To Study Solar Vapour Absorption Refrigeration Systems

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Abstract- An air-conditioning system utilizing solar energy would generally be more efficient, cost wise, if it was used to provide both heating and cooling requirements in the building it serves. Various solar powered heating systems have been tested extensively, but solar powered air conditioning systems have received very little attention. Solar powered absorption cooling systems can serve both heating and cooling requirements in the building it serves. Many researchers have studied the solar absorption air conditioning system in order to make it economical and technically viable. But still, much more research in this area is needed. This paper will help many researchers working in this area and provide them with fundamental knowledge on absorption systems, and a detailed review on the past efforts in the field of solar absorption cooling systems with the absorption pair of lithium-bromide and water. This knowledge will help them to start the parametric study in order to investigate the influence of key parameters on the overall system performance.

Index Terms- solar energy, absorption cooling system, air-conditioning, lithium bromide and water

I. INTRODUCTION

Solar energy is one of the most available forms of energy on the Earth’s surface, besides; it is very promising and generous. The earth’s surface receives a daily solar dose of 10E+8 KW-hr, which is equivalent to 500 000 billion oil barrels that is one thousand times any oil reserve known to man.

The major drawback of the vapour compression refrigeration system is that it requires large volume of refrigerant vapour which requires large mechanical power for its operation. If some methods are used to reduce this volume before compression, there would be considerable reduction in weight of the system and power requirement for its operation. Heat energy can be used instead of work for producing refrigeration because it gives high COP of the system with machine operated with supply of work energy.

Other hand, it has some attractive features such as its system requiring minimum maintenance and operation cost, and it does not have negative effects on the environment. Another important feature of solar energy is its ability to satisfy rural areas where conventional energy systems might be not suitable or uneconomical.

Solar energy is being invested in many forms. The first form is the most familiar and that is using it for supplying domestic hot water for residences which is the most worldwide spread form of solar energy use. Another form is the photovoltaic, and these are special cells that transfer solar energy to electric ones. Also, some power plants are now present that produce electricity from solar energy (e.g. US Pilot Power Plant of 516 degree Celsius average temperature (Friefeld & Coleman 1986) and the Japanese experiment stations of 1MW power out-put (Tanaska 1989).

Some other applications of solar energy being investigated are its use for cooling and heating of buildings. A lot of research is being conducted for this purpose especially in countries where there is high availability of solar energy just like in India. Solar energy is abundant in summer months where there is no heating load, but instead cooling is required. Solar air-conditioning has the advantage of both the supply of the sunshine and the need for refrigeration reaching maximum levels in the same season. As a result, solar air-conditioning is the particularly attractive application for solar energy.

II. PRINCIPLE OF ABSORPTION SYSTEM

There is the peculiar property of some substances to have affinity for another substances at some temperature and pressure conditions and less affinity at another conditions. This idea for the working principle of a vapour absorption system was generated by Michael Faraday in 1824. He knew that silver chloride (AgCl)m a white powder, had a
Two chambers are combined with the help of a tube. The white powder was kept inside the first chamber to which ammonia gas was supplied and sealed. The powder was heated up while other end was cooled using circulating water. Liquid ammonia was obtained in the cool end of the apparatus. After stopping heat, it was observed that, the liquid ammonia instead of sitting there, started boiling (bubbles produced) and vapour was reabsorbed by the white powder. Upon touching the boiling end, it was astonished to find that the vessel was very cold. It repeated the experiments and cooling was observed again. This led to invention of the intermittent Vapour absorption system having solid as an absorber.

III. REFRIGERANT–ABSORBER PAIRS

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Simple absorption system
The basic absorption cycle employs two fluids, the absorbate or refrigerant, and the absorbent. The most commonly fluids are Water/Ammonia as the refrigerant and lithium bromide/water as the absorbent. These fluids are separated and recombined in the absorption cycle. In the absorption cycle the low-pressure refrigerant vapor is absorbed into the absorbent releasing a large amount of heat. The liquid refrigerant/absorbent solution is pumped to a high-operating pressure generator using significantly less electricity than that for compressing the refrigerant for an electric chiller. Heat is added at the high-pressure generator from a gas burner, steam, hot water or hot gases. The added heat causes the refrigerant to desorb from the absorbent and vaporize.

The vapors flow to a condenser, where heat is rejected and condense to a high-pressure liquid. The liquid is then throttled through an expansion valve to the lower pressure in the evaporator where it evaporates by absorbing heat and provides useful cooling.

The remaining liquid absorbent, in the generator passes through a valve, where its pressure is reduced, and then is recombined with the low-pressure refrigerant vapors returning from the evaporator so the cycle can be repeated.

IV. ABSORPTION REFRIGERATION SYSTEMS

Another form of refrigeration that becomes economically attractive when there is a source of inexpensive heat energy at a temperature of 100 to 200°C is absorption refrigeration, where the refrigerant is absorbed by a transport medium and compressed in liquid form. The most widely used absorption refrigeration system is the ammonia-water system, where ammonia serves as the refrigerant and water as the transport medium. The work input to the pump is usually very small, and the COP of absorption refrigeration systems is defined as

$$\text{COP}_k = \frac{\text{COOLING EFFECT}}{\text{WORK INPUT}}$$
V. APPLICATION OF SOLAR ENERGY IN COOLING

In order to evaluate the potential of solar energy for the different solar cooling systems, a classification has been made by the scientists Best and Orgeta (1998). It is based on the two main concepts – solar thermal technologies for the conversion of solar heat into hot water, and the solar cooling technologies for the cold production.

The solar thermal technologies are:
- Flat plate collectors
- Evacuated tube collectors
- Stationary, non imaging concentrating collectors
- Dish type concentrating collectors
- Linear focusing concentrators
- Solar pond
- Photovoltaic

The solar cooling technologies are mainly classified into two main groups depending on the energy supply: a thermal/work driven system and electricity (Photovoltaic) driven system. Each group can be classified as the following:

1. Thermal/work driven system
   - Absorption refrigeration cycle
   - Adsorption refrigeration cycle
   - Chemical reaction refrigeration cycle
   - Desiccant cooling cycle
   - Ejector refrigeration cycle

2. Electricity (Photovoltaic) driven system
   - Vapour compression refrigeration cycle
   - Thermo-electric refrigeration cycle
   - Stirling refrigeration cycle

3. The solar-powered cooling system generally comprises three main parts: the solar energy conversion equipment, the refrigeration system, and the cooled object (e.g. a cooling box). A number of possible “paths” from solar energy to the “cooling services” are shown in Figure.

Solar absorption air conditioning system of the various air conditioning alternatives shown in Figure, the absorption system appears to be one of the most promising methods. The absorption cycle is similar in certain respects to the electrically driven vapour compression machines. A refrigeration cycle is...
operated with the condenser, expansion valve, and evaporator if low-pressure vapour from the evaporator can be transformed into high-pressure vapour and delivered to the condenser. The vapour compression system uses a compressor for this task. The absorption system first absorbs the low pressure vapour in an appropriate absorbing liquid. Embodied in the absorption process is the conversion of vapour into liquid, and since the process is akin to condensation, heat must be rejected during the process.

The next step is to elevate the pressure of the liquid with a pump, and the final step releases the vapour from the absorbing liquid by adding heat. Both cycles can be shown in the same figure. Figure shows the methods of transforming low-pressure vapour into high-pressure vapour in a refrigeration system.

Figure : Methods of transforming low-pressure vapour into high-pressure vapour in a refrigeration system

gle-effect solar absorption air-conditioning system with refrigerant storage (Grassie & Sheridan 1977). The refrigeration circuit includes the usual generator, condenser, evaporator and absorber together with a sensible heat exchanger, a mechanical pump and pressure reducing valves. A refrigerant store is associated with the condenser, while an absorber store is associated with the absorber. Heat rejection is accomplished by a cooling tower from which water is circulated through the absorber, condenser store and condenser in series.

The disadvantages of this system may be that:

• Generation of refrigerant ceases several hours before sunset and, although a significant amount of energy is still being collected, a lot of useful solar energy is wasted;

• The system may be very complicated. The generation power is not easily matched with the absorption and refrigeration power; besides, the control of valves 1 and 2 is difficult;

• Although the machine could store sufficient refrigerant during a typical day to allow overnight operation, the performance of the chiller is very low because of the decrease in concentration of the solution and the increase of the temperature and pressure in the system.
Single-effect solar absorption air-conditioning system with hot water storage

Efficient operation can be achieved by using two hot storage units for the collection of solar energy in different temperature ranges (Kreider & Krieth 1981). One storage unit would provide 70-75% of the total heat required at the lowest temperature, which can be utilized effectively at the part-load conditions. Typical temperature may be from 50 to 70°C depending on the building load pattern and the expected pattern of ambient temperature. The remaining 25-30% of the storage volume would be in a smaller tank, with more insolation in order to store the heat collected in 85-95°C. Still, higher temperatures may be used in this storage if it can be pressurized to prevent boiling, and if collectors are used which are capable of operating at higher temperature levels with good efficiency. Latent heat storage may be particularly worthwhile in the high-temperature unit since it tends to reduce its physical size for a given amount of kWh stored, and provides more heat at the levels needed for a full-loaded operation without significant temperature change.

In Figure, the pump P circulates the liquid from either the low or high temperature storage. Valves 1 and 2 are opened when the system is to add heat to the low temperature storage L, and valves 3 and 4 are opened for adding heat to the higher temperature storage H. Control C determines when the pump operates and which valves are opened.

The advantages of the above system are that separation of the storage into a high and low temperature subsystem may increase the heat collected by a given collector array by a factor of 1.30-1.50, depending on location and type of collectors. At the same time, the COP on a seasonal basis may rise from approximately 0.65 to 0.75, a 15% improvement. Taken together, these benefits may decrease the required collector area to cool a given building by 30-40%.

Double-effect solar absorption air-conditioning system

As technical development of absorption chillers allowed for lower generating temperatures as low as 73°C, the percentage of the solar contribution to air-conditioning become higher. The principle of the system is explained by using Figure. It is fundamentally a double effect absorption chiller, where the weak solution is circulated in series. In addition to the components listed in the single effect system, the double effect convertible system has a high pressure generator, a secondary heat exchanger and a heat recovery unit (Dai 1997).

The high pressure generator for steam is independently located from the low-pressure generator for solar and hot water vapour from the high pressure generator before being condensed. A high pressure generator gives a primary effect and a low-pressure generator a secondary effect, thus being called a double effect. Therefore, a double effect cycle requires lower heat input to produce the same cooling effect, when compared to a single effect system. Therefore, a double effect system results in higher COP. Two stage solar absorption air-conditioning systems. One of the restrictions for the practical use of the single stage cooling system is an economical aspect. The capital cost of single stage cooling system is too high. It is reasonable to lower the solar collector cost by using collector models of a lower temperature range, if the generator temperature of the chiller can be lowered by using two stages LiBr system instead of single stage system. Therefore, to bring down the initial cost of the system, the important variable is the generating temperature.
advantages of lowering the generator temperature are:

1. The ordinary flat plate collectors can be employed, thereby bringing down the cost of the system; and

2. Crystallization of the LiBr-H2O solution could be avoided.

In order to search for an approach to a more economical solution of solar absorption air-conditioning, a two-stage LiBr absorption chiller prototype, working on lower temperature heat source, has been designed and tested successfully by Huang et al. (1991) Initially, the two-stage LiBr absorption-cooling machine was designed for the purpose of low temperature industrial waste heat recovery, but it seems also suitable for a solar cooling application.

Figure 7 shows the schematic diagram of the two-stage solar absorption air-conditioning. The cycle is divided into a high-pressure stage and low-pressure stage. Diluted LiBr solution in the high-pressure generator is heated by hot water. Generated water vapour is condensed in the condenser. The condensed water flows into the evaporator (low-pressure stage) to be evaporated, producing the refrigerating effect. A concentrated solution from the high-pressure generator enters into the high-pressure absorber and absorbs water vapour generated from the low-pressure generator, thus changing back to a diluted solution. This solution is then pumped back to the high-pressure generator, completing a high-pressure cycle.

The concentrated solution in the low-pressure generator goes down into the low-pressure absorber and absorbs water vapour from the evaporator. The diluted solution from the low-pressure absorber is then pumped back to the low-pressure generator, completing a low-pressure cycle. Thus, refrigerant water is made in the high-pressure stage and the absorbent-concentrated solution is made in the low-pressure stage. So, through the high-pressure absorption process, the generation process in the low-pressure generator occurs under a low pressure, completing a full refrigeration cycle.

The two-stage system has the following advantages:

Figure 7: Schematic diagram of double effect solar absorption air-conditioning system
• The cooling system can work steadily though solar input is unsteady;

• The lower generator inlet and outlet temperature both increase instantaneously, and the daily efficiencies of the solar collector system;

• A required lower operating temperature provides the use a simpler model of a solar collector, e.g. flat plate collectors, instead of vacuum tube collectors, which are 3-4 times more expensive than the flat plate collectors, thus reducing the construction cost of the solar system.

The disadvantages of this system are the complexity of the chiller’s construction and the COP at the nominal generator temperature is lower than

![Figure 8: Schematic diagram of two-stage solar absorption air-conditioning system](image)

VI. RECOMMENDATIONS FOR FUTURE RESEARCH WORK

A solar powered absorption air-conditioning system is a complex, dynamic system and it is difficult to predict with any certainty the annual energy saving, and therefore, the return on investment. This uncertainty in system evaluation is a further obstacle to the wider application of solar cooling.

In order to improve the system design of a solar powered absorption air-conditioning system, a parametric study must be carried out to investigate the influence of key parameters on the overall system performance. If experiments were used to perform the parametric study, effects of one key parameter on the overall system performance would normally require several cooling seasons and hence, years to establish a conclusion. Also, it is extremely difficult to keep the performance of the system components to be constant over entire experimental period as the components deteriorate with time.

Therefore, in order to avoid extremely difficult and expensive experimentation, researchers can develop and validate a robust dynamic model of the solar powered absorption air-conditioning system and simulation can be done to study the system. This will help to perform the parametric study on the model rather than the physical system itself.

VII. CONCLUSION

Solar absorption air-conditioning has the advantage of both the supply of sunshine and the need for refrigeration to reach maximum levels in the same season. Of the two main technologies of solar cooling systems namely, solar thermal technology and solar
cooling technology, the emphasis in this paper is placed on solar cooling technology.

Some of the findings of this paper are as follows:

• Among the major working pairs available, LiBr-H2O is considered to be better suited for solar absorption air-conditioning applications.

• Generator inlet temperature of the chiller is the most important parameter in the design and fabrication of a solar powered air-conditioning system.

• A Single effect system with refrigerant storage has the advantage of accumulating refrigerant during the hours of high solar insolation but the double effect convertible system has a higher overall COP.

• A Two-stage system has the advantage of lowering the generator temperature, which provides the use of conventional flat plate collectors, thereby bringing down the cost of the system.

REFERENCES


