THERMOELECTRICITY APPLIED TO THE CRYOCONCENTRATION OF ORANGE JUICE

Miguel A. Sanz-Bobi*, Rafael Palacios*, Antonio Arenas**

Universidad Pontificia Comillas
* Instituto de Investigación Tecnológica
** Laboratory of Heat and Mechanical of Fluids
Alberto Aguilera 23
28015 Madrid, Spain

Abstract

The high content of water in natural fruit juices suggests the reduction of their volume by its elimination. This is a concentration process for juices that saves space and reduces costs for storage, transport and handling. A very important part of the industry dedicated to the production of fruit juices produces concentrated juices that are obtained using conventional refrigeration cycles based on gases such as NH_3. These technologies have been used throughout an important number of years with successful results. However, they require special care with the replacement and use of the fluids needed and for maintenance to be applied. These aspects induce to consider and to propose new ways of cooling.

This paper describes the main features of a prototype of a "cryoconcentration cell" for obtaining concentrated orange juice. This development is being supported by a research project within the program of the CICYT, a Spanish Government Agency to promote R&D activities. The prototype proposes the use of the Peltier effect as an alternative to the traditional methods of cryoconcentration using the aforementioned conventional techniques.

The cryoconcentration cell uses a set of thermoelectric elements to produce the cooling conditions able to convert the excess of water included in the juice into ice so that later it is possible to eliminate it and to concentrate the juice. The orange juice will be the hot sink in our application. The heat extracted from the orange juice will be transferred to water in circulation, which will be the cool sink.

A first prototype of this cell was constructed in aluminium [1]. From this experience another prototype was constructed in copper which is an improvement over the first one. Both prototypes of cryoconcentration cells use 16 thermoelectric elements on both main sides of the recipient that temporarily contains the juice.

A detailed description of the last prototype, its design and some initial results obtained will be presented in this paper.

Cryoconcentration of fruit juices

The contents of water in natural fruit juices is between 85 and 90 per cent of their total volume. This high content of water suggests its elimination by the concentration of the juice. This process will save important costs of packaging, transport and storage.

The most part of these concentrated juices are type "three plus one", that is, they require the addition of three volumes of water to one volume of juice to recover the original product. The degree of concentration is measured in Brix degrees. This unit indicates the content of soluble solids of the concentrated product. For example, if three volumes of water are added to a concentrated juice of 45 ° Brix a new product of 15 ° Brix results.

Two main industrial methods exist to concentrate natural juices [2][3]:

- Evaporation
  Different versions of the evaporation method exist, but in any case the water is eliminated by the addition of heat.

- Cryoconcentration
  This is the process of cooling juice till -8°C to obtain ice and fruit juice, because the freezing point of this is around -12°C. The next step is a mechanical separation of the ice from the juice.

The cryoconcentration of fruit juices has several advantages in respect to other methods. Some of them are the following:

- Volatile substances are not lost like in the evaporation process. This is important to keep the taste and aroma of the juice intact.

- The fermentation and growing of patogen microorganisms is disminished.

- This process is cheaper than evaporation.

Use of thermoelectricity in the cryoconcentration process as an alternative to current methods

Thermoelectricity as an alternative

The cooling requirements to be reached in the cryoconcentrated fruit juices are within a range where it is possible to think in the use of thermoelectric elements to fulfill these requirements.

In order to investigate this new application of thermoelectricity, a research project with this objective is being developed by the Instituto de Investigación Tecnológica (IIT) belonging to the Pontificia Comillas University. This

project is a subproject within another bigger project in which the objetive is the study of new fruit concentration techniques. Three Spanish research centers have collaborated: Instituto del Frío, Complutense University and IIT. IIT is in charge of the investigation concerning the application of thermoelectricity techniques. The project is supported by the CICYT, a Spanish Government Agency to promote R&D activities. A first prototype of cryoconcentration cell using aluminium as the main material for heat transferring was reported in a previous publication [1]. This paper starts from this point and presents the new results obtained.

Industrial use of the cryoconcentration of fruit juices

In order to understand the details about a cryoconcentration industrial process of natural fruit juices, we visited an industry of orange juice concentration that used the cryoconcentration technique. We used the main features observed in the process as a pattern to fit our development. Such features are summarized in the following paragraph.

Once the juice is obtained from the oranges, it is processed to eliminate microorganisms and put to cool. The cooling system is based on a typical NH_3 circuit with strict requirements of maintenance for its components. This system is able to cool the juice till -10° C obtaining ice and liquid juice inside the ice. The thickness of the ice is 10 mm. The next step to obtain the concentrated juice is a mechanical separation of the orange juice achieved by pressing the ice.

Description of the cryoconcentration cell

A first prototype able to demonstrate the feasibility of the thermoelectricity application was designed and built using aluminum as the main material to transfer heat [1]. Using this experience, another prototype was built improving both the design and performance characteristics of the previous one. This new prototype, named cryoconcentratation cell (in short CC), was designed using copper as the main material to transfer heat. As in the previous case, the new CC was designed according to the main parameters that we observed in the real process. These are:

- Thickness of ice produced:10 mm
- Temperature of the ice: between -8° C and -11° C
- Recipient containing the juice suitable for human consumption

Additional requirements to the prototype were:

- Design thinking toward an industrial use
- Modularity and interchangeability of CC
- Low cost

The CC objective is to extract heat from the orange juice till freezing its water content (not the juice) and to transfer this heat to another fluid, in the present prototype water, using a set of thermoelectric elements.

The CC operation is like a heat pump [4] where the orange juice is the hot sink and the water used to take the heat extracted from the juice is the cool sink.

According to these requirements the CC prototype consists of three main parts: recipient to contain the orange juice, module of thermoelectric elements, and heat exchanger. A description of each one follows.

Recipient to contain the orange juice

This recipient has two squared parallel sides separated 10 mm to store the orange juice to be concentrated. This separation corresponds to the thickness of ice necessary to obtain. A representation of the recipient is shown in figure 1.

The recipient was made of stainless steel. This material permits a good heat transfer and is suitable to store edible products. The orange juice is introduced and removed through side A (figure 1). This side is open to the environment. The aluminium plates C_1 and C_2 permit the heat transferring from the juice to the heat exchanger using the module of thermoelectric elements.

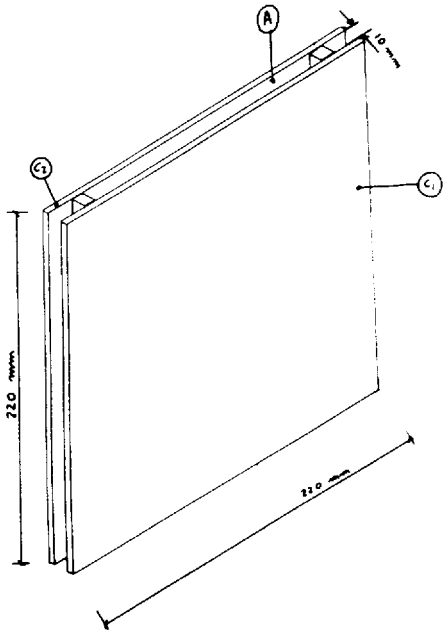

Figure 1

Module of thermoelectric elements

The CC has two modules of thermoelectric elements attached outside the recipient containing the orange juice, one to the surface of the side C_1 (figure 1) and another one to the side C_2.

These modules consist of 16 thermoelectric elements each. The physical disposition of the elements is a squared matrix of 4x4 elements equally spaced. The 12 outer elements are type Marlow model DT-1089 and the 4 inner elements are type Marlow model DT-1069 All these elements are connected in parallel and are supported by a copper plate that fits with the side C_1 or C_2 of the recipient that contains the orange juice. A picture of this module is shown in figure 2.

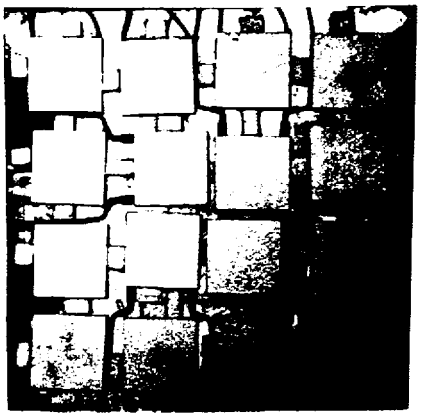

Figure 2

Heat exchanger

The heat exchanger permits the circulation of water coming from the general external water network. It is made of copper and put in contact with the hot side of the matrix of thermoelectric elements to transfer the heat to the water.

The heat exchanger consists of two elements. The first one is a squared plate that fits to the dimension of the module of thermoelectric elements covering it. The second one is a cooling coil made of copper pipe running along the surface of the plate. The cooling coil is joined to the plate by solder. The cylindrical pipe was deformed to obtain a plain side in contact with the plate.

The water flows forced through the pipe. There are two exchangers, one for each thermoelectric module. A picture of the heat exchanger is shown in figure 3.

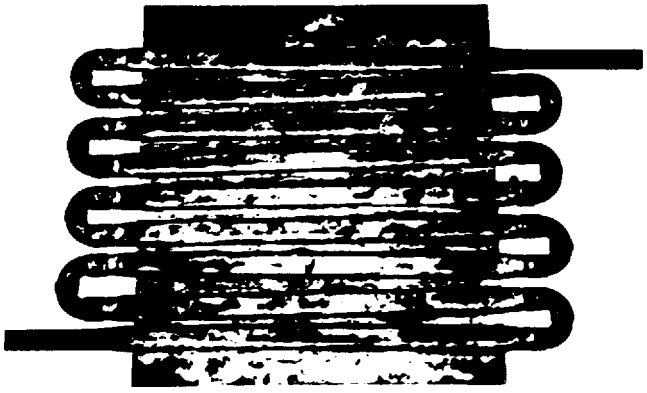

Figure 3

Several CC can be used in an industrial process working in parallel. The modular construction of the CC allows the easy change of any element if it should be necessary.

Electric supply for the cryoconcentration cell

For the purposes of our investigation, three DC power sources of 40, 40 and 120 A supplied the 32 thermoelectric elements included in the CC. The distribution of power to the thermoelectric elements is according to the scheme presented in figure 4.

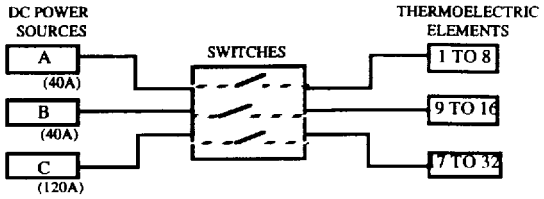

Figure 4

Cryoconcentration cell monitoring

In order to test the CC, several sensors were installed. These sensors collect the temperatures at various key points of the design. Thermocouples type K of 2 mm thickness were used for temperature measurement in the cooling side of the thermoelectric elements. The distribution of sensors in the CC is shown in figure 5.

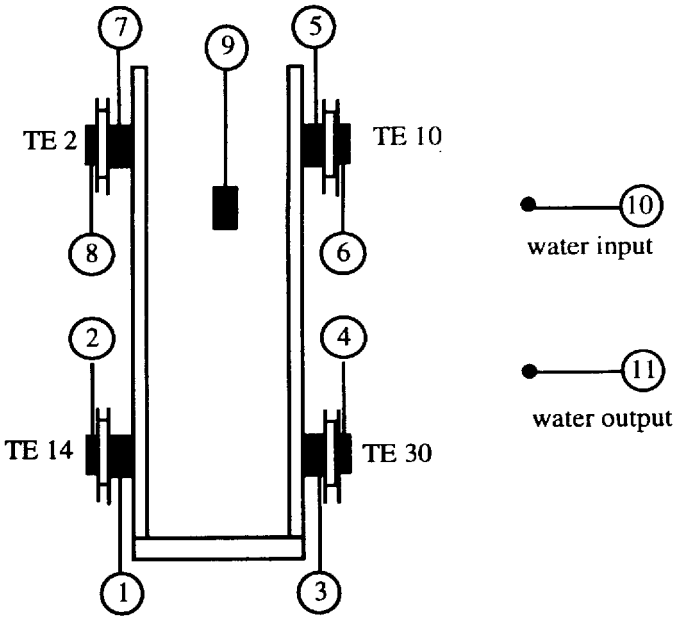

Figure 5

The description of the measurements indicated in figure 5 follows:

Thermocouple	Description
1	Cool side TE 14
2	Hot side TE 14
3	Cool side TE 30
4	Hot side TE 30
5	Cool side TE 10
6	Hot side TE 10

7	Cool side TE 2
8	Hot side TE 2
9	Juice in the middle
10	Water input
11	Water output

The TE (Thermoelectric Element) numbers 14 and 30 are on the same horizontal level on opposite sides of the recipient containing the juice. The TE numbers 10 and 30 are on the same vertical level on the same side of the recipient containing the juice.

The thermocouples were connected to a datalogger and this to a PC. A programme running in the PC was able to automatically collect the data from the sensors.

The water flow circulating inside the heat exchanger was measured using a counter not connected to the datalogger.

The consumption of electrical power used was noted reading the external panel of each DC power source.

Cryoconcentration cell performance

The CC has been tested in several working conditions and the results obtained have been analyzed to compare the performance observed with this design.

The different working conditions were obtained changing the DC current supplied to the thermoelectric elements because this parameter is the easiest to change for different tests. The temperature of the water circulating inside the interchanger is fixed by the water network. The flow of the water was also difficult to control because very small flows were required in the testing and a high precission flowmeter was not available. According to these restrictions, it was only possible to easily change the DC current.

Tests were done several times at 2, 3, 3.5, 4 and 5 A per thermoelectric element. In the entire test a pre-fixed flow of water running along the heat exchanger was used and orange juice was obtained from market oranges.

The following figures show the CC performance for 3.5 A as an example of the results obtained.

The evolution of the input and output water temperature in the heat exchanger is presented in figure 6. In this figure the temperature of the water input is constant (17.8 °C) and is fixed by the water network of the laboratory. The temperature of the water output increases to 22.8 °C when the CC is supplied by DC current. The decreasing trend of this temperature is similar to that observed in the hot side of the thermoelectric elements (see figure 8). The difference between water output and the hot side of the thermoelectric elements is around 13 °C.

The evolution of the orange juice temperature is presented in figure 7. This figure shows a decrease in the juice temperature after the thermoelectric elements are connected (90 s) till -8 °C, a temperature convenient for juice concentration by conversion of water into ice. The effect of this conversion is observed by a change in the decreasing trend around the mark 200 in figure 7.

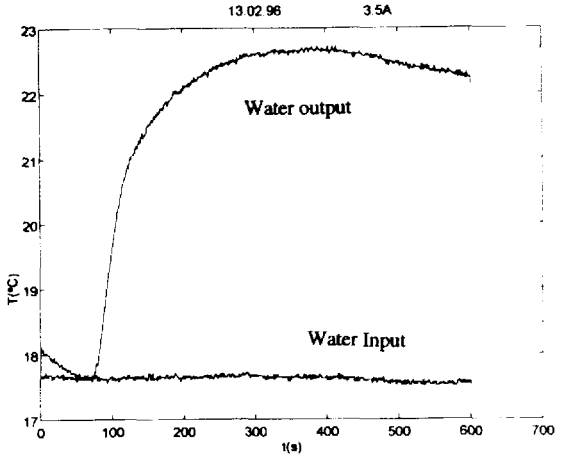

Figure 6. Water temperature

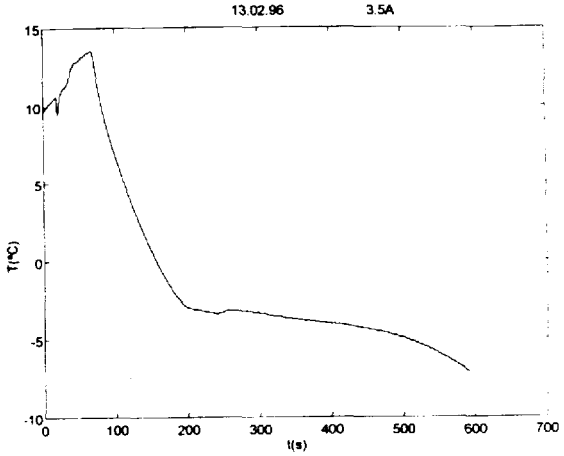

Figure 7. Juice temperature

The typical evolution on the hot and cool sides of the thermoelectric elements is shown in figure 8. The point where the water is converted into ice is discovered by the change of the decreasing slope. The difference between the hot and cool side can be observed at about 42 °C.

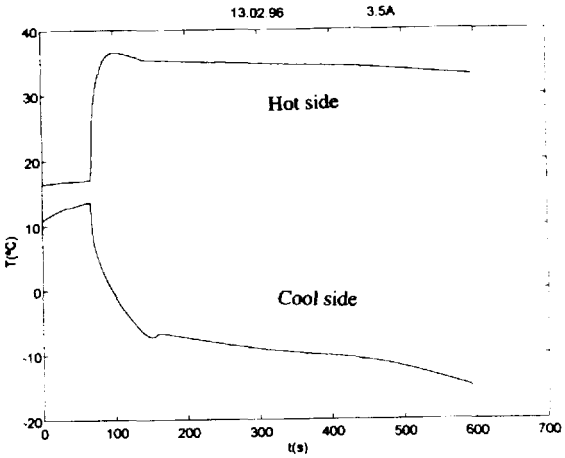

Figure 8. Thermoelectric element temperature

In figure 9, the evolution of the 4 temperatures measured in the cool sides of the thermoelectric elements is presented. The

two lower curves in the figure correspond to the monitored elements in the bottom of the CC and the other two to the elements located in the top. Also in the figure, it is possible to observe that the conversion from water to ice occurs in the bottom of the CC before it does in the top.

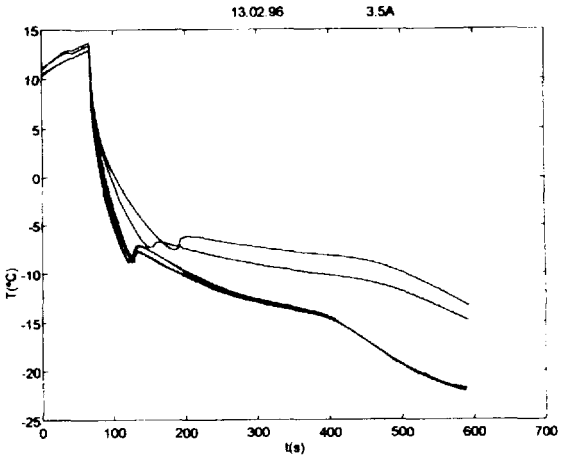

Figure 9. Cool side temperatures in themoelectric elements

For the test analyzed in figures 6 to 9 (3.5 A), the average values measured for heat and electrical power are the following: heat in the heat excanger 950W, heat extracted in the juice 210W, heat in the cool side of the module of the thermoelectric elements 280W, electrical power 1130W.

These results demonstrate that the CC can be used for orange juice cryoconcentration. The water is converted into ice, but the juice is liquid. The heat exchanger works heating the cool water as it was expected.

Tests for 2, 3, 4 and 5 amperes show a similar performance in the evolution of the variables. However the performance is degraded when the higher current is used. The recommendable range for an industrial application would be around 3 or 4 amperes.

The CC COP (ranged 0.3-0.2) is lower than the conventional cooling cycles used for cryoconcentration. However, the costs and requirements for operation could also be lower. Now, an economical investigation around these points is being done to complete the CC studies. The first task that it is currently being developed is the substitution of part of the energy required for the thermoelectric elements by energy coming from the sun using the photovoltaic effect.

Conclusions and future work

In this paper the investigation of the possible application of thermoelectricity to the cryoconcentration of orange juice has been presented.

For the purpose of this investigation a prototype of "Cryoconcentration Cell" able to reach the cryoconcentration objectives has been described. Design criteria, component description, test facility and performance results have also been shown.

This prototype of CC is based on a previous published experience [1]. The new prototype presented uses copper as the material for transferring heat and the design defects observed have been improved.

The performance tests demonstrate that the CC works according to the design criteria. This is to say, the CC is able to produce liquid orange juice inside the ice coming from the water, like the conventional cooling cycles used for cryoconcentration. The thermoelectric elements work cooling the juice and heating the water circulating in the cooling coil.

Now, more investigation is being done improving details to transfer this technology to industry. For this purpose, 8 photovoltaic modules have recently been installed to supply part of the DC power required for the thermoelectric elements.

Acknowledgements

The authors thank the CICYT of the Spanish Government for the economical support of the project and also Guillermo Bláquez and Juan Felipe López for their very valuable contribution in developing this project. Without their effort this work would have been impossible.

Finally, thank you to the Pontificia Comillas University maintenance personnel, especially to Pedro del Saz for his important help in the construction of the CC prototype.

References

[1] Sanz-Bobi M.A., Palacios R. "Application of thermoelectricity to the process of cryoconcentration of orange juice". Second European Workshop on Thermoelectrics. Nancy, France. 1995

[2] Proceedings of the XVIII TH International Congress of Refrigeration. Montreal, Canada. 1991.

[3] Food Technology. Cuadernos CDTI. 1993

[4] Sanz-Bobi M.A., Palacios R., Villar J., Arenas A. "Prototype of heat pump based on Peltier effect for application in ambient temperature conditioning". Proceedings 11TH International Conference on Thermoelectrics. Dallas, Texas, USA. 1992