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Cold storage for preserving medicines by using thermoelectric refrigeration

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ABSTRACT

Generally medicines must be stored and handled in accordance with the manufacturer's guidelines in order to maintain the quality of the product. Storage outside the recommended temperature range can result in chemical and physical changes to the product which may lead to a loss of efficacy and may cause harm to the patients. In order to maintain such recommended temperatures we generally use vapour compression refrigeration systems. The main drawback is emission of CFC compounds (refrigerants) like R22 upon leakage which could produce harmful effects on environment like ozone depletion. This work aims at developing alternate system for producing refrigeration effect called Thermo Electric Refrigeration. Thermoelectric cooling devices utilize the Peltier effect, whereby the passage of a direct electric current through the junction of two dissimilar conducting materials causes the junction to either cool down (absorbing heat) or warm up (rejecting heat), depending on the direction of the current. Finally using this thermoelectric principle a cold storage is fabricated for preserving the medicines and tested. The minimum cooling temperatures obtained are 10°C at 36°C ambient temperature in 210 minutes that is 3 hours 30 minutes.

Introduction

Improvements in manufacturing methods, driven by the electronics industry, have made TE devices effective in numerous applications [Peltier Device Info Directory, 2005]. Their compact size, light weight make TE modules especially well-suited for portable and dimensionally constrained applications. Currently the electronics industry is a large possible market for TE refrigeration applications. Ferrotec, sells modules that last an average of 68,000 thermal cycles, or about 20,000 hours - a thermal cycle is defined as 2.5 minutes from 30°C to 100°C and back down in 2.5 minutes from 100°C to 30°C, where a 5% change in electrical resistance denotes failure [Ferrotec, 2003]. Although TE performance is limited, new materials and module designs have potential to excel under various conditions. TE devices have many possible applications beyond cooling CPU chips, other applications are portable coolers, environmental control for optoelectronic equipment, and power generation in remote environments. Some consumer applications include a TE powered watch [Seiko, 2002], a TE temperature controlled vest, a Cannon digital camer [Peltier Directory, 2005], and a Colemann portable cooler [Colmann, 2002]. Since the SIA roadmap suggests that by the year 2015 there is currently no known thermal solution to meet industry performance needs, several researchers, such as Solbrekken, et al, and Phelan, et al, have proposed TE refrigeration as a possible solution [Solbrekken, 2004; Phelan, 2002]. Cryopreservation and storage of biological tissue are applications where precise temperature control and high cooling rates are necessary. In cryopreservation cells can be severely damaged if the cooling rate is not controlled precisely. For TE refrigeration, even with a current commercially available module (Ferrotec), the cooling rate can exceed 7.6°C/s (under no heat load) [Hanneken, 2005]. TE modules can be utilized to generate electricity. They are particularly suited to recover electricity from waste heat sources as they require a relatively small temperature difference to generate electricity from this usable power can be derived, just a few degrees or a few hundreds of degrees centigrade. Waste heat can come from any source that is typically expelled into the atmosphere such as car exhaust [Hi-Z, 2004], electronic components [Solbrekken, 2004], or even geothermal energy [NREL, 2004]. Solbrekken demonstrated that it is possible to use a thermoelectric generator to recover waste heat from a microprocessor to power a cooling fan [Solbrekken, 2004]. The system requires a TE module/heat sink in conjunction with a shunt heat sink i.e., some of the CPU heat is used for electricity generation, while the rest is dissipated to the ambient through a low thermal resistance path to ensure the CPU is kept below 85°C. It was shown that the TE device could generate sufficient electricity to drive a cooling fan to keep a 30 W heat source below 85°C [Solbrekken, 2004]. Recently, there have been multiple studies that explore the use of TE refrigeration in electronic applications. The main thrust of these studies is to design TE systems in order to eliminate or reduce losses in efficiency and performance. Simons, et al completed a case study using conventional off-the-shelf TE modules applied to a server application [Simons, 2000]. Their conclusion was that current TE materials cannot provide large enough COP's to be competitive with conventional vapor compression refrigerators. A similar finding was expressed by Phelan, et al [Phelan, 2002]. A study by Solbrekken, presented an operational envelope over which TE refrigeration provides a performance advantage over an air-cooled heat sink [Solbrekken, 2005], it presented a strategy for determining the operating current such that the junction temperature is minimized in the presence of a finite thermal resistance heat sink. Another main research track is to make TE materials cheaper. Polymers have made many products economically feasible in the last century. Work is being conducted to try to apply this paradigm to electronic equipment. Organic materials, such as polyethylene oxide, can be doped in order to make them

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electrically approximate to semi-conductors [Reeves, 1982; Shakouri, 1999; Heremans, 2003; Martin, 2003]. A thermoelectric (TE) cooler, sometimes called a thermoelectric module or Peltier cooler, is a semiconductor-based electronic component that functions as a small heat pump. By applying a low voltage DC power source to a TE module, heat will be moved through the module from one side to the other. One module face, therefore, will be cooled while the opposite face simultaneously is heated. It is important to note that this phenomenon may be reversed whereby a change in the polarity (+ and -) of the applied DC voltage will cause heat to be moved in the opposite direction. Consequently, a thermoelectric module may be used for both heating and cooling thereby making it highly suitable for precise temperature control applications. In a thermoelectric cooling system, a doped semiconductor material essentially takes the place of the liquid refrigerant, the condenser is replaced by a finned heat sink, and the compressor is replaced by a DC power source. The application of DC power to the thermoelectric module causes electrons to move through the semiconductor material. At the cold end (or "freezer side") of the semiconductor material, heat is absorbed by the electron movement, moved through the material, and expelled at the hot end. Since the hot end of the material is physically attached to a heat sink, the heat is passed from the material to the heat sink and then, in turn, transferred to the environment. The present work is to fabricate the cold storage for medical applications using thermoelectric refrigeration.

Peltier effect: If a voltage (V_{in}) is applied to terminals $T_1$and T_2 an electrical current (I) will flow in the circuit. As a result of the current flow, a slight cooling effect (Qc) will occur at thermocouple junction A where heat is absorbed and a heating effect (Qh) will occur at junction B where heat is expelled as shown in figure 1. Note that this effect may be reversed whereby a change in the direction of electric current flow will reverse the direction of heat flow.

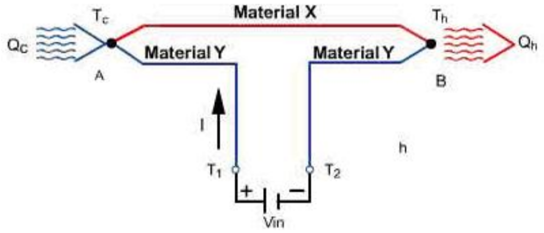

Fig 1: Peltier effect thermocouple circuit

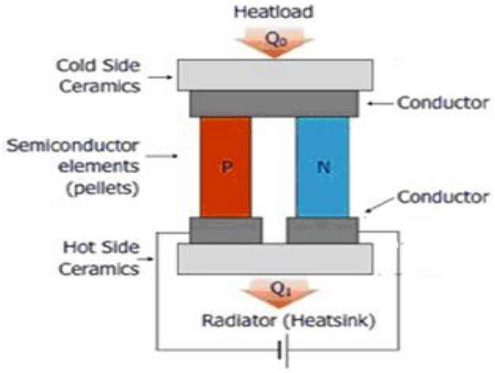

Fig 2: Thermoelectric module

Thermoelectric module:

TE module as shown in figure 2 consists of the following parts:

1. Regular matrix of TE elements – Pellets. Usually, such semiconductors as bismuth telluride (BiTe), antimony telluride or their solid solutions are used. The semiconductors are the best among the known materials due to a complex optimal TE performance and technological properties. BiTe material is the most typical for TE cooler.
2. Ceramic plates – cold and warm (and intermediate for multi-stage coolers) ceramic layers of a module. The plates provide mechanical integrity of a TE module. They must satisfy strict requirements of electrical insulation from an object to be cooled and the heat sink. The plates must have good thermal conductance to provide heat transfer with minimal resistance. The aluminum oxide (Al2O3) ceramics is used most widely due to the optimal cost/performance ratio and developed processing technique.
3. Electric conductors provide serial electric contacting of pellets with each other and contacts to leading wires. For most of the miniature TE coolers, the conductors are made as thin films (multilayer structure containing copper (Cu) as a conductor) deposited onto ceramic plates. For large size, high-power coolers, they are made from Cu tabs to reduce the resistance.
4. Solders provide assembling of the TE module. The most standard solders used include Lead-Tin (Pb-Sn), Antimony-Tin (Sn-Sb) and Gold-Tin (Au-Sn) alloys. The solders must provide good assembling of the TE module. The melting point of a solder is the one of limiting factors for TE Cooler reflow processes and operating temperature. Leading wires are connected to the ending conductors and deliver power from a direct current (DC) electrical source.

Heat sink: A heat sink (figure 3) is a term for a component or assembly that transfers heat generated within a solid material to a fluid medium, such as air or a liquid. Examples: heat exchangers used in refrigeration and air conditioning systems and the radiator in a car. Heat sinks also help to cool electronic and optoelectronic devices, such as higher-power lasers and light emitting diodes (LEDs).A heat sink uses its extended surfaces to increase the surface area in contact with the cooling fluid. There are three widely applied methods used for mounting: Mechanical mounting; Soldering; Adhesive bonding.

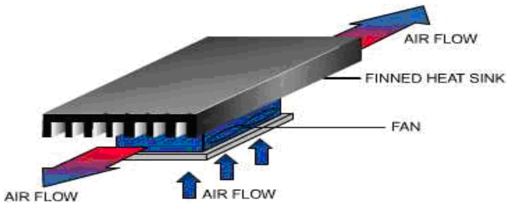

Fig 3: Air flow of heat sink

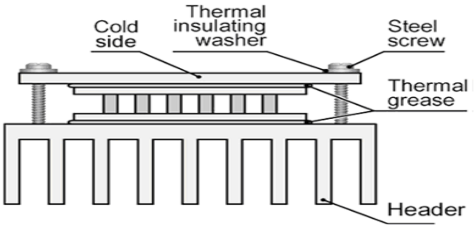

Fig 4: Mechanical mounting

Mechanical mounting method is used to place a TE module in heat sink and aluminium plate fixed by screws as shown in figure 4. For good thermal conductance the clearance between the plates should be filled by some substances of high thermal conductance. As such as anabond paste is used.

Apparatus:

Aluminium plate, Anabond paste, Insulating material, TEC element as shown in figure 5, Heat sink, MS bracket, Grill, 12v DC fan, PCB (Power circuit board), Sleeves, Screws, Washer and Casserole.

Fig 5: TEC Element

Fig 6: Cold storage before insulation

Fig 7: Cold Storage after insulation

Insulation material: Figure 6 and 7 shows the cold storage unit before and after insulation. Insulation material such as smooth polystyrene foam of 20mm is used. As its thermal conductivity (0.03W/mk) is low. The polystyrene foam is a type of a plastic that is certainly furnished from styrene. It is very good due to the fact that it is moisture resistive. It is light weight material that will be linked on your need of protection. Polystyrene actually contributes a great deal for any prolonged time.

Temperature requirements for medicinal storage:

Medicinal products should be stored under conditions which ensure that their quality is maintained. The temperature of storage is one of the most important factors that can affect the stability of a medicinal product. Storage conditions for most medicines can be satisfied by either cold storage (below 12°C) or storage below 25°C [storage below 30°C in reference to EEC regulations]. Storage conditions can influence the stability of medicines.

Results and discussion:

Load calculations:

Consider the heat load calculations before design of cold storage where the heat transfer process is by conduction.

Heat transfer through solid material

$$Q = \frac{(K)\,(DT)\,(A)}{X} \qquad (1)$$

Where, K= Thermal conductivity of the insulating material = 0.03W/mK

A= Cross section area= 0.0847 m^2

DT: Temperature difference between cold & ambient=38°C

X: Thickness of the insulating material=0.02m

Heat transfer through solid material Q=4.827w

Total load = Heat transfer through solid material+ 20% additional load =5.79w

Coefficient of performance (COP):

Coefficient of performance is given by

$$COP = \frac{\text{Total heat transfer through the system}}{\text{Electrical input power}} \qquad (2)$$

Input power (Pin) = voltage (v) X current (I) = 12 X 0.15 = 1.8W (3)

Maximum heat input to the housing P = 12 X 0.5 =6W

After insulation,

K= Thermal conductivity of the insulating material = 0.03W/mk

A= Cross section area= 0.0847 m^2

DT: Temperature difference between cold & ambient=26°C

X: Thickness of the insulating material=0.02m

Heat transfer through the system Q=3.3W

Therefore, Coefficient of performance COP = 3.3/ 6 =0.55

Cooling temperature vs power consumption:

The figure 8 is drawn for the practical values of the cooling temperature to power consumption. These values are taken after the insulation of the cold storage. Before insulation values of cooling temperature is not effective to compare cooling temperatures. From the graph, it is observed that the power consumption is increased when the temperature is reduced.

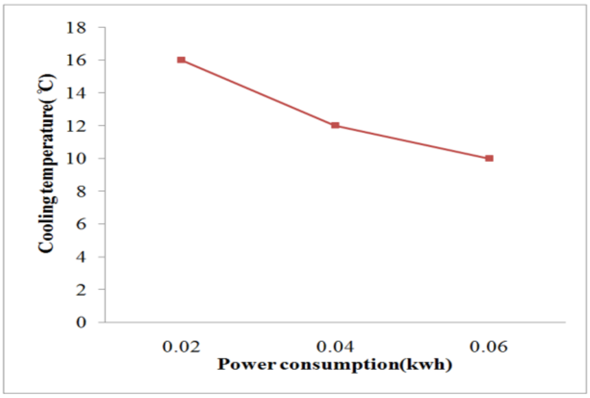

Fig 8: Cooling temperature vs power

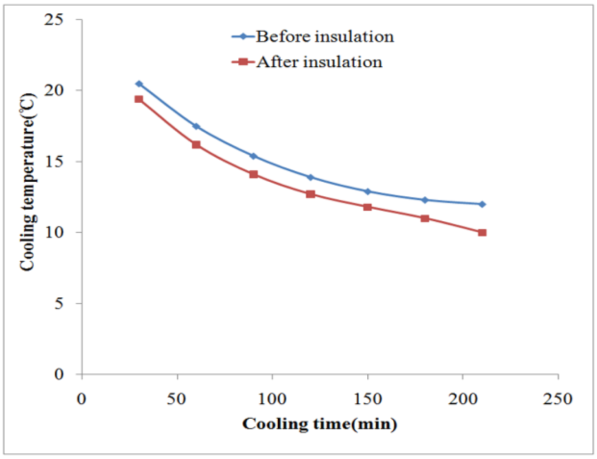

Fig 9: Cooling temperature vs cooling time consumption

Cooling temperature vs time:

The figure 9 is drawn for the practical values of the cooling temperature to the cooling time. The minimum cooling temperature is 12°C is obtained at 36°C ambient temperature before insulation and 10°C is obtained at 36°C ambient temperature after insulation. It is that observed when cooing time is increased automatically the cooling temperature is reduced. So when compared, after insulation reaches effective temperature values.

Cooling temperature vs ambient temperature:

The figure 10 is drawn for the practical values of the cooling temperature to the ambient temperature. The minimum cooling temperature obtained is 12°C and 10°C at 36°C before insulation and after insulation conditions. The cooling temperature changes are based upon the ambient temperature. When ambient temperature is high, the cooling temperature change will come slow and when ambient temperature is low, the cooling temperature changes very fast.

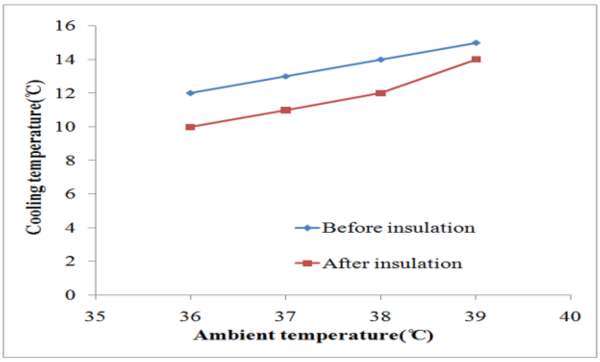

Fig 10: Cooling temperature vs ambient temperature

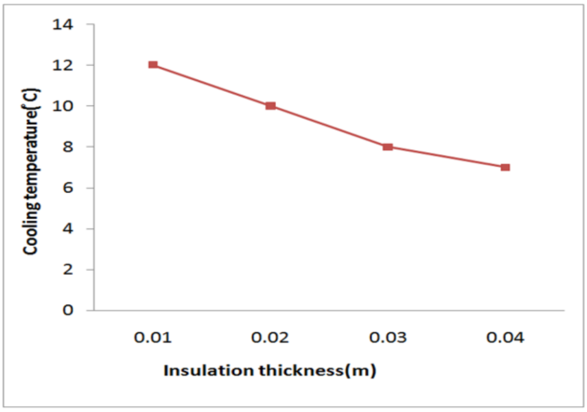

Fig 11: Insulation thickness vs cooling time

Insulation thickness vs cooling temperature:

The above figure 11 is drawn for the practical values of the insulation thickness to the cooling temperature. The minimum cooling temperature obtained is 10°C at insulation thickness is 0.02m, when the insulation thickness is increased, the cooling temperature is decreased. So the cooling temperature is depends up on the insulation thickness also.

Cost analysis: Cost analysis is conducted as per the temperature requirement and load calculations using 40X40 thermoelectric elements.

Cost of the thermoelectric element is Rs.1300.
Casserole of 1.3 liters its cost is Rs.200
Aluminium heat sink with mild steel bracket is Rs.700.
Smooth polystyrene foam cost is Rs.200
Cost of the 12v DC fan is Rs.100.
The total cost of equipment is Rs.2500.

So efficient cooling is obtained at low cost and this is the advantage of thermoelectric refrigeration system.

Conclusion:

Using the thermoelectric principle a cold storage is fabricated for preserving the medicines and tested. The cooling temperature values are considered before and after insulations. When compared, it is observed that after insulation cooling temperature is better and the power consumption is also low. Inside cooling temperature is dependent up on the ambient temperature. When compared to actual vapour compression refrigeration system this thermoelectric refrigeration is harmless to environment. The minimum cooling temperatures obtained are 10°C at 36°C ambient temperature in 210 minutes i.e; 3 hours 30 minutes.

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Nomenclature:

Q= Heat transfer through solid material, W
K= Thermal conductivity of the insulating material, W/m k
A= Cross section area , m^2
DT= Temperature difference between cold & ambient, °C
X= Thickness of the insulating material, m
Pin= Input power, W
V= Voltage, V
I= Current, Amp

Appendix:

Cold storage specifications:

Capacity=1.3Litres
Outer body=Insulation material (20mm thickness)
Inner cabinet=Stainless steel
Insulation= Polystyrene foam (20mm thickness)