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RESEARCH ARTICLE

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ANALYSIS AND FABRICATION OF MICRO COLD STORAGE PLANT AND IMPROVING ITS PERFORMANCE USING PHASE CHANGE MATERIAL (PCM)

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ABSTRACT

In rural areas the supply of power is non uniform and the load demand varies as per the requirement. Cold storage present in such areas are facing this difficulties because cold storage containing items like agricultural commodities and food items are prone to spoilage in absence of power. This project research proposes the introduction of a Phase Change Material in Cold storage plants to provide solution to such problems. This project promises to reduce and control the temperature drop for cold storage plant located in such areas with variable load. Also the project aims in supporting the cold storage vehicle in covering a long distance as the temperature drop will be controlled as per their requirements in even hot summer days.
Keywords: Phase Changing Material (PCM), Ethylene Glycol, Polyurethane Foam

Introduction:

Power Cut offs are often nowadays due to accidents, or because of implementation of demand side management schemes to shift power usage to avoid peak loads by the electricity supplier or shifting the user to the off loads electricity usage as per the pricing periods [1]. It is important to maintain regular temperature inside cold storage plants and cold storage vehicles.

Almost all frozen and chilled foods are very sensitive to temperature variations. Therefore Cold Storage plant is used to overcome this limitation [2][4][6]. TES systems for both heat and cold are necessary for good performance of many industrial processes.

PCM can be utilised in applications of load shifting so that electricity demand is shifted as per the demand [4][8][9]. PCM melts in the range of narrow temperature ranges and absorbs huge amount of energy while in the transition state so, minimizing the rise in the temperature after power cut off or any breakdown.

High energy storage density and high power capacity for charging and discharging are desirable properties of any storage system. The concept of Thermal Energy Storage calls for the demand of a material which can hold temperature for a longer time. This requirement can be fulfilled by utilising the Phase Changing Material[10][11]. PCM can considerably be able to hold the temperature, control the temperature as per the demand and requirement of the scenario.

Recently there are various research going on for utilising the PCM for residential building to control the temperature so that minimum cooling is required for the buildings [3][7].

KY Publications

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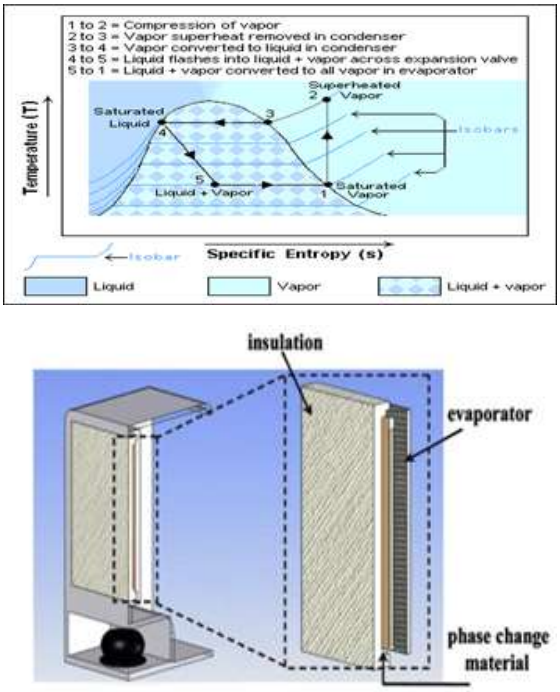

FIGURE 1 VCR Cycle

Analysis on ANSYS:

We have created a CAD model in SolidWorks using the ideal dimension as per the capacity. After importing the model in ANSYS, following results are derived which clearly shows in sight of manufacturing and operations parameters used are feasible and results can be drawn once the model comes in operation.

Evaporator:

For analysing the following given parameters were taken into consideration

TABLE 1: Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\Hasan Baig\Desktop\Sample analysis.IGS
Type	Iges
Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	0.3208 m
Length Y	0.3208 m
Length Z	0.31 m
Properties	
Volume	1.0033e-002 m^3
Mass	19.063 kg
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	3125
Elements	1500
Mesh Metric	None
Basic Geometry Options	
Solid Bodies	Yes
Surface Bodies	Yes
Line Bodies	No

Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Compare Parts On Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\Hasan Baig\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

TABLE 2

Model (A4) > Geometry > Parts

Object Name	*Part 1*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Material	
Assignment	FR-4 Epoxy
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	0.3208 m
Length Y	0.3208 m
Length Z	0.31 m
Properties	
Volume	1.0033e-002 m^3
Mass	19.063 kg
Centroid X	-2.5545e-012 m
Centroid Y	2.5545e-012 m
Centroid Z	0.1341 m
Moment of Inertia Ip1	0.43789 kg·m^2

Moment of Inertia Ip2	0.43789 kg·m²
Moment of Inertia Ip3	0.53482 kg·m²
Statistics	
Nodes	3125
Elements	1500
Mesh Metric	None

Object Name	*Temperature*	*Convection*	*Radiation*
State	Fully Defined		
Scope			
Scoping Method	Geometry Selection		
Geometry	5 Faces		1 Face
Definition			
Type	Temperature	Convection	Radiation
Magnitude	0. °C (ramped)		
Suppressed	No		
Film Coefficient		2.4e-002 W/m²·°C (ramped)	
Ambient Temperature		22. °C (ramped)	
Convection Matrix		Program Controlled	
Correlation			To Ambient
Emissivity			1. (step applied)

Methodology:

After analysis, we designed our storage space & its capacity which gives us feasible working parameters [21]. Now after that it is necessary to fix the target temperature i.e., the lowest temperature that we want to gain from our system.

According to the above requirement we need to select the compressor which can adjust with our capacity & make it possible for the system to reach the target temperature.

Now after the selection of a compressor we need to select other components which are directly related to the compressor.

1. Storage capacity: 10.160 liters
2. 0.01016 Tones of refrigeration
3. Target temperature = -20 'C
4. Compressor = 1/8 HP reciprocating type
5. Condenser =9*9*2 (cross flow type)
6. Throttling tube =1mm*12ft (maximum throttling tube length used with respect to compressor to gain target temperature)
7. Copper tubing 4mm
8. Temperature indicators (range -40 to 110 'C)
9. Pressure gauges (suction & delivery)

- First of all we have prepared a frame or a platform on which we can mount all components.
- After that we have constructed a cabin for the purpose of storage space, in it we placed an evaporator (folded in a square shaped).
- Fixed the cabin on the platform, between cabin & evaporator we filled Polyurethane Foam solution which on solidifying works as insulation.
- Now we fixed the compressor & condenser on the frame. After that we have connected them by tubing with gas welding (oxy-acetylene).
- Now fixed the throttling with evaporator & almost 95% of throttling tube is kept between the insulation only in the cabin to prevent heat loss in it.

- Now to fix the pressure gauges we bypassed the suction & delivery tubes & connected to the gauges.
- Now fixed temperature indicators at their respective places.
- Now filled the refrigerant R134a through compressor.
- Sealed the compressor.
- Fabrication completed
- Now start the setup & ensure the minimum temperature attained in the storage space
- Take the initial readings with no load & then further with load(both with & without PCM)

Fig 1: Setup for VCR

Observations:

1.When power is ON

Initial temperature of storage space=24.8 'C

Conditions	Compressor Cycle	Duration in Mins	Temp. Observed (T1) in °C	Temp. Observed (T2) in °C
Without load & without PCM	1st Cycle	4 min 26 sec	-2.7	28.4
With Load & without PCM	1st Cycle	4 min 26 sec	-3.5	31.5
With Load & with PCM	1st Cycle	4 min 26 sec	-3.0	30.5

2.Power cut off Readings

Without PCM :

Load temperature, Tl = -15 'C

Observation temperature To = 5 'C

Time taken to reach from T¬l to T¬o = 13 minutes

With PCM :

Load temperature, Tl = -15 'C

Observation temperature To = 5 'C

Time taken to reach from Tl to To = 71 minutes

Conditions	Compressor Cycle	Initial Temperature, T_i in °C	Final Temperature, T_f in °C	Time taken in minutes
Without PCM	1st Cycle	-15	5	13 minutes
With PCM	1st Cycle	-15	5	71 minutes

Calculations& Results:

Refrigerating effect (R.E.):

It is the difference between the enthalpy at evaporator outlet and the enthalpy at evaporator inlet or the total temperature dropped across the evaporator section.

R.E. = $h_2 - h_1$

Compressor Work (W_c):

It is the difference between the enthalpy at the compressor outlet and the enthalpy at compressor inlet.

$W_c = h_3 - h_2$

Coefficient of Performance (C.O.P.):

It is the ratio of the refrigerating effect produced in the evaporator to the amount of work done by the compressor.

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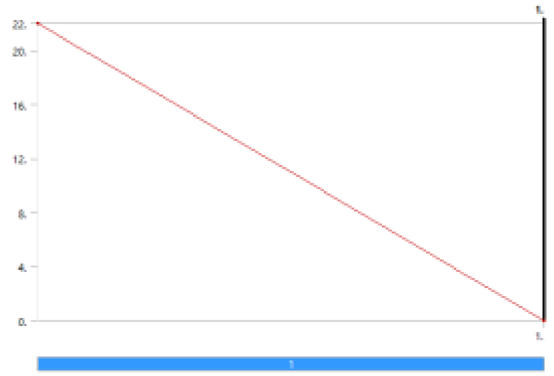
C.O.P. = (R.E.)/Wc

Result:

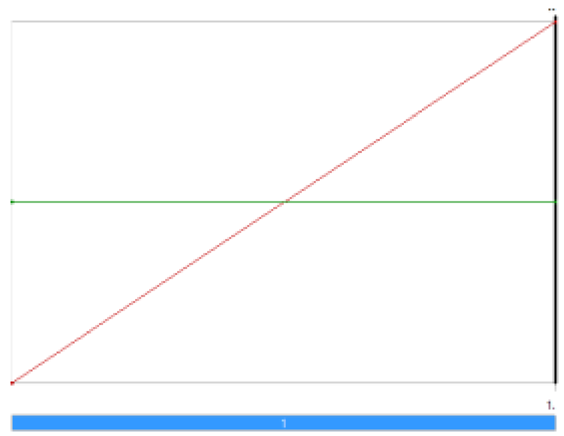
$(C.O.P.)_{\text{with PCM}} > (C.O.P.)_{\text{without PCM}}$

Following are the graphs which show the analysis results bases on the temperature and heat flow within the system. Heat Flow analysis includes both convection and radiation heat flow.



Graph 1: Model (A4) > Steady-State Thermal (A5) > Temperature

Below graph (Graph 2) explains about the temperature distribution. The temperature is distributed uniformly and as the time passes the drop in temperature is 0 after unity.

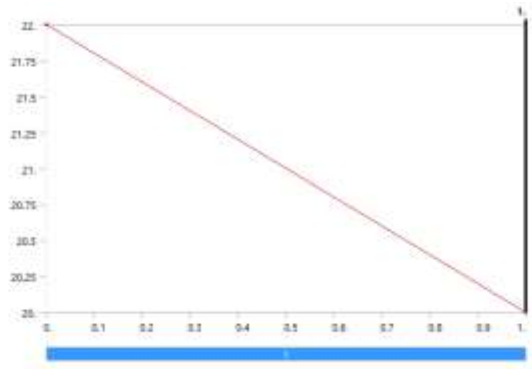


Graph 2: Model (A4) > Steady-State Thermal (A5) > Convection

X axis: Temperature Distribution

Y axis: Time

Below graph (Graph 3) explains about the heat flow distribution. The heat flow through convection remains constant at all the faces and as the time passes the convection heat transfer achieves maximum.

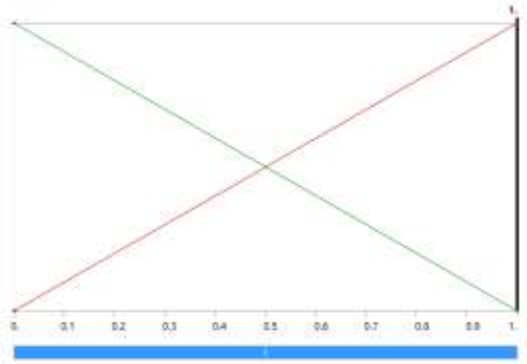


Graph-3

X axis: Convective heat flux distribution

Y axis: Time

Below (Graph 4) explains about the temperature distribution. The temperature is distributed uniformly and as the time passes the drop in temperature is 0 after unity.



Graph 4

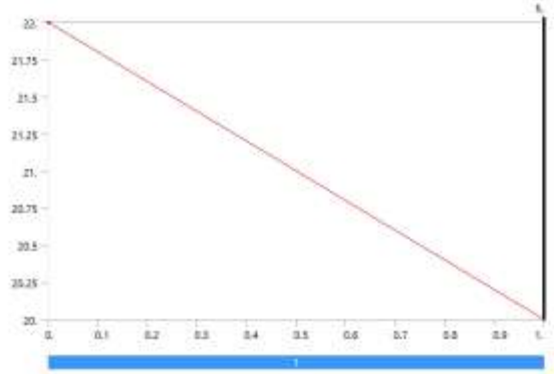
X axis: Temperature Distribution

Y axis: Time

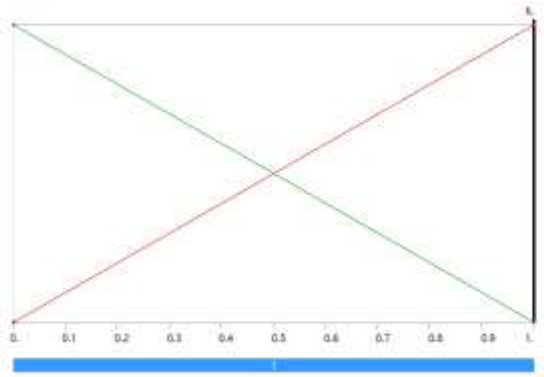
Below graph (Graph 5) explains about the heat flow distribution. The heat flow through convection remains constant at all the faces and as the time passes the convection heat transfer achieves maximum.

X axis: Temperature Distribution

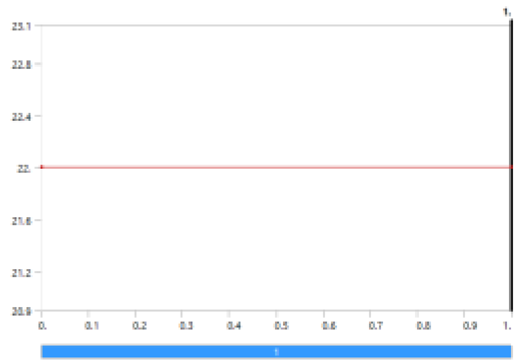
Y axis: Time



Graph 5: Model (A4) > Steady-State Thermal (A5) > Temperature



Graph 6: Model (A4) > Steady-State Thermal (A5) > Convection



Graph 7: Model (A4) > Steady-State Thermal (A5) > Radiation

Calculations for COP:

Without Load without PCM:

COP |max = $\frac{T1}{T2-T1}$

= 270.3/(298-270.3)

= **9.75**

From Steam Table (R134a)

h_1= h_g @ -2.7 'C

= 245.628 kJ/kg

h_2 = h_g @ 28.4 'C (saturated vapor)

= 262.50 kJ/kg

h_3 = h_4 = h_f @ 28.4 'C

88.61 KJ/kg

Refrigerating Effect **(R.E.)** = **h_1 – h_4**

= 245.628-88.61

= **157.018 kJ/kg**

Now, Compressor Work **(C.W.)** = **h_2 – h_1**

= 262.50-245.628

= **16.872 kJ/kg**

COP $= \frac{R.E.}{C.W.}$

$= \frac{157.018}{16.872} =$ **9.306**

With Load & without PCM

COP |max = $T_1/(T_2-T_1)$

= 269.5/(304.5-269.5)

= **7.70**

From Steam Table (R134a)

h_1= h_g @ -3.5 'C

=245.1912 kJ/kg

h_2 = h_g @ 31.5 'C (saturated vapor)

= 264.235 kJ/kg

h_3 = h_4 = h_f @ 31.5 'C

=93.665 kJ/kg

Refrigerating Effect **(R.E.)** = **h_1 – h_4**

= 245.1912-93.665

= **149.5262 kJ/kg**

Now, Compressor Work **(C.W.)**

= **h_2 – h_1**

= 264.235-245.1912

= **21.042 kJ/kg**

COP $= \frac{R.E.}{C.W.}$

$= \frac{149.5262}{21.042} =$ **7.10**

With Load & with PCM :

COP |max = T1/(T2-T1)

= 270/(303.50-270)

= 8.06

From Steam Table (R134a)

h1= hg @ -3.0 'C

=246.4825 kJ/kg

h2 = hg @ 30.5 'C (saturated vapor)

= 264.745 kJ/kg

h3 = h4 = hf @ 30.5 'C

=92.215 kJ/kg

Refrigerating Effect (R.E.) = h1 – h4

= 246.4825-92.215

= 153.2675 kJ/kg

Now, Compressor Work (C.W.) = h2 – h1

= 264.745-245.4525

= 19.2925 kJ/kg

COP = (R.E.)/(C.W.)

=153.2675/19.2925 = 7.84

Comparison of COPs

- **Ideal COP**

Without PCM With PCM

COP |ideal =7.7 COP |ideal =8.06

COP |with PCM > COP |without PCM

Percentage increase in COP with PCM = (8.06-7.7)/7.7 = 5 %

Actual COP

Without PCM With PCM

COP | = 7.10 COP |=7.84

COP |with PCM > COP |without PCM

Percentage increase in COP with PCM = (7.84-7.10)/7.10

= 10.42 %

Thus slight increment in COP is observed by 10.29% & 9.8% in ideal and actual case respectively .

Comparison on the basis of Time to recover a temperature limit

Load temperature , Tl = -15 'C

Target temperature , Tt = 5'C

Without PCM :

Time taken to reach 5'C from -15 'C = 13 minutes

In whole day , time = 24*60

=1440 min

No times system must should be started

= 1440/13

= 110.76 times (approx)

Energy consumed in one start = 0.1 kWh

Power consumed in a single day

= 110.76*0.1

= 11.07 kW

With PCM :

Time taken to reach 5'C from -15 'C

= 71 minutes

Time taken |with PCM > Time taken |without PCM

In whole day , time = 24*60

=1440 min

No times system must should be started

= 1440/71

=20 times

Energy consumed in one start = 0.1 kWh

Power consumed in a single day = 20*0.1

= 2 kW

In a single day , power saved = (11.07-2)

= 9 .07 kW

Conclusion:

- COP is seen to be increased by 5 % & 10.42 % in ideal & actual case when using PCM.
- Compressor work is reduced & refrigerating effect increased on using PCM
- In the absence of power supply PCM plays an important role in providing long lasting cooling effect. From observations previously mentioned it is clear that time taken for rise of evaporator temp after shut down of power is much slower with PCM than without PCM w r t time.
- As previously indicated in observation, power consumption of plant for 24 hrs is 11.07 kW & 2 kW without PCM & with PCM respectively Thus with PCM power consumption of plant can be decreased and energy can be save to a good extent. We can save 9.07 kW of electricity in 24 hrs .

  Note: Above readings are after steady state.
- Due to reduction in compressor work, compressor outlet temp. is also decreased. Thus it produces less heat in the surrounding environment.
- Time taken with PCM = 5.6 times * Time taken without PCM
- Thus potential losses due to power cut off can be reduced by a factor of 5.46.
- Cold Storage Plant fitted with PCM material can be useful in load fluctuating & rural areas as PCM can maintain required temperature for long period of time even without power supply.
- **Factors affecting performance**
- Placement of PCM : We have placed PCM inside the evaporator which leads to some of heat losses due to absorption by insulation. To ensure no heat loss , PCM should made an integral part of insulation at inner side so that heat which is lost to the insulation is now consumed by the PCM which can come in use during power loss.
- Polythene bags- PCM is filled in polythene bags. These polythene bags are bad conductor of heat so they act as barriers in cooling of PCM, thus it increases its cooling time and affects its performance.
- Heat loss in tubes & throttling tubes : Tubes should be insulated well to prevent heat losses. Also throttling tube can be insulated, instead we can make it in integral part in the insulation of cabin , the same as we have done in our project.
- Air Gap – When PCM is inserted inside the storage space air gaps are seen at various points. These air gaps causes heat loss and reduce cooling effect because air is also a poor conductor

If all these factors are overcome or minimized and PCM can be filled in liquid form by making an integrated design with the freezer of same material as freezer, outcomes of this project will be much better and power consumption can be decreased to a good extent making it more efficient.

This concept has a good future scope in the field of refrigeration and air conditioning if limitations are overcome by proper design. It can be used in following purposes with decrease in power usage and increased performance.

Future Scope:

- Large cold storage plants & Ware houses
- Air Conditioning systems
- Space cooling
- D-fridges
- Cold storage Vehicles
- Residential and Office buildings
- Control rooms in Remote areas
- Aircraft cooling system

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