A PHOTOVOLTAIC SOLAR REFRIGERATION SYSTEM FOR VACCINE PRESERVATION IN REMOTE AREA

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ABSTRACT

As per WHO report most of the vaccines likes Diphtheria, Tetanus, Pertussis, Hepatitis A, Hepatitis B, Hib, Influenza, Meningococcal, Pneumococcal, Rotavirus are required to be preserved at refrigeration temperature such as (2°C to 8°C). When the vaccines are preserved above or below the required temperature, the potency of a vaccine is lost resulting in loss of money, as vaccines are costly. In remote areas where electricity is not available, preservation of vaccines becomes a very serious concern. In order to provide the means to preserve the vaccines in remote areas, a portable refrigeration system working on photovoltaic effect has been designed and developed. The refrigeration system developed is of the dimension 24.50"×21.25"×14" and has the capacity of 30 liters capable of maintaining the evaporator temperature of 0°C to 8°C for 9hrs to 10 hrs once the battery is charged. The time taken by the battery to be charged is of the order 6 hrs to 8 hrs. The coefficient of performance (COP) of a developed refrigeration system is 3.19 and the payback period as per techno-economic analysis is found to be 8 years 5 month 6 days.

KEYWORDS: Solar Photovoltaic, Vaccine, Remote Areas & WHO

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INTRODUCTION

Among all vaccines many vaccines like as MMR, Diphtheria, Tetanus, Pertussis, Hepatitis A, Hepatitis B, Hib, Influenza, IPV, Meningococcal, Pneumococcal, Rotavirus are maintain between 0°C to 8°C temperature for proper preservation and some of the vaccines such as MMRV, Vricella, Zoster etc require freezer temperature as low as -15°C. When the vaccines are preserved above and below the required temperature, the potency of vaccines is lost. So excess heat and cold can damage the potency of vaccines. The damaged vaccine is very harmful to the health of children and adults alike. The cost of single vaccine could go upto \$280 so economic consequences of vaccine damage are equally important. The main reason for damage of vaccines is improper storage. So the preservation of vaccines at required temperature (0°C to 8°C) is useful from two points of view (1) Economical Point Of View: - The cost of a single vaccine may go upto \$285, which is very expensive. In old vaccine system normally 2-3 vaccines will be damaged in one box during the whole day in summer season. (2) Health point of view: - The damaged vaccine is very harmful for patients. People can die on use of such damaged vaccines. Various researchers regarding the feasibility of a Vapor Compression Refrigerator powered by solar photovoltaic panels carry out a lot of work. Modi, A. et al. [2] fabricated a solar refrigeration system by using a 165 liter LG vapor compression refrigerator and then analyzed the performance of this refrigeration system. To operate this system following devices are used:

- Two 12V 150 Ah Exide battery
- A charge control unit to overcome the problem of overcharging and deep discharging
- A transformer
- Four 75W solar panels.

On the basis of the various experiment, they conclude that from morning to afternoon COP decreases and the COP is maximum at 7 AM, which is 2.012. Economic feasibility of this refrigeration system is determined by using RET screen test. They conclude that solar panel is one of the most costly devices in this refrigeration system. The cost of producing 1 W power is Rs 80/- and this refrigeration system uses four 35 W solar panel costing Rs 11200/- hence it is necessary to provide the government subsidy on the solar panel. This whole experiment is done on the environmental condition of Jaipur city (India).

Kattakayam, T. A. and Shrinivasan, K. [3] analyzed the performance of 100 W AC power operated domestic vapor compression refrigeration system. To drive this refrigerator such component like solar photovoltaic panel, a battery and an inverter are used. By using these components a non-sinusoidal AC signal is formed. They analyzed the performance of this refrigerator and conclude that there no effect on the thermal performance by using non-sinusoidal AC signal. They also found that the thermal performance of this refrigerator is improved with the help of proper insulation of refrigerator and a vacuum insulated solar panel because of arresting heat losses. Vaccines are always stored away from the wall and door of the refrigerator. They suggest that it is necessary to improve the design of compressor motor of a domestic refrigerator.

Sarbu, A. and Sebarchievici, C. [4] studied different types of solar refrigeration system such as photovoltaic solar refrigerator, thermo-electric solar refrigerator, thermo-mechanical solar refrigerator (steam jet refrigerator), solar absorption refrigerator, solar adsorption refrigerator and desiccant solar cooling system. After this study, they compared the performance of all refrigerators. First, they compare the COP of the liquid desiccant solar cooling system and solid desiccant solar cooling system and they found that COP of the liquid desiccant solar cooling system is higher than a desiccant solar cooling system. By comparing the COP of absorption and adsorption solar refrigerator they found that the COP of absorption system is higher than adsorption system but operating temperature of absorption system is higher than adsorption system. Among all solar refrigeration system, the COP and operating temperature of a thermo-mechanical solar refrigerator (steam jet refrigeration system) are higher than other systems.

Nawaz, I. et al. [5] fabricated a solar refrigerator and then performed cost and eco-friendly analysis of this solar refrigerator. On the basis of cost analysis, it is trying to show that a solar power-operated refrigeration system is more economical in comparison to that refrigeration system which is operated with conventional electricity. Initial cost of the solar power refrigeration system is very high but after some time this refrigeration system is cheaper than electricity operated the system. In this paper, it shows that after five year this solar power system is cheaper than electricity operated system.

Bilgili, M. [6] determined hourly simulation and performance of solar electric-vapor compression refrigeration system. This experiment was performed at different evaporator temperatures in different months at Adana city located in the southern region of Turkey. They found that at 0°C evaporator temperature, the maximum compressor power

consumption was obtained as 2.53 kW at 15:00 PM on August 23. The required photovoltaic panel surface area was to be around 31.26 m².

Figure 1: Solar Power Vapor Compression Refrigeration System for Hourly Simulation [6]

Cherif, A. and Dhouib, A. [7] performed the dynamic modeling and simulation of a photovoltaic refrigeration plant by using hydraulic storage (latent heat storage). By using hydraulic or latent heat storage, they remove the battery bank from photovoltaic solar refrigeration plant. They analyzed the performance of a battery-less refrigeration system in different environmental condition and then compare performance between hydraulic storage refrigeration plant and battery storage refrigeration plant.

Mba E. F. et al. [8] presented a photovoltaic mathematical model is presented by using Mat Lab. This refrigeration system consist of a DC power operated compressor, a 12V battery, a solar panel and a charge control unit to prevent overcharging and deep discharging. In this system electrical analogy was performed; the input of one component will become the output of other component. The mathematical simulation was performed by using Mat Lab. This simulation was performed for 12 hours period and found that with increasing voltage the size of battery will decrease. This whole analysis was done for the KC65T photovoltaic panel and from mathematical modeling, it found that SPV panel more behaves like a current source rather than a voltage source. On increasing the solar panel insulation the power output also increased because of increasing the current at constant voltage (14.2 V).

Figure 2: A DC Power Operated Refrigeration System [8]

Kim, D. and Ferreira, C. A. I [9] presented a different type of refrigeration system in which solar energy as an input power. They determined that Coefficient of performance of a single absorption system is higher than single effect adsorption system and double effect absorption system. Although thermo-mechanical and photovoltaic solar refrigeration system has good COP than absorption system but their initial installation cost is very high. Desiccant system is more costly than other refrigeration systems.

Kablanis, S. and papanastasiou, N. [10] modified a conventional refrigerator with the help of SPV panel and then analyzed the performance of this modified refrigerator. The main modification in this refrigerator is that instead of AC compressor DC compressor is used so there is no need of inverter to convert DC power into AC power. To operate this DC compressor a small power battery is required and to protect this from overcharging and deep discharging a charge control unit is used. The main advantage of this modification is that energy consumption per day is decreased up to 1.53 kwh when this system is operate 15 hours per day. To reduce the cable loss maintained the distance between SPV panel and charge control unit is 1.5 m, battery and charge control unit is 1.5 m and charge control unit and refrigerator is 6 m.

The above studies have helped us to develop and design a portable photovoltaic solar refrigeration system and evaluating its performance for the sole purpose of its suitability for vaccine preservation. The block diagram of our system is simple and self-understandable as given below:

Figure 3: Photovoltaic Solar Refrigeration System

FABRICATION METHODS

A PV- refrigerator system is presented in figure-3 is the combination of five components (1) Refrigeration unit (2) Battery Bank (3) inverter (4) solar Panel (5) moving Frame.

Figure 4: A Portable PV Solar Refrigeration System for Vaccine Preservation

Refrigeration Unit

A simple vapor compression refrigeration cycle is used as a refrigeration unit, which are having following parts: -

Steel Tank

There are two tanks

Outer Tank

A thick 14.47"×21.25"×14" outer steel tank with base in which 15kg mild steel sheet is used to make this tank.

Inner Tank

A thin 8"×14"×10" inner steel tank in which 15kg mild steel sheet is used to make this tank. This is actually that space in which vaccine will be kept. The capacity of this inner tank is approximately 25-30 liters.

Figure 5: Inner Tank of Refrigeration Unit

Accessory Box

An accessory box is also attached with this refrigeration unit on the backside to keep extra items other than vaccines.

Figure 6: An Accessory Box on Backside of Refrigeration Unit

Design of Evaporator

A 100 feet long 5-16 no. (the diameter of the cooling coil is 5/16 inch) copper tube is used to make evaporator. This 100 feet long pipe is wrapped around inner steel tank. The low temperature low-pressure liquid R134a refrigerant is

passed through this copper coil. By taking the heat it converts to vapor refrigerant and this vapor refrigerant goes to a compressor.

Figure 7: Evaporator

Design of Compressor

The low pressure and temperature vapor R 134a refrigerant comes from the evaporator is compressed to a high pressure and temperature vapor refrigerant by compression. This high pressure and temperature vapor refrigerant goes to a condenser. A hermetically shelled THK compressor model no.1340 is used for compression purpose. Details of the compressor are given below:

Table 1: Specifications of Compressor

Manufactured by	Tecumseh
Model no.	THK 1340
Number of cylinder	1
Displacement per revolution	4 cc
Cooling capacity	350 btu
Rated condition current	0.67 amps
Power	90 watts
Weight	7.7 kg

Design of Condenser

When the high-temperature high-pressure vapor R 134a refrigerant comes from the compressor and passes through the condenser its convert into high temperature high pressure liquid refrigerant by condensation process. A 7"×8" two row 12 pipe condenser is used for condensation purpose.

Figure 8: A 7"×8" Two Row 12-Pipe Condenser

Design of Expansion Device

When the high-pressure high-temperature liquid refrigerant comes from the condenser and passes through the expansion device an isenthalpic expansion will take place. The high-pressure high-temperature liquid refrigerant converts

into low-pressure low-temperature liquid refrigerant. The capillary tube is 11 feet long, 036 no (diameter of this capillary tube is 0.0036 inch.).

Figure 9: An 11 Feet Long 036 No Capillary Tube

Design of Fan

In this project a 10-watt fan is used for enhancing condensation rate.

Figure 10: A 10 W Fan

Thermostat

A thermostat is used to monitor the temperature.

Figure 11: A Thermostat used to Monitor the Temperature

Charging of Refrigerant

In this project 250 ml R134a is the used as a refrigerant. R134a is latest refrigerant used nowadays, It is the eco-friendly refrigerant.

Figure 12: Charging Procedure of Refrigerant R134a

Design of Insulation

PUF (Poly Urethane Foam) is used as an isolating material. Filling the PUF is a difficult task. 5 kg PUF is filled between tanks. 2.5" thick layer is formed between tanks.

Figure 13: A 2.5" Layer of PUF is Formed as an Insulating Material

Battery Bank

A 75 Ah 12 V Exide battery is used in this project. DC power delivered by the solar panel is stored in this battery. This battery is used to stabilize current and voltage during fluctuations of solar power.

Photovoltaic Arrays

A 125W model No-HB125 is used on the upper side of frame. The PV arrays are at 45° angles in a south direction so maximum power is generated. A basic solar PV panel consists of connected PV cells, which contain a semiconductor material covered by protective glass connected to a load. When sunlight hits the semiconductor, electrons get excited. These excited electrons are separated by an internal field inherent in the semiconductor and collected into an external circuit generating electricity. Several connected PV cells form a PV module; connected modules form a PV array.

Inverter

A 650 VA Microtech Inverter Is Used In This Project: There are three major work of inverter:

AC compressor is used in this project. The power delivered by solar panel is DC. This inverter converted DC power of solar panel into AC.

- A charge control unit is also attached with this inverter to protect the battery from overcharging and deep discharging.
- 350 W powers are required for starting the compressor. The power delivered by the 650 VA inverter is approximately 550 W so this inverter is sufficient to start the compressor.

Frame

The size of the solar panel is 26"×52" and the size of the refrigeration unit is 24.5"×21.25"×14". So we have selected the base of the frame is 28"×52". To maintain the angle at 45° one edge is raised up to height 24" and other height is 14"

Figure 14: Frame

RESULTS AND ANALYSIS

LOAD ANALYSIS

Compressor

A 90Watts modal No-THK 1340 is used as the compressor of company Tecumseh Refrigeration Equipment.

- Input power= 90Watts

Fan

A fan is used for cooling purpose of the compressor.

- Power of fan=10Watts
- Total power required (compressor +fan) =30+10
- =100Watts

Battery Bank

To overcome the inertia of compressor & fan and considering wire losses power delivered by the battery must be higher than 80W. So we selected a 12V 80Ah rechargeable Exide battery model No-DB-12-80.

- Power delivered by battery= $V \times I$
- =12×80

- = 960Watt-h
- Efficiency of battery=90%
- Net power output=960×0.9
- =864Watt

Photovoltaic PV Array

We selected a 125-Watt solar panel on the topside of frame. The PV arrays are at 40° angles in a south direction so maximum power is generated.

Power deliver by solar panel model No. HB12125= 125Watts

Inverter

Input power of compressor is 350 Watts. So we must select an inverter, which has output power higher than 350 Watts. In this project, we selected a 650 VA micro tech inverter and power delivered by this inverter is approximately 550 Watts which is higher than 350 Watts.

CONCLUSIONS

From experimentation in our system, it has been observed that the developed system is able to maintain the required temperature range(0°C to 8°C) up to 10 hours without any power supply. System developed is eco-friendly because R134a is used as a refrigerant. We conclude that it is possible to use vapor compression cycle based refrigeration powered solely by solar panels for effectively preserving vaccines at remote areas. We propose using a DC compressor in place of AC compressor, which might reduce the power requirement allowing for small capacity battery and in the place of inverter, a cheaper charge control unit.

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