Effect of Ethylene glycol as Phase Change Material in a Cold Storage Unit on retention of cooling

Krishna Kumar Gupta 1, M. Ramachandran 2
MPSTME, SVKM’S NMIMS, Dhule, Maharashtra, India
KrishnaKumar.Gupta@nmims.edu, manickam.ramachandran@nmims.edu

Abstract. Many commodities such as food, medicines & vaccines are required to be kept in commercial cold storages within a specified temperature range. Problems arise in these systems within times of failure, power cuts, or transportation. The absence of refrigeration leads to an increase in temperature within the system which may lead to spoilage of products stored inside. Phase change materials may pose as a promising solution as they absorb the latent heat of the system at the expense of the phase change absorbing, latent heat. Ethylene glycol is selected as the phase change material due to its high latent heat content and negligible hazards. The system incorporated with phase change material was found to retain the cooling effect after cut off. In this paper, for investigation we conducted four experiments namely 0/0%, 75/25%, 50/50%, 100/0% Ethylene glycol and water respectively as phase change material for studying the retention of cooling within the system during power failures. The result shows that the retention of cooling in cold storage unit with 100% Ethylene glycol phase change material is very low 50% Ethylene glycol and 50% water has more retention of cooling. This indicates that addition of water in the phase change material increases the retention of cooling in cold storage unit.

Keywords: cold storage unit, phase change materials, Ethylene glycol

1. Introduction

There are various commodities such as vegetables, fruits, medicines, vaccines or food products that are commercially stored in cold storage units. A cold storage is basically a term used for refrigerated or frozen storage facilities, usually used to store food or pharmaceuticals. Cold storage units are well insulated. Problems arise in these storage units during technical failures or power cuts or generally during transportation. In absence of refrigeration, the temperature inside the system increases due to leakage of heat inside from high temperature surroundings, the heat generated inside the system or certain biological processes. Latent heat storage is one of the most efficient ways of storing thermal energy. Unlike the sensible heat storage method, the latent heat storage method provides much higher storage density, with a smaller temperature difference between storing and releasing heat. Adhering to this idea, a system can be thought wherein unwanted heat generation and heat leakage can be managed. This helps in retaining cooling in a desired system and helps in product quality assurance during times of system failure or during transportation. Many applications of PCM at low temperature can be found, such as, ice storage, conservation and transport of temperature sensitive materials and in air conditioning, cold stores, and refrigerated trucks [1]. But there are some practical problems like low heat transfer, super-cooling, corrosion of the PCM container and stability [2]. In-built and sectioned storage systems with large collector modules are economically more favourable due to the use of a small initial cost for a large heat recovery benefits [3]. The crystalline properties of ethylene glycol resulted from DSC analysis, reveal that intrinsic crystalline structure of ethylene glycol is not influenced by the crosslinking reaction with water [4]. Phase change temperature of Ethylene glycol could be changed using a blending with different materials [5]. The possible advantage of using Ethylene glycol blends to replace pure components is connected with the possibility of changing the temperature range and heat associated with melting/freezing [6].

2. Material Selection

The cooling tank is an insulated system where refrigeration effect is achieved. The cooling tank is made of galvanized steel. The cold atmosphere in held in the system with the application of insulation around the tank to compensate for its high thermal conductivity. The cooling tank dimensions is 20 inch x13 inch x 18 inch. An air cooled condenser is selected for the system. The condenser is a forced convection air cooled condenser and uses base mounted fan and motor assembly for cooling through forced convection [7]. The condenser consists of 18mm copper tubes and plate type fins. The model ‘THK1365YCG XL’ requires an air cooled system provided by a fan and motor assembly. The condenser is designed to handle high optimum temperatures up to 42°C [8].
Copper tubes of diameter 3mm are wound 5 sides of the cooling tank. The refrigerant flowing through the coils readily absorb the heat and evaporate, gradually decreasing the temperature of the system. The liquid refrigerant from the capillary tube enters into the evaporator where it boils and changes into vapor. The evaporating coil in the system is wound on 5 sides of the cooling tank and is torch brazed on the tank [9]. The expansion device used in this system is a capillary tube of 1 mm bore diameter or it is also known as capillary bore. The specification on the scale is no. 36 and is 15.21 feet long. A capillary tube is used because it is suitable for small capacity hermatically sealed compressors used in deep freezers and domestic refrigerators. A capillary tube of bore diameter 0.036 inches is used [10]. The pressure drop created is directly proportional to the length if the coil and inversely proportional to the diameter. The refrigerant from the condenser is first collected in a receiver and then is passed through a filter to separate impurities that may choke the expansion valve. The refrigerant used is R134-Aor 1, 1, 1,2Tetraflouroethane [11]. A vacuum is first created in the system using a suction pump. To create the buffer system and maintain the cooling effect inside, the phase change material chosen is Ethylene glycol. Ethylene glycol has a high latent heat content that lets it absorb huge amount of heat during phase change. Ethylene glycol Melting point is -12 °C, Latent heat content is 181 kJ/kg, Density is 1110 kg/m³ and thermal conductivity is 242 x (10)^(-3) Wm/K [12]. The figure 1 shows the fabrication of cold storage unit with copper coils containing Phase change material. The insulation chosen for the system is PUF or polyurethane foam since it has a significantly low thermal conductivity [13]. For investigation we conducted four experiments namely 0/0%, 75/25%, 50/50%, 100/0% Ethylene glycol and water respectively as phase change material for studying theretention of cooling within the system.

3. Analysis of vapour compression system

Considering the gas after compression is dry saturated vapour [14],

\[ S_1 = S_f + x(S_g - S_f) \]

But, \( S_f = 1.7081 \text{ kJ/kg K} \) (Isentropic compression) Therefore, \( x = 0.947 \)

\[ h_1 = h_f + x(h_g - h_f) = 372.643 \text{ kJ/kg} \]

\[ h_2 = h_f + x(h_g - h_f) = 422.69 \text{ kJ/kg K} \]

\[ h_3 = h_g = h_f = 268.53 \text{ kJ/kg K} \]

\[ \text{COPtheoretical} = \frac{h_1 - h_3}{h_2 - h_1} = 2.08 \]

Refrigeration effect= \( h_1 - h_3 = 104.21 \text{ kJ/kg} \)

Work done= \( h_2 - h_1 = 216.75 \text{ kJ/kg} \)

A beaker filled is filled with 15ml water and is placed in the system. The vapor compression system is then started and the initial temperature of water is noted and so is the time taken by the system to cool the water by 1°C.

We know that,

[15] Refrigeration effect= \( Q = m \times C_p \times \Delta T = 628.8 \text{ J} \)
For 32.4 seconds, heat transfer rate $Q = 194.992$ watts
Compressor rated work= 128 watts

\[
\text{COP}_{\text{actual}} = \frac{RE}{W} = 1.52337
\]

Efficiency of the system = \[
\frac{\text{COP}_{\text{actual}}}{\text{COP}_{\text{theoretical}}} = 0.7329 = 73.29\%
\]

4. Composite wall analysis

Conditions assumed:
1) Steady state heat flow
2) No internal heat generation
3) Materials are isotropic

| Area $A_1$ (hxb) | 0.1509 |
|------------------|--------|
| Area $A_2$ (lxb) | 0.1677 |
| Area $A_3$ (lxh) | 0.232  |
| Plywood thickness $t_1$ | 1 cm |
| PUF thickness $t_2$ | 3 cm / 3.5 cm / 4 cm |
| Cooling tank thickness $t_3$ | 0.1 cm |
| Ambient Temperature $T_1$ | 35°C |
| Temperature of cooling tank wall $T_2$ | -12°C |
| Thermal conductivity of wood $k_1$ | 0.12 W/mK |
| Thermal conductivity of PUF $k_2$ | 0.03 W/mK |
| Thermal conductivity of cooling tank $k_3$ | 18 W/mK |

Table 17: Specifications of composite wall

We know that,
Heat transfer rate = Temperature difference / Thermal resistance
$Q = \frac{\Delta T}{\sum R}$
Thermal resistances
At face A1, a 3.5 cm PUF insulation is provided.
$R_1 = \frac{t_1}{k_1} + \frac{t_2}{k_2} + \frac{t_3}{k_3} = 1.25022$
At face A2, a 3 cm PUF insulation is provided
$R_2 = \frac{t_1}{k_1} + \frac{t_2}{k_2} + \frac{t_3}{k_3} = 1.083055$
The bottom side of the box has a 4 cm of PUF insulation
$R_3 = \frac{t_1}{k_1} + \frac{t_2}{k_2} + \frac{t_3}{k_3} = 1.416355$
The top has a 1.5 cm thick insulation
$R_4 = \frac{t_1}{k_1} + \frac{t_2}{k_2} = 1.7893$

Heat transfer rate
$Q_1 = \frac{(T_1 - T_2)A_1}{(305-263)0.1509} = 5.06$ Watts
$Q_2 = \frac{R_1}{(T_1 - T_2)A_2} = \frac{1.25022}{(305-263)0.232} = 8.996$ Watts
$Q_3 = \frac{R_2}{(T_1 - T_2)A_3} = \frac{1.083055}{(305-263)0.167} = 4.97$ Watts
$Q_4 = \frac{R_3}{R_4} = \frac{1.4163}{0.6601} = 10.67$ Watts
Since the walls A1 and A6, A2 and A5 possess the same composite wall thickness and same material conductivity, the heat transfer rate will be similar.
Therefore, Q1=Q6 and Q2=Q5
Total heat transfer rate= Q1+Q2+Q3+Q4+Q5+Q6= 43.752 Watts
As we can observe, even though insulated, the net heat transfer is 43.752 Watts. Hence, we have to manage this heat that decreases the retention of cooling in the system.
Since most of our commercial materials spoil above 8°C in cold storage units, we calculate the time required to reach the temperature.
\[ \text{Time} = \frac{m C_p \Delta T}{Q} \]
\[ \text{Time} = 18.5 \text{ minutes} \]

Amount of phase change material required
Total latent heat content of PCM = mass of PCM x latent heat of fusion
The total latent heat content of the phase change material should be greater than or equal to the heat transfer inside the system. Therefore,
\[ Q_{\text{total}} = m \times \Delta h_f = 48.56472/181 = 0.26831 \text{ kg} \]
Volume of phase change material = mass of material/ Density of material = 0.24172 liters
Heat absorbed by phase change materials
Area of contact with walls = 0.0208 m²
Heat transfer through walls in contact with coils = 8.996 W
Effective heat transfer rate per unit area = 432.5 W/m²

5. Analysis and Discussion of retention of cooling
The system is first allowed to reach -12°C and ethylene glycol is allowed to freeze in the coils. When the optimum conditions are matched, the system is given a cut off. The rise in temperature inside the system is measured using a calibrated thermocouple for an interval of 30 seconds each.

![Decrease in Temperature during cooling](image)

Figure 2: cold storage unit decrease in temperature during cooling
As per the figure 2, the time taken to decrease the temperature in cold storage unit without Phase change material and with 100% Ethylene glycol phase change material is almost similar. But with 25% addition of water in ethylene glycol and 50% Ethylene glycol taken more time for cooling the cold storage unit.
As per the figure 3, the retention of cooling in cold storage unit without Phase change material and with 100% Ethylene glycol phase change material is very low. But with 25% addition of water in ethylene glycol and 50% Ethylene glycol has more retention of cooling. This indicates that addition of water in the phase change material increases the retention of cooling in cold storage unit. 50% of water with 50% Ethylene glycol gives the good retention of cooling.

6. Conclusion
A cold storage unit incorporating phase change materials was fabricated. The copper tube enclosed around ethylene glycol has a good thermal conductivity and hence facilitates in freezing the phase change material with can be used for a decent number of cycles. Compared the temperature vs. time graphs with 0/0%, 75/25%, 50/50%, 100/0% Ethylene glycol and water respectively as phase change material for studying the retention of cooling within the system. The retention of cooling in cold storage unit without Phase change material and with 100% Ethylene glycol phase change material is very low. But with 25% addition of water in ethylene glycol and 50% Ethylene glycol has more retention of cooling. This indicates that addition of water in the phase change material increases the retention of cooling in cold storage unit. 50% of water with 50% Ethylene glycol gives the good retention of cooling. Such a system can be useful during power cuts and system failures or also during loading and unloading while transportation of commodities.

References
[1]. Oró, E., A. De Gracia, A. Castell, M. M. Farid, and L. F. Cabeza. Applied Energy 99 (2012): pp. 513-533.
[2]. Veerakumar, C., and A. Sreekumar, international journal of refrigeration 67 (2016): pp. 271-289.
[3]. Safari, A., R. Saidur, F. A. Sulaiman, Yan Xu, and Joe Dong, Renewable and Sustainable Energy Reviews 70 (2017): pp. 905-919.
[4]. Fu, Xiaowei, Yao Xiao, Kai Hu, Jiliang Wang, Jingxin Lei, and Changlin Zhou, Chemical Engineering Journal 291 (2016): pp. 138-148.
[5]. Alkan, Cemil, Eva Günther, Stefan Hiebler, and Michael Himpel, Energy conversion and management 64 (2012): pp. 364-370.
[6]. Farid, M.M., Khudhair, A.M., Siddique, A.K.R., Said, A., 2004, Energy. Covers. Manage vol. 45, no. 9-10: pp. 1597-1615.
[7]. Lu, Y. Z., R. Z. Wang, M. Zhang, and S. Jiangzhou. Energy conversion and management 44, no. 10 (2003): pp. 1733-1743.
[8]. Maidment, G. G., and G. Prosser, Applied Thermal Engineering, 20, no. 12 (2000): pp. 1059-1073.
[9]. Bellas, I., and S. A. Tassou, International Journal of Refrigeration 28, no. 1 (2005): pp. 115-121.
[10]. Echeverría, G., T. Fuentes, J. Graell, I. Lara, and M. L. López, Postharvest Biology and Technology 32, no. 1 (2004): pp. 29-44.
[11]. Faizal, Mohammed, and M. Rafiuddin Ahmed, Renewable energy 51 (2013): pp. 234-240.
[12]. Ahuja, Akshay, and M. Ramachandran, International Journal of ChemTech Research 9, no. 4 (2016): pp. 192-196.
[13]. Cheralathan, M., R. Velraj, and S. Renganarayanan, International Journal of Energy Research 31, no. 14 (2007): pp. 1398-1413.
[14]. Navarro-Esbrí, Joaquín, Juan Manuel Mendoza-Miranda, AdriánMota-Babiloni, A. Barragán-Cervera, and Juan Manuel Belman-Flores, international journal of refrigeration 36, no. 3 (2013): pp. 870-880.
[15]. Hajidvalloo, E., and H. Eghtedari, international journal of refrigeration 33, no. 5 (2010): pp. 982-988.