International Journal of Mechanical Engineering and Technology (IJMET)
Volume 9, Issue 8, Aug 2018, pp. 204-212, Article ID: IJMET_09_08_022
Available online at http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=9&IType=8
ISSN Print: 0976-6340 and ISSN Online: 0976-6359

DESIGN AND DEVELOPMENT OF PHASE CHANGE MATERIAL ORIENTED COLD STORAGE FLASK

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ABSTRACT

Temperature sensitive, frozen food transportation and storage at low temperature is being viewed as a critical issue worldwide as it is related to the changing lifestyle and growing population of the people. The aim of this project is to propose a flask that can be used for cold chain supplies by incorporating a Phase Change Material (PCM) which has low freezing temperature. It is mainly focused to aid the end customers, to whom this flask will be more accessible while travelling and will act as a replacement to dry ice and gel packs. The flask design is a three layered hollow concentric cylinder with the outermost layer filled with insulation, the middle layer with encapsulated PCM tubes and the innermost is where the low temperature product is to be stored. A seal is provided on the top of the body is used to hold the PCM and avoid its leakage. The final portion which makes up the flask is the cap. The PCM selected is SAVE OM03 with properties like melting point of 3.5˚C, liquid density of 835 kg/m^3 and solid density of 935 kg/m^3. The latent heat of this PCM is 240 KJ/kg, having such a huge latent heat *makes the PCM to maintain its surrounding temperature for a longer time during its phase change from solid to liquid. Polypropylene (PP) test tubes of diameter 15mm and height 100mm are used for PCM encapsulation. The insulation material used for the flask is polyurethane because of its low thermal conductivity of 0.033 W/n^2K. Based on the theoretical studies, the flask diameter is taken as 114mm and the overall height is taken as 200mm. The method adopted for manufacturing this flask is 3D printing and the material used for the flask body is Polylactic acid. Finally, experimental study was carry out, to determine how long a product would be maintained at a low temperature in this flask and for this the PCM was freeze for about 48 hours and was placed in the flask. Several trials were taken and it was found that this PCM oriented flask could maintain a product at low temperature for about 6 hours.*

Keywords: Cold Storage Flask, Phase Change Material

Cite this Article: A.Rajendra Prasad, N. Vasudevan, S.Krishnaraj, S.M. Suresh and Balaji.S, Design and Development of Phase Change Material Oriented Cold Storage Flask, International Journal of Mechanical Engineering and Technology, 9(8), 2018, pp. 204-214.
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1. INTRODUCTION

The term "cold storage" refers to the storing of goods in a refrigerated atmosphere. This means heat is removed from the storage container or room to help keep items - often food - fresh for delivery, long- or short-term storage, and so on. Cold storage helps prevent spoilage of foods and other items meant for consumption, and it can be used in a variety of other settings, such as hospitals, warehouses, and anywhere else that stores products in need of preservation. A cold chain is a temperature-controlled supply chain. It involves the transportation of temperature sensitive products along a supply chain through thermal and refrigerated packaging methods and the logistical planning to protect the integrity of these shipments. The major cold chain technologies in providing a temperature controlled environment during transport involve dry ice, gel packs, eutectic plates, liquid nitrogen and quilts. A cold chain supply with gel packs or dry ice can't serve the purpose of carrying low temperature sensitive products while travelling because of cold chain failure i.e., failure of not maintaining the products within the prescribed temperature range and due to its limited accessibility to end users and this prevails mostly for pharmaceutical products which fall under the temperature range of 2°C to 8°C. The use of Phase Change Material (PCM) for the purpose of storing cold items is a recent upcoming trend in our country. Phase-change materials (PCMs) are considered suitable for various industrial applications due to their high-energy density and their ability to provide a relatively constant temperature during the solid-liquid phase-change process. Many applications of PCM at low temperature storage can be found, such as, ice storage, conservation and transport of temperature sensitive materials and in air conditioning, cold stores, and refrigerated trucks.

Eduard Oro´ et al. [1] studied about the enhancement of the ice cream storage using PCM when it is placed outside the refrigeration. Their aim was to design and to test a phase change material (PCM) package (E-21) for commercial ice cream containers. Eduard Oro´ et. al.[2] experimented with the aim to evaluate the thermal response of low temperature chambers incorporating phase change materials (PCM) having low freezing temperature when subjected to refrigeration system failure. Two commercial PCMs with different melting temperature were tested (Climsel C-18 from CLIMATOR and E-21 from CRISTOPIA). The results show that when there is no refrigeration, both the air and the frozen product temperatures remained at lower values for much longer time when PCM was employed. W. Lu et. al. [3] made a study to increase the thermal capacity of the equipment and maintain product temperature within safe limits during frequent door openings, on–off cycling of the compressor and mains power failure. The results showed that paraffin products (Paraffin RT-2) exhibited negligible super cooling but have low latent heat compared to water based products which have higher latent heat but exhibit a greater degree of super cooling. MD. Mansoor Ahamed et. al. [4] insists the use of a passive system integrated into the walls of the cold storage facility i.e., PCM (Ethylene Glycol). With PCM, the air temperature is kept constant at -8°C for 8 hours, compared to without PCM where the air temperature rises continuously and rises above -8°C in just 1 hour. A review of applications of PCM for cold storage has been carried out by E. Oró et. al. [5] in his paper. The scope of the work was focused on different aspects: phase change materials (PCMs), encapsulation, heat transfer enhancement, and the effect of storage on food quality. Materials used by researchers as potential PCM at low temperatures (less than 20°C) are summarized and some of their thermo physical properties are reported. The structure of the flask to be fabricated is to be a three-layered composite cylinder. The heat transfer rate of the system is to be calculated. Being a transient condition, the determination of heat transfer rate involves solving second degree higher order differential equations. This was found by referring to the journal presented by X Lu et. al. [6] The paper is about the numerical investigation of transient heat conduction in a multi layered cylindrical coordination with the temperature variation as a sinusoidal wave. Based on the above references, we can a get a clear idea of the various use of phase change materials for different applications. An idea for analyzing the system was also known based on the above references.

2. MATERIALS USED

Phase Change Material (PCM)

A phase change material is a substance with a high heat of fusion while, melting and solidifying at a certain temperature. It is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa; thus, PCM's are classified as latent heat storage units. They are materials which that change from one phase to another at a designated temperature. The most commonly used PCM's are slat hydrates, fatty acids and esters, and various paraffin's. The temperature range offered by the PCM technology provide a new horizon for the building service and refrigeration engineers regarding medium and high temperature energy storage applications. The phase change material should possess the following properties such as Melting temperature in the desired operating temperature range, High latent heat of fusion per unit volume, High specific heat, high density and high thermal conductivity, Small volume changes on phase transformation and small vapor pressure at operating temperatures to reduce the containment problem, Congruent melting, High nucleation rate to avoid super cooling of the liquid phase, High rate of crystal growth, so that the system can meet demands of heat recovery from the storage system, Chemical properties, Chemical stability, Complete reversible freeze/melt cycle, No degradation after a large number of freeze/melt cycle, Non-corrosiveness, non-toxic, non-flammable and non-explosive materials.

Based on the above criteria's, the suitable PCM for our work chosen by us is savE OM 03. It is an organic chemical based PCM having nominal freezing point and melting temperature of 3.5°C. It stores a thermal energy as latent heat in crystalline form. It is the right mixture of various additives allowing equilibrium between solid and liquid phases to be attained at the melting point. Also, OM 03 is free flowing in molten state and can be encapsulated in various forms. This PCM has a nominal phase change temperature of 3.50C, a temperature that makes it ideal for many heating/cooling thermal energy applications.

Table 1: Technical Specification

Properties		Value
Melting/Freezing temperature	:	3.5 °C
Latent heat	:	240 kJ/kg
Liquid density	:	835 kg/m3
Solid density	:	935 kg/m3
Liquid specific heat	:	3 kJ/kgK
Liquid thermal conductivity	:	0.146 W/mK
Solid thermal conductivity	:	0.224 W/mK
Congruent Melting	:	Yes
Flammability	:	Yes
Thermal stability	:	2000
Operating temperature	:	120 °C
Flash point	:	140 °C

Encapsulation

Since PCM's transform between solid to liquid and vice versa in thermal cycling, encapsulation naturally become the obvious storage choice. Since being an organic chemical the material chosen for encapsulating the PCM must be chosen with absolute care. Organic chemicals have degrading effect on most of the materials. The following materials are compatible for encapsulation of savE OM 03 PCM.

Table 2 Compatible material list for Encapsulation of PCM savE OM 03

Material	Al	SS-304	HDPE	PVC	PP	NYLON	EPS
Compatibility	Y	Y	Y	Y	Y	Y	N
Note: Here, "Y" means compatible and "N" means Not compatible.							

The encapsulations must be thin enough to give overall heat transfer coefficient as good as many metals with better mechanical strength. Polypropylene tubes are opted from the list of compatible materials because of its easy availability. The PCM were filled in PP test . We found that the PCM which is enclosed in the tubes were safe and there is no damage to the tubes.

Insulation

Thermal insulation are materials which assist in the reduction of heat transfer between objects in thermal contact or in range of radiative influence. The insulating capability of a material is measured with thermal conductivity (k). Low thermal conductivity is equivalent to high insulating capability (R-value). In thermal engineering, insulation performance is influenced by many factors, the most prominent of which include Thermal conductivity ("k" or "λ" value), Surface emissivity ("ε" value), Insulation thickness, Density, Specific heat capacity and Thermal bridging. Based on the above criteria's the insulation chosen is Spray Polyurethane foam. It is a chemical product created by two materials, isocyanate and polyolresin, which react when mixed with each other and expand up to 30-60 times its liquid volume after it is sprayed in place. This expansion makes it useful as a specialty packing material which forms to the shape of the product being packaged and produces a high thermal insulating value with virtually no air infiltration. The two- component mixture composed of isocyanate and polyol resin comes together at the tip of a gun, and forms an expanding foam that is sprayed onto roof tiles, concrete slabs, into wall cavities, or through holes drilled in into a cavity of a finished wall.

3. PRODUCT DESIGN

Description of the Flask

The flask consists of the body, the removable seal for loading and unloading the PCM and a cap for the flask. The body of the flask is three walled concentric cylinders with the inner hollow part holding the product to be maintained at the low temperature, the outer layer is packed with an insulating layer of polyurethane foam and the middle layer with the encapsulated PCM. The insulating material remains as an integral part of the body and cannot be removed. While the PCM in the middle layer can be loaded, and then unloaded from the body of the flask whenever needed. The innermost wall of the body (i.e. the one in between the PCM and the product) is extended upwards for a few millimeters, for two reasons. One is to prevent the accidental mixing of the encapsulated PCM and the product kept inside and the other reason is to provide a reverse threaded lock of the seal with the body. For this purpose, threads are provided on the outer periphery of the innermost wall and the inner periphery of the seal. Since the PCM has to be loaded or unloaded from the flask, there is a need for a seal on the top of the body to hold the PCM and to avoid its leakage. Hence, a frustum shaped seal is provided which forms the second part of the flask. This frustum shaped seal is provided with threads on its entire inner periphery, so that when it is turned over the extended thread of the innermost wall it gets locked. The final portion which makes up the flask is the cap. This is similar to any cap as in a normal flask. The innovative idea is using the reverse thread for locking the seal with the body and the normal thread for locking the cap with the seal.

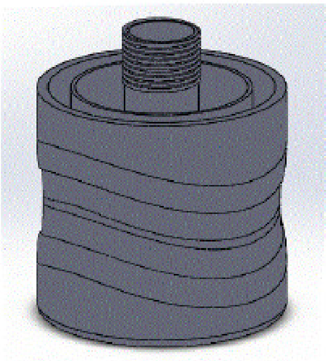

Figure 1 Body

Figure 2 Seal

Figure 3 Cap

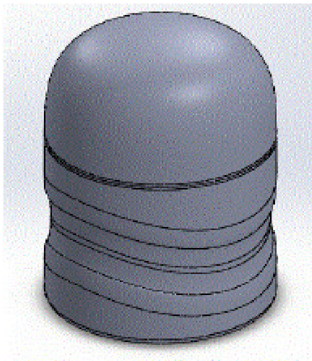

Figure 4 Assembled view of the Flask

Design calculation

Yoram Kozak et. al. [7] made a study on a similar model. In the analytical model developed, he derived a relation between the melting time of the PCM in the system and the thickness of the PCM layer. This relation helps to find the optimized thickness for the PCM and the critical insulation thickness. The simplified analytical model is developed to provide fast prediction and to reveal different features of the problem, under the following assumptions:

- 1-D axisymmetric heat conduction takes place
- The process is quasi-steady
- The solid PCM temperature remains at the melting temperature
- The material properties, heat transfer coefficient to the ambient and the ambient temperature are constant.

The General schematics of the model is as shown in the below figure. Based on the analytical model, the temperature distribution in PCM and insulation can be found using the following two equations.

$$T(r,t) = T_m + \frac{T_\infty - T_m}{\{\ln[R_p/R(t)] - \frac{k_l}{k_{in}}\ln[R_p/R_o] + \frac{k_l}{R_o h_o}\}}\ln[r/R(t)] \quad -(1)$$

$$T_{in}(r,t) = \frac{T_\infty - T_m}{\{\frac{k_{in}}{k_l}\ln[R_p/R(t)] - \ln[R_p/R_o] + \frac{k_{in}}{R_o h_o}\}}\left[\ln[r/R_o] - \frac{k_{in}}{R_o h_o}\right] + T_\infty \quad -(2)$$

The total melting time for the PCM in the flask can be found from the following equation

$$t_{melt} = \frac{q_{PCM} L}{4k_l(T_\infty - T_m)}\left[\left(\frac{2k_l}{R_o h_o} + 2\frac{k_l}{k_{in}}\ln[R_p/R_o] + 1\right)(R_p^2 - R_i^2) - 2R_i^2\ln[R_p/R_i]\right] \quad -(3)$$

For the PCM and the insulation chosen, the numerical values of various properties which are required for the calculations are as follows

Table 4.1 Properties of PCM and Insulation (required for calculation)

For PCM (savE OM 03)		**For Insulation (Polyurethane)**	
Liquid Thermal Conductivity, kl	0.146W/mK	Thermal Conductivity, kin	0.033 W/mK
Density, ρ	835 kg/m3		
Latent heat, L	240 kJ/kg		
Melting Temperature, Tm	3.5 0C		
Outer convection Coefficient of heat transfer, ho		10 W/m2K (Assumed)	
Ambient Temperature, Tœ		25 0C	

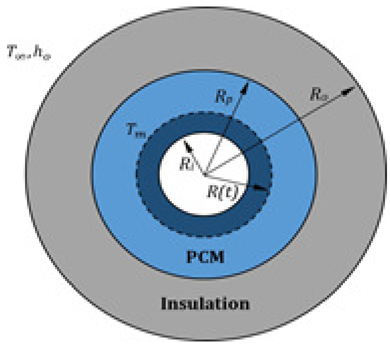

Figure 5 General schematics of the model

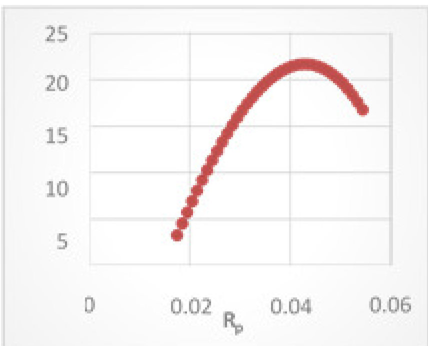

Figure 6 Graph of t_{melt} vs R_p

4. FABRICATION

The method adopted for fabrication of the flask is 3D printing which comes under additive manufacturing.

Additive Manufacturing

The term additive manufacturing is the common term for the 3D printing. Additive manufacturing creates a model which can be held by hand in the literal sense, by adding material to the object. Additive manufacturing builds up components layer by layer using materials which are available in powder or filament form. It enables a design driven manufacturing process where design determines the production and not the other way around. It provides a higher degree of design freedom, with optimization and integration of functional features, manufacture of small batch sizes at reasonable unit costs and also a high degree of product customization.

Procedure of Additive Manufacturing

The file, a Computer Aided Design (CAD), is created using a 3D modelling program, either from scratch or beginning with a 3D model created by a 3D scanner. The steps are as follows,
1. Creation of 3D CAD model

A 3D design software is used to develop the model of the flask with accurate dimensions. 2. Converting into a printer readable format - The model from a different format is needed to be first converted into a printer readable acceptable formats. Most preferably it is the .stl file format, which uses stereo lithography software to generate the information needed to produce 3D models. 3. Selecting a suitable printer - 3D Printers are machines that produce physical 3D models from digital data by printing and building layer by layer. Physical models of components designed using a CAD program or those scanned using a 3D scanner can all be made to appear in reality using these 3D printers. The selection of the printer depends upon the technology used in 3D printing and also the size of the model and the material used for printing.
4. Slicing the model into layers

Slicing is a process of generating the tool path for the 3D model for 3D printing by slicing the model into horizontal thin layers. 5. Generating G-codes - Finally, a tool path is defined by the G codes, an instruction which the printer understands and is fed to the 3D printer.

5. PRODUCT DEVELOPMENT

Product development includes the assembly of the various 3D printed parts and the further processes like incorporation of insulation in the outer layer of the flask body and then the PCM encapsulation using Poly Propylene (PP) test tubes.

Incorporation of Insulation

The Expandable Polyurethane Spray foam is used for providing insulation. The foam is sprayed into the insulation cavity which is the outer layer of the body. It's in a form of sticky liquid with low viscosity which oozes out as it expands and then solidifies with time. After solidification the expanded excess of insulation is removed. Then the insulation chamber is sealed with the lid to close it and keep it out of contact with the users.

Assembly

As already mentioned the basic construction of the flask consists of the body, the removable seal for loading and unloading the PCM and a cap. The assembly is very simple as of a normal thermal flask, the seal is placed over the body of the flask and is tightened by engagement of threads provided on the outer periphery of the extended part of the body and the inner periphery of the seal. Further the cap is assembled over the seal and it is similar to any normal cap with threads engaged over the seal. The threads are designed in such a way with tolerances, as it is to be printed by a 3D printer. Since the flask was finished by rapid prototyping the tolerance level of the thread was tight fit. So, both the inner and the outer threads in the body and those in the seal and cap were filed using sand paper and they were smoothened.

Figure 7 Incorporation of PCM

Figure 8 Insulation covered by lid

Figure 9 Encapsulated PCMs in middle layer

6. EXPERIMENTAL STUDY

An experimental study was carried out to practically find out the time for which the temperature of a low temperature sensitive product can be prolonged in the developed PCM assisted flask. Initially the PCM's, in liquid form were encapsulated in the Polypropylene tubes, so as to avoid any leakage. Further these PCM filled tubes are placed in the freezer of a household refrigerator and was allowed to freeze for about 48 hours. Then the frozen PCMs are placed in the middle layer of the flask, between the insulation and the space provided for the product. For testing, cold water at 2˚C was filled in the flask and the time for which the temperature of the water increased from 2˚C to 15˚C is noted. Simultaneously the same cold water at 2˚C was placed in the same insulated flask without PCM tubes and was tested for a temperature increase from 2˚C to 15˚. Several trials were taken for both cases with water and the results obtained are tabulated and the average time is found.

Table 7.1 Experimental trials

Trial no.	Withhold time	
	Without PCM	With PCM
1	3 hrs. 22 mins.	4 hrs. 34 mins.
2	3 hrs. 10 mins.	5 hrs. 02 mins
3	3 hrs. 15 mins.	4 hrs. 43 mins

It is found that the time for which the temperature increased was about 3 hours 15 minutes (average) in the insulated flask (without PCM) and was about 4 hours 45 minutes (average) in the insulated flask with PCM. Thus, from this it's noted that the PCM flask can have prolonged effect on time compared to a normal flask.

7. CONCLUSION

Based on the changing lifestyle of the people and with the increasing desire of leading a life at ease, this PCM cold storage flask will surely favor the need of cold storage and moreover when it comes to cold storage the list of applications has a wider scope. The PCMs are now being used in large scale in cold chain logistics and it acts as an effective replacement to dry ice and gel packs too. The reason for which it is better than dry ice and gel packs is because of the high latent heat content and the encapsulated form which prevents its leakage. So, we have just tried to use this potentiality of high latent heat content of PCM to increase the time of storage for low temperature sensitive products in a smaller scale.

The observations and the results shows that this PCM assisted cold storage flask is capable of providing prolonged time for low temperature storage more than the normal vacuum flask. Therefore, this product can be taken for the future development and can be effectively work upon on the aesthetics and the design can be modified to increase the storing capacity and also the prolonged time and thus as a small scale this PCM flask can serve as a replacement for the normal vacuum insulated flask.

REFERENCES

[1] Eduard Oro, Alvarode, Gracia, Luisa F. Cabeza, "Active phase change material package for thermal protection of ice cream containers", International journal of refrigeration, Vol. 36 Issue 1, pp:102-109, January 2013.

[2] Eduard Oro, Laia Miro, Mohammed M. Farid, Luisa F. Cabeza, "Thermal analysis of a low temperature storage unit using phase change materials without refrigeration system", International journal of refrigeration, Vol. 35 Issue 6, pp:1709-1714, 2012.

[3] W. Lu, S.A. Tassou, "Characterization and experimental investigation of phase change materials for chilled food refrigerated cabinet applications", Applied energy, Vol. 112, pp:1376-1382, December 2013.

[4] MD. MansoorAhamed, J. Kannakumar, P. Mallikarjuna Reddy, "Experimental Investigation on the Performance Analysis of Cold Storage Plant Using with and without Phase Change Material (PCM)", International Journal of Scientific Engineering and Research (IJSER), Vol. 1 Issue 4, December 2013.

[5] E. Oró,de Gracia, A. Castell, M.M. Farid, L.F. Cabeza, "Review on phase change materials (PCMs) for cold thermal energy storage applications", Applied energy, Vol. 99, pp:513-533, November 2012

[6] X Lu, P Tervola, M Viljanen, "An efficient analytical solution to transient heat conduction in a one- dimensional hollow composite cylinder", Journal of Physics A: Mathematical and General, Vol. 38, pp:10145-10155, 2005.

[7] YoramKozak, Mohammed Farid Gennady Ziskind, "Experimental and comprehensive theoretical study of cold storage packages containing PCM", Applied Thermal Engineering, Vol. 115, pp:899-912, March 2017.