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An examinaion about thermal capacities of thermoelectric coolers in battery cooling systems

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Abstract
Peltier is a solid state active heat pump which can create a difference in temprature between two sides of the device by using electrical energy, the heater and the cooler sides of peltier is determined by the direction of direct current(DC) applied to the system. A Peltier consists of a P and a N type semi-conducting materials which are serial electrically and parallel thermally. The surfaces of the peltier are coated with ceramic which is thermally conductive but not electrically. Peltiers usually have low COP values which means the system requiers more energy compared to the conventional refrigeration cycle to dissipate same amount of heat energy. Advantages of peltier system are the system's simplicity and being less prone to fault. In this study a series of experiments has been conducted and data has been collected for thermoelectric coolers systems which can be used for EV battery cooling. Through the experiments different current levels between 1 to 7 amps was applied to the system. Then coresponding voltage levels, temperature of water entering and exiting the system and surface temperatures of heater and cooler sides of the peltier were measured. All these measurements were after the system was stable and for a set period of time. The avarage of the measurements were used in calculations. It is observed that the thermal dissapation power of the system correlates with the amount of current that is drawed by the system.

Keywords: Battery management; peltier; electric vehicles

1. Introduction

Thermoelectric cooling systems are heat pumps that has no moving parts which can be used for temperature stabilisation or in applications that requiers cooling below room temperatures[1-3]. Thermoelectric cooling is obtained by drawing current through one or more thermoelectric modules which consists N and P type semi-conductor metals[2-4]. Thermoelectric cooling is based on Peltier effect which explains the increase and decrease of temperature at different sides of a thermoelectric cooler based on direction of the applied current[3]. The P and N type semi-conducting materials in a thermoelectrical module are serial electrically but paralel thermally. Thanks to advancements in technology the temperature range which an electronic material could perform with optimum efficiency can be predetermined so the cooler desing for these materials is a more important matter nowadays. The amount of research on design, analysis and implemantation of thermoelectric cooling systems by researchers is increasing day by day. Thermoelectrical coolers have many advantages against other cooling systems. Some of those are listed below[4,6]:

- Thermoelectric coolers can stabilize the temperature of an object below room temperature independent of surrounding temperature.
- Thermoelectrical coolers can be used as a cooler or as a heater based on the purpose of the system.
- It can be used for a wide range of applications ranging from milliwatt to kilowatt.
- Peltier elements come in different voltage levels and sizes. There are 6-12-24 V

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variants.
- Peltier coolers has no moving parts so they requier little maintenance.
- Peltier coolers last long. It has been proved they have 100.000 hours product life.
- Peltier coolers doesn't use liquid coolants so they are highly nature friendly.
- Peltier coolers can function both horizontally and vertically they can even work in gravity free enviroments
- They can work in small, packed places.

The disadvantages of thermoelectric coolers can be listed as:

- There is approximately 50-60°C difference of temperature between the sides of the peltier so the heater side must be cooled well in order to lower the cooling sides temperature to very low degrees.
- Peltier cooling systems are not suitable for computer cooling because of the high energy requirement of peltier cooling systems. The cooling system requiers to be plugged in to an external energy source. Peltier systems are not for daily usage because of their high energy needs.
- Another problem with using peltier systems in computer cooling is when the energy is lost peltier system shuts down as well as the computer and that causes the heat of the heater side to starts sliding into the cooler side and from there to the surface we are trying to cool. Which can creat some problems.
- COP value of peltier systems are very low between 0.3-0.7 tough it is between 2-4 for conventional cooling systems.
- Peltier cooling systems are not a good fit for high cooling loads. They can't compete with compressor based cooling systems in this regard.
- They require DC source to function.

The first scientific work for thermoelectric cooling modules was at Loffe institute in St. Petersburg Russia as a prototype.
In a study that inspects the state of peltier material in a set period of time; a standart air-air moduler cooling unit has been designed by using peltier and for this cooling unit it has been observed how does the cooling power and COP affects thermoelectric efficiency and cost. Also the COP value of the peltier cooler was compared to the COP value of a small compressor cooler.The affect of the materials that is used on surfaces and inside the peltier on cooling performance also was researched. When the performance, compact structure and the economical aspects of the peltier is taken into account it is easy to see that peltier cooling systems will see massive improvement just like the microelectric field in the last 10-15 years.[5,6].

In a study that was made in 2006 an thermoelectric cooler that supplies its energy from solar cells was designed for cooling in places that doesn't have electrical connection. The dimensions of the cooler was 29x29x29cm. An appropriate thermoelectric module and solar cells were chosen for this project. The system was tested in different enviroments and it has been observed how does the system reaches steady state in these enviroments. In order to calculate the COD of peltier and the efficiency of the solar cells; the temperature difference between inside and outside of the cooler, the difference between the surfaces of the thermoelectric module, the current and voltage levels that solar cell provides and the solar radiation levels were measured. In this research at 17,80°C external temperature and 775 W/m2 solar radiation internal temperature of the cooler was as low as 4,90°C the COD value of thermoelectrical cooler was 0.9 and the efficiency of the solar cell was around %10. The cost of the system was relatively high mainly because of solar cells. The system could be used in places that isn't connected to national grid. The experiment was also important as a proof of concept. [7,8].

In another study a thermoelectric and an air cooling system were used used together in order to obtain a low power, low noise cpu cooler. As a result a silent and compact cooler that has noise level of 40dB and 12W power usage has been developed. Also it has been proved thermoelectric coolers can be used in hybrid cooling systems that is silent and powerful[6,9].

There is a good amount of research about thermoelectric cooling systems globally. But research about utilisation of peltier materials in electric vehicle battery cooling solutions is relatively new and most of these research doesn't contain real world tests. In this paper an experimental cooling system was built to test the thermal power of the peliter unit. The thermal performance of the system was measured and experimental data about the system is collected.

2. Material and method

In order to measure the thermal power of the peltier unit, water was ran through both sides of the peltier. By measuring the temperature difference and flow of the water, we calculated the heat transfer in both sides of the peltier. These measurements were made when the system was in the steady-state. In order to circulate the water through the surfaces the aluminium blocks in figure 1 was made. The tubing for these blocks is shown in figure 2.

Figure 1. Aluminium blocks.

Figure 2. Tubing of the blocks.

Peltier material was put between the blocks. In order to measure the surface temperature levels of cooler and heater sides of the peltier two thermocouplers was planted on peltier's surfaces. Also two additional thermocouplers was also put in tubes in order to measure the temperature of the water. Then the tubes were taped in order to prevent leakage two more thermocouplers has been planted on the surfaces of the aluminium blocks in order to measure their temperature levels as seen in figure 3. Finally in order to isolate the whole system from the enviroment the whole system was wrapped with thermally insulating material. The flow of the water was measured with 2 rotameters which is tubed in to the system as seen in figure 4.

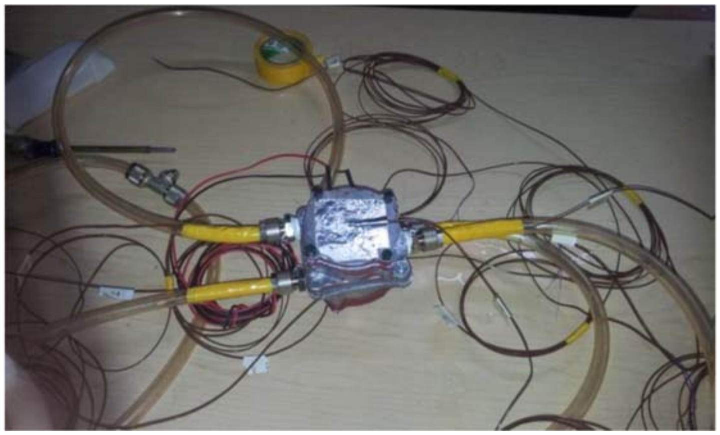

Figure 3. The peltier unit with thermocouplers planted.

Figure 4. The individual parts of the peltier system with tubed rotameters.

To track the temperature levels of the system an Agilent brand data collection system was used. The necessary thermocouple connections was made on the circuit board. And the hardware that was used in the experiment are as follows:

- The data collection system for collecting temperature levels.
- Rotameter for measuring the flow of the water.
- Thermocouples for temperature measuring.
- A laptop for data collection.
- Aluminium blocks for mounting on the surfaces of the peltier.
- DC power source for the peltier.
- Multimeter for current and voltage measurements.
- The necessary tubes and cables for connections of the system.

The final state of the experimental setup is as seen in figure 5.

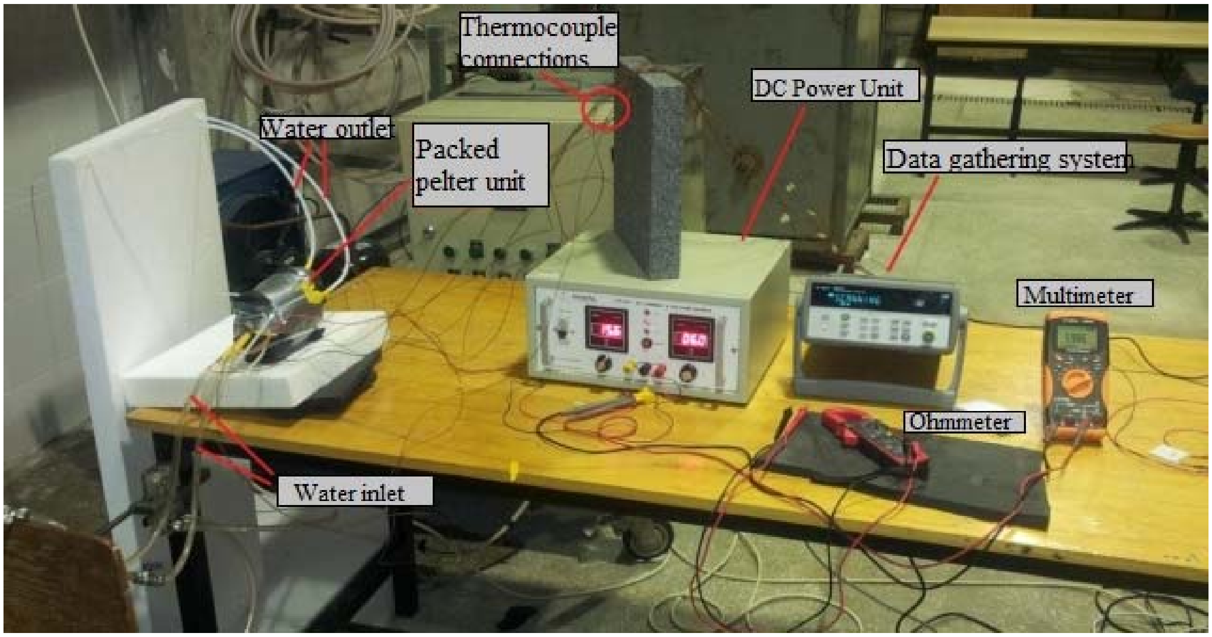

Figure 5. The experimental setup.

3. Results

Different levels of current was provided to the system between from 1 to 7 amps to the system during the experiment. Then coresponding voltage levels, temperature of water entering and exiting the system and surface temperatures of heater and cooler sides of the peltier were measured. All these measurements were after the system was stable and for a set period of time. The avarage of the measurements were used in calculations. Rotameters were used in measuring the flow also the mass of the flowing water was also calculated for a set period of time for flow calculation. The obtained measurents during the experiment is shown in table 1 below.

Table 1: Experimental results

	Set1	Set2	Set3	Set4	Set5	Set6	Set7
Current (A)	1	2	3	4	5	6	7
Voltage (V)	2.4	4.7	7.1	9.6	12	14.6	17.5
m_C (g)	1355	1365	1435	1405	1405	1470	1410
m_H (g)	1370	1410	1470	1360	1360	1410	1360
Ambient T	21.57	22.26	22.3	22.3	22.3	22.3	22.4
Peltier Surface_C	18.04	17.65	17.6	17.6	17.8	18.4	19.6
Peltier Surface_H	20.91	22.91	25.3	27.5	30	32.7	36.2
T out_C	18.23	17.85	17.5	17.2	17.1	17.1	17
T out_H	19.47	20.05	20.7	21.7	22.7	23.7	25.2
T in_C	18.84	18.78	18.8	18.7	18.7	18.7	18.7
T_in_H	18.87	18.8	18.8	18.7	18.7	18.7	18.7
Outer Surface_C	17.77	17.06	16.6	16.2	15.9	15.8	15.9
Outer Surface_H	20.12	21.17	22.6	23.8	25.1	26.1	27.6
Q_in (measured)	6.56	10.15	20.352	27.6	29.8	31.8	31.1
W_in	5.47	9.40	21.2	38	58.9	86.3	121
Q_out	12.59	20.13	42.24	66.24	89.26	118.61	152.72
COP	1.2	1.08	0.96	0.73	0.51	0.37	0.26
Q_in (calculated)	7.12	10.73	21.04	28.24	30.36	32.31	31.72

In the table Q_in represents the heat dissipated from the cold surface of the peltier. W_in is the power peltier consumes and Q_out is the amount of the heat dissipated from the hot surface of the peltier. In ideal conditions the equation below must be true.

$$Q_{in} + W_{in} = Q_{out} \quad (1)$$

Q_in values in the table 1 were calculated by using this equation. COP values of the system were calculated by using the measured Q_in and W_in values and also shown in the table 1. The amount of heat dissipation according to the current value of the system is shown in fig. 6 and the change in COP value is shown in figure 7. Figure 8 shown the change in Q_in (measured) and Q_in (calculated) according to system's current level. When the graph is examined, it is seen that these two values are very close to each other. Implicit uncertainties during the measurements can be the cause of the little differences between these values.

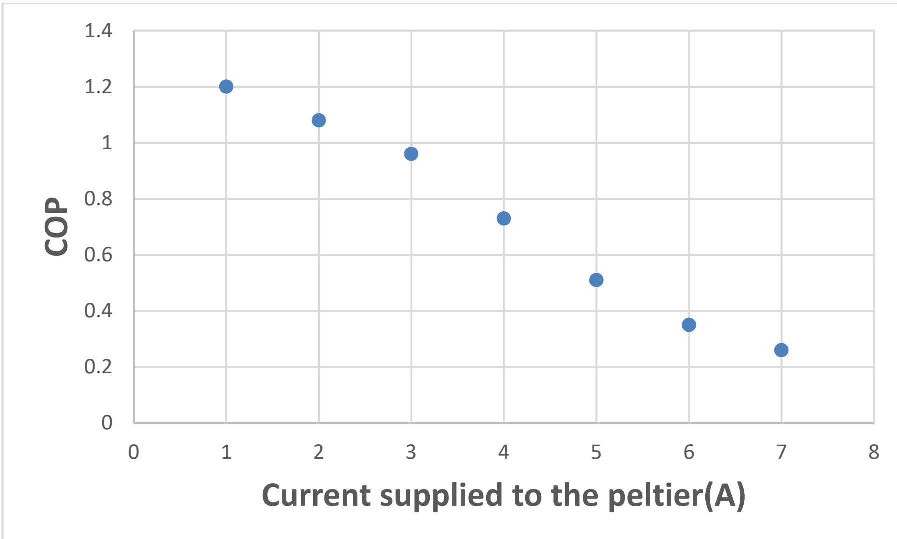

Figure 6. Experimental results.

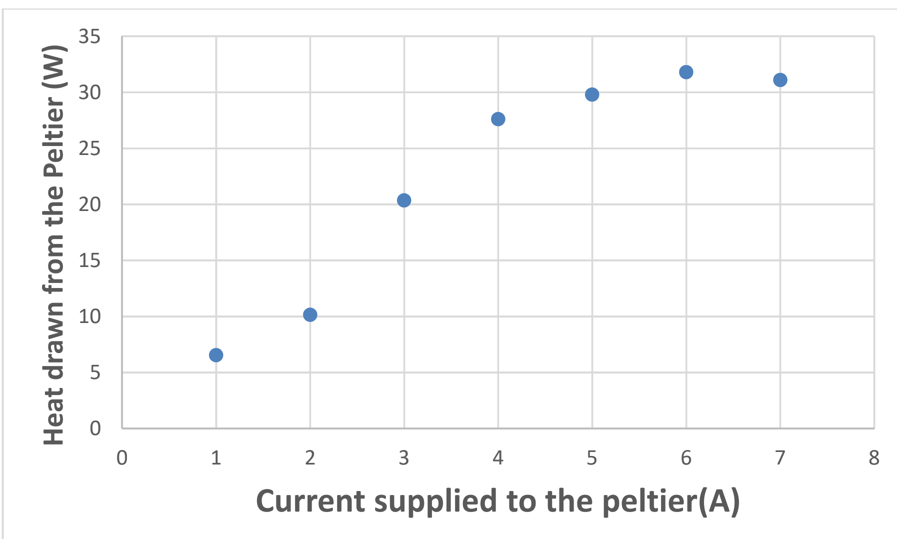

Figure 7. Experimental results.

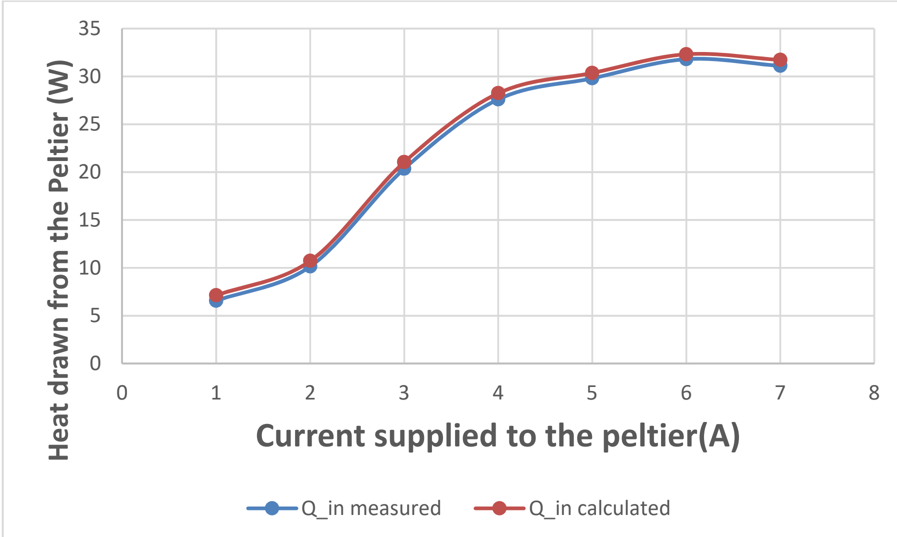

Figure 8. Experimental results.

As seen in the graphs increase in current levels causes the amount of heat drawn from the peltier to also increase and also causes decrease in COP value. Therefore, it is not a proper action to give more current when the required thermal power to be drawn from the system increases. This must be taken into account in the design of the battery cooling system and the current to be supplied to the peltier must be selected appropriately.

4. Conclusion and outlooks

Peltier systems are reliable, robust and maintenance-free cooling systems. Peltiers have lower COP values than conventional refrigerator cycles and this value is usually between 0,2 to 1,0 compared to refrigerator's 2,5. But unlike refrigerators, peltier systems doesn't consist any mechanical part. They are solid-state Technologies. Which makes them a good alternative to other conventional cooling solutions.

The heat Peltier draws from the system is increased by the current. However as the current increases, the increase in the amount of heat drawn from the system decreases so the amount of heat drawn from the hot surface increases. If this heat cannot be drawn from the hot surface, the temperature of both hot and cold sides increases. So the amount of power given to the peltier and the amount of heat drawn from the hot surface must be controlled in order to operate the battery in desired temperature levels between 15-25 ^{o}C.

In order to ensure that the temperature of the Peltier's hot surface is the same under all conditions, it can be considered to play with water currents at different current values. This will be possible with a control unit to be connected to the pump. Pumps used on the vehicle are driven by DC current. The power of the pump can be determined according to the thermal power requirement by playing with the speed of the pump by controlling the current.

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