Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 11, November-2016

An Optimum Novel Design & Performance Analysis of Energy based Approach by using Phase Changing Materials

Jithin J Menon
M. Tech: Mechanical Department
Nehru College of Engineering and Research Centre
Pampady, Thrissur, India

Sreejith K V
Asst. Professor
Mechanical Department
NCERC Pampady

Dr. Sankar S
Associate Professor
Mechanical Department
NCERC Pampady

***Abstract*: In this work, different PCMs are studied thermally and structurally, selected the optimum material and a practical application of personal usage of it (cooling vests) is fabricated and analyzed for its efficiency improvement. A new method and empirical design for the replenishment or recharging of the phase changing material used inside the vests is developed by circulating cooled water obtained by adopting peltier cooling, through the vest in a designed fashion, the conventional methods for which are practically difficult in day-to-day conditions. The fabricated vest can be used to maintain an optimum temperature ranging between 60ºF to 83ºF at high atmospheric temperatures.**

Key words: Personal cooling, phase changing material, cooling vest, Latent heat

I. INTRODUCTION

A personal cooling system has become the need of the century as the global climatic changes are bringing unpredictable environment conditions to survive. Global temperature is rising sturdily and researchers around the world are trying to come up with solutions. Massive research and development for personal cooling is being done by the military too. For instance, a soldier who needs to do his mission in a deserted area with temperatures going up to 130°F will find it thorny. If he/she can use a personal cooling attire to feel like 70°F instead of 130°F,then that is a definite need of the soldier. The same need of lessening fatigue is also very crucial in many other areas too such as athletics, high heat environments, and operating rooms. Different methods and concepts are being developed to develop such a personal cooling attire and one of the most discussed technique is the use of phase changing materials. A phase-change material (PCM) is a substance which is having a high heat of fusion ,which melts and solidifies at a certain temperature, and it is able to store and release huge amount of energy. When the material changes from solid to liquid, heat is wrapped up or released and vice versa. And hence PCMs are classified as latent heat storage (LHS) units. Latent heat storage of PCMs can be obtained through liquid to solid, solid to liquid, solid to gas and liquid to gas phase transitions. However, the only phase change used for PCMs is the solid to liquid change as all other transitions have viability issues. This effect could be achieved by using phase change material (PCM). Phase change materials possess the ability to change their state with a certain temperature range. These materials absorb energy during the heating process as phase change takes place, otherwise this energy can be transferred to the environment in the phase change range during a reverse cooling process.

II THEORY

A. *Working Principle Of Phase Change Materials*

Thermal energy storage was at all times a really indispensable technique for thermal energy exploitation. There main four alternatives for thermal energy storage are latent heat utilization , sensible heat utilization, , utilization of reversible chemical heat, and exploitation of heat of dilution. Solid, liquid, gas and plasma are the four states of a material. When a material converts from one state to another, it is called as phase change. There can be four kinds of phase change processes which are discussed here and are solid to liquid, liquid to gas, solid to gas and solid to solid. During the phase change process, heat is engrossed or released. Latent heat, is what we call this absorbed or released heat content. PCM which can convert from solid to liquid or from liquid to solid state is the most recurrently used latent heat storage material. It is suitable for the manufacturing of heat storage and thermo-regulated textiles and clothing. Modes of heat transfer are strongly depending on the phase of the substances engage in the heat transfer processes. Conduction is the predominate mode of heat transfer for substances that are solid. For liquids, convection heat transfer outweighs, and convection and radiation are the primary mode of heat transfer for vapors. The principles of solid to liquid phase change and liquid to solid phase change are to be discussed here. The phase change from the solid to the liquid occur when the melting temperature of a PCM is obtained during heating procedure. During this phase change process, the phase changing material absorbs huge quantities of latent heat from the surrounding area throughout the process. Phase changing material may be repetitively converted between solid and liquid phases to make use of their latent heat of fusion in order to absorb, store and liberate heat or cold. Phase change materials are not something new to us. They already subsist in various forms and various dimensions in our nature. Water at zero degree celcius is the most common example of a PCM that we can relate to in nature. Water crystallizes as it changes from liquid to a solid. A phase change also occurs when water is heated to a temperature near to 100ºC,the point at which it becomes steam. During the actual phase change with the amount of heat absorbed in a regular heating process, water is something that can be made use for comparisons in order to put side by side the amount of heat absorbed by a Phase changing material.

B. *Thermoelectric Cooling*

To create a heat flux linking junction of two dissimilar types of materials, thermoelectric cooling uses the Peltier effect. A Peltier cooler is essentially a solid-state active heat pump which transfers heat from one side of the device to the other side. It burns up the electrical energy, depending on the direction of the current. Peltier device, it the name that we use for such an instrument. It can also be termed as a Peltier heat pump or solid state refrigerator, or thermoelectric cooler. Even though the main application of it is cooling, it can be used either for heating or for cooling. It can also be used as a temperature controller and regulator that either heats or cools things as per requirement. This mentioned technology is not so common and is less applied to refrigeration compared to the vapor-compression refrigeration method. There are some primary advantages for a Peltier cooler in comparison to a vapor-compression refrigerator. It lacks moving parts or circulating liquid, it has avery long life, it is invulnerable to leaks, it is small in size and its flexible shape are some of the attributes. The main disadvantage of a peltier cooling system is its high cost and poor power efficiency which makes it less viable in common use. Lots of researches are being conducted all around the world to develop Peltier coolers that are both cheap and efficient. It is also to be noticed that a Peltier cooler can be used as a thermoelectric generator. When it is operated as a cooler, a voltage is applied across the device. As a result of this, a difference in temperature will build up between the two sides. Nevertheless, a well-designed Peltier cooler will be an average thermoelectric generator and vice versa, due to different design and packaging requirements. One n-type and one p-type, which are two unique semiconductors, are used as they need to have different electron densities. The semiconductors are positioned thermally in parallel to each other. It is also positioned electrically in series and then joined with a thermally conducting plate on each side. There will be a flow of DC current across the junction of the semiconductors when a voltage is applied to the free ends of the two semiconductors and it will cause a temperature difference. The side which is having the cooling plate absorbs heat and is then moved to the other side of the device where the heat sink exists. Thermoelectric coolers are typically connected side by side and sandwiched between two ceramic plates. The cooling ability of the total unit is then always proportional to the number of Thermoelectric cooler units in it.

Fig 1) Thermoelectric cooler (TEC1-12706)

III METHODOLOGY AND PROCEDURES

The major objective of this project work is to study different PCMs and they are analysed thermally and structurally using softwares. A practical application of personal usage of it (cooling vests) is to be fabricated and analysed for its efficiency improvement. The whole project can divide into several modules:

Module 1:

Short listing of suitable phase changing materials and their studies : The range of Phase changing materials available is huge and selecting the optimum material for the fabrication of the vest was a tedious task. In order to short list materials, different criteria were formed. Diminutive volume change on phase alteration and small vapour pressure at operating temperatures is recommended to trim down the containment crisis. It should satisfy some thermodynamic properties. Melting temperature should be in the preferred operating temperature array. The latent heat of fusion per unit volume should be high enough. High specific heat and high thermal conductivity is required and high density is also needed. It should satisfy many kinetic Properties. To avoid super cooling of the liquid phase, it should have High nucleation rate to. It should have high rate of crystal growth, so that the system can meet demands of heat recovery from the storage system. Some chemical properties are also to be satisfied. It should be having absolute reversible freeze or melt cycle. It should not have degradation after a large number of freeze or melt cycle. It should be having certain properties like, it should be non-corrosive, non-toxic, non-flammable and non-explosive material. It also need to have viable economic properties such as low cost and ease of availability. Considering all these criteria four Phase changing materials were identified. They are :

1) Poly ethylene glycol
2) Trimethyloethane
3) Methyl palmitate
4) Paraffin-18 carbon

Module 2 :

Selection of optimum material: According to the requirement of the work, a phase changing material with melting point in the range of 27-30 and heat of fusion above 190 was difficult to find and hence we decided to manufacture a eutectic material. As a part of that, we enquired to different companies around the globe who manufacture phase changing materials. After a long three months of interactions, discussions and negotiations, a company called PLUSS came out with a deal to provide a material which is more closer to our requirement. As per our instructions, the company provided us with the material coded, OM 29. It is an natural chemical based PCM having nominal freezing temperature and melting temperature of almost 28^0C to 29^0C. It is capable of storing thermal energy as latent heat in its crystalline form. When it changes its phase, this latent heat can be released or captivated, allowing the ambient temperature contained by the system to be sustained. It is made up of the precise mix of a mixture of additives allowing symmetry between solid and liquid phases to be obtained at the melting point. OM 29 has ostensible freezing temperature of 29^0C which is a temperature that makes it supreme for many heating or cooling thermal energy applications. Some of its prominent features are that OM 29 is chemically and thermally stable and noticeably is a intermingle of various organic fatty acids.

Fig. 2) Micro encapsulated OM 29 pouch front view

Fig. 3) Micro encapsulated OM 29 pouch back view

IV MATERIAL TESTING AND RESULTS

The selected material i.e OM 29 was tested for its efficiency and heat absorption distinctiveness. For this, A 25g sample was taken in a test tube in molten state and it was placed in a temperature controlled water bath. To record the temperatures,a temperature sensor was placed in the test tube and bath using a datalogger. The bath was maintained at 18^0C during the freezing cycle and at around 40^0C during the melting cycle.

Fig 4) Temperature data logger

Fig 5) Laboratory water bath setup

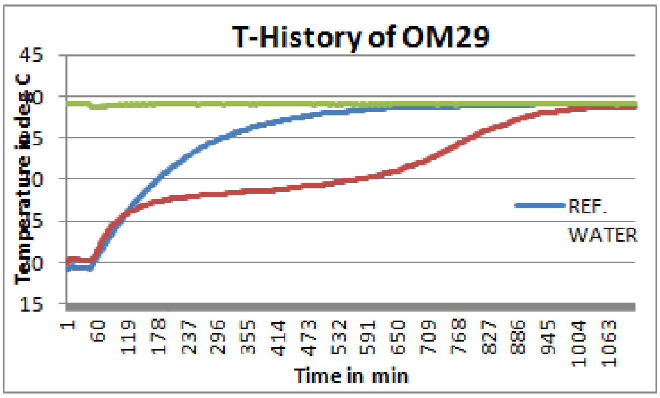


Fig 6) T-History graph for OM29 done in water bath

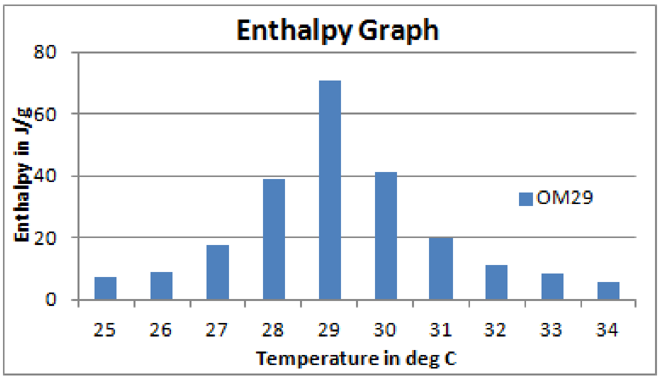


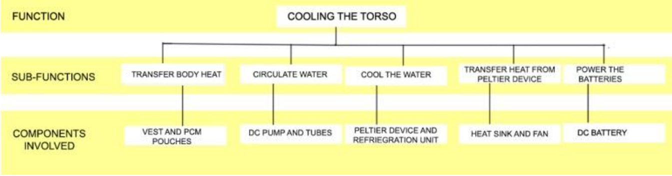
Fig 7) Enthalpy graph for OM29 done in water bath

Based on the iterations and observations, the following chart was prepared :

Table 1) Properties and data

Property	Value*	Test Method	Test Conditions (if any)
Melting Temp (°C)	29.0	T-History	@ 39^0C Liquid Bath
Freezing Temp (°C)	29.0	T-History	@ 19^0C Liquid Bath
Latent Heat (kJ/kg)	229	T-History	@ 34 to 24°C
Liquid Density (kg/m3)	870	ASTM D891-95	@ 39°C
Solid Density (kg/m3)	868	PLUSS® Internal	@ 20°C
Liquid Specific Heat (kJ/kgK)	3.9	Calorimeter	@ 40°C
Solid Specific Heat (kJ/kgK)	NA	Calorimeter	
Liquid Thermal Conductivity (W/mK)	0.172	KD2Pro	@ 40°C
Solid Thermal Conductivity (W/mK)	0.293	KD2Pro	@ 22°C
Base Material		Organic	
Congruent Melting		YES	
Flammability		YES	
Thermal Stability (Cycles)	~2000		
Max Operating Temp(°C)	120		
Flash Point (^{0}C)	200		

Table 2) Functional Diagram of the work



VII RESULTS AND DISCUSSION

First Testing Procedure

To authenticate the cooling vest a set of temperature testing actions were done. In order to do the testing, a thermocouple was used to get hold of the temperature readings. The thermocouple was positioned at the area between the chest and the abdomen. The first dimension taken was the steady-state skin temperature devoid of any of the vests on. This temperature was recorded as 90.5°F. Then a member of the team was asked to wear both the cooling vests with pcm pouches for a period of 20 minutes. At this point a temperature reading was taken and the result was 77°F. The cooling vest was then turned on and temperature readings were recorded every 5 minutes for a complete hour. Upon reaching this steady-state temperature the cooling vest kept the skin temperature within a standard deviation of .3°F of

90.5°F. This result proves that the cooling vest is removing the 58.24 watts that is anticipated in our thermo-model that the body is producing and since this heat is being removed and the body remains at a steady-state skin temperature. These results prove that the cooling vest in reality performs as it was intended to.

Second Testing Procedure

A second test was performed to establish the life of the battery powering the thermoelectric cooler. This battery drains faster than that the battery powering the fan and the pump and thus it determines the maximum operation time of the cooling vest. This validation was done concomitantly with the first testing procedure described above. An ammeter was clipped in series with the thermoelectric cooler's battery and the thermoelectric cooler itself. This allowed us to monitor the current being drained by the thermoelectric cooler and also to see when the batteries were no longer powering the thermoelectric cooler. From a full charge the battery powering the thermoelectric cooler was able to supply power for a total of 1 hour and 58 minutes, which nearly reaches the predicted time of 2 hours, before the required current was no longer able to be met. The actual operating time should be expected to be less than that of the estimated time due to losses of energy that are that are unpredictable. These results validate that the actual operating time is what we estimated it to be.

Strengths

The utmost facet of the cooling vest that our team has designed is its ability to provide mobile and a unrelenting cooling to the user. There are plentiful cooling vests on the market today, but none of them has endeavored to fabricate a cooling vest that does not need to be plugged in to an external power supply or water cooling system. This is a large plus to our objective client base which includes workers who would like to wear a cooling vest that allows them to move around the location in safety. Our vest is also light weight, works well in rooms as warm as 80° F and allows full movability to the person that will be wearing it. The vest is also quite robust and the nylon material is easy to clean. The vest is easy to maintain, since the water used is in a closed system, and the batteries are easy to plug into the vest and unplug. In the unlikely event of a leak, the cooling fluid is water and should pose no threat to the user.

Weaknesses

There are many things that prevent this product from being even better nevertheless the cooling vest works quite well. The first reason is that the polyethylene tubes are quite rigid and it is difficult for different people's body's to kowtow to the tube layout that has already been made. The tubes are also thicker than we had hoped, which results in lower heat transfer. Due to the layout of the tubes, it is difficult to fill or refill the water in the tubes if necessary. This process usually took our team at least 15 minutes to achieve, and was done numerous times throughout testing. The electrical system of the cooling vest is simple and not as refined as our team had hoped for. The back pack that contains the switches and the wiring for our electrical components was made by just placing them in corresponding positions. The lack of an overall system performance monitor is unfavorable to the maintenance and maneuver of the vest. Our team was force to attach strips of Velcro and glue to each of the components to attach them. The back pack also lacks a method to conceal the electrical wires that are required to connect each electrical device to the switches and the batteries.

VII CONCLUSION

Workers have always been affected by excess heat surrounding their bodies due to stress and other environmental factors for which they are looking for a cooling vest that they can wear to stay cool, but won't compromise their capability to move around. We researched several cooling technologies that are available today in the market to see if it was possible to utilize any of these technologies to our advantage. Phase changing materials are able to absorb heat over time through their chemical phase changes. Water flowing throughout the vest can act as a cooling device. Tubes with a cooling fluid could be placed throughout a vest and circulated to keep the body cold. Thermoelectric cooling devices can be used in a system to cool the body or any type of cooling material. The final design for our cooling vest includes a tube layout to circulate water throughout a vest, and a thermoelectric peltier cooler to cool the water inside the vest,which will help maintaining the PCM pouches sustain their temperatures. So whenever the PCM vest runs out of its charge,it is recharged by simply turining on the power source which will circulate water throughout the body. Polyethylene tubes would be constructed into a tube layout to distribute the water evenly throughout the vest. A heat exchanger will use a thermoelectric cooler to cool the water that circulates. The thermoelectric cooler works as a heat pump, absorbing heat through a water cooler on its cold side and heat sink and fan on its hot side. A DC water cooling pump will circulate water throughout the vest. This design would be powered using Lithium Ion and switches will control the power to the pump, the thermoelectric cooler, the heat sink fan and the pump, and the heat exchanger. The batteries and all the electrical components will be attached to a back pack that can be easily carried. We manufactured a model cooling vest to test the concept that we had engineered and to see that our vest was truly itinerant The vest was tested to ensure that it could provide the cooling ability that we had designed it to do. With the cooling vest turned off, skin temperature rose from 91° F to about 95° F in about 15 minutes. When the cooling vest was put on, his skin temperature returned to the normal 76° F and stayed constant for the duration that the cooling vest operated.

VIII REFERENCES

[1] James R. House , Heather C. Lunt, Rowan Taylor, Gemma Milligan, Jason A. Lyons, Carol M. House,The impact of a phase-change cooling vest on heat strain and the effect of different cooling pack melting temperatures,European Journal of Applied Physiology,
2012
[2] Bendkowska Wiesława, Kłonowska Magdalena, Kopias Kazimierz and Bogdan Anna,Thermal Manikin Evaluation of PCM Cooling Vests,FIBRES & TEXTILES in Eastern Europe 2010,Vol. 18, No. 1 (78) pp. 70-74
[3] Chuansi Gao, Kalev kuklane and Faming wang [3](2012), Personal cooling with phase change materials to improve thermal comfort from a heat wave perspective,2012
[4] Chuansi Gao, Kalev Kuklane and Ingvar Holmér,Cooling vests with phase change material packs: the effects of temperature gradient, mass and covering area,Ergonomics,Taylor Francis online,2009
[5] Chuansi Gao , Kalev Kuklane, Ingvar Holmér,Cooling vests with phase change materials: the effects of melting temperature on heat strain alleviation in an extremely hot environment,European Journal of Applied Physiology,2010
[6] Atul Sharma, V.V. Tyagi, C.R. Chen a, Buddhi,Review on thermal energy storage with phase change materials and applications,Renewable and Sustainable Energy,Science direct,2007

[7] S. Mondal,Phase change materials for smart textiles,Renewable and Sustainable Energy,Science direct,2007

[8] J. Rupp, Interactive textiles regulate body temperature, International Textile Bulletin 45 (1) (1999) 58–59. [9] B. Pause, Development of heat and cold insulating membrane structures with phase change material, Journal of Coated Fabrics 25 (1995) 59–68.

[9] M.M. Farid, A.M. Khudhair, S.A.K. Razack, S. Al-Hallaj, A review on phase change energy storage: materials and applications, Energy Conversion and Management 45 (9–10) (2004) 1597–1615.

[10] B. He, V. Martin, F. Setterwall, Phase transition temperature ranges and storage density of paraffin wax phase change materials, Energy 29 (11) (2004) 1785–1804.

[11] B. He, V. Martin, F. Setterwall, Liquid–solid phase equilibrium study of tetradecane and hexadecane binary mixtures as phase change materials (PCMs) for comfort cooling storage, Fluid Phase Equilibria 212 (2003) 97–109.

[12] Y. Takahashi, R. Sakamoto, M. Kamimoto, K. Kanari, T. Ozawa, Investigation of latent heat-thermal energy storage materials. I. Thermoanalytical evaluation of modified polyethylene, Thermochimica Acta 50 (1–3) (1981) 31–39.

[13] K.C. Rolle, Heat and Mass Transfer, Prentice-Hall, Inc., 2000, pp. 496–547 (Chapter 10).