POTENTIAL USE OF SMALL WASTE HEAT SOURCES BASED ON THERMOELECTRICITY: APPLICATION TO AN OVERHEAD PROJECTOR AND A BATTERY CHARGER

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Abstract

A general overview of the potential use of waste heat sources for the generation of energy will be described in this paper. Attention will be specially placed on low and medium levels of heat sources, in particular in appliances that are used almost daily. In order to demonstrate the effectiveness of the use of such waste heat sources, two applications are described: the generation of electricity from the heat of an overhead projector and the use of heat sources to charge batteries of domestic equipment such as telephones, radios and security systems.

1. Introduction

The use of waste heat sources is a very attractive area for the generation of electrical energy based on thermoelectricity. Waste heat is produced during the normal development of industrial activities. In general, a waste heat source is located in any process, whether industrial or not, where some type of work is performed.

Several methods based on conventional cycles of heat exchange have been tested where the amount of residual heat is great. Today, a very extended application of those methods is cogeneration. All of these techniques are based on an initial strong investment and the addition of new equipment.

However, energy is lost if the waste heat source has a medium or low level of thermal power, because the investments based on conventional techniques are very high. The potential use of thermoelectricity in these cases has to be taken into account. Units able to generate energy from waste heat sources of low or medium intensity, can be very attractive because they can use energy that would be lost in any case, they can replace some components of conventional equipment, and they reduce the need for regular maintenance.

In this paper a general overview of the potential use of waste heat sources for the generation of energy will be described. Attention will be specially placed on low and medium levels of heat sources, in particular in appliances that are used almost daily. In order to demonstrate the effectiveness of the use of such waste heat sources, two applications are described: the generation of electricity from the heat of an overhead projector in order to replace a transformer able to supply energy to the cooling fan, and the use of heat sources to charge batteries found in domestic equipment such as mobile telephones, radios, security systems, etc.

2. Potential use of the waste heat sources

The four major sources of energy in the world: petroleum, natural gas, coal and uranium are limited. A dramatic increase in the primary energy consumption has accompanied the rapid growth of human economical and social activities and it is evident that, at the current rate of consumption, supplies of all types of fuel could become difficult to obtain by the middle of the next century. Furthermore, increasing industrial activity has resulted in a steady increase in the carbon dioxide concentration in the atmosphere causing an increase in the atmospheric temperature of the world (global warming). However there are ways to counteract against these developments and to alter the overall future outlook to a better one than the above mentioned. Action has to be and is being taken in a variety of fields. These actions can be split up into two major groups: More efficient energy use (increasing the efficiencies of technical processes, avoidance of any form of waste and prolongation of the amount of time that they can be used) and the wider use of renewable energy sources. Due to all the reasons mentioned, there is great interest in lowering the amount of energy consumption and ultimately protecting the future of our planet. This is confirmed by the high number of publications concerning these topics, of which a small sample can be observed in references [1 to 17].

One of the consequences of less than optimum efficiencies of processes and apparatuses is that there are vast amounts of waste heat discharged into the atmosphere and its oceans. Evidently, it would be beneficial, both economically and environmentally, to recover some of this waste energy. This can be done by employing heat recovery systems, which mainly use high temperature waste heat to preheat or to evaporate process fluids. Today the use of such heat recovery systems differs widely depending on the region and country where they are used. Unfortunately, the major portion of the waste heat is at temperatures below 140°C, too low for use in conventional electricity generating systems such as steam turbines. However, two recovery technologies are available that operate above this temperature regime: Rankine cycle heat engines, employing low boiling point organic liquids such as ammonia, and thermoelectric generators. Although Rankine engines are more efficient than thermoelectric generators, over the range of temperatures under consideration, they are less reliable and are environmentally unfriendly.

At present, thermoelectric generation using waste heat from a variety of sources is being actively researched at a number of commercially funded institutions, universities and laboratories. The thermoelectric generator has some interesting advantages, for example it is free of moving parts, has a relatively simple construction, is easy to control, has a high reliability combined with a long life time and is environmentally friendly. Of course, there are also disadvantages, for example it has a low conversion efficiency combined with relatively high costs.

A wide investigation programme has been carried out at IIT concerning the potential use of thermoelectricity from waste heat sources [18]. Domestic and service sectors have been identified as the areas that would most likely benefit from applications of thermoelectricity recovering energy from waste heat sources. The main reasons supporting this conclusion are the following:

- Low and medium waste heat sources are more suitable for the current technology of thermogenerators.
- Important amount of devices. This can save cost in their production if they add thermoelectric modules.

- Easier individual integration with devices and appliances.
- Less attention to the pay-back periods.
- Source and use should be close together which could ideally be fulfilled by integrating the TEG

Some criteria have to be defined in order to promote the use of waste heat in the domestic and service sectors by TEG. These criteria can be used to determine the feasibility or not of a possible application and they should be taken into account. It is difficult to elaborate an exahustive list, but some of the most representative could be the following:

- Source. Waste heat emitted: temperature, flow, heat sink available.
- Use. Existing electrical use: performance, voltage and current required.
- Economical factors. Electricity produced, number of sold units, energy use cost savings, equipment cost savings.
- Source-use match. Distance, operating cycles.
- Fluids to use.
- Competitive systems.
- Feasibility of design, construction and installation.
- Advantages of TEG.

The exploration of the potential use of thermoelectricity for recovering waste heat is a promising field under development. In the next two sections of this paper two very simple samples are described as practical examples.

3. Recovering waste heat from an overhead projector

An overhead projector requires an intensive light supplied by a lamp. This simple process produces an important amount of waste heat that can cause damage to the components of the equipment and for this reason it has to be removed using more energy by moving a fan. This process produces waste energy and requires energy to remove it. Therefore it is attractive for the use of thermoelectricity.

An experiment of such an application is been performed at IIT [19] and some results obtained thus far will be described in the following paragraphs.

A simple scheme of the overhead projector used is presented in fig. 3.1. It consists of a lamp, a fan, an AC motor to move the fan and a power transformer that supplies electricity to the lamp and the AC motor.

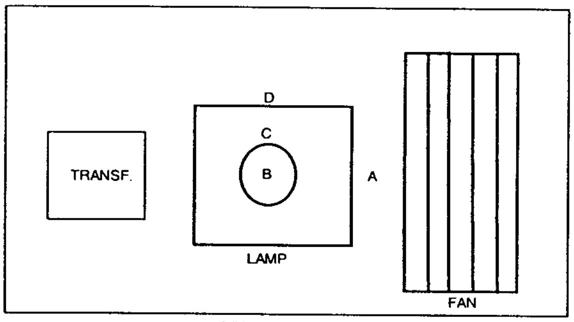

Figure 3.1

The objective of this application is the use of the waste heat produced by the lamp under normal operation of the overhead projector. This waste heat can be converted into DC current through thermoelectric modules in order to supply a DC electrical motor that will move the fan of the overhead projector. In this case the AC motor of the conventional projector has to be replaced by a DC motor. In this application the heat source will be the heat from the lamp and the heat sink is the circulating air which is forced by the fan.

The overhead projector voltage is 220 V and the lamp uses 24 V/150 W. The temperature measured in the lamp (point B, fig. 3.1) is around 200 °C. The ambient temperature measured at both points A and D in fig. 3.1 is around 35 °C.

Several tests have been done in order to evaluate the energy that is possible to recover. Fig. 3.2 shows an example of these tests. Two thermoelectric modules are used as is shown in fig. 3.2. There is no change in the rest of the overhead projector components. The hot side of the modules is at 140 °C and the cold side at 44°C. The voltage generated is 0.618 V at each module without any load. The same test using a load of 56 Ω produces a voltage of 0.455 V and a current of 1.72 mA. As can be inferred from fig. 3.2 the contacts of the theromelectric modules and both source and heat sink are not the most appropiate for the best performance of the thermoelectric modules, but this was preferred to disturbing the configuration of the overhead projector.

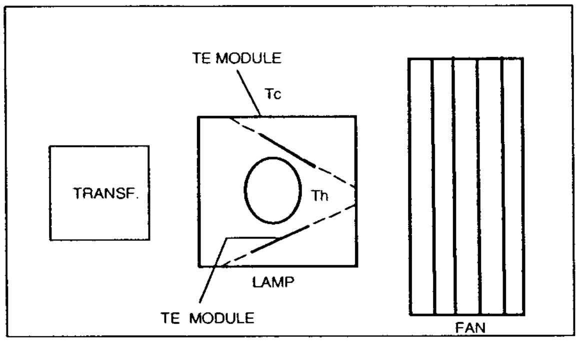

Figure 3.2

The orignal AC electrical motor was replaced by a DC electrical motor for moving the original fan of the overhead projector. The motor requires 1.5 V DC and 0.3 W for nominal performance (150 rpm). The results of the tests using the configuration shown in fig. 3.2 did not reach the electrical requirements for moving the fan and several configurations of thermoelectric modules were tried.

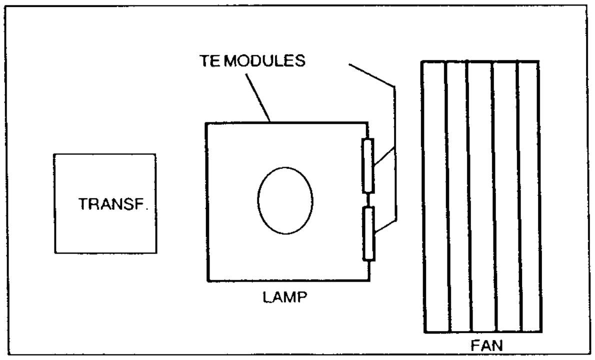

Figure 3.3

Fig. 3.3 shows the configuration of a test using 9 thermoelectric modules in 3 sets connected in parallel and each set containing 3 thermoelectric modules in a serial connection. The total voltage generated and supplying the electrical motor is 1.2 V DC and 0.22 W. The electrical motor does not reach the nominal performance, however it is very close. The speed of the fan is 120 rpm.

Several other locations and positions for the thermoelectrical modules are being analysed in order to improve the results obtained till now. They are good and it can be assumed that the investigation in progress will better reach the objective of the application.

4. Battery charger based on Thermoelectricity

Another simple application of the use of waste heat for energy generation based on thermoelectricity will be presented. The objective in this case is the development of a battery charger. There is a growing number of small devices in the domestic and service sectors that require small quantities of electrical energy for their operation: domestic appliances, mobile telephones, computers, etc. These energy needs could be satisfied using waste heat and thermoelectricity, for this reason the design of a thermoelectric battery charger could be useful.

A conventional battery charger supplied by electricity from the electrical network was studied in order to design another similar battery charger, but based on thermoelectricity. The conventional battery charger used as reference was able to charge up to 4 type AA batteries. The location of the batteries was in a 2x2 matrix. The main electrical characteristics were voltage, 2.4 V and current 70 mA. All of these characteristics were used as requirements for the design of the new thermoelectric battery charger.

The configuration of the thermoelectric battery charger is very simple and consists of a set of thermoelectric modules with electrical outputs to the batteries to be charged. One side of the thermoelectric modules is prepared to be in contact with a source of waste heat, and the other side is in contact with a cooling system.

For testing purposes, the source of waste heat is a set of electrical resistances aisolated from the environment. This permits the best control of all the tests performed.

The thermoelectric battery charger and the heat source used for tests is shown in Figure 4.1.

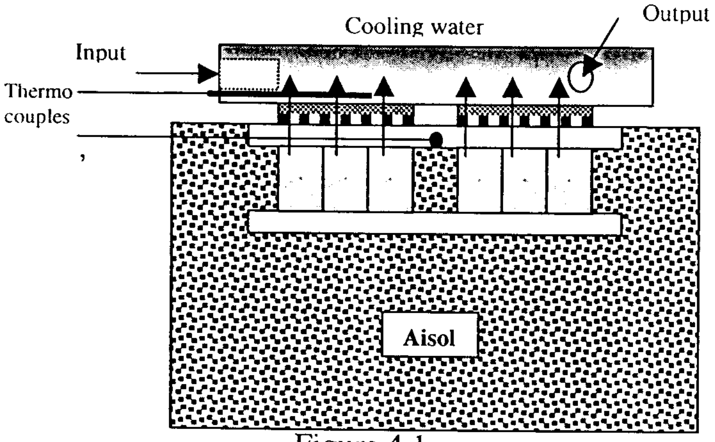

Figure 4.1

Several configurations of thermoelectric modules and their connections were considered and tested. Due to limited space it is not possible to include all in this paper, however some examples are presented below.

4.1 Two TE modules connected in series

This configuration is shown in Figure 4.2.

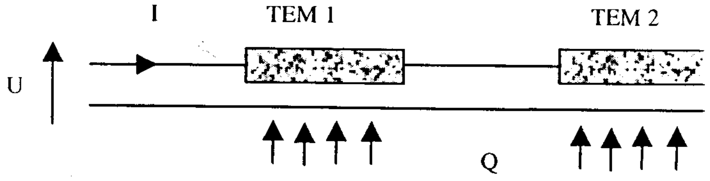

Figure 4.2

Several tests were performed at different Q values (10, 20, 30, 40, 50, 60, 70 and 80 W). Q represents the waste heat source.

Figure 4.3 shows the relationship between voltage and current generated at different values of Q and charging 4 type AA batteries from null charge. The temperature on the cool side was around 21°C and on the hot side between 75°C and 100°C. Figure 4.4 shows the relationship power/current for the same tests.

According to these tests and the requirements for the thermoelectric battery charger, the valid waste heat sources have to have more than 50 W in order to be useful (see fig. 4.3) using the serial configuration. The power in the TE modules is very small and they do not work in the region of best performance.

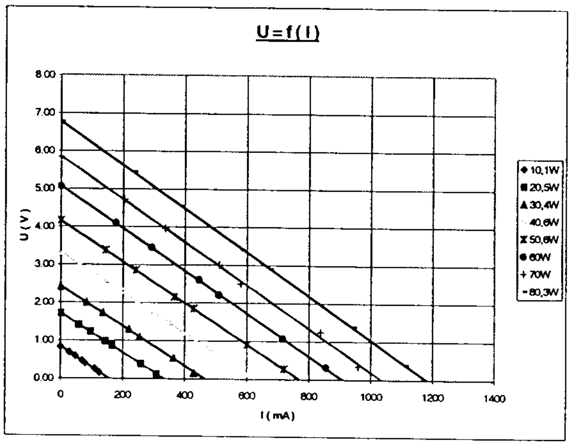

Figure 4.3

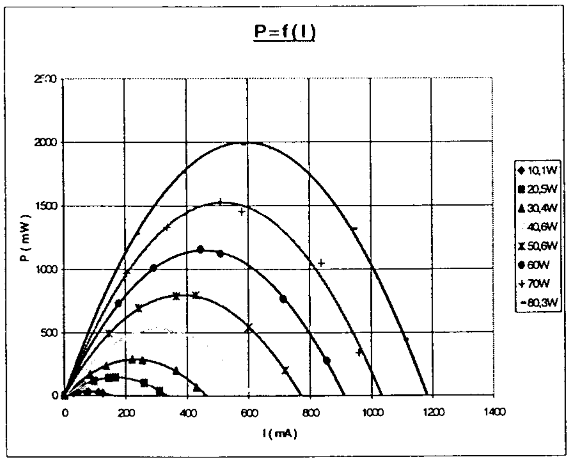

Figure 4.4

4.2 Two TE modules connected in parallel

This configuration is shown in Figure 4.5.

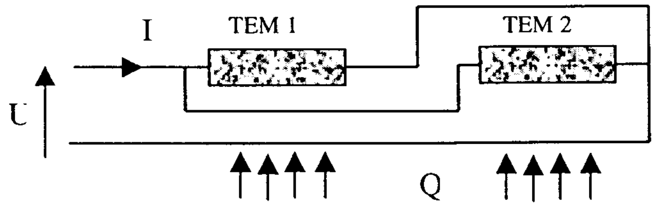

Figure 4.5

Similar tests were performed to those presented for the serial configuration for 2 TE modules and similar relationships which were obtained are presented in figures 4.6 and 4.7.

According to these tests and the requirements for the thermoelectric battery charger, the valid waste heat sources have to have more than 50 W in order to be useful (see fig. 4.6) using the parallel configuration. Now the range of currents is higher. The power in the TE modules is very small.

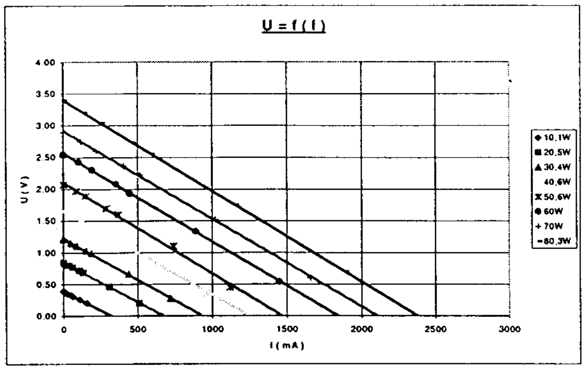

Figure 4.6

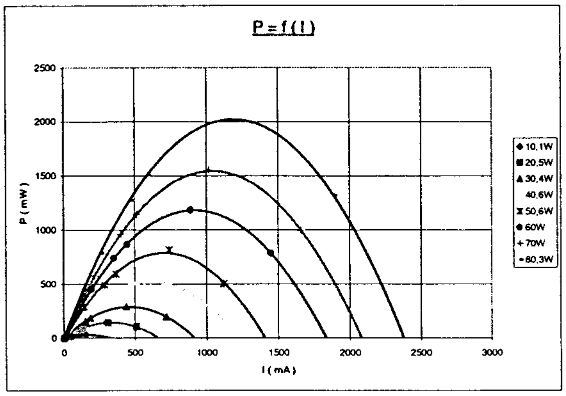

Figure 4.7

4.3 Comparison between serial and parallel configuration for two TE modules

The comparison between serial and parallel configuration for 2 TE modules is shown in figures 4.8 and 4.9. Both tests represented in those figures are using 50 W as waste heat source. The main result of this comparison is that the serial configuration is more suitable to the requirements of charge. The reason is that the performance better reaches the voltage and current required.

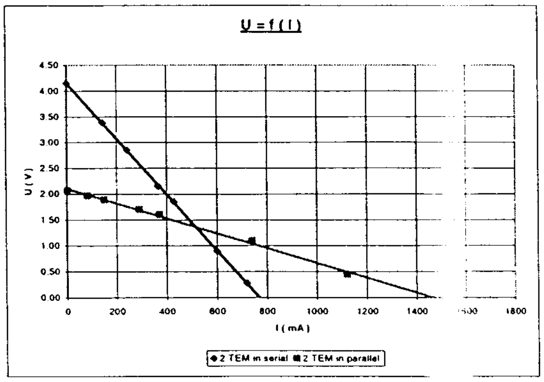

Figure 4.8

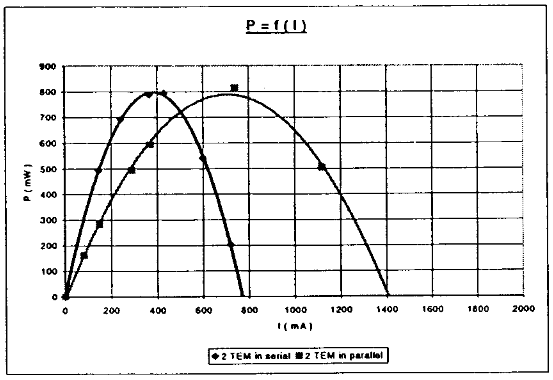

Figure 4.9

4.4 Four TE modules connected in serial

In order to perform a deeper investigation of possible configurations for the thermoelectric battery charger, 2 TE serial modules were added to the 2 TE modules in figure 4.2. In figure 4.10 this new configuration is shown..

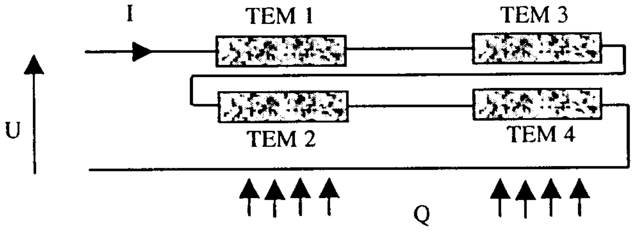

Figure 4.10

Figure 4.11 shows the relationship for both configurations between voltage and current generated at 50 W of waste heat charging 4 type AA batteries from null charge. The temperature on the cool side was around 21°C and on the hot side between 75°C and 100°C. Figure 4.12 shows the relationship power/current for the same test and both configurations.

According to this test and similar ones performed at different values of waste heat, there is no advantage increasing the number of TE modules.

The results of all these experiments demonstrate that when using two TE modules with a serial connection, it is possible to design a battery charger similar to a commercial one.

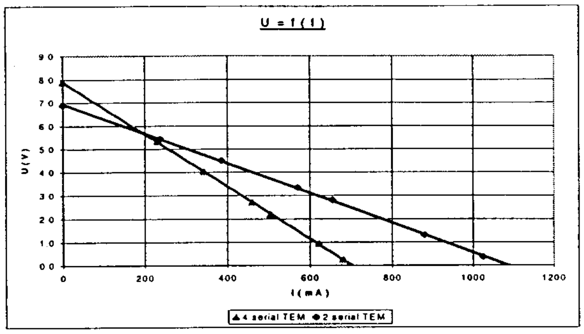

Figure 4.11

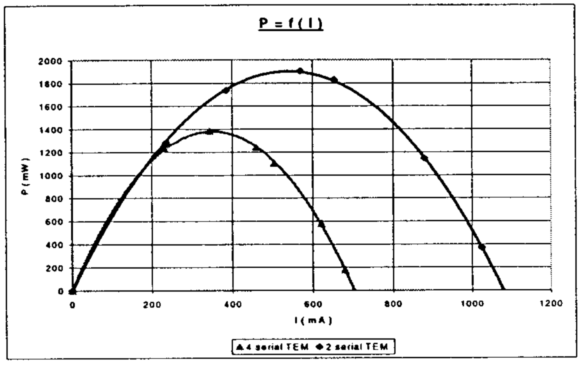

Figure 4.12

5. Conclusions

The use of waste heat is a promising field for the development of thermoelectricity applications. The domestic and service sectors have been identified as the areas that would most likely benefit due to the range of the temperatures of their waste heat sources and the number of devices related. Several criteria have been identified in order to analyze the feasibility of a thermoelectric application in electrical generation. As a sample of the potential mentioned, two very simple applications have been described. One of them is related to the use of waste heat produced in an overhead projector for moving its fan. The other one is the design of a battery charger for multiple devices that require electricity at low power. The results obtained in both applications are close to reaching the objectives proposed. Nevertheless more experimentation has to be done in the field.