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Research Article

Organ Transportation Thermoelectric Cooling System Design and Application

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ABSTRACT

Thermoelectric modules are used in medical devices, air conditioners, refrigeration cabinets, measuring devices, etc. widely used in the fields. Application areas of thermoelectric modules and efforts to increase efficiency are in continuous development. In this study, an organ transport device with the thermoelectric cooling feature, which can be used in the medical field, was designed and performed and performance analyzes were made. An animal kidney measuring 5x6x10 cm was placed in the designed and realized system, and performance analyzes of the system were made at ambient temperatures of 25ºC, 30ºC, 35ºC, 40ºC. Each experiment was repeated five times and the average was taken. It was seen that the system, whose performance analyzes were carried out at different temperatures, was usable. The system's small size, less weight and low cost compared to conventional cooling systems are among the important advantages of the system. It is possible to say that with the further development of the implemented system, larger organs can be cooled and transported, further studies can be carried out in this direction.

1. Introduction

Since the past, the need for heating and cooling systems has been increasing. In parallel with these, the need for cooling quickly entered the field of health. Since the acceleration of organ transplantation in the 1950s, the importance of delivering organs from the donor to the recipient has increased. In this sense, the ability of organs to be transported without deformation depends on the ambient temperature. In the early days, primitive cooling containers were used. These containers are not preferred because they can maintain their temperature for a short time and the temperature control is not stable [1].

In one study, an aluminum sheet was placed on the bottom of the box made of foam, a suitable sized piece was cut from the bottom of the box, and the peltier was placed on this part and sealed the edges with silicone. He mounted an aluminum plate and a 12V fan on the hot surface of the Peltier. He put all kinds of food and drink in the cupboard and cooled it to the desired amount by adjusting the thermostat [2]. Chaudhari et al. In their work, they produced a portable refrigerator using a peltier. With the system they created, they kept the inside of their cabinets between 3°C -5°C. In this way, they claimed that they produced a more environmentally friendly refrigerator than gas refrigerators [3]. In another study, they designed a mini refrigerator using a peltier. They have optimized for the operating conditions of the thermoelectric refrigerator. They determined the optimum ambient temperature as 293K (kelvin). They reduced the internal temperature of the Peltier refrigerator from 293K to 254.8K [4]. In another study, a gas refrigerator and a thermoelectric refrigerator were created. The cooling characteristics of both refrigerators were modeled and compared. Instead of blowing air in cooling the hot side of the thermoelectric modules, the removal of the air on the surface by suction has provided a better cooling of the inside of the cabinet [5]. In another study, a refrigerator was developed to carry cold chain health products for regions where there is no electrical energy. The refrigerator is portable and can be operated with a 212 Ah battery. It can store 5 liters of

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vaccine between 4°C and 6°C with a peltier consuming 37W power at 12V [6]. Since Saudi Arabia has the goal of being the world's largest solar energy producer among its 2030 targets, it only has studies on refrigerators that run on electricity. The internal temperature of the refrigerator they designed can be stable at 6°C. They aimed to use thermoelectric refrigerators and compressorless refrigerators [7]. In one study, an experimental analysis was performed for a hybrid interior refrigerator incorporating thermoelectric and evaporation technologies. The hybrid refrigerator consists of three compartments; One of them is operated by a thermoelectric cooling system based on the peltier module. The hybrid refrigerator was built and tested under local operating conditions. The performance of the thermoelectric refrigerator was evaluated at different voltages (5, 8.5 and 11 V) supplied to the peltier module and two fans on each side. As a result, they showed that the heat sink supported by heat pipes was used on the hot side of the thermoelectric module (11.5°C to 18.37°C), resulting in a reduction in the poly (11.5°C to 18.37°C) and power consumption of the thermoelectric refrigerator by about 8.5% [8].

In another study on thermoelectric modules, the cooling ability of the TEC 1276 module at 10W, 30W and 50W input power was investigated. It has been observed that higher power is needed to keep the temperature constant for a long time. They observed that the cooling capacity increased in parallel with the power consumption of the peltier [9].

Recently, with the increase in the use of electric vehicles, the usage area of batteries has also increased [10]. The heating of the batteries has become a problem [11]. For this purpose, studies have also been carried out on the cooling of batteries with thermoelectric modules. They revealed that thermoelectric modules can be effective in cooling batteries [12, 13].

In this study, the design and tests of a thermoelectric system for organ transport were carried out. 10 pieces of TEC1-12706 were used. The cooling of the heated surfaces of the peltiers was done with the water cooling system. Other parts of the article are planned as follows. In the second part, the thermoelectric module and the proposed system are introduced. In the third chapter, the results obtained from the tests of the designed thermoelectric organ cooling system are given. Discussion and conclusions are given in the last section.

2. Material and Methods

2.1. Thermoelectric modules

The basis of any thermoelectric circuit or system is a thermoelectric module consisting of thermo elements. Thermoelectric module is obtained by connecting many thermo elements electrically in series. Thermoelectric modules are heat pumps with no moving parts [14]. Thermoelectric modules are preferred because of their silent operation, long life and reliability. Figure 1 shows the structure of a thermoelectric module.

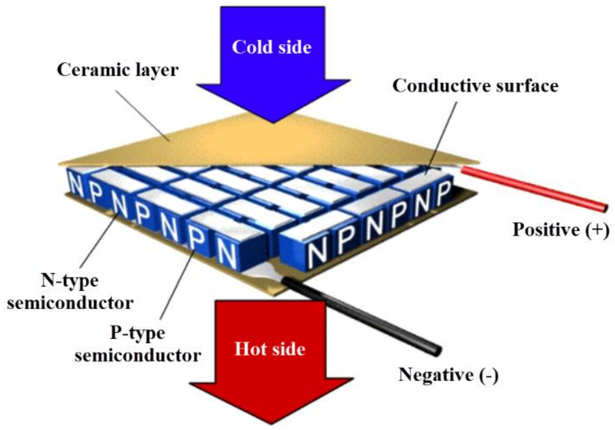

Figure 1. The structure of the thermoelectric module

Thermoelectric coolers are also sometimes called thermoelectric modules or "Peltier coolers" [15]. Thermoelectric coolers are semiconductors that work like small heat pumps. Thanks to a small voltage from a direct current source, heat moves from one surface of the module to the other. In this way, while one surface of the module heats up, the other surface starts to cool [16]. By changing the ends of the power supply, the cooling surface begins to heat up and the heated surface begins to cool. A thermoelectric module can be used as a cooler or heater, depending on where it is desired [17]. When the cold part of the module reaches the maximum temperature difference, the heat pumping is interrupted and the heat pump loses its functionality. Therefore, it is most efficient to use between -5ºC and -15ºC. In this range, the temperature difference between the surfaces reaches the highest level [18]. Thermoelectric coolers work on the same principle as the coolers we use in our homes. But there are some differences. In generally used systems, the refrigerant is replaced by semiconductors in thermoelectric modules [19].

2.2. Proposed organ cooling system

A prototype organ cooling system has been developed so that the organs can be transported cold during transport. In the developed system, 10 thermoelectric modules cool the inside of the organ cooling container. The cooling of the heated sides of the thermoelectric modules is done with copper blocks with water channels. There are 10 copper blocks in the cooling system. The heated parts of the thermoelectric modules are cooled by passing the water coming from the water tank through the copper blocks. There is a water tank, 1 condenser, 1 fan and 1 water pump for cooling and circulation of water in the system. The general view of the system is shown in Figure 2.

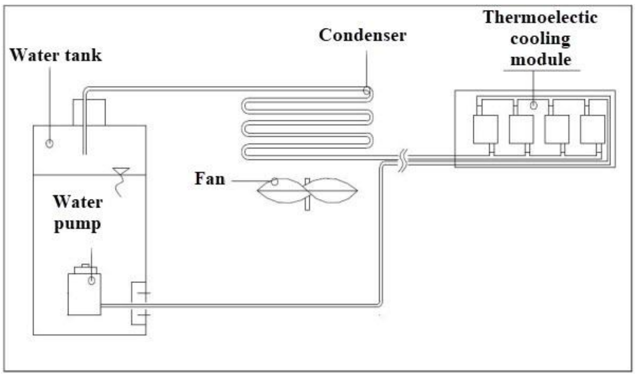

Figure 2. Thermoelectric organ cooling system diagram

There are two power supplies of 350 Watt and 250 Watt in the system to provide energy to the thermoelectric modules. A control device has been added to the system in order to keep the temperature inside the cooling container constant. Thanks to this device, the temperature of the cooling vessel can be kept constant at the temperature set on the controller. The water used for cooling the thermoelectric modules in the system is reduced to room temperature with the help of a condenser and fan. The organ cooling container in which thermoelectric modules and copper water cooling blocks are placed is shown in Figure 3.

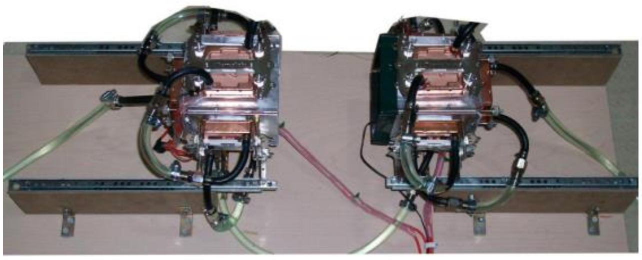

Figure 3. Thermoelectric cooling container

Thermoelectric modules that can operate with 12V voltage are used in the system. The model of the modules used is TEC1-12706. Each thermoelectric module consumes 96 Watts of power. The performance conditions of the TEC1-12706 thermoelectric module are shown in Table 1.

Table 1. TEC1-12706 performance conditions

	Hot side temperature (°C)	
	25	**50**
Qmax (Watts)	50	57
Delta Tmax (°C)	66	75
Imax (apms)	6.4	6.4
Vmax (volts)	14.4	16.4
Modul resistor	1.98	2.3

The images and features of the fan, condenser, temperature controller, system control unit and water pump used in the system are shown in Table 2.

3. Experimental Results

The performance analysis of the system was carried out at 25ºC, 30ºC, 35ºC, 40ºC for a period of 120 minutes by placing 5x6x10 cm (width, height, depth) animal kidneys in the system. Each measurement was repeated 5 times and averaged. In order to clearly measure the performance of the system, the temperature of the kidney piece used was kept constant at 25°C. The data obtained from the idle operation of the system at 25°C ambient temperatures are shown in the Table 3 and in the Figure 4.

Table 2. Devices used in the system

Devices	Features
	The heat condenser is used to reduce the temperature of the heated water in the designed device. The water circulating in the system takes the heat from the surface of the modules. The heat taken from the modules is thrown out with the help of the heat exchanger. The heat exchanger is manufactured from 8 mm diameter copper pipe with cross current passage.
	The device can keep the system constant at the desired temperature. When the temperature of the system drops below the desired level, it cuts off the electricity to the thermoelectric modules in order to keep the temperature constant. In case of any malfunction, it can give an audible alarm in case of excessive decrease or increase in temperature. Lower temperature limit, upper temperature limit, fixed temperature value can be selected from the device menu. In addition, there is an encryption system so that the device cannot be interfered with except by experts.
	There is temperature controller, condenser fan button, thermoelectric modules button on the cooling cabinet and water pump button on the module. The control of the system is provided via the control unit. There are 2 control units in total. Control units control both parts of the cooling vessel separately.
	A submersible water pump that can work in the water tank is used. The reason for this is that it can work longer in cold environments and circulate more water quickly in the system. Water transmission in the system is carried out with pneumatic hoses and fittings. The possibility of water leakage in the hoses and records in the system is zero. The water pump has the capacity to pump 1 liter of water in 1 minute.

Table 3. Empty container data at 25°C degrees ambient temperature

Time (second)	Container Temperature (°C)
0	24.9
30	16.5
60	1.9
90	-3.2
120	-5
150	-5
180	-5
600	-5

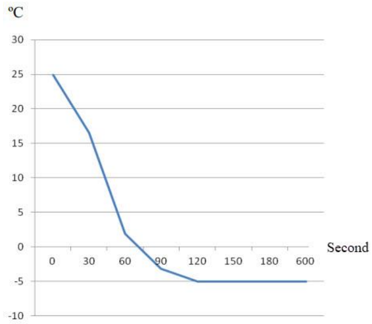

Figure 4. Empty container graph at 25°C degrees ambient temperature

After the system was stopped in each analysis process, it was allowed to cool completely. The water in the tank was emptied and a new one was filled. The reason for this was the increase in water temperature. A calf kidney weighing 500 g and at 25ºC was placed in the system and performance analyzes were made in this way. The graph in Figure 5 was created according to the data in Table 4.

Table 4. Test results with 25°C calf kidneys at 25°C ambient temperature

Time (second)	Container Temperature (°C)
0	24.9
30	17
60	4.2
90	-1
120	-5
150	-5
180	-5
600	-5

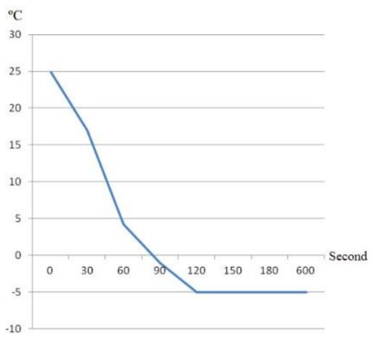

Figure 5. Test graph with 25°C calf kidneys at 25°C ambient temperature

Experiments were carried out by keeping the calf kidney temperature constant at 25°C, with the ambient temperature being 30°C, 35°C and 40°C. The results obtained at 30°C ambient temperatures are shown in the Table 5, and the graph obtained using the data in the Table 5 is shown in the Figure 6.

Table 5. Test results with 25°C calf kidneys at 30°C ambient temperature

Time (second)	Container Temperature (°C)
0	29.9
30	22.1
60	9.2
90	4.1
120	-1.1
150	-3.2
180	-5
600	-5

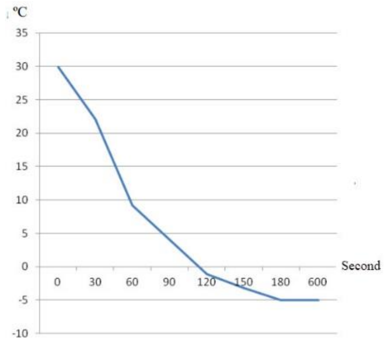

Figure 6. Test graph with 25°C calf kidneys at 30°C ambient temperature

The results obtained at 35°C ambient temperatures are shown in the Table 6, and the graph obtained using the data in the Table 6 is shown in the Figure 7.

Table 6. Test results with 25°C calf kidneys at 35°C ambient temperature

Time (second)	Container Temperature (°C)
0	34.6
30	28.2
60	17.1
90	10.3
120	5.2
150	1.6
180	-1
210	-3.1
600	-5

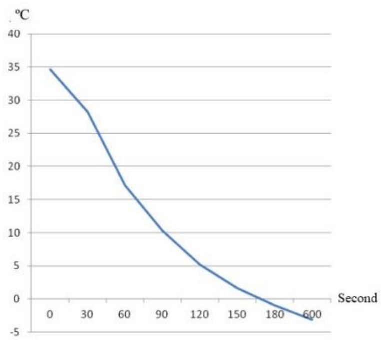

Figure 7. Test graph with 25°C calf kidneys at 35°C ambient temperature

The results obtained at 40°C ambient temperatures are shown in the Table 7, and the graph obtained using the data in the Table 7 is shown in the Figure 8.

Table 7. Test results with 25°C calf kidneys at 40°C ambient temperature

Time (second)	Container Temperature (°C)
0	39.3
30	33.2
60	23.7
90	16.6
120	11.1
150	5.3
180	1.2
210	-1.1
240	-3.2
600	-5

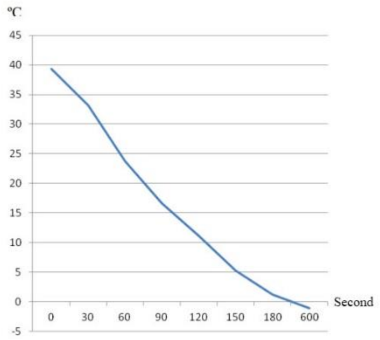

Figure 8. Test graph with 25°C calf kidneys at 40°C ambient temperature

When the test data were examined, it was reached to -5°C in 120 seconds at an ambient temperature of 25°C. At an ambient temperature of 30°C, -5°C was reached in 180 seconds. It was reached at an ambient temperature of 35°C at -5°C in 600 seconds. At an ambient temperature of 40°C, -5°C was reached in 600 seconds. The organ cooling system showed the best performance at 25°C ambient temperature.

4. Conclusions

The created organ cooling system has been tested at different ambient temperatures. Calf kidney was used in the test procedures. The temperature of the organ used was kept constant at 25°C. Thermoelectric cooling system was operated for 600 seconds at 25°C, 30°C, 35°C and 40°C ambient temperatures. At 25°C ambient temperature, the cooling vessel reached -5°C in 120 seconds. At the ambient temperatures of 30°C, 35°C and 40°C, the cooling vessel reached -5°C at 180, 600 and 600 seconds, respectively. In all ambient temperatures, the cooling container can work stably at -5°C for a long time. With the temperature control module, the internal temperature of the cooling container can be adjusted at the desired level. The system has an audible and visual warning system against excessive cooling and heating of the cooling container. Since the system has high power consumption, it is not portable. However, it can be made portable with a specially designed battery system.

The system can be further developed and used in cold chain logistics and organ transport logistics. It can perform faster and more stable cooling compared to cooling alternatives such as dry ice and refrigerator.

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