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Solar cooling systems for climate change mitigation: A review

S. Anand [a,*], A. Gupta [a], S.K. Tyagi [b]

[a] School of Energy Management, Shri Mata Vaishno Devi University, Katra 182320, J&K, India
[b] Sardar Swaran Singh National Institute of Renewable Energy, Kapurthala 144601, Punjab, India

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ABSTRACT

The impact of global warming and an increase in the indoor cooling equipments using energy sources other than conventional energy have become very attractive because they can reduce consumption of fossil fuels as well as harmful emissions in to the environment. The solar energy is one of the readily available forms of renewable energy which can be used to operate the cooling equipments depending on the geographical location of the area where solar cooling system needs to be installed. The effectiveness of solar cooling also needs to be evaluated based on various performance indicating parameters. However, different types of solar collectors also need to be evaluated in order to find out their feasibility for cooling applications. Thus in this article review of different types of solar cooling technologies have been carried out. The study reveals that evacuated tube collectors are best option for solar cooling where as desiccant cooling helps in improving the indoor air quality. Also, thermal energy storage and ejector based solar cooling efficiently improves the performance besides energy saving.

Contents

* Corresponding author. Tel.: +91 9419104580; fax: +91 1991 285535.
E-mail addresses: anandsanjeev12@gmail.com (S. Anand), guptaankush83@gmail.com (A. Gupta).

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1. Introduction

The electricity is one of the readily used energy source for heating, ventilation and air-conditioning in both working and living environments. About one third of the total electricity is used for air-conditioning and refrigeration purposes [1]. Also, about 80% of the electricity so generated globally comes from the oxidation of fossil fuels causing many environmental problems [2]. The increased use of air conditioning and refrigeration operated by electricity has also promoted the use of fossil fuels for the production of electricity which in turn increases the global warming. Therefore, it is quite urgent to minimize the consumption of fossil fuels and to promote renewable energy sources like solar energy for refrigeration and air-conditioning. The concept of solar energy for cooling application was suggested 35 years ago as a solution to cooling problems in dry and desert areas where electricity was not readily available and the energy crisis in 70's has again attracted the attention of scientists and engineers to develop cooling machines which can work efficiently and economically with solar energy [3]. The various cooling techniques are confined with two major challenges which include the phasing out of Chloro–Fluoro Carbon based refrigerants and to curb the consumption of high grade electricity besides water as cooling medium [4]. It is also well appreciated that with gradual technological developments the solar energy turns out the best complimentary to conventional energy. The phasing out of R-12 (Dichlorodifluoromethane) refrigerant has led to the synthesis of the R-22 (Chlorodifluoromethane) as a substitute, but it is also associated with the problem of higher compression work and high operating pressure which can be overcome if it can operate at condenser temperature below the ambient [5,6] and therefore, solar-driven ammonia–water vapour absorption systems help in overcoming the problem. Different authors worked on the choice of working pairs for absorption systems driven by thermal energy sources and also various demonstration projects have been launched to gain more experience in the design and operation of solar refrigeration and air-conditioning [7–11]. It is also stressed that for the continual population and economic growth, wider use of solar energy in air-conditioning would secure the increasing energy demand. Among various technologies, absorption refrigeration has been most frequently adopted technology for solar cooling. It however, requires very low or no electrical input and also shows the high heat and mass transfer coefficient. Although a number of studies have been reported employing various absorption cycles [12–17] but some disadvantages of traditional absorption refrigeration systems, such as a low coefficient of performance (COP) and strict demand of heat supply, both in quality and quantity, have not been overcome yet. In particular, as the solar input constantly varies, indicating that solar powered refrigeration system will not be able to work consistently in the day which may lead to the deterioration of the performance of the system. Therefore certainly, there is a need of modifications in the absorption systems so that their performance can be improved effectively.

2. Different types of solar cooling systems

2.1. Absorption cooling systems

2.1.1. Test and simulation of a solar-powered absorption cooling machine

Alfred Erhard and Erich Hahne [18] carried out the simulation study of the solar powered absorption cooling machine suggesting the use of solar cooling in countries with a high solar energy supply. The workers also stressed on the fact that absorption cooling machines with solid absorbent are the best suited in hot and dry areas than wet absorption machines because such machines are easy to handle and have no moving parts, therefore do not require extra cooling equipment for high ambient temperature. However, as a drawback, these machines alternatively produce absorption (cooling) cycle during the night and desorption (heating) cycle during the day. Therefore, a cold storage like ice or some cold mass has to be provided for daytime cooling to power a cooling system. However, solar-powered cooling systems using a solid sorbent have frequently been discussed by many researchers [19–21]. An analysis of a solar-powered dry absorption cooling system with a collector integrated reactor was carried out [18]. The reactor consists of two steel pipes insulated with steel wool, filled with the absorbing medium, namely strontium chloride ($SrCl_2$). About 15% of graphite is also added to improve the thermal conductivity of the $SrCl_2$ and to prevent the salt from caking. The working of the cycle can be divided into four phases. Desorption (high-pressure phase) followed by an intermediate cooling phase and the absorption phase (low-pressure phase) followed by an intermediate heating phase. The reactor during the day is heated and acts as desorber which means that ammonia is driven out of the compound $SrCl_2 \cdot 8NH_3$ and stored in the degassing pipe. After sun set, the reactor works as an absorber and cool down until the absorption temperature is reached where the absorption takes place. The heat of absorption is transferred into ambient by means of pipes operating in a reverse way resulting in the temperature drop in the cooling compartment. A simulation study for a process is carried out based on a data base containing physical properties of all materials and working fluid pairs. A model program has also been developed for the cooling machine and working fluid in order to calculate the temperature and concentration in the desorber/absorber. The results obtained from the simulation study indicate about the system pressure and ammonia mass inside the ammonia reservoir. The results obtained also revealed that ammonia mass increases in the morning and reach maximum in the evening when heating process ends. There occurs a steep decrease of ammonia mass followed by an increase at the beginning of absorption process which probably originates from the pressure influence increasing up to 14 bars. During absorption process the pressure decreases and matches the pressure at the evaporating temperature. The temperature inside cooling compartment does not rise above 6 °C during the whole measurement period. However, during the desorption process the temperature inside the reservoir increases which is found to be slightly higher than ambient temperature because of the fact that the condenser temperature is above the ambient temperature. The Coefficient of performance obtained is quite less but with certain modifications in the system there could be an improvement in the performance.

2.1.2. A new absorption refrigeration cycle using solar energy

Chen and Hihara [22] proposed and evaluated a new refrigeration cycle driven by heat and electricity using LiBr–H_2O as working fluid as shown in Fig. 1. The electricity operated compressor is augmented in the system so that a constant energy input to the system can be maintained. Many authors have performed many modifications like introduction of thermal storage, electricity