Solar Cooling System: Progress, Prospect and Future Directions

Satyajit Mojumder[1], Sourav Saha[1], M. M. Rahman[2,3], M.A.H. Mamun[1],
[1]Department of Mechanical Engineering,
[2] Department of Mathematics,
Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh
[3]Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603, Kuala Lumpur, Malaysia
E-mail: sjit018@gmail.com

Abstract

The paper provides a review on the use of solar energy as a renewable energy source. Special attention has been given to the solar cooling methods which are in use at present. The paper discusses the need, existing technologies, studies and a tentative way to improvise the existing cooling methods using solar energy on the basis of researches carried out. While electricity- powered conventional cooling systems are providing us with a better output it is imperative to look for a new, economic and greener way to produce cooling effects since electrical energy is dependent on non-renewable energy sources. Again thermo-electric method of cooling has an adverse effect on climate which can't be ignored. This paper highlights the role of solar energy as an alternative to electrical energy to provide cooling effects with literary explanations and numerical evidences..

Keywords: Solar Energy, Cooling Technology, Liquid Desiccant, Solar cooling performance, Solar cooling.

1. Introduction

Different refrigeration and cooling systems are inseparable parts of our modern life. From preservation of food to scientific researches we use various cooling methods to meet our demand. While refrigeration or air-conditioning is very much available in the industrialized countries, people from all over the world don't have access to these necessities. The reasons behind that are the existing comparatively costly methods of producing cooling effect using electricity and unavailability of a stable alternative energy source. Moreover the production of electricity ultimately depends on the burning of fossil fuels which is detrimental to the environment too. Utilization of solar energy can be a solution to all these problems. There exist different cooling cycles like absorption cooling, adsorption cooling, desiccant cooling etc. At present many researches are being carried out by scientists all over the world in order to find a way to make an efficient and inexpensive solar cooling system. Although the idea of solar cooling may seem a very attractive one its practicality is still in question as it needs costly components for solar energy storing and merging with cooling components. Also the present solar driven cooling systems are not giving enough output to outrun the electrically driven or gas-fired cooling systems. Since the existing cooling cycles are providing very good output completely replacing them with new ones will not be very intelligent way to approach, rather merging the common and more advanced cooling techniques (like desiccant cooling or Metal hydride cooling or ejector driven cooling) with solar energy source is the only way of improving efficiency of cooling methods. Throughout the paper gradually traditional cooling cycles, cooling methods, analysis of existing plants, environmental and economic impact etc. have been discussed to observe the recent trend on solar cooling technology.

2. Cooling systems using solar energy

As the civilization is developing the demand of cooling is also increasing at a proportional rate. A huge amount of electrical energy is used on cooling. This electrical energy in most cases comes from the fossil fuel. But if we can use renewable energy like solar energy as an alternative it will be both cost effective and environmental friendly.
There are different ways of cooling using the solar energy. These are discussed below along with various designs. There are different cycles for cooling using solar energy. The basic ways are shown in the diagram [1] given below.

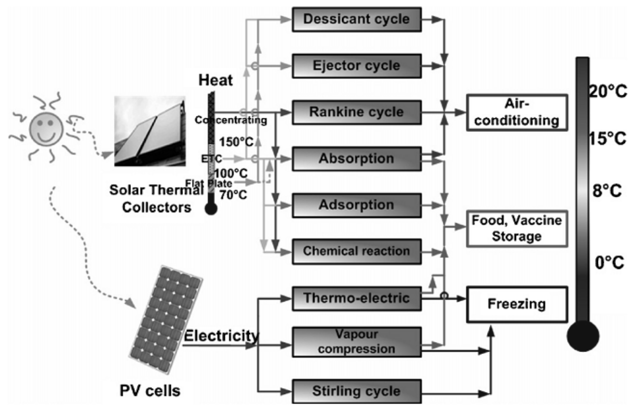

Fig.1. Solar cooling paths

2.1. Adsorption chiller

Adsorption chillers generally use silica gel and water pair as a working fluid. This chiller operates on 60-80 degree Celsius hot water. We have to use two adsorbers, one condenser and one evaporator for the continuous cooling power. By using a mass recovery system and heat recovery system between the two beds the COP can be improved. This is done by introducing vacuum valve. But in the practical system we place our adsorber, condenser and evaporator in a vacuum chamber. As for this system temperature needed is about 60-80 degree Celsius, it is efficient to use flat plate solar collector rather than vacuum tube solar collector. Later in Germany it was further developed [2, 3, 4] and now it is possible to get cooling capacity about 5.5 KW and hot water temperature (18-15 degree Celsius) and chilled water temperature about 67-75 degree Celsius. Saha et al. [5, 6] first developed four bed two stage silica gel water adsorption chiller and at 2006.

2.2. Ammonia –water absorption chiller

This type of chiller is quite popular. Here we use ammonia and water solution as the working fluid where water is the absorber and ammonia is the refrigerant. This chiller consists of generator, condenser, evaporator and absorber. As the solar collector heat the solution (here ammonia is a solute) the concentrated or rich solution becomes weak solution and ammonia becomes vapor. This ammonia vapor is condensed and then goes through the throttle valve and is evaporated in the evaporator creating the cooling effect. There is a GAX (generator-absorber exchanger) which improves the COP of the cycle but for this we need higher temperature [4]. For supplying heat we can use flat plate, evacuated tubes or concentrating collector. This solar collector working temperature is normally 80-120 degree C and COP developed is .3-.7.In Germany 10 KW single effect ammonia –water absorption chiller is developed by the solar next company. In this chiller the driving temperature is about 68-75 degree C and cooling water temperature is about 24-29 degree C and the chilled water temperature is about 16-19 degree C. Robur company in Italy has produced a Cooling capacity of 17 KW.[7] In a research in Austria using a 40 m^2 flat plate collector chilled temperature was 16-19 degree C and it produced a cooling capacity of 9 KW.[8].

2.3. LiBr-water absorption chiller

In this type of chiller weak solution of LiBr-water solution enters the generator. The generator is heated by the solar collector. So after entering into the generator the weak solution becomes concentrated and rich solution. This strong solution returns back to the absorber through an inner heat recovery system. This desorbed water become liquid in the condenser then it passes through an evaporator. By the absorber the strong solution absorbs water vapor continuously and causes evaporation. This evaporation gives the desired cooling effect. This process required higher temperature about 88 degree C. By this system we can now make 100 KW cooling capacity [9] By using double stage hot water temperature can be reduced to 70-75 degree C and a COP of about 0.4 can be developed. In the University of Hong Kong Li and Sumathy developed a system[10] in which a flat plate collector array with a surface area of $38m^2$ is used to drive a LiBr–water absorption chiller that gives 4.47 KW cooling capacity and COP .07.

2.4. Solid desiccant cooling system

In this system ambient air flows through the desiccant wheel where the desiccants material consumes the moisture. A heat exchanger is used for the adsorption of heat and for the preheating of the regeneration air. This is a continuous process where the desiccant material is heated one time and cooled again. Nowadays desiccants materials are LiCl, Silica gel, molecular-sieve. Molecular sieve is used since it has a good dehumidification capacity but it requires high temperature. So for using solar energy it is not convenient. Researchers are now focusing on how to lower the regeneration temperature. Vacuum tube collector is proposed for this system as it needs high temperature for the regeneration. The important thing to notice about the solid desiccant cooling is that this is a CFC free system and requires no pump.

2.5. Liquid desiccant cooling system

Liquid desiccant (LiCl) has strong affinity for water. At first air is dehumidified by the desiccant solution. Then the processed air is again cooled by evaporator. There is a regenerator to regenerate the concentration of the liquid desiccant. This regeneration can be done in a very low temperature at 50-80 degree C. As the temperature required is low so we can use flat plate solar collector for this purpose. Jain and Bansal [11] showed that this system can work on 40 degree C temperature. Mei and die [12] describe about three kinds of regenerators powered by solar energy exist, i.e. open regenerator/collector, closed regenerator/collector, and regenerator plus collector. Gommed and Grossman [13] settled a system whose average dehumidification capacity reaches 16 kW powered by 20m^2 solar collector areas.

2.7. Ejector based cooling system

Ejector based cooling system is basically the jet refrigeration. We can reduce throttle loss by using an ejector. The ejector is introduced in order to utilize energy from the high-pressure side of the weak solution in the generator. The high-pressure weak solution in the generator expands through the nozzle in the ejector and creates a vacuum at the other end of the ejector. As a vacuum occurs, the vapour from the evaporator is drawn into the ejector. So Zen and O zalp [14] proposed a solar-driven ejector-absorption system operated with aqua-ammonia.

3. Data and analysis

The different system gives different ranges of temperature, COP cooling capacity. In this section we compare between different systems of cooling. Quality of cooling systems depends on the following facts:

- Temperature range that can be attained by solar collector.
- Desired cooling capacity
- Expected temperature.

Some graphs are plotted on monthly average COP and solar thermal gain to compare between the methods in figure 2. [15]This analysis shows us the year around performance of different solar systems along with COP and solar thermal gain for different type of cooling system and collector type.

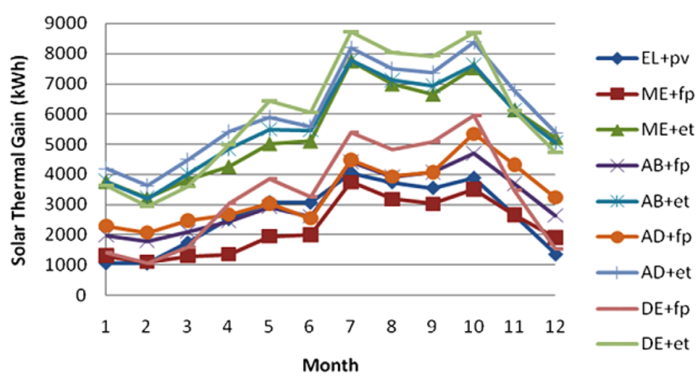

Fig.2. Annual profiles of solar thermal gain of different solar cooling systems. (Abbreviations: AB: absorption refrigeration; AD: adsorption refrigeration; DE: desiccant cooling; EL: electric compression refrigeration; ME: mechanical compression refrigeration; et: evacuated tubes; fp: flat plate collectors; pv: photovoltaic panels)[15]

From this analysis it is clear that the solar thermal gain is very high in the desiccant cooling system and low in the vapor compression cycle. From the analysis of the figure 3 it can be concluded that desiccant cooling gives higher COP, but the COP is varying with time where adsorption cooling gives a constant COP around the year.

It can be said that every system has some advantages and some disadvantages. So it is wise to use different system on the basis of condition available. However vapor compression cooling gives very low output where others give better output.

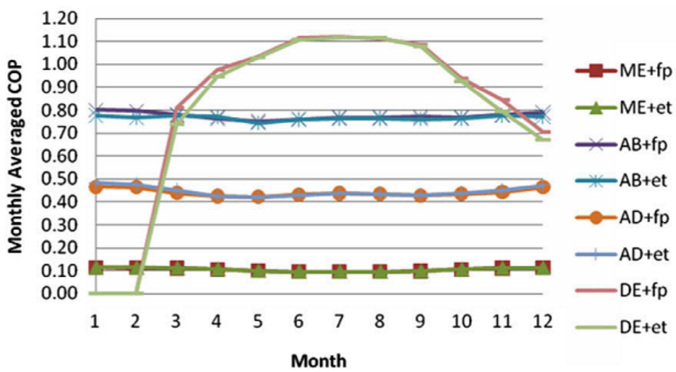

Fig.3. Annual profiles of co-efficient of performance of different solar cooling systems. (Abbreviations: AB: absorption refrigeration; AD: adsorption refrigeration; DE: desiccant cooling; ME, mechanical compression refrigeration; et, evacuated tubes; fp: flat plate collectors; pv: photovoltaic panels)[15].

Table 1. Comparison and main feature of different available cooling technology

Sorption Refrigeration technologies		**Refrigeration output**	**Capacity range**	**Cooling method**	**COP**	**Suitable application**
LiBr-H_2O Absorption	Single effect	5-10 degree C chilled water	5-7000kw	Cooling water	0.5-0.7	Industry, commercial and institutional building
	Double effect	5-10 degree C chilled water	20-11630kw	Cooling water	1.0-1.2	Industry, commercial and institutional building
	Triple effect	5-10 degree C chilled water	530-1400kw	Cooling water	1.4-1.7	Industry, commercial and institutional building
Water-ammonia absorption	single effect	5-10 degree c chilled water	10-90kw	Cooling water or air cooled	0.5-0.6	Large capacity industrial use and residential use, building cooling
	Double effect	5-10 degree c chilled water	<110kw	Cooling water or air cooled	0.8-1.2	Large capacity industrial use and residential use, building cooling
Adsorption	Silica gel-water	7-15 degree c chilled water	5-1000kw	Cooling water	0.3-0.7	Experimental and ice making
	Activated carbon	Ice or -10to-15 degree c glycol water	<12kw	Cooling water	0.1-0.4	Experimental and ice making
Solid desiccant cooling	-	18-26 degree c dehumidified cold air	5-50kw 500-50000 m^3h^{-1}	Cooling water	0.3-1.0+	Industrial process and storage.
Liquid desiccant cooling	-	18-26 degree c dehumidified cold air	50-500kw 3000-140000 m^3h^{-1}	Cooling water or air cooled	0.5-1.2	Large capacity industrial deep drying building comfort and indoor air quality control ,removing airborne particles

Comparisons on different solar cooling technology along with their application field are presented in the table 1. From the comparison it is clear that though absorption cooling has higher value of COP still dessicant cooling show good results also. And for some perspective dessicant cooling show excellent result such as for liquid dessicant cooling it can also work for a few hour in night hour

4. Economic feasibility

Economic feasibility is the major issue for any kind of engineering system design. At present days the absorption system is mostly used, but it is not economically feasible always. For the adsorption chiller large solar collector area is required. As a result the COP of the cycle decreases. So the researchers are trying to improve the silica gel water adsorption chiller and their control system to make them more profitable.

The desiccant cooling system is very much cost effective. It is better than any other sorption system on the point of economic feasibility. Its installation cost and maintenance cost both are significantly less than other systems. A 5 KW solar system is capable of heating, cooling and providing hot water supply could be with a cost of 5 K£ , which means the rated kW cooling cost is 1 K£/ kW.[16]A typical installation of dessicant cooling plant in Althengstett of Germany is shown in the figure 4.From which the distribution of installation cost can be found.

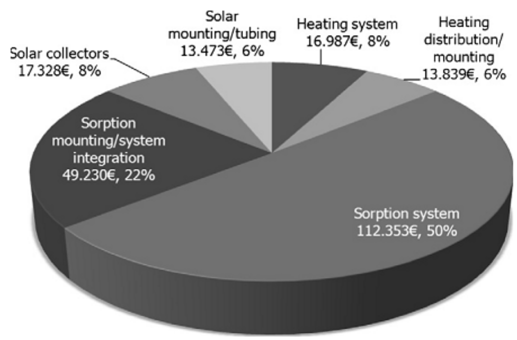

Fig .4. Distribution of investment costs for the German desiccant cooling plant in Althengstett

5. Environmental issue

Refrigerants are the major element in a cooling system. Some refrigerants yielding high performance are not environment-friendly. Some have a high ODP (an impact on the stratospheric ozone layer compared to R11) or a high GWP (a factor indicating the relative effect on global warming compared to CO_2). Many working fluids such as R11, R113, or R114 are nowadays forbidden. New refrigerants are now developed and under study, for example, R123, R134a, R152a and ammonia. Using the solar energy we are able to reduce the use of electrical energy. As most of the electrical energy come from burning the fossil fuel by using solar technology we can reduce the carbon emission. This can make a little contribution to the improvement of the world temperature-rise crisis as well as greenhouse effect.

6. Results and Discussion

Every engineering system has its pros and cons. To discuss on solar energy aided cooling systems we can mention the following key points on the viability issue:

- This technology completely relies on the solar power and hence can’t be used at nights unless there is a backup power system. But backup power system means unwanted cost. However a recent liquid desiccant technology can store thermal energy which can give 4 hours of backup.

- In absorption and adsorption system we need pump which is a rotating machine. If any how it stops working it will disturb the whole process. For this we can pay attention to the ejector based cooling system.

- For using the liquid desiccant cooling system we need the regenerator temperature of only 40-50 degree C. But it is not achievable as it has corrosive effect. So we need to develop some kind of desiccant by which we can create cooling effect using very low energy

- If there is any kind of bad weather, it is not possible to operate the cooling system from poor solar radiation. So we should always be careful about the backup system. It can be either electrical heating or gas heating.

- The cooling capacity largely depends on the solar collector. As the collector is not yet that improved so we can't convert the maximum solar energy into heat energy. So a careful attention should be given on improving the solar collector and the thermal storage system.

7. Conclusion

The paper gives a general overview of the modern cooling systems and most recent developments on the field of cooling. From discussion it can be seen that many of the technologies which are used nowadays have a great potential for improvement and some have practical shortcomings. In an era when severe energy crisis is sauntering towards the modern civilization it is impossible to be completely oblivious to the new prospects in alternative energy source. Proper attention and extensive research can make solar cooling technology an attractive option for us.

8. References

[1] J.M. Abdulateef, K. Sopian, M.A. Alghoul , M.Y. Sulaiman, "Review on solar-driven ejector refrigeration technologies", Renewable and Sustainable Energy Reviews ,Vol.13 ,pp 1338–1349,2009

[2]Jakob, U.,. "Recent developments of solar air-conditioning in Europe" Cryogenics and Refrigeration – Proceedings of ICCR, 5–9 April 2008,Shanghai, China, pp. 659–667, 2008.

[3]Jakob, U., Huber, M., Dubbelfeld, D., Aubele, R., "Experimental investigation of a novel solar cooling system based on a small-scale water/silica gel adsorption heat pump." In: International Symposium on Innovative Materials for Processes in Energy Systems, Kyoto, Japan, 28–31 October 2007.

[4]Jakob, U., Pink, W., "Development and investigation of an ammonia/water absorption chiller – chillii PSC – for a solar cooling system." Proc. of the 2nd International Conference Solar Air-Conditioning, Tarragona, Spain, 18–19 October 2007, pp. 440–445.

[5] Saha, B.B., Akisawa, A., Kashiwagi, T. "Solar waste heat driven two-stage adsorption chiller: the prototype", Renewable .Energy Vol.23,pp. 93–101, 2001.

[6]Saha, B.B., Koyama, S., Ng, K.C., Hamamoto, Y., Akisawa, A., Kashiwagi, T., "Study on a dual-mode, multi-stage, multi-bed regenerative adsorption chiller". Renewable Energy, Vol.31, pp.2076–2090, 2006.

[7] Ha ¨berle, A., Luginsland, F., Zahler, C., Berger, M., Rommel, M.,Henning, H.M., Guerra, M., De Paoli, F., Motta, M., Aprile, M "A linear concentrating Fresnel collector driving aNH3–H2O absorption chiller." Proc. of the 2nd International Conference Solar Air-Conditioning, Tarragona,Spain, 18–19 October 2007, pp. 662–667, 2007.

[8] R.Z. Wang, T.S. Ge, C.J. Chen, Q. Ma, Z.Q. Xiong , "Solar sorption cooling systems for residential applications: Options and guidelines", international journal of refrigeration Vol.32,pp. 638–660,2009.

[9] Ma, W.B., Deng, S.M., "Theoretical analysis of low-temperature heat source driven two-stage LiBr/H2Oabsorption refrigeration system.", Int. J. Refrig. Vol.19, pp.141–146, 1996.

[10] Li, Z.F., Sumathy, K., "Experimental studies on a solar powered air conditioning system with partitioned hot water storage tank." Solar Energy Vol.71, pp.285–297, 2001.

[11] Jain, S., Bansal, P.K., "Performance analysis of liquid desiccant dehumidification systems.",Int. J. Refrig. Vol.30,pp.861–872,2007

[12] Mei, L., Dai, Y.J., "A technical review on use of liquid-desiccant dehumidification for air-conditioning application" Renewable and Sustainable Energy Reviews. Vol.12,pp. 662–689,2008.

[13] Gommed, K., Grossman, G., "Experimental investigation of a liquid desiccant system for solar cooling and dehumidification." Solar Energy Vol.81, pp.131–138,2007.

[14] So ¨zen A, O ¨ zalpM. "Solar-driven ejector-absorption cooling system." Applied EnergyVol.80;:pp97–113,2005.

[15] Fong K.F.,. Chow T.T,. Lee C.K, Z. Lin, Chan L.S., "Comparative study of different solar cooling systems for buildings in subtropical city" Solar Energy Vol.84, pp. 227–244, 2010

[16] Eicker U., Schneider D., Schumacher J, Tianshu Ge , Dai Y, "Operational experiences with solar air collector driven desiccant cooling systems " Applied EnergyVol. 87, pp. 3735–3747, 2010.

[17]. Deng J., Wang R.Z. , Han G.Y., "A review of thermally activated cooling technologies for combined cooling, heating and power systems," Progress in Energy and Combustion Science ,Vol.37 pp.172-203,2011.