Solar Powered Refrigerator for Vaccine Transportation in Remote Areas

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Abstract : The large areas of developing countries have no grid electricity. Moreover, this is a serious challenge that frightens the continuity of the cold chain. The main alternatives for electrically powered refrigerators have been available for many years such as kerosene and gas driven refrigerators are besotted by problems with gas supply interventions, low efficiency, poor temperature control and constant maintenance needs. Currently, there are no kerosene and gas driven refrigerators that will be qualified under the minimum standards. Solar refrigeration is a promising development which provides an alternative to absorption technology to meet cold chain needs in remote areas. There was a time when Traditional solar refrigerators relied on relatively expensive battery systems which have demonstrated short lives as compared to the refrigerator. There are now many alternatives to the battery based systems and also there is a clear understanding that solar refrigeration systems need to be designed, installed and maintained by well known skilled people with the predetermined knowledge and training. The technology is now assured to be the refrigeration method of the cold chain in areas with no electricity or extremely capricious electricity and abundant sunlight.

I.INTRODUCTION

The healthcare systems are deteriorating and the health standards are breaking down in the aftermath of disasters such is covid-19. Thereby essential services such as sanitation facility, vaccination programs cannot be provided to rural or off-grid areas. The lack of good storage, cold chain management and transportation results in a loss of vaccines which may lead to poor immunization coverage. Vaccines are intended to protect but when they are exposed to too hot temperature, they may lose their power and can also lead to problems for the vulnerable population. Reports show that many doses of vaccines were lost due to cold chain disruptions, lack of transportation or cooling facility. This may lead to the prices for vaccines to rise. In order to face these challenges, we must come up with a solution that can solve some of the challenges of vaccine cold chains. Vaccines can only save lives if they are cool, they are developed for the safe range of 2-8°C.

Therefore refrigeration is important for safe storage of vaccines. To achieve this temperature range, continuous supply of electricity is required but in most rural areas or off-grid areas electricity is not reliable, hence alternate source of energy is required. Solar powered refrigeration is the best solution, based on economic and practical viability. By making the entire system more compact and increasing its efficiency using a flexible photovoltaic cell, the transportation of vaccines to rural areas can prove a lot more effective.

The critical factors for the successful introduction of solar units into immunization in the future programs mainly includes:

1. Sustainable financing mechanisms and motivation for health workers and highly skilled persons are in place to support long term maintenance, repair and renewal parts.
2. While installation the system design is carried out by the highly qualified solar refrigerator professionals considering the conditions.
3. The installation and overhaul are conducted by highly skilled technicians.
4. Also, the temperature performance is continuously observed and formalities are in place to act on data that specify complications.

II.THE VACCINE COLD CHAIN

Introduction

Refrigerators are designed to store vaccines and also medical products at a fixed temperature to make sure they do not degrade. Moreover vaccines must be particularly stored at low temperatures where the temperature should be between 2 to 8°C and sometimes it goes below -7.6°C. The vaccines may lose effectiveness if they are not stored properly. Then, all vaccines should be stored in a refrigerator that is designed clearly for the storage of medical products. The refrigerator-freezer unit should have only one exterior door, no matter where the vaccine has been placed inside the unit. Actually, the value of critical vaccines has reached new heights because it is specially stored in pharmaceutical refrigerators. They are also very sensitive to biological products. The quality of vaccines should be maintained at maximum temperatures. Sometimes vaccines may lose their strength due to inappropriate temperatures and also once the vaccine power is lost it cannot be regained. The vaccines should not be freezed too much and it is also sensitive to light.

Importance

Arrange the vaccines properly in a refrigerator and also label them clearly. If a vaccine is supplied individually in a container use a separate plastic tray or box in an order. The temperature should be maintained accurately especially in cold boxes and vaccine carriers. Moreover, it is important to keep multi dose vaccines that do not contain preservatives which are cooled at temperatures between 2 to 8°C. Also the temperature should be monitored accurately.

Fig:1. The cold chain

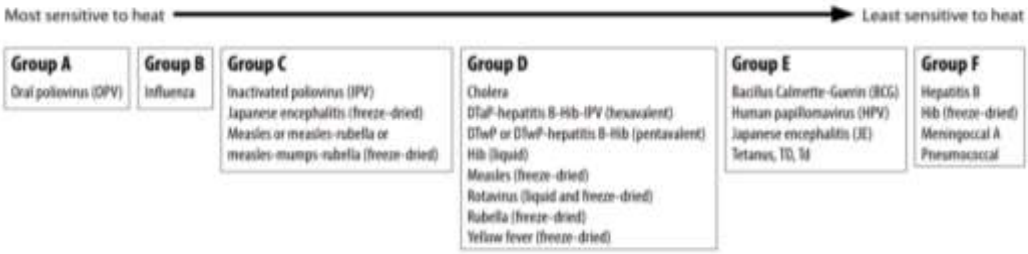

Fig:2. Vaccine Heat sensitivity

III. METHODOLOGY

Working:

In the vapour compression cycle , the main purpose is to obtain the low pressure low temperature vapour refrigerant which flows inside the evaporator that actually absorbs the heat from the space and cooling effect takes place. In order to get the low pressure low temperature vapour , there is a necessity of obtaining high pressure liquid which after converts itself as low pressure vapour.To make this happen Hermetically compressor is installed, It is basically the reciprocating compressor . It is objective is to convert low pressure vapour refrigerant into high pressure high temperature vapour . After this action the excess heat found in the refrigerant shall be removed , it is done by condenser . The high pressure high temperature vapour is made to pass through the condenser . Condenser rejects the heat to the atmosphere and it converts high pressure high temperature vapour to high pressure liquid . Here the transition of phase happens . The nature of the refrigerant should have the ability to change its phase. The refrigerant we have used is R134a .After the transition of refrigerant , it is made to pass through the channel that is called expansion value , when the refrigerant is being moved in the expansion value , again slowly the transition of phase from high pressure liquid to low pressure partial vapour is formed. And this low pressure partial vapour is transferred to the evaporator .As this low pressure partial vapour flows through the channel of evaporator, it starts absorbing the heat from the space and due to absorption it converts itself as low pressure vapour and then the cycle repeats. The source of power is the solar panels .Since DC is obtained from panels , An invertor is used that converts DC to AC. Here we have used an alternate source of power that is battery.

Hermetically sealed compressor: compressor takes the low pressure vapour refrigerant coming from the evaporator and converts into high temperature high pressure vapour by its reciprocating action and deliver it to the condenser.

Condenser: condenser takes the high temperature high pressure vapour refrigerant and convert into high pressure liquid by removing heat to the atmosphere. Here the transition of phase takes place from vapour to liquid.

Expansion valve: expansion valve takes the high pressure liquid from the condenser and convert into low pressure partial vapour, this is due to the throttling effect happening inside the expansion value .

Evaporator: this is the place where the actual cooling effect takes place. As the low pressure partial vapour flows through the pipes of evaporator , it chills the space as the refrigerant absorbs the heat from the space and low pressure partial vapour refrigerant converts itself as low pressure vapour refrigerant when the heat is being absorbed.

Solar panels: It is the device which is actually a collection of solar cells, it is used in the generation of electricity through the principle of photovoltaic effect .It absorbs the sun rays and converts them to electricity.

Temperature sensors: it is the sensor used to measure temperatures of inlet and outlet of the condenser and also to measure the temperature in the evaporator.

Battery: It is the alternating source of energy that store energy as DC. It is charged by solar panels.

IV.TERMINOLOGIES RELATED TO REFRIGERATION

Refrigeration effect

The amount of heat that is to be removed from the storage space in order to maintain lower temperatures is called Refrigeration effect.

Coefficient of Performance (COP)

It determines the efficiency of the refrigerator. It is the ratio of the refrigeration capacity to the energy supplied to the compressor .

$$COP = \frac{\text{Refrigeration capacity}}{\text{Work done by compressor}}$$

COP represents the running cost of the system , greater the COP lesser is the running cost. Therefore, systems with higher COP are desired.

Unit of Refrigeration(TOR)

1 Ton of refrigeration means the amount of heat that is to be removed from 1 American ton (907 kg) of water at 0°C in 1 day.
Therefore , ton of refrigeration represents heat transfer rate not mass.

$$TOR=\frac{m*LH}{1\ \text{day}} = \frac{907*334}{24*3600} = 3.5\ \text{kJ/sec}$$

RefrigerationCapacity(RC)

RC = m x RE

RE is expressed in kJ/kg or kJ/sec or kW.

Energy Efficient ratio (EER)

EER is the ratio of refrigeration effect to work input to the compressor is taken into account.

$$EER = \frac{RE}{Win}$$

Compressor Efficiency(η_{comp}) = $\frac{Pcomp}{Pmotor}$

Actual COP

The actual COP must take into account the effect of irreversibility in the individual processes as well as heat losses too or heat gain from the surroundings and the walls of interconnect piping.

$$COP_{(act)} = \frac{\text{Cooling effect}}{\text{Work output to compressor}}$$

Relative COP

$$COP_{(relative)} = \frac{COP_{act}}{COP_{th}}$$

HP per TON of Refrigerant,HP/TON

$$\frac{HP}{TON} = \frac{mq*Qc}{210}$$

CALCULATIONS

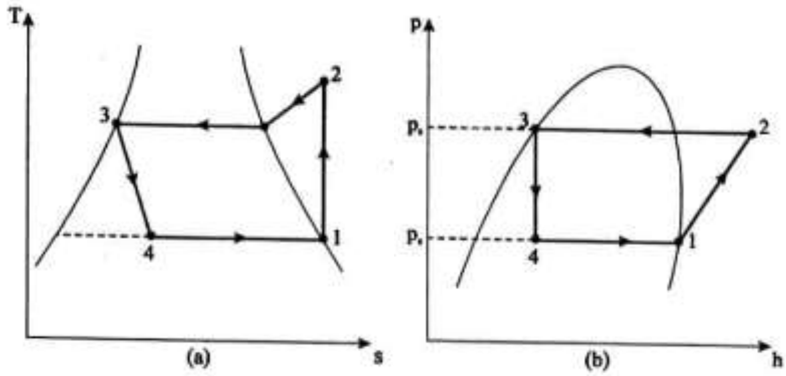

Fig:4. (a) Temperature- entropy (T-S) and (b) Enthalpy- entropy (H-S)

From R-134a P-h diagram, thermodynamic properties are,

At state 1

T_1= -7.6°C

P_1=220kPa

h_1=245.9 kJ/Kg

S_1= 0.9361 kJ/kgK

At state 2

T_2= 40.3°C

P_2=1000kPa

h_2=271.7 kJ/Kg

S_2=0.918 kJ/kgK

At state 3

T_3=36.2°C

P_3=1000KPa

h_3=101.6 kJ/Kg

S_3= 0.9170 kJ/kgK

At state 4

T_4= -7.6°C

P_4=220KPa

h_4=101.6 kJ/Kg

S_4=0.3924 kJ/kgK

where ,

T= temperature in °C

P= Pressure in kPa

h= enthalpy in kJ/kg

S=entropy in kJ/kgK

x= quality of steam

Refrigerant quality x_4 at state 4

h_4= h_3= 101.6 kJ/kgK at 220 kPa

h_f = 41.7 kJ/kgK

h_g= 245.9 kJ/kgK

$x_4 = \frac{h4-hf}{hg-hf} = \frac{101.6-41.7}{245.9-41.7}$=0.2933

$S_4 = S_f + x_4(S_g - S_f)$

At 220 KPa

S_g= 0.9361 kJ/kgK, S_f=0.1668 kJ/kgK

S_4=0.1668+0.2933(0.9361-0.1668)=0.3924 kJ/kgK

$COP_{(ideal)} = \frac{h1-h4}{h2-h1} = \frac{245.9-101.6}{271.7-245.9}$

$COP_{(ideal)}$= 5.59

V.EXPERIMENTAL ANALYSIS

Materials and Specification

Components	**Material**	**Specification**
Primary cooling cabin	Stainless steel	250 * 370 *230mm
Phase change material	propylene glycol with distilled water	20-80% by volume
Evaporator tubes	copper	5m
Insulation	Polyurethane foam	250 * 370 *230mm
Compressor	Hermetically sealed Compressor	220-240 V 50Hz 75W
Compressor model	LG NS24LAEG	Height : 147mm
Condenser	Copper	6m
Condenser fan	Company :Eddy aircon	45W, 1500 rpm
Solar charge controller	Maximum power point tracking	Maximum output power:1000W Surge capacity : 2000W
Solar PV panels	Polycrystalline silicon	12W

Table: Materials and Specification

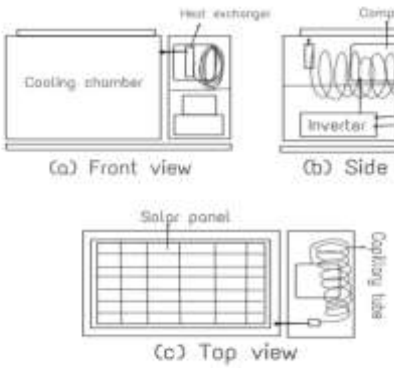

Fig:5. 2D Sketch of Refrigerator

V. RESULTS AND DISCUSSION

The solar refrigerator was tested on 7th May 2021. The ambient temperature recorded was 29.5C, clear sky. The system was started at 10am and left running for the whole day till sunlight was available. The system took a few minutes to reach the required temperature. Temperature was noted at every interval of 1hour. Cabin temperature was able to reach -8.6C. The system was switched off at 4pm in the evening. The refrigerator was working for 6 hours in total. Hence the refrigerator meets our requirements.

Time(hour)	**Temperature(C)**
0	29.5
1	-6.5
2	-8.6
3	-8.1
4	-7.8
5	-7.6
6	-7.5

Table: Temperature readings for every 1hour

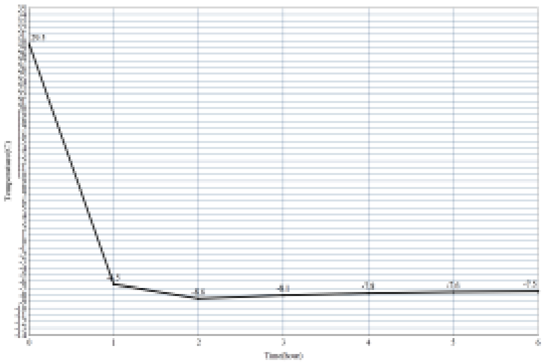

Fig:6. Performance chart of the refrigerator temperature versus time(hours)

Time(mins)	Temperature(C)
0	29.0
1	28.9
2	28.2
3	26.3
4	23.5
5	19.6
6	15.5
7	11.3
8	7.4
9	3.7
10	0.3
11	-2.6
12	-4.5
13	-6.1
14	-6.9
15	-7.6

Table: Temperature readings for every 1minute

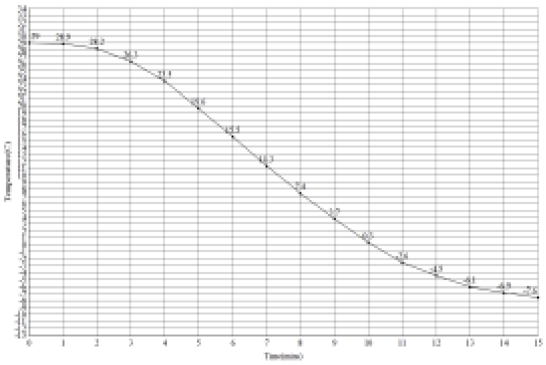

Fig:7. Performance chart of the refrigerator temperature versus time(minutes)

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