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Cold storage system Integrated with Phase Change Material

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Abstract:Storage at low temperatures particularly food storage is always a matter of concern. Storage temperatures of 4°C is required for chilled food items such as vegetables. A concept is proposed in which vapour compression refrigeration is carried out with solar PV panels as power source for the available period. For the remaining period Phase Change Materials, an application of thermal energy storage, is used where it absorbs heat by melting.
Keywords: Storage, food storage , Solar energy, ethylene glycol, Phase Change Material

1. Introduction

Domestic and industrial requirements need food products to be stored or transported at low temperatures. Cold storage facilities, refrigerated trucks are some of the facilities used to maintain products at low temperature. It is also true that temperature fluctuations in the storage affect the quality of the food. Temperature drops due to the electrical power failure causes deterioration of low sensitive temperature products. Alternatives to this can be non-refrigerated systems which use insulation where it doesn't extract heat from the load and it only maintains the temperature. This alternate is not suited for longer period. The temperature control plays a serious role because quality of the foodstuffs can be seriously affected. Both temperature and time can have impact on the microbial and chemical properties of the food products.All these situations could degrade the quality of food. Moreover production facilities such as vapor compression refrigeration involve high energy and it represents a higher economic environmental impact, because of the increased CO2 emissions. Making this process energy efficient by combining Thermal energy storage would gain much importance. Industrial processes use Phase change material as thermal energy storage mediums for both heat and cold application [1,2]. Desirable properties of any thermal energy storage system would be charging and discharging with high energy storage density and high power capacity. Among the three methods of Thermal Energy Storage- Sensible, Latent and chemical heat storage, Phase change materials are based on latent heat. Here the energy density is increased by having a phase change within the temperature range. The amount of heat stored in Phase change material can be calculated-

$$Q_H = \int_{T_1}^{T_{PC}} C_{P,S} dT + \Delta H_{PC} + \int_{T_{PC}}^{T_2} C_{P,L} dT$$

Where ΔHpc is the heat of fusion and Tpc is the phase change temperature. The requirements for any material to be used as Phase change material in a Thermal energy storage system must have high latent heat and high thermal conductivity, and also they should have a melting temperature lying in the required temperature range of operation. Furthermore it should be chemically stable, low in cost, nontoxic and non-corrosive[1].

2. Literature Review

Phase change materials characteristics, limitations, classifications are described in detail by Mehling and Cabeza[3]. Ryu(1991)[4] experimented the mechanism of heat transfer of cold thermal storage unit which used 2 wt% of sodium sulphatedecahydrate in aqueous solution as Phase change material. Velraj(1999)[5] did various enhancements in heat transfer characteristics of latent heat storage systems. Also Setterwall(2002)[6] experimented paraffin waxes as phase change materials for cold storage. Models of simulation of charging and discharging of latent heat storage system using phase change material wa developed by Ismail(2003)[7]. The thermal storage behavior of Al_2O_3-H_2O nanofluids were experimented by Wu(2009)[8] in which the solidification time related with the addition of weight fraction of Al_2O_3 was discussed. Oro(2012)[9] did a review on the selection of Phase change material. Various attempts of improving the thermal conductivity by methods of providing fins, dispersion of thermally conductive particles and providing metal matrix were also done. In an experiment conducted by Zeng(2009)[10], carbon nanotubes were dispersed in palmitic acid and the thermal properties were investigated.

3. Methodology

The initial step of any refrigeration process is to calculate the amount of cooling load required for the available area. There are many factors taken into consideration while calculating the cooling load. The available input conditions are,

Volume=1000Ft3=27m3

Mass=3Tons= 2721.5 kg = 6000lb

Indoor conditions: DBT=5°C, RH=95% (storage conditions for potatoes)

Outdoor conditions: DBT=35°C, RH=55% (mid-day atm conditions)

We also assume that there are 6 air changes per day (door openings) and there is a 60 watts bulb for lighting the whole of the area. The room is also insulated so the solar irradiation is neglected.

Air change load- Infiltration load is a space cooling load due to the infiltrated air entering from openings and cracks and entering through a conditioned room due to a pressure difference across the building envelope. Infiltration and ventilation loads consist of sensible and latent cooling loads for which the values are shown below.

Infiltration Air volume V(m3/min)=27×6/(24×60)=0.1125 m3/min

Air change load, sensible heat= $\dot{m}\times C_p\times\Delta T=\rho\times V\times C_p\times\Delta T$ kJ/min

ACLSH= 1.225×0.1125×1.005×(35-5)/60 =0.069 kW

Air change load latent heat= V× ρair× Latent heat of vapourisation× change in humidity

Change in humidity=w_1¬w_2=0.016 – 0.00475

Where,W_1=16g/kg of air

W_2=4.75g/kg of air - from psychometrics chart

ACLH=0.1125×1.225×2465×(0.0160.00475)/60=0.0633 kW

Total Air Change load= 0.069+0.063= 0.132 kW

Product load- this part explains the amount of cooling load the 3 tons of potato takes.

Assuming the product(potatoes) temperature=40°C

$C_p$for potatoes=3.433 kJ/kgK

Product load= $m\times C_p\times\Delta T$ =(2721.55×3.433×(40-5)) / (24×3600)= 3.785 kW

Product load is 3.785kW.

Respirational Heat Q= Mass of Product × respiration heat of product

(Respiration heat of potatoes=0.03 btu)

Q = 6000(lb) × 0.03=180 Btu/hr= 0.0528 kW

Total product load=3.785+0.0528= 3.8378 kW

Light load- In estimating a cooling load, heat gain from all heat-producing equipment and appliances must be taken into account. For every appliance there is a particular factor and for lights it is 1.25.

Load= total watt × 1.25=60×1.25=0.075 kW

Load due to occupants- Humans release both sensible and latent heat. A simple factor is formulated for calculating the load for each person.

Heat equivalent/person =1250 btu/hr. (for 5°C)

Load Q= factor×number of person× number of hours

Load Q= 1250×2×1=2500 btu/hr=0.733

Total load=0.733+0.075+0.0528+3.785+0.132=4.778kW.

Now that we have a total of 4.8 kW cooling load, the next step is designing of refrigeration components. The compressor should work equal to the cooling load and since it doesn't work with 100% efficiency we choose a commercially available compressor of around 6 kW. The novelty in this work is the integration with phase change materials so the vapor compression refrigeration system design is done as available commercially. Now that the whole refrigeration setup is complete we make the choice of Solar PV panels. Since we need the power both compressor and pump of the whole refrigeration circuit we choose a 10kW solar PV panel system. The selection of exact phase change material plays an important role and it is done widely in the literature review. Ethylene glycol is found to be a perfect satisfaction for the required condition. For the storage of the phase change material and its transfer copper, carbon steel and aluminium is not recommended since copper and carbon steels have high corrosion rate and aluminium is prone to pitting effects. So the required material for storage and transfer of phase change materials would be stainless steel 316 alloys. They have high resistance to corrosion and specially pitting.

The Figure 1 shows the layout of the whole working. For the 8 hours while the solar power is available the refrigeration is done with the help of the secondary refrigerant

Ethylene glycol + water (90%+10%) and also it is stored in the cold tank for future use when solar power is not available. Ethylene glycol and water stores the energy required to cool the room for remaining hours. The properties of ethylene glycol is that it is a clear, colorless, odorless liquid with a sweet taste. It is hygroscopic and completely miscible with many polar solvents such as water, alcohols, glycol, ethers and acetone. Its solubility is low however, in non polar solvents such as benzene and chloroform. Physical properties are:

Boiling point at 101.3kPa - 197.6°C
Freezing point - -13°C
Density at 20°C - 1.1135g/cm3
Heat of Vaporisation at 101.3kPa - 52.24kJ/mol
Heat of Combustion - 19.07MJ/kg
Critical Temperature - 372°C
Critical Pressure - 6515.73kPa
Critical Volume - 0.186L/molframe

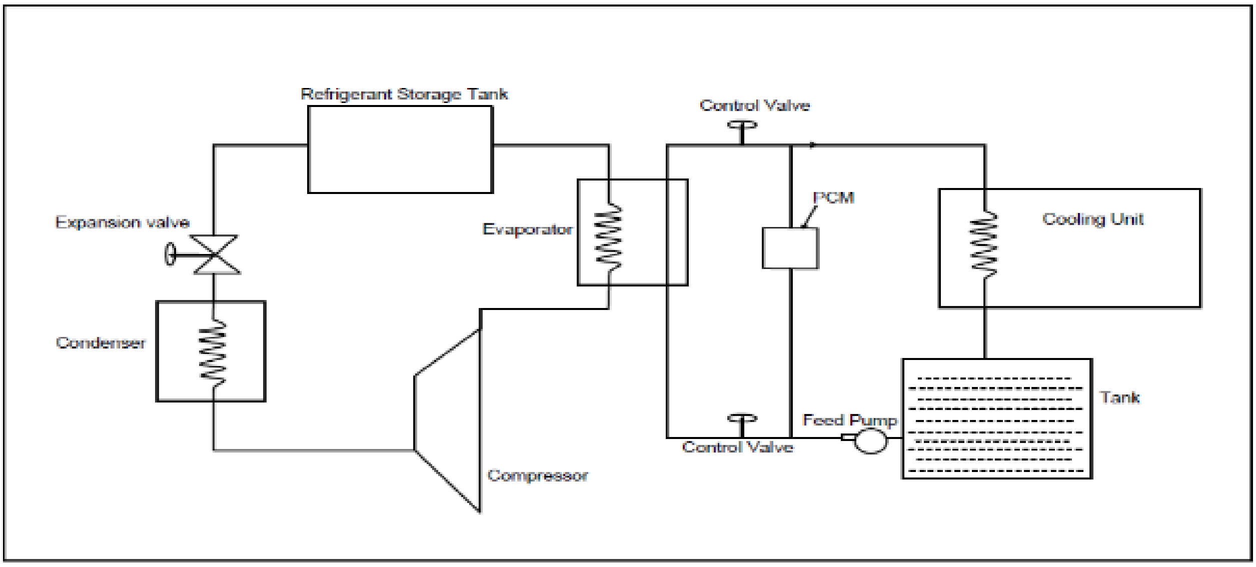

Figure 1: Schematic diagram of cold storage system integrated with PCM Module

4. Result

With the solar power for the compressor, a perfect refrigeration effect for the required cooling area with a storage temperature of 5°C is possible. In the other cycle where there is power only for the pump, the phase change material takes care of the refrigeration effect. Without the product load, initially, ethylene glycol could be taken upto -6°C and when the compressor power was turned off, i.e when no solar power, the refrigerated area was maintained at 7°C for 17 hours. After this refrigeration process when products where placed, ethylene glycol was taken upto -7°C from where it provides the cooling area a temperature of 4.5°C for 10 hours. The coefficient of performance was found to be 3.24.

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