A Review of Solar Refrigeration for Cooling Applications

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Abstract The need for total energy is fast increasing as the standard of living and global population rise, and it is expected that existing fossil fuels will be depleted by the middle of this century. Energy consumption per capita per year is increasing every day around the world, and the pace of increase in sophisticated countries is even faster. Therefore, more attention has been focused on developing the potential methods to use solar energy, which is considered an unlimited source of energy. This study explores several solar refrigeration systems, with a particular focus on solar absorption refrigeration systems. The different parts of solar power refrigeration systems are illustrated by considering their basic working principles. Many review papers have been studied based on the investigation of performance, life cycle cost analysis, solar thermal cooling and refrigeration method, etc. This study shows the consumption of energy and fossil fuels can be minimized by increasing the coefficient of performance of solar power absorption system by using generator temperatures in the range of 60 °C to 80 °C, using lithium bromide as the absorbent and water as the refrigerant, as well as a higher evaporator and generator temperature, a lower condenser temperature, a double liner heat exchanger, a gravity heat pipe, and a single-effect vapor absorption refrigeration system.

Keywords Solar power refrigeration · Coefficient of performance · Solar thermal cooling

1 Introduction

The process of eliminating heat from a substance or a restricted or enclosed place is known as refrigeration. Thus, refrigeration means pumping of heat from lower to higher temperature. The refrigerant is pressed into the capillary tube and condenser for that reason increasing its pressure and temperature inside the cooled refrigerator

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depending on the present ambient temperature. Refrigeration is used in many places such as to avoid spoiling of food and to provide cooling, etc.

1.1 Solar Power Refrigerator

It is the refrigeration system that runs on the solar energy where the power is supplied not by the electrical supply system, but from the solar panel. In this process we produce refrigeration effect with the help of energy of sun and thermal energy or photovoltaic may be included in this. Solar power refrigerators are mostly used in rural locations where there is a lack of reliable grid access or unavailability of AC power.

1.2 Uses of Solar Power Refrigerator

Solar power refrigerators are used in the making of ice, freezer, cooling, for the preservation of food, to build an air conditioning system, etc. In this, direct current electricity using semiconducting materials is used directly by the conversion of solar radiation. Solar power refrigeration is used in off-grid rural areas for the preservation of food and vaccine. For transportation, solar power refrigeration is used in cars, buses, etc.

1.3 Working of Solar Power Refrigerator

Solar power refrigerator uses natural sunlight and converts it into energy which we finally use this energy to chill its storage compartment as shown in Fig. 1. There is no requirement for an electrical source, the only requirement is sunshine. The refrigerant solution is converted into the liquid through thermal energy.

Solar refrigerators uses several refrigerant solutions. Water and ammonia or water and lithium bromide remain the most common solution.

For the cooling of the storage compartment, the coolant converts into the liquid from vapor or vice-versa. In the solar refrigerator, the thermal energy gets created by the conversion process. This thermal energy can be used for supplying the power to the DC electrical systems. In the beginning, refrigerants in gaseous form are supplied to solar refrigerators. Due to heat produced by the sunlight, more pressure acts on the gases until they condense into a liquid.

Heavy insulation is applied to the solar-power refrigerator around the lining to maintain the cooling for hours. The items inside the fridge stay cool and is in good condition even when the device is left out in the sunlight.

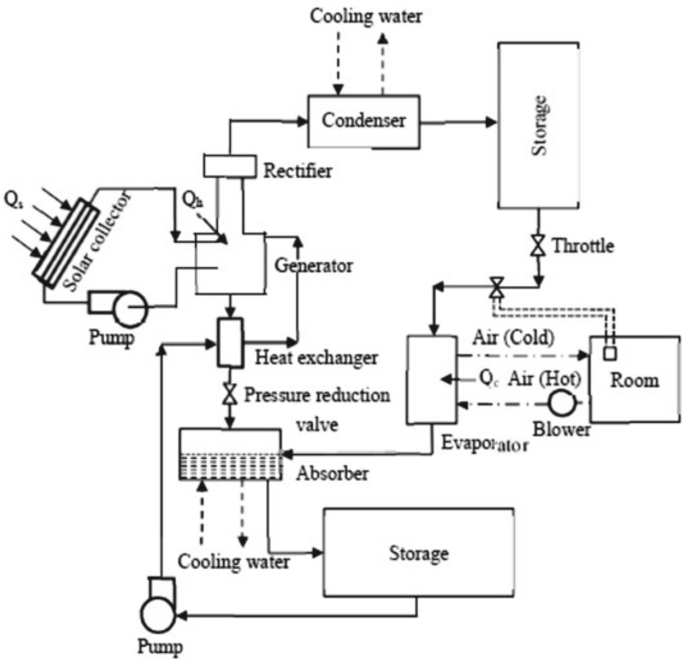

Fig. 1 Solar absorption refrigeration system schematic diagram

The change in refrigerant from gas phase to liquid phase produces enough thermal energy to give power to the fridge even if it is not in direct sunlight. In this way, no batteries are required to power solar refrigerators at night.

1.4 Types of Solar Power Refrigeration Systems

The three types of solar power refrigeration systems are:

- Photovoltaic operated refrigeration system
- Solar mechanical refrigeration system

Absorption refrigeration system.

1.5 COP of Solar Power Refrigeration System

$$\text{COP (refrigerator)} = \frac{Q_c}{W} = \frac{Q_s}{Q_r - Q_c} = \frac{T_c}{T_a - T_c}$$

where T_h, T_a and T_c are the temperatures of source, sink (atmosphere) and refrigeration respectively.

The overall COP of the system is given by.

$$\mathrm{COP} = \frac{Q_c}{Q_s} = W\left(\frac{T_c}{T_a - T_c}\right) \times \left(\frac{T_h - T_a}{W_{\mathrm{Th}}}\right)$$
$$= \left(\frac{T_c}{T_h}\right)\left(\frac{T_h - T_a}{T_a - T_c}\right) \quad (1)$$

where $T_c < T_a < T_h$.

The absorption system's COP is calculated as follows:

$$\mathrm{COP} = \frac{Q_e}{Q_s}$$

where Q_s is the heat withdrawn from the evaporator and Q_s is the incident energy on the collector. But the actual heat given in the generator is Q_h which is less than Q_s, (where Q_s is incident energy on collector therefore net COP will be reduced by the factor (Q_h/Q_s).

$$(\mathrm{COP}) = \frac{Q_c}{Q_s} \times \frac{Q_h}{Q_s} = \frac{Q_h}{Q_s}\left(\frac{Q_c}{Q_s}\right) \quad (2)$$

But the (Q_c/Q_s) is the COP of the system as shown. Substituting the value of (Q_c/Q_s) from Eq. (1) into Eq. (2).

$$\mathrm{COP} = \left(\frac{Q_h}{Q_s}\right)\left(\frac{T_c}{T_s}\right)\left(\frac{T_h - T_a}{T_a - T_c}\right) \quad (3)$$

$$Q_h = Q_s - \text{Loss in the collector} = Q_s - U(T_h - T_a) \quad (4)$$

where T_h is the collector temperature and T_a is atmosphere temperature.

Substituting the value of Q_h in Eq. (3)

$$\mathrm{COP} = \left[1 - \left(\frac{U}{Q_s}\right)(T_h - T_a)\right]\left(\frac{T_c}{T_h}\right)\left(\frac{T_h - T_a}{T_a - T_c}\right) \quad (5)$$

The equation shows that for the fixed atmospheric temperature T_a and required evaporator temperature T_c, the COP is dependent on T_h. Therefore, the COP will be maximum when

$$\left(\frac{d}{d_{\mathrm{Th}}}\right)(\mathrm{COP}) = 0$$

$$\left(\frac{d}{d_{\mathrm{Th}}}\right)\left\{\left[1-\left(\frac{U}{Q_s}\right)(T_h-T_a)\right]\left(\frac{T_c}{T_h}\right)\left(\frac{T_h-T_a}{T_a-T_c}\right)\right\}=0$$

$$\frac{T_h}{T_a}=\frac{1}{\frac{T_c(T_h-T_a)}{\frac{Q_S}{U}-(T_h-T_a)}-T_h} \tag{6}$$

The COP of the system increases with increasing T_h while the output of the collector falls as per the Eq. (4).

2 State of the Art Review

2.1 Performance Investigation

In 2021, the performance of a solar adsorption cooling system was investigated by adding a SAPO-34 zeolite and comparing the optimal performance of the silica gel system to the SAPO-34 zeolite system that was operated throughout the experiment [1]. The cooling capacity and performance coefficient of the silica gel system were found to be more substantially influenced by adsorption time than those of the SAPO-34 zeolite system. The Munters and Platen cycle was used to test a diffusion absorption refrigeration machine (DAR) [2]. The global heat transfer coefficient of the evaporator (UA) is calculated using static and dynamic state approaches. It was discovered that the global heat transfer coefficient is 0.3 W/°C. To ensure the desired condition of this device, the required heating power supply for the generator should be in the range of 35–45 W. In 2017, results on the performance of an ice-storage system in a solar absorption cooling system for workplace cooling were presented [3]. The outcome showed that chiller average COP is 0.43 during charging for the months of March and 0.47 for month of October. An electron diffusion model was used to determine the current voltage characteristics of the DSSC [4]. The optimum values of this film thickness, current density, and structure parameter were about 5.62 um, 11.7 Acm^{-2}, and 0.000465 cm^{-1}, respectively for parametric design. Performance investigation of a thermoelectric solar cell refrigerator was done in 2008 [5]. This was done by installing a conventional thermal cooler, which represents its own autonomous photovoltaic system for domestic use. The effect of opening the door on cooling, the temperature of which is produced by the sun element driving the thermoelectric refrigerator, was studied.

2.2 Cooling Capacity Increase

A dynamic model was created to predict the behavior of the variable speed photovoltaic direct-current refrigerator (VSPVDR) system [6]. The impact of the compressor speed control method, radiation intensity, and ambient temperature were examined using this model. A multi-stage traveling-wave thermo-acoustic refrigerator using SAGE software the working mechanism was studied numerically. The calculation results shows that in multi-stage traveling-wave thermos-acoustic refrigerator three to five stages is more appropriate by striking a balance inside the temperature range of cooling efficiency and cooling power [7]. As a zero energy cool chamber, a system with two cooling systems, a solar-driven adsorption refrigerator and evaporative cooling, were developed (ZECC). The outcome suggested that new ZECC which is proposed is more useful for storing vegetables and fruit [8].

2.3 Enhanced Economic Performance

The effect of nano-sized oil droplets was studied in order to determine the effectiveness of a diffusion absorption refrigerator (DAR) [9]. In the absorption refrigeration cycle, a solar double product system was proposed [10]. Through the proposed system with matched system output, the energy saving achieved was 25.64%. The proposed system had an external energy efficiency of 9.83%, which was 2.97% higher than the reference systems. An optimized roll channel evaporator/collector was used to develop, build, and test the Direct Expansion—Solar Assisted Heat Pump Water Heating System (DX-SAHP) [11, 12]. Solar Vapor Absorption C.O.P. Improvement, a study of the refrigeration system was conducted. The efficiency of a steam absorption system can be improved by utilizing a generator set between 65 and 80 °C, as well as using lithium bromide as an absorbent and water, as in a refrigerator. [13, 14].

2.4 Refrigerator Analysis

Theoretical and practical evaluation of a small-scale ammonia water absorption refrigerator powered by a solar condenser was done. The results demonstrated that a parabolic concentrator (P.C.) with an average power supply and an efficiency of 530 W and 26 percent, respectively, can give a temperature above roughly 200 °C for around 6 h [15]. Annual performance of Absorption-compression solar driven cascade refrigeration system is investigated [16]. Void tube analysis on solar energy absorption system for process optimization in hot regions was carried out [17]. Cooling the water temperature below 40 °C will considerably diminish the unit's performance, which is necessary when the outside temperature is excessively hot. The first and second laws of thermodynamics were used to analyze a single stage absorption refrigeration cycle [18]. Under the steady state condition, the proposed model (first and second law analysis) was tested. Circulation Ratio (CR), Coefficient of Performance (COP), and Carnot Coefficient of Performance are the parameters considered (COPc). A computational model was used to conduct a theoretical analysis of the Lithium Bromide/Water Absorption Refrigeration system [19]. The single-effect and series flow double-effect water lithium bromide absorption refrigeration systems were investigated using this model. With the help of three condensers, a thermodynamic analysis of the triple effect parallel flow water/lithium bromide chiller was performed [20]. The conservation equation that governs the cycle was stated like this, and the cycle was explored using the first and second laws.

2.5 Prototype Model

To create a cold storage refrigerator car model, SolidWorks was used, and analysis was performed to run simulations. The results reveal that as the temperature rises, the melting process of the storage plate accelerates and the time it takes for thermal energy to be discharged decreases [21]. Powered by an activated carbon/methanol pair, a multifunctional solar-powered kitchen appliance was constructed and tested [22]. Field experiments revealed that the prototype can produce 5 kg of ice with a COP of 0.08. TRANSYS was used to create a simulation model for the PV hybrid system, and the performance of the 1.44 kW PV hybrid system was assessed [23].

2.6 Effect on System Performance

An experimental refrigerator was constructed and tested of 1 kW cooling capacity [24]. The effect of a cylindrical adsorber on the operation of a solar adsorption refrigeration machine has been determined. The experimental results reveal that the primary nozzle geometry has a significant impact on the ejector performance and, as a result, on the system COP [25] outcome has shown that the adsorber with fins has optimal diameter larger than one without fins.

2.7 Engine Exhaust Gas as an Energy Source

An absorption refrigeration system that utilizations fumes gas by the motor and a LiBr water arrangement have been tried [26]. This test was carried out at various motor speeds of 1000, 1200, 1400, and 1600 rpm, with development valve opening levels of 54.5%, 72.7%, and 90.9% at the power source separator and 3.41%, 4.55%, and 5.68% at the power source condenser, respectively.

3 Conclusion

This review indicates the following research opportunities in the area of solar refrigeration.

3.1 Increase in COP

Methods of increasing COP.

- Using a roll-bond panel with an optimum channel layout can improve COP.
- When the refrigerator is operated at boiler temperature of 110 °C, evaporator temperature of 17 °C, and cooling capacity of 3000 W, the maximum COP of 0.45 is attained.
- To get the highest possible COP, the refrigeration system should be designed with current density, film thickness, and structure characteristics of 11.7 Acm^{-1}, 5.62 μm, and 0.000165 cm, respectively.
- The use of binary nanoemulsion fluid will improve the COP of the Diffusion Absorption Refrigerator (DAR). A binary nanoemulsion is defined as a nanoemulsion with a binary base liquid, such as an NH3/H2O solution.
- The C.O.P. of a Vapor Absorption system will be improved by using generator temperatures ranging from 65–80 °C, using Lithium Bromide as an absorbent and water as a refrigerant, using higher evaporator and generator temperatures, low condenser temperatures, double liner heat exchangers, gravity heat pipes, and a single effect vapor absorption refrigeration system.

3.2 Increase in Cooling Power

Methods of increasing cooling power.

- Using multi-stage traveling-wave cooling will boost cooling capacity (three to five stages may be most suitable) refrigerator with a thermos-acoustic system.
- When photovoltaic (PV) cells are directly connected to the compressor without batteries or inverters, cooling power increases, and the DC compressor speed changes with radiation intensity in the VSPVDR system.

3.3 Enhance Performance

Methods of enhancing performance.

- When the evaporator temperature is set to 7.5 °C and eight primary nozzles with different shapes are employed, performance improves.

- Using a cylindrical adsorber will improve the performance of a solar adsorption refrigeration machine.
- To improve the multi-generation system's economic performance, the absorption chiller is increased, along with liquid desiccant dehumidification, which can result in cooling and water without the use of a desalination unit.
- The use of phase transition materials that increase the latent heat of fluid will improve performance.
- When SAPO-34 zeolite system is employed as a working pair, the performance of solar adsorption cooling system will improve.
- Using nanoparticles will considerably improve the performance of a vapor absorption refrigeration system.

3.4 Decrease in Cost and Energy Saving

Method of decrease in cost.

- The cost of a refrigerator with two cooling systems, a solar-driven adsorption refrigerator and an evaporative cooling system, will be lower.

  Method of saving energy.

- LiBr-H2O and R134a are used as working pairs in the absorption cycle and refrigerant in the compression cycle, respectively, and evacuated tube collectors are used to feed the refrigeration system.

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