretical values of thermal efficiency for modules INBC1-127.0HTS and TEHP1-24156-1.2 were 60.32 W and 16W respectively.

To perform the experiment, first off electric placed on a stove with a metal plate approximately 20 mm thick and on top of this plate is placed the four thermoelectric modules distributed side by side on the same. On the other side of the modules is placed a heat sink which is coupled to a metal box, with dissipation fins are inside this box. The housing comes with an opening in its top so that it can be placed within this coolant in order to obtain a greater temperature gradient. Fig. 6 shows an image of the experiment.

FIG. 6 IMAGE OF THE EXPERIMENT

The realization of measurements is used thermocouples for temperature measurement, two thermocouples being placed on the warm side and two on the cold side of the experiment. To finish carries out the measurement voltage of thermoelectric modules. Given that the experiment will be performed without charge, the values of current and power output are discarded. For this measurement the voltage uses a multimeter. Measurements are performed on each module individually.

When the modules are connected in series to the output voltage increases, and when connected in parallel the current that is larger modules bear. The modules can also be associated in parallel thermally, one over another, and thus obtain a higher output power.

In Fig. 7 it is possible to observe a thermographic image taken from experimental and simulation in Fig. 8 shows the values collected in behavior analysis module in the experimental analysis.

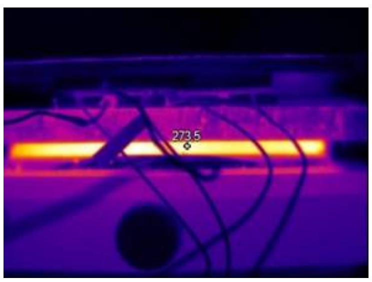

FIG. 7 ANALYSIS OF THERMAL OF THE SYSTEM

After analyzing the behavior of thermoelectric modules in the system, we performed load application. This in turn presents a resistance of 6 Ω.

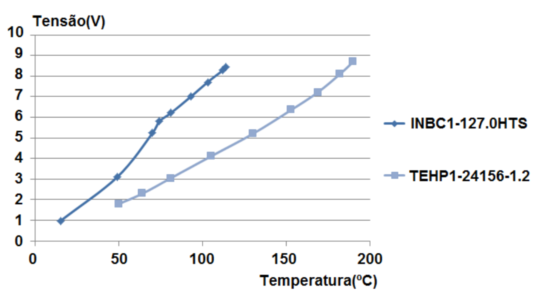

FIG. 8 SHOWS VOLTAGE RESULT THAT OCCUR AT INCREASED TEMPERATURE.

The chart of Fig. 8, generated by the results, shows that occur at increased temperature gradient, it has therefore a higher output voltage at the load.

In Fig. 9 there are power values supplied by the modules INBC1-127.0HTS and TEHP1-24156-1.2. The chart of Fig. 9, generated by the results shows that occur at increased temperature gradient, it has therefore a higher power supplied to the load by the thermoelectric module.

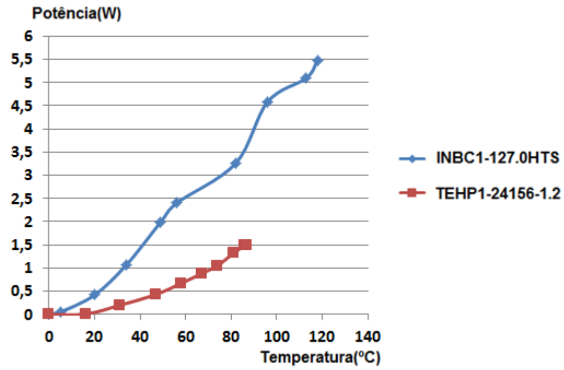

FIG. 9 SHOWS ENERGY RESULT THAT OCCUR AT INCREASED TEMPERATURE

Microcomputer Application

Initially perform the calculations for understanding the performance of the modules. Following the calculation of yield demonstrated previously for the module INBC1-127.0HTS, obtaining the values I = 1.4 A and P = 1.82 W. As to the thermoelectric modules TEHP1-24156-1.2 using the same calculation procedure has the following results: A I = 2.32 and P = 7.19 W. Knowing well the theoretical values for analyzing the behavior of a thermoelectric module of the two models available.

Due to the dimensions of 35.1 x35 processor, 1 mm and thermoelectric modules available for the experiment was applied in the experiment module thermoelectric model INBC1-127.0HTS by presenting cohesion along with the processor. Joined to the thermoelectric module processor, the wall of the hot source module. The values obtained for the thermal efficiency modules INBC1-127.0HTS and TEHP1-24156-1.2 were 1.82 W and 7.19 W respectively. On the wall of the cold source of the thermoelectric module was attached heat sink, this being the source cold (room temperature). The application module at this location did not affect the performance of computer processing. The amounts collected in the analysis of thermal processor are shown in Fig. 10.

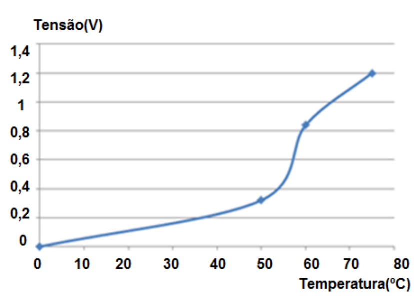

FIG. 10 ANALYSIS OF THERMAL PROCESSOR

It is observed in Fig. 10 that as the processing rate of temperature change is the processor, which in consequence of this the heat sink temperature rises.
Therefore, it is perceived that the power generated increases proportionately with the processing rate, ie the greater the processor utilization, the higher the temperature dissipated by it.
The Fig. 11 shows a thermographic image processor temperature.

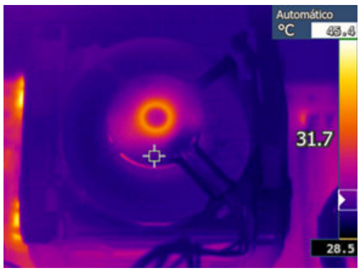

FIG. 11 THERMOGRAPHIC IMAGE PROCESSOR TEMPERATURE

In the chart of Fig. 10 it can be seen that with increasing processing rate is increasing temperature gradient and thus a higher output voltage.

ANALYSIS OF RESULTS

By analyzing the theoretical results found in the experiments, such as 1.2 Volts in the application of thermoelectric module INBC1 127.0HTS-in microcomputer, and 8.65 Volts on the analysis of experimental show a big difference between the two case studies, where the levels of temperatures reflect the values of the discrepancies.
The amounts collected and presented in Fig. 10 where it has a value of 1.2 Volts for a temperature gradient of 40 °C show a very low yield, with the primary cause instability of the temperature gradient, showing variations of values due the processing fee that undergoes variation as a function of their use, however it has become a stress response. This application is difficult, because the voltage found is very limited and unstable, with the consequence that the need for processing of the processor 100%, which does not occur continuously, since not use this degree of processing all the time. If the voltage is stable application would be restricted, however one could use location.
In laboratory simulation of application of thermoelectric modules for temperature gradients elevated responses are shown in Fig. 8, demonstrates superior performance to study the microcomputer. The thermoelectric module is allocated with his face close to hot exhaust and cold along with your face cooling, occurring so a temperature difference. With the aid of measuring equipment it appears generating energy from a source residual. Tensions at levels of 8.69 V responses were found, with such satisfactory answers.
It is noteworthy that strains of 8.69 Volts feeds are values applicable at various levels of signals present in automobiles as well as battery chargers, thus justifying possible uses. Fig. 9 shows graphically the power consumed by a load of 6 ohms, and can reach levels of 5.5 watts, which confirms the micro power.
Overall the results are satisfactory, proving that it is possible to generate power through the use of thermoelectric materials. The different responses provided between the application module and the microcomputer simulation occurs primarily by the temperature gradient obtained in each test.

ANALYSIS OF THE POTENTIAL FOR COGENERATION - BRAZIL

According to the capabilities and limitations of current technology of thermoelectricity and knowing the advantages and efficiency of thermoelectric modules, this stage of the work will look and how much you can save energy with their application in some systems. The calculations involve the Brazilian national scene, and comparisons are made in order to facilitate the interpretation of the final values obtained.

Ceramics Industry

In industrial processes, the Brazilian industrial consumption in 2012 was 62.89 TWh [11], and 1348 GWh are consumed by ceramic industries [12]. It is estimated that only about 3% of all domestic industries adhered to the use of thermal cogeneration system and considering the increased yield of 0.5% aircraft industry which is easily reached. The potential annual savings of electricity would be of 9.43 GWh. Applying the factor of adhesion arbitrated only 3% has to be using the system to capture energy industries ceramics have a savings of 202.2 MWh / year.
If 100% of cogeneration systems industries utilizassem the economy would reach 314 GWh. Knowing that each Brazilian consumes on average 2400 kWh / year of electricity [13], the value previously found would be enough to supply a city with over 131,000 inhabitants.

Fleet Car Ride

In the last decade the number of vehicles in the country nearly doubled and as presented in the previous chapters vehicle efficiency combustion is less than 33%. Confirming that there will be studies to application of thermoelectric modules for cars with the goal of capturing the thermal losses for power generation in order to raise the efficiency of the overall system.

Consequently, one can perform an analysis of discerning the market potential for reducing fuel consumption by capturing residual energies, using the thermoelectricity.

To carry out this analysis is a survey of the number of vehicles, for the purpose of emphasizing the amount of fuel to be saved feasible, with reuse of the thermal energy of the exhaust system of the automobile.

The fleet of cars in Brazil in December 2012 was 42,682,111 cars during the same period in 2011 totaled 39,832,919 the same cars. [14] Since the number of cars increased by 7.15% in one year period, as shown in Fig. 12.

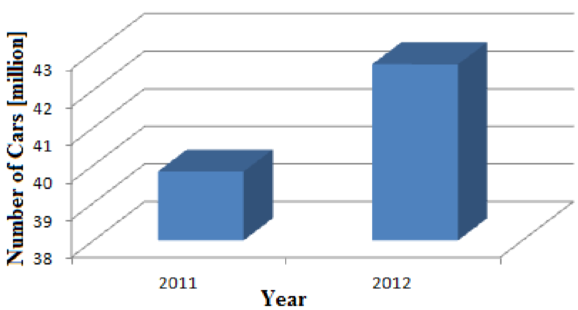

FIG. 12 BRAZILIAN CAR FLEET

Considering that in December 2013 the percentage increase fleet is maintained, there will be 3,051,770 new vehicles in Brazil. Since the average fuel consumption equivalent tonnes of carbon is 1.4 toe / year [15]. Soon consumption expected to increase the fleet of vehicles will be 4,272,478 toe / year.

Currently, thermoelectric materials have an efficiency of 3 to 7%. Therefore it is possible to capture thermal losses of 5% of a vehicle in and around 57% of all fuel that is consumed by the car. This can be used for cogeneration of energy through thermoelectric corresponding to 2.85% of total heat loss. Knowing that the maximum theoretical yield of a combustion engine is 33% (burning fuel), a relationship is made to know the total percentage that fail to spend, ie, the real value of savings is of 8.64%.

Thus, if every new car that emerge in 2013 comes equipped with thermoelectric microgenerator, the economy in this period will be 369,142 toe. This economy is more than the consumption of all cars in the city Florianópolis - SC in 2012, and the same at the end of the year 198,705 vehicles had [14], which multiplied by the average consumption of each car (1.4) , amount to 278,187 toe / year.

Commercial Aviation

Fuel consumption by the Brazilian aeronautics industry is considerably high. The Brazil in 2012 consumed 7292 billion liters of jet fuel - jet fuel. This value compared to 6955 billion liters in 2011 consumed obtained an increase 4.8%, or 337 million liters [16]. This increase can be seen in Fig. 13.

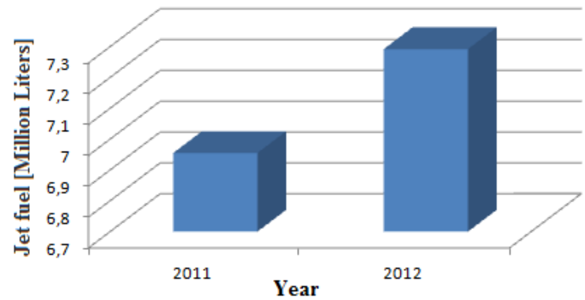

FIG. 13 JET FUEL CONSUMPTION IN BRAZIL

Based on the data in Fig. 13 performs an analysis of the amount of fuel which can be saved in one year in Brazil. The increase in annual consumption of kerosene due to the increase of Brazilian air traffic, and consequently with the emergence of new aircraft.

Considering that every new plane could be equipped with thermoelectric microgenerators these being able to reduce by 0.5% kerosene consumption [17]. Then, with an annual increase of 337 million liters of jet fuel, could save 1,685,000 gallons of jet fuel a year.

The Boeing 737-800 consumes in 1 hour flight from an average of 2970 liters of aviation fuel [18] and has a top speed of 840 km / h. Considering the economy jet fuel previously found he could travel 567 425,505 km traverse this plane, this means providing more than 10 times around the earth, since it has a length of approximately 40.000km [19].

CONCLUSIONS

Based on the results presented in this article, it is clear that cogeneration power using thermoelectric modules is a promising source and presents results that are technically feasible for large scale use. The results were very significant, considering that only a few systems have been analyzed in this model can be applied cogeneration.

It is worth noting that there are ongoing research aimed at improving the efficiency of thermoelectric materials, as well as the need to use renewable sources are increasing, making cogeneration energy by capturing waste energy becomes an attractive alternative for industries.

Has been emphasized that there are other industries with great potential to capture residual energies for energy cogeneration. Among these are the power plants (8.5% of national power generation) processes, foundries and potteries, and particularly the fleet of buses and trucks.

REFERENCES

[1] A. Nascimento, et al. Fontes Alternativas de Energia Elétrica: Potencial Brasileiro, Economia e Futuro. Bolsista de valor. *Revista de divulgação de Projeto Universidade Petrobras e IF Fluminense. v. 2, n. 1, 2012, p.23-36.*

[2] D. N. Campos; T. C. Oliveira. *Controlador de Temperatura Microprocessado Utilizando Célula Peltier*. Monografia (Engenharia Elétrica). Universidade Gama Filho. Rio de Janeiro, 2011.

[3] D. H. SOUZA. *Otimização do Uso de Refrigeradores Termoelétricos em Processos de Refrigeração*. Monografia(Engenharia Mecânica) Universidade de Brasília, Brasília, 2007.

[4] R.E Sonntag.; G.J.V Van Wylen. *Fundamentos da termodinâmica clássica*. São Paulo: Edgard Blucher, 1976.

[5] NASA. *Multi-Mission Radioisotope Thermoelectric Generator.* Space Radioisotope Power Systems, set. 2006.

[6] G. Min. *Thermoelectric Energy Harvesting*. Energy Harvesting, 2011.

[7] M. Rahman; R. Shuttleworth; Thermoeletric Power Generator For Battery charging, *IEE, n.95 TH8130,1995,* p. 186 – 191.

[8] I. Watronix.; *Thermoelectric Power Generator.* Avaliable: <www.inbthermoelectric.com> Acess 08.08.2012

[9] M. Thermonamic; *Specification Of Thermoelectric Module*. Avaliable: <www.thermodinamic.com> Acess 08.08.2012.

[10] X. Zhang.; K.T. Chau; C.C. Chan; Overview of Thermoelectric Generation for Hybrid Vehicles: *Journal of Electric Vehicles*, *v.6, n.2*, dez. 2008, pp. 1119-1124.

[11] AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA, Disponível em: http://www.aneel.gov.br/area.cfm?idarea=550

[12] MINISTÉRIO DE MINAS E ENERGIA – MME. PRODUTO 43CADEIA DA CERÂMICA DE REVESTIMENTO Relatório Técnico 69 Perfil da Cerâmica de Revestimento. Ago.2009.

[13] GANDRA, Alana, Brasil necessita da energia nuclear para crescer, avalia engenheiro da Eletronuclear. Disponível em: http://agenciabrasil.ebc.com.br/noticia/2011-03-15/brasil-necessita-da-energia-nuclear-para-crescer-avalia-engenheiro-da-eletronuclear

[14] DENATRAM, Disponível em: http://www.denatran.gov.br/frota.htm, Acessado em: 20/02/2013.

[15] SEPLAG, Site: http://www.seplag.rs.gov.br/trilhas/conteudo.asp?cod_conteudo=565, Acessado em: 20/02/2013.

[16] ANP, VIII Seminário de Avaliação do Mercado de Derivados de Petróleo e Biocombustíveis. Ano-Base: 2012.

[17] HUANG, James. Aerospace and Aircraft Thermoelectric Applications. Boeing Management Company, 1 out. 2009.

[18] http://www.portalbrasil.net/aviacao_comparativo.htm

[19] CENTRO BRASILEIRO DE PESQUISAS FÍSICAS – CBNF, A pulsação da Terra. Rio de Janeiro, abr. 2012.

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