Performance Study of Solar Adsorption Refrigeration System, Working on AC-Methanol.

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Abstract. Adsorption refrigeration powered by solar energy is an efficient way to serve the purpose of refrigeration and air conditioning. The current study focuses on the performance of solar adsorption refrigeration system using activated carbon- methanol as the working pair. The reason for employing this working pair is due to its advantages over other available pairs. Also, it possesses least harm to the environment due to its negligible values of GWP and ODP. The performance evaluation is done mainly based on the COP of the system. However, the values of COP vary with location. Besides this, the other aim is to study the change in COP values with changing collector type.

Keywords: Solar adsorption refrigeration, activated carbon, methanol, COP, flat plate collector.

INTRODUCTION

Recently, in the past few decades, with the increasing population and technology, the demand for crude oil-based fuels has also increased incredibly. This ever-increasing consumption of fossil fuels is now leading to very fast depletion of these conventional resourcesand also affecting the environment severely, due to the CO_2emission on ignition of the fossil fuel. These factors have a direct impact on the ozone layer depletion and global warming. So, the trend of switching towards non-conventional sources has taken a good pace as far as the upcoming technologies are concerned. These non-conventional technologies have already started replacing some of the conventional technology; maybe we consider electricity generation for various purposes or for some other applications including refrigeration and air-conditioning, cooking, steam generation, automobile sector and many others.

Due to global warming, there is a sharp rise in the average temperatures. As a consequence of the increasing temperature,refrigeration and air-conditioning is becoming a major part of the entire human race.As a result, there has been a tremendous increase in the consumption of electricity required to these machinesand, also theCFC and HFC refrigerant used to serve the purpose of refrigeration and air-conditioning poses a great threat to the environment, due to its high GWP and ODP values(D. C. Wang et al., 2010).

So, in-order to reduce the impact on environment due to these CFC and HFC based refrigerants, and also to reduce the electrical energy consumption by these machines, a lot of research and experimentation has been carried out in the past few decades in order to utilize the waste heat from any process that uses energy, as a byproduct and also some non-conventional technology withlower values of GWP and ODP for serving the purpose of cooling.

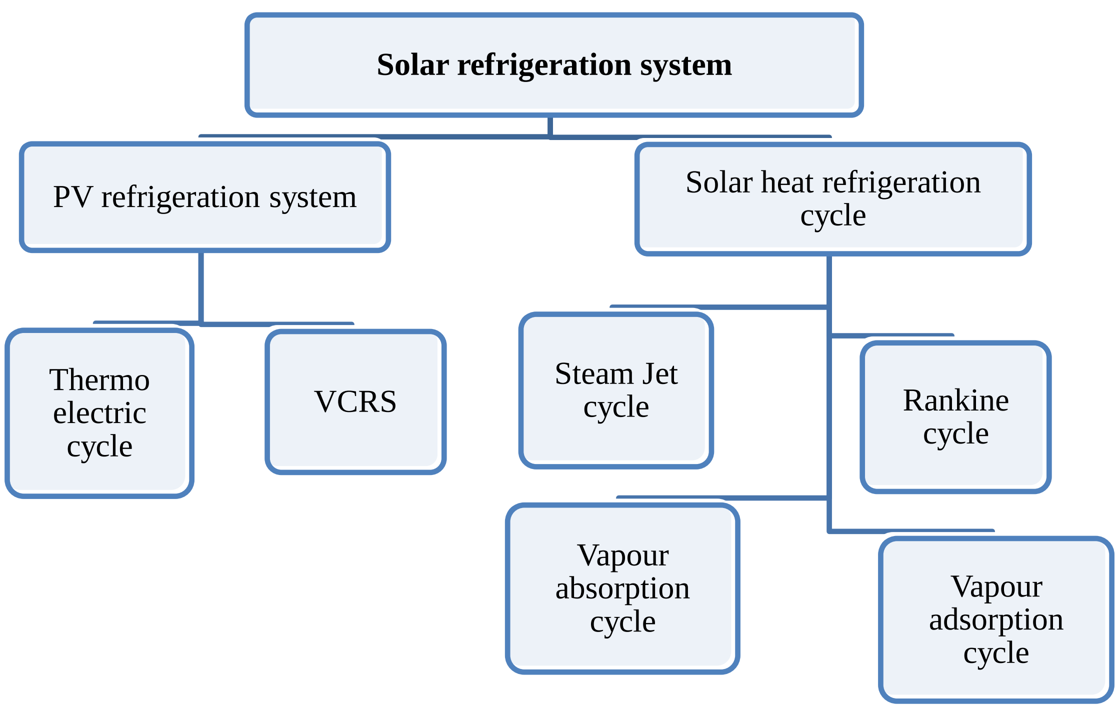
As solar energy is available in abundance in the tropical region, its use for refrigeration and air-conditioning has gained a lot of importance over conventional refrigeration technologies, in sight point of research and experiments.However, the solar intensity keeps on varying indefinitely, leading to dilute form of energy available at randomglobally. This reduces the COP and SCP of the cooling system. This is the reason that the refrigeration and air-conditioning (RAC) technology utilizing solar energy has not been commercialized on large scale. Despite of a lot of research, a wide variation has been observed in every aspect of utilizing solar based RAC technology; consider it from the geographical location, application, system requirement, refrigerant used, quality of refrigerant and other component available and many others. In-fact these factors plays a vital role in deciding the performance of the RAC machines. As the solar energy has no environmental effects in terms of pollution and also it is available for free and in abundance, it has been a wise choice by the researchers to switch towards the solar based systems for RAC purposes.

The current research focuses on the use of systems utilizing waste heat or solar energy for refrigeration purposes. Some of the heat operated cooling systems which can operate on solar energy are vapour absorption refrigeration system, vapour ejector refrigeration system and vapour adsorption refrigeration system(Choudhury et al., 2013). Although absorption system and ejector system have some major disadvantages as corrosion problem, regular maintenance requirement, noisy and vibrating components (due to moving/rotating parts), crystallization issues, refrigerant with high values of GWP & ODP. However, all these factors prove to be contradictory in case of adsorption system. The solar adsorption refrigeration system possess almost zero GWP and ODP values along with operating on non-polluting refrigerants, works without consuming electricity and has no moving parts(Grokhovsky et al., 2016). The only drawback of adsorption system is that it has low COP and SCP values and requires large space.

Hence, switching towards solar based refrigeration system is the only key to this energy crisis. So, due to the advantages of solar adsorption refrigeration system over other solar based systems, as mentioned above, it is best suitable for the tropical region, where solar radiation is available in abundance throughout the year.

Now, before starting with solar adsorption refrigeration system, it is important to know the categories in which solar coupled refrigeration systems can be classified, and the different cycles available for utilizing the waste heat as well as the solar energy.

Classification of Solar Refrigeration System (Pridasawas, 2006):-



Solar Adsorption Refrigeration System

A basic adsorption refrigeration system consists of four major components, namely adsorption bed collector, evaporator, condenser, and capillary tube. Besides these two non-return valves are also placed, each at the entry and exit of the evaporator respectively. The adsorption bed (also known as a thermal compressor) thermally compresses

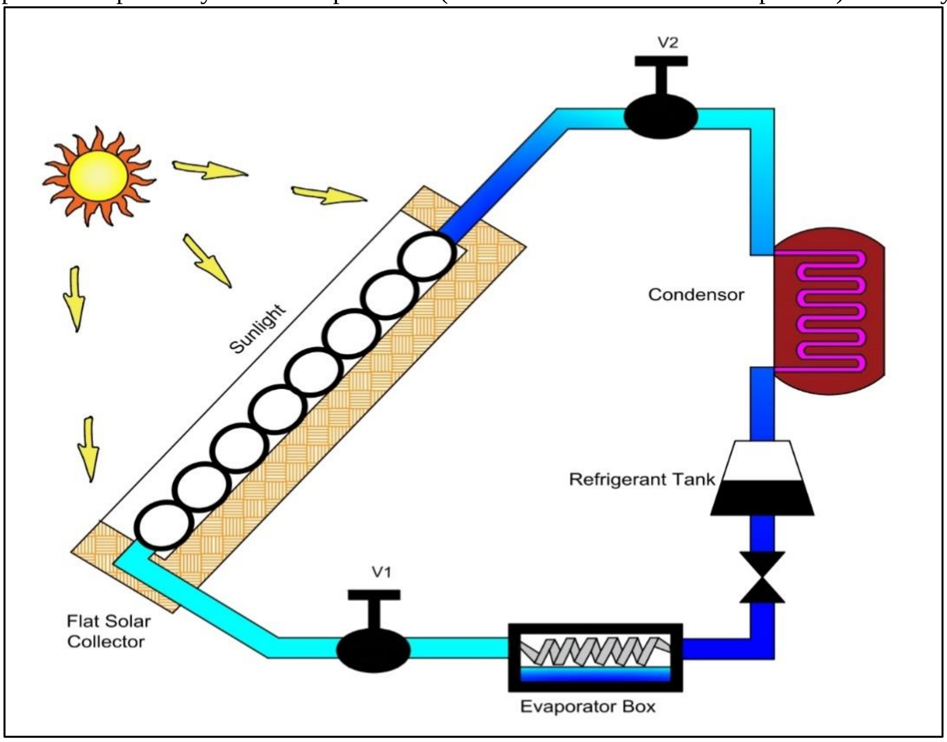


FIGURE 1. Solar Adsorption Refrigeration System Cycle Diagram

the desorbed vapour to condenser pressure, in a similar way as the hermetically sealed compressor does in a VCRS system.Refrigerant vapour from the evaporator is adsorbed by adsorbent at a low temperature corresponding to evaporator pressure. The adsorbent on heating with solar energy reaches the desorption temperature and at the same time adsorbate begins to fume out of the bed as vapour. Thus, the adsorbed vapour is driven out using solar radiation falling on the collector. The vapour from the sorption bed enters the condenser and subsequently the condensed liquid refrigerant is stored in a storage tank kept below the condenser. Indeed, the high-pressure liquid from the storage tank is throttled through capillary tube and thus creating low pressure at evaporator. The low-pressure refrigerant liquid absorbs heat in the evaporator becoming vapour and ready to enter the sorption bed. Therefore, the operation of system cycle is executed intermittently in the vapour adsorption refrigeration system.

Operating Principle of Solar Adsorption Refrigeration

The cycle of the adsorption refrigeration machine is, limited by four temperatures as shown in Figure 2, namely: T_a, T_{S1}, T_g and T_{S2} in addition to the evaporation temperature T_e and the condensation temperature T_c(Cherrad et al., 2018). The four temperatures are indicated by the intersection of two isobars and two isosteres curves in the thermodynamic cycle (Figure 2) are simply related by two equations. Furthermore, the temperatures at the start of both desorption and adsorption are expressed as a function of parameters of thermodynamic cycle of the system (temperature at the end of desorption, condensing temperature, evaporating temperature and limiting mass ratio of adsorbate). The relationship between the evaporation temperature T_e and the temperature at start of adsorption T_{S2} was also determined as a function of the properties of adsorbate.

The process A to C (occurring during day time) consists of heating phase, which further involves an isosteric heating process from A to B and a desorption condensation process from B to C. During start of the day the valve 1 and 2 are closed. The isolated adsorber from the condenser and evaporator is at adsorption temperature T_a and theevaporator pressure P_e. Solar radiation heats the adsorber. The pressure and temperature of adsorbent and refrigerant increases during that the total mass adsorbed of refrigerant remain constant. Once the saturation pressure P_c in the adsorber is achieved at T_c of the condenser, valve 1 is opened and condenser linked with the adsorber (B).

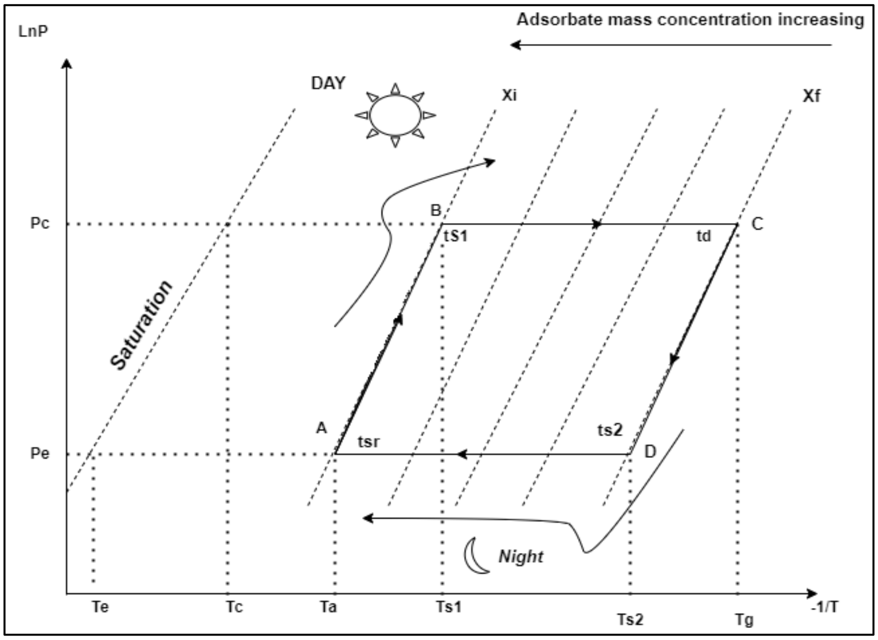


FIGURE2. Ideal cycle of solar adsorption refrigerator in Clapeyron diagram (Cherrad et al., 2018).

Solar energy allows the simultaneous increment of the adsorber temperature and desorption of the refrigerant contained in the adsorbent. The refrigerant vapour released by the adsorbent will be condensed in the condenser, and the pressure phase imposed by the condenser continues as long as the temperature of the adsorbent increases. The desorption ends at point C, when the adsorbent reaches the maximum temperature T_g(generator). The condensate is discharged to the evaporator by gravity during its formation.

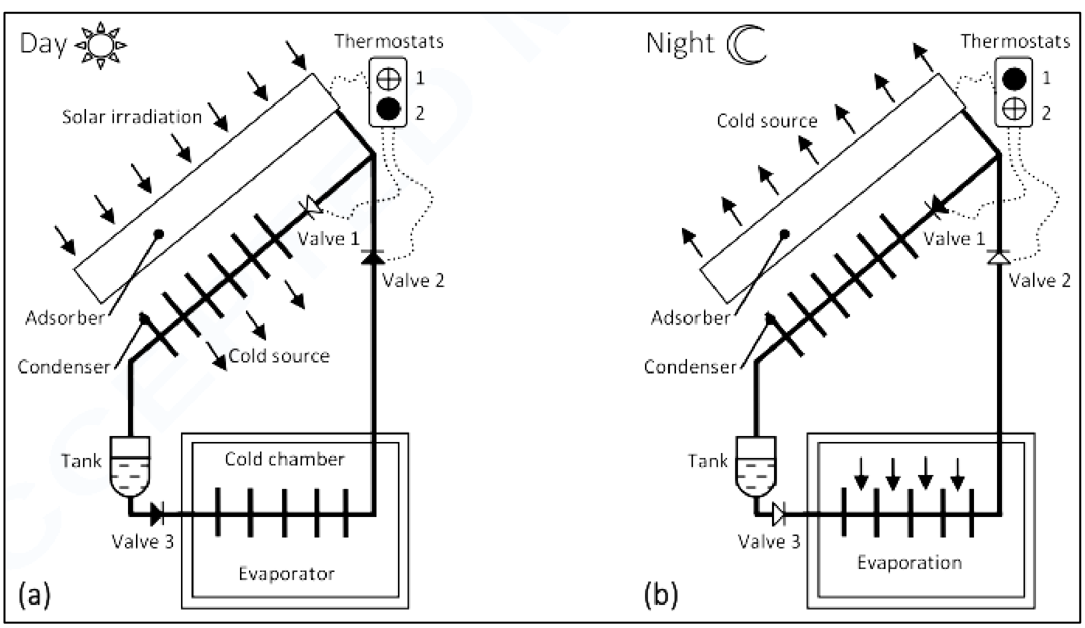


FIGURE3. Solar adsorption refrigerator cooling machine(Cherrad et al., 2018).

The process C to A (during night time) consists of cooling phase. It involves an isosteric cooling process from C to D and an evaporation process from D to A, hence completing the cycle. When the solar flux decreases, the temperature & pressure of the adsorber decrease according to an isoster. At night valve 2 is opened and the adsorber connected to the evaporator, which imposes its pressure, continues to cool. The adsorbent adsorbs the refrigerant which evaporates & generates cold production. This cycle has the particularity to be intermittent because the adsorber is heated during day & cooled at night, which is suitable for the intermittency of solar energy.

Advantages of Activated Carbon-Methanol Pair

The following are the advantages of using activated carbon-methanol(Mahesh & Kaushik, 2012), as a working pair for the solar adsorption refrigeration system over the other available pairs.

1. High COP
2. Low generation temperature required
3. Low freezing point
4. No corrosion problem
5. High adsorption capacity

The flat plate collector, which is used to serve the purpose of thermal compressor is sufficient to provide favorable temperature for desorption of methanol (approx. 65℃). Hence, this working pair further proves to be cost effective as well. However, on heating methanol beyond 120℃ result in decomposition of methanol into dimethyl, which is highly corrosive. Therefore, using flat plate collector has got an added advantage, along with cost effectiveness.

PERFORMANCE EVALUATION OF SARS SYSTEM

In order to calculate the adsorbed quantity of activated carbon and methanol at different temperatures, a simplified form of Dubinin-Astakhov equation(Dasore et al., 2021) is used. The equation is given by,

$$x = x_0 exp\left[-K\left(\frac{T}{T_s} - 1\right)^n\right]$$

Where x is the concentration ratio; for adsorption process, $T_s = T_e$ and for desorption, $T_s = T_c$.

For activated carbon-methanol as the working pair, $x_0 = 0.682$, K = 10.84, and n = 1.21(Dasore et al., 2021).

The COP of the system is evaluated by calculating the values of heating power and cooling power initially. The heating power (Q_h) and the cooling power (Q_{ref}) are calculated as follows,

$$Q_h = \frac{\int_0^{t_{cyc}} C_w\, m_{w,h}(T_{h,in} - T_{h,out})dt}{t_{cyc}}$$

$$Q_{ref} = \frac{\int_0^{t_{cyc}} C_w\, m_{w,e}(T_{chill,in} - T_{chill,out})dt}{t_{cyc}}$$

The COP of the system can be evaluated by using the ratio of cooling power to the heating power as is given as,

$$COP = \frac{\int_0^{t_{cyc}} C_w\, m_{w,e}(T_{chill,in} - T_{chill,out})dt}{\int_0^{t_{cyc}} C_w\, m_{w,h}(T_{h,in} - T_{h,out})dt}$$

Hence, by evaluating the COP value, we can analyze the performance of the solar adsorption refrigeration system.

LITERATURE REVIEW BASED ON TYPE OF COLLECTOR AND LOCATION

Working Pair	Reference	T_{evap} (℃)	COP	Origin	Application	Collector type
Solidified activated carbon / Methanol	(L. W. Wang et al., 2003)	-7.2	0.239	Shanghai	Ice maker	-
Consolidated activated carbon / Methanol	(L. W. Wang et al., 2006)	-10.31	0.125 (SCOP)	Shanghai	Ice maker	-
Activated carbon / Ammonia	(Fadar et al., 2009)	0	0.43	Morocco	Refrigeration	Parabolic trough (PTC)
Maxsorb III / Methanol	(El-Sharkawy et al., 2009)	7	0.79	Fukuoka	Air Conditioning	-
		-5	0.68	Fukuoka	Ice maker	
Activated carbon / Methanol	(Abu Hamdeh & Al-Muhtaseb, 2010)	8	0.688	Jordan	Refrigeration	Flat plate
Silica gel / water	(Alam et al., 2013)	14	0.55	Tokyo	Air Conditioning	CPC
Activated carbon / Methanol	(Hassan & Mohamad, 2013)	0	0.66	Riyadh	Water chiller	Flat plate
Olive waste / Methanol	(Abu-Hamdeh et al., 2013)	8	0.75	Jeddah	Refrigeration	PTC
Activated carbon / Methanol	(Kumaraguru, 2013)	12	0.57-.073	Madurai	Refrigeration	Flat plate (Unglazed)
Activated carbon(granular) / Methanol	(Taylor et al., 2013)	-	0.196 (SCOP)	Calicut	Water chiller	Parabolic
Activated carbon / Methanol	(Ji et al., 2014)	-	0.122 (SCOP)	Kunming	Ice maker	Finned tube adsorbent bed
Activated carbon / Methanol	(Berdja et al., 2014)	4	0.49	Algeria	Water chiller	Flat plate adsorbent bed
Activated carbon / Methanol	(Qasem & El-Shaarawi, 2015)	-3	0.32	Dhahran	Ice maker	Flat plate adsorbent bed

Activated carbon / Methanol	(Alahmer et al., 2016)	-	0.491	Hobart	Refrigeration	CPC
Activated carbon / Methanol	(Hadj Ammar et al., 2017)	-3	0.73	Ouargla	Ice maker	Flat plate adsorbent bed
Activated carbon / Methanol	(Mahesh, 2017)	8-13	0.33-0.75	Anand	Water chiller	Vacuum tube collector
Activated carbon fiber / Methanol	(Bhargav et al., 2018)	20	0.43	V.V Nagar	Water chiller	Water Tank with Electrical Heater
Activated carbon / Methanol	(J. Wang et al., 2018)	-10	0.487	Australia	Ice maker	Flat plate adsorbent bed
Activated carbon / Methanol	(Cherrad et al., 2018)	-5	-	Ouargla	Refrigeration	Flat plate adsorbent bed
Activated carbon / Methanol	(Y. Wang et al., 2018)	-3	0.142	Kunming	Ice maker	CPC
Silica gel - water	(Reda et al., 2019)	-	0.41	Aswan	Water chiller	Flat plate collector
Activated carbon / Ammonia	(BOUSHABA et al., 2020)	0	0.209	Maroc	Refrigeration	Flat plate adsorbent bed

CONCLUSION

From all the literature surveys done in this paper, it can be concluded that the activated carbon-methanol is the best working pair for the solar adsorption refrigeration system. However, it has been found that the values of COP vary with location for the same working pair. This is due to the fact that the COP values directly depends on the adsorption capacity of the adsorbent. Consequently, the adsorption capacity is mainly dependent upon the quality of the adsorbent used, which varies with location too. So, it can be deduced that besides working temperatures, the quality of adsorbent available is also a deciding factor for evaluating the performance of solar adsorption refrigeration system. Hence, the activated carbon-methanol working pair along with flat plate collector can be employed for some of the application requiring less temperature drop compared to surrounding. Further it is observed that flat plate collector and parabolic trough collector are the mostly widely used collectors. But it is observed for the literature survey that difference in the COP values of both the collectors is almost negligible. This is due to the fact that the minimum temperature (65℃) for evaporation of methanol can be easily achieved using a flat plate collector as well as the parabolic collector. But as parabolic collector can provide temperatures beyond the evaporation temperature of methanol, which is of no much significance as the vaporization enthalpy of methanol has already been reached. Hence, it is more preferable to use flat plate collector for water chilling and air conditioning applications, where parabolic collector is more preferable for ice-making application where achieving temperatures beyond 0℃ becomes mandatory.

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