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COOLING TIME OF WATER IN A GLASS ON A THERMOELECTRIC COOLER

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Abstract

Thermoelectric cooling uses the Peltier effect to create a heat flux between the junctions of two different types of materials. A thermoelectric or Peltier device transfers heat from one side of the device to the other side (from cold to hot) with consumption of electrical energy and is commonly used in portable coolers. In this study, cooling time of water in a glass at 20°C temperature on a thermoelectric device is investigated numerically. Two different values for aspect ratio, H/R=0.05m/0.05m and H/R=0.025m/0.1m, are taken into consideration. The results show that weak convection currents develop inside the glass container. The results also show that a large heat transfer surface should be used for an effective cooling of water.

Key words: *thermoelectric cooler, Peltier,*

1. INTRODUCTION

Thermoelectric cooling uses the Peltier effect, which was discovered in 1834 by Peltier (Peltier, 1834), to create a heat flux between the junction of two different types of materials. A thermoelectric or Peltier device transfers heat from one side of the device to the other side (from cold to hot) with consumption of electrical energy. The Seebeck Effect- is the reverse of the Peltier effect. By applying heat to two different conductors a current can also be generated. Peltier devices have a low efficiency compared to conventional coolers. Present thermoelectric devices operate at about 10% of Carnot efficiency, whereas the efficiency of a compressor-based refrigerator is about 30% of Carnot efficiency (Gurevich and Lugvinov, 2007). However, they have a small size and weight and are highly reliable; their lifetimes are more than 20 years. Therefore, thermoelectric coolers find a lot of applications such as vehicle refrigerator, automobile seat cooler, portable picnic cooler, residential water cooler, computer microprocessor cooler (Gurevich and Lugvinov, 2007; DiSalvo, 1999; Venkatasubramanian et al., 2001).

Most commercial thermoelectric coolers use bismuth telluride (Bi_2Te_3), which is the best thermoelectric material around room temperature. Alternating legs of p-doped and n-doped Bi_2Te_3 are connected electrically in series and thermally in parallel. In the p-doped legs, positively charged holes carry heat in the same direction as the current flow, and in the n-doped legs, negatively charged electrons carry heat in the opposite direction (Mann, 2006). The net effect is that heat is carried from the cold side to the hot side in both legs. A commercial cooler is generally constructed of dozens of pairs of legs in a fashion that maximizes cooling per unit area (Mann, 2006).

The aim of this study is to investigate cooling time of water in a glass on a thermoelectric cooler numerically by Comsol Multiphysics finite element analysis software.

2. ANALYSIS

In this study, cooling time of water in a glass on a Peltier device is investigated numerically. The geometry and the coordinate system are given on the Fig. 1. To obtain higher heat transfer surface, a shallow glass container is taken into consideration. The thickness of the glass container is assumed to be 2mm. The environmental temperature and convection heat transfer coefficient are assumed to be T=20°C and h=7W/m^{2}°C. The cooling rate of thermoelectric device depending on the temperature difference of hot and cold surface is shown in Fig. 2 for various values of electric current. After some calculations, it is seen that the cooling time for 2 amper is very long and water begins to freeze for 4 amper before a significant amount of cooling. Therefore, 3 amper is selected in this study for the electric current. The line of cooling rate-temperature difference for 3 amper is specified by a second degree polynomial interpolation.

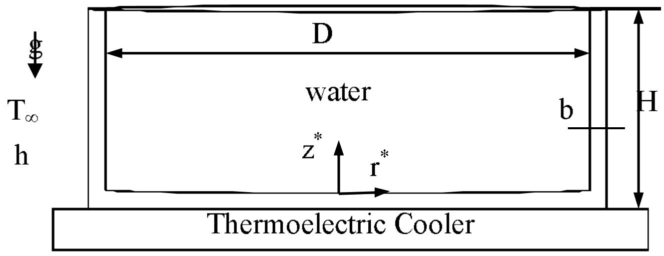


Fig. 1. Geometry and coordinate system.

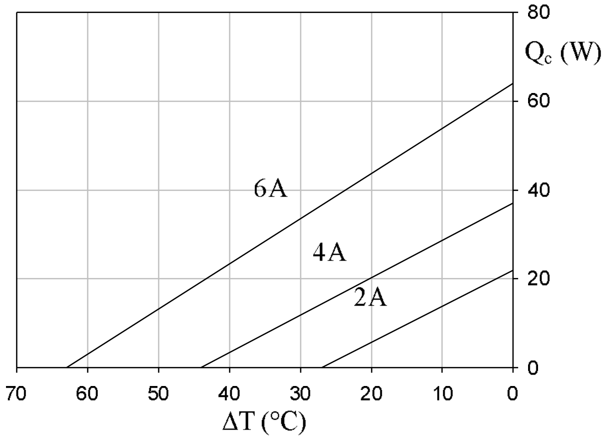


Fig. 2. Cooling rate-temperature difference line for various values of electric current (TEC1-12708, 2012).

In this study, flow is assumed to be Newtonian, steady and incompressible. The buoyancy effects are incorporated in the formulation by invoking the Boussinesq approximation. The viscous dissipation terms and the thermal radiation are assumed to be negligible. In this case, the governing equations become as follows:

For fluid

$$\frac{\partial v_r}{\partial r} + \frac{v_r}{r} + \frac{\partial v_z}{\partial z} = 0 \qquad (1)$$

$$\rho\left[\frac{\partial v_r}{\partial t}+v_r\frac{\partial v_r}{\partial r}+v_z\frac{\partial v_r}{\partial z}\right]=-\frac{\partial p}{\partial r}+\mu\left(\frac{\partial^2 v_r}{\partial r^2}+\frac{1}{r}\frac{\partial v_r}{\partial r}+\frac{\partial^2 v_r}{\partial z^2}-\frac{v_r^2}{r^2}\right) \tag{2}$$

$$\rho\left[\frac{\partial v_z}{\partial t}+v_r\frac{\partial v_z}{\partial r}+v_z\frac{\partial v_z}{\partial z}\right]=-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 v_z}{\partial r^2}+\frac{1}{r}\frac{\partial v_z}{\partial r}+\frac{\partial^2 v_z}{\partial z^2}\right)+\rho g\beta(T-T_\infty) \tag{3}$$

$$\rho c_p\left[\frac{\partial T}{\partial t}+v_r\frac{\partial T}{\partial r}+v_z\frac{\partial v_z}{\partial z}\right]=k\left(\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}+\frac{\partial^2 T}{\partial z^2}\right) \tag{4}$$

For glass

$$\rho c_p\frac{\partial T}{\partial t}=k\left(\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}+\frac{\partial^2 T}{\partial z^2}\right) \tag{5}$$

where v_r and v_z are the velocity components in the r and z directions, respectively, p is the pressure, T is the temperature, ρ is the density, μ is the dynamic viscosity, β is the coefficient of thermal expansion, c_p is the specific heat, g is the gravitational acceleration and k is the thermal conductivity.

The governing equations are subjected to the following initial and boundary conditions:

$$v_r(r,z,0)=0\ ,\ v_z(r,z,0)=0\ ,\ T(r,z,0)=20°C \tag{6}$$

$$v_r|_s=0\ ,\ v_z|_s=0\ ,\ T_\infty=20°C \tag{7}$$

$$T_f=T_g\ ,\ \vec{n}\cdot(\vec{q}_f-\vec{q}_g)=0\quad at the water-glass interface \tag{8}$$

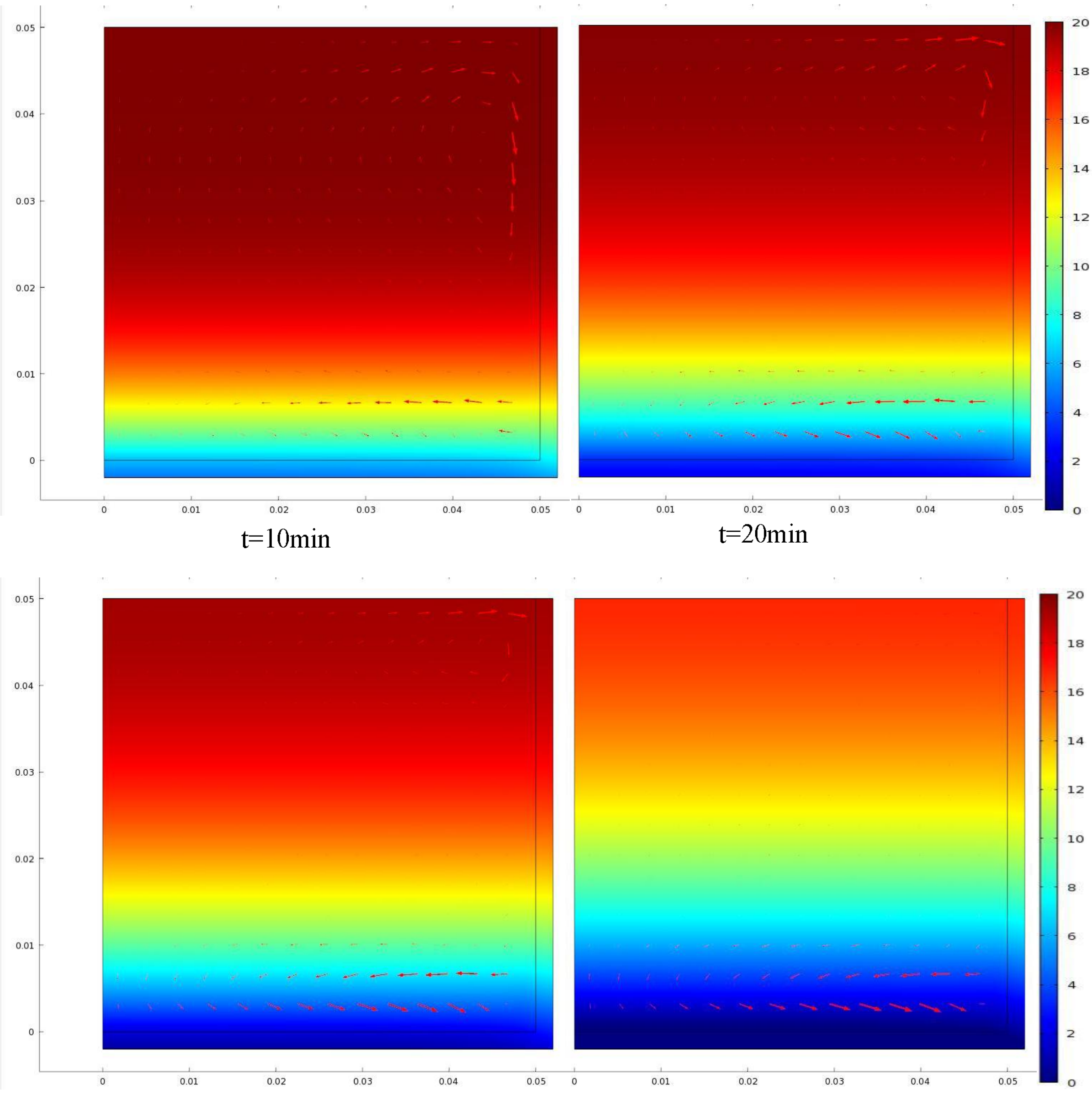
$$q=-[17.078-0.4845*(25-T)]10^3(W/m^2)\quad at the bottom surface \tag{9}$$

where q is the heat flux, $\vec{n}$ is the unit normal vector. f and g stand for fluid and glass, respectively.

3. RESULTS AND DISCUSSION

The solutions are obtained with the Comsol multiphysics finite element analysis software. Absolute tolerance that is used by the solver to control the absolute error is taken as 10^{-5} for each variable in the equations. The computational domain was meshed using triangular elements. Much more mesh elements are used near the surfaces where the large velocity and temperature gradients are expected to develop. The computational results were obtained with the parallel sparse direct linear solver PARDISO, which is based on a Level-3 BLAS update (Comsol, 2010).

The solutions are obtained for shallow container cases to increase the surface area for heat transfer and therefore the cooling. The temperature and velocity fields at various values of cooling time are shown in Figs. 3 and 4 for H/R=0.05m/0.05m and H/R=0.025m/0.1m. With the beginning of the cooling, sidewall of the glass container takes lower temperatures from the nearby fluid particles because of its higher thermal conductivity. Therefore, a weak clockwise circulation develops on upper right region of the container. Also, a weak counter clockwise circulation develops on the lower right region of the container. As the cooling progresses, these weak convective circulations become weaker. As shown from the figures, temperature decrease for the H/R=0.05m/0.05m case is quite slow due to the lower heat transfer surface for the cooling and the weak convection currents. Eventually, temperatures inside the container are still at high values even after 1 hour of cooling. On the other hand, temperature decrease for the H/R=0.025m/0.1m case is relatively fast due to the higher heat transfer surface for the cooling. Consequently, temperatures inside the container are at preferred values after 40min of cooling.



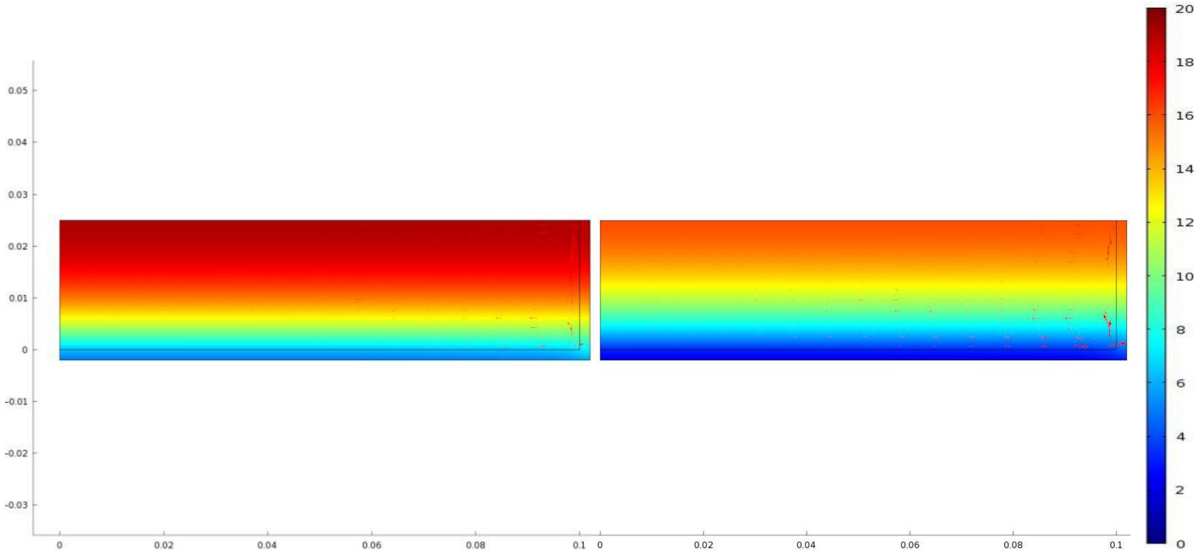
t=10min

t=20min

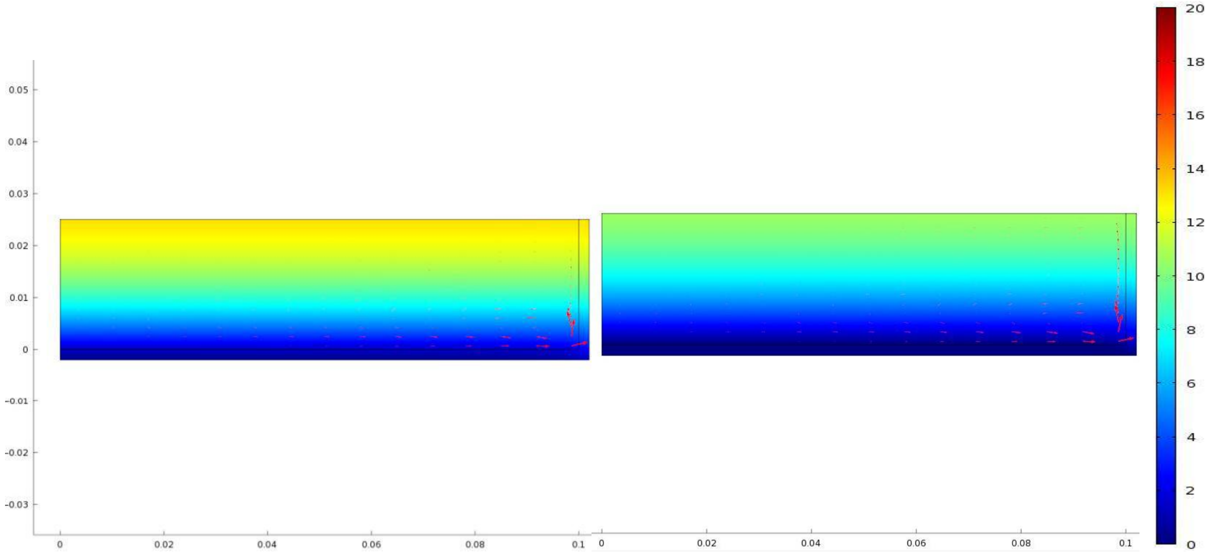
t=30min

t=60min

Fig. 3. Temperature and velocity fields for H/R=0.05m/0.05m at various values of cooling time.



t=10min t=20min



t=30min t=40min

Fig. 4. Temperature and velocity fields for H/R=0.025m/0.1m at various values of cooling time.

Average temperatures inside the glass container during the cooling are given in Table 1. As it is observed from the table, average temperature is quite high and beyond the preferred temperature (T=4-6°C) for the 0.05m/0.05m aspect ratio case even after 1 hour of cooling. As it is stated before, this is because of lower heat transfer surface for cooling and weak convection currents inside the container. However, average temperature becomes the preferred level after 40 min of cooling for the 0.025m/0.1m aspect ratio case. It can be concluded from these results that for an effective cooling by a thermoelectric cooler, either a large heat transfer surface should be used or a configuration producing stronger convection currents should be chosen.

Table 1. Average temperatures inside the glass container during the cooling.

H/R	t (min)	T_{ave} (°C)
0.05m/0.05m	10	17.55
	20	15.73
	30	14.24
	40	12.98
	50	11.90
	60	10.97
0.025m/0.1m	10	15.19
	20	11.62
	30	8.82
	40	6.61

4. CONCLUSION

In this study, natural convection cooling of water in a glass at 20°C temperature on a thermoelectric device is investigated numerically by Comsol multiphysics finite element analysis software. Governing equations are obtained by the Boussinesq approximation. Two different values of aspect ratio, H/R=0.05m/0.05m and H/R=0.025m/0.1m, are taken into consideration. The results show that weak convection currents develop inside the glass container. The results also show that a large heat transfer surface should be used for an effective cooling of water.

REFERENCES

Comsol Multiphysics Reference Guide, Version 4, (2010), pp. 378.

DiSalvo, F.J., (1999) Thermoelectric cooling and power generation. Science, 285, pp. 703-706.

Gurevich Y.G. and G.N. Lugvinov, (2007) Theory of thermoelectric cooling in semiconductor structers. Revista Mexicana De Fisica, 53(5), pp. 337–349.

Mann, B.S., (2006) Transverse effects for cooling and heat flux sensing. MSc Dissertation, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA.

Peltier J.C.A., (1834) Nouvelles experiences sur la caloricite des courants electrique. Ann. Chim.Phys., 56, pp. 371-386.

TEC1-12708, (2012) Technical specifications of TEC1-12708, HB Corporation.

Venkatasubramanian R., E. Siivola, T. Colpitts and B. O'Quinn, (2001) Thin-film thermoelectric devices with high room temperature figures of merit. Nature, 413(6856), pp. 597-602.