DESIGN AND THERMAL ANALYSIS OF THE COMPONENTS IN A THERMOELECTRIC FINGER ICE-MAKER INCORPORATED IN A DOMESTIC RFRIGERATOR

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Abstract

This paper studies the behaviour of a thermoelectric finger ice-maker incorporated in a domestic refrigerator. There are a lot of studies about thermoelectric refrigerator devices, as it is developed in [1] and [2], nevertheless the application in a thermoelectric ice-maker is innovative. In thermoelectric devices a comprehensive thermal study is needed, in order to calculate the component thermal resistance. The thermal optimizations allow improving the efficiency of the thermoelectric devices. It can be seen in [3].

Introduction

Thermoelectric refrigerator devices increase its COP if the thermal resistance of the components joined to the Peltier module diminishes, as it is shown in ref. [3].

We determine by means of a computational model the thermal resistance of the hot side dissipater, the thermal resistance between the cold side Peltier module and the water, and the thermal resistance between the vessel and the water. The model simulations were created with FLUENT.

Thermal resistance between the cylinder and the water is hard to calculate. The natural convection between the water and the cylinder depends on the dimensions of the cold body submerged in the water and the water temperature.

The results obtained with different configurations of the components proposed of the thermoelectric ice-maker are shown. The thermal design allows determining and analyzing the thermal resistances of each thermoelectric ice-maker component; therefore, with this value we can study the influence in the efficiency of the device.

Objectives

The aim of this paper is to improve the thermal resistance of the following components of the thermoelectric ice maker:

- The dissipater join to the hot side of the Peltier module
- The cylinders submerged into the water.
- The vessel that contains the water in which the cylinders are submerged.

Description of the thermoelectric ice maker components linked to the Peltier module.

The most usual way in order to dissipate heat flow on the hot side of Peltier module is to use an aluminium dissipater with fins which is refrigerated by a flow of air driven by a fan.

In the case of thermoelectric ice maker is used as heat dissipater a flat plate of aluminium of 423•155•15 mm with a fan, which is used to dissipate the heat flux produced by the hot side of the Peltier module; this element connects the hot side of the Peltier module with the freezer compartment.

These types of optimizations made by means of computational model were implemented with FLUENT, and their thermal design are studied like is shown in reference [4]. In Fig. 1, can be seen the geometry of the model and the mesh used in the resolution of finite elements method.

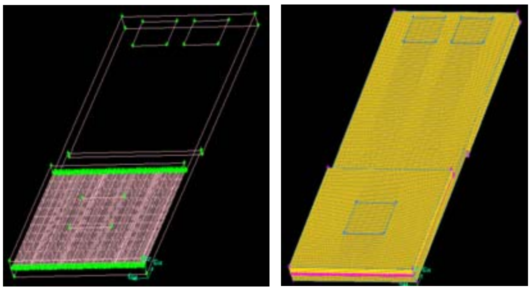

Fig. 1: Mesh and geometry of the thermal simulation of the heat dissipater.

The components on which the ice cubes are formed are called "fingers" and consist of a flat aluminium plate, which has one side in contact with the cold side of Peltier module; the other side is connected to the cylinders which are in contact with the water, the dimensions of the cylinder are 35 mm length and 10 mm diameter. The water used to produce the ice cubes is a methacrylate vessel of 164•50•50 mm with a thickness of 2 mm.

When the absorption of heat flux is initiated, the temperature of the fingers that are in contact with the water in the vessel falls below freezing (Tsolid=0 ºC), and ice cubes start to form.

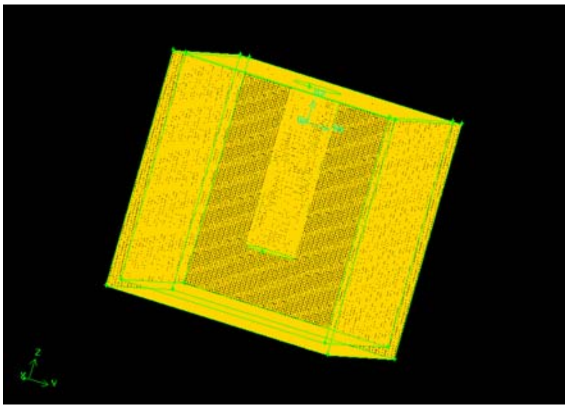

Fig. 2: Mesh and geometry of the thermal simulation of the cylinder submerged in water.

In Fig. 2 are shown the mesh and the geometry of the cylinder submerged in the water of the vessel. This model allows simulating the fluid mechanics of the water when the cylinder is cooling.

Calculation model.

The calculation model developed in order to study the heat dissipater of the hot side in the Peltier module is described in ref. [4].

In respect to the cylinders (fingers) is not possible to find an analytical solution that solves the problem due to the complexity of the natural convection. As it can be seen in the ref. [5] and [6] some researchers have developed experimentally expressions for bodies with small aspect ratios.

$$Nu^T = G \cdot \overline{C}_l \cdot Ra^{1/4}$$

$$\overline{C}_l = \frac{0.671}{\left[1 + \left(0.492/\mathrm{Pr}\right)^{9/16}\right]^{4/9}}$$

$$Ra = \frac{g \cdot \beta \cdot \Delta T \cdot D^3}{\upsilon \alpha}$$

$$Nu_l = \left[\left(Nu_{COND}\right)^n + \left(Nu^T\right)^n\right]^{1/n}$$

$$Nu_t = \overline{C}_t \cdot Ra^{1/3}$$

$$Nu = \left[Nu_l^m + Nu_t^m\right]^{1/m}$$

$$Nu = \frac{hL}{k_{agua}}$$

The previous expressions do not take into account the dimensions of the vessel. In our case the dimensions of the vessel are similar to the dimensions of the cylinder and the results with these expressions are not accurate.

In order to improve the accuracy of the results we developed a model by (FLUENT) and determined the temperatures and heat fluxes in the studied surfaces. With these values obtained, we calculate the thermal resistances.

$$R=\frac{T_s - T_{water}}{\dot{Q}_s}=\frac{1}{h*S}$$

Results and discussion

1. Thermal resistance optimization of the hot side dissipater

With the computational model developed, we have studied the influence of the hot side dissipater for the followings configurations:

- Configuration 1: without fins and with fan
- Configuration 2: with fins and with fan
- Configuration 3: with fins and with two fans

The thermal resistances obtained between the heat dissipater and the freezer for each configurations is shown in Table 1.

Configuration	Technical characteristics	**Thermal resistance [K/W]**
1	Dissipater without fins and with a fan	**0.82**
2	Dissipater with fins and with a fan	**0.30**
3	**Dissipater without fins and with two fans**	**0.24**

Tabla 1: Thermal resistances

2. Thermal resistance optimization of the finger submerged in water.

The room temperature used in the simulation of the vessel and the cylinder was 278 K and the initial water temperature was 293 K. The heat flux absorbed in the cylinder by the Peltier module is an input of the model.

The simulation solves the velocity distribution in the fluid, as can be seen in the Fig. 3.

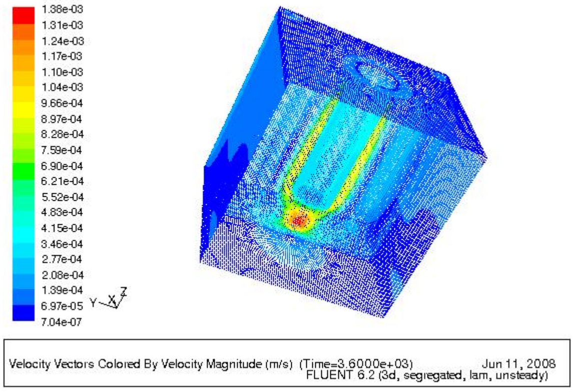

Fig. 3: Velocity distribution in the fluid.

In order to determine the thermal resistance, is necessary to calculate the temperature distribution in the vessel, water and cylinder (finger).This temperature distribution is shown in Fig. 4.

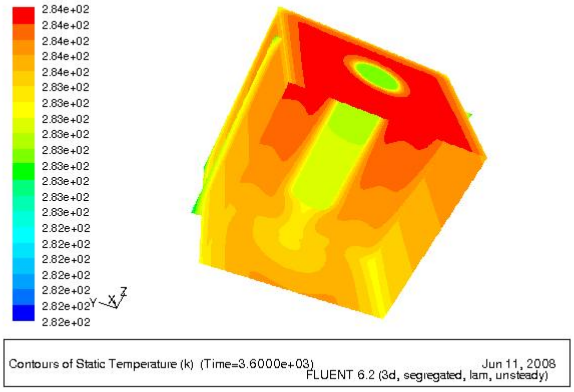

Fig. 4: Temperature distribution in the fluid.

The convection coefficient in these kinds of problems depends on the difference of temperature between the surface and the fluid, and the heat flux per surface unit absorbed. In order to study the influence of the cylinder length three tests with 25, 30 and 35 mm were developed and its results are shown in Fig. 5.

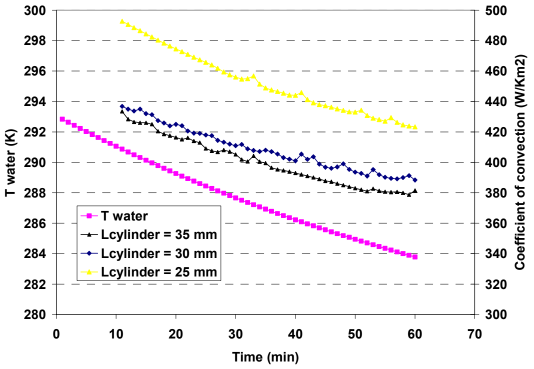

Fig. 5: Convection coefficient in function of the length cylinder.

The thermal resistance depends on the convection coefficient and the surface that absorbs the heat flux. For the cylinder length of 35 mm the convection coefficient is the lowest, but its thermal resistance is lower than the 30 and 25 mm because its surface is higher, the thermal resistance as function of water temperature and cylinder length can be seen in Fig. 6.

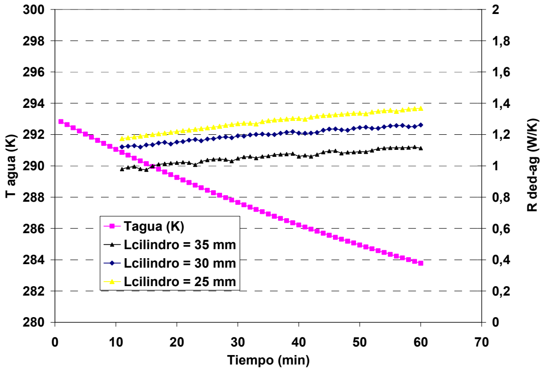

Fig. 6: Thermal resistance between the cylinder and the water in function of length of the cylinder.

3. *Calculate of the thermal resistance between the vessel and the water*

The distribution of velocities on the fluid, shown in Fig. 3, indicate that the velocities are faster near of cylinder and are slower in the rest of the vessel. Therefore, the influence of the length cylinder in the thermal resistance between the water and the vessel is neglected and only depends on the water temperature, as can be seen in Fig. 7.

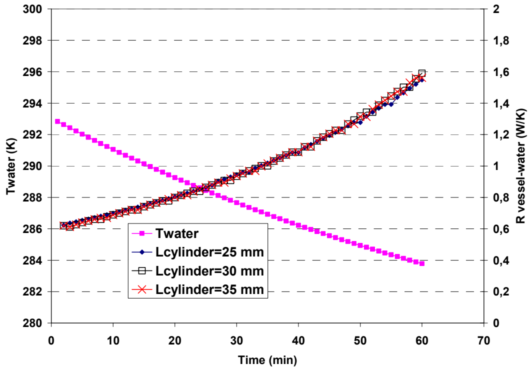

Fig. 7: Thermal resistance between the vessel and the water.

Conclusions

We have developed a computational model that analyzes and optimizes thermally the components of a thermoelectric ice maker.

The heat dissipater of the Peltier module has been optimized obtaining a decrease of 70 % in the thermal resistance.

The thermal resistance between water and cylinder decreases 18 % when used 35 mm cylinder length instead 25 mm.

We have determined the cylinder length do not have influence in the thermal resistance between water and vessel.

References

[1] G. Min, D.M. Rowe, Experimental evaluation of prototype thermoelectric domestic-refrigerators. Applied Energy, 83, (2006), p.p. 133-152

[2] J. Chen et al, Comparison of the optimal performance of single and two-stages thermoelectric refrigeration systems. Applied Energy, 73, (2002), p.p. 285-298

[3] D. Astrain, J. G. Vian, M. Domínguez, Increase of COP in the thermoelectric refrigeration by the optimisation of heat dissipation, Applied Thermal Engineering. 23 (17), pp. 2183- 2200, Dec 2003

[4] Tesis. Optimización de la disipación de calor en pastillas de efecto peltier. Aplicación en refrigeración doméstica. David Astráin Ulibarrena, noviembre 2001.

[5] A. V. Hassani and K. G. T. Hollands, “On natural convection heat transfer from three dimensional bodies of arbitrary shape”, J. Heat Transfer (111): 363-371, 1989.

[6] A. V. Hassani and K. G. T. Hollands, “On natural convection heat transfer from three dimensional bodies of arbitrary shape”, J. Heat Transfer (111): 363-371, 1989.