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CURRENT APPROACHES IN SOLAR PV REFRIGERATION SYSTEM

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Abstract: *In this paper, a review has been conducted on different type's solar powered refrigeration systems and also presents the available technologies to provide cooling from solar energy. Solar refrigeration methods such as solar electric method, solar mechanical method, and solar thermal methods have been discussed.*

Keywords: *Solar System, Electric Method*

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INTRODUCTION

In the present context the energy demand is increasing with increasing the population and improvement in the living standard. Solar-powered refrigerator is a refrigerator which runs on electricity provided by solar energy. Solar-powered refrigerator are able to keep perishable goods such as meat and dairy cool in hot climates, and are used to keep much needed vaccines at their appropriate temperature to avoid spoilage. Solar-powered refrigerators may be most commonly used in the developing world to help mitigate poverty and climate change. In developed countries, plug-in refrigerators with backup generators store vaccines safely, but in developing countries, where electricity supplies can be unreliable, alternative refrigeration technologies are required. Therefore, in rural areas where electricity is not available or shortage with abundant availability of solar radiation the solar energy is the alternative option to run the refrigeration systems for preserving the life saving drugs and also household purpose.

There are three methods by which solar energy can be utilized for refrigeration purposes. They are as follows- Solar Electric Method, Solar thermal Method and Solar Mechanical Method.

Solar Electric Method

In Solar Electric Method, the solar energy is directly converted to DC current by an array of solar cells known as Photovoltaic (PV) panel. Photovoltaic Cells are nothing but semiconductors which allow direct conversion of solar energy to direct current. This DC power can be stored in batteries and can be used to run the DC compressor or by using inverter this DC power can be converted to AC and be used as ordinary source of power.

Solar Thermal Method

In this system the more incoming solar radiation is used than the photovoltaic system. In a conventional PV collector, 65% of the incident solar radiation is lost as heat whereas in solar collectors over 95% of the incoming solar radiation is absorbed. But all of this is absorbed energy is not converted to useful energy due to inefficiencies and losses.

A typical solar thermal refrigeration system consists of four basic components - a solar collector array, a thermal storage tank, a thermal refrigeration unit and a heat exchange system to transfer energy between components and the refrigerated space. Selection of the solar array depends upon the temperature needed for refrigeration system. Generally for temperature range 60-100^{o}C, flat plate collectors, evacuated tube collectors and concentrating collectors of low concentration can be used. Concentrating collectors are avoided for residential purposes due to high cost of solar trackers. Selection of the thermal storage tank depends upon the type of storage medium and the temperatures desired. Water is mainly selected for its low environmental impact and high specific heat.

Solar Mechanical Method

In this system mechanical power is required to drive the compressor is generated by solar driven heat power cycle. This cycle is based upon Rankine cycle. In this cycle, fluid is vaporized at an elevated pressure by heat exchange with a fluid heated by solar collectors. A storage tank can be included in this process to provide some high temperature thermal storage. The vapour flows through a turbine or piston expander to produce mechanical power. The fluid exiting the expander is condensed and pumped back to the boiler pressure where it is again vaporized. The efficiency of the Rankine cycle increases with increasing temperature of the vaporized fluid entering the expander. Whereas, the efficiency of a solar collector decreases with increasing temperature of the delivered energy. The disadvantages of using solar trackers are cost, weight and complexity of the system. The efficiency of such a system is lower than solar electric method using non-concentrating PV modules. Solar Mechanical is advantageous only when solar trackers are used but, the use of such systems is limited to large refrigeration systems only i.e. atleast 1000 tons.

Literature survey of work carried out by various authors

Solar Electric Refrigeration

[1] Kattakayam et al. (1996) investigated the electrical characteristics of a 100W AC operated domestic refrigerator using R-12 powered by a field of SPV panels, a battery bank and an inverter. A minimum current region was observed in the mains voltage range of 180-190 V and at the inverter voltage range of 210-230 V. The refrigerator was then started on a high voltage (about 230-250 V) with the inverter mode to complete the transient quickly so that the thermal overload relay of the compressor does not trip. A 25-30% saving in energy consumption without sacrificing the temperature profiles inside the refrigerator was made possible with this scheme. With an uninterrupted supply refrigeration unit powered by a field of SPV panels backed up by a petrol run generator, they observed no difference in the cool-down and warm-up of the cabinet, whether operated with mains or the inverter, and at the same time, the increase in the cycle time in the inverter operation resulted in considerable energy saving making a back up of 3.7 days possible with the battery ban. Tests were performed by Kattakayam et al. to develop the cool down, warm up, steady state and ice making characteristics of the fridge and to calculate the COP, and the influence of opening the door of the refrigerator on its thermal performance when powered by an inverter. They also presented the characterization of a lead acid battery system as a component of the above system, and the calculation method for the battery bank capacity

[2] Sukamongkol et al. (2002) developed similar simulation model to predict the performance of a PV system with refrigerator and alternating current (AC) loads respectively. A thermodynamic analytical model based on the PV panel is employed to solve for the array temperature. In their

studies, performance coefficients are used to mathematically model the PV components performance. The values are obtained empirically.

[3] Enibe (1997) has discussed the possibility of using photovoltaic powered vapour compression systems; continuous and intermittent liquid or solid absorption system and adsorption systems for refrigeration purpose in rural or remote locations of developing countries, and concluded that with probable increase in the costs of conventional energy sources, solar cooling technologies are expected to become competitive with the conventional systems in future.

[4] Sumathy K. et al. (2008) presented the discription and operations of solar powered ice maker with solid adsorption pair of activated carbon and methanol. A domestic type charcoal is chosen as the adsorbent, and a simple flat plate collector with an exposed area of 0.92 m2 is employed to produced ice of about 4-5 kg/day. Also, it is intended to introduce a hybrid system consisting of solar water heater and ice-maker, which can satysfy the requirement of both the solar ice-making needs as well as good heat collection and heat release in the adsorber.

[5] Sabah et al. (2009) build an affordable solar thermoelectric refrigerator for the desert people living in remote parts of Oman. It was designed to store and transport the medications and biological material. The major component such as thermoelectric module, solar cells, aluminum box, plastic plates, finned surface (or heat sink), and the cooling fan were used in this study. The dimension of the prototype refrigeration system was 180×230×320 mm. the temperature difference was obtained up to 26.6 °C when the current was 2.5 A, and the voltage was 3.7 V. The results indicated that the temperature of the refrigeration was reduced from 27 °C to 5 °C in approximately 44 min. The coefficient of performance of the refrigerator (COP) was calculated and found to be about 0.16.

[6] Mehmet Bilgili (2011). A solar electric-vapor compression refrigeration (SE-VCR) system has been proposed in this study. The SE-VCR system was investigated for different evaporating temperatures and months in Adana city located in the southern region of Turkey. First, the hourly cooling load capacities (heat gain) of a sample building during the 23rd days of May, June, July, August and September months were determined by using meteorological data such as hourly average solar radiations and atmospheric temperatures. The hourly total heat gain of the sample building comprised of wall, window, humans, illumination and devices were determined by using the Cooling Load Hourly Analysis Program (HAP) 4.4. Then, the hourly variations of various parameters such as coefficient of the performance, condenser capacity and compressor power consumption were calculated. In addition, the minimum photovoltaic panel surface area was determined to meet the compressor power demand according to the hourly average solar radiation data. For evaporating temperature $T_e = 0^oC$, 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 found to be around 31.26 m^2. It was determined that the SE-VCR system could be used for home/office-cooling purposes during the day in the southern region of Turkey.

[7] Rui Long et al (2016). An analysis of a solar-powered electrochemical refrigeration system consisting of a photovoltaic (PV) system and a thermally regenerative electrochemical refrigerator (TRER) was conducted. To evaluate the system performance, the impacts of operating temperatures of the PV module, hot/cold reservoir temperatures, and direct irradiation of the sun on the power consumed, refrigerating capacity, and coefficient of performance (COP) were systematically analyzed. For each calculation, the voltage and current of the TRER system are iterated to make them equal to those of the PV modules based on the fact that the power consumed by the TRER is supplied by the PV modules. Results revealed that the refrigerating capacity and COP decrease with increasing temperature of the hot reservoir and increase with increasing temperature of the cold reservoir. There existed an optimal PV operating temperature leading to the maximum refrigerating capacity. Meanwhile the COP of the TRER achieved its minimum value. Larger surface irradiance resulted in larger refrigerating capacity, however lower COP. Furthermore, the performance of the proposed solar-powered electrochemical refrigeration system for practical use in real life applications was also simulated.

[8] A. Allouhi et al (2015). An intermittent solar adsorption refrigerator can supply cold needed in third world countries, especially for vaccine and medicine preservation. This paper investigated theoretically the potential of solar adsorption refrigerators in Sub-Saharan Africa. The dynamic behaviour of the system and its performance were assessed using real climatic conditions of four Sub-Saharan African sites. A refrigerator operating with activated carbon/methanol as a working pair was simulated using a 1-D mathematical model to investigate its dynamic optimization. The results showed that the best solar coefficient of performance (SCOP) was predicted in Garoua (Cameroon) and Beitbridge (Zimbabwe). The maximum specific cooling power (SCP) was achieved in Beitbridge (Zimbabwe). Under the climate of Lamu (Kenya), the system presented the lowest performance indices.

[9] Anadi Mondal et al (2015). Solar driven ammonia absorption refrigeration system was designed, constructed and tested. It was an intermittent system where ammonia and calcium chloride were used as refrigerant and absorbent respectively. A small capacity vapor absorption system was first analyzed and its characteristics at various points were measured. The main components like evaporator, condenser and generator were designed based on capacity. The necessary heat and mass transfer equations describing the working properties were specified .The experimentally obtained COP was in the range of 0.104-0.126, average 0.118.

[10] N. S. Rathore and N. S. Panwar (2016) tested the solar photovoltaic operated refrigeration system. The solar PV-based refrigerator has shown good results in Udaipur (27° 42’ N, 75° 33’E). It was observed that there was considerable temperature drop inside the chamber during operation, which is suitable for refrigeration. This system is most suitable for those areas where either electricity is not available or available for few hours. In no load condition the COP obtained was 3.0, 2.6 and 2.0 when thermostat were at positions 2° C , 4 ° C and 6 ° C respectively whereas the COP obtained was 1.8, 1.6, and 1.2 when thermostat were at positions 2° C , 4 ° C and 6 ° C respectively in full load condition.

[11] Asmaa Ahmed M. et al (2015). In this study, an experimental investigation on performance of solar driven with direct current (DC) motor vapor compression refrigerator through indoor and outdoor tests with/without thermal storage and with/without loading is carried out in hot arid areas. The experimental setup main components are multi-crystalline Photovoltaic (PV) module, battery as a buffer for constant 12V DC and 50 liter portable refrigerator with/without PCM thermal energy storage. In addition, a theoretical model is established to evaluate the refrigerator performance when operated under different environmental conditions of the design point. Thereafter the model is used to size a larger cooling capacity solar driven refrigerator. The results show that this system can be used in remote hot arid areas for refrigeration of post-harvest crops transportation activities. From outdoor results at PCM-full load condition, a COP of 1.22 is achieved and storage temperature of 5°C is achieved at third day and 0°C at sixth day.

Solar Thermal Refrigeration

[12] Assilzadeh et al (2008) presented a solar cooling system designed for Malaysia and other similar tropical region using evacuated tube solar collectors and a LiBr absorption unit. The simulation of the system was investigated with TRNSYS software. The authors concluded that the system can produce 1t of refrigeration and determined the optimum design parameters (a 35m^2 of evacuated tube collectors sloped 20°C, a 0.8m^3 hot storage tank and a pump flow rate of 0.25kg/s).

[13] Said et al (2012) developed an alternate design for a continuous operating solar- powered absorption refrigeration system using water-ammonia as working pair. Their analysis indicates that the proposed solution allows an uninterrupted supply of cooling with a COP larger than 0.6 under some conditions.

Solar Mechanical Refrigeration

[14] Lior (1977) studied the application of a combined solar-powered, fuel-superheated Rankine cycle heat pump involving a steam turbine. This cycle drives the heat pump in the cooling mode. In the heating mode, fuel-fired drives the heat pump. According to the obtained results,

energy savings of 50–60% were obtained in the cooling mode. In the heating mode, the resource energy use was reduced by a factor of 3 to 4.

[15] Biancardi et al (1982) achieved the higher performance and described the design, the fabrication and the test of a prototype involving a solar-driven Rankine cycle heat pump, as well as the assembly and field test of the solar powered chiller. R11 was used as the working fluid and the COP in heat pump mode was claimed to be in the range of 1.5 to 3.0.

Hybrid Solar Refrigeration System

[16] Dai et al (2002) presented a hybrid solar cooling system, which combines the technologies of rotary desiccant dehumidification and solid adsorption refrigeration in order to provide cooling of grain storage. The key components of the system are the rotary desiccant wheel and the solar adsorption collector. Three sub systems were considered: solid intermittent adsorption refrigeration, desiccant dehumidification, and cold storage. The system use deactivated carbon and methanol as working pair. The study concluded that compared with the solid adsorption refrigeration system alone, the new hybrid system performs better. Under typical conditions, the COP of the system is greater than 0.4 and the outlet temperature is less than 20^{o}C.

[17] Zhang and Wang (2002) proposed a solar driven combined solid adsorption–ejector refrigeration and heating hybrid system The performance simulation and analysis were made under normal working conditions. In this combined system, a zeolite–water working pair was selected. Compared with an adsorption system without an ejector having a COP of 0.3, the combined system's COP was improved by10% and reached a value of 0.33.

[18] Jiang et al (2002) presented a thermo-economical analysis comparison between an absorption–ejector hybrid refrigeration system and a small double-effect absorption system. They concluded that the COP of the three-pressure absorption–ejector refrigeration system reached 0.9–1.0 and was slightly lower than that of the commercial double-effect absorption refrigeration system. Economically speaking, the hybrid system had a lower annual total cost.

Conclusion

Solar cooling is an innovative, promising alternative to reduce the peak energy consumption generated by excessive use of vapor compression systems, especially during summer months. The attractiveness of utilizing solar energy is mainly due to the demand and supply of energy coincides. In fact, cooling is required when the solar radiation is abundantly available. Furthermore, great majority of solar techniques employs harmless working fluids. Based on an extensive literature review, various types of the available technologies using both thermal and electric options were presented. It is clear that all solar cooling systems have a great potential due to their environmental and energy advantages like energy saving and reduction of CO_2 emissions. Despite the undeniable success achieved by solar cooling processes, several barriers come across their worldwide implementation. The major obstacles are the high installation cost and the low performance. Subsidies proposition, payment facilities together with cost reduction must be the most realistic actions to be undertaken by policymakers and manufacturers to remove the first barrier.

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