

A State of Art Review of Solar/Heat Powered Absorption Cooling Systems Employed in Buildings

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Abstract

Despite the widespread availability of industrial-scale, heat-driven absorption cooling systems, the concept of a solar-powered chillers in air conditioning systems is only getting off the ground. It is not practical to employ absorption chillers for domestic air conditioning since their efficiency is lower than that of compression refrigeration systems, even when operating at smaller scales. In this study, we investigate the viability of using a solar-powered ammonia-water absorption chiller for residential cooling. An air-cooled ammonia-water absorption chiller with a 10 kW capacity that is powered by solar thermal energy has been used to construct a thermodynamic model. In order to gauge how well this cooling system performs at the domestic scale, energy and exergy assessments have been carried out. Most of the exergy is lost in the absorber (63%), next in the generator (13%), and finally in the condenser (11%), as determined by the analysis. As temperatures rise, exergy loss is greatest in the condenser and absorber, drops little in the generator, and is least affected by temperature changes in the evaporator.

Keywords: Solar Absorption Chiller; Refrigeration; Cooling Systems; Heat Powered Absorption.

Introduction

Present energy supply and consumption are not sustainable from an economic, environmental, or

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social perspective, says the International Energy Agency. According to the International Institute of Refrigeration, cooling and heating systems use around 15% of the world's total power production. Moreover, air conditioners account for 45% of all energy used in homes. About 80% of the power produced worldwide comes from fossil fuels, the main source of greenhouse gas emissions. As the global average summer temperature rises by 2–4 degrees Celsius by the turn of the century, this is expected to worsen. The need for air conditioning is expected to rise as a result of both climate change and rising living standards, which will have a major impact on primary energy consumption. This is particularly important to keep in mind in emerging nations, where a rising middle class has led to a spike in the popularity of traditional air conditioning systems. Increases in population, air conditioning use, and industrialization are driving up demand for electricity at a faster rate than supply can keep up with in these nations. In India, for instance, the Central Electricity Authority reports that the country experiences an annual average of 8% of peak demand in excess of its available electricity. Because of this, there are frequent power outages throughout the summer, and they might linger for several hours. However, solar energy is readily accessible throughout the year and provides a sustainable alternative power source in many poor nations. Due to the abundance of solar energy, solar cooling technology may be a viable option, especially for those who live in rural locations and have limited access to electricity.

Several waste-heat-driven cooling methods exist today, but most are designed for capacities of 50 kW or more. In contrast, technology on a smaller scale (less than 10 kW) is still in its infancy and necessitates inexpensive, low-maintenance solutions. Some businesses have made recent efforts to better absorption chillers in the 50 kW to 5 kW power range. However, there aren't many chillers designed specifically for use with solar thermal power, and those that do exist aren't suitable for use with smaller-scale cooling needs. Research and development (R&D) is needed to design small-scale systems so that low-cost systems may be developed, integrated with existing equipment, and optimised for operation in future projects, says the International Energy Agency. Miniaturized machines with high COPs at mild engine temperatures should be the focus of localised technological advancement.

Sorption cooling is the most prevalent approach for creating thermally activated cooling. Adsorption is the process of using a solid to adhere or attach ions and molecules of another substance onto its surface, whereas absorption is the integration of a substance in one state into another substance in a new phase (for example, gas being absorbed by a liquid). Instead of using mechanical compression, sorption cooling systems employ thermal compression on the refrigerant. The two most prevalent uses for these innovations in central air conditioning systems are decentralised fan coils and cooled ceilings. Absorption systems that use air cooling might help save the outlay for cooling tower installations and routine maintenance. This project aims to deliver air conditioning through a solar-powered, ecologically friendly refrigerant-using air-cooled absorption refrigeration system.

Solar absorption refrigeration

In order to cool things down, solar refrigeration utilises a system that runs on solar energy. Solar energy has the potential to revolutionise the global cooling and refrigeration industries by providing low-

cost, environmentally friendly power. If Mediterranean nations, for instance, adopted a solar-powered cooling system, they might cut their energy bills by half. The agriculture industry is another huge beneficiary of solar energy. Irrigation systems may benefit from solar pumps. When conventional means of crop preservation and storage are not possible, solar refrigeration may play a crucial role. In addition, certain nations in sub-Saharan Africa with high solar potential may employ solar refrigeration to keep vaccines and other medications at a more stable temperature; these systems can even be made mobile. Desiccant gases like LiCl (lithium chloride) and LiBr (lithium bromide) or water are used in place of toxic Freon gas, making solar refrigeration an increasingly viable cooling option. There are two primary ways to accomplish cooling. The first is a solar energy system based on PV (Photovoltaic) technology, which uses the sun's heat to generate electricity, which is then utilised to cool food in much the same way as traditional cooling techniques do. The second makes use of solar thermal refrigeration, in which the refrigerant is heated directly by a solar collector via collector tubes. The schematic of a closed sorption system is shown in Fig. 1.

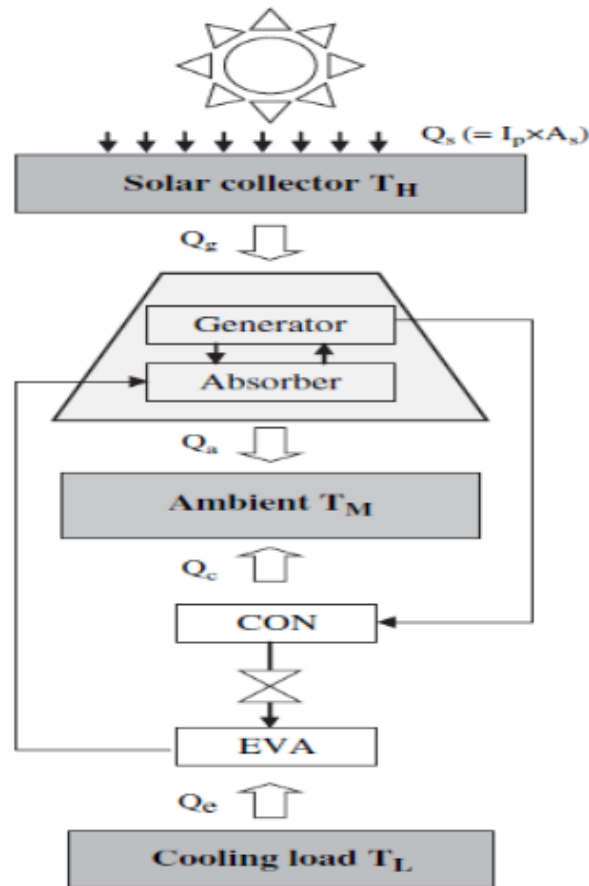


Fig.1 Solar absorption refrigeration system

Solar absorption cooling systems

Compressing the refrigerant vapour is the job of the condenser, generator, evaporator, pump, and absorber that make up a vapour absorption refrigeration system. The vapour refrigerant is created in the evaporator with the use of extra thermal energy for separation from the solution. A refrigerant is distilled in the condenser and expanded in the evaporator. The chiller's generator in a solar absorption cooling system is heated by the solar collector's tank. The coefficient of performance (COP) is defined as follows across all contexts, and it is a critical metric for comparing the efficiency of various absorption cooling systems:

$$\text{COP} = \frac{\text{Cooling load}}{\text{Heat input to the generator}} = \frac{Q_E}{Q_G}$$

The generator's thermal input can come from a variety of renewable (solar) and non-renewable (fossil fuel) energy sources, or a combination of the two.

The solar absorption systems may be broken down into the following groups based on the regeneration of the solution and thermal operating cycle:

- Single-effect.
- Half-effect.
- Multiple-effect (double-effect and triple-effect)

Single and half-effect chillers need warmer temperatures than their double and triple-effect counterparts. Triple-effect absorption chillers powered by high-temperature solar thermal collectors provide the highest COP. For a higher COP, it is necessary to operate the generator at temperatures higher than 150 degrees Celsius, although doing so requires more up-front investment. Cascaded cycles and an ejector make the heliostat- and central receiver-driven, triple-effect absorption chiller a better fit for low-temperature generator refrigeration cycles (80–50oC). Single, double, and triple effect chillers with identically sized components all have different needed deriving temperatures and coefficients of performance (COP), as shown in Figure 2. As can be seen in Fig. 2, combining high-temperature solar collectors with multi-effect absorption chillers results in a significant improvement in COP. There is a maximum COP of 0.7 for single-effect chillers, and the driving heat source temperature is normally between 80 and 100oC. In order for double-effect chillers to function, the generator temperature must be kept between 100 and 150 degrees Celsius, and the COP must not exceed 1.4. In the end, triple-effect chillers call for a temperature range of 180 to 240oC as their driving temperature, and their COP may peak at 1.8 under ideal circumstances. If a high-temperature heat source is readily accessible, using absorbers with a strong effect may increase the COP. Previous research did not address the question of whether or not solar-driven cooling systems using multi-effect absorption chillers may be cost-effective due to the high upfront and ongoing costs of their components, tracking, and maintenance. However, they have the drawback of being dependent on DNI alone for power.

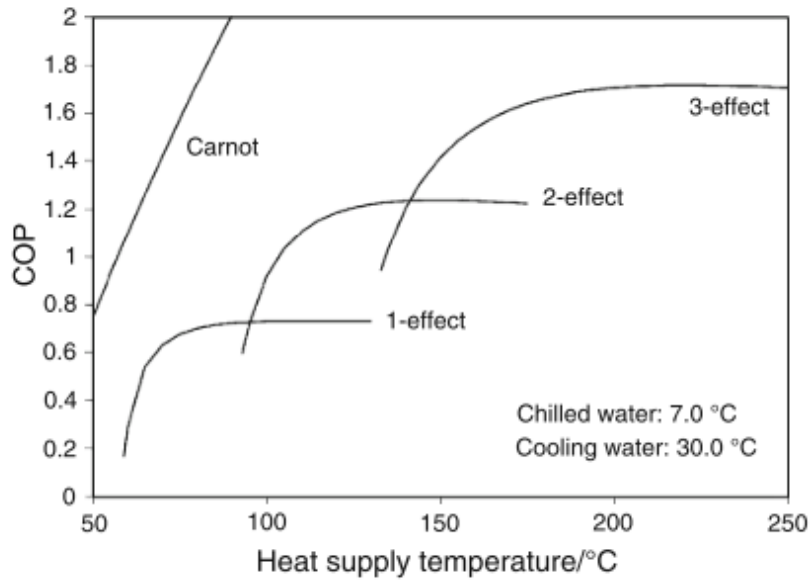


Fig. 2 Variation of COP as a function of solar heat supply temperature for various LiBr–H₂O absorption chiller types

Air conditioners that rely on solar energy must have a hot water tank because of the relatively consistent heat it provides. It was estimated by Lof and Tybout that 50 kilogramme per square metre of collection area is the optimal storage tank capacity. There was also an increase from 80 to 200 kg per m² of collector area, which is the nominal storage quantity used for cooling. Heat loss in the hot water storage tank's periphery is a major issue. Jacobsen calculated a coefficient of real heat loss of 1.65 W/m²°C, which is 50% higher than the prior estimates. Heat loss from a hot water tank may sometimes be as much as two hours of daily use of a solar air conditioner. Chilled water storage tanks may be used as part of solar cooling systems. The hot water storage tank endures significant heat losses, whereas the chilled water storage tank receives heat at a slower pace. The primary cause of this is the narrowing temperature gap between the outside and the chilled water tank. In addition, the chilled water tank may help with cooling by absorbing heat if it is placed strategically (near the air-conditioned room). The chilled storage may improve operational stability as a buffer tank, but it cannot boost the performance of the system when used for solar cooling.

Literature Review

(Hu et al., 2022) This system makes use of a specialised module consisting of a flat-panel solar collector operating at medium temperatures and an absorption chiller for selective radiative cooling; the collector captures solar thermal energy during the day to power the chiller, and at night, the collector is turned so that the bottom layer faces the sky, allowing the chiller to cool the building more efficiently.

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(Stanciu et al., 2017) Parabolic trough collectors are used to concentrate solar energy for use in heating water in a tubular receiver in the system under consideration. Used in the absorption cooling system's vapour generator, this is held in a completely mixed thermal storage tank. The cooling load for cooling a two-story home is assessed on a time-dependent basis. The reliability of the cooling system's functioning is examined by a parametric analysis that takes into account the size of the solar collector and the storage tank.

(Siddiqui & Said, 2015) Refrigeration and air conditioning are two essentials in the growing sector of solar energy use. This study provides a comprehensive assessment of the literature on such topics as the prevalence of electricity and energy use, the characteristics of different absorption refrigeration systems, and the fluids used in them, and their applications.

(Linjawi et al., 2017) The towns of Abha, Dhahran, Hail, Jeddah, and Nejrán, as well as the state capital of Riyadh, put flat plate and evacuated tube collectors through 4, 6, and 8 hours of operation, respectively. Researchers found that flat plate collectors outperformed their evacuated tube contemporaries when it came to energy efficiency. While the planned gas-fired absorption chiller would decrease operating costs, more savings cannot be achieved by installing solar collectors owing to their unreasonably large initial investment.

(Wang et al., 2018) Based on a case study of a solar cooling system at a hotel, we know that on an average day of operation, the absorption chiller has a performance coefficient of around 1.195, and the whole system has an efficiency of 61.98 percent when it comes to harnessing solar energy.

(Aman et al., 2013) This research explores the feasibility of a solar-powered ammonia-water absorption chiller for home air conditioning. We have created a thermodynamic model using data from a solar-powered, ammonia-water absorption chiller with a 10-kilowatt power output and air-cooling. In order to gauge how well this cooling system performs at the domestic scale, energy and exergy assessments have been carried out.

(Baniyounes, 2020) Due to its better humidity management, solar cooling systems are proven to be economically and environmentally favourable for their usage in conserving energy, removing moisture from the air, and improving indoor air quality. Using solar energy as their primary driving medium, they are able to control the environment within a conditioned room in terms of temperature, humidity, and air exchange.

(Sheikhani et al., 2018) Review of solar cooling systems including the flat-plate collector, evacuated tube collector, compound parabolic collector, and parabolic trough collector. We compare and contrast using key metrics including performance coefficient, yearly energy usage, and payback time.

(Singh et al., n.d.) Since these systems cut power usage during peak hours, which often occur on hot, bright summer days, they result in significant cost savings. These days, lithium bromide absorption chillers are the solar cooling technology of choice. Renewable energy systems offer low operating costs

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and also give an excellent performance of energy efficiency, but the expensive cost of installation serves as a hurdle to their promotion.

(Mustafa et al., 2021) Solar collectors (common plate or evacuation tubular) are often used to power these chillers. In this study, both practical and theoretical investigations on the impact of isolated absorption cooling systems are surveyed. In addition, fresh suggestions for the solar collectors' layout, as well as energy- and cooling-system backbones, will be made. In addition to a review of two-stage and half-effect absorption coolers, this study provides a comprehensive overview of the primary twofold affect of the cooling absorption systems.

Conclusion

This investigation set out to enhance an absorption chiller's efficiency so that it may be used to efficiently cool dwellings while being driven by low-temperature sources, such as solar thermal energy. The energy and exergy analysis has been used to assess exergetic efficiency, the performance, and exergy loss of different parts of a 10 kW air-cooled ammonia-water absorption chiller.

The system's first- and second-law efficiency have been studied and compared across a range of operating situations. The findings reveal that when the temperature of the heat source and the evaporator are both raised, the system's COP rises, but it falls as the temperature of the absorber and the condenser are raised. However, when temperatures in the generator, evaporator, condenser, and absorber rise, the exergetic efficiency falls. The research shows that the absorption cooling system operates most efficiently when heated by low-temperature rather than high-temperature sources, and that lowering the temperatures of the condenser and absorber toward ambient conditions has little effect on the system as a whole. A flat plate solar collector may be used to provide heat for an ammonia-water absorption chiller, and the absorber and condenser can be cooled using just ambient air.

According to the exergy study, the generator and the absorbing process account for around 76% of the total exergy loss in this absorption cooling system. The absorber is where most of the work has to be done to increase the efficiency of the cycle; the generator is a close second.

Last but not least, this paper's energy and exergy studies provide a straightforward, practical means of pinpointing the source(s) of performance-degrading losses in a miniature ammonia-water absorption cooling system. It also provides information on which system components may benefit from design changes. Absorption systems can be optimised from a thermoeconomic standpoint using the findings. In order to maximise the system's thermoeconomic efficiency, it is possible to consider "the costs and advantages (or "profitability") of the different systems for using and collecting available energy to conduct work".

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