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Research Article

Performance Evaluation and SWOT Analysis of Solar Powered Vapour Absorption Refrigeration System

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A B S T R A C T

The solar cooling absorption system requires more research because of its poor COP. So, the study examined the performance of specific effect lithium bromide water (LiBr-H20) absorption system of cooling with 15 kW solar power. Space heating modes were also examined and improved methods were analyzed and discussed. The Vapor Absorption Machine (VAM) uses the LiBr-water solution to generate absorbent - refrigerant pair. The absorption system of cooling was operated by a trough collector of parabolic type of 36 sq m aperture are and 325 sq. feet was used to cool the meeting room. The results of the research show that For Parabolic Trough Collector maximum solar radiation was 954.86 W/m^2 and the minimum solar radiation was 507.52 W/m^2. The average COP of Parabolic Trough Collector was 0.46 and for absorption Refrigeration System the average COP calculated was 0.47.

Keywords: Vapor Absorption System, Lithium Bromide

Introduction

Solar energy refers to energy from the sun. The sun generates large amounts of energy due to continuous thermonuclear fusion reaction in its interior. This solar energy can be used by two different technologies. Is a solar thermal technology that uses thermal energy and the second is solar photovoltaic which converts light energy into electricity.

The average annual solar separation coming on top of the Earth's atmosphere is 1366 watts/m^2. Approximately 30% is reflected into space and approximately 19% is absorbed by the environment and clouds. Only 50% of the solar energy reaches the ground surface above the earth's atmosphere. A solar thermal system uses solar energy by using solar energy, utilizing solar radiations to generate heat for hot energy, hot steam etc. That can be made more effective for meeting many applications in different areas like electricity generation, space heating and cooling, community cooking etc.

A small part of the Sun's energy meeting the Earth's exterior is converted to electrical energy through photovoltaic cells and used for power lights and machines.

To maintain our current environment, the entire energy of the atmosphere, the oceans and the land should be transmitted back to space. If the amount of energy returned in space decreases, it can increase warming.

Air conditioners, which we all see, require electricity to cool the room. Solar air conditioners use energy from the sun to get some or all the energy needed to cool. Therefore, by using the solar air conditioner we can either reduce the requirement of electricity to cool down.

In the absorption refrigeration system, refrigerated water used is water that is pollution-free and there is no other pollution effect. It is non-toxic, non-corrosive and environment-friendly. It is also a very high heat of evaporation which absorbs much heat during boiling it. Heating or cooling load is thermal energy that should be supplied or removed from the interior of a building to maintain the desired comfort.

Literature Review

Much research has recently investigated the applications of solar power absorption refrigeration system and related performance improvements.

Ghaddar et al. (1996) presented the Modeling and Simulation of an H_2O-LiBr Absorption System of solar type in Beirut, Lebanon. The results show that minimum collector area should be 23.3 sq m per ton of refrigeration and optimum water storage capacity should be 1000 to 1500 L so that only solar energy can be worked on for seven hours.

Henning and Glaser (2006) studied about the Solar powered refrigeration system for a University Laboratory Freiburg. There is a vacuum tube collector is used in this system. The collector area is 170 m^2 and the COP of the system varies in between 0.2 to 0.3.

Mazloumi et al. (2008) H_2O-LiBr presented a solar powered system for a 120 m^2 room, with a cooling weight of 14.5 kW, in Rasht, Iran. They proposed a minimum parallel area of trough collector of 57.6 m^2 and related hot water storage tank volume of 1.26 m^3. The system runs between 6.49 hours and 18.82 hours (approximately 6 am to 7 pm).

Li et al. (2016) Investigating the experimental performance of single effect H_2O-LiBr refrigeration system of absorption type (23 kW refrigeration capacity) operated by aperture area of parabolic trough collector of 56 m^2 for air conditioning of 102 m^2 meeting room. They analyzed the appropriate methods for improvement in the cooling performance.

Manjit Singh et al. 2017, studied the flow through unsaturated porous media by extension of Darcy's law and Richard differential equation. They presented finite difference techniques using forward Euler time-marching coupling simulation approach for soil-water content-pressure head curve.

Material and Method

Brief Description of Solar Absorption Refrigeration System

15 kilowatt prototype system based on water cooling absorption cycle was established by Thermax India Pvt. Limited in December 2015 in Gujarat, India, Relaxo Footwear's limited. Objectives were to develop indigenous components for the cost-effective high-efficiency cooling engine and steam absorption machine (VAM), and the non-fictional solar collector system was designed to utilize the energy of the sun in an efficient manner, Integration, system performance. The system has a high efficiency three-phase vapor absorption machine, which is based on the COP 0.5 on the basis of the Schematic- H_2O cycle, in which the approximate storage system is at the appropriate moderate temperature of the solar-centric collectors. 36 m^2 Parabolic Trough Collector (PTC) provide 210°C temperature pressure water. This heat is used to generate 7°C chilled water, which, in turn, is dispersed through the fan coil unit installed in various cooling rooms.

Industrial refrigeration is one most energy consuming area among the conventional refrigeration system of vapour compressor type, compressor is the dominant power consumer element. Steam absorption refrigeration system is one of the best replacement for vapor compression refrigeration system.

Construction and Working of Absorption Refrigeration System

As the name suggest, lithium bromide is used as an absorbent in this system. Lithium bromide solution is a corrosion solution. So to reduce the corrosion nature lithium chromite is added in this solution. Lithium chromites is used in this solution to protect from corrosion of various parts of the system. Lithium Bromide is worked as an absorbent in this system. Inside the water in the system, it is like a refrigerant because lithium bromide is a strong efficiency with water vapor, whereby it absorbs the water vapor and we use this system where we need more than 4°C temperatures like air conditioner, chilling of drinking water, chilling of beverages and fruit juices and the system which is the operating system in which the refrigerant's operating temperature is the freezing point of water that is 0°C is approximate 4°C plus or around 4.4°C.

Basically, It consist of two cylindrical cell, one is of HPS (high pressure side) and other is of LPS (low pressure side). In Low pressure side it consist of two components Absorber and Evaporator. In high pressure side it also consist of two components Condenser and Generator. The number of tubes is visible inside this diagram. There is a chilled tube inside the evaporator and in an absorber there is cooling water tube and this tube is also within the condenser. or in a generator there is a heat coil inside it this is for steam and warm water. Now there is a cooling pond or tower, pump, heat exchanger in this system. Two pump is separately engaged in it one is of solution pump and second one is evaporator and refrigerant pump.

In evaporator there is a refrigerant (water) inside it and this refrigerant is flow from tube with the help of refrigerant pump and with the help of nozzle, spray is done on the chilled water tubes. Inside these tubes there is a chilled water is flowing and it will extract heat and the heat spray that has been extracted from extracting the heat will be evaporated. After the evaporation, it will move to the side of the absorber. In absorber there is a Li Br solution inside it which is called weak solution.

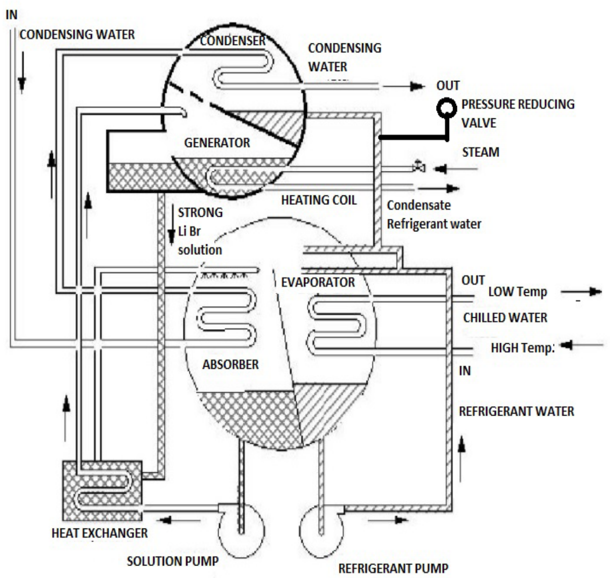

Figure 1.Schematic diagram of Vapour Absorption refrigeration system

Now due to vaporization the vapor enter in the absorber will mix up in the absorber. when lithium bromide (LiBr) and water vapor mixed with each other then weak solution is obtained from it. Then after that weak solution flow from absorber to the solution pump. Then with the help of solution pump it flow from heat exchanger into the generator. Where it spray inside the generator on heating coil. This weak solution is evaporated due to heating coil. Due to evaporation it will rise up and it enters into the condenser. Then due to this water vapour will be separated from this weak solution and the remain solution in the generator will call it Strong Solution or concentrated of strong solution of lithium bromide. Then this strong solution will pass to the heat exchanger and then this Strong Solutions will go to the absorber with the help of tubes and it will be sprayed with the help of nozzles.

When the strong solution flow from heat exchanger then it extract some amount of heat from it. The advantage of this is that to separate the water vapor from solution, there is no need of large amount of heat from heating coil. When the strong solution sprayed inside the absorber then the water vapor comes from evaporator and the refrigerating water flow from cooling pond among the help of pump through tubes then this spray is done on this tubes then this flow will extract some amount heat from it. Due to extraction of heat from the strong solution it condensate or convert this vapor into liquid form and the water vapor mix up will become a strong solution. Then cooling water flow to the condenser.

Now how they work in the condenser when the Water Vapor from Generator went to Condenser The water that comes in the cooling water condenser will extract heat from water vapor and convert it into condensate or liquid form and the cooling water from tubes will go out of the way. The water vapor condensate has been stored in condenser, then it supply from condenser to the evaporator. The main reason is to supply it into the evaporator is that to compensate or to maintain the level of the liquid inside the evaporator which will reduced due to be spraying with help of nozzle over the chilled water tubes. Now there is a pressure reducing valve the function of pressure reducing valve is to maintain or to reduce the pressure from pressure from condenser to the evaporator because it flow to the side of low pressure from high pressure side. Main reason is to reduce pressure as we know when we reduced the pressure then the boiling point of water will also reduced and also to extract heat from the warm water tubes of evaporator and become watery. In evaporator tubes have one outlet and one inlet. Inlet is for warm water and outlet is for chilled water. This chilled water is supply to the air condition system according to requirement such as chilling of beverages and fruit juice etc.

Performance Test

The major performance parameter used for study is the cycle COP and the solar cooling coefficient of performance.

Cycle Coefficient of Performance (COP)

Cycle COP is defined as the ratio of cooling effect to the total energy required for desired cooling effect.

where;

Q_e – Cooling effect, kilowatt (kW)

Q_T – Total energy input, kW

Cooling effect is as follows:

Cooling effect:

where;

m_w – mass flow rate of water, kg/s

C_{PW} – specific heat of water, kJ/kg K

T_W – Temperature of water, °C

Q_e – Rate of heat transfer (kW)

The total heat supplied to the system is change of solar heat equal to the enthalpy change of solar heated water.

m – mass flow rate of water, kg/s

C_p – specific heat of water, kJ/kg K

T_{fi} – Temperature of fluid input, °C

T_{fo} – Temperature of fluid output, °C

Solar COP

Solar COP is defined as the ratio of cooling effect to the net solar energy input:

Where;

Q_s – Solar energy input, kW and where,

GHI – Global Horizontal Irradiance,W/m^2,

DNI – Direct Normal Irradiance, W/m^2, DHI – Direct Horizontal Irradiance, W/m^2,

Absorption refrigeration system and Parabolic trough collector, PTC collector, solar radiation and temperature and hot water inlet and outlet flow and chilling water inlet and outlet performance were recorded and recorded three times in a day regularly and from the observed values, COP was calculated both for Parabolic Trough Collector and Absorption Refrigeration System

Result and Discussion

Solar COP of Parabolic Trough Collector (PTC)

The maximum solar radiation was 954.86 W/m^2 on 02.02.2018 and the minimum solar radiation was 507.52 W/m^2 on 06.03.2018. The solar radiations variation depends on the sun rays falling on the surface of the collector. During cloudy days, the radiation will be low and at the time of sunny days, the radiations will be high. The variation in the solar radiation affects performance of the PTC collector. So, if the radiation is high, the PTC efficiency will be more and if it is low, PTC efficiency will be less.

At the time of morning, the solar radiations are slightly less in comparison to the evening time. In the morning, the efficiency of PTC is less due to the low radiation and in the afternoon time, the radiations are high so the efficiency of PTC is more at that time. At sometimes, the efficiency is found more at less radiation at the evening time because the heat received by the collector is more so that at low radiations the efficiency calculated was high.

The maximum inlet temperature of PTC was 140.40°C on 02.03.2018 and the minimum inlet temperature was 117.20°C on 05.02.2018. The maximum outlet temperature of PTC was 127.70°C on 02.03.2018 and the minimum outlet temperature was 103.20°C on 15.03.2018. PTC inlet and outlet temperature varies according to the change in the solar radiations.

The collector area of PTC is 36m^2, the calculation of the maximum solar COP was 0.59 on 05.02.2018 and the minimum solar COP was 0.30 on 02.02.2018. Calculation of average COP was 0.46. Various recorded parameters and calculations are mentioned in the recorded table of COP.

Efficiency of 15kW Absorption Refrigeration System

The maximum value of Chilled water inlet (CHW IN) was 30.9°C on 06.02.2018 and the minimum value of Chilled water inlet (CHW IN) was 7.2°C on 08.02.2018. The maximum value of Chilled water outlet (CHW OUT) was 29.8°C on 19.02.2018 and the minimum value of Chiller water outlet (CHW OUT) was 5.9°C on 02.02.2018. The maximum value of Hot water inlet (HW IN) was 177.9°C on 02.03.2018 and the minimum value of Hot water inlet (HW IN) was 131.6°C on 19.02.2018 while the maximum value of Hot water outlet (HW OUT) was 171.1°C on 22.03.2018 and the minimum value of Hot water outlet (HW OUT) was 123°C on 19.02.2018.

In the 15kW Absorption Refrigeration System, the maximum COP calculated were 0.76 on 27.02.2018 and minimum COP were 0.37 on 22.02.2018. The average COP calculated was 0.62. On the four parameters i.e. CHW IN (inlet), CHW OUT (outlet) and HW IN (inlet), HW OUT (outlet) the Coefficient of Performance of the system depends. If the value of COP is less it means the output of PTC collector is less due to low radiations and if the weather is sunny, the system achieves high COP. The COP varies according to the variation in Hot water, inlet and outlet and Chilled water, inlet and outlet.

SWOT analysis of Solar Powered Vapour Absorption Refrigeration System

In this study, we use to analyze the characteristics of Vapor Absorption Refrigeration system from the various aspects.

Strength

- Moving parts is pump, which consumes very less power than compressor.
- Load variation does not affect the output performance.
- Capacity can be more than 15KW at 4.5TR it saves approximately 90% electricity.
- It is more economical to use above 4.5TR comparison to conventional compressor based system.
- Its running cost is low.
- It can be integrated with solar thermal source easily.
- It can be converted into multiple effect and which raised the COP of the system.

Weakness

- COP is lower than conventional compressor based system
- Initial investment is more than conventional compressor based system
- When operated using kerosene/ oil/ gas gives bad smell
- COP of the system during the day, It doesn’t not remains constant
- This system is used for big scale industry not for small scale industry due to its size and cost

Opportunity

- It can be integrated with solar which will make it more economical and eco-friendly in long term.
- We can explore multiple effect with the VAM, at present with triple effect we can achieve COP of approx. 1.7.
- We can explore this system for household purpose also because it consume less power than compressor.

Threats

- Its absorbent is usually toxic in nature to humans as well as environment
- When we look at the parabolic trough & the naked eyes, its reflection can have a bad effect on the human eye
- Due to PTC higher temperature range, as we know the surrounding temperature of PTC is 70% higher than the normal temperature, this temperature will affect the body temperature of human being as well as animals also

Conclusion & Recommendation

The efficiency of Parabolic Trough Collector (PTC) was calculated using the parameters like the inlet and outlet temperature, solar radiations received by the collector surface. The maximum solar radiation was 954.86 W/m^2 on 02.02.2018 and the minimum solar radiation was 507.52 W/m^2 on 06.03.2018. The maximum inlet temperature of PTC was 140.40°C on 02.03.2018 and the minimum inlet temperature was 117.20°C on 05.02.2018. The maximum outlet temperature of PTC was 127.7°C on 02.03.2018 and the minimum outlet temperature was 103.20°C on 15.03.2018. PTC inlet and outlet temperature varies according to the change in the solar radiations. The collector area of PTC is 36m^2, the maximum Solar COP calculated were 0.59 on 05.02.2018 and minimum Solar COP were 0.30 on 02.02.2018. The average COP calculated was 0.47

The efficiency of absorption refrigeration system was calculated using the parameters like chilled water, mass flow rate of water, hot water, inlet & outlet. In 15kW Absorption Refrigeration System, the maximum value of Chilled water inlet (CHW IN) was 30.9°C on 06.02.2018 and the minimum value of Chilled water inlet (CHW IN) was 7.2°C on 08.02.2018. The maximum value of Chilled water outlet (CHW OUT) was 29.8°C on 19.01.2018 and the minimum value of Chiller water outlet (CHW OUT) was 5.9°C on 02.02.2018. The maximum value of Hot water inlet (HW IN) was 177.9°C on 02.03.2018 and the minimum value of Hot water inlet (HW IN) was 131.6°C on 19.02.2018 while the maximum value of Hot water outlet (HW OUT) was 171.1°C on 22.03.2018 and the minimum value of Hot water outlet (HW OUT) was 123°C on 19.02.2018. The maximum COP calculated were 0.76 on 27.02.2018 and minimum COP were 0.37 on 22.02.2018. The average COP calculated was 0.62.

Absorption refrigeration system can be a good option for controlling cooling and greenhouse gas emissions from the perspective of renewable energy in the future. Water is used as refrigerant in this system which is non polluting and environmentally friendly. The total efficiency of the system was 62%. Further research is needed to increase the efficiency of the system.

SWOT analysis of vapor refrigeration system of absorption type was to analysis the strength, weakness, opportunity, threats of the system. In case of Strength it is more economical to use above 4.5TR comparison to conventional compressor based system and to consume less power. Further in case of Weakness COP of the system during the day, It doesn't not remains constant and is lower than conventional compressor based system and moreover in case of opportunity we can explore multiple effect with the VAM, at present with triple effect we can achieve COP of approx. 1.7 and In case of threats its refrigerant is usually toxic in nature to humans as well as environment.

Based on present study, the following recommendations are.

- Hot water and chilled water, temperature sensors should be calibrated.
- Insulation in partition between evaporator and absorber.
- Condenser outlet temperature measurement should be placed or maintained.
- Regular care of condenser coil should be done. The fan and condenser unit is situated apart from the office/ room. The dust makes it highly complex for hot air and heat to disperse outward. The inferior heat diffusion results in heating of condenser. Thus to work efficiently, a monthly cleaning of condenser coil is extremely essential for the condenser.
- Cleaning of coils fins should be done. One can easily see the aluminum fins on the condenser and evaporator coils. The coil fins should be regularly cleaned to protect the evaporator and condenser.
- Proper maintenance of condenser, expansion valves and evaporator should be done by weekly and monthly basis.
- There should be no any leakages within the body of the refrigeration system so that the efficiency of all does not drop down.

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