Comparative Study of Solar Thermal Cooling Techniques for Absorption Refrigeration System

Madhulesh Yadav [1], Dr. N.K Saikhedkar[2]
Department of Mechanical Engineering, Ph. D Scholar, *Dr. C.V Raman University,Kota, Bilaspur (C.G),*
Department of Mechanical Engineering, Professor RITEE, Raipur (C.G)
madhmink1416@gmail.com, nksaikhedkar@gmail.com

Abstract— In this paper a survey of the various types of solar Refrigeration Technologies and applications for Cooling system is presented. A introduction into the uses of solar energy for cooling systems is attempted followed by a description of the various types of collectors including flat-plate, compound parabolic, evacuated tube, parabolic dish collectors. Typical applications of the various types of cooling technologies are presented These include multiple components used for cooling which comprise refrigeration applications

Keywords—Solar collectors; cooling system, condenser , evaporator, absorption refrigeration system

1. INTRODUCTION

Sunlight is the world's largest energy source and the amount that can be readily accessed with existing technology greatly exceeds the world's primary energy consumption. Furthermore, sunlight is free, clean, renewable and technically exploitable in most part of the inhabited earth. Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a fluid (usually air, water, or oil) flowing through the collector.

There are basically two types of solar collectors: non-concentrating or stationary and concentrating. A non-concentrating collector has the same area for intercepting and for absorbing solar radiation, whereas a sun-tracking concentrating solar collector usually has concave reflecting surfaces to intercept and focus the sun's beam radiation to a smaller receiving area, thereby increasing the radiation flux. solar radiation, convert it to thermal energy and deliver the thermal energy to a heat transfer medium with minimum losses at each step.

Due to the nature of solar energy, two components are required to have a functional solar energy generator. These two components are a collector and a storage unit. The collector simply collects the radiation that falls on it and converts a fraction of it to other forms of energy (either electricity and heat or heat alone). The storage unit is required because of the non-constant nature of solar energy. Solar Collectors are practical due to their inherent simplicity and consequent lower costs. Solar Collectors are very important especially for isolated areas where there is no fuel supply.

2. LITERATURE SURVEY

N Nakahara et al developed a single-effect H_2O/LiBr absorption chiller of 7 kW nominal cooling capacity, assisted by a 32.2 m2 array of flat plate solar collectors. In their system, thermal energy produced by the solar collector was stored in a 2.5 m^3 hot-water storage tank. Their experimental results during the summer period showed that the cooling capacity was 6.5 kW. The measured COP of the absorption system was in range of 0.4–0.8 at the generator temperature of 70 ◦C to 100 ◦C.
Z F Li and K Sumathy observed a H_2O/LiBr absorption system with a partitioned hot-water storage tank. The system consisted of a 38 m^2 flat plate collector and a 4.7 kW absorption chiller. They concluded that the system exhibited 15% more COP (approximately 0.7) than a conventional whole-tank mode system. Another investigation on a H2O/LiBr absorption system consisting of 49.9 m^2 of flat plate collector was performed by A Syed et al The system performs cooling within generator temperatures of 65–90 ◦C, maintaining a capacity of 35 kW. They calculated three different COPs and achieved an average collector efficiency of approximately 50%. In an intermittent single-stage NH_3/H_2O absorption system, the solution pump is eliminated and the density difference is utilized for the NH_3/water circulation. In this way, the auxiliary power is saved.
Since V Trombe and M Forx suggested using an intermittent single-stage NH_3/H_2O absorption system

assisted by the solar energy for ice production, several researchers explored the feasibility of such systems To improve the unsteady nature of the solar heat from the solar collector to the absorption system, G Chen and E Hihara proposed a new type of absorption cycle that was co-driven both by solar energy and electricity. In their proposed system, total energy delivered to the generator could be controlled by adjusting the mass flow rate through the compressor. Their numerical simulation model results showed the steady COP value of 0.8 for the new cycle, which was higher than the conventional cycle.
J C Chinnappa et al proposed a conventional vapor compression AC system cascaded with a solar-assisted NH_3/H_2O absorption system. They concluded that the hybrid system achieved of a COP = 5, which is higher than that of the vapor compression cycle at 2.55, by reducing the R-22 condensation temperature to 27 °C.
S Arivazhagan et al performed an experiment with a two stage half-effect absorption system using the working pair of R134a/DMAC. They were able to attain an evaporation temperature of −7 ◦C with the generator temperature varying from 55 ◦C to 75 ◦C. They concluded that within the optimum temperature range (65–70 ◦C), a COP of approximately 0.36 could be achieved.
K Sumathy et al proposed a two-stage H_2O/LiBr chiller for cooling purposes in south China. They found a cooling capacity of 100 kW through the integration of a solar cooling system with these chillers. They concluded that the system had a nearly equivalent COP as the conventional cooling system, but at a 50% reduced cost.
M Izquierdo et al designed a solar double-stage absorption plant with H_2O/LiBr, which contained flat plate collectors to feed the generator. They reported that within a condensation temperature of 50 ◦C, the COP was 0.38 while providing a generation temperature of 80 ◦C. They also performed an exergetic analysis of this system and conclude that the single-effect system had 22% more exergetic efficiency than the double-stage half-effect system.
P Srikhirin et al conducted an analysis showing that the COP of a double-effect system is 0.96, whereas the single-effect system has a COP of only 0.6 In the past few years, the COP of double effect absorption systems has reached values of 1.1–1.2 by using gas-fired absorption technology.
M J Tierney performed a comparative study among four different systems with a collector of 230 m^2 and concluded that the double-effect chiller with a trough collector had the highest potential savings (86%) among the four systems to handle the demand for a 50 kW load. Z F Li and K Sumathy stressed the importance of the generator inlet temperature, chiller, collector choice, system design and arrangement, in the design and fabrication of a solar powered air conditioning system. P Srikhirin et al have discussed a number of absorption refrigeration systems and related research options. In this section, literatures pertaining to the improvement of absorption cooling systems, theoretical and experimental studies on solar absorption cooling, and finally, on subjects with a thrust on thermal storage integrated cooling systems are reviewed.

3. SOLAR COLLECTORS

Evacuated Tube Collector : The name "evacuated" is used to describe the process that expels the air from within the space between the tubes, forming a vacuum. A vacuum is an excellent insulator against heat loss, and so evacuated tubes are able to operate very efficiently when there is a big difference between the inside of the tube and the outside ambient air. For this reason evacuated tubes are the ideal choice for high temperature hot water applications or locations that get cold in the winter.

Evacuated tubes are the absorber of the solar water heater. They absorb solar energy converting it into heat for use in water heating. Evacuated tube consists of two glass tubes made from extremely strong borosilicate glass. The outer tube has very low reflectivity and very high transmissivity (about 90%) that radiation can pass through. The inner tube has a layer of selective coating that maximizes Absorption of solar energy and minimizes the reflection, there by locking the heat. Fig.1 Shows the heat transfer in evacuated tube in different layers of the tube. Reflectance of the outer glass is about 7.5% of total incident solar radiation. It absorbs 1.8% of total radiation and transmits the rest to the inner glass tube which have coating of a selective surface inside it. Selective coating absorbs 93% of heat transmitted by the outer glass [4].

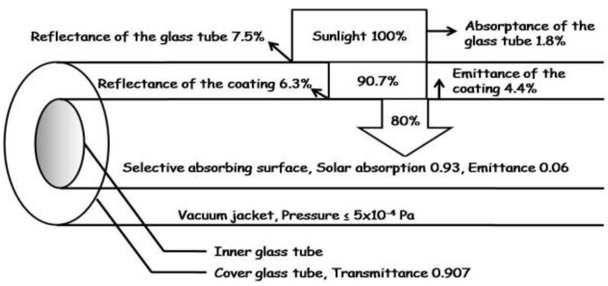

Fig 1 : Heat Transfer in Evacuated tube collector in Different layers of the tube

Water-in-glass evacuated tube solar collector is one of most efficient and cost effective solar collector. Water in glass evacuated tube solar collector works on the principle known as “Thermo-siphon” (natural circulation by heat). Due to density difference between the cold & hot water, the lighter hot water flows up into the tank and the heavier cold water enters the collector. It consists of evacuated tubes connected to a shell or tank. The working fluid, generally water, flows from the tank to the tubes, captures heat, and then flows back to the tank by a natural circulation mechanism.

ETC have demonstrated that the combination of a selective surface and an effective convection suppressor can result in good performance at high temperatures. The vacuum envelope reduces convection and conduction losses, so the collectors can operate at higher temperatures. However, their efficiency is higher at low incidence angles. ETC use liquid–vapor phase change materials to transfer heat at high efficiency. These collectors feature a heat pipe (a highly efficient thermal conductor) placed inside a vacuum-sealed tube. The pipe, which is a sealed copper pipe, is then attached to a black copper fin that fills the tube (absorber plate).Evacuated heat pipe tubes are composed of multiple evacuated glass tubes each containing an absorber plate fused to a heat pipe.

Parabolic Disc Type Solar Collector :

The solar parabolic dish collector is known as most efficient system among solar thermal devices. The solar parabolic dish collector maintains its optical axis always pointing directly towards the sun. The geometry of the concentrator allows reflecting the incident solar rays onto the receiver, which is located at the focal plane of the collector. During its rotation, the receiver experiences change in the complete behavior of the fluid and the heat transfer characteristics. The orientation of the receiver might alter the thermal performance of solar parabolic dish system. The estimation of heat losses from the receiver is an important input to the performance evaluation of the solar collector.

Solar energy is converted into thermal energy in the focus of thermal concentrating systems. These systems are classified by their focus geometry as either point focus concentrators (Central receiver systems and parabolic discs) or line-focus concentrators (paraboilic trought collectors (PTCs) and liner fresnel collectors).

A parabolic dish collector is a type point focusing concentrating collector. The incoming beam radiations falling on the surface parallel to the axis of the dish concentrated at the focal point of the dish. This system uses a dual axis tracking which clearly means that it had to follow sun throughout the day in order for high efficiency. This system can attain temperature as high as 1500^0C.

4. SOLAR REFRIGERATION TECHNOLOGIES

Solar refrigeration offers a wide variety of cooling techniques powered by solar collector-based thermally driven cycles. Fig. 2 shows a schematic diagram of a solar thermal cooling system. The solar collection and storage system consists of a solar collector (SC) connected through pipes to the heat storage. Solar collectors transform solar radiation into heat and transfer that heat to the heat transfer fluid in the collector. The fluid is then stored in a thermal storage tank (ST) to be subsequently utilized for various applications.

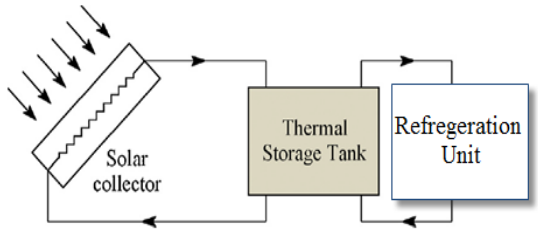

Fig 2 :Schematic of Solar Thermal Cooling System

Solar collectors transform solar radiation into heat and transfer that heat to the heat transfer fluid in the collector. The fluid is then stored in a thermal storage tank (ST) to be subsequently utilized for various applications.
Solar refrigeration technology engages a system is used for cooling purposes. Cooling can be achieved through four basic methods:
Solar PV Cooling : The first is a PV-based solar energy system, where solar energy is converted into electrical energy and used for refrigeration much like conventional methods [5].
Solar Thermo-electrical Cooling : The second one produce cooling by thermoelectric processes [6].
Solar Thermo-mechanical Cooling : The third one converts the thermal energy to mechanical energy, which is utilized to produce the refrigeration effect.
Solar Thermal Cooling : The fourth method utilizes a solar thermal refrigeration system, where a solar collector directly heats the refrigerant through collector tubes instead of using solar electric power [7].

5. SOLAR THERMAL COOLING TECHNIQUES

Solar thermal cooling is becoming more popular because a thermal solar collector directly converts light into heat. For example,[8] described a thermal system that is capable of absorbing more than 95% of incident solar radiation, depending on the medium. Absorption technology is utilized in thermal cooling techniques. The cooling effect is obtained from the chemical or physical changes between the absorbent and the refrigerant. Absorption technology can be classified either as open absorption systems or closed absorption systems [9]

Open Absorption Systems : Open Absorption Systems refers to solid or liquid desiccant systems that are used for either dehumidification or humidification.

Closed Absorption Systems : In closed absorption technology, there are two basic methods: Absorption refrigeration and Adsorption refrigeration.

6. ABSORPTION REFRIGERATION SYSTEM

Absorption is the process in which a substance assimilates from one state into a different state. These two states create a strong attraction to make a strong solution or mixture. The absorption system is one of the oldest refrigeration technologies.

Absorption machines use a liquid–gas working pair, i.e. a working fluid that is a mixture of a refrigerant and an absorbent. The absorbent has a high affinity towards the refrigerant i.e. it exhibits a strong potential to absorb the vapor phase of the refrigerant. An absorption machine consists of four main components, a generator , an absorber, a condenser and an evaporator. In the a solar collector, solar heat is supplied to the working fluid. The working fluid increases in temperature and releases to the refrigerant in the generator, which flows into the condenser where it is condensed. The absorbent obtained at the end of desorption is circulated to the absorber while the liquid refrigerant resulting from the condensation drops in the evaporator, where it is evaporated by heat from the load. Depending on the design of the process, various additional components would be required, mostly a solution heat exchanger in order to increase the COP of the process.

The attractive feature of the absorption system is that any types of heat source, including solar heat and waste heat, can be used. Typical refrigerant/absorbent pairs used in the absorption system are NH_3/H_2O and H_2O/LiBr. The thermodynamic characteristics of these have been described in various studies and experiments [9]. Even though NH_3/H_2O and H_2O/LiBr pairs have been used all over the world, researchers are still looking for new pairs][10]

Based on the thermodynamic cycle of operation and solution regeneration, the absorption systems can be divided into three categories : single-effect, half-effect and multi-effect (double-effect and triple-effect) solar absorption cycles. The single-effect and half effect chillers require relatively lower hot-water temperatures with respect to multi-effect systems [13]. Best absorption refrigeration technology applications are heat activated refrigerators, gas-fired residential air conditioners, and large industrial refrigeration plants.

The operation of the H_2O/LiBr-based absorption system is limited in the evaporating temperature and the absorber temperature, due to the freezing of the water and the solidification of the LiBr- rich solution, respectively. The operation of the NH_3/H_2O-based absorption system is not limited in either the evaporating temperature or the absorption temperature. However, ammonia is toxic and its usage is limited to the large capacity system.

7. SOLAR ABSORPTION COOLING SYSTEMS

Solar absorption systems utilize the thermal energy from a solar collector to separate a refrigerant from the refrigerant/absorbent mixture. The flat plate solar collector can be used for the single-effect cycle. However, the multi-effect absorption cycles require high temperatures above 85 $^{\circ}$C, which can be delivered by the evacuated tube or concentrating-type collectors.

7.1 Single-Effect Solar Absorption Cycle

Recent statistics show that most absorption cooling systems are made using single-effect absorption cycle with a H_2O/NH_3 or H_2O/LiBr pair, where a solar flat plate collector or an evacuated tubular collector with hot-water is used to implement these systems [11]. Single-effect absorption cooling system is based on the basic absorption cycle that contains a single absorber and generator. In the generator, the refrigerant is separated from the absorbent by the heat provided by the solar collector. The vapor-refrigerant are condensed in condenser, then laminated in expansion valve 1 and evaporated at low pressure and temperature in the evaporator. The cooled refrigerant is absorbed in the absorber by weak-solution that returns from generator after the lamination in the expansion valve 2..

The rich-mixture created in absorber is pumped by pump and returned in generator. The usual a solution heat exchanger (SHX) can be used to improve cycle efficiency [H Hassan et al, 2012] [50]. A 60% higher COP can be achieved by using the SHX. The absorption being exothermic, the absorber is chilled with cooling water. For low temperature heat sources results unacceptably low values of degassing zone and vapor-refrigerant release in generator is slow down and the operation of the system becomes unstable or impossible. In this case, in generator, the refrigerant is also separated from the absorbent by the heat provided by the solar collector, but vapor-refrigerant are reabsorbed by a weak-solution from resorber Rb and the system operates similarly to the above mentioned cycle. System pressures may be allowed as close to atmospheric pressure as possible, which simplifies sealing problems, pumps built and reduce temperature in generator.

A single-effect absorption cooling system is simpler than other when the design depends on the types of working fluids. If volatile working pair such as NH_3/H_2O is used, then an extra rectifier should be used before the condenser to provide pure refrigerant [14]. A low cost non-concentrating flat plate or evacuated tube solar collector is sufficient to obtain the required temperature for the generator. Though economical, its COP is lower. For obtaining a higher COP, multi-effect systems such as double-effect and triple-effect absorption chillers are used, which are run by steam produced from concentrating solar collectors.

7.2 Half-Effect Solar Absorption Cycle :

The primary feature of the half-effect absorption cycle is the running capability at lower temperature compared to others. The name "half-effect" arises from the COP, which is almost half that of the single-effect cycle [12]. The half effect cycle, also called two-stage or double-lift cycle, can provide cold with a relatively low driving temperature. The half effect systems would require about 40% more heat exchange surface and 10– 60% more collector area compared to single effect system of the same cooling capacity. More over, the half effect system can yield higher average cooling efficiency than single effect system with the low cost flat plate collector or its comparable types. They concluded that a half-effect cycle would be most promising for air-cooled solar absorption air conditioning in terms of initial solar collector cost.

7.3 Double-Effect Solar Absorption Cycle :

Double-effect absorption cooling technology was launched in 1956 for developing the system performance within a heat source at higher temperatures [24]. A double-effect absorption system with a $H_2O/LiBr$ pair. The cycle begins with generator G-I providing heat to generator G-II. The condenser C rejects the heat and passes the working fluid towards the evaporator V; within this step, the required refrigeration occurs. Then, the fluids pass through the heat exchangers HX-I and HX-II from the absorber Ab to G-I by means of a pump P. Through this process, HX-II can pass the fluids to G-II and then G-II passes to HX-I. The complete cycle follows three different pressure levels: high, medium and low. Two single-effect systems effectively form a double-effect absorption cooling system. Therefore, the COP of a double-effect system is almost twice that of the single-effect absorption system.

7.4 Triple-Effect Absorption Cycle

Triple-effect absorption cooling can be classified as single-loop or dual-loop cycles. Single-loop triple-effect cycles are basically double-effect cycles with an additional generator and condenser. The resulting system with three generators and three condensers operates similarly to the double effect system. Primary heat concentrates absorbent solution in a first-stage generator at about 200–230 ˚C. The refrigerant vapor produced is then used to concentrate additional absorbent solution in a second-stage generator at about 150 ◦C. Finally, the refrigerant vapor produced in the second-stage generator concentrates additional absorbent solution in a third-stage generator at about 93 ◦C. The usual solution heat exchangers can be used to improve cycle efficiency. Theoretically, these triple-effect cycles can obtain COPs of about 1.7 [26].

A double-loop triple-effect cycle consists of two cascaded single effect cycles. One cycle operates at normal single-effect operating temperatures and the other at higher temperatures. The smaller high temperature topping cycle has a generator temperature of about 200–230 ◦C. Heat is rejected from the high temperature cycle at 93 ˚C and is used as the energy input for the conventional single-effect bottoming cycle. Theoretically, this triple-effect cycle can obtain an overall COP of about 1.8 Multi-effect cycles are costlier but energy efficient. Double and triple-effect chillers employ an additional generator and heat exchanger to liberate the refrigerant from the absorbent solution with lesser heat input. The available solar intensity, cooling capacity requirements, overall performance and cost, determines the selection of a particular configuration.

7.5 Hybrid Solar Absorption Cooling Systems

A hybrid cooling concept arose due to integrate different pairs or systems for obtaining better cooling performance. Hybrid solar absorption cooling system refers to the integration of three individual cooling technologies: radiant cooling, desiccant cooling and absorption cooling. Solar absorption cooling systems are used in air conditioning applications, for food preservation and in ice production.

8. RESULTS AND DISCUSSIONS

Different researchers have done lot of work in absorption refrigetation systems. It is observed that different cooling systems works in different cycles using solar applications. The performance of double effect and triple effect solar absorption is better than single effect by using different sets of generators. The performance of single effect absorption cycle can be improved by using sets of solar collector in series which can increase the generator temperature hence increase the performance of absorption refrigeration system.

9. CONCLUSION

A detailed study of an absorption based refrigeration systems that are powered by solar energy is presented in this paper. Different system designs that are operating with different absorbate–absorbent working pairs along with the related theoretical and experimental work are discussed. These systems include both closed and open cycle types of machines. As a consequence, this present review is very helpful in terms of development and performance enhancement for each of these systems.

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