RESEARCH ARTICLE

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Performance Analysis of Refrigerated Storage Chamber Using Phase Change Material

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ABSTRACT

The research work aims to analyze the refrigerated storage chamber using phase change materials to solve the problem related to improper storage and handling of vaccines, blood samples and organs. This analysis focuses mainly on design and fabrication of an environment friendly refrigerated storage chamber which can be used in areas where electricity supply is erratic and to fabricate a model to maintain optimum temperature for vaccine storage, blood sample and organ storage using a phase changing material. PCMs behaves isothermally in nature, and thus gives higher density energy storage and the ability to operate in a range of temperature conditions. Three phase change materials namely acetic acid, sodium sulphate decahydrate and glycerol are used for the experimentation purpose. These phase change materials are used in frozen form. The results obtained from experimentation are verified using Ansys software. Results shows that the PCM Sodium Sulphate Decahydrate [H20Na2O14S] maintains lowest temperature in range of 1.5 – 8 degree for 350 minutes and extract maximum heat. Similarly, for server unit the temperature ranges to be maintained is 10 to 22 degree which is maintained for 1500 minute.

Keywords: PCM: Phase Change Material, Vaccine, Isothermal, Server units.

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INTRODUCTION

Thermal Energy Storage (TES) is widely employed system of storing heat energy. TES may be broadly classified as sensible and latent heat storage. The total energy stored per unit weight is the product of specific heat of material in phase transition and its temperature difference with the surrounding. Sensible heat transfer largely requires a medium to store it as compared to latent heat transfer. Because of less latent heat transfer in solid to solid transformation and need of large volume for liquid to gas transformation, these two options are not technically viable. Further due to energy storage in case of solid to liquid transformation is of higher density and operates at a constant temperature as of PCM, it will only bring up energy storage due to this transformation. The system used for maintaining the vaccines in good condition and to distribute it smoothly is termed as cold chain. Cold Chain is a system of storing and transporting vaccine within recommended temperature range of 2 to 8°C from the place of production to place of use. For the storage of energy, systems like batteries or Phase Change Materials (PCM) with better latent heat storage

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efficiency are better to use. However, storage capacity of battery in kWh holds a limited life and hence this brings phase change materials as an alternative option for energy storage. [1]

Paraffins: Chemically, the crystallization of the paraffins, (CH3) stores and releases a good amount of latent heat. The main reason of selecting paraffin's as an energy storage material is that they are accessible in wide range of temperatures. They are consistent, safe and generally, non-corrosive. Fatty acids like capric acid, lauric acid, palmitic acids have melting points between 30-65p C, having latent heat between 150-180 KJ/KG. Salt hydrates are more efficient materials for phase change because of their cost effectiveness, higher thermal conductivity and small volumetric changes for storage. [1]

PCM is having the ability of thermal protection because of its inertia behavior to thermal changes. This protection is helpful in hot and cold environment during its storage and transport of solid food, beverages, pharmaceutical products, electronic circuits, cooked food, biomedical products etc. [2]

In medical sector, transport of blood samples and organs is the most sensitive work to do. Containers used for these purpose works similar to that of general containers. Other medical applications could be hot or cold pads to treat spot pain in body and vaccine storage as per necessary need of vaccination.

For avoiding unnecessary discharge of the PCM and the latent energy to release back to the conditioned space, a system with PCM used along the facade with direct contact between inner and outer side of the wall is the best alternative. [3]

Modern vaccine needs to be stored at -20°C but can be kept at 2 to 8°C Celsius. India has the required source of cold chain to store this vaccine but it is very limited in number. [4]

Applications of PCM covers a wide range of energy dependable entities and systems. These applications are solar energy (such as dryers and heaters), heat recovery systems, worker equipments such as helmets, electrical power peaking regulation, textiles, healthcare, liquefied natural gas, green house agriculture, buildings and aerospace. [5-7]

Basic modes of heat transfer for storing thermal energy are sensible heat, latent heat and the thermochemical energy. The sensible heat transfer consists of translational, rotational and vibration motions of the atoms and molecules. The latent heat transfer consists of phase change in solid, liquid and gaseous states due to intermolecular forces of the PCM material. The chemical energy component consists of energy stored in the chemical bonds between atoms. [8]

Procedure

Experimental Setup

Setup consists of a box of aluminum and its alloys whose thermal conductivity is 88 to 251 W/m K. Fabricated size of box is (0.144 × 0.144 × 0.144) m which consist of different sections as shown in figure 1. A layer of insulation material is followed by the outer surface of box. Inside there is PCM chamber as shown in figure 2, which has opening on its top section for filling the PCM. This PCM chamber is made removable to freeze the filled PCM by using some external refrigeration system. The innermost part of this box is a storage chamber where vaccine would be stored and preserved. CAD model of entire experimental setup is shown in figure 3. All the temperatures are monitored manually by using thermocouples. Two thermocouples are used to monitor the PCM temperature continuously and one thermocouple is used to measure the PCM chamber temperature.

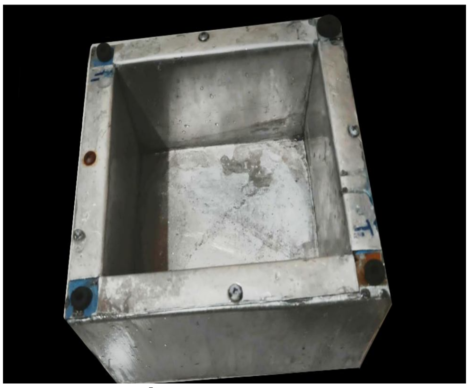

Figure 1: PCM Box

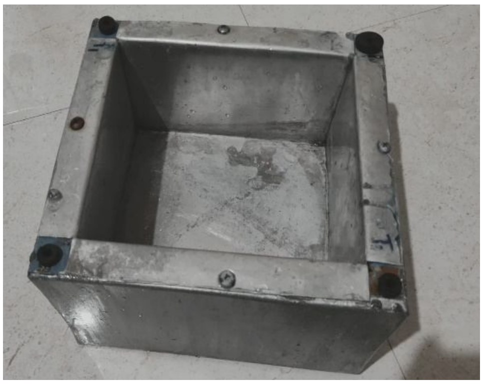

Figure 2: Removable PCM Chamber

Table-1: Details of PCM Material

Sr. No.	Composition	Melting Pt.(k)	Heat of fusion h_{fg} (kJ/kg)	Quan tity used	Specific Heat C_p (kJ/kg.K)
1	Acetic acid	289.6	184	1.5 lit	2.043
2	Sodium Sulphate Decahydrate (31% wt)	305	252	1.5 kg	2.9 (liquid)
3	Glycerol	290.9	198.7	1.5 lit	2.22

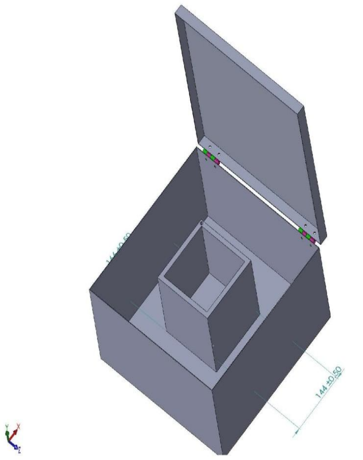

Figure 3: CAD Model of PCM BOX

Three thermo-couples are used to monitor the changes in temperature of storage chamber. For insulation, Polystyrene whose thermal conductivity is 0.033 W/(mK) is used outside the PCM Chamber box. The storage chamber is of 3 liters and thickness of aluminum sheet is 1mm.

Details of PCM materials used are tabulated below

Experimentation

After filling the PCM material in PCM chamber shown in figure 2, the primary step was to freeze it using another refrigeration system. Initial temperature of frozen PCM is noted first. Immediately after freezing the PCM, the PCM chamber is placed in PCM box shown in figure1. During experimentation, atmospheric temperature, storage chamber temperature (T_{in}), and PCM temperature (T_1 and T_2) has been recorded after every 5 minutes. This process was repeated till the PCM achieves its melting temperature. Final temperature value of PCM gives the heat load of storage chamber. During experimentation it was ensured that PCM box is leak proof, PCM is completely freezed, the time required for melting is recorded with high accuracy, and PCM box is not opened in midway of experimentation.

Table-2: Experimental Calculations

Sr. No.	Name of PCM	Sensible heat (KJ)	Latent heat (KJ)	Total heat (KJ)
1	Acetic Acid	23.42	270.48	293.5
2	Glycerol	44.64	350.50	395.1
3	Sodium Sulphate Decahydrate	144.63	515.08	659.71

Calculation

Sensible heat (Q_s) absorbed by the PCM material in KJ is calculated as,

$$Q_s = m \times C_p \times dT \qquad \text{........(1)}$$

Where,

m = mass of PCM material = Density × Volume

C_p = Specific heat capacity of PCM material in KJ/KgK

ΔT= difference between melting temperature of PCM (T_2) and minimum temperature achieved in the vaccine storage area(T_1)

Latent heat (Q_L) required for PCM to change its phase in KJ is calculated as,

$$Q_L = m \times h_{fg} \qquad \text{...........(2)}$$

Where, h_{fg}= latent heat of PCM material

Heat (Q_T) absorbed by PCM material in KJ is calculated as,

$$Q_T = Q_s + Q_L \qquad \text{............(3)}$$

Table-3: ANSYS Fluent Calculations

Sr. No.	Name of PCM	Sensible heat (KJ)	Latent heat (KJ)	Total heat (KJ)
1	Acetic Acid	45.34	270.48	315.82
2	Glycerol	48.55	350.50	399.5
3	Sodium Sulphate Decahydrate	181.97	515.08	697.05

Equation no 1, 2 and 3 are also used to calculate sensible, latent and total heat for the data obtained from Analysis using ANSYS Fluent.

Results and Discussions

Experimental Results

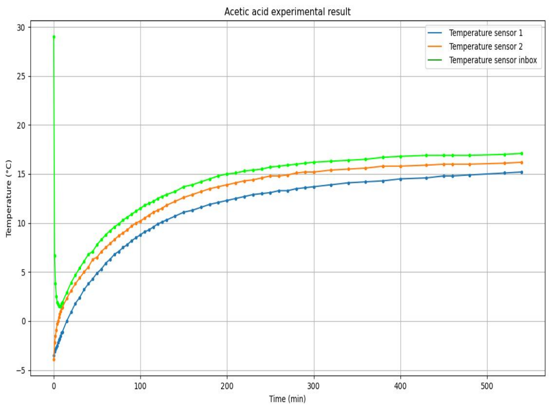

Figure 4: Temperature variation of PCM material w.r.t time for Acetic Acid

For Acetic acid PCM from figure 4, it was observed that melting point reached within 250minutes (Almost after 4 hours). Required temperature range for vaccine storage and blood samples is achieved after 50 minutes. The minimum required temperature for server units is achieved after 80 minutes

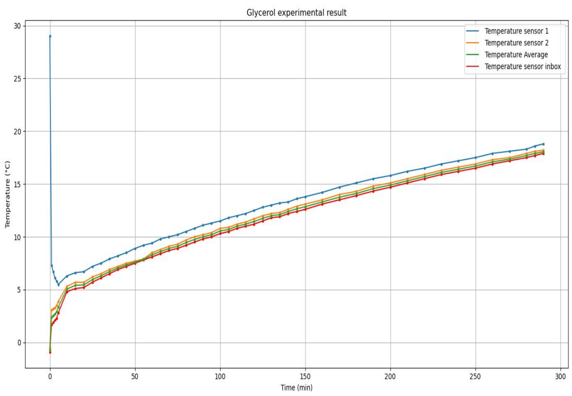

Figure 5: Temperature variation of PCM material w.r.t time for Glycerol

For glycerol from figure 5, it was observed that melting point reached within 250minutes (Almost after 4 hours). Required temperature range for vaccine storage and blood samples is achieved after 70 minutes. The minimum required temperature for

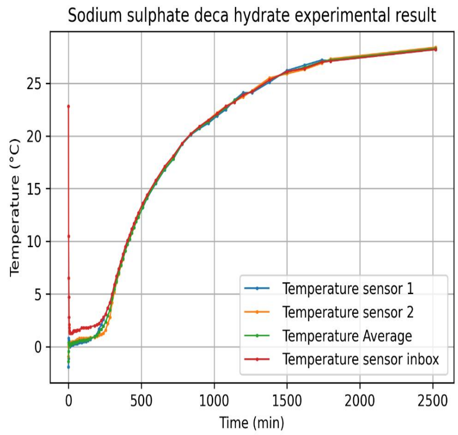

Figure 6: Temperature variation of PCM material w.r.t time for Sodium sulphate Deca hydrate

server units is achieved after 100 minutes.

For Sodium sulphate Deca hydrate from figure 6, it was observed that melting point reached after 2000 minutes (almost after 30 hours). Required temperature range for vaccine storage and blood samples is achieved after 300 minutes.

CONCLUSION

From the results obtained, it is conclude that:

i. Sodium Sulphate Decahydrate had achieved required temperature range for vaccine storage and blood sample of around 1.5 to 8 degree for 350 minutes which is best suited.
ii. Based on real data of working server units, the temperature range required is 10 to 20 degree which is best achieved by sodium sulphate Deca hydrate for the duration of 1500 minutes

Experimental and Ansys analysis is carried out to find the best suitable PCM and it was found that sodium sulphate Decahydrate with distilled water by weight composition gives better performance amongst the chosen PCM materials.

This experimental setup can be implemented with solar powered compressor system which will increase storage capacity of PCM box.

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