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Design of PCM based Thermal Storage System for Cold Chain Storage Application

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Abstract - *This dissertation concentrates on using Phase Change Materials to satisfy efficient cooling in the thermally insulated chamber. Current refrigeration systems used to achieve similar cooling effects run on convention fossil fuels. These fuels are depleting in nature and there is a need to find substitute solutions to achieve similar cooling effect without using fossil fuels. The system which runs without use of any conventional fuel and create an environment where temperature sensitive fruits and vegetables of approximately 10 ton weight can be stored is designed and studied here. Various Phase Change Materials are studied and tested here to find an optimal solution to resolve the respected problem of cooling.*

Key Words: Phase Change Materials, cooling, chamber, refrigeration system, fossil fuels, 10 ton.

1. INTRODUCTION

Phase Change Materials (PCMs) are widely used to satisfy heating and cooling applications for buildings. PCMs has tendency to melt and get solidified at various temperature ranges. The increasing population and extreme use of fossil fuels has taken the world to the stage where searching a substitute for the decreasing fossil fuel storages is must.

For the storage of fruits, vegetables, medicines etc. materials, refrigeration is one of the important aspects that should be considered. World Health Organization is now using solar operated refrigeration systems to store medicines in the rural areas of Africa and South Asia. Eutectic plates can be used as a solution for temperature controlled logistics which allows transport of specific temperature sensitive beverages without use of any fossil fuels.

Two steel sheets are cold formed and welded together by using Electric Resistance Welding. Phase Chang Material is placed between the plates and external surface of plates is coated by zinc material. Evaporator coil of copper material is placed into the plates to generate cooling effect to the solution. Condensing unit is further coupled with these plates. These plates are attached to the thermally insulated chamber which further keeps constant temperature inside the chamber.

2. PHASE CHANGE MATERIALS FOR DIFFERENT OPERATING CONDITIONS

Properties	Content	Operating range (°C)	Latent Heat (KJ/Kg)
HS 33N	Inorganic Salts	-34 to -25	224
HS 26N	Inorganic Salts	-28 to -19	272
HS 23N	Inorganic Salts	-24 to -15	262
HS 18N	Inorganic Salts	-22 to -13	242
HS 15N	Inorganic Salts	-19 to -10	308
HS 10N	Inorganic Salts	-15 to -6	290
HS 7N	Inorganic Salts	-12 to -3	296
HS 3N	Inorganic Salts	-8 to 1	346
HS 01N	Inorganic Salts	-5 to 4	350
OM 03	Organic Material	-2 to 7	229
FS 03	Form Stable Mixture	-2 to 7	161
OM 08	Organic Material	0 to 9	180

Table – 1: Phase Change Materials

3. SELECTION OF PHASE CHANGE MATERIALS

3.1 Thermodynamic Properties

The material selected should have large enthalpy of transition with respect to the volume of storage unit. Enthalpy of the material should change tremendously near temperature of use. The phase change material should change its phase within the working temperature range of the application only. The physical size of the storage should be as small as possible and to achieve this target, the latent heat should be as high as possible. We should be clearly known about the exact phase change temperature of the material.

3.2 Kinetic Properties

The material should not go undercooling process during the freezing process.

3.3 Chemical Properties

The most important chemical property that the material should possess is its non-corrosiveness as it directly affects life of the system. To ensure secured environment while handling the material, it should be non-toxic and non-explosive in nature.

3.4 Physical Properties

The density of material should vary in a specific small range as it will impact on the storage tank capacities. The density of the material should be high which should not vary according to conditions in a wide range.

3.5 Economic Properties

The material should be available in large quantity in the nature and its cost should be less to design a system which will be economically feasible.

4. COOLING SYSTEM OF REFRIGERATED TRUCK

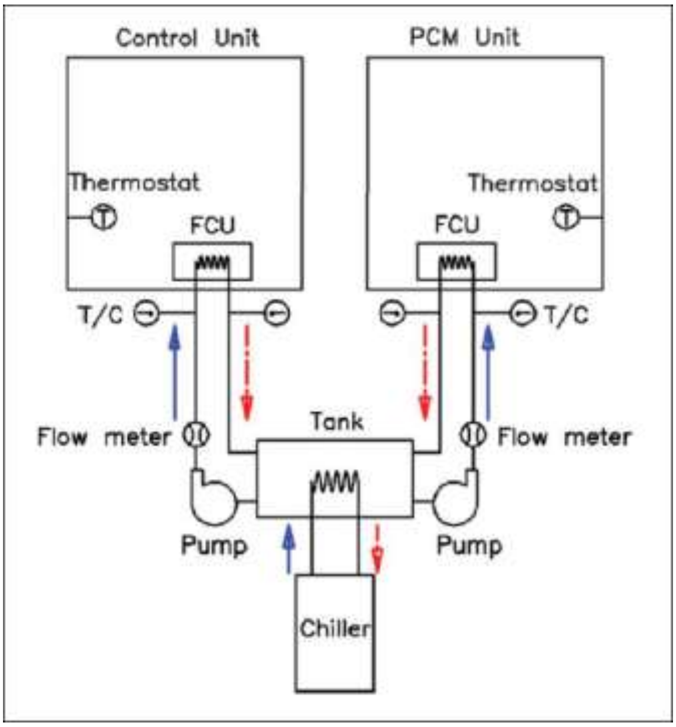

Fig – 1: Cooling diagram of the refrigerated truck

Initially the conventional method of insulation of refrigerated truck trailer by adding phase change materials on the walls of truck was developed. An innovative refrigeration system came into use which had abilities to maintain desired thermal conditions in the truck by using phase change materials.

In the given figure it can be seen that phase change material storage tank is charged by a refrigeration unit which is located outside the vehicle when the vehicle is stationery and then it provides cooling effect when the vehicle is in service.

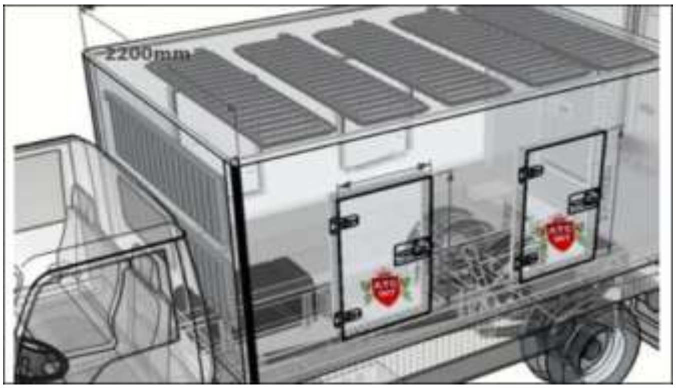

Fig – 2: PCM refrigerated truck

5. CALCULATIONS

Fig – 3: Experimental setup

Tare Weight	Payload Capacity	Cubic Capacity	Internal Length
3080 kg	27400 kg	28.3 cu. m	5.44 m
6791.4 lbs	60417 lbs	999 cu. ft	17.9 ft

Table – 2: Reefer container dimensions

Internal width	Internal height	Door opening width	Door opening height
2.29 m	2.27 m	2.23 m	2.10 m
7.5 ft	7.5 ft	7.3 ft	6.9 ft

Table – 3: Reefer container dimensions

1. Product Load

   Given: Consider 10,000 kg of fruits and vegetables. Specific average heat capacity above freezing is 4 KJ/kgK. Storage temperature is 1°C. Ambient temperature is 5°C.

   i. Q = m*Cp*(T2-T1)

      = 10000*4*4

= 160000KJ

ii. Product Respiration = m*resp

= 10000*1.9

= 19000 KJ

iii. Total Product Load = 179000 KJ

iv. For 8 hours operation,

Product Load = 179000/8*60*60

= 6215 Watts

2. Lighting Load

i. Q = 6*20

= 120 Watts

ii. Fan Motors

Q = 2*100

= 200 Watts

iii. Total Load = 1638 + 6215 +120 + 200

= 8173 Watts

= 2.35 Ton of Refrigeration

Considering HS01 PCM, for 8 hours operation;

Energy = 8.173*8*60*60

= 235382.4 KJ

For PCM latent heat = 350 KJ/kg

Mass of PCM = 235382.4/350

= 672.52 Kgs of PCM

Density = 1010 kg/cu. m

Volume = 0.665 cu. m of PCM

To store this volume of PCM, we need to select eutectic plates. If we take 12 plates, thus 0.665/12; 0.055 cu. m of PCM needs to be stored in each plate. If we consider 70% PCM can be stored in the plate then we need a plate of volume 0.084 cu. m volume.

Now standard plate selected according to our needs has dimensions; 76cm*168cm*6065cm.

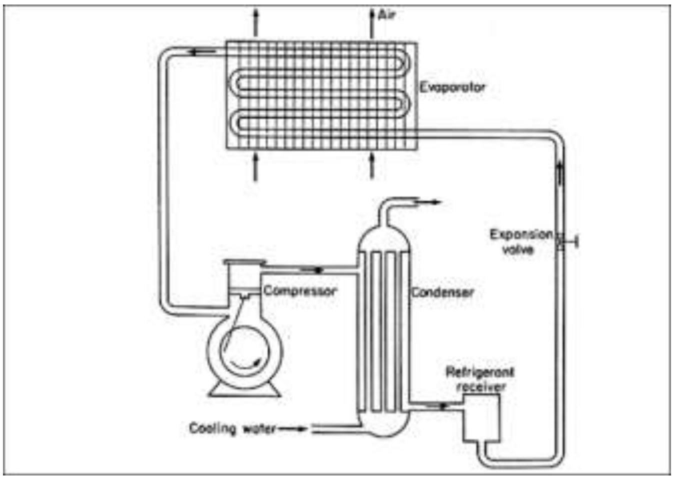

Fig – 4: Experimental setup

6. CAD DESIGN OF PLATE AND TUBING DIMENSIONS

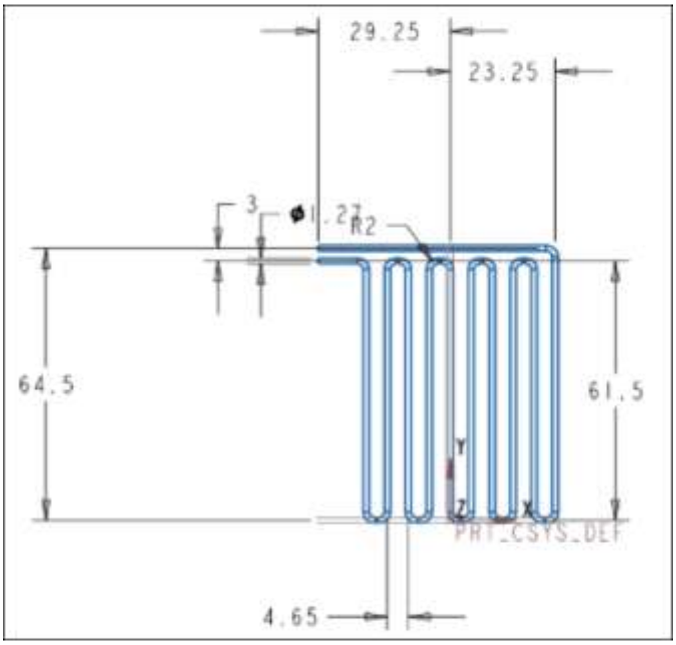

Fig – 5: Tubing Design

Fig – 6: Plate assembly with tubing

The volume of PCM to be enclosed would be roughly 80% of the plate volume.

therefore;

Volume of PCM to be enclosed = 725*525*49*0.8/1000000

= 14.92 Liters

The material selected after considering multiple factors like thermal conductivity, feasibility and cost is 1mm Aluminum Sheet. And the tubing which allows the flow of refrigerant is of ¼ inch copper pipe.

7. CONCLUSION

From the above results, conclusions drawn are;

1. Effective use of Phase Change Materials can be done to design a modified mobile refrigeration unit which gives same cooling conditions as that of conventional systems.

2. The systems which run on conventional fuels to achieve refrigeration conditions can be replaced by this newly designed systems as the fossil fuels are deploying in nature.

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