*Available online www.jsaer.com*

***Journal of Scientific and Engineering Research*, 2020, 7(2):44-52**

**Research Article**

**ISSN: 2394-2630**
**CODEN(USA): JSERBR**

# The Design and Development of a Solar-powered Picnic Refrigerator

**Adedeji, Kasali A, Olaleye, Joshua O, Babs-Fashola, Lukmon, Salami, Fatai Opeyemi**

Department of Mechanical Engineering, Lagos State University, Epe, Lagos State, Nigeria

**Abstract** Due to the high demand for environmentally friendly energy resources due to the rapid depletion of non-renewable energy sources, which have been the main source of energy for many applications, a refrigeration system using solar energy as a source of energy has been developed. While the solar-powered refrigerator built in this project serves as cooling storage for food items during outdoor activities, particularly for families who would love to go out for a picnic and need a cooling system for their perishables, the system is quite compact and inexpensive.

The system was developed by integrating solar and cooling components such as a solar panel, a hybrid inverter and charge controller, a compressor battery, an evaporator, a condenser and a wire link. The system was tested during the day for 180 minutes at a time interval of 15 minutes and at night for 150 minutes at a time interval of 15 minutes to determine its cooling capacity, and it was discovered that it took more time to cool the cooling chamber during the day than at night. The 100MAH battery used in the experiment lasted two and a half hours, which was enough to cool the refrigerator. The Coefficient of performance for this project was estimated to be 0.75 which is quite promising.

**Keywords** Solar-powered, Picnic Refrigerator, hybrid power charge

## 1. Introduction

In contrast to other non-renewable energy sources, the scarcity of fossil fuels has contributed to the need for more reliable energy sources with an exponential depletion speed. Renewable energy options that use natural sources such as solar energy, oceans, rain, wind and steam from the Earth's crust among other natural energy sources are legitimate alternatives to non-renewable energy sources that are likely to cause harmful effects for humans and plants on the planet [1]. Solar power is the most valuable resource that can be used to generate energy among these different energies. Throughout developed countries, photovoltaic refrigerators are most widely used to further reduce carbon emissions. These refrigerators are capable of storing perishable items such as medications and vegetables in hot weather by using energy from the sun and are used to maintain much-needed vaccines and other perishable goods at their proper temperature to avoid spoilage. The proposed compact refrigerator can be made with basic components and is suitable for places where energy is poor or non-existent in developing countries. The solar cooling system is operated using electricity generated directly from the sun by photovoltaic cells or solar heat collected from the sun by various kinds of solar collectors.

Mahendru on Steady-State Analysis of Vapour Absorption Refrigeration System used lithium and bromide water solution as a Refrigerant. It was obtained that the Minimum generation temperature for the proposed system is typically set to 10 to 15°c which is lower than the minimum heat source temperature [2]. Mohmedtausif designed and fabricated a refrigeration system with a high coefficient of performance (COP), increased efficiency of operation and reduced overall power consumption by changing the shape of the condenser as well as the cooling medium [3]. Chandrashekhar Khadia reviewed a simple vapour compression refrigeration system and in their research, It was established that the vapour compression cooling device used in different devices, such as domestic refrigerators, water coolers, milk chillers, ice plants, etc., is an advanced form of air cooling system in which an acceptable operating material, known as refrigerant, is used to create a cooling effect. [4]. In the place of the conventional cooling methods used in cooling the temperature of a workpiece during machining operations, Darshan in their research proposed a thermoelectric refrigeration system to constantly cool the coolant before applying it on the workpiece [5]. As a result of the country growth and demand for energy, Rahul Yadav used the theory of the coefficient of performance (COP) to evaluate an ammonia-water vapour absorption cooling system dependent on solar energy [6].

## 2. Materials and Methods

### 2.1. Experimental Setup

The experimental set-up comprises of two components, a cooling system and a power supply unit. The cooling unit consists of a household cooler used as a container, an AC-operated compressor, an evaporator, a condenser and an expansion valve. The total size of the cooler is 50 litres. The maximum compressor power consumption is 138W, whereas the ozone-friendly R134a is used as a coolant.

The Power Unit consists of a solar panel connected to a charging controller with an integrated inverter that ensures that the battery is properly charged while converting the DC source of the battery to an AC that is useful to the compressor. While the charge regulator ensures that the battery is not drained, it also means that the cooling unit only retains the voltage and current accepted. In the absence of daylight, a 100AH powered lead-acid battery is used to power the unit for more than 16 hours.

In the design, the solar-based cooling system consists of a solar power supply unit and a cooling unit to provide cooling effects. The processes are addressed in this session:

### 2.2. Solar Power Unit

In this photovoltaic powered device, using semiconducting materials, solar radiation is converted directly into direct current electricity [7]. The mechanism that makes it possible to refrigerate is to convert sunlight into DC electrical power, done through the PV board. The unit is fitted with a charge controller and an inverter. A charging controller is used to regulate the amount of electricity stored by the battery so that it is not charged beyond the threshold level, resulting in battery damage.

Therefore, the battery stores DC, which requires an inverter to convert its DC output to AC which can be used by the cooling unit. Under sunny conditions, the cooling unit can be powered directly from the output of the solar cells, and when the intensity of the sun is reduced, the battery will become the cooling unit's main source of power. DC electrical power pushes the compressor through a steam compression cooling loop to circulate refrigerant which removes heat from an isolated enclosure. This enclosure features a thermal reservoir and a phase change component.

The components that make up the solar unit are given below:

**Solar panel**: Solar cells convert sunlight to DC power, which is stored by a charging regulator in batteries. The amount of energy generated by the solar panel is directly proportionate to the sunlight intensity it receives. Such batteries can be powered directly from DC loads. The cables from the batteries are attached to the inverter to convert the DC produced from the solar system to AC so that the refrigerator can work.

**Specifications**:

- Rated voltage: 17.5V DC 2A
- Rated power : 15W × 2 = 30W
- Positioned at $190^0$facing south/west at an angle of $215^0$

*Figure 1: Solar Panel*

**Battery**: It is vital for later use in the storage of electrical energy. The size of the battery bank shall be calculated on the basis of the average watt-hour and the required days of storage capacity. The current is transferred to the rechargeable battery from the panel. The battery function stores energy from the solar cell that is subsequently supplied to the load when the solar cells do not have direct power. This project uses a 100AH battery running at 12V DC.


*Figure 2: Battery*

**Inverter with an inbuilt Charge controller**: This project uses an inverter with an integrated charge regulator. A solar inverter is a type of electrical converter which transforms a photovoltaic (PV) solar panel's variable direct current (DC) output into a utilities alternating current (AC) [8].

A charge controller adapts to the amperage of the solar array's incoming power. This avoids overcharging of the battery A system that incorporates a single unit with an inverter and a charge controller.

**Specifications:**

- 2000W PWN and Charger
- Input voltage 12V DC
- Output voltage 230V AC


*Figure 3: Inverter and charger*

The flowchart details how the refrigerator gets electricity from the solar panel.

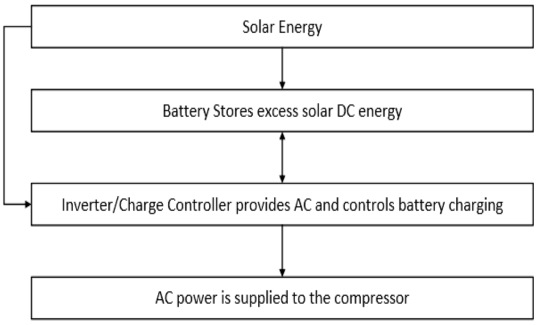


*Figure 4: Solar system*

From figure 3 above, it is seen that the solar system is the main source of power for the refrigeration system.

### 2.3. Vapour Compression Refrigeration Process

Given the figure below, the following depicts the processes involved in the vapour compression refrigeration system.

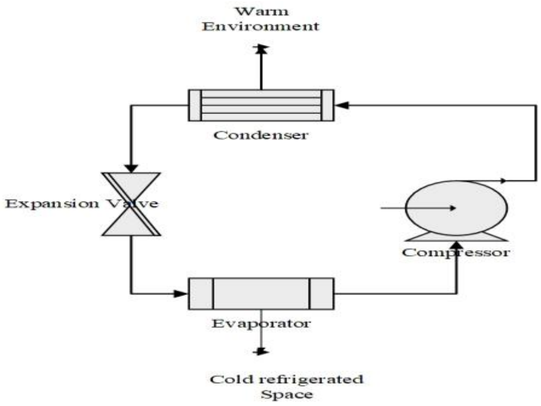


*Figure 5: Block diagram of the refrigeration system*

**a. Compression:**

The refrigerant exits the compressor at a low temperature at this phase as a low-pressure gas. The coolant is then adiabatically squeezed, taking the system to high pressure and high temperature.

Compressor specifications:

- Rating: 80Watts, 230V
- Starting current: 4.5A (AC)
- Running current: 0.6 A

*Figure 6: Compressor*

**b. Condensation:**

Heat energy and condensation are released by high pressure, high-temperature gas. The condenser is in contact with the cooling system's hot storage tank. (Due to the external work applied to the gas, the gas discharges heat to the hot reservoir.) The coolant escapes as an elevated-pressure liquid.

*Figure 7: Condenser*

**c. Throttling:**

A throttling mechanism moves the fluid refrigerant which allows it to extend. As a consequence, while still in the liquid state, the coolant has low pressure and low temperature. (The throttling valve can either be a small gap or a solid tube. If the coolant is pushed through the pipe, the stress is lowered and the water expands.)

*Figure 8: Expansion valve*

**d. Evaporation:**

The low temperature and low-pressure refrigerant, which is in touch with the cool reservoir reach the evaporator. The refrigerant will steam at a low temperature because constant pressure is retained. Thus, the liquid absorbs and evaporates heat from the cold reservoir. The refrigerant exits the evaporator as low temperature, low-pressure gas and is delivered to the compressor at the start of the process.

*Figure 9: Evaporator*

The figure below is a flow chart of the vapour compression refrigeration cycle.

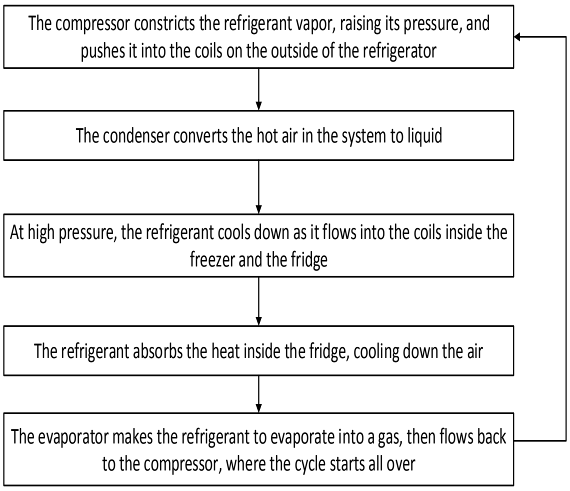


*Figure 10: Working principle of the refrigeration system*

The main energy source in a vapour compression cooling system is the electricity needed to run the compressor and the solar system supplies it. [10].

Basically, the components used in the refrigeration unit are:

- Compressor
- Condenser
- Expansion Valve
- Evaporator
- Picnic cooler as a cooling chamber
- Fan for cooling the compressor

## 2.4. Design Calculations

### 2.4.1. Energy Analysis

The energy analysis for the compressor, condenser, expansion valve and evaporator are given:

For an adiabatic compressor, the energy balance is given as:

$$\left(\dot{E}x_{in} - \dot{E}x_{out}\right)_{comp} - \dot{W}_{comp} - \sum \dot{\Gamma}_{comp} = 0, \qquad (1)$$

Where $\dot{W}_{comp}$ is the exact power which is supplied to the compressor.

The energy balance for a condenser is given as:

$$\left(\dot{E}x_{in} - \dot{E}x_{out}\right)_{cond} - \dot{Q}_{cond}\left(1 - \frac{T_o}{T_{cond}}\right) - \sum \dot{\Gamma}_{cond} = 0. \qquad (2)$$

For the expansion valve, the energy balance is given as:

$$\left(\dot{E}x_{in} - \dot{E}x_{out}\right)_{\exp} - \sum \dot{\Gamma}_{\exp} = 0. \qquad (3)$$

The expression for the energy balance of an evaporator is given as:

$$\left(\dot{E}x_{in} - \dot{E}x_{out}\right)_{evap} + \dot{Q}_{evap}\left(1 - \frac{T_o}{T_{evap}}\right) - \sum \dot{\Gamma}_{evap} = 0. \qquad (4)$$

### 2.4.2. PV Energy

The total energy generated by the PV panel can be calculated by Eq. (5). Energy output by PV system EPV (Wh)

$$E_{pv} = \frac{\int_{t=0}^{T} VIdt}{3600} \quad (5)$$

where, dt (s) is the time period, over which the performance can be averaged. V (V) is the instantaneous voltage at time t, I (A) is the instantaneous current at time t. The experiment started at t=0 and ended at t=T (s).

The power input to the compressor, Wnet, in (W) can be determined by Eq. (6) as below.

$$W_{net,in} = \frac{E_{pv}}{\Delta t} \quad (6)$$

where Δt (h) is the total time period over which the experiment is done and EPV (Wh) is the total energy generated by the PV panel.

The PV electricity can also be determined by Eq. (7)

$$E = A.r.H.PR \quad (7)$$

where E (Wh) is the energy generated by the PV panel, A is the effective solar panel area ($m^2$), r (%) is the solar panel efficiency, H ($Wh/m^2/day$) is the annual average daily solar irradiation on tilted panels (shadings not included), PR is the performance ratio, coefficient for losses (range between 0.5 and 0.9, default value = 0.75).

**Cooling load**

Cooling load is an amount of heat energy that would need to be removed from water (cooling substance) to cool water to the desired temperature. The cooling load delivered to water Qw (Wh) can be determined by the Eq. (8) below.

$$Q_w = \frac{m_c c_p \left(T_{initial} - T_{final}\right)}{3600} \quad (8)$$

where $Q_w$ (Wh) is the cooling load delivered to water, mw (kg) is the mass of water in the container, $C_p$ (J/kg.K) is the specific heat of water, ($T_{initial}$ -$T_{final}$) is the initial and final temperature difference of water.

The cooling effect created by the refrigerant can also be determined by the equation below.

$$\dot{Q}_L = \dot{m}_L \left(h_1 - h_2\right) \times 1000 \quad (9)$$

where $Q_L$ (W) is the cooling load of refrigerant, $\dot{m}_L$(kg/s) is the mass flow rate of refrigerant, and ($h_1$-$h_2$) is the enthalpy difference in the evaporator (kJ/kg).

The compressor work is given as:

$$\dot{Q}_L = \dot{m}_L \left(h_2 - h_1\right) \quad (10)$$

**Coefficient of performance (COP)**

COP is defined as the ratio of the desired output to the required input. There are equations below that can be used to calculate the COP.

$$COP = \frac{\dot{Q}_w}{W_{net,in}} \quad (11)$$

$$COP = \frac{\dot{Q}_L}{W_{net,in}} \quad (12)$$

The coefficient of performance for an air conditioner can also be obtained using the formula below:

$$COP_{cooling} = \frac{T_H}{T_H - T_C} \quad (13)$$

Where $T_H$= Temperature of the hot reservoir of the system

$T_C$= Temperature of the cold reservoir of the system

## 3. Results and Discussion

This section presents the results of the technical performance of the solar-powered refrigeration system. The coefficient of performance for the refrigeration unit was determined in relation to the cooling effect of the refrigerant. The experiment was conducted day and night for a duration of 180 minutes. The temperature of the inner chamber was measured every 15 minutes.

During the day, electrical energy from the solar panel was used to deliver power to the compressor, while at night, the battery was made active.

### 3.1. The energy delivered by the PV panel

In view of the following parameters, the total energy supplied by the PV panel for 180mins for which the system was operated using solar energy was obtained.

- Instantaneous voltage (AC) = 230V
- Instantaneous current (AC) = 0.6A
- Starting experiment time = 0 min = 0sec
- Final experiment time = 150 min = 9000secs

The total energy was calculated using equation 5.

$E_{PV}$= 345W

### 3.2. Power input to the compressor

Using equation 6, the power supplied to the compressor from the PV panel was obtained. The following parameters were used:

- $E_{PV}$ = 345W
- $\Delta t$ = 2.5 hrs

Equation 6 was used to compute the average power supplied to the compressor and was thus obtained to be:

$W_{net,in}$= 138W

### 3.3. Cooling Effect Created by the Refrigerant

Refrigerant 134a is a working fluid in an ideal steam-compression refrigeration process that interacts thermally with a cold region of-8.1 °C and a warm region of 34.7 °C. The saturated vapour enters the compressor at -8.1 °C and the saturated liquid leaves the condenser at 34.7 °C. The refrigerant mass flow rate is 0.08 kg.

#### 3.3.1. Operational Refrigerator Temperatures

The table below shows the temperature of the inside of the cooler during the experiment.

All measurements were taken for daytime temperatures and night temperatures. It has been found that the temperature of the atmosphere has had an influence on the temperature of the cooler as, during the day, the sun's effect has raised the temperature of the cooler while a lower temperature has been observed at night.

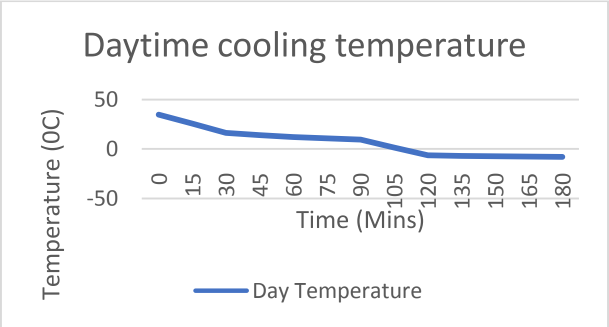


*Figure 11: Water temperature during 180mins of the daytime experiment*

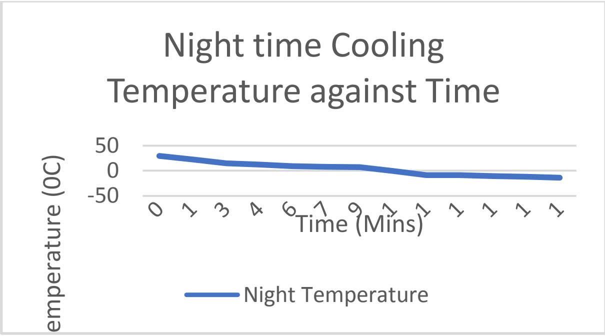


*Figure 12: Refrigerator Temperature during 180mins of the night experiment*

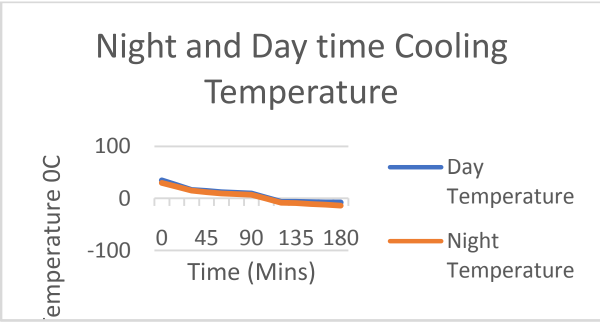


*Figure 13: Comparison of daytime and a nighttime temperature of the refrigerator*

**3.3.2. Battery discharge rate during night experiment**

The 100AH, 12V rated battery used for this experiment lasted 2 hours, 30 minutes. When the system was put into operation, the voltage delivered was recorded to be 12.3V, which decreased to 10.73V when the refrigerator could no longer be powered.

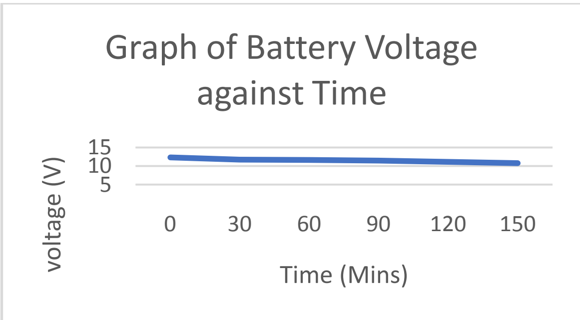


*Figure 14: Battery discharge rate*

**3.4. Coefficient of performance**

The coefficient of performance for the refrigeration system is calculated using equation 12. The COP during the daytime experiment when the system was powered using the solar panel while the battery is charged simultaneously and the COP during the night experiment when the system was powered using the 100MAH battery. The average of both COPs is taken as the overall COP of the system.

**3.4.1. COP during the day time experiment**

Given the following data:
The temperature of the hot reservoir (TH) = 34.7
The temperature of the cold reservoir (TC) = -8.1
Using the equation of 12, the COP was computed to be:
COP = 0.81

**3.4.2. COP during the day time experiment**

Given the following data:

The temperature of the hot reservoir (TH) = 29.5
The temperature of the cold reservoir (TC) = -14.14
Using the equation of 12, the COP was computed to be:
COP = 0.68
Overall coefficient performance of the system is given as:
(0.81+0.68)/2=0.75

## 4. Conclusion

A solar-powered vapour compression refrigeration system, which finds application in outdoor activities, has been developed in this work. The refrigerator can be used to keep materials cold as long as solar energy is available to power the system as well as the battery that is charged when solar energy is available. Performance analysis was carried out both in the presence of solar energy during the day and at night when the battery was charged to power the system. At a time interval of 15 minutes during which the experiment was conducted for three hours, it was observed that the temperature of the sunny environment had a slight effect on the cooling process of the refrigeration unit. The 100AH battery was effective for two and a half hours which is quite commendable.

The COPs for both experiments were determined to yield a COP of 0.81 during the daytime experiment and a COP of 0.78 for the nighttime experiment. The average was obtained and it was concluded that the overall performance coefficient for the experiment was 0.75.

## References

[1]. Essays, UK, "Alternate Energy Sources," [Online]. Available: https://www.ukessays.com/essays/environmental-sciences/the-renewable-energy-future-of-solar-power-environmental-sciences-essay.php?vref=1. [Accessed 26 November 2019].
[2]. P. Mahendru, S. K. Agrawal and P. Pachorkar, "Steady-State Analysis of Vapour Absorption Refrigeration System using li-br-h2o as a Refrigerant," International Journal of Emerging Technology and Advanced Engineering, vol. 2, no. 9, pp. 328-332, 2012.
[3]. B. P. Mohmedtausif, C. P, M. Parthiv, P. R. Kumar and P. Janish, "Development And Modification Of Refrigeration System," International Journal of Advance Engineering and Research Development, vol. II, no. 6, pp. 369 - 374, 2015.
[4]. Chandrashekhar Khadia, S. Prakash Kumar and K. B. Shailendra, "Review on Simple Vapour Compression Refrigeration System," International Journal for Research in Applied Science & Engineering Technology (IJRASET), vol. 3, no. 4, pp. 1020-1023, April 2015.
[5]. D. Suryawansh, V. Pokale, N. Pokharkar, A. Walgude and P. Patunka, "A Review of Performance Analysis & Potential Applications of Thermoelectric Refrigeration System," International Journal of Research and Science Institute (IJRSI), vol. 3, no. 3, pp. 29-32, 2016.
[6]. R. Yadav and M. Sharma, "Analytical Study of Ammonia –Water ($NH_3$-$H_2O$) Vapor Absorption Refrigeration System Based On Solar Energy," Imperial Journal of Interdisciplinary Research (IJIR), vol. II, no. 11, pp. 1245 -1250, 2016.
[7]. B. K. Mandal and R. Roy, "Solar Refrigeration," 10 February 2017. [Online]. Available: https://www.linkedin.com/pulse/solar-refrigeration-cooling-india/. [Accessed 12 October 2019].
[8]. Wikipedia contributors, "Solar inverter," 26 September 2019. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Solar_inverter&oldid=917932310. [Accessed 2 December 2019].
[9]. Joshi A. S. Evaluation of Cloudiness/Haziness Factor and Its Application for Photovoltaic Thermal (PV/T) System for Indian Climatic Conditions, PhD thesis. – IIT Delhi, 2006
[10]. Würfel P. Physics of Solar Cells. – John Wiley & Sons, 2005. – 244 pp.