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Optimization of Absorption Chiller by Assisting it with Solar Thermal Energy

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ABSTRACT

An air conditioning system utilizing the solar energy would always be an attractive one because of its cost effectiveness in either we are full filling our heating or cooling requirements. Many solar powered air conditioning systems are in operation in the world but its application in the Pakistan is very little even negligible. Somehow vapor compression unit are being operated with the solar energy by using photo voltaic cells in Pakistan. Whose efficiency is very low and it is also very expensive to full the cooling load of a large building with this photo voltaic cells assisted cooling system. This research paper gives us a comparison of the solar thermal technologies and the cold production technologies. And selected the most suitable one and make it applicable by converting absorption chiller (electrically driven) of 10 ton of refrigerating capacity on the solar power by keeping its COP almost the same.

Key words, solar energy, cooling systems, solar assisted absorption system

INTRODUCTION

As the energy demand is growing rapidly that's why for full filling that demand, combustion of coal and oil is increasing. Emission levels of air pollutants and ambient air quality examined by the state of air quality according to which increase in sulphur dioxide is 23-fold, nitrogen dioxide is 25-fold and carbon dioxide is 4-fold. However until this time Pakistan's greenhouse gas emission are very less as compare to the global average but it is increasing rapidly [2]. Air conditioning and refrigeration is the basic need of an hour and due to increase in their demands as the demands of human comforts increasing, the consumption of electricity is increasing and because of which the load on electric grids is increasing too. That increase in the electricity demand can be overcome by using the renewable energy etc. solar energy (for driving the cooling process). This use of solar energy for cooling system can replace the conventional cooling systems as it is given that cooling demands matches the solar irradiations available [1].

In this case the use of renewable energy source decreases the adverse impact of hydrocarbon fuel's emissions on environment. However it's costly as compare to the conventional vapour compression cooling system. Cooling loads for the residential building is in phase of solar energy is available in [3]. By using that solar energy to full fill the requirement for cooling instead of using vapour compression cycle system can reduce the electricity load and because of this reason small scale (less than 50KW) solar assisted cooling systems are under consideration. That's why the absorption chillers assisted by solar energy are most widespread [4].

SOLAR ASSISTED COOLING SYSTEM - AN OVERVIEW

The technical problem which can be faced in solar assisted refrigeration or air conditioning is that it highly depends on the environmental factors like , solar radiations , air temperature etc. so for the evaluation of the solar assisted cooling system. It is classified by the [5] which is based on two main concepts,

1. Solar thermal Technologies
2. Cold production technologies

Solar Thermal Technologies
The solar thermal technologies consist of solar thermal collectors; the most commonly available are the flat plate collectors, evacuated tube collectors and the parabolic dish type collectors. However as the flat plate collectors are the most common one and easily available in the market [7] but the evacuated tubes are also making their best place in the market with time because of their ability to produce high temperature and low reduction in the efficiency. However the flat plate collectors and evacuated tube collector's efficiency can be calculated or defined by the general efficiency curve equation given as

$$\eta = \eta_0 - a_1 [(T_{avg} - T_{amb})/G] - Ga_2 [(T_{avg} - T_{amb})/G]^2 \quad (1)$$

Where η = Intercept efficiency, a1 = Negative of first order efficiency and a2 = Negative of second order efficiency [6] gives the comparison of the evacuated tube collectors with the flat plate collectors and according to them the evacuated tubes collects the same amount of heat at the solar radiation of about 0.14 KW/m^2 as the flat plates collects at 0.25-0.30 kW/m^2. So the evacuated tubes can collect more heat at the morning time and the evening time too. So our major problem of getting continues heat energy can be overcome by using the evacuated tube collectors and as the greater strength of the tube it is more durable as compare to the flat plate collectors.

Evacuated Tube Solar Collectors
The main component in the solar assisted cooling system is the solar collector which converts the solar energy into the thermal useful energy [1] as evacuated tubes are more efficient and have the ability to produce the high temperature as compare to the flat plate solar collector. So due to high temperature requirement for driving the chiller, evacuated tubes will be a best choice. As the temperature required for driving the absorption chiller is in the range 80 – 90 degree Celsius which the evacuated tubes can arrange easily. Evacuated tubes are of two types,

Heat Pipe Type Evacuated Tubes
In heat pipe type evacuated tube the heat is transferred between the header and the absorber. It is very suitable because if any of the absorber tube is damaged then we can easily change it without empting the solar circuit. Generally the heat pipe contains alcohol or water and filled in vacuum so it evaporated at 25 degree of Celsius [1].

Direct Flow through Type Evacuated Tube
In this type of evacuated tube collectors the heat transfer fluid led via a tube in the tube system to the glass tube base in which the fluid take's the heat from the absorber and flow back with the U-shaped tube [25].

Advantages of the Evacuated tube Collectors
Following are the enlisted advantages of the evacuated tube solar collectors [25].
- It achieves a high efficiency even with the low solar radiations.
- It achieves the high temperature to run the solar assisted cooling system.
- It is portable because it can be mobilize easily and tubes can be detached or attached whenever we want.

Fig. 4 shows the area dimensional definitions of the evacuated tube collectors as the area is divided into three parts [7] as-
Absorber area, it is the area in which the total solar radiations are absorbed in the surface (plates),

Aperture area, total area of the glass & **Gross area**, it is the total area includes the frame and the rigid area

Solar Thermal Storage
In solar assisted cooling systems it is very necessary to store the hot water which is heated by the solar collector [8-9] because it helps in providing the constant heat input in cloudy weather too. It is suggested by the [10] that the storage volume should be 80-200Kg/m^2 of the collector area and according to [11] storage volume should be of 50Kg/m^2 of collector area [12] stated that the loss coefficient of the heat is actually 1.19 W/m^2 C and where 1.19 W/m^2 C is the predicted value. According to [13] sometimes the heat loss is equivalent to the 2 h per day from the storage tank of the solar assisted cooling system where according to [7] heat can be store in the form of hot water storage and storage with the phase change in which the hot water can be store in the well-insulated tank so that maximum heat loss can be avoided and to use material under phase change to store heat in latent form. Phase change materials can be used like fatty acids or paraffin wax etc.

Back up Heat Source
Sometime a backup is required in the solar assisted cooling system and that back up can be provided either by the gas heater or the electric heater which helps in maintain the COP of the cooling system even when the weather is cloudy. According to [14] an axillary heater should be attached in series to the solar assisted cooling systems storage tank as the chiller (absorption cycle with lithium bromide–water working fluid) required the temperature of approximately 88 degree Celsius. So the axillary heater will directly drive the chiller when the temperature of the

storage tank is less than the required temperature. In this case as the heater is attached in series so it provides the heat to achieve the energizing temperature and also maintain the temperature of storage tank as the heater is installed in the series to the chiller and the storage tank.

Fig. 1 Evacuated tube solar collector [Thermomax, UK]

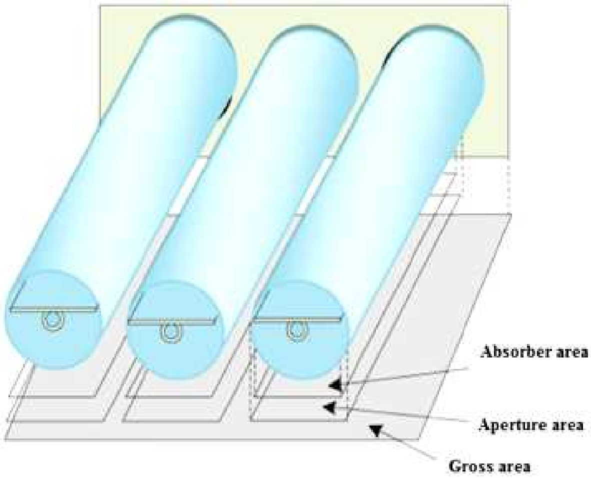

Fig. 2 Heat Pipe Evacuated Tube solar collector [SUNDA solar, China]

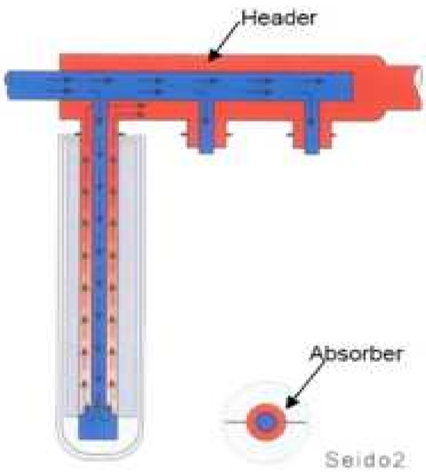

Fig. 3 Direct flow through type evacuated tube collector [SUNDA solar, China]

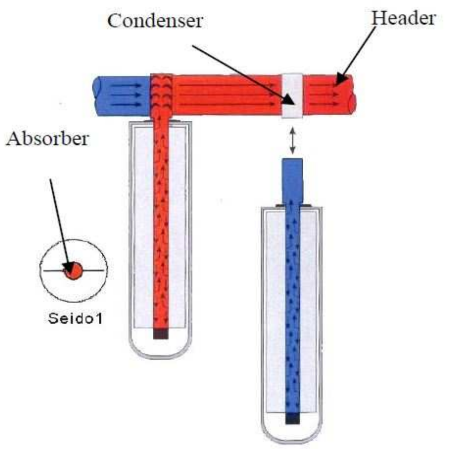

Fig. 4 Evacuated Tube Collectors, Area Definition [Martin Henning et al]

Cold Production Technologies

In past many researchers [15-17] most of the time used absorption cycle for cooling purpose with the fact that the solar energy is the intermittent source of heat energy. But as with the development in the technologies and the improvement made worldwide. It made the continuous solar absorption air conditioning system widely reported.

As the COP of the absorption cooling system is the ratio of the heat transfer rate into the evaporator to the heat transfer rate into the generator. Here the COP of absorption system with different working fluids are compared by the [17] in which the LiBr+H_2O and H2O+NH_3 are the major working pairs in the solar absorption air conditioning systems. where the LiBr+water has a higher COP then the all other working fluids although it has a drawback of the crystallization in the absorber which sometimes block the system but it can be avoided by working under controlled conditions as defined by the manufactures. The factors like low cost, less temperature requirement and excellent performance by this working fluid make it most demanding for the solar cooling cycles.

The comparison between the LiBr+water and NH_3+water by [17-19] **is enlisted below**,

- Ammonia is hazardous that's why there are restrictions in the usage of ammonia in the in–building applications.
- At the generator outlet more complex rectifier is required for the separation of ammonia and water.
- NH_3+water required high pressure so it required higher pumping power.
- NH_3+water absorption system require the temperature of 90-180 degree Celsius where the LiBr+water required the temperature of 70-88 degree Celsius. because of which NH3 + water system shows less COP by using solar collectors
- The COP of Solar assisted NH_3+water absorption cycle is less than the COP of the LiBr + water absorption cycle

Hence it is the reason that the lithium bromide + water system is almost the perfect match for the solar assisted absorption air conditioning system.

As mentioned earlier about the thermal technologies and the cooling technologies. The most suitable for the thermal technologies are the evacuated tubes with hot water storage and an auxiliary heater attached in series and the most suitable for the Cold production technologies is solar assisted Absorption cooling system with the LiBr+water working fluid.

ABSORPTION CHILLER

Steps according to which the absorption cycle works is enlisted in [7] -
- Refrigerant is evaporated inside the evaporator and produces the cooling effect.
- Then the refrigerant vapours are absorbed by the concentrated solution in which the generated heat is absorbed by the cooling water from the cooling towers.
- Then the diluted solution is pumped towards the generator in which the heat is supplied by the solar collectors. So the refrigerant vapours are released with high pressure and the remaining concentrated solution is drained back to the absorber.
- Then the refrigerant vapours are condensed in the condenser where the heat of the condensation is removed by the cooling towers water.

Then pressure of the refrigerant vapours is reduced by the throttle valve and then return back towards the evaporator.

As the LiBr+water absorption cooling system is most appropriate among the solar assisted absorption cooling system enlists the following advantages of using the LiBr+water absorption cooling system.
- Its COP is high (even 40% higher than the NH3 + water absorption system)
- Rectification of refrigerant is not required (refrigerant is non-volatile)
- Working pressure is low
- Nontoxic working fluids

Some of the disadvantages are also enlisted as-
- Because of the requirement of the water cooling. A cooling tower is required which have risk of legionella
- System has bigger size. It's because of the larger volume of the water vapours.

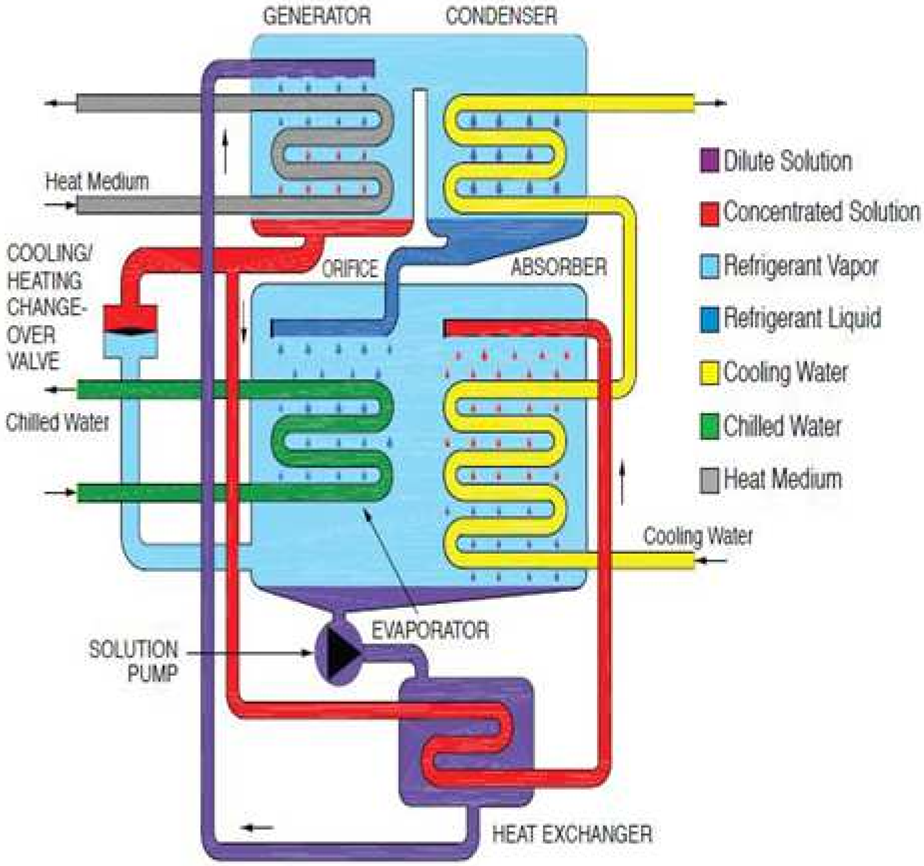

Fig. 5 Absorption chilling cycle schematic diagram

OBJECTIVE AND OUTLINES

To convert a commercial (Lithium bromide + water) absorption chiller of 10-Tons of cooling capacity into solar assisted absorption chiller.
Following milestones have to achieve to full fill the main objective.

- Measure the COP (coefficient of performance) of the commercially available absorption chiller having a cooling capacity of 10 Tons (Approximately 35.1685KW).
- Then find the required area for solar collectors (Evacuated tube collectors) according to the environment of Pakistan and also find the hot storage capacity for the solar collectors.

EXPERIMENTATION AND RESULTS

Experiment is performed on a commercial chiller who COP has to find for converting it into solar assisted absorption chiller and then we will calculated the required area for the collectors .

COP of Absorption Chiller

COP of the absorption chiller can be finding by knowing the rate of heat transfer in the evaporator and in the generator as the COP is the ratio of the rate of heat transfer in the evaporator to the rate of heat transfer in the generator. For finding that rate of heat transfers at different portion of the chiller. We will discuss the circuits of fluid attached to the chiller as these circuits are divided into three fluid circuits -

Generator Circuit

This circuit of the fluid have a path from the chiller's generator heat-exchanger to the electric supply heaters. In which the electric heater had a capacity of the approximately 65KW which helps in attaining the required inlet temperature for the generator heat-exchanger. A pump is used for circulating this fluid and desire flow rate can be achieved by adjusting manually the balanced valve. Temperature at the inlet of the generator heat exchanger can be varied from the 75-90 degree of Celsius and the chiller automatically shut down if the inlet temperature increases the inlet temperature range over the 94 degree Celsius and the water flow rate through the circuit is varied from the 0.8 – 1.4 L/s. And these all the ranges are as according to the manufactures recommended.

Evaporator Circuit

This circuit of the fluid have a path from the chillers evaporator heat-exchanger to the AHU Heat-exchanger where the cooling loads have to full fill. As at that time the building cooling load was 19KW so that load was available at the AHU heat-exchanger. Temperature at the inlet of the evaporator heat exchanger is varied from the 15- 20 degree of Celsius and the temperature of the fluid coming out is having the temperature of less than 7 degree Celsius and the water flow rate through that circuit could be the 1.1 – 1.3 L/s.

Absorber/ Condenser Circuit

This circuit of the fluid have the path through the cooling tower, absorber, condenser and then again to cooling tower. This helps to absorb the heat during the absorption process and during the condensation process. This circuit have the flow rate of approximately 5L/s and helps to not increasing the temperature of the absorber as if the temperature of the absorber is increased to 32 degrees of Celsius the chiller will shut down automatically as because of the safety purpose and if the temperature is fall below the 27 degrees of Celsius then the crystallization of the salt will occurs and that blocks the absorber In fact the chiller. That's why this circuit's flow rate is more than the other circuits and the cooling towers helps in creating the temperature gradient of 6-7 degrees of Celsius.

Instruments Used

For getting the value of flow rates and the temperature at the different places of the chiller we use positive displacement flow meter of the oval-gear type for finding the flow rate of the fluid through the chillers generators heat-exchanger to the heater and to find the flow rate of the fluid through the chillers evaporator heat-exchanger to the AHU and to find the flow rate of the absorber/condenser fluid circuit. Each flow meter was calibrated by the manufacture and certified to have ha bias error +_1% of the reading and for finding the temperature at different parts of the chiller we used the thermopile which was fabricated by the (T-type) copper-constantan thermocouple who's beads were immersed in the water stream and we get our desire area's temperature on the panels

Derived Data

The measurements made in the previous sections are used for finding the performance of the absorption chiller. The rate of heat transfer by the generator circuit into the chiller's generator heat-exchanger is derived by the energy balance

$$q_{gen} = V_g \,.\, \rho \,|\, T_{g,o} \,.\, c_p \,|\, .\, \Delta T_g \qquad (2)$$

Where, q_{gen}, rate of heat transfer (kW), V_g, flow rate of water through the generator's heat exchanger (L/s), ρ, density of water (kg/L), $T_{g,o}$, temperature at generator output , c_p, heat capacity (kJ/kgK) of water evaluated at $T_{g,}$ ΔT_g, the average of T g,i and T g,o, Whereas the q_{gen} extracted is round about the 53.16KW.

The heat transfer rate by the evaporator of the absorption chiller into the evaporator circuit is also derived by the energy balance

$$q_{evap} = V_e \cdot \rho \mid T_{e,o} \cdot c_p \mid \cdot \Delta T_e \quad (3)$$

Where, Q_{evap}, rate of heat transfer (kW), V_e, flow rate of water through the evaporators heat exchanger (L/s), ρ, density of water (kg/L), $T_{,e,o}$, temperature at evaporator output , c_p, heat capacity (kJ/kgK) of water evaluated at $T_{g,}$ ΔT_e, the average of T e,i and T e,o., Whereas the extracted q_{evap} is the 39.46KW

As the coefficient of performance is the ratio of the rate of heat transfer at the evaporator to the ratio of rate of heat transfer at the generator so

$$COP_{th} = q_{evap} / q_{gen} \quad (4)$$

And the derived COP of the absorption chiller is the 0.7422

Experimentation Results

Series of Test was conducted on the absorption chiller for evaluating its COP by considering its boundary conditions given by the manufactures. During calculations all the desired properties have been taken with respect to time. Following are the comparison of calculated properties.

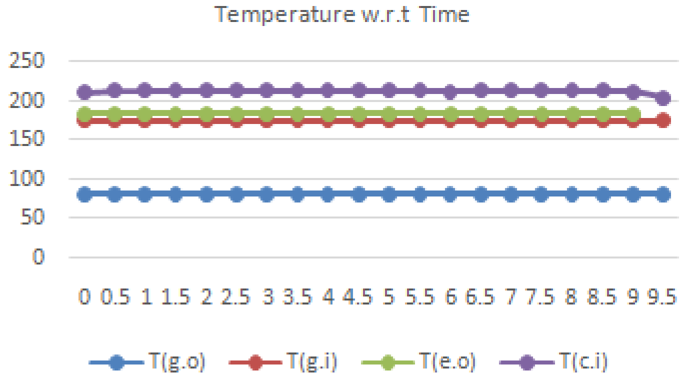

Fig. 6 The temperatures at the inlet and outlet of generators heat exchanger $T_{g.i}$ and $T_{g.o}$, at the outlet temperature of evaporator Heat Exchanger $T_{e.o}$, and the temperature of cooling water inlet $T_{c.i}$ with Respect to time

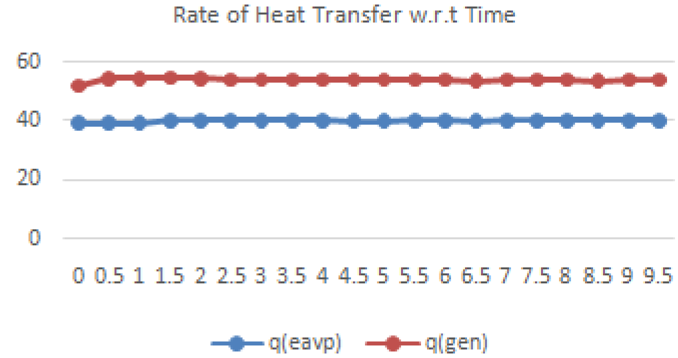

Fig. 7 The heat transfer rate in the Evaporator's heat exchanger and in the generator's heat exchanger and the evaluated COP

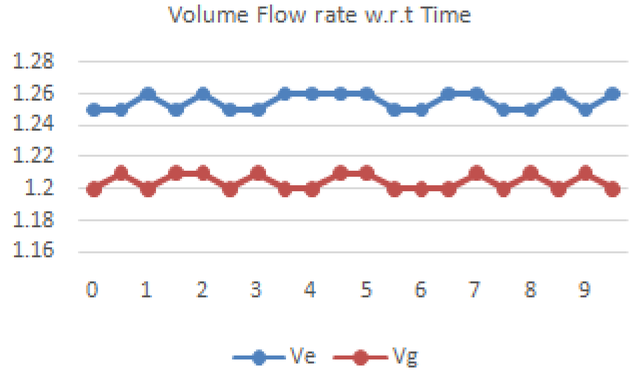

Fig. 8 The volume flow rate (with respect to time) in the generator circuit and in the evaporator circuit

Fig. 6 represents the temperatures at the inlet and outlet of generators heat exchanger $T_{g.i}$ and $T_{g.o}$ Respectively, at the outlet temperature of evaporator Heat Exchanger $T_{e.o}$, and the temperature of cooling water inlet $T_{c.i}$ with Respect to time. Fig. 7 represents the heat transfer rate in the Evaporator's heat exchanger and in the generator's heat exchanger and the evaluated COP. Fig. 8 represents the volume flow rate (with respect to time) in the generator circuit and in the evaporator circuit.

The average value of the rate of heat transfer w.r.t to time in the evaporator's heat exchanger and generator's heat exchanger is as follows

q_{evap} = 39.81 kw
q_{gen} = 54.05 kw

Fig. 9 is representing the change in the COP value with respect to time. The average COP obtained by the Data is **0.73.**

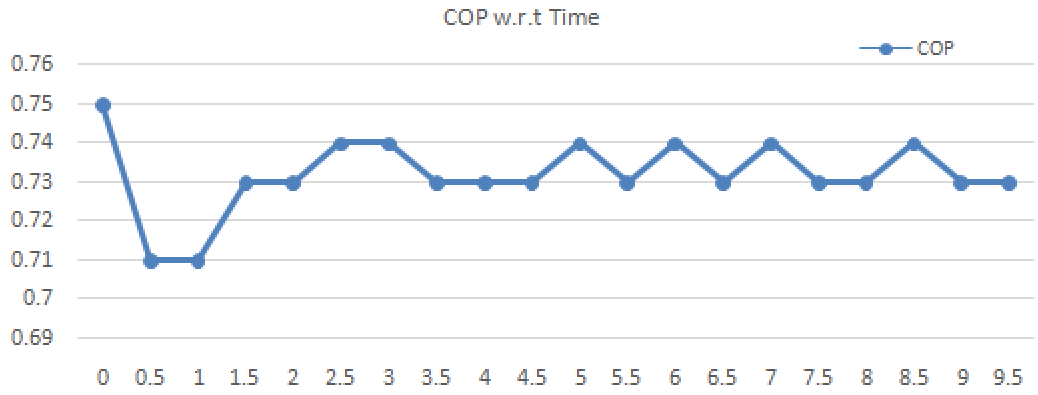

Fig. 9 The change in the COP value with respect to time

Calculating the Area required for the Solar Collectors (Evacuated Tubes Solar Collector)

Accordingly the incident solar radiations in the Asia region in which the Pakistan lies. We calculate the area required by the solar collectors. As in this region the approximate incident solar radiations are of 800w/m^2 or can said 0.800 KW/m^2 (G) according to [24] and the efficiency of the required solar collectors (evacuated tube) is approximately (ή) 70% which is the greater one as compare to the flat pate or parabolic dish [19] and as the COP of the chiller have been derived out which is 0.742 now for calculating the area required for the solar collectors.

A= 1/ {G. ή . COP}
A= 1/{0.800*0.70*0.742}
A = 1/0.4155
A= 2.40 m^2 per KW

As our absorption chiller's capacity is 35.1685KW
2.40 * 35.1685

Evacuated tubes at the area coverage of 84.64 m^2 required

According to the manufactures the area of each tube of the evacuated tubes is of 0.1 m^2
Number of tubes required for full fill the area for solar collection

84.64/0.1

Approximately 847 evacuated tubes required for running a Lithium Bromide- Water absorption chiller of the capacity of 10 ton of refrigeration and at the COP of the 0.74

Thermal Storage

Thermal storage for the solar collector is defined by the [11] according to which the storage should be 50Kg/m^2 of the evacuated tubes collectors - Area m^2 required for the Evacuated Tubes= 84.64m^2

Area of the thermal Storage tank should be= 50*84.64 =4232Kg

So for the thermal heat storage we required the storage tank of 4232 Kg. which we can easily store the heat energy and help in providing the continuous source of heat for operating the Chiller

CONCLUSION

Experimentally the COP of a commercial Absorption chiller of 10 tons of the refrigeration is derived for converting it solar assisted. For calculating the COP the temperature at inlets and outlets are measure by the T –type of the thermocouple and the flow rate of the fluid at the inlet and the outlet is measured by the flow meter of Volvo-type with the error of 0.1% in the measured reading. Then by the energy balance we calculate the rate of heat transfer in the evaporator and the generator which are 39.46KW and 53.16KW respectively. COP is the ratio of the rate of heat transfer in the evaporator to the generator so the COP of the Absorption chiller running at the electric heater of the 65KW is 0.74. That COP value is necessary for find the area of the solar collectors required then. By researching about the approximate efficiency of the evacuated tubes we found it approximately 70%. The area of a single tube is 0.1 m^2 as provided by the manufactures. Solar incident radiations in this Asia region is found 800W/m^2. By formulation and calculation it is found that 84.64m^2 covered area with evacuated tubes is required for operating this chiller at solar assisted power which mean 847 number of tubes with the storage of the 4232Kg of the thermal storage tank. Hence that is all the setup which is required for operating the chiller at the solar power with the COP of the 0.74. However its installation (capital) cost is much more as compared to the electrically or gas operated chiller but its running cost is almost negligible because all the heat energy which was the basic energy utilization in the chiller is extracted from the sun and it is environment friendly too. As these days the problem of global warming and the air pollution is increasing and we are facing the economic problems too. This method is not only environment friendly but also economical friendly. Which can easily full fill our requirement and can help us in achieving the human best comfort zone at very cheap cost. But the only need is to consider it seriously.

REFERENCES

[1] HM Henning, *Solar Air-Conditioning and Refrigeration*, Wien, Springer, **2004.**
[2] Asian Development Bank, *Asian Environment Outlook,* Manila, **2001**.
[3] H Henning, *Solar Assisted Air-Conditioning in Buildings*, Springer, **2007**.
[4] W Sparber, A Napolitano, G Eckert and A Preisler, Solar Air-Conditioning and Refrigeration, State of the Art on Existing Solar Heating and Cooling Systems, *International Energy Agency*, **2009**, 38.
[5] R Best and N Ortega, Solar Refrigeration and Cooling, *World Renewable Energy Congress*, Italy II, **1998**.
[6] DS Ward, WS Duf, JC Ward and GOG Lof, Integration of Evacuated Tubular Solar Collectors with Lithium Bromide Absorption Cooling Systems, *Solar Energy*, **1979** ,22,335-41
[7] Martin Henning, Carlos A Infante Ferreira, Erich Podesser, Lei Wang and Edo Wiemken, Solar Air Conditioning in Europe- An Overview, *Renewable and Sustainable Energy Reviews*, (**2007**) 299 – 314.
[8] PJ Wilbur and CE Mitchell, Solar Absorption Air-Conditioning Alternatives, *Solar Energy*, **1975** , 17,193-9
[9] RM Lazzarin and B Boldrin, Experimental Investigation on Control Modes for an Absorption Chiller of Low Capacity, *Proceedings of the ISES, Silver Jubilee Congress*, Atlanta, Georgia, **1979**, 1.
[10] JF Kreider and F Kreith, *Solar Systems for Space Cooling, Solar Energy Handbook*, New York, McGraw-Hill, **1981**.
[11] AS Jacobsen, Solar Heating and Cooling of Mobile Homes, Test Results, *Proceedings of the Annual Meeting of the American Section of the International Solar Energy Society*, Orlando, Florida, **1977,** 1.
[12] GOG Lof and RA Tybout, The Design and Cost of Optimized Systems for Residential Heating and Cooling by Solar Energy, *Solar Energy*, **1975** ,17,193-9
[13] AS Jacobsen, Solar Heating and Cooling of Mobile Homes, Test Results, *Proceedings of the Annual Meeting of the American Section of the International Solar Energy Society*, Orlando, Florida, **1977**, 1.
[14] DS Ward and GOG Lof, Design Construction and Testing of a Residential Solar Heating and Cooling System, *Report to the Committee on the Challenges of Modern Society (CCMS) Solar Energy Pilot Study*, **1976**.
[15] DS Ward, CC Smith and JC Ward, Operational Models of Solar Heating and Cooling Systems, *Solar Energy*, **1977** ,19,55-61
[16] Suzuki M Sakada, Simultaneous Transportation of Heat and Adsorbate in Closed Type Adsorption Cooling System Utilizing Solar Energy, *Journal of Solar Energy Engineering*, **1986**,108,239-45
[17] M Pons and P Grenier, Experiment Data on a Solar-Powered Ice Maker using Activated Carbon and Methanol Adsorption Pair, *Journal of Solar Energy Engineering*, **1987**,109,303-10
[18] RE Critoph, Performances Limitations of Adsorption Cycles for Solar Cooling, *Solar Energy*, **1988**, 41, 21-31.
[19] DJ Ward, Solar Absorption Cooling Feasibility, *Solar Energy*, **1979**, 22,259-68.
[20] DS Ward, WS Due, JC Ward and GOG Lof, Integration of Evacuated Tubular Solar Collectors with Lithium Bromide Absorption Cooling Systems, *Solar Energy*, **1979**, 22,335-341.
[21] HM Henning, *Solar-Assisted Air-Conditioning in Buildings*, Springer-Verlag Wien New York, **2007**.