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Detailed Review on Adsorption Refrigeration System for Different Adsorbent/Adsorbate Working Pair Green Composite Materials - An Environmental Aspect

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Abstract

Adsorption refrigeration is one of the greatest encouraging system for the refrigeration applications due to use of low grade energy. Present study deals with detailed review of adsorption refrigeration system. This article mainly concern with as working pair are better at low generation temperature. Silica gel/water is appropriate pair because of its lower operating temperature. COP of adsorption refrigeration system of activated carbon Fiber-methanol is superior when contrasted with that of activated carbon–methanol system. Explicit cooling power and COP of adsorption refrigeration framework can improve with the utilization of composite adsorbent material as it further develops intensity and mass exchange. It is likewise seen that multi bed, multistage, mass recuperation, heat recuperation, intensity and mass consolidated recuperation frameworks gives better execution of the adsorption refrigeration frameworks.

Keywords: Adsorption refrigeration, COP, green composite, mechanical properties, specific cooling power, thermal analysis

INTRODUCTION

"Refrigeration system consumes about 15 to 20% of world's total energy produced. This could be decently carried down with the utilization of nanoparticles in refrigerants. Colloidal suspensions of nanoparticles plays a vital role as in a heat transfer that could supplant the regular refrigerants by and by utilized in refrigeration frameworks, because of its enhanced intensity move and mechanical properties. Researchers are mainly focusing on vapour compression, vapour absorption, and adsorption refrigeration system for the cooling applications. Researchers have focused on different aspects like effect of mechanical properties of refrigerants, pair of working fluid on the thermal performance of the refrigeration system etc. Vapour compression refrigeration system provides better performance, but it also causes serious environmental problems due to use of non-green materials like CFC/HCFC/HFC refrigerants. Looking towards the same, use of natural refrigerants and utilization of low-grade energy are the main concern now-a-days in refrigeration systems. Consequently, specialists began addressing in on adsorption cooling innovation from late 1990s" [1].

Adsorption refrigeration system produces cooling effect with the use of low-grade energy. Hence, adsorption refrigeration system is considered as most promising solution of vapour compression refrigeration system. Adsorption refrigeration system worked with the use of low-grade energy like sun-based energy, squander intensity, and fumes heat from the motors. Adsorption refrigeration system powered by the intensity source

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temperature of around 60°C to 90°C. Adsorption refrigeration framework is ecological agreeable and has low support prerequisite. However, practical use of adsorption refrigeration system is big challenge for the researchers due to its much lower COP compared to vapour compression refrigeration system. Now-a-days, biopolymer adosrption technology, electrocoagulation adsorption system for the waste water cleaning, nanoparticles based adsorption refrigeration system, biosorption that is physical adsorption system and many more becoming popular.

Solar energy is clean and inexhaustible energy source as well as it can be captured easily. Nearly all parts of India obtain 4-7 kWh of sunlight-based radiation/ m^2 area which is alike to 2300–3200 daylight hours/year. Use of the solar energy to the adsorption refrigeration system is most viable option. Large amount of work have been done by the researchers on adsorption refrigeration system using green solar energy with different green composite adsorbent/adsorbate working pairs. Researchers are also focusing on execution improvement of adsorption refrigeration framework. Few work is also observed about use of waste heat as heat input in adsorption refrigeration system.

SYSTEM DESCRIPTION

The characteristics of green composite adsorbent/adsorbate pair assumes an imperative part in determining exhibition of the system. Main components of adsorption refrigeration system are adsorber, condenser, expansion valve, and evaporator as shown in Figure. 1. Working of adsorption refrigeration system is similar to absorption refrigeration system except the adsorbate vapour is adsorb on to the solid surface. Remaining all other three processes which occurs in condenser, expansion valve and evaporator are similar as that occurs in absorption refrigeration system. Desiccant material is used to pack desorber and adsorber, which has capacity to desorb or adsorb the refrigerant during desorption or adsorption process. Cooling water is used to eliminate the intensity of adsorption. Then again, hot water is used in desorption process to let the refrigerant out of the adsorbent pores. Adsorption refrigeration system requires huge surface region for the intensity move to and from the adsorbent materials.

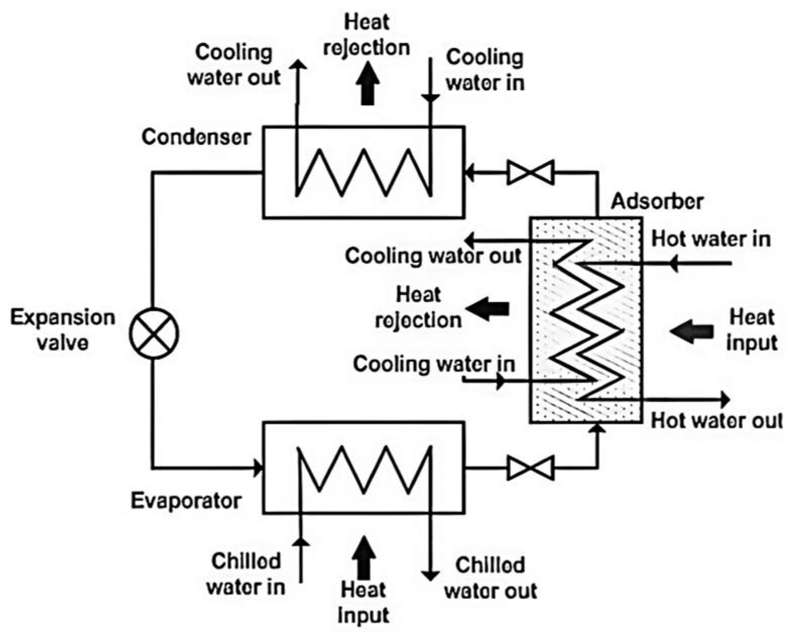

Figure 1. Schematic diagram of adsorption cooling system [40]

Figure 2. shows the four processes of adsorption refrigeration system namely pre-heating (process 1-2, isosteric warming), desorption (process 2-3, isobaric desorption), pre-cooling (process 3-4, isosteric cooling), and adsorption (process 4-1, isobaric adsorption). Adsorption refrigeration framework enjoys a few benefits like driven by low-temperature squander heat or environmentally friendly power sources, no moving parts, consequently high durability and minimum maintenance, synthetic lubricants are not required. It has several disadvantages like lower cycle COP and discontinuous cooling effect.

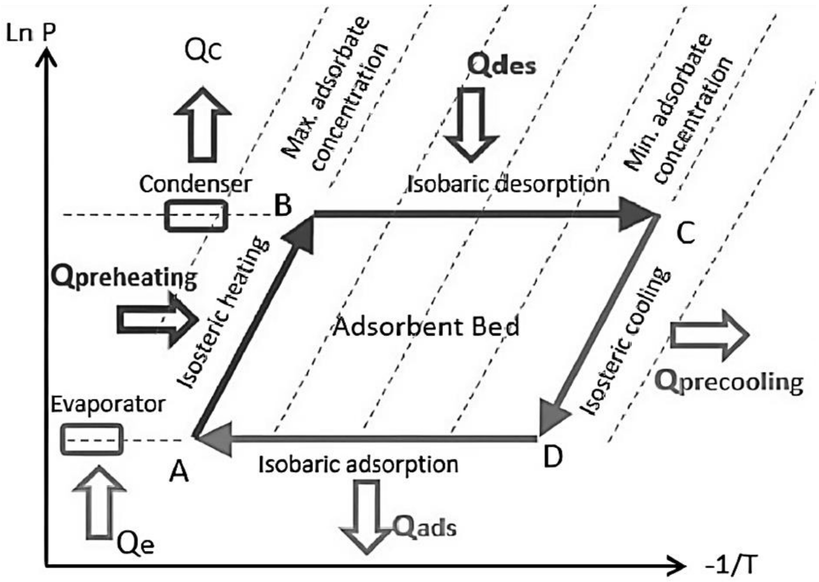

Figure 2. Clapeyron diagram of an ideal adsorption refrigeration cycle [41]

Adsorbent/Adsorbate Pair

"Functioning pair dramas a vital role in adsorption refrigeration system. An adsorbent bed contains adsorbent such as silica gel, zeolite, activated carbon etc. with large surface area. Adsorbent should have strong adsorptive property to adsorbate/refrigerant such as ammonia, water, methanol etc. The exhibition of adsorption refrigeration framework is fundamentally impacted by adsorbent/adsorbate working pair. Some desirable mechanical properties of green composite working pair are listed as follows" [13]:

Desirable properties of adsorbent:
- Extensive variety of adsorption limit with enormous temperature variety.
- It ought to have high intensity and mass exchange properties.
- Low susceptibility to contamination.
- It should be chemically harmonious with the refrigerant and have low cost.

Desirable properties of adsorbate:
- Large latent heat of vaporization.
- It should have high thermal conductivity and stability.
- It should have low viscosity.
- It ought to be non-poisonous, non-combustible, and non-destructive.
- It should not be harmful to the environment.
- It should have low freezing point temperature.
- Researchers are working on performance improvement of adsorption refrigeration system using different appropriate adsorbent/adsorbate working pair.

LITERATURE REVIEW

In 1848, Faraday introduced the adsorption phenomena for refrigeration purpose. He found that cooling effect can be produced when silver chloride adsorbs ammonia. An inclusive variety of working pairs are promising for the adsorption chillers or adsorption refrigeration system. In the majority of the functioning matches water is utilized as refrigerant because of certain benefits like simple to deal with, non-harmful, and high dormant intensity of vaporization contrasted with other potential refrigerants. The only disadvantage is its use for the applications lower than 0°C temperature, due to solidification issue. "Hence for the applications below than 0°C, methanol or ammonia are preferable refrigerants for the pair of adsorption refrigeration system" [2].

Several researchers have worked on enacted carbon-methanol adsorption refrigeration framework. Douss and Meunier [3] completed exploratory work to foresee impact of working temperatures on execution of enacted carbon-methanol adsorption refrigeration framework. The exhibition of adsorption refrigeration framework viewed as extremely delicate to dissipating temperature. Their exploratory outcomes showed that COP viewed as more noteworthy than 0.5 at the vanishing temperature lift under 25°C. “Theoretical and experimental investigation was carried out for the performance prediction of solar assisted adsorption refrigeration system utilizing enacted charcoal-methanol pair. It was concluded that wall thickness, selective absorbing surface and the convergence of methanol surged into the system unequivocally affected the framework execution. Thermal analysis results showed that sun based COP was tracked down in the scope of 0.1 to 0.2 at the level plate gatherer region 0.92 m^2 to deliver 4 to 5 kg ice/day” [4,5]. “Design of gas flow, condenser and evaporator pressure, and design of bed of adsorption refrigeration system plays a vital role on performance of activated charcoal-methanol working pair adsorption refrigeration system. It was also concluded that solidified beds, lower condenser and higher evaporator pressure, and that two bed adsorption cycle gives improved performance of the system” [6-8]. Two industrially accessible carbon tests to be specific 207EA granules and WS-480 pellets were utilized by Wu et al. [9] to introduce adsorption isotherms and isosteric intensity of adsorption. Their outcomes showed that WS-480 gives a lot higher measure of intensity adsorbed when contrasted with 207EA. Energy and exergy investigation of consolidated 9 MW of Rankine warm cycle and sun based fueled twofold bed fume adsorption heat recuperation and space cooling framework were broke down by Dubey and Mishra [10]. Highest irreversibility originate in boiler and solar generator in coal based power plant and adsorption system respectively. It was observed that double bed adsorption system provides 15% higher overall cooling effect. Solar based adsorption refrigeration system with the use of hybrid composites were experimentally investigated at Cairo, Egypt climate condition by El-Ghetany [11]. Maximum COP obtained as 0.92 at 2 lit/min hot water flow rate and 20% concentration of additives. It was also concluded that cycle COP was increased by 49% and 46% at 3 and 2 lit/min hot water flow rate respectively.

Silica gel is mainly used to pair with liquids. Several researchers have worked on silica gel/water adsorption refrigeration system. “Thermal analysis of silica gel-water adsorption system was carried out to find performance of the system for the different operating conditions. Intensity and mass exchange investigation of sunlight based controlled silica gel/water adsorption refrigeration framework provides better results of COP and cooling effect as compared to basic adsorption cycle” [12,13]. “Performance prediction of silica gel/water four bed adsorption cooling system [14] and two bed [15] system was analyzed. To boost the general exhibition of framework, impact of various working temperatures and process duration on COP, refrigeration limit and mass were contemplated”. Najesh et al. [16] did mathematical reproduction of sun-oriented silica gel/water adsorption refrigeration framework. Their exploratory outcomes were contrasted with mathematical model outcomes and tracked down great understanding between them. Sun oriented fueled adsorption framework with the utilization of measured adsorber was analyzed by Yu et al. [17] for homegrown cooling and water warming application. In their work, approach of intensity recuperation between two adsorbers and mass recuperation between two evaporators were embraced. The most extreme COP of warming and cooling were gotten as 1.39 and 0.59 individually at cooling water temperature of 35°C. Optimum time of heat recovery, mass recovery, and cogeneration were found as 40s, 40s, and 600s respectively. A silica gel/water adsorption cooling system were developed and examined under the climate condition of Iraq by Lattieff et al. [18] to find effect of inconsistent adsoprion/ desorption times on the outcome of the system. It was concluded that optimum system performance found at unequal adsoprion/ desorption times. In the Japan market of shut sort adsorption refrigeration and intensity siphon frameworks are expanding. “Experimental investigation on a 3.5 kW cooling capacity silica gel/water adsorption heat pump were carried out by Saha et al. to find the system performance under different operating temperatures. Utilization of low temperature waste heat around 55°C as driving source at cooling source of 30°C in the two stage adsorption chiller was the novelty of their work” [19].

Industrial waste water can be treated by using electrocoagulation with adsorption system by the use of natural zeolite. Numerous researchers have also worked on green composite zeolite-water working pair, because zeolite is one of the potential adsorbent with better mechanical properties like its high surface area, good adsorbent capacities for small molecules, and its porous structure. Thermal analysis was done by Chang and Roux [20] to predict the performance of zeolite/water adsorption refrigeration system powered by solar system. It was inferred that framework execution was basically relies upon encompassing temperature, safeguard properties, and sort of sun oriented authority. "Adsorption air conditioner using green composite zeolite-water as working pair was designed by Wang et al." [21] to predict its performance for the fan coil application to supply 8 to 12°C chilled water. "Their results showed that refrigerating power of the adsorption system was found up to 10 kW at evaporating temperature of 6.5°C, cooling water temperature of 40°C, heating/cooling time of 1060s, heat recovery time of evaporator of 40s, and gas inlet temperature of 450°C, which comes out from I. C. Engine" [21]. Saravanan and Rathnasamy [22] carried out optimization of adsorption cooling system based on solar energy using zeolite-water as working pair. It was reasoned that mass focus proportion has greatest effect on the COP of the framework when contrasted with other working boundaries. Their work was focused on maximization of COP for the optimum mass concentration ratio. "Mobile vaccine refrigerator based on solar powered adsorption cooling system using zeolite/water as working pair was presented by Djubaedah et al." [23]. In their work, pressure drop was created by adsorption of water in zeolite which ultimately reduces temperature also. Around 2°C to 8°C temperature is preferable for the preservation of vaccine. Tubreoumya et al. [24] completed reenactment of sunlight-based adsorption refrigeration framework utilizing zeolite-water working pair at Burkina Faso environment condition. According to their result, highest values of average solar flux density, soar COP, and cold produced obtained as 590 W/m^2, 0.25, and 6.391 MJ respectively for the month of March. Their outcomes were exceptionally encouraging for the presentation improvement of sun-based adsorption refrigeration to essentially utilize it. Single bed zeolite-water adsorption cooling system was simulated by Ahmed et al. [25] by preparing mathematical model. Simulation was carried out using EES software. "Effect of condenser, evaporator, and adsorption bed temperatures on the system performance was studied. According to their results, maximum COP was found as 0.4 at 174°C and 12°C of heating fluid and evaporator temperatures respectively" [25]. Nasruddin et al. [26] presented adsorption thermal energy storage system for 160°C charging temperature with the use of zeolite-water as working pair. Their core work was on adsorption thermal energy storage. It was found that natural zeolite has high energy storage capabilities with 63.94 kWh/m^3 energy density. "Ship gas emission can be minimize with the use of continuous adsorption cooling and heat pump system powered by waste heat was presented by Ezgi" [27]. "According to their conclusion, zeolite-water found most appropriate working pair for ships in physical adsorption system. It was found that COP of the cooling system lies between 0.109 and 0.384, while it lies between 0.104 and 0.367 for the heating, when exhaust gas temperature varied from 170°C to 410°C" [27].

Few work is observed on adsorption cooling system with zeolite in some different form. Trisupakitti et al. [28] arranged and utilized zeolite-4A in adsorption refrigeration framework to foresee execution of the framework. It was found that COP of the adsorption system with only zeolite 4A was 0.38 while that with 6% addition of copper was of 0.56. Kowalska and Ambrozek [29] concluded that adsorption heat pumps yield comparatively low performance than other heat pumps. "Mathematical modeling and numerical simulation was presented by the authors to predict the performance of adsorption heat pump using water-zeolite 13X working pair. It was also concluded that COP of cooling found lower as compared to that of heating" [29].

Performance comparison based on different working pairs is the way to find out most appropriate working pair for the adsorption system. "Comparative study of flat plate solar collector-based adsorption refrigeration system using zeolite/water and activated carbon/methanol working pair was presented by Jrad et al." [30]. Outcomes showed that actuated carbon/methanol pair yields preferable execution over that of zeolite/water pair. It was also concluded that combined adsorption-ejection cycle provides better performance as compared to simple cycle for both the working pairs. "Soni and Gaba carried out comparative study of adsorption refrigeration system using silica-gel/water and zeolite/water as working pair. It was concluded that at lower refrigeration temperature range, COP and specific cooling capacity of zeolite/water found better as compared to silica-gel/water working pair. It was also found that silica-gel/water provides better performance at high refrigeration temperature, while zeolite/water provides better results at low generation temperature" [31].

Apart from common working pairs, several researchers have also worked on some other adsorbent-adsorbate working pair to predict the performance of the adsorption refrigeration/cooling system. Experimental investigation was carried out using activated carbon-ethanol working pair [32,33] to predict the performance of the system for the different adsorption temperature range. "Several researchers have worked on activated carbon fiber (ACF)-methanol adsorption refrigeration system to predict the performance of the system. It was concluded that ACF provides about 15% greater COP than that of activated carbon–methanol system. Based on their results, at cold fluid inlet temperature of -15°C, ACF-methanol provides better performance compared to silica gel system for the different operating parameters" [34,35]. "Ei-Sharkawy et al. worked on adsorption cooling system for the performance improvement with the use of new working pairs namely activated carbon fiber (A-15) and (A-20) with ethanol. The D-R (Dubinin-Radushkevich) equation was used for experimental data. It was observed that (A-15)/ethanol working pair provides lower adsorption capacity as compared to (A-20)/ethanol pair" [36]. Maggio et al. [37] fostered a model to find COP of the adsorption cooling framework for the ice making application with an original composite material for example lithium chloride in silica gel pores. Their outcomes showed that greatest sun-oriented COP of the framework delivered was 0.33. Mahammad et al. [38] introduced a recreated investigation of adsorption refrigeration fueled by wing type compound parabolic concentrator (CPC) to foresee execution of the framework. Their simulation results showed that performance of the system with wing type CPC provides 2% higher in winter and 6% higher in summer as compared to simple CPC collector for the same solar collector length. Ultimate conclusion of their work was wing type CPC collector preferred over simple CPC collector for the same length and without requirement of tracking. "Du et al. carried out experimental study of solar adsorption refrigeration system. Their results showed that COP and specific cooling power for any cooling mode of SAPO-34 zeolite found better than that of ZSM-5 zeolite" [39]. Their experimental results also revealed that SAPO-34 zeolite provides better mass transfer while ZSM-5 zeolite provides better heat transfer. Their final conclusion was SAPO-34 zeolite found superior than ZSM-5 zeolite.

It is observed that activated carbon/methanol, silica gel/water and zeolite/water are the most appropriate working pair for the adsorbent refrigeration system. This paper is detailed review of adsorption refrigeration system using different mentioned working pair. Novelty of this paper is it provides complete information about which working pair with what condition provides best performance. Hence, future researchers can select appropriate working pair for their experimental work by referring this paper.

DISCUSSION

At lower refrigeration temperature range, performance and precise cooling capacity of zeolite/water found better as compared to silica-gel/water working pair. Zeolite/water is more suitable pair than that of activated carbon/ methanol for the source temperature above 200°C. Silica gel destroys above 120°C temperature, while zeolite does not destroy at high temperature. It was perceived in activated carbon-methanol adsorption cooling system, wall thickness, selective absorbing surface, the centralization of methanol raced into the framework, and evaporating temperature sturdily influenced the system performance. For the multi-purpose applications, adsorption system can combined with other technologies like nanoparticles. To improve COP and explicit cooling power multi bed, multistage, mass recuperation, heat recuperation, intensity and mass consolidated recuperation frameworks are most favorable techniques. COP of the adsorption refrigeration system can also improve by improving warm conductivity of the adsorbent which is possible by addition mixture of more conducting material such as copper, aluminum silver powder etc. Use of green composite adsorbent material improves heat and mass transfer which ultimately improves the particular cooling power and COP of the adsorption framework.

CONCLUSIONS

Based on the literature survey of adsorption refrigeration system several conclusions are highlighted. Zeolite/water provides better results at low generation temperature. It was inferred that silica-gel/water provides enhanced performance at high refrigeration temperature. Silica gel/water yields better performance as compared to other working pairs for the short cycle time. It is more suitable pair due to its lower operating temperature. Activated carbon/ methanol pair yields improved enactment than that of zeolite/water pair. Activated Carbon Fiber-methanol provides almost 15% greater COP as compared to activated carbon–methanol system based on the thermal analysis. Adsorption refrigeration system based on wing type CPC provides better thermal performance as compared to simple CPC collector.

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