Design and Simulation of Adsorption Refrigeration System

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Abstract

Adsorption refrigeration systems have become promising alternatives in cooling technology for refrigeration and air conditioning applications. Thermal energy is a primary source of such systems for producing cooling capacity with less electricity usage compared to vapour compression systems. Solar energy with free – access and abundant availability in the tropic have great potential as a renewable heat source to drive the adsorption refrigeration system through direct convection from solar irradiation to thermal energy. Paper describes the performance of solar adsorption refrigeration working with activated carbon/ methanol pair. The solar refrigeration has an evacuated tube collector as an adsorber. Solar adsorption refrigeration can be applied to pre-cooling post-harvest agriculture products, mainly tomatoes, before distribution to the grocery stores, end consumers, ice production applications, etc.

Keywords: *- Solar Adsorption, Activated Carbon/Methanol Pair, Solar Energy*

INTRODUCTION

Refrigeration machines are generally working on the vapour compression cycles and use electricity as input power. The electricity comes mainly from fossil-energy based power generators, which contribute indirectly to global warming by CO2 gas emissions. And also, the refrigerants used in VCR systems like chlorofluorocarbons (CFCs), hydro fluorocarbons (HCFCs) and hydro fluorocarbons (HFCs) are primarily responsible for the ozone-layer depletion potential that is very harmful to the environment.

The solar adsorption refrigeration (SAR) system is an attractive solution to provide more environmentally eco-friendly cooling by using natural refrigerants (e.g., water, methanol, ethanol and ammonia). The SAR system employs refrigerant and adsorbent as a working pair and operates under pressure or partial vacuum conditions [3]. Some important working pairs are silica gel/water, zeolite/water, activated carbon/ammonia, activated carbon/ethanol, activated carbon/methanol [4-5]

The activated carbon/methanol can be driven with a low grade temperature heat source, such as solar energy [6]. The maximum desorption temperature is 120°C, and working at a high vacuum pressure [7]. Activated carbon is a sorbent material with a large adsorption capacity of 0.45 kg/kg with a specific surface of 400-2500 m2/gram and low desorption heat of 1800-2000 kJ/kg[8-9]. Methanol is a refrigerant with a high latent heat of evaporation and freezing point lower than water, suitable for ice-making and refrigerant applications [10].

LITERATURE REVIEW

Many researchers reported experimental works on the activated carbon/methanol SAR system. Buchter et al. [11] built and tested an adsorptive solar refrigerator equipped with a 2 m^3 of single-glazed solar collector/adsorber in Burkina-Faso. The gross solar COP obtained was 0.09-0.13, with the water of 40L immersed in the evaporator. The solar irradiance during the test was 19-25 MJ/m2. Santori et al. [12] carried out a stand-alone solar adsorption refrigerator for vaccine storage in Messina, Italy. They used a solar collector exposed area of 1.2 m2. A solar COP of 0.08 was achieved by producing5 Kg of ice.

Anyanwu and Ezekwe [13] tested a solid adsorption solar refrigerator in Nsukka, Nigeria. The refrigerator used a flat type collector with an effective exposed area of 1.2 m2. The best cooling capacity yielded 266.8 kJ/m2 per day, and the useful cycle COP achieved 0.056-0.093.

Lemmini and Errougani [14] tested a flat plate solar adsorption refrigerator in Marocco under a Mediterranean climate. They found that solar COP achieved was 0.05-0.08 at 12-28 MJ/m2 solar insolation and daily mean ambient temperature of 20°C. The lowest evaporator temperature was at -11°C.

In recent years different approaches were made to increase cooling performance. In this connection, Niemann et al. constructed a 1.6 m2 ETC coupled with a parabolic concentrator was reach the maximum temperature of 170°C [15]. Recently, Li et al. reached a maximum temperature of 200°C by ETC system [16]. It was found that system performance is relatively high compared to the flat plate collector system.

Mahesh used a vaccum tube collector as a heat source and conclude that with an increase in collector area, the cooling production and COP of the solar system can be increased. Bansal et al. was attained a minimum COP of 0.08 for 2.1 m2 ETC with daily irradiation of 26 MJ/m2 [17]. Similarly, Qi achieved the lowest COP of 0.069 for 4.2 m2 collector area [18].

Yunfeng Wang et al. consist of the novel solar adsorption system that used the mass transfer method on the basic adsorption cycle with the working pair of AC/Methanol. They consist of the number of tests at different weathers. The experimental results show that the system employing an active enhancing mass transfer method will increase the mass of desorbed refrigerant by about 20% compared with a natural desorption refrigeration system. It was also proved that the novel way is very effective for low adsorbent temperature operation, which may help obtain a COP solar increase of at least 16.4%. And about one and half hours can be saved by enhancing the desorption refrigeration system to get the same desorbed refrigerant as the natural desorption refrigeration system. The experiments show that the novel system has improvements in the coefficient of performance, the mass of desorption and desorption rate, and the characters of the solar adsorption refrigeration system can benefit from the further application [21].

Prof. B. A. Shah makes reviews the adsorption refrigeration technology. The adsorption refrigeration system developed for transport refrigeration has been discussed and evaluated. Comparison with conventional vapour compression and absorption refrigeration system is given. An assessment is made about the current and future development of adsorption refrigeration technologies. Adsorption systems can be an alternative to reduce the CO2 emission and the electricity demand when they are driven by waste heat or solar energy.

Compared with the vapour compression refrigeration and absorption refrigeration systems, the adsorption refrigeration system has drawbacks, such as low mass and heat transfer performance, low coefficient of performance (COP) and low specific cooling power. Besides the simple intermittent cycle and to provide steady refrigeration and improve the performance of adsorption refrigeration system. Some advanced processes have been proposed and investigated, such as the multi-bed cycles, the thermal wave cycle, the forced convection cycle, the heat and mass recovery based on different adsorbent bed and different control strategies, heat pipe technologies hybrid. To this date, lower temperature adsorption refrigeration systems are still under laboratory testing stages. So we find only laboratory experiments of adsorption machines in the open literature [22].

AO Dieng et al. make a study on a fundamental understanding of the solar adsorption system and give helpful information regarding the design parameters of adsorbent bed reactor and the applicability of solar adsorption both in airconditioning and refrigeration with an improvement of the coefficient of performance. The adsorption system can be sued in ice making, medical or food preservation in remote areas. They are also noiseless, non-corrosive and environmentally friendly. For this reason, the research activities in this sector are still increasing to solve the crucial points that make this system not yet ready to compete with the well-known vapour compression system. The study concludes that the possibility of using non-pollution materials and saving more than half of the primary energy involved in this sector is the most AO Dieng et al. make a study on a fundamental understanding of the solar adsorption system and give helpful information regarding the design parameters of adsorbent bed reactor and the applicability of solar adsorption both in air conditioning and refrigeration with an improvement of the coefficient of performance. The adsorption system can be sued in ice making, medical or food preservation in remote areas. They are also noiseless, non-corrosive and environmentally friendly. For this reason, the research activities in this sector are still increasing to solve the crucial points that make this system not yet ready to compete with the well-known vapour compression system. The study concludes that the possibility of using non-pollution materials and saving more than half of the primary energy involved in this sector is the most important characteristic, but simplicity, low maintenance and the absence of noisy components are also some very important features that make this type of system suitable for numerous other applications, such as air conditioning in cars, trains, bus or food transportation or solar cooling. The absence of harmful or hazardous products such as CFCs, together with a substantial reduction of CO2 emissions due to very low consumption of electricity, creates an environmentally safe technology. Low-temperature waste heat or solar energy can be converted into a chilling capacity as low as 5°C with minor maintenance costs [23].

Z. Tamainot-Telto et al., study on the different AC consist of the simulation results of 26 various activated carbon– ammonia pairs for three cycles (single bed, two-bed and infinite number of beds) are presented at typical conditions for ice making, air conditioning and heat pumping applications. The driving temperature varies from 80 C to 200 C. The carbon absorbents investigated are mainly coconut shell and coal-based types in multiple forms: monolithic, granular, compacted granular, fibre, compressed fibre, cloth, compacted cloth and powder. Considering a double bed configuration at a low driving temperature of 100 C (solar or low grade waste heat source driven machines) and a high driving temperature of 200 C (engine exhaust gas or machines driven by gas fire), the best performances [24]

Ahmed A. Askalany et al. introduces a review for the potential cooling systems which uses carbon materials as an adsorbent. Also, the adsorption carbon pairs (pairs where the carbon is the adsorbent), which is still under researches, were reviewed. The cooling systems' maximum COP (coefficient of performance) was 0.8 for the activated carbon/ethanol pair. The study concluded that the performances of the potential adsorption cooling systems using carbon are still not satisfactory. It was concluded that there is an opportunity for the adsorption carbon pairs to introduce a new cooling system with promising performances. Activated carbon and methanol are among the most common working pairs due to the large adsorption quantity and lower adsorption heat, which is about 1800–2000 kJ/kg. However, activated carbon/methanol has the disadvantage of operating under sub-atmospheric pressure. Theoretical results showed the superiority of the Maxsorb III/methanol pair among other carbonaceous pairs for air conditioning and ice-making applications. The highest values of COP were achieved by the systems which used methanol and ethanol as a refrigerant where it was 0.78 and 0.8, respectively. Many of the new pairs showed a promising future for cooling applications. The study concludes that adsorption cooling is still needed for more attention and is still have the opportunity to be a traditional device [26].

Mohand Berdja et al. work on the experimental realization of a refrigerator prototype that uses an adsorption tube collector for cooling, in which solar energy can be directly absorbed. The development of software giving an estimate of the activated carbon and methanol quantities in the refrigeration system, the quantities of energy used in its various parts, their design, the refrigeration and solar performance coefficient was carried out, and this according to the temperature data, total radiation and the dimension of the refrigeration compartment to be cooled. His work aims to develop an adsorption refrigeration system for cold production able to fulfil the socio-economic requirements, in particular in terms of low total costs (solar collector, equipment, maintenance) and technological simplicity (system without valve and self-adapting in the external conditions). The thermal COP of the prototype was found equal to 0.49 depending thus on the refrigerating effect and the energy absorbed in the collector-adsorber. The solar COP was equal to 0.081 depending on the refrigerating effect and the solar radiation [27].

M. Attalla et al. also make the experimental model work for a solar adsorption ice maker system (SAIMS) using working pair of activated carbon (AquaSorb 2000) and methanol. The isotherm and isobar characteristics of the used team are investigated by using Dubinin-Raduskevich (D-R) equation. Then, the SAIMS is constructed and tested at real weather conditions in Qena, Egypt. The model consists of the acrylic sheet on the solar plate for efficient heat transfer. High adsorbent temperature increases the amount of the methanol desorbed and condensed and therefore improves the gross COP of the system. Subsequently, the ice production and the net COP are increased [28].

Mahmoud Salem Ahmed et al. [38] studied classification and compared the working pairs to use. The comparison is based on the use limits as maximum COP, driving temperature, evaporation temperature and SCP (Specific Cooling Power) are introduced. The study introduces the most promising adsorption cooling pairs.

Working pair		COP	T_e °C	T_d °C	SCP W/kg
Physical adsorbent	Activated carbon/ammonia	0.61	-5	100	2000
	Activated carbon/methanol	0.78	15	90	16
	Activated carbon/ethanol	0.8	3	80	N.A
	Silica gel/water	0.61	12	82	208
	Zeolite/water	0.25	6.5	350	200
Chemical adsorbent	Metal chloride/ ammonia	0.6	-10	52	N.A
	Metal hydrides/hydrogen	0.83	-50	85	300
	Metal oxides/water	N.A	100	200	78
Composite adsorbents	Silica gel and chlorides/water	1.65	7	70	N.A
	Silica gel and chlorides/methanol	0.33	-10	47	N.A
	Chlorides and porous media/ammonia	0.35	-15	117.5	493.5
	Zeolite and foam aluminum/water	0.55	10	250	500

Fig.1 Comparison between the adsorption working pairs

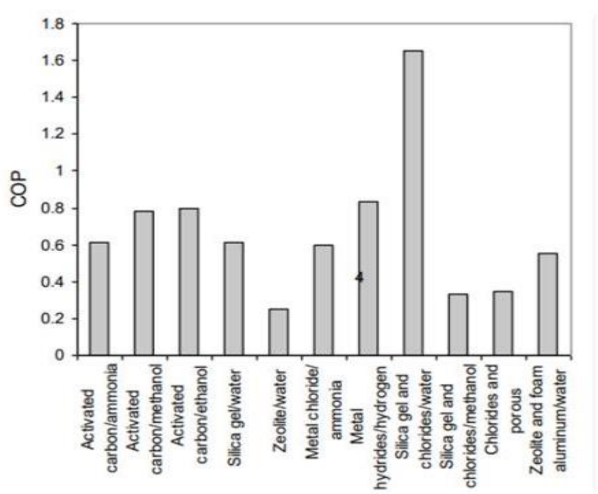

Fig.2 Coefficient of performance for working pairs

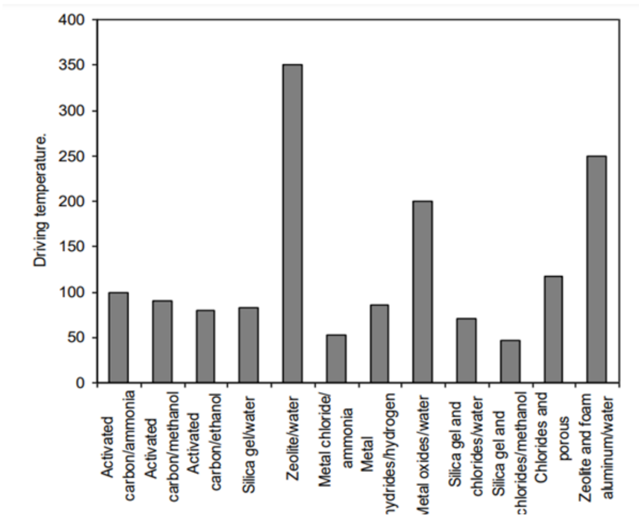

Fig.3 Driving Temperature for the working pairs

Activated Carbon

The activated carbon is made of wood, peat, coal, fossil oil, bone, coconut -shells and nut stone. The structure of activated carbon is shown in Fig.1. The specific area of activated carbon is between 500 and 1500 m2 /g. The difference between the activated carbon and other types of adsorbent is the surface feature. The whole surface of activated carbon is covered by ab oxide matrix and some inorganic materials, and therefore, it is non-popular and has a weak polarity. The adsorption heat of activated carbon pairs is lower than that of other types of physical adsorbent pairs.

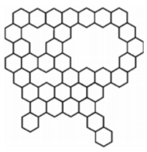

Fig.4 Structure of activated carbon [19]

Fig.5 AC particle size 4-8 mesh

Refrigerants

The requirements for a suitable refrigerant are generally as follows: (1) high latent heat of vaporization per volume unit or mass unit. (2) thermal stability (3) environment harmless (4) non-flammable (5) innoxious (6) saturation pressure between 1 and 5 atm. in working temperature (an excellent value would be close to 1 atm.). Unfortunately, no refrigerants have all the characteristics above, and the common refrigerants for adsorption refrigeration systems are ammonia, water, and methanol. Some physical properties of refrigerants for adsorption systems are shown in Table no.1.

Activated carbon/methanol is one of the most common working pairs due to the large adsorption quantity and lower adsorption heat, about 1800-2000kJ/kg. The activated carbon /methanol is also suitable working pair to use solar energy as a heat source due to the low desorption temperature, which is about 100°C. Temperature higher than 120°C should be avoided because methanol decomposition into other compounds occurs above this temperature [16]. However, activated carbon /methanol has the disadvantage of operating under sub-atmospheric pressure. So the necessity of a vacuum inside a machine using this pair increases the manufacturing complexity and reduces the system's reliability.

METHODOLOGY

In the VCR system, we are using high grade energy with the help of a compressor, while in the ARs, it uses low grade solar energy to produce the power.

The prototype of an experimental set-up contains three major parts: A solar collector/adsorber, a condenser and an evaporator/cooler box. A solar collector is an evacuated tube collector. The adsorber is placed into the solar collector and connected to the condenser through a pipe header.

Table no.1 Some Physical properties of common refrigerants for adsorption systems [19]

Refrigerants	Chemical formula	Normal boiling point (°C)	Molecular weight	Latent heat of vaporization L (kJ/kg)	Density ρ (kg/m^3)	$\rho \times L$ (MJ/m^3)
Ammonia	NH_3	−34	17	1368	681	932
Water	H_2O	100	18	2258	958	2163
Methanol	CH_3OH	65	32	1102	791	872
Ethanol	C_2H_5OH	79	46	842	789	665

The machine's operation principle consists of heating by solar radiation the adsorbent contained on the adsorption collector, which is disposed of horizontally. This energy should be sufficient to desorb the adsorbent (methanol) molecules and be transformed from their liquid phase into vapour. Then, the methanol vapour is condensed and collected in a tank, then evacuated toward the evaporator in a liquid phase. The adsorbent starts to cool gradually when solar radiation decreases in the evening to reach the ambient temperature. This decrease in the temperature involves the adsorption phenomenon of the activated carbon with the methanol. Cold production results from the energy needed to evaporate the methanol in the evaporator, which the activated carbon will absorb. This phenomenon will occur when the adsorbent is wholly saturated with methanol for a temperature slightly higher than the environment temperature and the initial vacuum pressure.

CONCLUSION

It was found that there is a lot of scope for renewable energy in the coming days. An adsorption system is a green energy system that is not harmful to the environment and has fewer moving parts. Hence, it's noiseless and required less maintenance in comparison to the VCR system. Using proper adsorbent- adsorber working pair can increase the COP of the system, which is helpful to increase the use of ARS for domestic purposes. The most studied physical adsorption working pairs are activated carbon/methanol, activated carbon/ammonia, silica gel/water and zeolite/water. The study shows that the methanol and ethanol with activated carbon pairs had the highest COP value. According to the driving temperature, methanol with activated carbon pair has the lowest driving temperature compared to other physical adsorption pairs. So it concludes that increasing the COP of adsorption refrigeration system with lowest driving temperature Activated Carbon/ Methanol pair is an ideal working pair.

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