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Experimental Investigation and Analysis of Solar Refrigeration System

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Abstract

A solar cooling system consisting of parabolic trough collector array, absorption machine of 100 KW, cooling tower was studied under real time conditions. The system worked entirely with solar energy and produced cooling for 5h (under permanent regime) on a hot day. Cooling produced by this technology was absolutely CFC free and there was no production of CO2, during this process because we were not using the electricity from the thermal sources. Working and operation of the solar powered Li-Br-H_20 absorption systems was totally dependent upon the solar thermal (heat). This system was found more suitable for the countries where sunshine hours and summer session are longer i.e. near the equator. Efficiency parameter of the chiller that is co-efficient of performance was determined and analyzed that this system has highest cop up to 1.56 as compared with the single and double effect system. Cop of the solar powered was varying with the solar radiations. At high solar intensity temperature of the hot water goes maximum and produced the maximum cooling effect up to 1.7 depending upon the intensity and duration of the solar radiations.

Keywords: C.O.P, Parabolic trough, Solar cooling, Vapour Absorption

INTRODUCTION

Air conditioning units and refrigerators already consume 20% of the electrical energy world-wide. The energy requirement for air conditioning alone is grown at an average of 7% annually until the year 2050 in developing countries [1]. The rapidly increasing demand for refrigeration and cooling and the associated problems of gas emissions, which damage the ozone layer and climate, as well as the consumption of energy and resources may only be solved sustainably with a change-over to natural refrigerants. Refrigeration which runs on electricity provided by solar energy is known as solar refrigeration. Solar-Powered refrigeration may be most commonly used in the future generation.

The sun provides an annual average energy (worldwide) of approximately 1150KWh/m^2/yr on a horizontal surface at its surface with a peak power of approximate 1.0KW/m^2 at sea level, with an annual number of sunshine hours ranging from 1600to values greater than 3600.It is therefore no doubt that a vast amount of energy is available to us from the sun and all we need is fairly efficient devices for collecting this energy. [2]

Solar refrigeration has the potential to improve the quality of life for people who live in areas where electricity supply is inadequate and important role in industrial and commercial sector for cooling and heating applications. The use of refrigeration is to keep food fresh, has become a part of our daily life in this society. Several solar refrigeration systems have been proposed and are under development such as absorption systems including liquid/vapor compression and photovoltaic vapor compression systems. However major goal is to develop a CFC-free refrigeration system that can utilize waste heat or renewable heat or renewable sources. Solar adsorption cooling systems promise to provide a safe alternative to CFC based refrigeration device. In the last few decades, more investigations on the performance of the absorption refrigeration system were conducted considering various absorbent –absorbate working pair.

Solar cooling is a very attractive topic for researches of solar thermal field .The reason for this is that the cooling load usually reaches its peak value when solar energy is mostly available. The conventional refrigeration system is basically of two types; the vapour compression refrigeration system and vapour absorption of refrigeration system. The absorption cooling cycle is usually a preferable alternative since it uses thermal energy collected from the sun without the need to covert this energy into mechanical energy as required by the vapour compression cycle. [3].

MATERIALS AND METHODS

Collectors used for concentrating are usually parabolic troughs that use mirrored surfaces to concentrate the sun's energy on an absorber tube (called a receiver) containing a heat-transfer fluid, or the water itself. This type of solar collector is generally used for commercial production applications, because very high temperatures can be achieved. The main disadvantage of this type of system is that it is reliant on direct sunlight and therefore does not perform well in overcast conditions. There are various types of collectors, but for the purpose of this study a parabolic-trough type solar collector is considered.

A parabolic trough is a type of solar thermal energy collector. It is constructed as a long parabolic mirror (usually coated silver or polished aluminum) with a dewer tube running its length at the focal point. Sunlight is reflected by the mirror and concentrated on the Dewar tube. The trough is usually aligned on a north-south axis, and rotated to track the sun as it moves across sky each day.

SYSTEM DESCRIPTION

Solar powered LiBr-H_2O absorption systems mainly consist of following components.

1) Solar field: Solar field was composed of the solar collectors, so it is necessary to have a look on the type of collectors and why we are using concentrating parabolic trough as collectors in the solar field.

2) Stationary Collectors: These collectors are permanently fixed in position and do not track the sun. Three types of collectors fall in this category:

   -flat plate collectors (FPC)

   -Stationary compound parabolic collectors (CPC)

   -Evacuated tube collectors (ETC)

3) Concentrating Collectors: These types of collectors rotate according to solar angle. These collectors can rotate both in single and double axes.

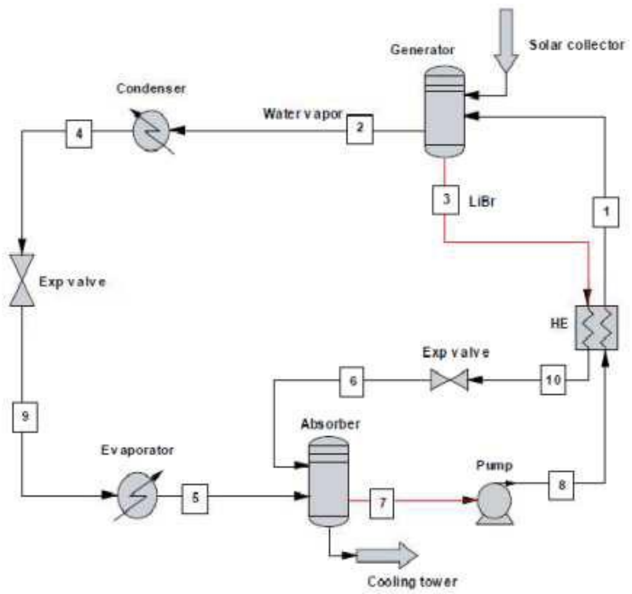

Figure 1. Schemtic diagram of absorption cycle

A **solar field** was created in the solar energy center with the concentrating parabolic trough working as collectors. There were six rows of parabolic troughs in the solar field and each row having eight numbers of the collector modules. The parabolic modules are made up of the aluminum metal and each module having an absorber area of 5.9m^2. This leads to the total absorber area of 284m^2. A steel pipe was passed through the focal line of parabolic trough covered with black surface with the glass rode to maximum absorption and reduces the losses. The line focusing solar fields of parabolic trough reflect the incident radiation on an absorber positioned in the focal line of the concentrator. The collector tracks the sun in one axis. This solar field also had temperature sensor which are located on the piping system so that accurate information about the temperature can be obtained and transferred to the control room so that temperature of the every row can be highlighted at the every minute of the sun hours and the sensors showed about the all information regarding to the temperature at every point of exit head.

Solar Tracking control panel: The concentrating parabolic trough which concentrate the maximum sun radiation on the absorber, so it is necessary to command the concentrating parabolic trough according to the sun so that the maximum radiation can be obtained. That's why a tracking system was configured with software installed in tracking control panel, which rotate the collector according to the sun rotation. This tracking control panel consists of:

1) Pyranometer – to measure the sun radiations at every instance.

2) Two P.L.C. – One for the rotation of first three rows and another for the next three i.e. fourth to sixth rows. This P.L.C. commands the trough from east to west direction according to angle of the sun. These are based on the calculation of solar angle of the sun. These are based on the calculation of the solar angle calculated and solar angle commanded by the software and rotate the collectors by using an electrical motor with a gear box. Tracking system can be operated on both manual and automatic mode. Mostly, we use the automatic mode of operational manual mode in case of mismatching between the rows of the collector. A lot of sensors were connected in the tracking control panel regarding to the rotation mechanism based on the electric motor for tracking system.

All the data regarding to solar radiation, wind velocity, total direct normal incidences, rotation direction, speed of rotation, solar angle calculated and commanded, temperature profile of the every trough was obtained through this control panel. And this data is being transferred to the control room so that operator can easily check the problem.

Vapour absorption Machine: Chiller was installed by the Thermax India pvt.ltd in the centre having a capacity of 100 kW i.e. 30TR. This machine can operated on the temperature of 210^{o}C obtained from solar field depending upon the solar radiations. This is the main part of the whole system because the heat produced by the solar field is used here for converting it into the chilling effect. The generator design of the machine allowed the use of hot water in the temperature range of 140-210 ^{o}C.The cold production was observed to begin when the temperature range is above or equal to 140 ^{o}C. The measured volumetric flow rate of hot water delivered by generator pump was ranging from 2 to 5.6m^3/h. Since the temperature of hot water entering and leaving the generator was also measured, at any given time, the heat delivered to the generator was evaluated from the following equation:

$$Q_g = mhw * C_p * (tlhw - tehw) \quad \text{-----} \quad (1)$$

Nominal cooling capacity of 100 kW can be produced with this chiller at the following operating conditions:

Entering/leaving hot water temperature 140 to 210 ^{o}C (at mass flow rate: 0.5 to 1.55 kg/second). Entering/leaving cooling water temperature 30.5/35 ºC (at mass flow rate: 6.1 to 9.16kg/second).

A set of the fan coil unit (FCU) was used to supply cold air into the centre space. A second FCU was used to regulate the chilled water temperature and provided a safety measures for ensuring that the evaporator temperature was kept above 4-5 ºC at all time, irrespective of the cooling coil load. Lower evaporating temperatures can result in a freezing problem. The cooling coil was directly connected to the evaporator. The chilled water temperature was kept within 7-12 ºC by thermostatic control. Chilled water flow rate was measured about at every application depending upon the load variation. The entering and leaving chilled water temperatures were measured, which allowed the estimation of the evaporator load at any given time from the following equation:

$$Q_e = mchw * C_p * (techw - tlchw) \qquad \text{---- (2)}$$

A cooling tower was used for rejecting the heat of absorption and condensation and supplied cooling water in absorber and condenser in parallel at about 30 to 35 ºC. Crystallization problem was not encountered by supplying low cooling water temperature. The measured flow rate of cooling water delivered by the condenser pumps was varying depending upon the heat gain by evaporator and generator. The cooling tower used was of open forced-draft type (fan located at the base of the unit). The total heat rejection rate was evaluated from the sum of the heat dissipated at the condenser and the absorber.

$$Q_a + Q_C = mcw * C_p \qquad \text{---- (3)}$$

The equation is an energy balance relation applied to the main heat exchangers of the absorption machine. The result showed that the machine was operating near adiabatically, such that minor losses to the surroundings were found.

$$Q_g + Q_e = Q_C + Q_a + Q_a; loss \qquad \text{---- (4)}$$

Total heat losses during the operation can be determined as:

$$\text{Heat balance error} = Q_e - Q_c + Q_g/100 \qquad \text{---- (5)}$$

Heat balance error should be less than seven percent for effective functioning of the chiller.

Capacity of the machine also changed during its working hours depending upon the temperature variation of the generator because of variations of solar heat. It also changed the flow rate of the chilled water and temperature differences among the inlet and outlet temperature of the chilled water. Maximum capacity of the 100KW chiller can be 30 TR. It can be determined as:

$$\text{Capacity} = mchw * C_p * (itch - otchw)/3.024 \qquad \text{----- (6)}$$

Another system parameter of the chiller was instantaneous solar cooling ratio, which was evaluated from the ratio of cooling produced and the solar radiation incident on the tilted plane of the collectors given by the following relation:

$$SCR = \frac{Q_e}{DNI} \qquad \text{----- (7)}$$

And ratio of heat input to generator and solar radiations tilted on the collectors can be determined as:

$$= \frac{Q_g}{DNI} \qquad \text{------- (8)}$$

Total freezing effect produced was measured in terms of the co-efficient of performance of that system. It was a system efficiency parameter of the chiller and shows the output over input. The refrigerator coefficient of performance (COP) was calculated as equation (8):

$$COP = \frac{Q_g}{Q_e} \qquad \text{----- (9)}$$

Although the COP varied widely, during the day duet the chiller operating in transient regime, a maximum COP of 1.7 can be obtained from this triple effect chiller.

Pressurized hot water is being supplied to the machine via pipes covered with the thermo coal so that heat losses can be avoided. Vapor absorption machine has various components like the high temperature generator, medium temperature generator, low temperature generator, condenser, evaporator, absorber, heat exchanger, vacuum pump.

Two thermal energy storage tanks are also had been put with the experimental set up. One tank for the storage of the high pressurized hot water specially designed for the high temperature generator usages and another one for the low temperature generator to maintain the temperature fluctuation in cloudy day of the season.

A control room was also established for operator so that all the activities whether regarding to the solar field or chiller and flow of hot or cooling water and reverse osmosis water can be easily supervised with the help of the computer monitor. The whole set up is connected with the sensors so that a single person can operate the whole system easily in automatic mode.

RESUTL AND DISCUSSION

Effect of the solar time on solar cooling ratio: Solar cooling ratio was totally dependent on the total heat dissipated by evaporator and direct normal incidence on the concentrated parabolic trough. Value of the direct incidence varies according to the solar time i.e. value of the direct normal incidences increases as the solar time increases from morning to afternoon hours and it again start decreasing from afternoon to evening. But the heat dissipated by evaporator was a function of the chilled water flow rate and temperature difference among the chilled water inlet/outlet. So it conclude that as a solar time increases value of the direct normal incidences also increases , which lead to increases in the heat dissipated by evaporator , so value of the solar cooling ratio also increase up-to increase of the direct normal incidences. But when the solar radiation decreases with solar time, it also decreases solar cooling ratio.

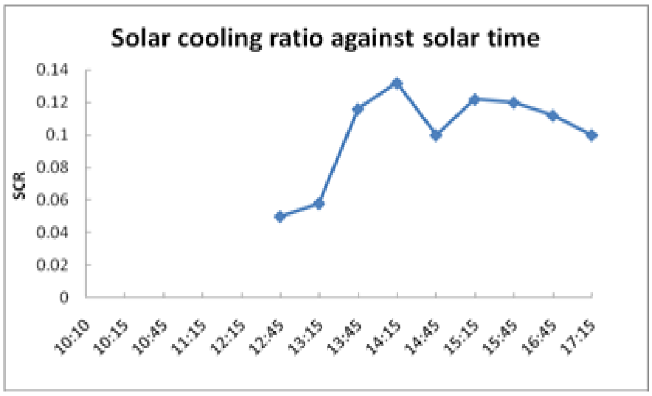

Figure 2. Solar cooling ratio against solar time

As shown in figure 2. solar cooling ratio was going to increase from 12:45 to 14:15 because value of DNI was maximum at this time which leads to great cooling production. The value of the solar cooling ratio at 12:15 was 0.072 and it had a highest value of 0.132 at 14:15.Solar cooling ratio goes down with respect to time, it also decreases the value of the solar cooling ratio, which was about 0.10 at 17:15, when machine shuttled down.

Heat flows in the absorption cooling process against solar time: The absorption cooling process was analyzed by representing the heat inputs and outputs to the machine to establish a heat balance. The equation (1)-(5) were used to calculate the generator, evaporator and condenser plus absorber heat loads. The heat input to the chiller at the generator and evaporator was found to be approximately equal to the sum of the heat rejected at the condenser and absorber. The heat flows were not exactly balanced due to the heat loss from the absorption machine, since the refrigeration process was non-adiabatic. The figure 3 concludes that in this triple affect system heat dissipated by the generator, which gives a higher value of the coefficient of performance. And the heat rejected by the condenser and absorber will be equal to sum of the both heat dissipated by evaporator and generator. The analysis of figure 3, also clearly indicate that heat flows in the absorption cooling process increases with the solar time when solar radiation have a maximum value of the direct normal incidences but

it start decrease when radiations goes down which lead to evaporator and generator also goes down. And same pattern was also followed by the condenser and absorber for the heat rejection. The figure 3 also shows that value of heat input to generator and evaporator and heat rejection by the condenser and absorber are totally dependent upon solar time. Defining that as the solar time increase from 12:45 to 15:15, value of heat input and rejection, both also increases. But after 15:45 due to sharp decrease in solar radiation with solar time, values of the heat input and rejection also decreases from maximum to minimum of each energy flow.

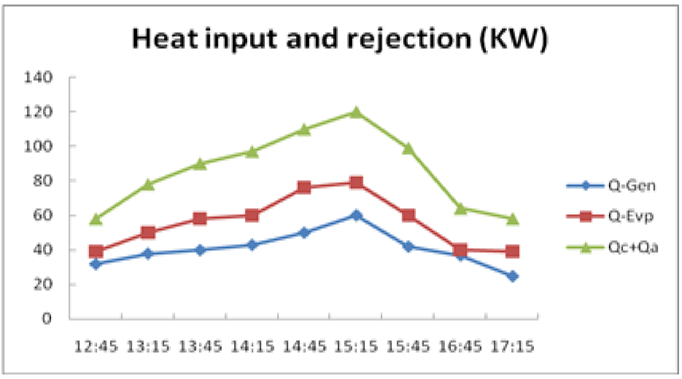

Figure 3. Heat input & rejection(KW)

Effect of solar time on co-efficient of performance: The variation of c.o.p. with respect to solar time is shown in figure 4. This shows that the value of c.o.p varied according to solar time, mean and variation of the solar radiation with respect to time, because solar radiations vary according to the time of the day. The temperature of the chiller also vary, when radiations increase or decrease with the duration of the day and it will definitely increase or decrease the efficiency parameter i.e. c.o.p of the machine.

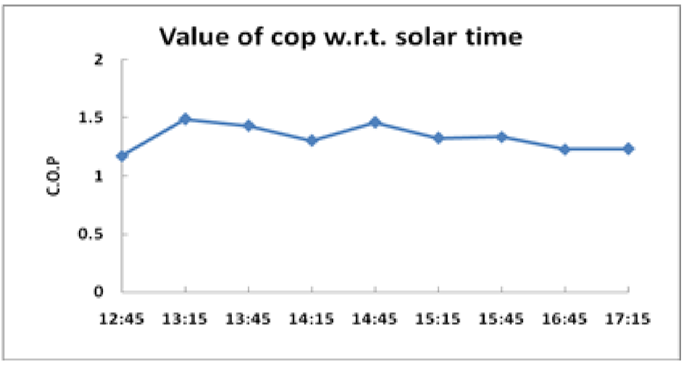

Figure 4. Values of Coefficient of performance with respect to solar time

As shown in figure 4, that at solar time of 12:45 c.o.p was 1.17 and at same time radiation was 696 w/m^2. Figure 4 also depicts that maximum cop value obtained was 1.5 at the solar time of 14:15. As the solar radiation decrease at evening, the cop value of the chiller also decreases, showing a clear message that large value of solar radiations produce maximum value of the heat input to the generator and evaporator and give maximum cop or cooling effect.

Variation of the solar radiation with solar time: As shown in figure 5, the variations of solar radiations with respect to the solar time. Because of solar radiations do not have a constant value, it change according to earth rotation from east to west direction. Therefore, solar radiation has a definite value at a particular instant of time.

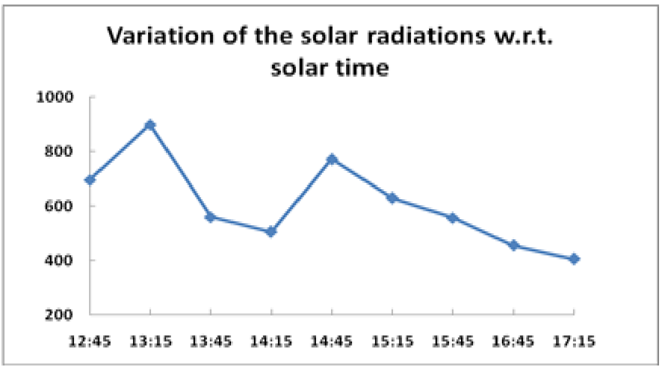

Figure 5. Solar radiation variations with respect to solar time

The variation as shown in figure 5 indicate that solar radiations are going to increase from morning to afternoon from 695.6 at 12:45 to 898 at 13:15, at that day and this time this was the maximum radiation, after this radiation goes down due to cloudy season up to 505at 14:15 and again rise to 771 at 14:45. After this solar radiations goes down with the time and reached to a value of 406 at 17:15.

CONCLUSIONS

The experimental setup provides the solar time, system components temperature and solar insolation at which the main processes occurred: start and end of cold production; start and end of heat input to generator; maximum cooling capacity and COP. For the monitored day, the following conclusions were drawn:

- •Working and operation of the solar powered Li-Br-H20 absorption systems was totally dependent upon the solar thermal (heat). This system was found more suitable for the countries where sunshine hours and summer session are longer i.e. near the equator.
- •A coherent data set consisting of instantaneous and daily results of heat flows and energy balance in a real solar cooling system were determined showing that in this system total heat input to the evaporator was greater than heat input by the generator i.e. triple effect system: a single heat was used three times to increase the overall system efficiency.
- •Efficiency parameter of the chiller that is co-efficient of performance was determined and analyzed that this system has highest cop up to 1.56 as compared with the single and double effect system.
- •COP of the solar powered vary with the solar radiation. At high solar intensity temperature, the hot water reaches maximum and produced the maximum cooling effect up to 1.7, and it also depends on the duration of the solar radiation.

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