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A Comprehensive Review of Combined Solar Drying and Cooling Systems for Vegetable and Fruit

Abstract: - In refrigeration technology, combining adsorption principles with solar energy applications represents a vanguard of innovation. This abstract encapsulates the synergistic integration of these two domains, presenting a succinct overview of their unification. Adsorption refrigeration systems, powered by solar energy, exemplify an innovative approach to sustainable cooling solutions. Meticulously engineered to harness the inexhaustible power of the sun, these systems eschew traditional compressor-based methodologies, ushering in a new era of environmentally conscientious refrigeration. Solar dryers, integral to this green revolution, utilize solar energy to effectively dry agricultural products, enhancing food preservation while reducing energy consumption. This abstract navigates through the intricate intricacies of adsorption refrigeration technology and solar dryers, elucidating their multifaceted applications within the solar energy paradigm. From elucidating fundamental principles to delineating cutting-edge advancements, this discourse serves as a beacon for researchers and practitioners alike, embarking on a journey towards greener, more efficient refrigeration and drying solutions.

Keywords: Computational fluid dynamics (CFD), simulation, Adsorption Refrigeration, Solar Energy Sustainable Cooling, Environmental Innovation, Solar Dryer

I. INTRODUCTION

In the domain of refrigeration, the combination of solar energy with adsorption technology marks a paradigmatic shift towards sustainable cooling solutions. Solar Thermal Powered Adsorption Refrigeration Systems (STPARS) epitomize this synthesis, proffering a pioneering approach to refrigeration that capitalizes on the copious and renewable energy of the sun. These systems harness the tenets of adsorption to achieve refrigerative effects, utilizing solar thermal energy as their primary power source.

The STPARS function operates on the principle of adsorption, where a solid adsorbent material selectively sequesters and releases refrigerant molecules, thereby producing refrigerative effects. At the core of these systems resides the adsorption chiller, where the adsorbent material undergoes cyclic loading and unloading processes to manifest refrigeration effects. Solar energy, captured through solar collectors or concentrators, provides the necessary thermal input to drive these processes, endowing STPARS with inherent eco-friendliness and sustainability.

The operation of STPARS can be broken down into several key stages. Solar collectors or concentrators initially capture sunlight and convert it into thermal energy, which is subsequently conveyed to the adsorption chiller. Within the chiller, the adsorbent material adsorbs refrigerant vapor at low temperatures and desorbs it at high temperatures, producing refrigerative effects. This process is iterative, with the adsorbent material undergoing recurrent loading and unloading cycles to perpetuate continuous refrigeration output.

Numerous factors impinge upon the performance and efficiency of STPARS. The selection of adsorbent material, its surface area, and pore structure assume pivotal roles in determining the system's refrigeration capacity and energy efficiency. Additionally, the design of solar collectors or concentrators, along with the incorporation of heat exchangers and other ancillary components, affects the overall performance of the system. Research and development endeavors in the realm of STPARS have been focused on enhancing system efficiency, refining component design, and exploring new adsorbent materials. Scholars and researchers worldwide have contributed to the advancement of this technology through theoretical investigations, experimental studies, and numerical simulations.

Seminal research by luminaries such as Wang RZ, Tchernev DI, and Mayor has elucidated the underpinnings of STPARS and explored sundry design configurations and operational stratagems. Studies have examined the performance characteristics of various adsorbent materials, analyzed heat and mass transfer phenomena within

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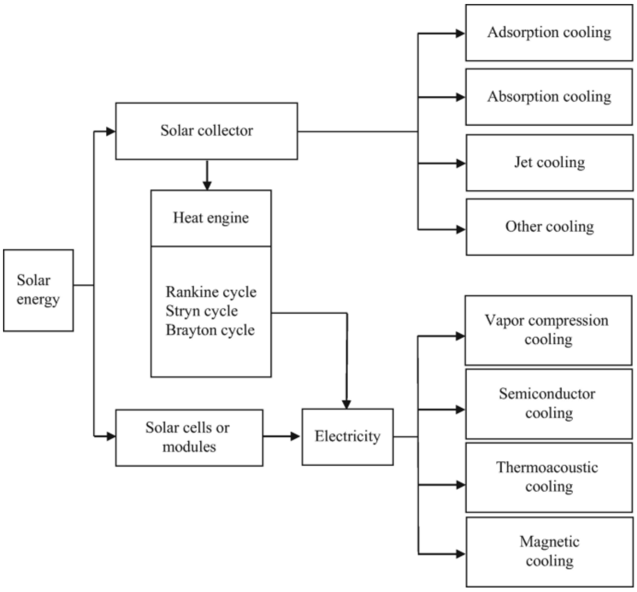
the chiller, and adjusted system parameters to achieve maximum efficiency. Strides in system integration, control algorithms, and heat management methodologies have bolstered the performance and reliability of STPARS. Collaborative research initiatives among academic institutions, industrial collaborators, and governmental entities have propelled the development and commercialization of STPARS, paving the way for their widespread adoption as sustainable cooling solutions.

In summary, Solar Thermal Powered Adsorption Refrigeration Systems epitomize leading-edge technology with vast potential for meeting the growing demand for sustainable refrigeration solutions. Through ongoing research and innovation, STPARS is poised to revolutionize how we cool residences, commercial establishments, and communities, heralding a new epoch of eco-friendly and energy-efficient refrigeration.

The exploration of silica gel-water adsorption chillers has yielded significant advancements in refrigeration technology. Wang et al.'s comprehensive studies, divided into design and performance prediction (Part I) and experimental investigation (Part II), provide valuable insights into the development and validation of novel adsorption cooling systems.

Further research by Chen et al. has focused on integrating silica gel-water adsorption chillers with closed wet cooling towers, highlighting the potential for enhanced efficiency and performance through innovative system configurations. Their work also extends to the design and experimental study of compact adsorption chillers without vacuum valves, demonstrating the feasibility of simplified yet efficient cooling solutions.



1. Figure 1 Solar Cooling Systems

Additionally, investigations into multi-stage, multi-bed regenerative adsorption chillers by Saha et al. underscore the complexity and versatility of adsorption refrigeration technologies. These dual-mode systems offer flexibility and adaptability, catering to a wide range of cooling needs and operating conditions.

The application of solar energy to drive silica gel-water adsorption air conditioning, as analyzed by Lu et al., represents a significant step towards sustainable cooling solutions. Their analysis provides valuable insights into the performance and feasibility of solar-powered adsorption systems, contributing to the ongoing efforts to mitigate environmental impact and reduce reliance on conventional energy sources.

Moreover, developments such as the solar-thermal Eiserzeuger mit Zeolith-Technik (solar thermal ice generator with zeolite technology) by ZeoTech GmbH underscore the growing interest in solar-driven refrigeration solutions for various applications, including logistics cooling.

Collaborative efforts between academia and industry, such as the partnership between Mande et al. and ZeoTech GmbH, exemplify the interdisciplinary approach to developing advanced solar-hybrid adsorption cooling systems. These collaborations leverage scientific expertise and technological innovation to address real-world challenges, such as India's decentralized storage of agricultural products.

Integration enhances thermal efficiency in hybrid photovoltaic-thermal (PVT) solar dryers, as investigated by Erdem et al. [18], both with and without fins. Matavel et al. [19] found improvements in thermal efficiency and product quality compared to open sun drying in their evaluation of a passive indirect solar dryer for drying amaranth and maize grains.

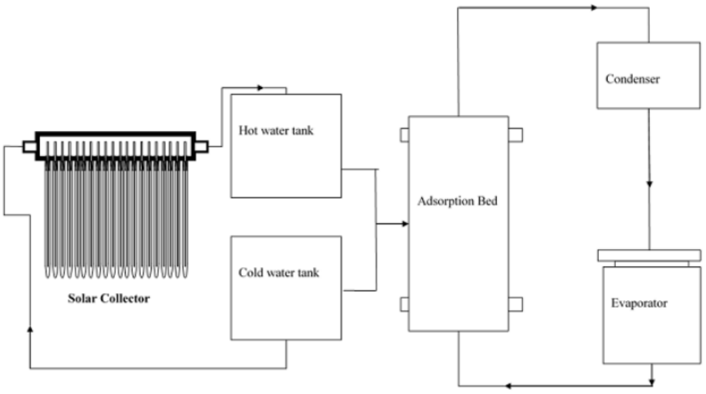


Figure 2. Line diagram of solar adsorption chiller

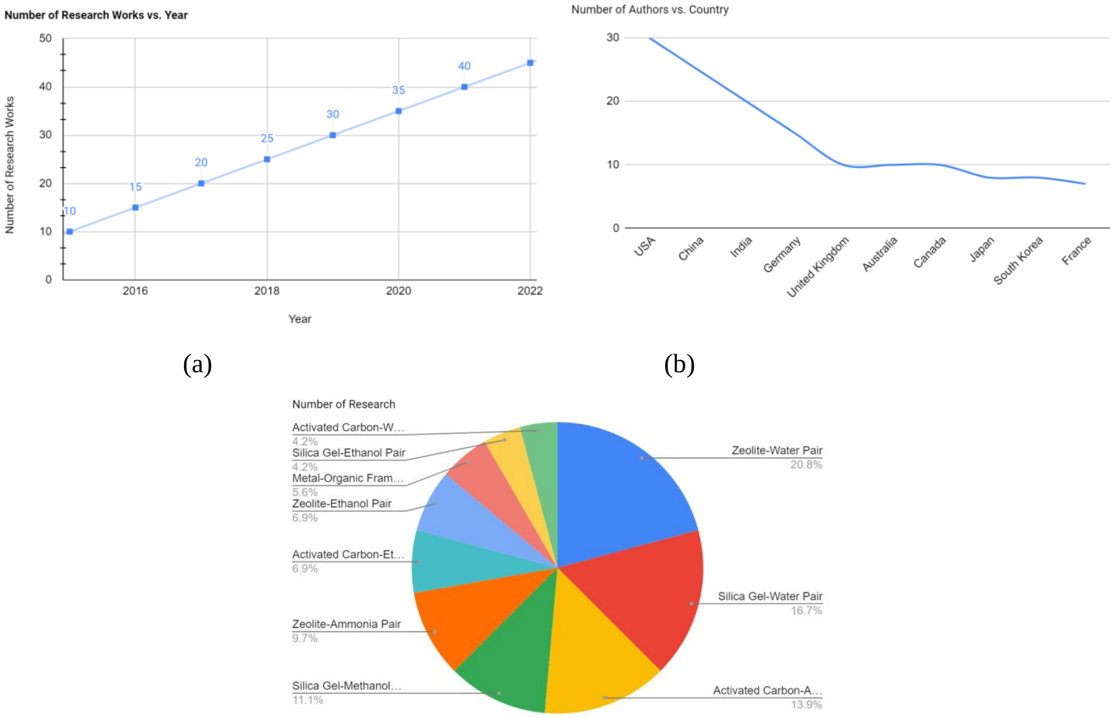
Heating & Desorption Cycle:

In this cycle, the primary objective is to elevate temperature and trigger desorption processes. This involves applying heat to facilitate the release of adsorbed substances. The elevated temperature induces a desorption phase, where substances previously adsorbed are released from the adsorbent material. This cycle is crucial for efficiently operating systems reliant on adsorption principles, particularly in heat-driven processes.

Cooling & Adsorption Cycle:

Contrarily, the focus shifts to lowering temperature and inducing adsorption processes in the cooling and adsorption cycle. This involves removing heat to enable the adsorption of substances onto the adsorbent material. By reducing temperature, the adsorbent material becomes more receptive to capturing substances from the surrounding environment. This cycle is crucial in achieving cooling effects within adsorption-based systems, playing a pivotal role in various applications that require temperature control.

Sections 1 and 2 of the research cover technology, drying principles, performance indicators, and various types of solar dryers. Section 3 provides a detailed look at photovoltaic systems, measurement devices, and the installation of sun-drying systems. Section 4 covers geometric parameters, operational conditions, CFD simulation studies, and factors affecting sun drying efficiency.



(a) (b)

(c)

Figure 3. a. Authors Vs Research work b.Number of Authors Vs Country c. Number of Authors Vs Country %

II. MATERIALS AND METHODS

2.1 Techniques and Technology for Different Solar Thermal-Powered Adsorption Refrigeration Systems

In the realm of Solar Thermal Powered Adsorption Refrigeration Systems, various techniques and technologies are employed to enhance performance and efficiency. These encompass a spectrum of methodologies tailored to suit different operational requirements and environmental conditions. The nuances of these approaches highlight the intricate tapestry of technological innovation within the domain. Solar Thermal Powered Adsorption Refrigeration Systems employ various methodologies to optimize system performance and functionality. These encompass meticulous design considerations, innovative heat management strategies, and precision-engineered componentry. Moreover, advancements in material science and thermodynamic modeling have catalyzed the evolution of these systems, enabling enhanced efficiency and operational flexibility.

At the core of these systems lie the foundational principles of adsorption refrigeration, wherein solid adsorbent materials selectively capture and release refrigerant molecules to achieve cooling effects. Techniques such as zeolite-water pairs, silica gel-water pairs, and activated carbon-ammonia pairs exemplify the diverse array of adsorption material combinations employed in Solar Thermal Powered Adsorption Refrigeration Systems. Each combination offers unique advantages in terms of performance, stability, and environmental impact, thereby catering to specific application requirements and operational constraints.

Technological advancements in heat exchanger design, system integration, and control algorithms have augmented the efficacy and reliability of Solar Thermal Powered Adsorption Refrigeration Systems. These innovations encompass a spectrum of methodologies, ranging from advanced computational modeling techniques to experimental validation protocols, aimed at optimizing system performance and ensuring operational robustness in diverse environmental conditions.

The landscape of Solar Thermal Powered Adsorption Refrigeration Systems is characterized by a tapestry of techniques and technologies, each contributing to the broader quest for sustainable and efficient cooling solutions. Through meticulous research, innovation, and interdisciplinary collaboration, these systems continue to evolve, poised to redefine the refrigeration paradigm in an increasingly eco-conscious world.

2.2 Among several advanced adsorption refrigeration cycles, the relevant technologies are:

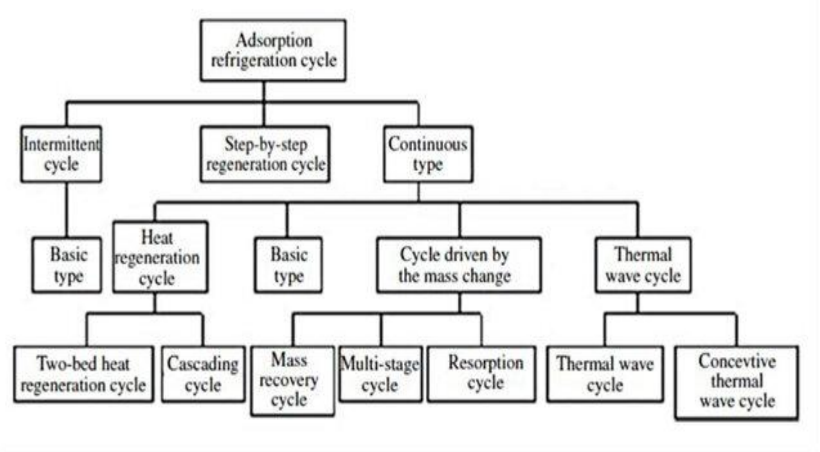


Figure 7. Classification of adsorption refrigeration cycle

a. Heat recovery adsorption refrigeration cycle
b. Mass recovery adsorption refrigeration cycle
c. Thermal wave adsorption refrigeration cycle
d. Convective thermal wave adsorption refrigeration cycle
e. Multistage and cascading adsorption refrigeration cycle
f. Hybrid systems

In the realm of cooling marvels, adsorption refrigeration cycles reveal a symphony of thermal dynamics and material mastery. From the valorization of residual warmth in the Heat Recovery cycle to the meticulous liberation and recapture of gaseous captives in the Mass Recovery iteration, each cycle embodies the artistry of thermodynamic finesse. Thermal undulations conduct a celestial ballet in the Thermal Wave variant. At the same time, convective currents intertwine with thermal waves in the Convective Thermal Wave rendition, forging a synergy of fluid mechanics and thermodynamics. Meanwhile, the Multistage and Cascading cycle orchestrates a crescendo of cooling prowess across sequential tiers, epitomizing the harmonious interplay between complexity and efficiency in the refrigerative realm.

a. In this marvel of thermodynamic ingenuity, the warmth, often dismissed as waste, is repurposed as a vital resource. Through meticulous orchestration, the residual heat, once squandered, is harnessed to drive the adsorption process, bestowing upon us the benefit of refrigeration without the conventional constraints of electricity. This cycle embodies the ethos of resourcefulness, where every joule finds purpose and every degree Celsius a destiny.

b. Behold the elegance of this cycle, where no molecule is left unclaimed, no vapor left adrift. With surgical precision, the adsorbent material surrenders its captives, yielding cooling and the very essence of its quarry. This cycle embodies a symbiosis between function and conservation through judicious extraction and reclamation, epitomizing the adage: Waste not, want not.

c. Herein lies a symphony of temperature gradients, an intricate dance of thermal dynamics. Heat waves propagate through the system, orchestrating the delicate ballet of adsorption and desorption. This cycle harnesses the rhythm of thermodynamic flux, sculpting cooling efficiency with the finesse of a maestro conducting a celestial orchestra.

d. Picture, if you will, a tempest of thermal currents, swirling and eddying through the annals of this refrigeration marvel. As convective forces intertwine with thermal waves, a synergy of motion and heat ensues, propelling the adsorption process to unprecedented heights of efficacy. This amalgamation of convection and thermodynamics makes the cycle a testament to the marriage of fluid dynamics and cooling finesse.

e. In this saga of sequential stages and cascading coolants, complexity finds harmony with efficiency. Each stage bequeaths its thermal legacy to the next, building upon the foundation of its predecessor. Through this cascading symphony of refrigeration, the cycle scales the heights of cooling prowess, unfurling its potential across a multi-tiered landscape of thermal equilibrium.

f. Herein lies the fusion of disparate energies, a confluence of thermal, electrical, and perhaps even sorcerous forces. Hybrid systems defy convention, blending the venerable traditions of refrigeration with the avant-garde innovations era. A new paradigm emerges through this fusion of methodologies, wherein sustainability meets versatility, and tradition embraces transformation.

Table 1. Commercial use of adsorption refrigeration systems

Application	Company/Utilization
Large cooling capacity adsorption chillers	Nishiyodo Kuchou Manufacturing (1986), Mayekawa (Japan), Mayekawa (Japan)
Solar adsorption icemaker	BLM (France)
Adsorption chiller	HIJC (Heat Integrated Joint Companies, USA), Nishikido Kuchiki Co. Ltd. (Japan), SorTech AG. (Germany), InvenSor GmbH (Germany)
CCHP (Cogeneration system for cooling, heat and power)	Malteser Hospital in Kamenz (Germany), Macom Company (Japan), Tokai Optical Co. Ltd. (Japan)
Solar thermal freezer	Zeotech GmbH (Germany)
Adsorption chiller aggregates	SorTech AG. (Germany)
Solar-powered silica gel-water adsorption air-conditioning system	Freiburg University Hospital (Germany)
Solar adsorption air-conditioning system	Sarantis S.A. (Greece)
Locomotive air conditioner	Shanghai Railway Bureau (China)
Adsorption refrigeration system for the production of chilled water	Fishing boat
Adsorption air-conditioning system – engine exhaust gas	Automobile
Adsorption air-conditioner	Cooling the interior of cockpit in a locomotive
Adsorption refrigeration cycle	Waste heat from a fuel cell electric vehicle

2.5 Stages and Performance Parameters

The current iteration suffers from drawbacks due to its diminished coefficient of performance and specific cooling power. Scholars persistently endeavor to address this challenge by integrating diverse stages and modifying various performance metrics. An illustrative portrayal of the cycles and performance fluctuations is delineated herein.

A. Thermal Recuperation:

The primary objective of this cycle is the retrieval of heat energy through the inherent temperature differential between the absorber and desorber during the transition between the evaporation and condensation phases. The energy within the higher-temperature bed is directly transferred to the lower-temperature bed upon passage to the absorber and subsequently to the desorber, thereby augmenting pressure during the absorber-to-condenser traversal and decreasing pressure (depressurization) during desorption. Cooling water flow into the heated adsorber facilitates its heating, subsequently transferring the heated water to the cold desorber for pre-heating. The cooling water recirculates, while the hot water bypasses the system, obviating the need for external thermal energy during this process.

B. Mass Retrieval:

The methodology of mass retrieval proves highly effective in augmenting the cooling capacity of the refrigeration system, which is the primary objective of any cooling mechanism, thereby enhancing the Coefficient of Performance (COP). Unlike the heat recovery process, where temperature increments lead to refrigerant pressurization exceeding the inlet condenser pressure, and vice versa during desorption (bed cooling), mass retrieval induces fractional pressure changes without temperature fluctuations within the bed. Here, the adsorber and desorber may be interconnected, facilitating the circulation of refrigerant mass in the bed under pressure differentials at either the adsorber or desorber.

C. Multi-Stage Modality:

This modality is particularly applicable in systems that rely primarily on solar energy radiation. A multi-stage configuration can be judiciously employed in fluctuating climatic conditions where energy sources naturally dwindle. Here, the setup enables simultaneous operation at two distinct stages. Two pairs of adsorbent beds, alongside the conventional evaporator and condenser, are necessary, thereby encompassing the thermodynamic states of the adsorption system: pre-heating, desorption, pre-cooling, and adsorption. Empirical evidence corroborates the practical functionality of this system even at a waste heat temperature of 55°C. Combining two identical processes through a combined stage technique enhances efficiency by approximately 20%.

D. Multi-Bed Approach:

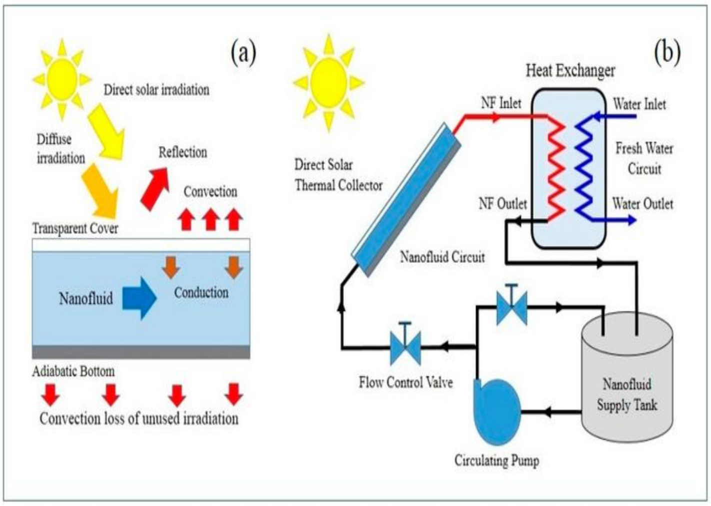
Among the techniques, as mentioned earlier, the multi-bed approach significantly increases efficiency and performance. It boasts significant advantages in maximizing cooling capacity and enhancing instantaneous cooling quality. Through prior experimentation and research, it is evident that a multi-bed adsorption chiller mitigates fluctuations in chilled water outlets, thereby amplifying waste heat recovery efficiency. Integrating a multi-bed adsorber chiller system with waste heat recovery techniques yields a significant performance improvement. Furthermore, techniques such as thermal recovery, cascade cycle, and cycle time parameterization hold promise for enhancing system efficacy. However, their efficiency depends on suitable environmental conditions. It's essential to continually compare conventional cooling systems with adsorption systems when integrating novel techniques to determine performance metrics, including Coefficient of Performance (COP), specific cooling power (SCP), economic viability, and environmental impacts.

III. TYPES OF SOLAR ADSORPTION REFRIGERATION SYSTEMS

In the realm of Solar Thermal Powered Adsorption Refrigeration Systems, a range of types emerges, each distinguished by unique operational characteristics and technological configurations. These typologies exemplify the breadth of ingenuity inherent in harnessing solar thermal energy for refrigeration purposes, embodying a convergence of science, engineering, and environmental consciousness.

Direct Solar Thermal Adsorption Refrigeration Systems:

In this variant, solar thermal energy directly drives the adsorption refrigeration process without intermediate steps or auxiliary power sources. The adsorbent material, often coupled with a refrigerant, undergoes cyclic loading and unloading processes driven solely by solar irradiation, thereby producing refrigerative effects.



2. Figure 8. Direct solar absorption schematics: (a) irradiation and significant sources of heat loss; and (b) transfer of heat from the nanofluid circuit via a heat exchanger.

3.

4. *Indirect Solar Thermal Adsorption Refrigeration Systems:*

5. Unlike direct systems, indirect variants use solar thermal energy to generate high-temperature heat, which is then transferred to the adsorption chiller through a heat transfer fluid. This approach enables greater flexibility in system design and operation, allowing for optimization of solar collector performance and integration with other renewable energy sources.

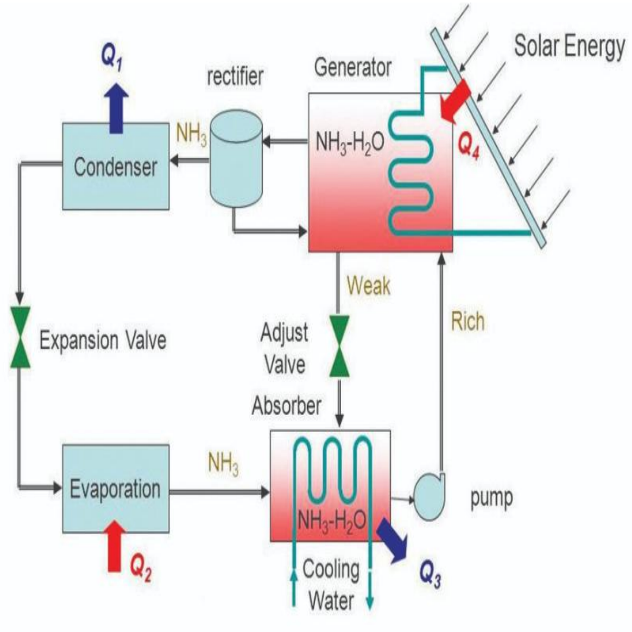


Figure 9. Indirect Solar Thermal Adsorption

Mixed-Mode Solar Thermal Adsorption Refrigeration Systems:

Mixed-mode configurations combine elements of both direct and indirect systems, leveraging the advantages of each approach to enhance overall system performance. These systems achieve synergistic effects by strategically integrating direct and indirect heat transfer pathways, maximizing energy efficiency and operational robustness.

Hybrid Solar Thermal Adsorption Refrigeration Systems:

Hybrid systems integrate solar thermal energy with supplementary power sources, such as fossil fuels or grid electricity, to augment system performance and reliability. This hybridization enables continuous operation under varying environmental conditions, enhancing system resilience in the face of intermittent solar irradiation.

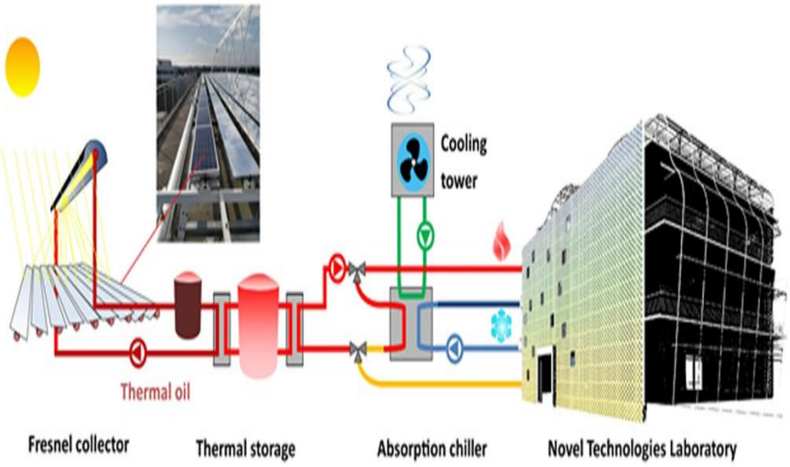


Figure 10. Hybrid Solar Thermal Adsorption

Advanced Solar Thermal Adsorption Refrigeration Systems:

Advanced variants incorporate cutting-edge technologies and innovative design features to push the boundaries of solar thermal adsorption refrigeration. These systems may include novel adsorbent materials, advanced heat exchanger designs, and sophisticated control algorithms, resulting in enhanced efficiency, reliability, and scalability.

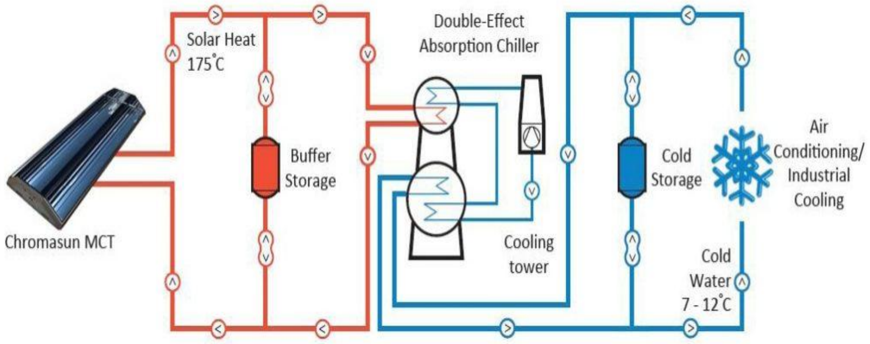


Figure 11. Advanced Solar Thermal Adsorption

IV. EXPERIMENTAL PROCEDURE FOR THE SOLAR DRYING PROCESS

Installation Process and Use of Measuring Instruments

Two experimental methods of solar drying tomatoes were investigated: indirect solar drying and mixed-type solar drying. The setup included a collector, a polycarbonate-covered drying chamber, and a chimney for exhausting moist air. Anemometers, moisture analyzers, temperature sensors, humidity sensors, and a weight-balanced apparatus were used to measure various variables and regularly monitor the weight of tomato slices [47].

In a separate experiment, maize was dried using a mixed-type sun drying system equipped with a flat plate collector coated in copper oxide nanoparticles. The monitoring of relative humidity and airflow velocity was conducted using a hygrometer and an anemometer. Additionally, five thermocouples were strategically placed to record temperature fluctuations [48].

An indirect-type, preheated solar drying chamber containing 24 kg of sliced mangoes was used for drying the slices. A moisture analyzer was utilized to measure both the initial and final moisture content. Assisting the drying process were a three-phase inverter fan and heating device, while temperature sensors were positioned at the inlet and exit of the evacuated collector and drying chamber [49].

The indirect-mode convection-forced solar drying device, featuring a converging-type drying chamber, was utilized for drying lemon balm leaves. Instruments such as a hygrometer, hot wire anemometer, digital balance weight machine, and thermocouples were mounted on the collector, which was angled 40° southward in accordance with the location's latitude, to measure temperature, sample weight, relative humidity, and wind velocity at various points within the solar dryer [50].

In an experiment involving fins attached to the air heater, a collector connected to a centrifugal pump circulates heated air. Paraffin wax was applied to the 1 mm-thick copper absorbent plate, secured to the plate with seven copper fins to enhance its thermal conductivity. Instruments such as temperature sensors, pyrometers, and anemometers were employed, with data recorded using an Arduino-based system [51].

Below the absorbing plate of a double-glazed solar air heater, mounted at a 30° angle, paraffin-based phase transition material was utilized. Aluminum powder was incorporated to enhance the thermal transfer coefficients of the paraffin wax [52]. Additionally, the solar air heater featured a baffle to improve turbulence, and two clear top plates with a 3.5 cm gap were installed to enhance transmittance. Styrofoam insulation was used to maintain ideal drying conditions [53]. Lastly, either pure thermal oil or Al2O3 was employed as the solar working fluid in a solar dish concentrator with a cylindrical cavity receiver for drying mint [54].

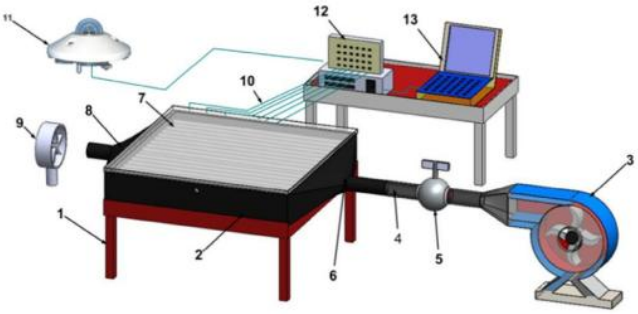


Figure 12. Phase-change material solar air heater schematic diagram [51]

Utilizing Photovoltaic Devices in the Desiccation Procedure

To dry tomato slices, an experimental PV-integrated solar dryer device has been developed. The setup includes a sun-tracking system, a drying chamber, a PV panel, a DC motor, a blower, a battery, a charge controller, and a collector. Temperature, solar radiation, airflow, and relative humidity inside the solar dryer are measured using T-type thermocouples, solarimeters, anemometers, and digital hygrometers, respectively [56].

In a different configuration, absorbent plates made of fiber-reinforced polyester, aluminum, zinc, and silicon composites are integrated into an active-type, mixed-mode dryer. Insulation composed of polystyrene is employed to maximize thermal efficiency. The DC blower is powered by a solar panel, battery, and charge controller, while data monitoring is conducted using temperature sensors and an Arduino microcontroller [57].

Additionally, a direct-type dryer has been installed in the village of Markondi, located 30 kilometers away from Berhampur. This dryer, sponsored by VIEWS, an organization dedicated to ensuring the livelihood security of fisherwomen in south Odisha, utilizes four DC blowers powered by solar panels to extract moisture from the air and efficiently circulate warm air within the drying chamber [58].

Figure 13. Drying products

Forced convection is employed in the construction of a solar dryer, as illustrated in Figure 6(a). The collector is oriented due south and inclined at a 20° angle, adjusted according to the location's latitude. Aluminum is utilized in the construction of the solar dryer, and stainless wire mesh trays are integrated. An exhaust fan is powered by a solar panel [59].

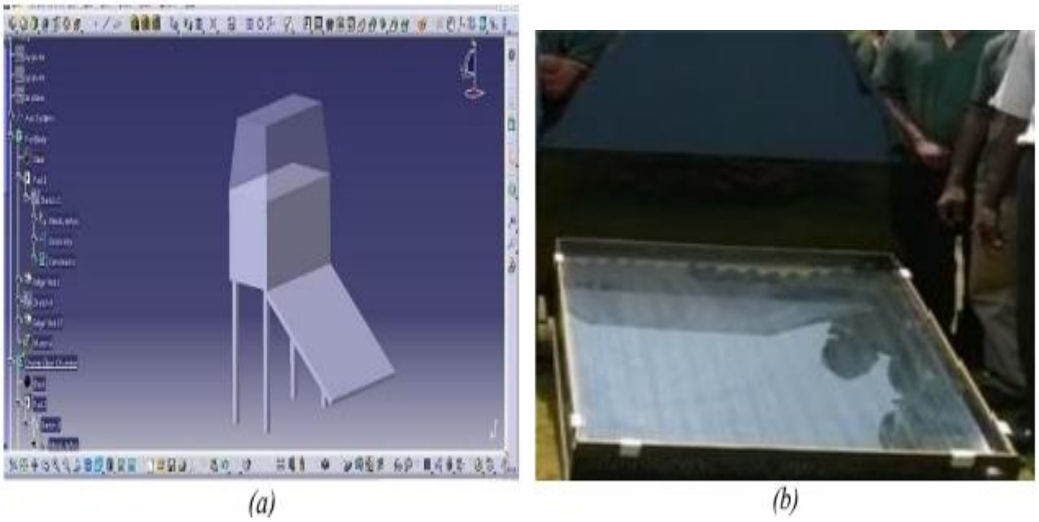

(a) (b)

Figure 14. (a) Design and b) assemble solar drying systems in the form of forced convection cabinets

For drying vegetables like potatoes, tomatoes, and ginger, a hybrid solar dryer has been developed. As depicted in Figure 7(a, b), the solar panel, battery, and charge controller are powered by four DC blowers, which regulate the exhaust process and circulate hot air. Baffles are integrated to enhance drying efficiency by increasing turbulence. A heated coil is used to operate the dryer at night. An electric coil and inverter, powered by a battery charged during the day, provide 24-hour backup for this system [60-63].

(a) (b)

Figure 15. A hybrid solar dryer uses light sources during the day and dark during the night. 1) Compressor; 2) Plates of glass;3) Confusion, 4) The drying box 5) Solar panels 6) Coil for heating 7) The inverter 8) Foam

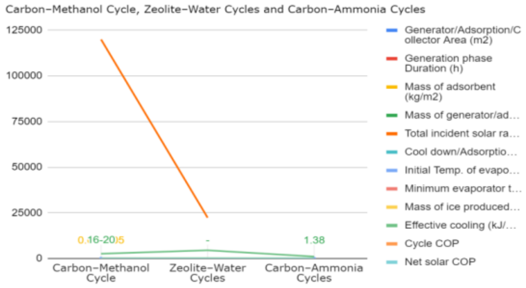


Figure 16. Cycle Vs methods

Table 2. Authors and sample

Author	**Sample**	**Remark**
Sur A, Das RK	Review on solar adsorption refrigeration cycle[60]	Int J Mech Eng Technol (IJMET) 2010;1(1):190e226
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Lemmini F, Buret-Bahraoui J	Performance of an adsorptive solar refrigerator using two types o activated carbon[71]	Energ Env 1990;2:774e9
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Islam MP, Morimoto T, Hato K	Dynamic optimization of inside temperature of zero energy cool chamber for storing fruits and vegetables using neural networks and genetic algorithms[73]	Comput Electron Agr 2013;95:98e107
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Tarutani T, Kitagawa H	Distribution, storage and processing of horticultural foods[87]	Tokyo: Yokendo Co; 1982
Ben-Yehoshua S	Transpiration, water stress, and gas exchange[88]	Proceedings of the post Post-Harvest Physiology of vegetables. New York: Marcel Dekker; 1987
Sondi I, Salopek-Sondi B	Silver nano-particles as antimicrobial agent: a case study on E. Coli as a model for gram-negative bacteria[89]	J Colloid Interface Sci 2004;275:177e82
Islam MP, Morimoto T	Zero energy cool chamber for extending the shelf-life of tomato and eggplant[90]	JARQ JPN AGR Res Q 2012;46(3):257e67
Lopez CAF, Gomez PA	Comparison of color indexes for tomato ripening[91]	Hortic Bras 2004;22(3):534e7
Tijskens LMM, Evelo RG	Modelling colour of tomatoes during postharvest storage[92]	Postharvest Biol Technol 1994;4(1e2):85e98
Messina V, Dominguez PG, Sancho AM, de Reca WN, Carrari F, Grigioni G	Tomato quality during short-term storage assessed by colour and electronic nose[93]	Int J Electrochem 2012:1e7. Hindawi Publishing Corporation, USA
Paull RE, Chen NJ	Heat treatments and fruit ripening[94]	Postharvest Biol Technol 2000;21:21e37
Lelievre JM, Latche A, Jones B, Bouzayen M, Pech JC	Ethylene and fruit ripening[95]	Physiol Plantarum 1997;101:727e39
Gomez PA, Camelo AFL	Postharvest quality of tomato fruits stored under controlled atmospheres[96]	Hortic Bras 2002;20:38e43
Zhuang R, Huang Y	Influence of hydroxypropyl methylcellulose edible coating on fresh-keeping and storability of tomato[97]	J Zhejing Univ Sci 2003;4(1):109e13
Basseto E, Jacomino AP, Pinheiro AL	Conservation of ‘Pedro sato’ guavas under treatment with 1-methylcyclopropene[98]	P Agro Bras 2005;40:433e40
Suparlan HJ, Itoh KJ	Effects of modified atmosphere and storage temperature on the quality of tomatoes[99]	J Hokkaido Univ Grad Sch Agr 2000;70(1):19e27
Gordon EA, Michelle L, Diane MB	Changes in pH, acids, sugars and other quality parameters during extended vine holding of ripe processing tomatoes[100]	J Sci Food Agric 2011;87(11):2000e11
Batu A, Thompsor K	Effect of modified atmosphere packaging on postharvest qualitie of pink tomatoes[101]	Tr J Agric Forest 1998;22:365e72

This table shows different studies about using sunlight to make things cold and keep fruits and veggies fresh. It talks about making refrigerators that run on solar power and using special materials to cool things down. It also discusses methods to store fruits and vegetables after they're picked to make them last longer. These studies help us understand how to use renewable energy and smart techniques to keep food fresh, which is important for both saving energy and reducing waste.

Table 3 Test result for some solar adsorption refrigeration cycles

Adsorbent	Adsorbate	Heat of Adsorption (kJ/kg)	Density of Adsorbate (kg/m3)	Remarks
Activated alumina	H2O	3000	1000	Water is applicable except for very low operating pressure.
Zeolite	H2O	3300 - 4200	681	Natural zeolite has lower values than synthetic zeolite.
Zeolite	NH3	4000 - 6000	791	
Zeolite	CH3OH	2300 - 2600	791	
Silica gel	CH3OH	1000 - 1500	791	Suitable for temperature less than 200°C.
Silica gel	H2O	2800	1000	Used mostly for descent cooling.
Charcoal	C2H4	1000 - 1200	789	Ammonia and methanol are not compatible with copper at high temperatures.
Charcoal	NH3	2000 - 2700	681	
Charcoal	H2O	2300 - 2600	1000	
Charcoal	CH3OH	1800 - 2000	791	
Charcoal	C2H5OH	1200 - 1400	798	
Calcium Chloride	CH3OH	1800 - 2000	791	Used for cooling.
Metal hydrides	Hydrogen	2300 - 2600	1000	For Air-conditioning.
Complex compounds	Salts and ammonia or water	2000 - 2700	681	Refrigeration.

This table lists different materials used in cooling systems and the substances they absorb to create cold temperatures. For instance, activated alumina absorbs water, while zeolite can absorb water, ammonia, or methanol. Silica gel, on the other hand, absorbs methanol or water. Charcoal can absorb various gases like ethylene or ammonia, and calcium chloride absorbs methanol. Metal hydrides are explicitly used for absorbing hydrogen for air conditioning. Complex compounds, like salts mixed with ammonia or water, are also used for refrigeration. Each material has specific heat absorption capabilities and densities of the substances they absorb, making them suitable for different cooling applications.

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