Final Report on

"DESIGN & EXPERIMENTAL ANALYSIS OF SOLAR POWERED VAPOR ADSORPTION REFRIGERATION SYSTEM USING SILICA GEL"

submitted by

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ISHRAE LTCoE Student Chapter

Lokmanya Tilak College of Engineering

(2022-2023)

STUDENT RESEARCH PROJECT GRANT

2022-23

FINAL REPORT

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Project Title Design & experimental analysis of solar powered vapor adsorption refrigeration system using silica gel

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ABSTRACT

We present the design of a Solar Powered Vapor Adsorption Refrigeration System that uses Silica Gel as the adsorbent. The system includes a Solar Collector, Evaporator, Condenser, Silica gel Adsorber, and cooling chamber. The solar collector provides the required thermal energy to desorb the water vapor from the silica gel adsorber, generating a cooling effect from through adsorption. The system has the potential to achieve high levels of energy efficiency & environmental friendliness, making it a promising refrigerating solution for various applications.

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Chapter 1

Introduction

1.1 Introduction

Adsorption is the process in which a gas or liquid accumulates on the surface of a solid substance, known as the adsorbent. This process creates a film of the adsorbate (the molecules or atoms being accumulated) on the adsorbent's surface. It is different from absorption, in which a substance diffuses into a liquid or solid to form a solution.

As the world is facing an energy crisis, solar technologies have become increasingly important due to their non-polluting and renewable nature. Over the past 30 years, solar technology has matured, and one of its various applications is refrigeration. The need for refrigeration often coincides with the maximum levels of sunshine, making solar cooling extremely useful in areas with high insolation but no access to electricity.

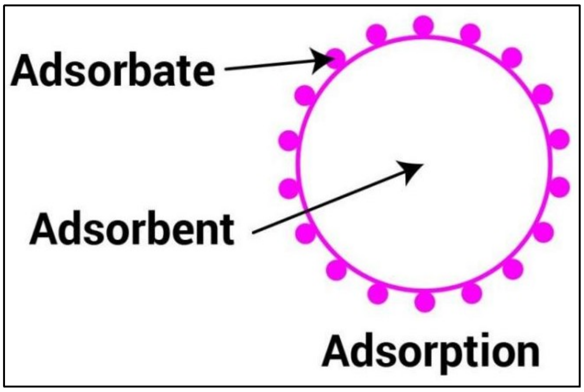

Fig 1.1.1 Process of Adsorption

A solar-powered adsorption refrigeration system is a perfect example of how renewable energy can be utilized to create sustainable and efficient technologies. Such systems use solar energy as the heat source to drive the refrigeration cycle, which makes them ideal for use in remote areas where there is no electricity. These systems are also highly efficient and environmentally friendly, with little to no pollution.

Fig 1.1.2 Silica Gel

In our proposed design, we have proposed a hybrid system of a solar-powered adsorption refrigeration system that will provide hot water for domestic purposes as well as refrigeration for multiple applications, such as storing vegetables or vaccinations in areas where there is a need for such technology. This hybrid system is an excellent example of how renewable energy can be utilized in multiple ways to create sustainable and efficient technologies that have a positive impact on the environment and society.

1.2 Problem Statement

Refrigeration and air conditioning are essential for modern living and have become an integral part of our daily lives. With the increasing demand for comfort and the need to preserve perishable goods, the importance of refrigeration and air conditioning has increased significantly. As a result, there has been much research going on to improve the efficiency and effectiveness of refrigeration and air conditioning systems.

One of the significant advancements in this field is the technology of the adsorption refrigeration system, which was first introduced in the 1970s. Since then, multiple adsorbent/adsorbate pairs and various designs of adsorbent beds have been tested out to invent the most economical and efficient system. This technology uses a solid adsorbent to adsorb a refrigerant gas or liquid, which is then released by heating the adsorbent. This process produces a cooling effect, which can be used for refrigeration and air conditioning.

The study of Solar Powered Adsorbent Ice makers has been somewhat successful, but the study of Hybrid systems of Solar Power Adsorption System is still limited. Our work focuses on developing a hybrid system that can provide both heating and cooling with the help of a Flat Plate Collector for Hot water and using Silica Gel to gain the desired Refrigerating effect with Adsorption of water in Evaporator. This system uses solar energy to provide the required heat for adsorption, which makes it an economical and environmentally friendly option.

The use of Silica Gel as an adsorbent provides many advantages, including low cost, high surface area, and high adsorption capacity. The water adsorption capacity of silica gel is also high, which makes it an ideal choice for adsorption refrigeration systems. The system's flat plate collector helps in collecting solar energy efficiently and providing hot water for domestic use during the daytime. This hot water is then used to regenerate the silica gel bed, which releases the adsorbed water vapor into the condenser, producing the desired refrigeration effect.

In summary, the development of a hybrid system using Solar Power Adsorption System technology is an exciting and promising area of research. With its potential for providing both heating and cooling, this system could be a game-changer in the field of refrigeration and air conditioning. Our work aims to contribute to the development of this technology, making it more efficient, cost-effective, and environmentally friendly.

1.3 Objective

1. To reduce the emission of greenhouse gases by using water as a refrigerant.
2. To reduce the energy consumption as the system primarily runs with Solar Power.
3. To provide an alternative technology of Refrigeration where the grid electricity is not available for VCRS.
4. To achieve simultaneous heating and cooling from a single system.

Chapter 2

Literature Review

2.1 Literature Review

1. Vineeth P. Babu, R. Vasanth, Varun Babu M K wrote a thesis that proposed a compact & improved adsorption refrigeration system design which is powered by engine exhaust heat for the vehicles. They compared VCR, VAR & Adsorption Refrigeration used in vehicles in detail with their benefits as Adsorption Refrigeration System works on zero Ozone Depletion Potential (ODP) & unlike conventional VCR with mechanical compressor an adsorption refrigeration system is a heat driven machine & the construction of it simpler that as of VAR.

2. M.H. Rahman, A.R. Akhanda, A.K.M. Sadrul Islam illustrated a design & fabricated a solar powered adsorption refrigeration system with adsorption pair of activated charcoal & methanol & also with the pair of activated charcoal R-11. The prototype was a combination of solar water heater & adsorption refrigeration & could run on continuous cycles by employing two adsorber together. In experimental analysis it was found the maximum system pressure reaches is up to 4.2 bar & at lowest it attains 1.7 bar which is the desired condition for the cycle & the pair of activated carbon & R-11 follows it closely.

3. A.V. Kanade, A.V. Kulkarni, D.A. Deshmukh built a Solar Power Adsorption Ice Maker using the adsorbent/adsorbate pair of Activate carbon/Methanol. Designed Adsorbent Bed made of Stainless Steel with Activated carbon (from coconut shells) sealed inside it which will receive incident rays during day time & a trapezoidal shaped Evaporator immersed in the water tank & placing it inside an insulated wooden box. Using a standard Condenser, a circuit was made to complete the cycle. The formation of ice at -5°C was achieved & the COP of the System was around 0.12.

4. Banala Dinesh, Sai Manikanta M, Dishal Kumar T, Debjyoti Sahu designed and studied a sustainable eco-friendly refrigeration system using vapor adsorption refrigeration system which requires fewer moving parts. They did a CFD analysis using coarse mesh on ANSYS. The one-fourth of the generator is filled by activated carbon and methanol is sprayed over the adsorbent bed. Hot water is generated in a separate chamber with an electric immersion coil and the Methanol vapor rises by taking the heat. Liquid refrigerant is sprayed over the Evaporator coil in the Evaporator section. They obtained a pressure drop till 8oC with a COP of 0.34.

5. Sohan Singh, Sunil Dhingra reviewed the thermodynamics modeling and the COP of vapor adsorption refrigeration systems working with single or double bed intermittent cycle and found out various advantages of vapor adsorption systems over conventional VCR systems. The literature shows that SAR devices can supply, among others, the need for ice making, air conditioning, and for refrigeration applications with extraordinary potential in the protection of some goods (e.g., medicines, food supplies) in remote areas.

6. R. Z. Wang and R. G. Oliveira presented a paper in which they showed various accomplishments of Solid Sorption Systems Prototypes which were designed to use waste heat or solar energy as main heat sources. The applications of these prototypes were ice making & air conditioning. They reviewed multiple solar powered adsorption ice makers with different adsorbent adsorber working pairs & concluded that higher generation temperature is a necessity for adsorbent beds to improve COP or it may be only obtained with newer, better designs that will reduce the thermal capacity of adsorber, as at low temperatures limited heat recovery is possible.

7. M. Li and R.Z. Wang introduced a new design for the adsorbent bed which contains the activated carbon inside it with removing the traditional design of having a metal plate under the glass cover & the solar energy directly transmits from glass cover into the activated carbon additional advantage of this design was reducing requirement of standard vacuum welding. 4 kg of ice was formed, exposing to 13MJ/m2 for 3hrs & COP was in range of 0.15-0.17 as compared to 0.1-0.2 of traditional sealed adsorbent bed.

8. Himsar Ambarita, Hideki Kawa did experimental study on solar- powered adsorption refrigeration systems & they filled the generator with activated alumina & carbon & mixture of both with Methanol. They carried the experiment in 4 cases giving 3 days for each case. 1st case they used only activated alumni, 2nd case 75% AA & 25% AC & vice versa. Their results showed that adsorption capacity of activated alumina was more but its desorption pressure requirement was more. Hence for Solar Energy as a heat source Activated Carbon proved to be more advantageous.

9. Shahab Edin Hamrahi, Koorosh Goudarzi, Mahmood Yaghoubi designed a continuous adsorption chiller system with micro and Nano activated carbon/methanol as a working pair of adsorbents that runs on solar energy. A compound parabolic type collector was used in the system. Since two adsorbent beds were used in the refrigeration system, it resulted in a cooling effect being produced even in the daytime. The results showed that the addition of Nano-activated carbon with various mass fractions increases the adsorption level. As a result, the adsorption capacity increased and the COP improved.

10. Allouhi, T. Kousksou, A. Jamil, T. El Rhafiki, Y. Mourad, Y. Zeraouli did a performance analysis of 7 pairs of adsorbates and adsorbent to use in solar adsorption cooling systems, based on the adsorption capacity and solar coefficient of performance. In the analysis it was found that activated carbon fiber with methanol has the highest adsorption capacity at 0.3406 kg/kg followed by activated carbon with methanol at 0.2565 kg/kg and activated carbon with ethanol at 0.2008 kg/kg.

11. Sami M. Alelyani, Weston K. Bertrand, Zhaoli Zhang, Patrick E. Phelan proposed a novel design that combines an evacuated tube solar collector and adsorption cooling system in a single module. The module consists of a simple adsorption refrigeration system placed inside and evacuated glass tube with the top section of the tube representing the adsorbent bed(generator) and the bottom section representing the condenser / evaporator having the adsorbate. Major advantage of this design is that multiple such modules can be connected in series to form an array and achieve lower cooling temperatures. Also if multiple arrays are used some of the arrays can be used to provide cooling while others will be under regeneration process to make the system run continuously.

Chapter 3

Methodology

3.1 Methodology

Literature Review : Conduct a comprehensive review of literature on adsorption refrigeration systems and solar-powered refrigeration systems to determine best practices and identify potential challenges.

System Design : Design the system components, including the adsorber, condenser, evaporator, and generator, and determine the optimal working parameters, such as the flow rate and temperature of the silica gel and heat source.

Component Selection : Select the appropriate materials for each component, such as high-quality silica gel and durable metal tubing.

System Construction : Assemble the system components and connect them using appropriate fittings and seals.

Experimental Setup : Configure the experimental setup, including the heat source, temperature and pressure sensors, and data acquisition system, to measure the system's performance.

Data Collection : Collect data on the system's performance under different conditions, such as varying heat source temperatures or flow rates, and record the measurements using the data acquisition system.

Data Analysis : Analyze the collected data to determine the system's coefficient of performance (COP) and other relevant parameters, such as the heat transfer rate and pressure drop.

Comparison with Other Technologies : Compare the performance of the solar-powered vapor adsorption refrigeration system with traditional refrigeration systems, such as vapor compression refrigeration, and evaluate its efficiency, cost, and environmental impact.

Future Work : Identify potential areas for further research or improvements to the system, such as optimizing the silica gel regeneration process or incorporating energy storage capabilities.

3.2 Flow Chart of Methodology

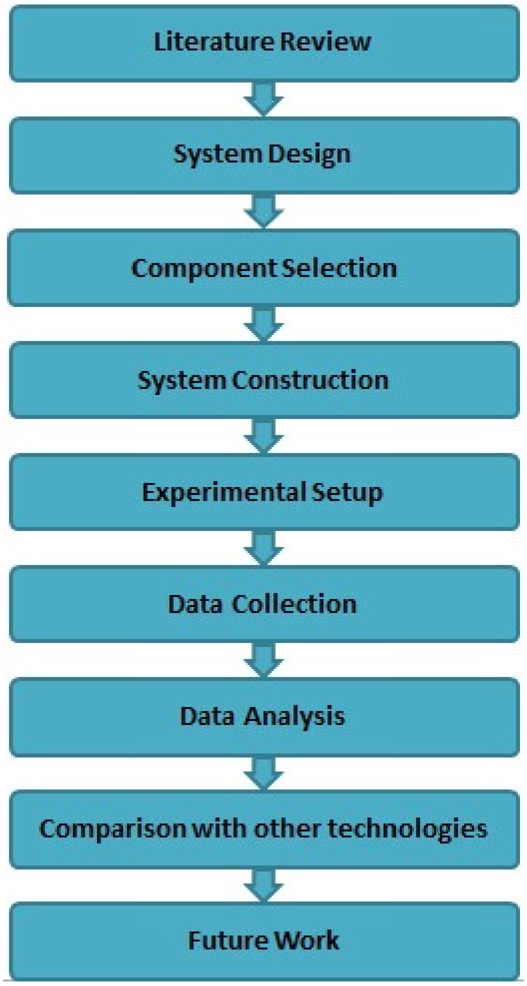

Fig. 3.2.1 Flow chart of Methodology

Chapter 4

Experimental Setup

4.1 Layout

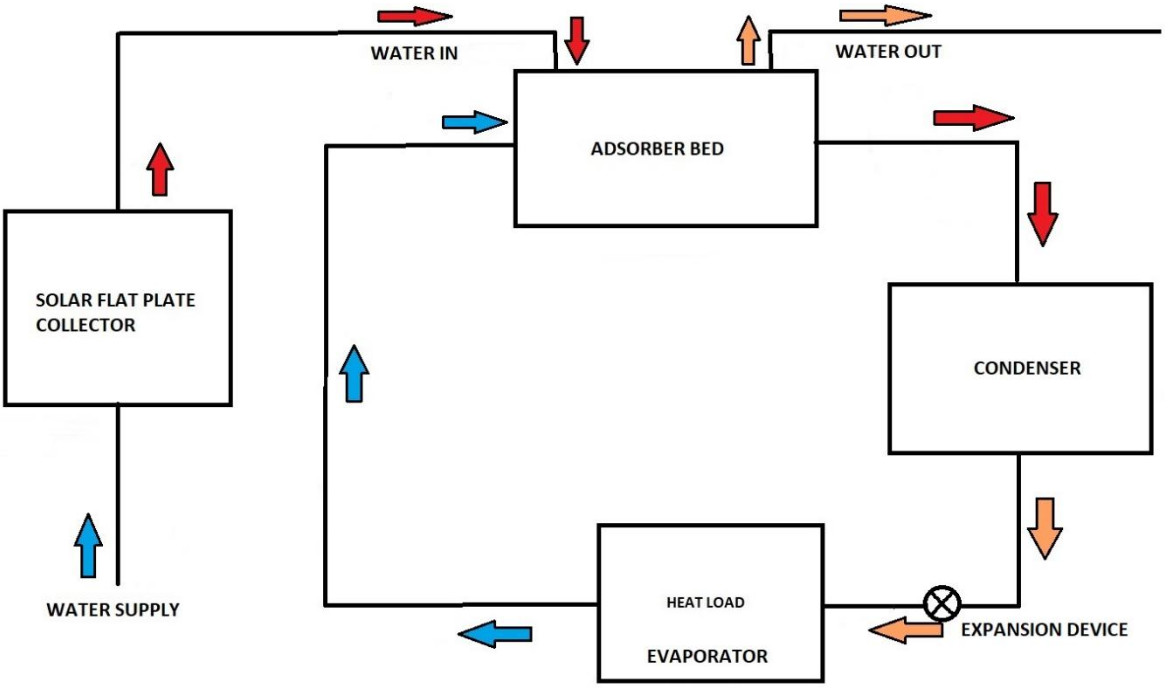

Fig 4.1.1 Circuit Diagram

The Incident rays falling on to the Collector plate increased the water temperature causing it to rise up and enter the Storage tank encompassing the Adsorbent Bed hence increasing the pressure and temperature of Adsorbent Bed. This increase in temperature of adsorbent bed will cause regeneration of the water out of silica gel and will follow the path to the condenser ultimately falling in the Icebox having evaporator due to gravity. During the daytime the hot water will be stored in tank and can be used for domestic purposes & after the sunset this water drains out & recirculation of cold water will start, causing the temperature and pressure of Adsorbent bed to decrease & the evaporation of water from the Icebox will start hence producing the desired Refrigeration Effect and completing the Cycle.

4.2 Components

4.2.1 Solar Flat Plate Collector

Fig 4.2.1 Solar Flat Plate Collector

A solar flat plate collector is a type of device that captures the heat from the sun and converts it into usable thermal energy. It consists of a flat plate made of a thermally conductive material, such as metal or glass, which is covered with a dark-colored coating to absorb sunlight. Beneath the plate, there are tubes or channels that carry a fluid, usually water or a mixture of water and antifreeze, which is heated by the absorbed sunlight. The heated fluid can then be used for various applications such as space heating, domestic hot water, or for powering a solar-powered refrigeration system. Flat plate collectors are relatively simple and efficient, making them a popular choice for residential and commercial applications.

4.2.2 Adsorber Bed

Fig 4.2.2 Adsorber Bed

An adsorber bed is a container filled with a material called an adsorbent, which has the ability to adsorb or accumulate molecules of a particular gas or liquid on its surface. In an adsorption refrigeration system, the adsorbent is typically silica gel and the adsorbate is water vapor. The adsorber bed is where the adsorption process takes place, with the silica gel adsorbing water vapor from the evaporator during the cooling cycle and releasing it to the condenser during the regeneration cycle. The design of the adsorber bed is critical for the efficiency of the refrigeration system and involves factors such as the type and amount of adsorbent used, the size and shape of the container, and the flow of the refrigerant through the bed.

Specifications: (Double Coil Vaporiser)

1st Coil:

Pipe size - 1/4”

No. Of turns - 12

Total coil length - 330mm

Diameter of coil (OD) - 75mm

Total tube length - 3mtr

Material of Tube - Copper

2nd Coil:

Diameter of coil (OD) - 130mm

No. of turns - 10

Pipe diameter - 1/4”

Total coil length - 300mm

Total tube length - 4mtr

Total tube length of both coils - 7mtr

4.2.3 Evaporator

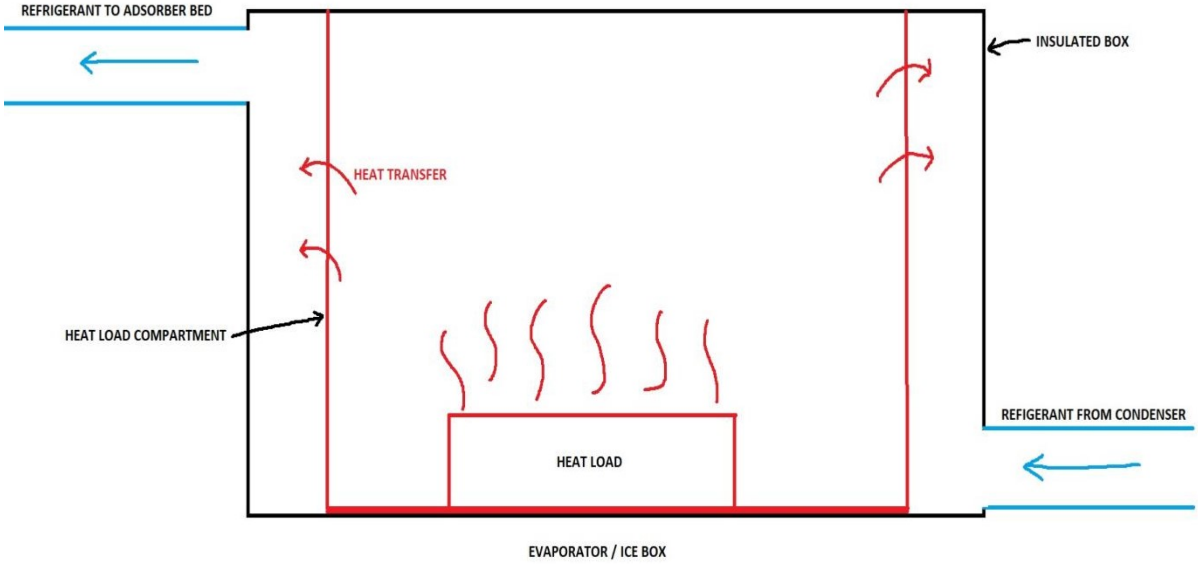

Fig 4.2.3 (a) 2D Model of Evaporator

Fig 4.2.3 (b) Evaporator

An evaporator is a component of a refrigeration system that removes heat from a substance (usually a liquid) and changes it into a gas or vapor. The process of evaporation cools down the remaining liquid, allowing it to absorb more heat from the environment, which in turn increases the cooling effect. In a refrigeration system, the evaporator absorbs heat from the surroundings and uses it to evaporate the refrigerant, which is then carried away to the compressor. This process helps in generating the cooling effect required for refrigeration or air conditioning.

Specifications:

10 ltr. Roll Bond Evaporator

4.2.4 Condenser

Fig 4.2.4 Condenser

A condenser is a component in a refrigeration system that is responsible for converting the refrigerant gas back into a liquid form. It does this by transferring the heat from the refrigerant to a cooling medium, such as water or air. The refrigerant enters the condenser as a high-pressure gas and leaves as a high-pressure liquid. The liquid refrigerant then flows to the evaporator, where it expands and evaporates, causing the refrigeration effect. The process then repeats itself, with the refrigerant returning to the compressor to start the cycle over again.

Specifications:

Condensor Cooling Coil:

Pipe size - 1/4”

No. Of turns of coil - 12

Length of coil - 330mm

Total Tube length - 3mtr

Diameter of coil (OD) - 75mm

Material of Tube - Copper

Condensor Shell:

Length of shell - 400mm

Diameter of shell - 100mm

Material of shell - PVC

4.2.5 Capillary Tube

Fig 4.2.5 Capillary Tube

The capillary tube controls the flow of refrigerant in a refrigeration system. It creates a pressure drop, allowing high-pressure liquid refrigerant to convert into low-pressure gas in the evaporator. This phase change enables the refrigerant to absorb heat and cool the surroundings. The capillary tube ensures the proper flow rate into the evaporator, optimizing cooling efficiency. It is commonly used in small refrigeration systems due to its simplicity and cost-effectiveness.

Specifications:

Material - Copper

Internal diameter - 2mm

Length - 1700mm

4.3 Working

Our solar-powered adsorption refrigeration system uses solar energy to drive the refrigeration cycle. The system consists of an adsorber bed, a condenser, an evaporator, a solar collector, and a storage tank. The adsorber bed contains an adsorbent material such as silica gel, and the evaporator contains a refrigerant such as water.

During the daytime, solar energy is absorbed by the collector plate, which heats up the water flowing through it. The hot water then enters the storage tank and surrounds the adsorber bed, causing the temperature and pressure of the adsorbent material to increase. As a result, the adsorbent material desorbs or releases the water vapour (refrigerant) adsorbed on it. This refrigerant then flows to the condenser.

In the condenser, the refrigerant vapour is condensed into liquid form by rejecting its heat to the surroundings. The condensed refrigerant then flows to the evaporator, where it expands and evaporates, cooling the evaporator.

Meanwhile, a vacuum is created between the evaporator and the adsorber bed, causing the refrigerant to flow towards the adsorber bed and be adsorbed by the silica gel. This adsorption process causes the refrigerant left in the evaporator to cool down further, producing the desired refrigeration effect.

During the daytime, the hot water stored in the tank can be used for domestic purposes. After sunset, the hot water is drained out, and the recirculation of cold water starts, causing the temperature and pressure of the adsorbent bed to decrease. As a result, the evaporator's refrigerant starts evaporating, producing the desired refrigeration effect and completing the cycle.

Fig 4.3.1 Experimental Setup

Chapter 5

Results

5.1 Results

5.1.1 Component Temperature Readings

No. of Reading	Time	Component	Temp (°C)
1	10:00 AM	Solar Collector	37.8
		Adsorber Bed	32.6
		Evaporator	36.4
2	11:00 AM	Solar Collector	39.4
		Adsorber Bed	34.3
		Evaporator	35.6
3	12:00 PM	Solar Collector	45.6
		Adsorber Bed	40.7
		Evaporator	39.6
4	1:00 PM	Solar Collector	52.2
		Adsorber Bed	46.9
		Evaporator	41.1

5.2.1 Water Temperature Readings

Time	Water Inlet	Water Outlet
10:00 AM	31.2	35.3
11:00 AM	31.5	36.5
12:00 PM	31.8	43.8
1:00 PM	32.3	50.2

In an adsorption refrigeration system, the COP is defined as the ratio of the cooling capacity (Qc) to the heat input (Qin) from the solar collector:

COP = Qc / Qin

Flow rate of water = 0.1 kg/s.

The cooling capacity (Qc) is the amount of heat removed from the refrigerated space and can be measured using temperature sensors or heat flow meters.

The heat input (Qin) is the amount of thermal energy supplied by the solar collector.

$$Q = m * Cp * \Delta T$$

We can calculate the cooling capacity (Qc) using the following steps:

1. Calculate the temperature difference (ΔT): ΔT = Outlet temperature - Inlet temperature

$\Delta T = 36.4°C - 32.6°C$

$\Delta T = 3.8°C$

2. Calculate the cooling capacity (Qc): $Qc = m * Cp * \Delta T$

$Qc = 0.1$ kg/s * 4186 J/kg°C * 3.8°C

Qc = 1590.8 J/s or 1590.8 W

Now we can calculate the heat input from the solar collector (Qin) using the provided data:

1. Calculate the temperature difference (ΔT): ΔT = Outlet temperature - Inlet temperature $\Delta T = 50.2°C - 32.3°C$ $\Delta T = 17.9°C$

2. Determine the specific heat capacity of water (Cp): The specific heat capacity of water (Cp) is approximately 4,186 J/kg°C.

3. Calculate the heat input from the solar collector (Qin): $Qin = m * Cp * \Delta T$ Qin = 0.1 kg/s * 4186 J/kg°C * 17.9°C

Now, we can calculate the value of Qin:

Qin = 0.1 kg/s * 4186 J/kg°C * 17.9°C

Qin ≈ 7515 J/s or 7515 W

With the cooling capacity (Qc) estimated at 1590.8 W and the heat input from the solar collector (Qin) estimated at 7515 W, we can now calculate the coefficient of performance (COP) of your adsorption refrigeration system.

COP = Qc / Qin

COP = 1590.8 W / 7515 W

COP ≈ 0.2115 (Reading 1)

Similarly,

COP ≈ 0.2639 (Reading 2)

COP ≈ 0.3043 (Reading 3)

COP ≈ 0.3241 (Reading 4)

Average COP ≈ 0.27

Chapter 6

Conclusion

6.1 Conclusion

Thus we designed a solar powered refrigeration system using silica gel and performed experimental analysis on it. We calculated the average COP of the system and cooling capacity to be 0.27 and 1.59 KW respectively. The COP is low but it can be improved by using even better materials and better insulation. The COP can also be improved by using concentrated parabolic solar collector as it would help adsorb more amount of water onto the silica gel.

Chapter 7

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