Experimental Study on Solar Adsorption Refrigeration System Integrated With Heat Pipe

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Abstract- **As per recent studies, about 40% total power consumption of any building is for Heating Ventilation and air conditioning (HVAC) purposes. However the steady increase in such power consumption can lead to a greater power crisis by mid of this century. Also as per Kyoto protocol it is expected to reduce 60% of total greenhouse gas emission recorded on the year 2000 by the year 2050. In such a scenario, effective uses of renewable resources especially for refrigeration purposes are of high importance. Imagine a Refrigeration system which uses zero electricity, 100% environmental friendly, silent operation and with a Coefficient of performance (COP) more than one. In countries like India, where solar energy is of abundance and cooling is much required, a conversion of these abundant energy into cooling effect is of high requirement. Hence this work 'Solar Adsorption Refrigeration System Integrated with Heat Pipe' deals with the fabrication and experimentation of a water chiller working with solar energy and adsorption refrigeration cycle with a capacity of 8 liters of cooling water. Parameters such as temperature and pressure readings of all components at various points of time are noted during experiment and COP (Coefficient of Performance), SCP (Specific Cooling Power) are calculated for the same.**

Keywords- **Adsorption cooling, Activated carbon, Solar trough collector, Heat pipe integration**

I. INTRODUCTION

Solar energy is a completely natural form of energy. They does not pollute the environment like other crude oils. They can be extensively used in countries like India where there is abandoned solar energy. Hence this system uses solar energy as an energy source and a heat pipe for effective heat transfer. [1] In 2009, an experiment was conducted on solar adsorption refrigeration system and the results were simulated with FORTRAN. They also developed a working model of the same with the working pair ammonia and activated carbon and obtained a maximum COP of about 0.18. [2]. In 2006, an experiment was conducted with silica-gel and water as a working pair achieving a COP of 0.4. An adsorption refrigeration chiller was developed which was capable of working on both carbon-methanol and silica-gel and water however a trough collector was not used. [3]. In 2005, prototypes of adsorption refrigeration chiller and an adsorption air conditioning system were built with silica gel-water adsorption pair in order to achieve a COP of about 0.7 and a solar COP of 0.14. A solar flat plate was used to heat the adsorbent directly. [4]. In all the above systems, either a carbon-ammonia or a silica-gel water adsorption pairs were used. As ammonia is said to be poisonous and has very big disadvantage of harming people near by the system in case of a leak which overrules the advantage of higher vapor pressure and silica gel-water pair is said to exhibit a lower COP than the former. [5] . Hence, in this system Activated carbon-methanol pair were used. Heat pipes provide an efficient way of heat transfer and hence, integration of heat pipe for high efficient heat transfer from parabolic concentrator to the adsorbent bed. Methanol is safer compared to ammonia and has a better COP compared to silica gel and water [5]. Latent heat of vaporization of fluid inside heat pipe (water) is used for vaporization of adsorbent compared to the works done so far which uses sensible heat of another fluid (water) to heats the adsorbent or it is heated directly by passing through adsorbent tube [3-4]. Due to this reason, higher values of COP were recorded which are discussed below.

II. EXPERIMENTAL PROCEDURE

Fig 1 shows a schematic diagram of the system. It consists of the following major parts:

1. Parabolic Solar concentrator
2. Heat pipe
3. Adsorbent bent
4. Condenser
5. Evaporator
6. Expansion valve

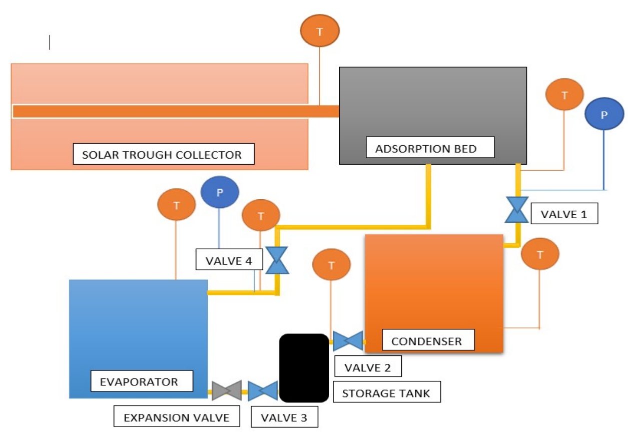

Fig 1 Schematic diagram of solar adsorption refrigeration system

The parabolic solar concentator (Parabolic Trough collector) is parabolic shaped, made of stainless steel and has the provision to integrate the heat pipe at its focal point. This heat pipe is cylindrical in shape with a needle valve at one end to fill water which acts as working fluid inside the heat pipe. The evaporator section of the heat pipe runs over the trough collector and condenser section goes inside the bed. A copper wire mesh is coiled a the inner periphery of the heat pipe touching its walls and runs over the complete length of heat pipe. It is coiled to a thickness of 20 mm. Copper pipes of diameter 3/8 inch provides connection for adsorbent to flow between components. Adsorbent bed which is cylindrical in shape is completely filled with granular activated carbon (4.7 kg). Heat pipe runs throughout its length from the center. Methanol is charged on to it with the help of needle valve. Condenser consists of copper of total length 10 meter coiled and immersed in water. 27 liters of water are filled inside the tank. A thermostatic expansion valve (Danfrost expansion valve) is used in this system. Evaporator consists of copper, a total length of 6 meter is coiled inside a container. This has a capacity to cool 7 liters of water.

III. WORKING

The working of the system starts with the heating of fluid inside the heat pipe. As the heat pipe is placed at the focal of the concentrator. Hence all rays falling on the trough collector are directed to the heat pipe mounted on the focal point of the concentrator. The evaporator section of the heat pipe is partially filled with water. The water heats, vaporizes and rises against gravity through the center space of the heat pipe. The heat pipe is placed in such a way that the evaporator section lies below and he condenser section lies above, i.e. it is tilted to a particular angle to facilitate the flow of vapor against gravity from evaporator to condenser section of heat pipe. As the condenser section is relatively cooler, the vapor from the evaporator section condenses and then returns back to the evaporator through the copper mesh via capillary action which then heated and vaporized at the evaporator section again repeating the same cycle. The Latent heat of vaporization is given to the bed. The fins projecting from heat pipe on to the bed allows effective heat transfer from the heat pipe to activated carbon on the bed. 1 Liter of methanol is charged on the bed which absorbs heats and rises to a higher temperature of about 85 degree Celsius and pressure of 14 psi. Then high pressure and high temperature gas passes through the condenser which cools the gas to normal room temperature which a very negligible loss of pressure. The condensed methanol is stored for some time in order to achieve a non-intermediate flow to the expansion valve. When almost all the methanol vapor are condensed and stored in the tank, the valve is opened which allows the flow to the expansion valve. The expansion valve reduces both temperature and pressure of the condensed liquid. The emerging liquid absorbs heat from the evaporator and becomes vaporized. Hence a high temperature low pressure vapor is formed. Now in order to facilitate cooling effect, the bed is cooled during the expansion and evaporation stage. Hence, the property of the activated carbon which adsorbs the gas during cold condition and desorbs the gas during hot condition is made use to adsorb the gas from the condenser on to the bed again. Thus the entire vapor takes the heat of water inside the evaporator chamber cooling the water inside it. During experimentation, a total of 15 degree fall of temperature from the atmosphere was recorded with a time span of 4 hours from the time of opening the valve which allows the flow of refrigerant from the tank to expansion valve. The copper piping are connected in such a way that flow is either assisted by gravity or rises up due vaporization from start to finish of the refrigerant cycle.

IV. RESULT

Repeated experiments have been conducted in the fabricated system in order to estimate various performance parameters such as SCP, COP and refrigeration effect. In thissection the tabulated results are discussed.

4.1 Performance Parameters

The main performance parameters used for the present study are,

a) Refrigerating effect
b) Coefficient of performance(COP)
c) Specific cooling power(SCP)

a) Refrigerating effect

Refrigerating effect is an important term in refrigeration that defines the amount of cooling produced by a system. This cooling is obtained at the expense of some form of energy.

b) Coefficient of performance (COP)

It is defined as the ratio of the refrigeration effect to energy input.

$$COP = \frac{\text{Refrigeration Effect}}{\text{Heat Supplied}}$$

c) Specific cooling power(SCP)

Specific cooling power indicates the size of the system as it measures the cooling output per unit mass of adsorbent per unit time. Higher SCP values indicate the compactness of the system

$$SCP = \frac{\text{Cooling effect}}{\text{Cycle time per unit of adsorbent mass}}$$

4.2. Temperature of Adsorbent Bed vs. Time

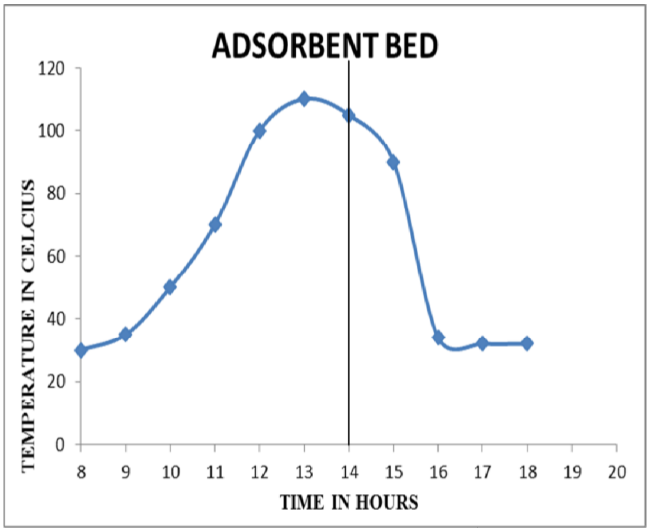

Fig 2 Temperature of adsorbent bed vs. Time

The Fig.2 shows variation of adsorbent bed temperature with time since it started. Here the line shows maximum temperature before the bed subjected to cooling by using. Since the cooling process occurs only during adsorption phase, it is necessary to cool down the bed. Hence cold water is supplied at 14: 00(2 pm) in order to initiate adsorption.

4.3 Temperature of Solar Concentrator vs. Time

The Fig.3 shows the maximum temperature at 1pm is due to the rise in atmospheric temperature. Continuous concentration of heat also adds up to temperature rise. The trough collector concentrates heat to the heat pipe and then it sends the heat to the bed.

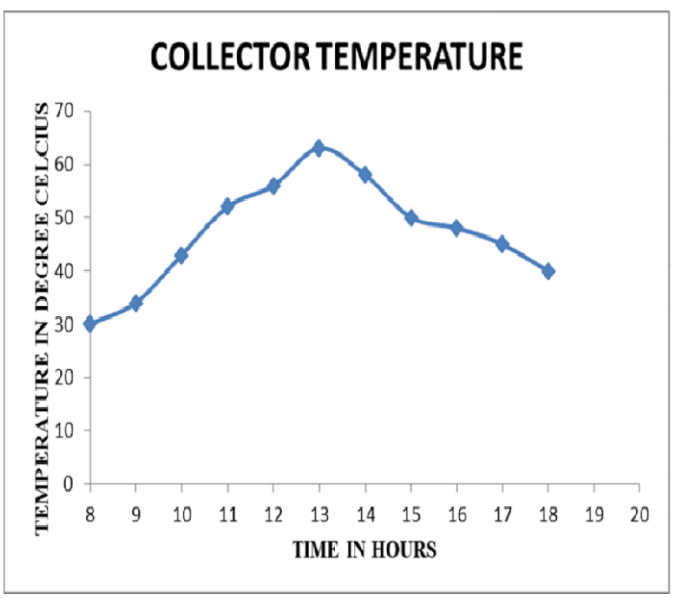

Fig 3 Temperature of collector vs. Time

4.4 Condenser water temperature vs. Time

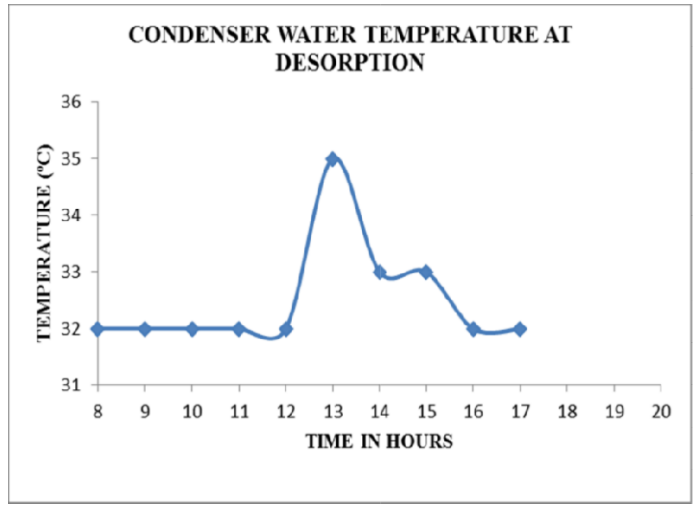

Fig 4 Condenser water temperature vs. Time

The Fig.4 shows the maximum temperature is due to the fact that the continuous desorption process occurs at the 1 pm (13:00hrs) and outer temperature rises. Then a fall in temperature is due to the fact that the outer temperature decreases and desorption process completes and the temperature returns to the room temperature.

4.5 Refrigerant temperature at condenser outlet vs. Time

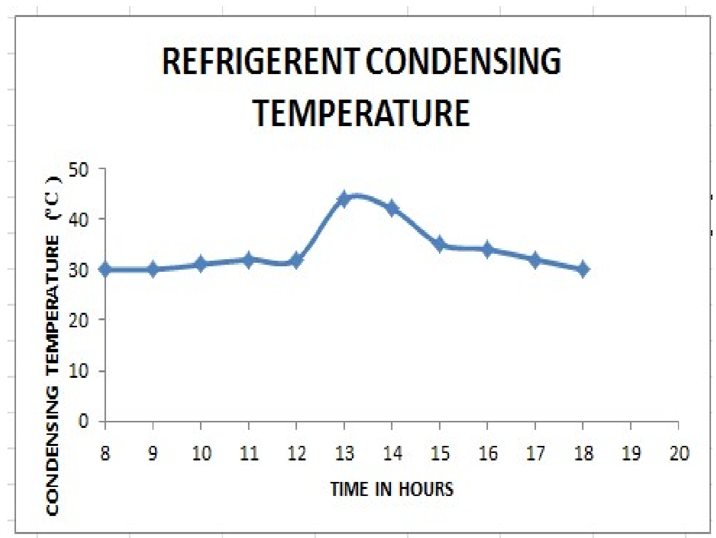

Fig 5 Refrigerant temperature at condenser outlet vs. Time

The refrigerant condenses from a higher temperature (about 80 degree) to a temperature nearly equal to that of cooling water temperature. To achieve this condition about 10 turns of copper pipe is used inside the condenser.

4.6 Chilled water temperature vs. Time

It is clear from Fig.6 the chilled water temperature decreases gradually. The cooling effect is generally experienced during thestart of adsorption process. The lowest temperature is obtained on the last stage of the experiment about 15 degree.

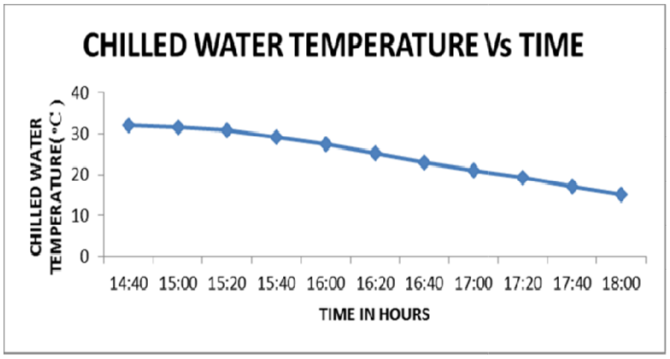

Fig 6 Chilled water temperature vs. Time

4.7 Adsorbent bed pressure (PSI) vs. Time

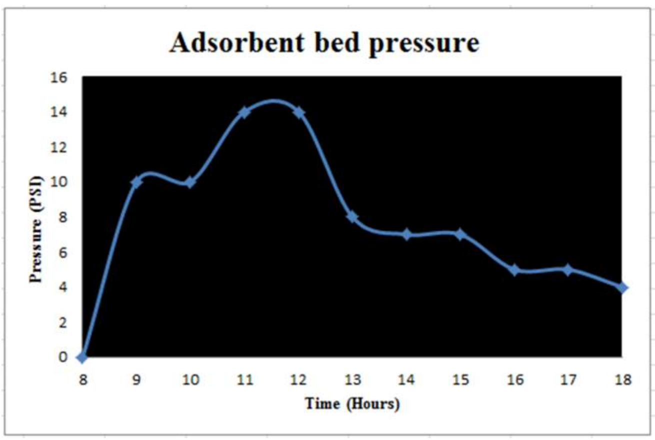

Fig 7 Adsorbent bed Pressure (PSI) vs. Time

From the Fig.7 it is clear that the maximum pressure occurs at around 12 pm where the temperature becomes maximum and the discharge also increases. It is also seen that the maximum pressure is 14 psi (1 bar) which is the vapor pressure of methanol.

4.8 Refrigeration effect vs. Chilled water temperature

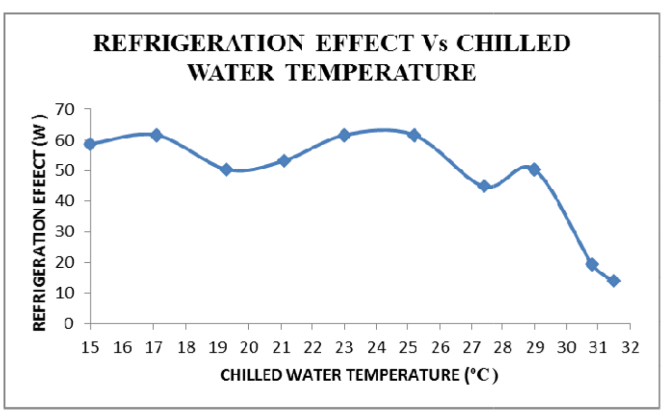

Fig 8 Refrigeration effect vs. Chilled water temperature

The Fig.8 shows the variation between chilled water temperature and refrigeration effect. The refrigerating effect is found to be increasing with a decrease in chilled water temperature. The maximum value obtained for refrigeration effect is 61 W and has an average value of 47.6 W. In this experiment mass and specific heat values are constant. The temperature difference and time are varying factors. The variation in refrigerating effect is due to the effect of varying temperature difference and time.

The COP and SCP varying with cooling water temperature figures are as shown below. It can be seen that the figures of COP and SCP are similar due to the fact that heat supplied is constant throughout the process for a single day as solar insulation doesn't change. Values of COP, SCP, Heat supplied and cooling effect are shown in the table given below.

TIME	COOLING EFFECT	COP	SCP
HOUR	W	-	W/Kg
15	14	0.311111	3.29
15.2	19.6	0.435556	4.61
15.4	50.4	1.12	11.85
16	44.8	0.995556	10.54
16.2	61.6	1.368889	14.494
16.4	61.6	1.368889	14.494
17	53.2	1.182222	12.51
17.2	50.4	1.12	11.85
17.4	61.6	1.368889	14.49
18	58.8	1.306667	13.85

4.9 COP vs. Chilled water Temperature

The Fig.9 shows COP and chilled water temperature. The variation in COP is due to the variation in values of refrigeration effect and heat input from the solar. COP of the system depends on refrigeration effect. The maximum value obtained for COP is 1.4 and has an average value of 0.98.

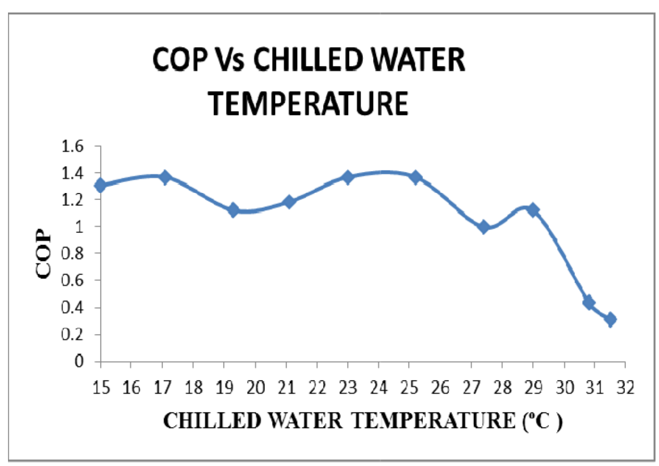

Fig 9 COP vs. Chilled water Temperature

4.10 SCP vs. Chilled water temperature

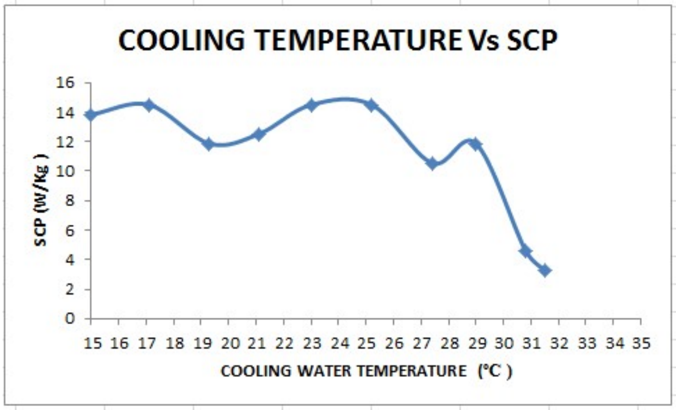

Fig.10 SCP vs. Chilled water temperature

Fig 10 shows the variation between SCP and chilled water temperature .The maximum value obtained for SCP is 14.49 W/kg and has an average value of 9.74 W/kg. Since the mass of adsorbent is constant the SCP depends on refrigeration effect only. As the refrigeration effect increases SCP increases.

V. CONCLUSIONS

In the present study a solar adsorption Refrigerator system integrated with Heat pipe has been designed, fabricate and its performance has been studied with Activated Carbon-Methanol as working pair. Most of the SAR systems fabricated are works with sensible heat load. Hence the reported COP and SCP are low. The average COP reported is 0.3-0.6 for Activated Carbon – Methanol pair.

- From the present study the average values of Refrigeration effect, COP and SCP the system is obtained as 47.6 W, .98 and 9.74 W/kg respectively. From this it can be concluded that Solar Adsorption system integrated with heat pipe shows an enhanced COP as comparing to the conventional solar adsorption systems.
- From this work it can be clear that Solar system integrated with heat pipe technology can be studied further for commercial adsorption technology.
- Also from the environmental point of view this system is eco-friendly as it involves the use of methanol as a refrigerant which is not responsible for ozone layer depletion. Furthermore, it also saves the power of engine as it replaces the compressor by an adsorbent bed.
- The increasing of thermal conductivity of the adsorbent is important to reduce the period of the refrigeration cycle and to increase the average refrigerating capacity of the adsorption refrigeration system.
- This system facilitates long time applications. Since there are no moving parts the system is silent and vibration free.

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