PROTOTYPE OF HEAT PUMP BASED ON PELTIER EFFECT FOR APPLICATIONS IN AMBIENT TEMPERATURE CONDITIONING

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ABSTRACT

Air conditioning based on the Peltier effect has many theoretical advantages over other air conditioning techniques. This idea encouraged the development of a research project oriented to study the applicability of this technique to industrial and domestic applications. In this project an experimental heat pump has been designed and built to study the behaviour of Peltier cells. At this moment the pump is built and installed in the laboratory of the Universidad Pontificia Comillas and different performance tests are being carried out. Most sensors and the data acquisition system have already been installed, and the first measurements have been taken. This paper describes the pump components and gives an overview of the first but partial results. Further results will be communicated in later papers.

INTRODUCTION

Currently, most commercial heat pumps are based on a thermodynamical cycle that uses an inert gas, usually CFC, and movil elements such as compressors and at least a fan.

A Peltier cell is an electronic device that pumps heat from one of its sides, cold focus, to the other one, hot focus, when a direct current is supplied.

Refrigeration based on Peltier effect is currently being applied to very specific processes of low power such as small electronic devices. There are two main restrictions for the application of this technology:

- The high cost of the cells

- The difference of temperature between the sides of the cells is limited.

However there are important advantages using this technology. Some of them follow:

- There are no movil parts. This fact prevents noises and vibrations and increases the equipment reliability.

- The use of typical fluids it is not required preventing any leakage and environmental damage.

- Easy control by voltage and direct current that are supplied to the cells.

Based on these ideas, a research project is being developed to study, design and build a prototype of heat pump based on the Peltier effect. This project is being developed as a collaboration between the spanish utilities ADAE and Fagor and the Universidad Pontificia Comillas. This project is financed within the research programme of spanish electrical utilities. The resources are coordinated by OCIDE.

RESEARCH OBJECTIVES

The main project objectives are the design and construction of a heat pump based on the Peltier effect. This will allow the study of the characteristics and performance of this heat transfer technique and its applicability to domestic and industrial applications.

This prototype might assert the advantages of the equipment based on the Peltier effect and will probably suggest several modifications to improve the performance of heat or cooling systems. It is expected to find new applications in fields where the Peltier effect could be a good approach. In addition, several industrial processes currently in use could be implemented with this technique, obtaining the benefits already pointed out.

The main phases of this research project are:

1.- Study of the performance of all commercial Peltier elements available.

2.- Overall specification of the heat pump based on the Peltier effect.

3.- Detailed calculations and design of each pump component.

4.- Prototype construction.

5.- Installation of measurement instruments and sensors and testing of the prototype.

Currently, the project is in its final stage. The prototype is built and several tests are being carried out. The first and very partial results obtained will be presented in this paper.

DESIGN OF THE PROTOTYPE OF A HEAT PUMP BASED ON PELTIER EFFECT

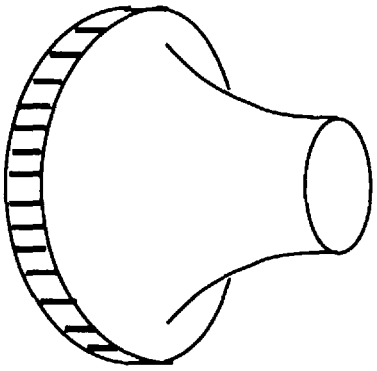
General prototype overview

The main idea behind this heat pump prototype is to use it as an equipment for air conditioning. Therefore, the use of air as a fluid to be heated or cooled is obviously required. One of the sides of a Peltier cell can transfer heat or cold depending on the direction of the direct current supplied to it. To use this property for air conditioning, an air heat exchanger must be placed at one side of the cell. The losses between the cell and the heat exchanger must be minimized. At the other side of the Peltier cell, another fluid is required, to make possible the Peltier effect. This fluid pumps heat from one side of the cell to the opposite one. For this purpose, water was chosen and a water heat exchanger was placed at one side of the cell and an air heat exchanger at the opposite one.

Once the way to transfer heat or cold to the air by means of a Peltier cell has been designed, it is necessary to estimate the heat power required for air conditioning. For this purpose, several cells are needed. These cells must be located between the air and water heat exchangers in order to transfer the heat power required. The prototype is designed to transfer 1450 hot watts to the air.

Summarizing, the heat pump prototype consists of three main parts: air heat exchanger, water heat exchanger and Peltier cells. The following subsections of this paper describe the most relevant design details of these main parts.

Air heat exchanger description



Air heat exchanger

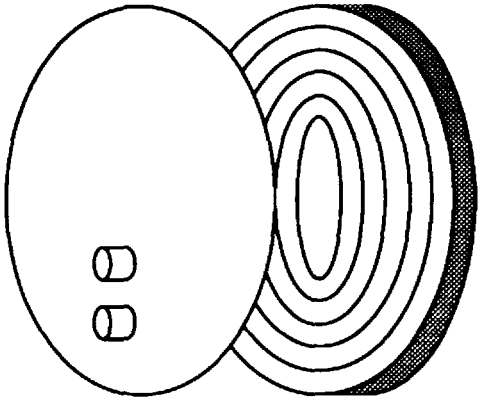
Figure 1

The air heat exchanger has been designed to transfer about 1450 hot watts, from a plate where the Peltier cells are mounted, to the air. A circular and needle heat exchanger was chosen to allow forced air flow as cooling or heating fluid, using a fan. The fan is then located in the center. Its rotation axis is perpendicular to the plate so the air flows in radial direction from the outside to the middle of the plate and leaves the exchanger through the fan, in axial direction.

The needles are perpendicular to the plate so there is a temperature gradient along each needle. This has been taken into account by using the thermal-efficiency coefficient in the calculus process. Also, the needles are disposed in several concentric circles. Each circle has the same number of needles. The height of each needle is the same in a circle but different from one circle to another and increases from outer to inner circles. This configuration keeps constant the Reynolds number and the velocity through the exchanger along the radial direction.

The number of needles, their diameter, height and distribution, as well as the overall size of the heat exchanger have been calculated iteratively, optimizing the global size and maintaining enough heat transfer power. Several restrictions in dimensions and fan characteristics were imposed at this stage.

Water heat exchanger description



Water heat exchanger

Figure 2

The shape of the water heat exchanger is fixed by the air heat exchanger. The water heat exchanger is circular and has five concentrical channels distributed from an internal radius to an external one. The water flows through these channels and may serve as a cooling or heating fluid, depending on the sign of the direct current supplied to the cells. The heat transfer takes place in the lugs that separate the channels.

One of the sides of the cylinder is in direct thermal contact with one of the sides of the cells. At the other one there is a circular aluminum sheet which serves as a cover for the channels, and supports the water inlet and outlet.

The possible residual air contained at each channel can be vented independently by means of five venting devices placed at the top of each channel. At this point, it is necessary to say that the circle is in vertical position. The water flow through each channel can also be regulated independently, using five butterflies placed at the output of each channel. This allows a higher water pressure inside the channels, helping the venting process. It also gives water flow control.

Both exchangers, air and water, have an external radius of about 720 millimeters.

The water heat exchanger was designed to work using the water flow coming from a domestic tap.

Peltier cells

In order to obtain the heat transfer required a set of 24 Peltier cells was chosen. These cells are located between the air and water heat exchangers in two circular coronas. Their position was decided seeking the most uniform distribution of temperature along the sides of each exchanger because uniform temperature in the surface of the bases of both exchangers was a design hypothesis.

The calculations were estimated using direct current values between 5 and 6 Amperes.

PROTOTYPE CONSTRUCTIVE ASPECTS

Unfortunately, the situation of the project at this moment does not permit to expose the exact construction details in this paper because the prototype has not been patented yet. For this reason only a general description will be given.

Constructive details of the air heat exchanger

The air heat exchanger was the most difficult component to build. It has been made of aluminium. It consists of a platform and a very large number of needles. A copper model was also designed, because copper has better thermal properties than aluminium and the resulting size was much smaller. However its cost was very high.

Each needle has been mechanized to its particular dimension and introduced with a hammer in the hole made in the platform for this purpose. Previously, the hole was filled with thermal conductor silicone. This procedure guarantees the most perfect heat transmission from the Peltier cells to the needles of the exchanger.

After the needles were put into the platform, this showed some deformations, and the side in contact with the cells had to be rectified.

The fan was located at the middle of the heat exchanger, over an area where no Peltier cells were mounted.

Constructive details of the water heat exchanger

The channels of this exchanger were cut in an aluminium cylindrical block. This process was easier to realize than the air exchanger construction, but more machine time was required. The cover was also made of aluminium, wide enough to hold the venting devices, the water inlet and outlet and the flow regulators, which have all been screwed. The cover was attached to the exchanger by means of two concentrical rings of screws, at the most internal and external radius. There is also a line of screws from the cover to the aluminum lug separating the entry and exit of the channels in order to avoid any flow communication between the water entering and the water leaving.

Peltier cells

The cells were distributed in order to obtain uniform temperature in the surface of the bases of both exchangers. The space among the cells was filled with insulating material in order to prevent heat transfer through the air contained between the exchangers. For this reason the cavities inter semiconductors of the cells were also filled with the same material. This construction guarantees the best possible heat transfer from the cells to the exchangers.

The cables to supply the cells are very easily accessible outside the heat pump.

INSTRUMENTATION AND SENSORS INSTALLED

In order to carry out the performance test of the prototype heat pump, several sensors, a data acquisition system, a personal computer and three power sources have been installed.

The data acquisition system is a standard datalogger able to take 23 differential inputs.

The personal computer is a PC 486.

Three power sources supply the cells.

The measurements that are being taken during the experiments can be divided into four groups:

- external measurements

- measurements to study the performance of the Peltier cells

- measurements related to the air heat exchanger

- measurements related to the water heat exchanger

Not all the measurements are taken on-line. All sensors are permanently installed but depending on the kind of test only a few of them are connected to the data acquisition system.

All the temperatures are measured using thermocouples type K.

External measurements

There are 7 signals external to the heat pump. These are the electrical characteristics of the electrical power sources and the ambient temperature, and more specifically:

- voltages of the 3 electrical power sources

- currents of the 3 electrical power sources

- environmental temperature (this is the temperature of the air at the input of the exchanger).

Measurements to study the performance of the Peltier cells

Ten variables are measured to test the performance of the Peltier cells. These are the voltages, currents and temperatures of 3 cells mounted in different areas of the pump. Due to the electrical connection between the electrical sources and the cells their voltages are the same and it is only necessary to measure the cells currents.

The temperature on both sides of each cell are also necessary and are estimated from the temperatures measured in the exchangers.

Measurements related to the air heat exchanger

Several temperature measurements as well as parameters of the fan are necessary to evaluate the performance of the air exchanger. There are as follows:

- Air temperature measured at two different heights at one outer and at one inner needle. Air temperature is also measured at the outlet of the fan.

- Needles temperatures are measured at two different heights at one outer and one inner needle, and at one needle located in the middle of the internal and external radius of the exchanger.

- Air flow and fan speed will also be measured.

Measurements related to the water heat exchanger

In order to test the efficiency of this exchanger three measurements are needed:

- water flow.

- leaving-water temperature.

- entering-water temperature.

HEAT PUMP TESTING

The objective of this phase is to measure the most representative variables of the pump behaviour, in order to check the design specifications of the exchangers, the behaviour of the Peltier cells and the global performance of the pump.

At the present stage, most sensors, the data acquisition system and the personal computer have already been installed. Several tests have been carried out but the results are not representative enough to issue definitive conclusions about the pump performance. More information about these and future tests will be communicated in later papers. Here we will briefly describe the first results pointing out the main aspects of the pump behaviour.

The cell current, the water flow and the fan speed can be used to control the behaviour of the pump. So far, the influence of the water flow and the fan speed have been investigated.

Figure 3 shows a situation where the fan was off, the current that supplies each cell was 6 A and the initial water flow, although not measured directly, was 100% of the total flow. This flow was reduced twice during this test. As shown in figure 3 the temperature of the air heat exchanger falls to zero degrees and the leaving water temperature rises some degrees, demonstrating that the cells are operating, from a qualitative point of view, as it was expected. It can also be seen that reducing the water flow, the leaving water temperature increases. This is due to the fact that it is easier to heat less volume of water, and this is also why the needle-temperature slope decreases.

I=6A. , Water flow 100% , Fan speed 0%.

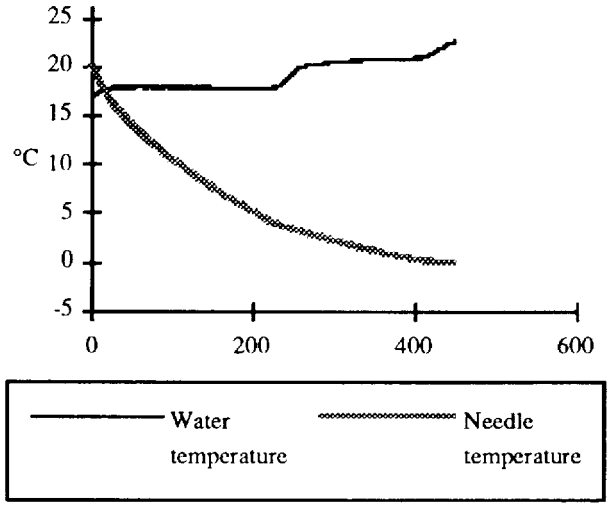


Figure 3

Figures 4 and 5 show the evolution of the temperatures of the air and water leaving the pump, operating under two different fan speeds. In both cases the air is being cooled down. It can be seen that the temperature of the air leaving, strongly depends on this variable, while the temperature of the water leaving behaves similarly in both situations. The cooling power of the air heat exchanger is directly related to the fan speed.

I=6A, Water Flow 100%, Fan Speed 50%.

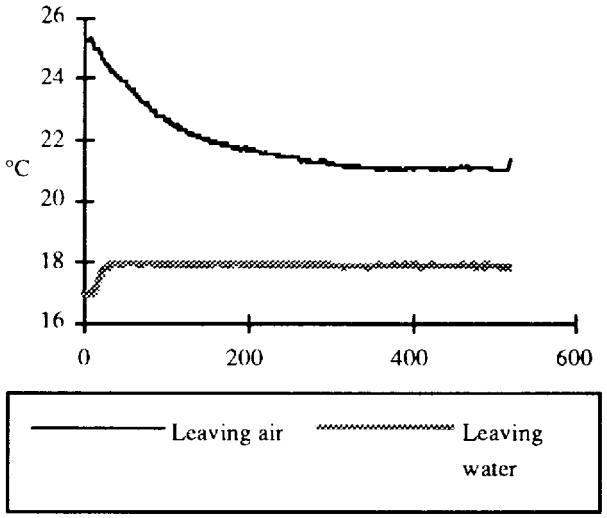


Figure 4

I=6A, Water flow 100% , Fan speed 100%.

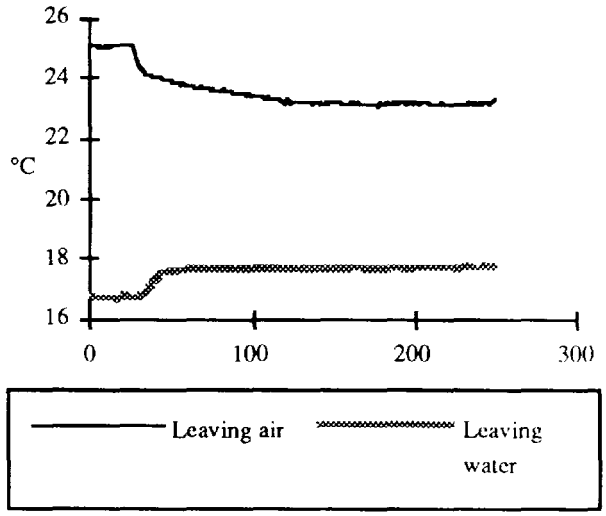


Figure 5

Figure 6 shows the evolution of two variables of the air heat exchanger, the temperature of a needle and the temperature of the air flowing next to the needle. The air temperature shows a sudden rise that we have not been able to explain, yet.

I=6A, Water flow 100%, Air flow 100%.

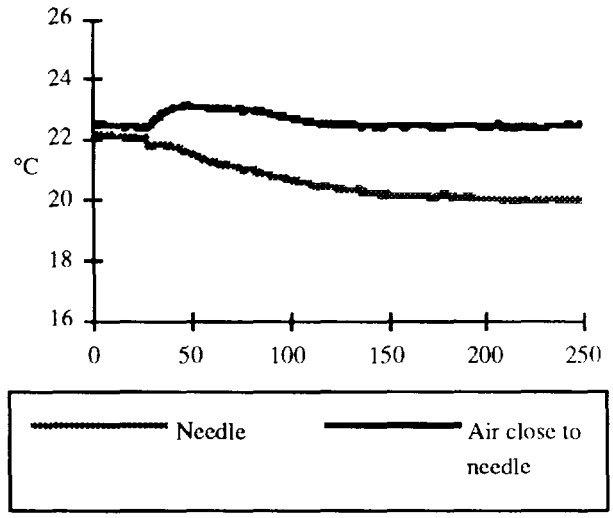


Figure 6

SUMMARY AND FURTHER WORK

This paper has described a prototype of heat pump based on Peltier effect. This technology looks as very promising because it overcomes problems that today are present in the existing heat pumps, such as the type of fluids required, the noise, lack of reliability of the equipments, etc...

The prototype has been built and the first steps in order to test the design hypothesis have being taken. The prototype will be thoroughly tested in the next few months and the final results will be published in a another paper.

New aspects to investigate are related to new composition and structure of the Peltier cells and optimal design of the heat exchangers.

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REFERENCES

[1] Ioffe A.F. "Semiconductor thermoelements and thermoelectric cooling" Infosearch Limited, 1957

[2] Goldsmith H.J. "Thermoelectric refrigeration" Tempel Press Book Limited, 1964

[3] Heikes R.R., Ure R.W. "Thermolectricity: Science and engineering" Interscience Publisher, 1961

[4] Cadoff I.B., Miller E. "Thermoelectric materials and devices" Reinhold Publishing corp., 1960