Design and Demonstrated Enhanced Performance of Solar Vaccine Refrigerator by using Phase Change Materials

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Abstract: ***Storage and transportation of goods very essential in any field; especially such as foods, vaccines, items require cold storage. In medical field the importance of this is much more. In rural, forest based villages don't have any cold storage places, where this type of problems much more , to overcome such kind of issues, solar based vaccine refrigerator gives the best results. In this point we designed and demonstrated solar based vaccine refrigerator for medical field. The refrigerator system is designed for a capacity of 150 liter. The supply of electricity to run AC compressor is provided by solar panels through the inverter. In addition to this, provision is made to work at night. Considering with, without Phase change material we worked for different loads with different temperatures. For domestic and small business applications, this type of solar refrigerator can be used .It can be ideal solution to store vaccines or food, which requires low temperature during transportation For domestic and small business applications, this type of solar refrigerator can be used. It can be ideal solution to store vaccines or food, which requires low temperature during transportation***

Keywords: Solar energy, refrigerator, phase change materials, PV panels, Charge controller

1. Introduction

The Earth receives 174 peta watts (PW) of incoming solar radiation (isolation) at the upper atmosphere. Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The spectrum of solar light at the Earth's surface is mostly spread across the visible and near-infrared ranges with a small part in the near-ultraviolet. Solar energy, radiant light and heat from the sun, is harnessed using a range of ever-evolving technologies such as solar heating, solar photovoltaic's, solar thermal electricity, solar architecture and artificial photosynthesis. Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Active solar techniques include the use of photovoltaic panels and solar thermal collectors to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

1.1 Need of Solar Vaccine Refrigerator

Preserving life saving vaccines making it available even at remote places is commitment under health care by government. The vaccines were to be kept refrigerated all the time, and are challenge as power supply is erratic in remote places. Vaccines are most precious, to protect them is essential. They are maintained temperature below 40 C for 6 non- Sundays. Electricity supplies are poor and the power can be cut off for days at a time. The vaccine refrigerator gives reliable cooling in the environments. A vaccine refrigerator is a much safer way of storing vaccines, water packets medicines and vegetables etc.

1.1.1 Innovative

Solar vaccine refrigerator works without power it gives cooling for 6non- Sundays. Solar vaccine refrigerator runs by using the solar energy and battery it can be used both domestic and medical purposes.

1.1.2 Reliable & Convenient: Solar vaccine refrigerator maintained temperature below 40 C. The amount of cooling us depends upon the capacity of the phase change materials. Vaccine refrigerator occupies less space and easy to move. The fridge design is easy and easily manages the stock.

1.1.3(a) Durable: Both the exterior top and bottom are constructed from hard wearing white, galvanized steel. The fridge interior liner is made from quality composite materials that are both durable and easy to clean.

1.2 Refrigeration

The term refrigeration refers to cooling an area of substance below the environmental temperature, the process of removing heat. Mechanical refrigeration uses the evaporation of a liquid refrigerant to absorb heat. The refrigerant goes through a cycle so that it can be reversed. The main cycles are vapour compression, absorption; stem jet or steam ejector and air.

1.2.1Methods of refrigeration

Ice-refrigeration, Evaporation refrigeration, Refrigeration by expansion of air, Steam jet refrigeration, Vapor absorption refrigeration, Vapor compression refrigeration. Most commonly used refrigeration system is vapour compression refrigeration system which works on Bell colleman cycle.

1.2.2 Vapor-compression cycle

The vapor-compression cycle is used in most household refrigerators as well as in many large commercial and industrial refrigeration systems. Figure 1 provides a schematic diagram of the components of a typical vapor compression refrigeration system

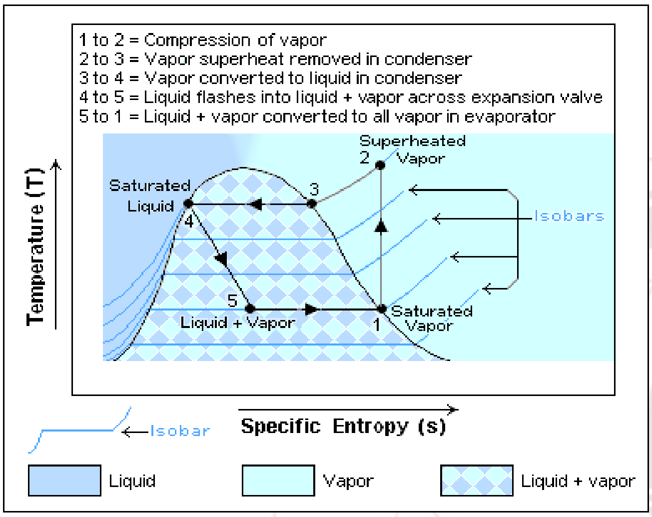


Figure 1: Thermodynamic Cycle (T-S Diagram)

In this cycle, a circulating refrigerant such as Freon enters the compressor as a vapor. From point 1 to point 2, the vapor is compressed at constant entropy and exits the compressor as a vapor at a higher temperature, but still below the vapor pressure at that temperature. From point 2 to point 3 and on to point 4, the vapor travels through the condenser which cools the vapor until it starts condensing, and then condenses the vapor into a liquid by removing additional heat at constant pressure and temperature. Between points 4 and 5, the liquid refrigerant goes through the expansion valve (also called at throttle valve) where its pressure abruptly decreases, causing flash evaporation and auto-refrigeration of, typically, less than half of the liquid. That results in a mixture of liquid and vapor at a lower temperature and pressure as shown at point5, The cold liquid-vapor mixture then travels through the evaporator coil or tubes and is completely vaporized by cooling the warm air (from the space being refrigerated) being blown by a fan across the evaporator coil or tubes.

1.2.3 Solar panels

There are several factors that are been carefully considered while selecting the panels first of all we had estimated the load at which the compressor runs in the daily situation at ambient temperature (350C-450 C) from that a calculations done and it is finally we concluded that for a 100 liter refrigerator the minimum power consumption is 70 watts, where as the maximum power consumption is 72 watts. For a mean solar day the availability of solar energy is for duration of 6 hours. From the above assumptions calculations of panel sizing is done

Total power required = 72 watts

Total duration = 6hrs

The amount of power to be produced in an hour = 72/6=12 watts

Based on the above calculation, considering the factor of safety we have considered two 100 watt panels. The module that which we used is shown in the below photograph

Figure 2: Solar Panels

1.2.3 (a) DC Compressor

The main components of our vaccine refrigerator is that the DC compressor. The reason that why we have chosen our DC compressor is The operating voltage is low, Due to low operating voltage the power fluctuations in the system will be mostly eradicated, So there is no chance of compressor failure except under certain given conditions. This type of compressor that we used BD 80F type which is manufactured by DANFOSS which is the stable compressor manufacturing company by using this modern type of compressor modern comfort is brought into life when leaving home. The excellent performance of the BD series safeguards preservation. With our outstanding DC compressor for cars, vans, trucks etc., the direct current compressor BD80F for 12/24 V DC power supply can be used in mobile refrigerators and freezers with refrigerant R134a. All compressors are equipped with an electronic unit with built- in thermal protection which also protects against destructive battery discharge that which helps in constant system running of good consequences.

Figure 3: DC Compressor

1.2.3(b) Evaporator
Evaporator problems required solution of the system material and energy balances with the accompanying property and heat transfer equations.
The coil length = 20feet
The diameter used = 5/16 inches

1.2.3(c) Capillary Tube
The capillary tube is mainly used as an expander device in a refrigerator. The main aim of the capillary is to reduce the pressure of the refrigerant reduces drastically for the effective working of the system we have chosen the capillary tube of Length = 45 cm, Diameter= 0.36mm

Figure 4: Capillary Tube

1.2.4 Battery
The deep cycle batteries have much battery pack up capacity when compared to that of any other batteries. Deep cycle batteries are nothing but a type of lead acid battery. But due to lack of availability of deep cycle battery readily available in the market we had shifted to make use of lead acid battery as an alternative. The charging and discharging capacity of these batteries are more or less equivalent to the capacity and functioning of deep cycle battery.

Figure 4: Battery

The power availability from 200 watts panel is = 200/12, = 16.6 Amp/hr. But the total amount of light available is for min of six hours therefore the charging power available in a mean sun- day=16.6x6 =99.6Amp/hr. A part from these six hours the panels are able to generate some amount of power. So as a better choice we are planned to have a 150 A-h battery. Not only this reason to consider150 A-h.

1.2.5 Charge Controller
Charge controller is a device that controls the flow of voltage from panels to the battery or system and vice versa. This controls the reverse flow of charge during the non sun days. This also regulates the cut of power, 12V-10 Amps that which serves our usage purpose.

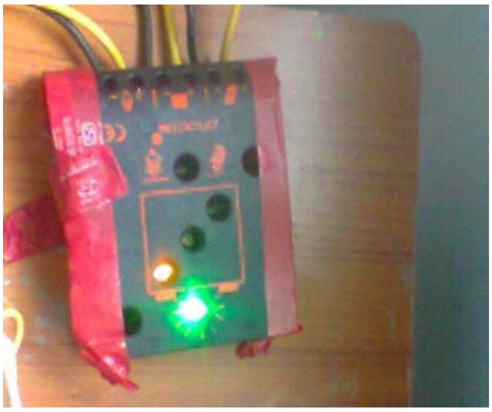


Figure 5: Charge controller

2. Refrigerant

The major reason that why we use R 134a as the refrigerant is that, the instruction from the compressor manufacture is that to use R134a as the refrigerant. It has no harmful influence on the ozone layer of the earth's atmosphere (ozone depletion level is zero). It is an eco friendly refrigerant.

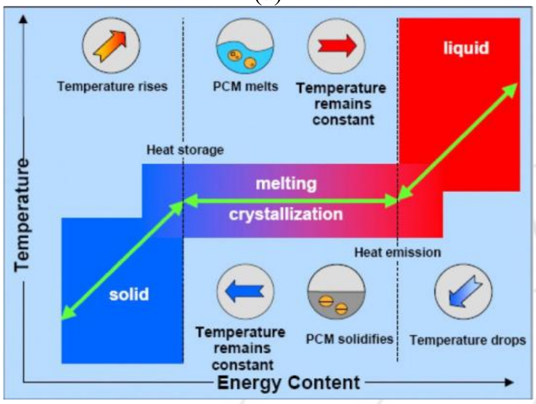
2.1 Purpose of Insulation

A thermal insulator is a poor conductor of heat and has a low thermal conductivity. Insulation is used in refrigerators and in manufacturing processes to prevent heat loss or heat again. It prevents condensation on cold surfaces and the resulting corrosion. Such materials are porous, containing large number of dormant air cells. Thermal insulation delivers the following benefits, minimizes the heat losses from the refrigerated space, Reduces over-all energy consumption. Offers better process control by maintaining process temperature Provides fire protection to equipment Absorbs vibration.

3. Phase Change Materials

A phase-change material (PCM) is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa; thus, PCMs are classified as \ storage (LHS) units The PCM we are used in the system is hydrated salts (HS-O)The freezing temperature is 0 °C. The latent heat of fusion is 279 kj/kg. Initially, the solid–liquid PCMs behave like sensible heat storage (SHS) materials; their temperature rises as they absorb heat A large number of PCMs are available in any required temperature range from −5 up to 190 °C.[1] Within the human comfort range between 20–30°C, some PCMs are very effective. They store 5 to 14 times more heat per unit volume than conventional storage materials such as water, masonry or rock.

(a)



(b)

Figure 7: (a) Phase Change Materials Packets, (b) Phase Diagram for Phase Change Materials

3.1 Applications of PCM

Conditioning of buildings, such as 'ice-storage', Cooling of heat and electrical engines, Cooling: food, beverages, coffee, wine, milk products, green houses, Medical applications: transportation of blood, operating tables, hot-cold therapies, Waste heat recovery, Off-peak power utilization: Heating hot water and Cooling

4. Load Calculations

With Out Phase Change Materials Cool Down Time For Load

Table 1: 6 liters of water in side freezer within 75 minutes it reaches to -4.3^{0}C

Time (min)	Temperature(^{0}C)
0 minutes	26.3
15 minutes	17.1
30 minutes	9.9
45 minutes	-0.6
60 minutes	-3.2
75 minutes	-4.3
105 minutes	-6.6

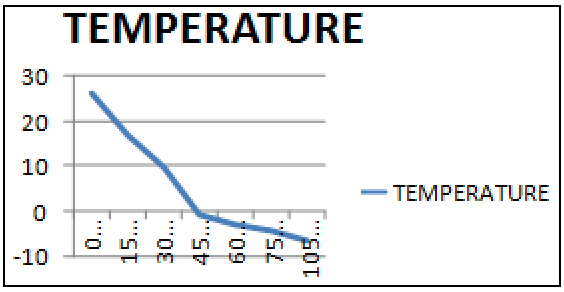


Figure 8: We are placed 6 liters of water in side freezer within 75 minutes it reaches to -4.3^{0}C.

With Out Phase Change Materials Warm Up Time for Load

Table 2

Time (min)	Temperature(0C)
30 minutes	16
45 minutes	24
60 minutes	28

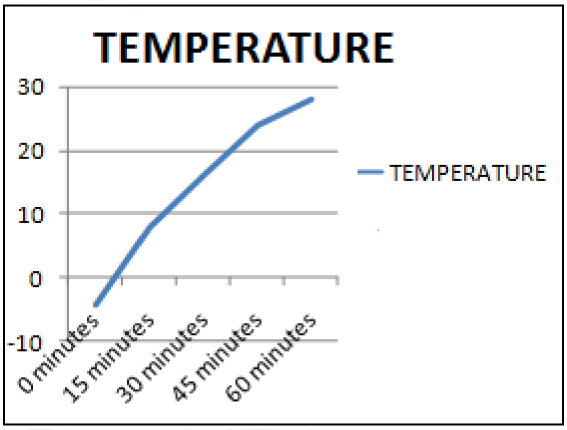


Figure 9: In warm up cycle initially having -4.30C without phase change materials it reaches 28^{0}C within 60min.

With Phase Change Materials Cool Down Time for 10kg's Load

The time required to cool the 2 liters of water with 10kg's Phase change materials is nearly 36 hours from ambient temperature of 26.90C to-4.20C

Table 3:

Time (min)	Temperature(0C)
0 hours	26.8
12 hours	4.3
24 hours	0.4
36 hours	-4.2

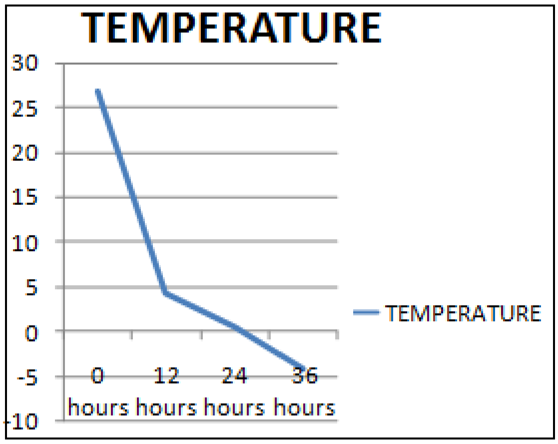


Figure 10: By using D.C compressor Time required to cool the load =36 hours

Amount of energy consumed by compressor per hour= 12 watts Hence, Energy required to cool the load with phase change materials=36x12 =432 watts. Coefficient of performance=heat rejected/work done
Heat rejected=mcpΔt,
Where,
M= mass of load with P.C.M=10Kgs
CP=Specific heat at constant pressure=1.
Δt=change in temperature=26.9^{0}C
C.O.P=10x1x26.9/432 =0.622
Coefficient of performance (C.O.P) = 0.622

Warm Up Cycle with P.C.M:

Table 4:

Time (min)	Temperature(0C)
0 hour	-4.3
12 hours	-2.2
24 hours	-1
36 hours	0.6
47 hours	3.9

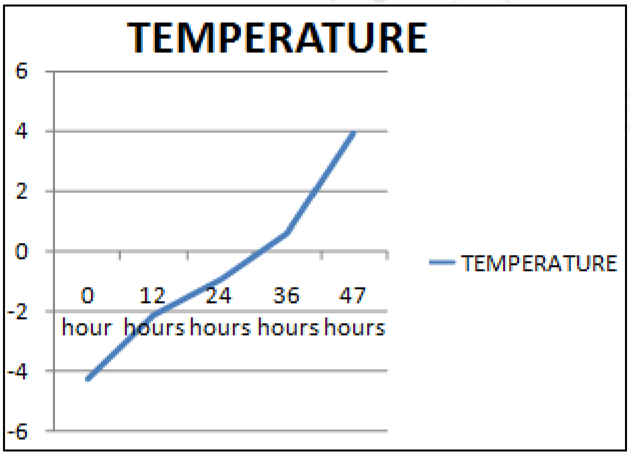


Figure 11: warm up cycle phase change materials maintained temperature below 40^{0}C up to 2 days

With Phase Change Materials Cool Down Time For 30kg's Load

The time required to cool the 6 liters of water with 30kg's Phase change materials is nearly 72 hours from ambient temperature of 27.80C to-3.20C. The graph is drawn showing the steep slope in decrease in temperature

Table 5

Time (min)	Temperature(0C)
0 hour	26.8
12 hours	12.2
24 hours	8.2
36 hours	4.4
48 hours	0.4
60 hours	-2.8
72 hours	-3.2

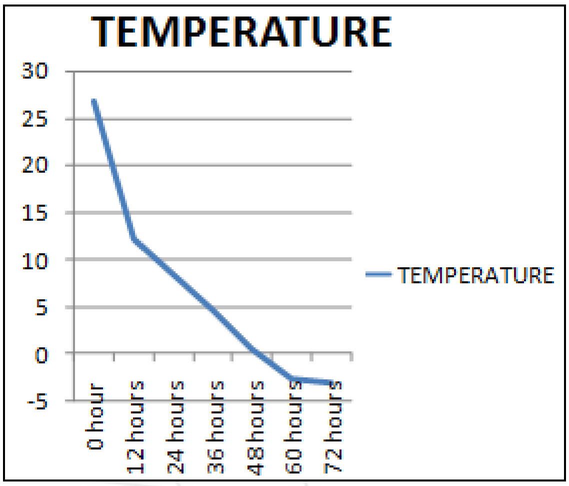


Figure 12: By using D.C compressor time required to cool the load =72 hours

Amount of energy consumed by compressor per hour= 12 watts, Hence,
Energy required to cool the load with phase change materials=72x12 =864 watts
Coefficient of performance=heat rejected/work done
Heat rejected=mcpΔt, Where,
M= mass of load with P.C.M=30Kgs
CP=Specific heat at constant pressure=1.
Δt=change in temperature=27.80c
C.O.P=30x1x27.8/864 =0.965
Coefficient of performance=0.965.

With P.C.M Warm Up Time For 30 kg's Load

Table 6

Time (min)	Temperature(0C)
0 hour	-3.2
12 hours	-2.8
24 hours	-1.4
36 hours	-1
48 hours	0.9
60 hours	1.2
72 hours	1.6
84 hours	1.8
96 hours	2.4
108 hours	2.8
120 hours	3.1
132 hours	3.5
144 hours	3.9

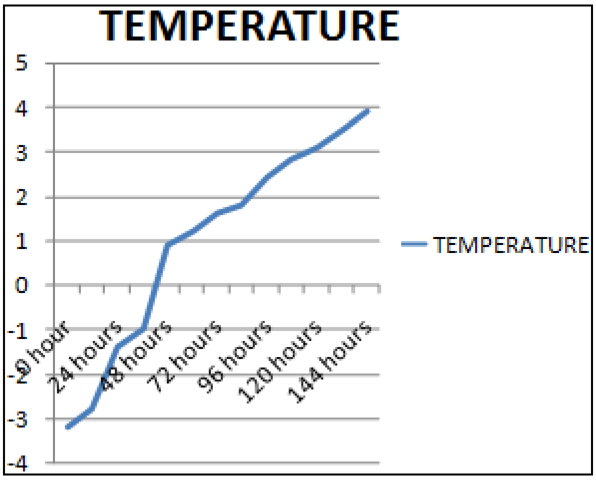


Figure 13: In warm up cycle we are placed 30 liters p.c.m and 6 liters of water, p.c.m's maintained below 40C up to 6days

When the Power supply is cut off; where there is no chance of Compressor work the graph is drawn by taking Time in Hours on X-axis& Temperature in 0C on Y-axis. The graph clearly shows that the amount of heat to be rejected during the Refrigeration process is sucked by the P.C.M materials. There is a long time taken nearly 144 hours for change of Phase from Solid P.C.M to Liquid phase which is the latent heat of it and also the heat rejected by the load.

Figure 13: Outer dimensions are22*22*31.5 inches

Table 7: Technical Data

S.NO:	Parts	Specification
01	Chest dimensions	22x22x31.5inches (lx b x h)
02	Net volume	100 liters
03	Solar panels	2 x 100 watts with 12v output connected in series
04	DC Compressor	BD80F
05	Evaporator	Coil length = 40 feet, diameter = 5/16 inch
06	Capillary tube	length = 9 feet Diameter = 0.36mm
07	Condenser	Length = 30 feet Diameter =1/4 inch
08	Battery	Lead acid battery with 12v-150 AH power
09	Charge controller	12v ,10 amps
10	Insulation	100mm thickness PUF
11	Refrigerant	R134a (ECO Friendly)

5. Conclusions

We have designed, developed, installed and demonstrated through calculations; enhanced performance of solar vaccine refrigerator by using phase change materials. The performance of it is evaluated where the system uses the D.C Compressor that makes it efficient it efficient and can be directly coupled to solar panel output via Deep cycle battery through charge controller which endures reliable and a long time usage. Phase change materials are the direct user of backup of chill effect in this system. This is best suited for remote villages where power is not available. This can be operated 6days without power supply and makes it beneficial in remote places. This development has given opportunity for us to design and develop the total system and that is very relevant to our basic needs of refrigeration.

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