PROJECT REPORT

On

# "Design and Development of Solar Power Adsorption Refrigeration System"

*Submitted By*


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*Submitted in partial fulfilment of the requirements.*

*For*

*Degree of Bachelor of Engineering*

*Guided by-*

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**S.B. JAIN INSTITUTE OF TECHNOLOGY, MANAGEMENT & RESEARCH, NAGPUR.**


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# CERTIFICATE

This is to certify that the project titled **"Design and Development of Solar Powered Adsorption Refrigeration System"** is a bonafide work carried out for the partial fulfillment of the requirement for the award of Degree of Bachelor of Engineering in **Mechanical Engineering, Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur.**

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**Date:** ______________________

॥ विद्या धनम् सर्वधन: प्रधानम् ॥

# DECLARATION

We, hereby declare that the Project titled "**Design and Development Of Solar Powered Adsorption Refrigeration System**" submitted herein has been carried out by us in the Department of Mechanical Engineering of S.B. Jain Institute of Technology Management and Research, Nagpur under the guidance of **Mr. Himanshu Wagh.** The work is original and has not been submitted earlier as a whole or in part for the award of any degree / diploma at this or any other Institution / University.


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# ABSTRACT

The rapid expansion of human life and industrial development has led to a significant increase in energy demands. However, the reliance on limited fossil fuel resources has resulted in environmental problems and energy scarcity. Consequently, the search for alternative green energy sources has gained considerable interest. Solar energy, being abundant and non-polluting, has attracted global attention as a viable solution. Solar cooling, particularly in regions with high solar insolation and a demand for refrigeration, offers great potential. Among the various solar cooling technologies, solar adsorption refrigeration has emerged as a promising option. This report presents and discusses the experimental methodology, along with typical test results, highlighting the potential of the proposed system. A lab level test apparatus of a double bed Adsorption refrigeration framework utilizing Silica-gel as Adsorbent and Water as an eco-friendly Adsorbate is created for the utilization of refrigeration.

This work is intended for 0.5 TR cooling limit in which Hot water in the temperature scope of 45 to 65°C is utilized as a hot source while water at environmental temperature and weight is utilized as a cold source. Chilled water is yield as a output from the system. Adsorber bed heat exchangers utilized as a part of the system goes about as a 'Thermal compressor'. The Adsorber bed warm exchangers are composed and manufactured such that, the heat and mass exchange rate are to be as high as could be expected under the circumstances and heat resistance are to be as low as would be prudent. It comprises of Mass Transfer Channel (MTC), an incorporated structure which is comprised of number of copper tubes and blades of roundabout shape made of aluminium are given on copper tube to build maximum heat and mass exchange rates. Silica-gel is filled minimally around the copper tubes to diminish heat resistance. Binder PVAC is utilized to fill the silica gel in space between balances around the MTC to hold the substance and encased in a sealed external packaging. The framework is examined through arrangement of examinations against various working conditions to get the execution parameters as, Specific Cooling Power (SCP) and Coefficient of Performance (COP). A modern and surely knew strategy is embraced here to limit the mistakes in experimentation. Impacts of working conditions on the execution parameters are investigated and given the assistance of graphical instruments to comprehend the general working of the System.

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# Chapter No. 1
# INTRODUCTION

## 1.1 Theory Introduction

As the human life expands, energy demands are continuously increasing rapidly as the development of the industrial. The main source of the energy used nowadays which is the fossil fuel is extremely limited to deal with the worldwide demand and has been causing series of environmental problems. Thus, the search for alternative green energy resources has been drawing a lot of interest in the research. Solar energy, as the most abundant resources all over the world as reported that amount of solar energy received from Sun every year is reaching to 1×1018 wk. It is almost ten thousand times human energy consumption annually Solar energy technologies attract worldwide attention owing to their non-polluting nature. Indeed, the technology is matured in some countries and for more than 30 years exploitation has proceeded. Among various applications, refrigeration is one of the attractive applications of solar energy, because the amount of sunshine and the need for refrigeration reach maximum levels in the same season.

Solar cooling could be a useful technology in areas of the world where there is a demand for cooling, high insolation levels, and no firm electricity supply to power conventional systems. One of the very effective forms of solar refrigeration is the production of ice with the ozone-depletion problem of traditional vapor compressed refrigeration growing more serious, substituting traditional refrigeration with green technology has become a hot topic in recent years. Among those green technologies, the solar adsorption refrigeration has attracted much of the attention of researchers. Driven by low-grade thermal energy, the adsorption refrigeration system has the advantages of being environmentally friendly, small, and flexible. This adsorption system can also be driven with non-solar energy, for instance by waste heat discharged from thermal equipment or by engine exhaust gases from vehicles, as mentioned by Hu et al.1 In an adsorption cooling system, the adsorption bed is the key component. Its work directly affects the performance of the whole system. Therefore, the design of the adsorption bed is the most important issue as pointed out by Sutuki.2 A decade ago, the flat bed was mostly used in the adsorption cooling system.3,4,5 Without any solar concentrating device, the flat bed temperature was usually low and hence the COP of the system was unsatisfactory. In contrast, the tubular adsorption bed improved the COP. It was reported that the COP could reach 0.21 in sub-Sahara region by Hadj Ammar et al.6 Furthermore, Wang et al.7 developed a spiral plate adsorber that was distinguished by the characteristic of continuous heat regeneration. The novel design of the adsorption bed shortened the cycle time of the system.

Abu-Hamadeh et al reported their study on the solar adsorption refrigeration system with a parabolic trough collector. Their test results showed the COP of the system varied from 0.18 to 0.20. El Fader et al.9 studied an adsorption refrigeration system that was coupled with a heat pipe and powered by parabolic trough collector, which showed an optimum COP of 0.18. In the current study, we experimentally studied an improved solar adsorption refrigeration system, in which a solar tracking parabolic trough collector was applied, and an internal cooling tunnel was deployed. With the SAPO-34/ZSM-5 zeolite and the water vapor as the working pair, the system showed interesting characteristics in terms of thermodynamics and refrigeration. The experimental methodology as well as the typical test results will be presented and discussed in this report.

## 1.2 Aim

Assessment of the performance of Solar Powered adsorption Refrigeration system which is. developed for refrigeration of compartment.

## 1.3 Objectives

- To find the perfect working pair of adsorbent and refrigerant for maximum COP
- To Improve design of Generator used in Adsorption refrigeration System.
- To Improve the design of solar collector used in Adsorption Refrigeration system.

## 1.4 Necessity

- For sustainable development refrigeration system working on renewable energy sources are needed because all the refrigerating units requires electricity which is majorly produced by burning fossil fuels results in huge Carbon Emission.
- Also, majority of refrigeration units uses CFC as a refrigerant which are the major contributors in global warming.
- An energy efficient system which utilizes waste energy and give useful refrigerating effect are needed.
- Refrigeration Units driven by green energy is in future demand.

# Chapter No. 2
# LITERATURE REVIEW

## 2.1 Related Work

The phase out of CFC's and HFC's had made it necessary for us to find out an alternative to the conventional system. Adsorption refrigeration system is found out to be a most suitable alternative to VCR system. Adsorption refrigeration system has been employed in a much cooling application such as icemaker for a fishing boat, vehicles air-conditioning of subcompact vehicles, large capacity ice makers using waste heat source or solar energy, water chiller etc. As this technology has no adverse effect on the environment is seen as more prominent technology. But due to very low overall efficiency, it is facing very big problem for commercialising. There is large amount of heat transfer and mass transfer resistance inside the adsorber bed which results in low SCP and COP. These issues are required to be solved by some technical improvements. This chapter reviews the concept of adsorption cooling system's basic principle and working.

## 2.2 Adsorption Refrigeration System

The system operates by using a heat source, such as solar energy or waste heat, to desorb the adsorbent material, which releases water vapor or other refrigerant gases. This process creates a low-pressure environment that draws in ambient air, which is then cooled as it passes over the adsorbent material. The cooled air can be used for various cooling applications, such as air conditioning, refrigeration, or food preservation. Adsorption refrigeration systems have several advantages over traditional compression-based refrigeration systems, including lower energy consumption, quieter operation, and the ability to use renewable energy sources. However, adsorption refrigeration systems also have some limitations, including lower cooling capacity and longer cycle times. As a result, they are generally used in smaller-scale applications or in conjunction with other cooling systems to provide supplemental cooling.

### 2.2.1 Basic Nomenclature

1) **Adsorbent: -** A material having capacity to adsorb another material on its surface. E.g. Silica-Gel, Activated Carbon, Zeolite.
2) **Adsorbate (Refrigerant): -** A material that is capable of being adsorbed by adsorbent. E.g., Water, Ammonia, Ethanol.
3) **Sorption: -** Adsorption and absorption both are abbreviated as sorption together.
4) **Adsorption: -** It is process of adhesion of any ion, atom, and molecules on a surface. It is physical process when molecules of any phase are adsorbed on a solid surface and adsorption is a surface phenomenon. Exothermic reaction takes place and heat is evolved during this reaction which is extracted by cold source.

5) **Desorption: -** With the application of heat the adsorbate is released from adsorbent surface it is known as process of "Desorption".

### 2.2.2 Difference between Absorption and Adsorption

There is considerable difference between adsorption and absorption processes which are as follows: -

**Table 2.1: -Difference between Adsorption and Absorption.**

| Parameters | Adsorption | Absorption |
|---|---|---|
| **Principle** | Molecules of liquid or gas (Adsorbate) accumulates or adheres to the solid (adsorbent) surface | Molecules of liquid or gasses (Adsorbate) penetrates inside the porous (absorbent) surface |
| **Phenomenon** | Surface phenomenon | Volumetric phenomenon |
| **Source temperature requirement** | As low as 50 °c to as high or higher than 500 °c | Should be greater than 70 °c |
| **Fluctuation in heat source temperature** | Does not affected | Affects much on working of the system |
| **Hot and dry working environment** | Can work effectively. | Not suitable |
| **Corrosion** | Not severe | Severe |
| **Size** | Large | Small |
| **Life** | More than 30 years | 7 to 9 years |
| **Efficiency** | Low | High |
| **Cooling capacity** | 5.5 to 500 kW | 4.5 to 5 MW |
| **Installation cost** | Very high | Low |
| **Maintenance cost** | Low | High |

### 2.2.3 Principle of adsorption: -

Adsorption refrigeration system is operated with the help of principle of adsorption. It is accomplished by evaporator, condenser, expansion device and the adsorber bed which is filled with solid adsorbent. When gaseous molecules come in contact with solid adsorbent surface it interacts with it as the surface is unsaturated. The gaseous molecules get attracted and retained to balance the residual forces. In quick interval of time, the large amount of concentration of molecules is build up near the solid surface; this is caused by process of “Adsorption”. When this process is going on inside the bed, the cooling effect is produced at the evaporator section. For the continuous operation, heat energy is supplied to bed to desorb the refrigerant from adsorbent and this process is known as “Desorption”. Due to the Van der walls forces, the pressure and temperature inside the system increases during adsorption. Adsorption refrigeration cycle can be divided into two halves “Heating-Desorption-Condensation” and “Cooling-Adsorption-Evaporation”[1].

### 2.2.4 Single bed adsorption refrigeration cycle: -

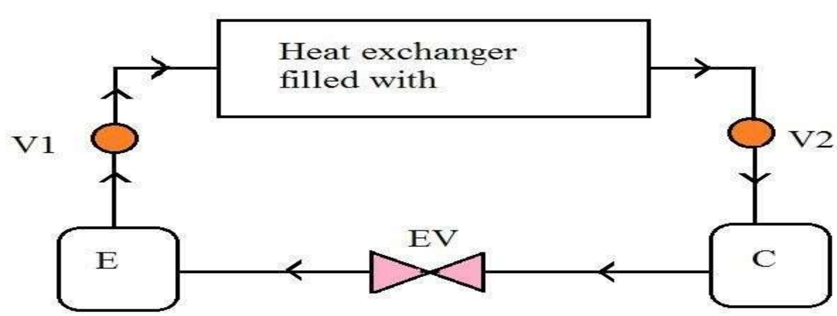



**Figure 2.1:-Single bed adsorption refrigeration cycle[1]**

Single bed adsorption refrigeration system consists of one adsorption bed heat exchanger, an evaporator, condenser, an expansion device, and valves to regulate the flow of vapour. Specially designed packed bed heat exchanger is used to increase the pressure and temperature of refrigerant as shown in figure 1. The compressor of VCRS is replaced by adsorber bed heat exchanger. In single bed adsorption refrigeration system cooling effect is pulsating as during desorption period there is no cold production.

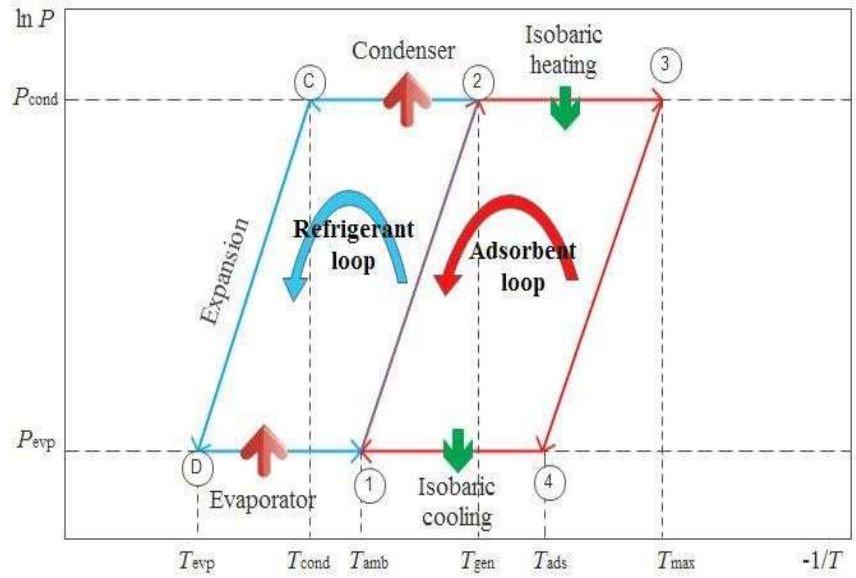



**Figure 2.2: Single bed Adsorption cooling cycle on Clapeyron's diagram.**

Description: 1-2 = Isosteric heating process, 2-3 = Isobaric heating process, 3-4 = Isosteric cooling process, 4-1 = Isobaric cooling process, 2-C = Condensation process, C-D = Expansion process, D-1 = Evaporation process [2].

Processes in a single bed sorption cooling cycle can be explained by Clapeyron diagram (ln P vs. -1/T) as shown in Figure 2. A complete cycle can be divided in between two half cycles. Initially, the reactor is charged with Adsorbate at atmospheric temperature ($T_{amb}$) and at evaporator pressure ($P_{evp}$), i.e., position 1 in Clapeyron diagram. Now the bed is heated continuously so that both temperature and pressure will increase. The process is known as Isosteric (concentration of adsorbent does not changes) heating (process 1-2). At point 2, Pressure is $P_{cond}$. Now at condenser pressure, heating continues up to point 3 and Asorbate go into the condenser. This process is known as Isobaric (at constant pressure) heating (process 23). Adsorbate (vapor) is condensed in the condenser (process 2-C). From condenser pressure, Adsorbate (liquid) is expanded up to evaporator pressure (process C-D). Evaporator pressure is lower than atmospheric pressure so that the Adsorbate starts evaporating in the evaporator by absorbing surrounding heat. During this process cooling effect is obtained (process D-1). Within this time, bed is cooled by outside media up to $P_{evp}$ (process 3-4) and then bed will start adsorbing molecules of Adsorbate. As the reaction is exothermic, heat need to be removed at constant pressure $P_{evp}$ by cooling media (process 4-1). Reactor and Adsorbate attain position 1 and the cooling cycle gets completed.

ADCS using single bed produces cooling power only during half cycle 'Cooling - Adsorption – Evaporation'. Adsorber bed heat exchanger needs to be regenerated during 'Heating – Desorption – Condensation'. During this cycle, there is no cooling effect and to take over this issue of single bed ADCS, Double-bed ADCS can be implemented.

**2.2.5 Double bed adsorption refrigeration cycle: -**

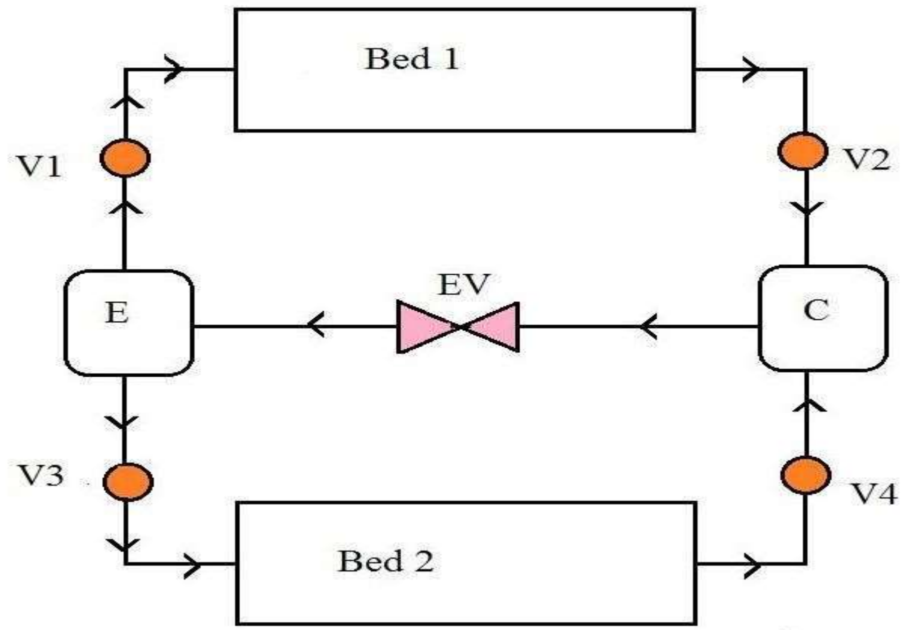



**Figure 2.3:Double Adsorption refrigeration system**

Double bed heat exchanger system consists of two adsorber bed heat exchanger in order to produce continuous cold production with evaporator (E), condenser (C) and expansion device (EV). The two-bed adsorption system is heavier than single bed. The valves are to be switched after a definite interval of time to alter the working bed for adsorption and desorption process.

## 2.3 Adsorbents: -

In adsorption cooling system physical adsorbents are commonly used, adsorbents are the main pillars of any adsorption cooling system. The main adsorbents used in Adsorption refrigeration system are silica gel, activated carbon, zeolite etc.

**2.3.1 Silica Gel: -**

The regenerative temperature of silica gel crystal is very less hence silica gel can be effectively utilised for the adsorption refrigeration system with hot source temperature as low as $70^0$ C[3] due to very low regenerative temperature silica gel is in very interest of many researchers and can be effectively used for the system powered by low-grade temperature source and solar energy[4]. Following table shows experimentation outcomes obtained by researchers who have used Silica-gel as an Adsorbent in their experimentation. Values of COP and SCP can be compared from following table for different parameters.

**Table 2.2: Literature review of experimental investigations using Silica-gel as Adsorbents.**

| Source | Method of heat addition | Working pair (Adsorbent + Adsorbate | Qty. of Adsorber bed | Cooling capacity (kW) | SCP (W/Kg of adsorbent) | COP |
|---|---|---|---|---|---|---|
| [5] | Hot water loop | Silica gel/water | 2 | 3.6 | - | 0.39 |
| [6] | Hot water loop | Silica gel/water | 2 | 4.2 | - | 0.42 |
| [7] | Hot water loop | Silica gel/water | 4 | - | 335 | 0.29 |
| [8] | Hot water | Silica gel/water | 2 | - | 430 | - |

The following table shows technical specifications of Blue Silica-gel which is easily available. in the market.

**Table 2.3: Technical Specification of Silica-gel Blue As per IS-3401-1979/1992/2003.**

| DESCRIPTIONS | SILICA-GEL BLUE |
|---|---|
| Type | Indicating Type |
| $SiO_2$ content | 97 – 99 % |
| pH | 6-7 |
| Bulk Density | 0.600 - 0.700 gm/cc |
| Loss on Drying % | < 5-6 % |
| Loss on Attrition % | 2.5% |
| Adsorption Capacity at 100 % humidity | 27 – 40 % |
| Friability | 99.5 |
| Chloride (as Nacl) | 0.4 ppm |
| Sulphates ($Na_2SO_4$) | 0.5 ppm |
| Ammonium ($NH_3$) | NIL |
| Particle size (Mesh) available | 1-2,3-4, 3-8, 5-8, 9-16, 16-30 |
| Chemical Formula | $SiO_2$+$H_2O$+$CoCl_2$ |

### 2.3.2 Zeolite: -

Zeolite has very high regenerative temperature ranging from $180^0C$ to $600^0C$ hence it cannot be used for low grade waste energy sources. Zeolite can be utilized for the waste heat source of furnaces and boilers as the source temperature is high. Zeolite and water pair is three times more efficient than silica gel water pair, as zeolite is destructive over 700°C hence it does not have more application and is not suitable for solar sources[9].

### 2.3.3 Activated carbon: -

Wood is used as main material to make activated carbon with peat, coal, and coconut shell. When the microcrystal for activated carbon is produced from bones it has a structure of six elemental carboatomic rings. The proposed specific surface area of activated carbon is between 500-1500$m^2$/g. Activated carbon has narrow pore area within the grains and composed of the net structure with irregular channels.[10] Activated carbon differs from other physical adsorbent in the surface feature, that is oxide matrix covering whole surface with the help of inorganic material, hence have weak polarity and is non-porous in actual. The heat of adsorption is less when compared to another adsorbent.

## 2.4 Adsorbate (Refrigerants): -

Adsorbate contributes to the cooling effect in the adsorption refrigeration systems; adsorbate must possess maximum properties of ideal refrigerant as ideal refrigerant is an imaginary concept. The GWP and ODP of the adsorbent must very low so that the system can contribute to eco-friendly refrigeration system.[11] The commonly used adsorbent with physical adsorbent are water, ethanol, methanol, and ammonia. But ammonia is not preferred as it is poisonous and can harm a human.[12]

**Table 2.4: Properties and suitability of Adsorbates used in ADRS.**

| Adsorbate | Boiling point(°C) | Latent heat of vaporization(kj/kg) | Density(kg/$m^3$) |
|---|---|---|---|
| Water | 100 | 2258 | 958 |
| Methanol | 65 | 1102 | 791 |
| Ethanol | 79 | 842 | 789 |
| Ammonia | -34 | 1368 | 681 |

# Chapter No. 3
# DESIGN CALCULATION AND FABRICATION

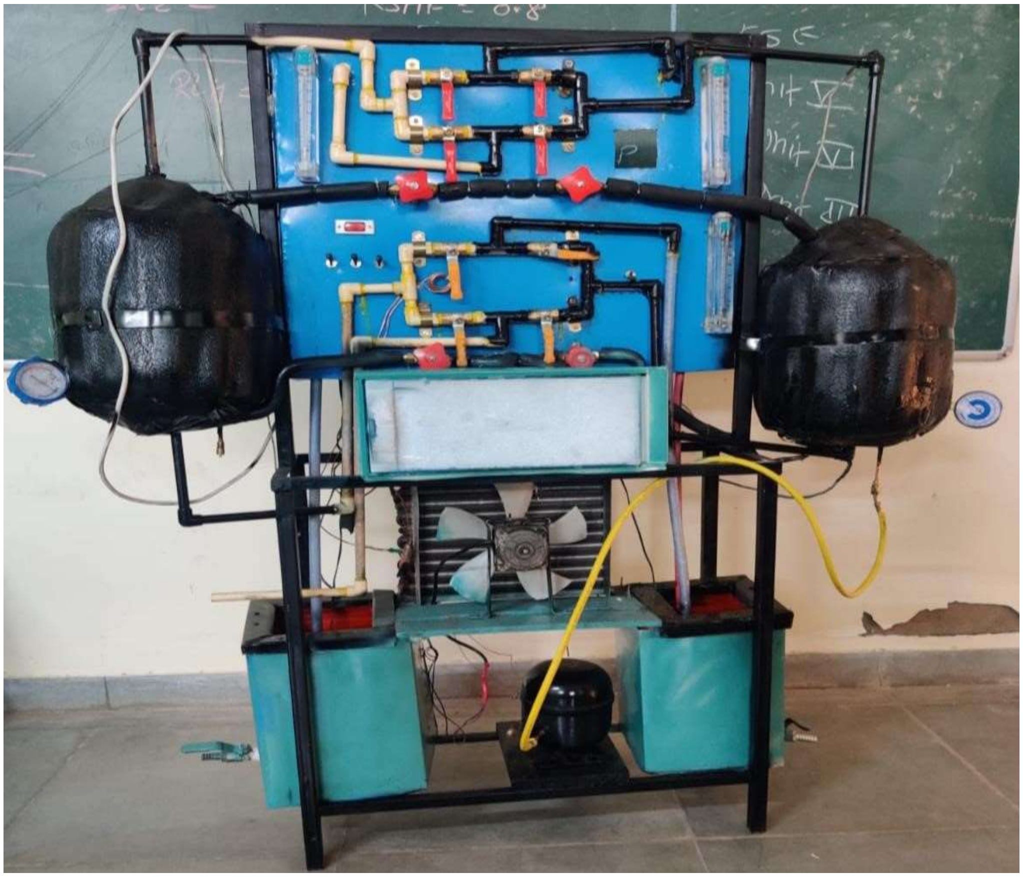


**Fig.3.1 Experimental setup**

Description Of Fig.3.5: ((1) Evaporator Section (2) Adsorber Bed 1 (3) Adsorber Bed 2 (4) Inlet Circuit for both the bed (5) Outlet Circuit for both the bed (6) Condenser (7) Expansion Device (8) Hot Water Tank (9) Hot Water Pump (10) Rotameter in hot water line (11) Solar water Heater (12) Cold water tank (13) Cold Water Pump (14) Rotameter in cold water line (15)valve connecting evaporator and adsorber bed 2 (16) valve connecting evaporator and adsorber bed 2 (17) valve connecting condenser and adsorber bed 1 (18) valve connecting condenser and adsorber bed 2

## 3.1 Introduction

The design is the major tool take on to construct a mechanical system effectively. It is a customary procedure adopted to ensure safety and effective utilization of most suitable construction techniques to construct a prerequisite test facility. Adsorption refrigeration system is manufactured with respect to its application, i.e., for refrigeration of insulated compartment. There are many parameters that can be considered for design of such refrigeration system. These all parameters either be redecided or else post-realized. An experimental test rig is essential to check its suitability for selected application. In this chapter, details of experimental test rig are elaborated and are discussed to carry out experiments to proceed further for results. Experimental test rig entails of the set-up of all the required components of the system. An organized approach is adopted to make provisions of components. The sophisticated design method is developed, and fabrication is done to lessen probable errors.

## 3.2 Design of experimental test facility

### 3.2.1 Capacity of Adsorption System

Prior to fabrication of the test rig the capacity of the chilling unit must be decided so that the rig must efficiently meat the cooling load. In present invention adsorption refrigeration system is to be designed for the application of cooling of insulated compartment. Here, the system is decided to be designed for 0.5TR capacity which is sufficient to cool the selected compartment.

A methodical procedure is followed now after deciding capacity of the system.[1]

### 3.2.2 No. of Adsorber bed heat exchanger

Single bed adsorption refrigeration system produces intermittent cooling effect as during the process of desorption process there is no evaporative effect in evaporator, but in the refrigeration application we require continuous cooling effect. This is fulfilled by using double bed adsorption refrigeration system. Only disadvantage posed by this system is the space requirement, as we are using double bed system, we will require extra space for the second bed. In the present invention we are using double bed adsorption system. Both the beds are identical in design. Every design parameter, configuration and working are same for both the beds.

### 3.2.3 Design of an Adsorber bed heat exchanger:

Adsorber bed is the Soul of the adsorption refrigeration system. Adsorber bed is a distinct type of heat exchanger in which Adsorbent material is filled with care. Heating and cooling arrangements for adsorber bed were made externally. The flow of an Adsorbate is regulated in the heat exchanger with the help of valves. In adsorber bed the phenomenon of heat transfer and mass transfer occurs simultaneously. The design of Adsorber bed is of at most important because poor design leads to low heat and mass transfer rates, which eventually affects the cycle time, SCP and COP [2]. However, the design of an Adsorber bed is not given prior importance in the older available adsorption systems. In the present invention, more focus is made on the improvement of heat and mass transfer rates. After analysis, it has been found that Heat transfer rate of the heat exchanger can be enhanced by increasing the heat transfer area and mass transfer rate can be enhanced by decreasing the thermal resistance between Adsorbent-Adsorbate particles or by creating voids. According to this, Adsorber bed heat exchanger is designed and assessed [3].

While designing the adsorption system for Refrigeration system powered by waste heat, method of heat addition and extraction, size and shape should be considered. Available adsorption systems were somewhat bulky because of the large size of Adsorber bed heat exchangers and hence cannot be appropriate for application. In the present invention, efforts were made to reduce the size of the whole system. In available systems, exhaust heat at the outlet of the engine was utilized as a heat source. It is a good utilization of heat content, but practically it creates a problem of handling the gas at a temperature around 400 °C. In the present system, it is decided to use hot water which is heated by heater for experimentation otherwise would have been heated by waste heat from exhaust.

**A. Selection of an Adsorber bed heat exchanger configuration**

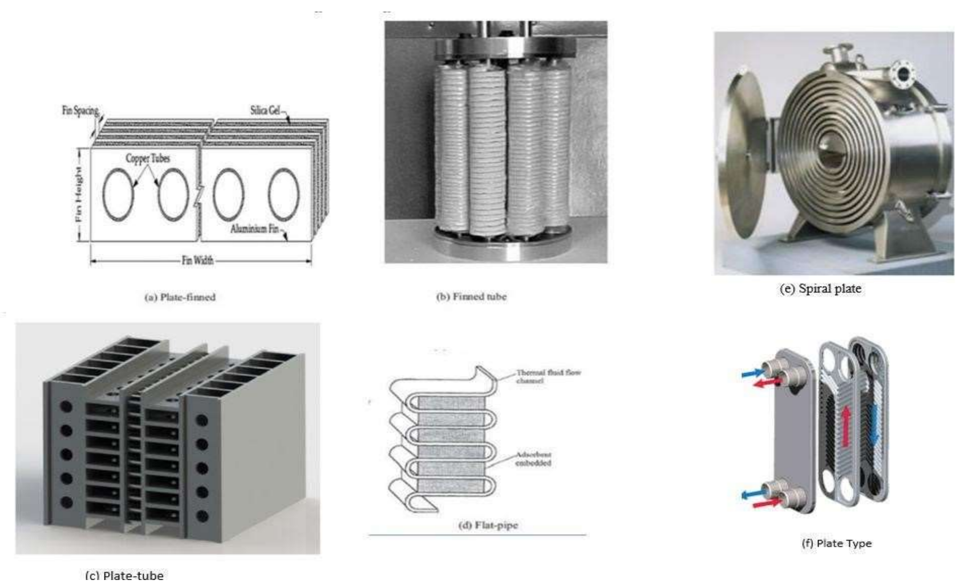



**Figure 3.2: Different types of Adsorber bed heat exchanger configurations**

As it has been observed earlier that heat and mass transfer in the heat exchanger is at most important, so it is important to adopt such configuration of the heat exchanger which has a maximum area of heat transfer as well as lowest thermal resistance to the flow of Adsorbate over the Adsorbent. There are so many configurations of heat exchangers available and used before by many researchers. Prior to information, Amir Sharafian et al. [1], Listed various types of heat exchanger designs can be used effectively in the adsorption cooling system.

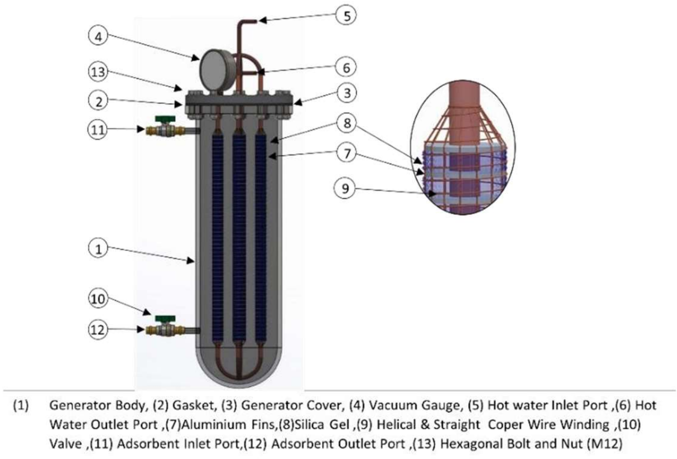
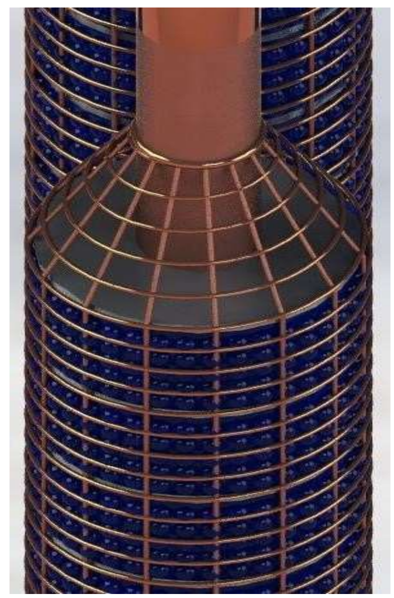



**Fig 3.3 Design of Generator**



Isometric view Closed Front View

**Fig 3.4 Design of Generator Tubes**

The effect of Adsorber bed design on COP, SCP, and Adsorber bed to Adsorbent Mass Ratio (AAMR) is compared to nine different types of configurations of Adsorber bed heat exchangers.

Those are Spiral plate type, Shell and Tube type, Hair-pin type, Annulus tube type, Plate-fin type, finned tube type, Plate tube type, simple Tube type, and simple Plate type, as shown in the figure above. Amongst all these configurations, highest COP, and SCP is reported for the finned tube type heat exchanger. With this analysis, it is decided to go with finned tube Adsorber Heat Exchanger so that we can assure higher heat and mass transfer rates. The design of finned tube Adsorber bed heat exchanger includes a heat transfer tube of material having higher thermal conductivity and it is surrounded by extended surfaces which increase surface area. The adsorbent material is filled in the gaps available between the fins surrounding to heat transfer tubes and are binder to the tubes by using binder polyvinyl alcohol. This section is called as Mass Transfer Channel (MTC) 'and now the whole assembly is enclosed in the outer casing so that it would be subjected to vacuum.

**B. Selection of Adsorbent-Adsorbate pair**

Adsorbent-Adsorbate pair combination is an important aspect of mass transfer inside the adsorber bed. It has been decided to use the hot water with temperature range $80^0$C to $90^0$C. Hence, while selecting the suitable Adsorbent and Adsorbate, it is important to ensure that, regeneration of an Adsorbent material is in between this temperature range. Following important points are considered while selecting suitable Adsorbent material [4]:

Adsorbent material should be capable of adsorbing maximum amount of an adsorbate vapor at minimum input conditions.

- When subjected to hot source must regenerate as soon as possible.
- Adsorbent material must have long life and must not deteriorate with time and use.
- It should be non-corrosive and non-toxic.
- It should have low cost and easy availability.

Following important points are considered while selecting suitable Adsorbate.(Refrigerant) [4]:

- It should have a high value of the latent heat of vaporization and low value of specific volume.
- It should saturate at low pressures (above atmospheric pressures)
- It should easily adsorb on the Adsorbent material and should not damage Adsorbent material.
- It should be thermally stable at operating range.
- It should be non-corrosive, non-toxic and non-inflammable.
- It should have low cost and easy availability.

From the above discussion, Blue Silica-gel beads (2mm) are selected as an Adsorbent material and Water is selected as a refrigerant. Blue Silica-gel can be easily regenerated at a temperature below 80 °C, at higher vacuum pressures, and easily available in the market. The capacity of adsorption of silica-gel beads can be easily restored by soaking it in the acidic solution followed by washing with distilled water [5]. Water is non inflammable and non-toxic as well. It has a high latent heat of vaporization around 2250 kJ/kg. Hence, water is the most suitable Adsorbate with Silica-gel [6].

**C. Amount of an Adsorbate (Refrigerant) required.**

For 0.5 TR capacity, amount of Adsorbate required can be calculated as follows: We have, Equation to calculate amount of Adsorbate (Refrigerant) required as follows [1]:

$$m_{Adsorbate} = \frac{Q_e\ (kW) \times\ t_{ads}\ (S)}{\left[h_{sat,water\ vapor@\ Tevp} - h_{sat,liquid\ water@\ Tcond}\right]\left(\frac{kJ}{kg}\right)}$$

Where,

$Q_e$ = Cooling effect = 1.758 kW; because system is to be designed for 0.5TR refrigeration capacity.

$t_{ads}$ = Adsorption time = 300 S; for any compartment to be cooled, 10 min is the standard time in which we need cooling effect and total cycle time is addition of Desorption time and Adsorption time. In this way, Desorption time is 300 S and Adsorption time is 300 S, but we get cooling effect during Adsorption time which is equal to 300 S [1],

$h_{sat,water\ vapor@\ Tevp}$ = enthalpy of water Adsorbate vapor at $T_{evp}$ = 10 °C = 2519.2 kJ/kg [1]

$h_{sat,liquid\ water@\ Tcond}$ = enthalpy of liquid water (refrigerant) at $T_{cond}$ = 45 °C = 188.44 kJ/kg [1]

Now, $m_{Adsorbate} = \frac{1.758\ (kW)\times 300\ (S)}{[2519.2-188.44]\left(\frac{kJ}{kg}\right)}$

Therefore, $\mathbf{m_{Adsorbate}} = \mathbf{0.0.226\ kg}$

**D.Amount of Adsorbent required.**

For 0.5 TR capacity, amount of Adsorbent required can be calculated as follows [1]:

$$m_{Adsorbent} = \frac{m_{Adsorbate}}{\Delta\omega}$$

Where, $m_{Adsorbate}$ = amount of Adsorbate needs to be circulated in system in order to meet cooling requirement, calculated as earlier= 0.226 kg,

$\Delta\omega$ = Water uptake and discharge difference capacity of Silica-gel = 0.09 to 0.1 kg/kg of dry Silica-gel [1].

Now, $m_{Adsorbent} = \frac{0.226}{0.09}$

Therefore, $\mathbf{m_{Adsorbent}}$ =**2.5 kg of dry Silica-gel per bed.**

**3.2.4 Selection of material and other parameters of main components**

According to the requirement, finned tube Adsorber bed heat exchanger consist of heat transfer channel surrounded by circular fins and the whole assembly is known as MTC which is packed in outer casing with the help of flanges. The whole bed can be evacuated from one end. Selection is as follows –

1. Mass Transfer Channel (MTC):

   Material used for tubes– copper (higher thermal conductivity and easy availability)

   Orientation – coiled tubes (5 tubes – to assure maximum heat transfer)

   Diameter of tube – 3/8 (9.54 mm)

   Shape - Circular

Length – 300 mm

Fins:

- Type - Circular fins
- Material – aluminium
- Thickness of each fin – 0.5 mm
- Dimension of single fin - (Diameter * thickness) cm= 5 * 0.05 cm
- Space between two fins –10 mm
- No. of fins on one tube- 48

2. Outer casing:
   - Material – G.I. Sheet
   - Dimensions - (Diameter * height) cm= (30 * 60) cm
3. Condenser:
   - Air-cooled
   - Tube material – copper
4. Capillary tube:
   - Diameter – 2 mm
   - Length – 60 cm
5. Evaporator:
   - Material of outer body – Aluminium sheets
   - Shape – Rectangular Box
   - Plate type evaporator

There are two openings for the evaporator, one passes liquid Adsorbate from expansion capillary to evaporator, and one passes vaporized Adsorbate to Adsorber bed for adsorption.

In this way, main components are selected, and system is now ready for fabrication.

### 3.2.5 3D modelling on Solid work

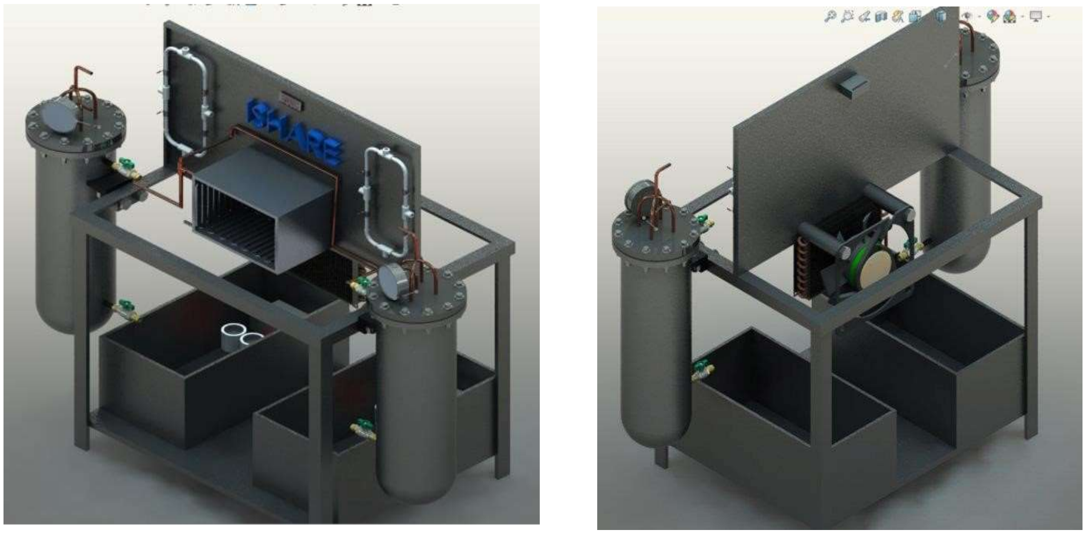



**Fig 3.5 Design of Model**

3-D modelling on solid work Adsorber bed heat exchanger is designed and modelling is done on 3-D interface by using solid work software. Solid work is used to create a 3-D view of Adsorber bed heat exchanger.

## 3.3 Performance parameters required to be calculated.

Any thermodynamic system has performance parameters which are required to analyse the performance of the system. These parameters may be calculated through experimentation and realized through discussion. ADCS has been analysed for performance parameters which are Coefficient of Performance (COP), Specific Cooling Power (SCP) and Adsorber bed to Adsorbent Mass Ratio (AAMR). It was pre-decided to calculate these performance parameters, so instrumentation has been done in experimental setup.

## A. Specific Cooling Power (SCP)

SCP is the most important performance parameter in Adsorption cooling system as it represents the amount of cooling output obtained per unit of mass of dry adsorbent. SCP is defined as the ratio of cooling energy to the mass of unsaturated adsorbent multiplied by required cycle time. Unit of SCP is W/kg of dry adsorbent. SCP depends on the Adsorbate uptake capacity of adsorbent. If Adsorbate uptake capacity of an adsorbent is large with minimum consumption of time, then SCP is more [1]. It is well and good that SCP is as large as possible. The definition of SCP stated here does not consider the weight of an extra metal of an Adsorber bed heat exchanger other than Adsorbent. Also, the volume of Adsorber bed is also neglected here. To resolve this issue, Volumetric SCP can be calculated. Prediction of SCP can be possible as follows,

$$(\mathrm{SCP})_{\max} = \frac{\mathrm{Q_e}\ (\mathrm{kW}) \times \ \mathrm{t_{ads}}\ (\mathrm{S})}{\mathrm{m_{Adsorbent}}(\mathrm{kg}) \times \ \mathrm{t_{cycle}}(\mathrm{S})}$$

$Q_e$ designed condition is equal to 0.5 TR, which is equal to 1.75 kW. $T_{ads}$ is nothing but 300 S out of 600 Seconds of total cycle time. 2.5 kg of Silica-gel is to be filled in each Adsorber bed which is calculated earlier. In this way, maximum value of SCP obtained.

$$(\mathrm{SCP})_{\max} = \frac{1.75\ (\mathrm{kW}) \times \ 300\ (\mathrm{S})}{2.5\ (\mathrm{kg}) \times \ 600\ (\mathrm{S})}$$

$$\mathbf{(SCP)_{max}} = \ \mathbf{350}\ \frac{\mathbf{W}}{\mathbf{kg}}\,\mathbf{of\ dry\ adsorbent}$$

## B. Coefficient of Performance (COP)

To evaluate the efficiency of Adsorption refrigeration system here, a parameter called COP is to be calculated through experimentation. COP is a dimensionless term which defined as the ratio of cooling power obtained through the evaporator to the heat energy supplied to Adsorber bed heat exchanger through the hot source. It is always expected that COP should be above one but, sorption systems have COP less than one. If the hot source is available in abundance, then COP will not be as important as other performance parameters.

## 3.4 Selection of all other components

The other supplementary setup consists of parts as, hot, and cold-water tank, Pumps, In-way and Out-way circuits, valves, heater, control panel, instrumentation, Insulations, etc. these components are chosen according to market suitability and price.

## 3.5 Fabrication of Experimental test facility

Fabrication of Experimental setup includes the building of a structure which includes main and supplementary components. Manufacturing techniques are adopted in such a way that, all components of the system should be assembled properly and working may not be disturbed during experimentation. Suitable manufacturing techniques are adopted according to material and accuracy required. The test facility is discussed in the following sections.

### 3.5.1 Line Diagram of an Adsorber bed heat exchanger and detail description

Line diagram of Adsorber bed heat exchanger shows the assembling of all different parts through suitable manufacturing processes as follows:

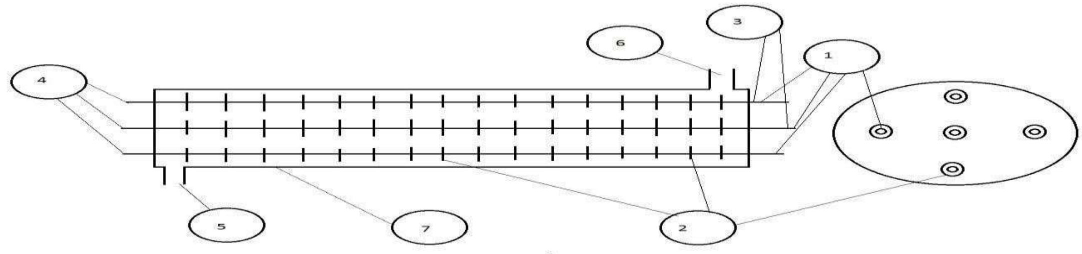


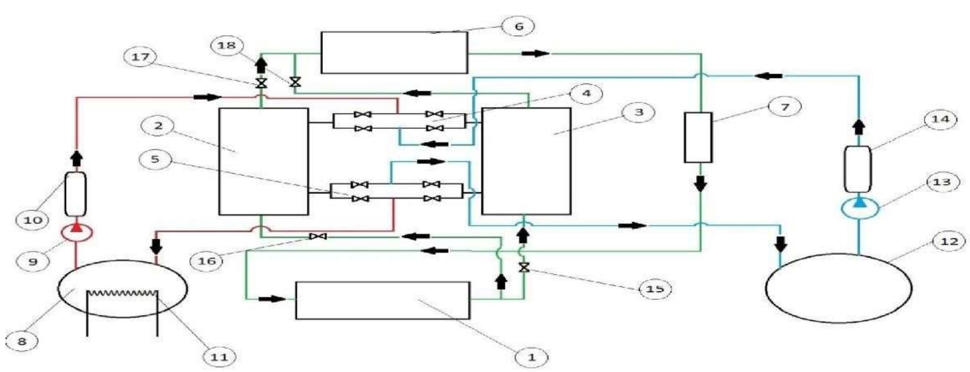
**Figure 3.6: Line diagram of an Adsorber bed Heat-Exchanger**

Description**: -** (1) Mass transfer channel (2) adsorber binded copper fins (3) Mass transfer inlet (4) Mass transfer outlet (5) Refrigerant inlet (6) Refrigerant outlet (7) Outer shell with insulator Figure 3.6 shows the line diagram of an Adsorber bed heat exchanger. All the parts of the bed are listed below the diagram. The same design is adopted for the Adsorber bed heat-exchangers. Mass transfer channel (Callout 1) is a refillable and having compact structure. Mass transfer channel consist of 5 copper tubes having inlet (Callout 3) and outlet (Callout 4), through which heat transfer fluid circulated. Copper tubes have silica gel binder aluminium fins on each tube

(Callout 2) were fixed around the periphery of the tube. Gap available between the fins is utilized for binding more of Adsorbent material. The mass transfer channel is enclosed completely in the outer shell (Callout 7) and fitted with the help of leak proof enclosure. There is inlet (Callout 5) and outlet (Callout 6) for the vapor refrigerant.

**3.5.2 Line diagram of complete experimental setup facility and description**

Line diagram of a complete set up shows connections of all primary and secondary components as follows,



**Description: ((1) Evaporator Section (2)Adsorber Bed 1 (3)Adsorber Bed 2 (4)Inlet Circuit for both the bed (5)Outlet Circuit for both the bed (6)Condenser (7)Expansion Device (8)Hot Water Tank (9)Hot Water Pump (10) Rotameter in hot water line (11) Heater/ Waste heat input (12)Cold water tank (13)Cold Water Pump (14)Rotameter in cold water line (15)valve connecting evaporator and adsorber bed 2 (16)valve connecting evaporator and adsorber bed 2 (17)valve connecting condenser and adsorber bed 1 (18) valve connecting condenser and adsorber bed 2**

**Figure 3.7– Line drawing of primary experimental set-up.**

Figure 3.7 shows a line diagram of the experimental set-up. All the components of the setup are listed below the diagram. Adsorber bed 1 (callout 2) and Adsorber bed 2 (callout 3) are state of the art heat exchangers of the system. Adsorber bed 1 connected to condenser (callout 6) via valve (callout 17). The outlet of Condenser is connected to inlet of an Evaporator (callout 1) via a Expansion device (callout 7). Adsorber bed 1 is connected to Condenser and Evaporator by valves (callout 17 and 16 respectively). Similarly, Adsorber bed 2 connected with Condenser and evaporator by valves (callout 18 and 15 respectively). Hot and cold water supplied to bed via inway circuit (callout 4) while, received back throughout-way circuit (callout 5). Hot water tank (callout 8) is provided and fitted with an electrical heater (callout 11) to supply hot water via a pump (callout 9). Similarly, cold water tank (callout 12) is provided which acts as a common reservoir of cold water required to cool the adsorber bed via pump (callout 13) as well as water circulated in evaporator via submersible pump (callout 21) to achieve the desired output. Rotameters (slot 14 and 10) fitted in pipeline with hot and cold water to measure mass flow rate. Refrigerant is used as water and charged in the evaporator via a separate arrangement by creating a vacuum (external arrangement, not shown in line diagram).

### 3.6 Description of test facility

The primary experimental setup consists of a two Adsorber bed heat exchangers, air cooled condenser, an expansion device (Capillary tube) and an evaporator. The other supplementary setup consists of parts as hot and cold-water tank, Pumps, In-way and Out-way circuits, heater, valves etc. Two Adsorber beds of same configurations are incorporated as a Thermal compressor in the system. Two beds operate during their respective half cycles. Common air-cooled condenser and evaporator is connected to the Adsorber beds with the help of valves. Valves are operated manually to evaluate the system for changing parameters. The function of valves in the refrigerant line is to regulate the flow of an Adsorbate through Adsorber bed, followed by a condenser, evaporator and back to the Adsorber bed. Valves present in the in-way and out-way circuits are used to regulate the flow of cold and hot water in the Adsorber bed heat exchangers. Two reservoirs used in the system to provide hot and cold water. Hot and cold water is being circulated in the system with the help of pumps. Submersible pump dipped in the cold-water tank is used to circulate chilled water through the evaporator. Rotameters are fitted in the pipeline of hot and cold water after the pumps. The temperature at the different locations is measured by ktype thermocouples and indicated by digital indicator present on the control panel. Pressure gauges used to measure pressure. The separate external arrangement is provided in the system to create a vacuum to charge Adsorbate. A pictorial view of complete experimental setup is as shown in the Figure 3.7.

### 3.7 Fabrication of Experimental Setup

Design: The first step is to design the adsorption system based on the specific requirements and objectives. This includes determining the adsorbent material, system capacity, operating conditions, and overall configuration.

Material selection: Select the appropriate materials for constructing the system components such as adsorbent beds, piping, valves, and instrumentation. The materials should be compatible with the adsorbent material and the operating conditions (temperature, pressure, corrosive environment, etc.).

Construction of adsorbent beds: Fabricate the adsorbent beds or columns where the adsorption process takes place. The construction method depends on the system design and may involve welding, casting, or assembling pre-made sections. The beds should be structurally sound and capable of holding the adsorbent material securely.

Installation of valves and instrumentation: Install valves, pressure gauges, temperature sensors, and other necessary instruments to monitor and control the system. Ensure proper sealing and connections to prevent leaks or pressure losses.

Piping and plumbing: Connect the adsorbent beds with piping to allow the flow of the process fluid or gas. Consider factors such as fluid velocity, pressure drop, and pressure ratings when designing and installing the piping system. Proper insulation may be required to maintain desired operating temperatures.

Support structures: Fabricate support structures or frames to hold the adsorption system components securely in place. These structures should be stable and able to withstand the weight and forces exerted by the system.

Testing and quality control: Once the fabrication is complete, thoroughly test the system to ensure its proper functioning. This may include pressure testing, leak detection, performance evaluation, and compliance with safety standards and regulations.

Installation and commissioning: Install the adsorption system at the designated location and integrate it with the existing infrastructure. Conduct the necessary commissioning procedures to verify its performance and functionality.

**Figure 3.8: Fabrication Images of Adsorber Bed**

**Figure 3.9: Fabrication Images of Experimental setup**

## 3.8 Solar Water Heater

**Figure 8.10: Design of solar water heater**

The design of a solar water heater with dimensions of 80cm x 80cm and water tube size of 3/4 inch made up of aluminium fixed on a copper plate of 2 feet by 2 feet is relatively straight forward.

Material Selection: As per the design requirement, aluminium and copper plates are chosen to build the system. Aluminium is an excellent conductor of heat and is also lightweight, while copper is a good thermal conductor with high thermal stability. The 3/4-inch water tubes will be made of copper for the best thermal conductivity. Water Tank: A water tank of the size 25 cm ×25 cm will be used to store hot water. The tank is placed at a higher level than the collector to ensure natural flow.

**Copper Plate:** The copper plate of 2 feet by 2 feet is fixed to the bottom of the collector to ensure maximum heat transfer.

**Water Tubes:** The 3/4-inch aluminium tubes are then fixed on the copper surface with the help of a thermal adhesive. The tubes are arranged in a serpentine pattern to maximize heat transfer. The inlet and outlet pipes are connected to the water tank.

**Insulation:** The collector is insulated on all sides to prevent heat loss.

**Mounting:** The collector is mounted on a stand made with mild steel angles such that it includes the collector 30 ° with roof.

**Operation:** The solar water heater works by converting solar energy into heat. When sunlight falls on the collector, it heats the water in the tubes. The heated water is then stored in the tank for later use.

# CHAPTER NO. 4
# EXPERIMENTAL ANALYSIS OF ADSORPTION REFRIGERATION SYSTEM

## 4.1 Introduction to Experimentation

Experimentation is be performed with a specific end goal to discover execution parameters. Experimentation is a standard system took after to acknowledge working of specific process or marvel. Here, a cooling framework considering the standard of Adsorption is tried for various cases and perceptions are recorded in the perception tables. Experimentation performed on the test apparatus and safety measures are taken to limit blunders. In this section, a complex execution technique is talked about which is adjusted to lead experimentation. The investigation is led for three unique situations where starting conditions shift while marvel continues as before.

## 4.2 Procedure of Experimentation

The double bed Adsorption refrigeration system comprise of two Adsorber bed heat exchangers, the entire work is separated into two sections: one a player in Adsorber bed 1 and another piece of Adsorber bed 2. Both the beds associated with in way and the out-way circuit through which hot and cool water supply is made. Consider, Adsorber bed 1 i.e., one section is experiencing the desorption procedure. At this, high temperature water is provided to bed 1. The desorption process is followed by condensation in the condenser and refrigerant is expanded to the evaporator pressure by a capillary tube. In the evaporator refrigerant is utilized to cool environmental water, which is kept in the bottle. In the meantime, another part is provided with cool water and gets refrigerant which is extended in the initial segment. This procedure is exchanged after halftime of cycle slipped by. Presently, second part is ready to be first part and vice versa. All operations were exchanged, and this exchanging time is disregarded. During this time, position of valves was interchanged. Position of valves is as per the following,

### 4.2.1 Position of valves

Valves present in the system are divided into three categories as,

1. Valves present in the Refrigeration line,
2. Valves present in the In way circuit and,
3. Valves present in the Out-way circuit.

Position and nomenclature of valves are as shown in the following figure,

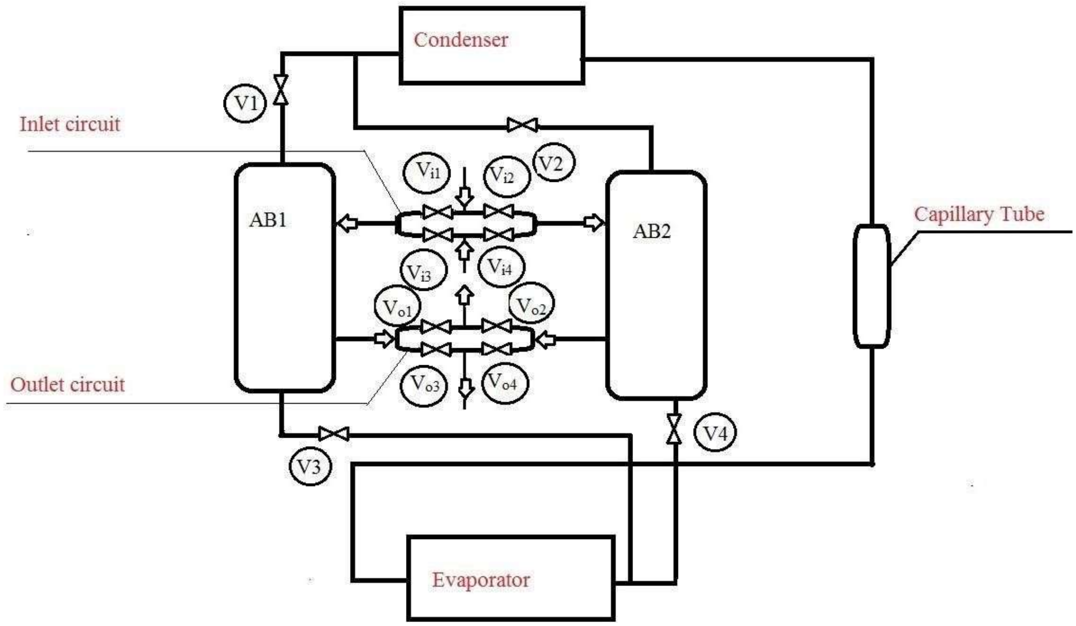



**Figure 4.1: Position of valves**

### 4.2.2 Operation of valves according to process

Following table categorizes operation of valves to operate bed for a particular process.

**Table 4.1: Operation sequence of valves present in the system.**

| Adsorber bed | Process | Valves in the Refrigeration line | | | | Valves in the In way circuit | | | | Valves in the Out way circuit | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | V1 | V2 | V3 | V4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Adsorber bed 1 | Desorption | On | Off | On | Off | On | Off | Off | On | Off | On | On | Off |
| Adsorber bed 2 | Adsorption | On | Off | On | Off | On | Off | Off | On | Off | On | On | Off |
| Adsorber bed 1 | Adsorption | Off | On | Off | On | Off | On | On | Off | On | Off | Off | On |
| Adsorber bed 2 | Desorption | Off | On | Off | On | Off | On | On | Off | On | Off | Off | On |

## 4.3 Instrumentation

### 4.3.1 Measurement of temperature

Temperatures at the different locations are measured with the help of K-type thermocouples. Different locations of thermocouples and nomenclature of temperatures are as shown in the following table,

**Table 4.2: Location of thermocouples to measure temperatures.**

| Sr.no | Temperature | Position of thermocouple in system |
|---|---|---|
| **1** | T1 | Inlet of Adsorber bed 1 |
| **2** | T2 | Outlet of Adsorber bed 1 |
| **3** | T3 | Inlet of Adsorber bed 2 |
| **4** | T4 | Outlet of Adsorber bed 2 |
| **5** | T5 | Evaporator |
| **6** | T6 | In the refrigerant line at the Outlet of Adsorber bed 1 |
| **7** | T7 | In the refrigerant line at the Outlet of Adsorber bed 2 |
| **8** | T8 | In the refrigerant line at the Inlet of Evaporator |
| **9** | T9 | In the refrigerant line at the outlet of Evaporator |
| **10** | T10 | In the refrigerant line at the inlet of Condenser |
| **11** | T11 | In the refrigerant line at the outlet of Condenser |

### 4.3.2 Measurement of mass flow rate of hot and cold source

The mass flow rate of hot and cold water is calculated by Rotameters fitted in hot and coldwater lines respectively. Rotameters are calibrated in LPM of water from 0 to 20 LPM of water.

### 4.3.3 Control panel

The control panel consists of digital indicators, temperature knob and on-off switches at the front side. Control panel used as a supportive structure to hold temperature sensors in the plugs of digital indicators. Readings of temperature at different locations can be calculated by rotating the temperature knob which has 12 no. of steps.

## 4.4 Experimental cases

To compute different performance parameters and to establish a relation between them, it is necessary to keep constant some operating parameters and some to be changed. Experimentation is divided into three cases as follows,

### 4.4.1 Case A: The Varying mass flow rate of a hot and cold source for a range of operating conditions at the constant cycle time.

In this case, mass flow rate of the hot and cold source is varied in the range of 3 to 15 LPM of water. Cycle time is decided 10 min earlier but, to compensate the effect of switching time, the cycle time is kept constant at 15 min. Three inlet temperatures of hot source are analyzed as follows,

1. For Thot in = 45 ˚C, Tcold in = 30˚C and Tbottle, in = 30 ˚C.
2. For Thot in = 55 ˚C, Tcold in = 30˚C and Tbottle, in = 30 ˚C.
3. For Thot in = 65 ˚C, Tcold in = 30˚C and Tbottle, in = 30 ˚C.

### 4.4.2 Case B: Keeping constant mass flow rate of a hot and cold source for varying operating conditions at constant cycle time.

In this case, mass flow rate of the hot and cold source and cycle time kept a constant while, the inlet temperature of the hot source is varied from 45 °C and 60 °C.

### 4.4.3 Case C: Keeping constant mass flow rate of a hot and cold source for varying operating conditions at varying cycle time.

In this case, mass flow rate of hot and cold source kept constant and Inlet temperature of the hot source along with cycle time is changed.

## 4.5 Observation table

**Table no 4.3 General layout of the observation table**

This is general layout of the observation table; every observation is shown in the annexure.

| Bed 1: Hot Water, Bed 2: Cold water | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\dot{m}_h$ (LPM) | $\dot{m}_c$ (LPM) | $T_{ads}$ (min.) | $T_{des}$ (min.) | $T_{cycle}$ (min.) | Temperature ($^0$C) | | | | | | | | | | |
| | | | | | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | $T_6$ | $T_7$ | $T_8$ | $T_9$ | $T_{10}$ | $T_{11}$ |
| | | | | | | | | | | | | | | | |

## 4.6 Formulation

**Table 4.4: - Table of Formulation**

| Parameter | Symbol | Equation used for calculation | Unit | Reference |
|---|---|---|---|---|
| Heat supplied to the Desorber bed | $Q_h$ | $\dot{m}_h$(kg/s)× $C_{p_h}$ (kJ/kg°C)× $\Delta T_{hot}$ (°C) | kW | |
| Heat extracted from the Adsorber bed | $Q_c$ | $\dot{m}_c$(kg/s)× $C_{p_c}$ (kJ/kg°C) × $\Delta T_{cold}$ (°C) | kW | |
| Heat given at the Condenser | $Q_{cond}$ | U (kW/m$^2$) ×A (m$^2$)×$\Delta T_{cond}$ (°C) | kW | [1] |
| Cooling effect obtained at the Evaporator | Qevap | U (kW/m$^2$) ×A (m$^2$)×$\Delta T_{LMTD}$ (°C) | kW | |
| Coefficient of Performance | COP | $Q_e$ (kW)/$Q_h$ (kW) | - | |
| Specific Cooling Power | SCP | $\frac{Q_e\ (W) \times t_{ads}\ (min.)}{m_{Adsorbent}\ (kg) \times t_{cycle} (min.)}$ | W/kg | |
| Total cycle time | $t_{cycle}$ | $t_{ads} + t_{des}$ | min. | |

## 4.7 Calculations

Following assumptions before evaluation of performance parameters

1. The Adsorbate vapor in the system is assumed as an ideal gas.
2. Properties of Adsorbent particles, copper tube, and fins are Isotropic.
3. System has no heat losses.
4. There is no thermal resistance between the copper tube and the adsorbent bed.

Sample calculations are shown as below for Available data,

### A. Varying mass flow rate of hot and cold source for constant operating conditions and at the constant cycle time

**From,**

Table 4.5: For $(T_{hot})_{in}$ = 45 ˚C

| Bed 1: Hot Water, Bed 2: Cold water | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\dot{m}_h$ (LPM) | $\dot{m}_c$ (LPM) | T ads (min.) | T des (min.) | Tcycle (min.) | Temperature ($^0$C) | | | | | | | | | | |
| | | | | | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | $T_6$ | $T_7$ | $T_8$ | $T_9$ | $T_{10}$ | $T_{11}$ |
| 3 | 3 | 7.5 | 7.5 | 15 | 45 | 36 | 30 | 34 | 29 | 33 | 31 | 30 | 35 | 34 | 31 |

### 4.7.1 Calculation of $\dot{Q}_h$

$$Q_h = (\dot{m}_h/60) \times C_{p_h} \times \Delta T_{hot}$$

From the available data,

$\dot{m}_h$ = 3 LPM of water = 3/60 kg/s,

$C_{p_h}$ = 4.181 kJ/kg ºC at 50 ºC

$\Delta T_{hot} = T_1 - T_2$ = 9 °C

Therefore,

$$\mathbf{Q_h} = \frac{3}{60} \times 4.181 \times 9 = 1.88145 \text{ kW}$$

### 4.7.2 Calculation of $\dot{Q}_c$

$$Q_c = \dot{m}_c \times C_{p_c} \times \Delta T_{cold}$$

From the available data,

$\dot{m}_c$ = 3 LPM of water = 3/60 kg/S

$C_{p_c}$ = 4.178 kJ/kgºC at 30 ºC

$\Delta T_{cold} = T_4 - T_3$ = 4 ºC

Therefore,

$$\mathbf{Q_c} = \frac{3}{60} \times 4.178 \times 4 = \mathbf{0.8356kW}$$

### 4.7.3 Calculation of $Q_e$

$$Q_e = U(W/m^2C) \times A_c(m^2) \times (\Delta T_{LMTD}) (ºC)$$

U =825 W/m$^2$K for Water-to-Water heat transfer from Data book $A_c = \boldsymbol{\pi}{*}D_i{*}L$= 0.1645 m$^2$ =Total heat transfer area. $D_i$ =0.006m

L =7.29m

$\Delta$TLMTD = T1- T2/ln( T1/ T2)

$\Delta T_1 = T_5$-10 ºC

$\Delta$T2 = Tbottle,in -10 ºC

Therefore,

$Q_e$ = 825*0.1645*1.69= **0.23kW**

**4.7.4 Calculation of Coefficient of Performance (COP)**

$$\mathrm{COP} = {}^{Q_e\,(kW)}/_{Q_h}\ (kW)$$

From the calculated data,

$$\mathrm{COP}\quad {}^{0.23}/_{1.8818} =$$

Therefore,

**COP = 0.12018**

## 4.7.5 Calculation of Cycle time:

$$t_{cycle} \quad t_{ads} + t_{des} =$$

From the available observations,

$$t_{cycle} \quad 7.5 + 7.5 = \text{min.}$$

$\mathbf{t_{cycle}}$ **= 15 min**

**4.7.6 Calculation of Specific Cooling Power (SCP)**

$$\mathrm{SCP} = \frac{Q_e\,(W) \times T_{ads}\,(\text{min.})}{m_{Adsorbent}\ (kg) \times T_{cycle}(\text{min.})}$$

Where,

$$t_{cycle} \quad t_{ads} + t_{des} = = 15 \text{ min.}$$

From calculated data,

$$\mathrm{SCP} = \frac{230 \times 7.5}{5 \times 15}\ \text{W/kg of dry Adsorbent}$$

**= 46 W/kg of dry Adsorbent.**

# CHAPTER 5
# RESULTS AND DISCUSSIONS

## 5.1 Results

In this section, results are mentioned which are obtained from the complete analysis of the experimentation facility. Base case operating conditions are decided to determine the nominal performance parameters and working model of the Double-bed Adsorption cooling system are analysed to calculate those parameters. Then, Analytical study is conducted to find the effect of different parameters on the performance of the system. Different types of analysis tools are used to compare results and based on its effective discussion has been done which is mentioned in subsequent sections.

Varying mass flow rate of hot and cold source for constant operating conditions at the constant cycle time.

**Table 5.1**: **Results for $(T_{hot})_{in}$ = 45 ˚C, $(T_{cold})_{in}$ = 30˚C and $(T_{bottle})_{in}$ = 30 ˚C.**

| a. Bed:1 Hot water, Bed:2 Cold water | | | | |
|---|---|---|---|---|
| **Qc(kW)** | **Qh(kW)** | **Qevap(kW)** | **COP** | **SCP** |
| 0.84 | 1.88 | 0.23 | 0.12018 | 45.22 |
| 1.11 | 2.51 | 0.39 | 0.15428 | 77.40 |
| 1.74 | 2.44 | 0.45 | 0.18542 | 90.44 |
| 2.09 | 2.09 | 0.48 | 0.22764 | 95.18 |
| 3.41 | 1.95 | 0.52 | 0.26511 | 103.45 |
| 4.46 | 3.34 | 1.10 | 0.32872 | 125.55 |
| 6.27 | 4.39 | 1.65 | 0.37568 | 152.22 |
| 6.96 | 6.27 | 2.51 | 0.39945 | 178.35 |
| 10.45 | 5.23 | 2.46 | 0.47067 | 178.35 |
| **Bed:1 Cold water, Bed:2 Hot water** | | | | |
| **Qc(kW)** | **Qh(kW)** | **Qevap(kW)** | **COP** | **SCP** |
| 0.84 | 1.88 | 0.23 | 0.12018 | 45.22 |
| 1.11 | 2.51 | 0.39 | 0.15428 | 77.40 |
| 1.74 | 2.44 | 0.45 | 0.18542 | 90.44 |
| 2.09 | 2.09 | 0.48 | 0.22764 | 95.18 |
| 3.41 | 1.95 | 0.52 | 0.26511 | 103.45 |
| 3.90 | 3.34 | 1.10 | 0.32872 | 125.55 |
| 6.27 | 5.02 | 1.76 | 0.35112 | 152.22 |
| 6.96 | 5.57 | 2.23 | 0.40058 | 178.55 |
| 10.45 | 7.32 | 3.59 | 0.49100 | 178.55 |

Tables of result for other operating conditions are given in the annexure.

## 5.2 Discussion

### 5.2.1 Effect of Cycle time on the Coefficient of Performance

Assess the impact of cycle time on the COP of system, trial is performed by keeping mass flow rate of hot and cold source steady at 15 LPM. Working conditions were kept steady to variation were made in cycle time while hot source inlet temperature is embraced as 45°C, 55°C, and 65°C. Information gathered by experimentation is gathered in Table 5 and results got after definition is arranged in Table 11.

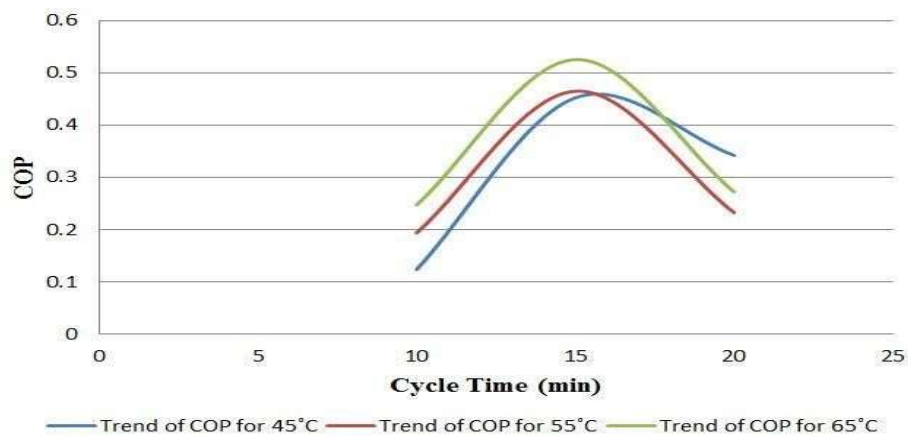



**Figure 5.1: Trend of COP at different Cycle time for a Constant mass flow rate of the hot and cold source**

As appeared in above figure, Bell-formed smooth bend of COP got against Cycle time. The bend demonstrates that higher COP is obtained for Cycle time of 10 to 15 min and for higher process duration period, COP decreases continuously. At the beginning of the cycle, if we consider Desorption prepare then the temperature of the bed is insufficient to make enough flow of Adsorbate in the system and hence, low COP are accounted for at the process duration of 10 min. when heat exchange rate expands, the bed gets warmed and temperature of bed expanding ceaselessly alongside Adsorbate vapor.

Contrasted with the process duration of 10 min, we get enough heat transfer rate in 15 min. a lot of Adsorbate vapor goes into the condenser and higher COP is acquired. Most noteworthy COP detailed through experimentation is around 0.53 when temperature of the hot source is around 65 °C. It is all around acknowledged in the use of refrigeration where 15 min is adequate to get a cooling impact in the wake of beginning of the system. Experimentation is rehashed for 20 min of process duration; however low COP are accounted for due to transient conduct of Adsorber bed heat exchanger. As process duration expands, more heat is exchanged to the bed; this builds the temperature of part of the Adsorber bed other than Adsorbent. More heat is used to build the temperature of uncovered metal instead of Adsorbent and low COP acquired. Along these lines, it is constantly desirable over keep process duration around 10 to 15 min. along these lines, that Desorption and Adsorption process can be successfully exchanged in the middle of half cycles and the cooling impact acquired in the acknowledged range.

### 5.2.2 Effect of mass flow rate of hot source on the Coefficient of Performance

To assess the impact of mass flow rate on the COP, Experimentation is finished by continuing working conditions and process duration consistent. The process duration of 15 min. is received to remunerate time required for exchanging of valves after every half cycle. Mass flow rate of the hot and cold source is shifted from 0 to 15 LPM of water and perceptions recorded in the perception tables under case A. because of the goodness of experimentation office, the most extreme conceivable mass flow rate of the hot source is 15 LPM of water. The inlet temperature of the hot source is shifted in the scope of 45 to 65 °C with the progression of 10 °C and results are talked about as appeared underneath in the sub-segments.

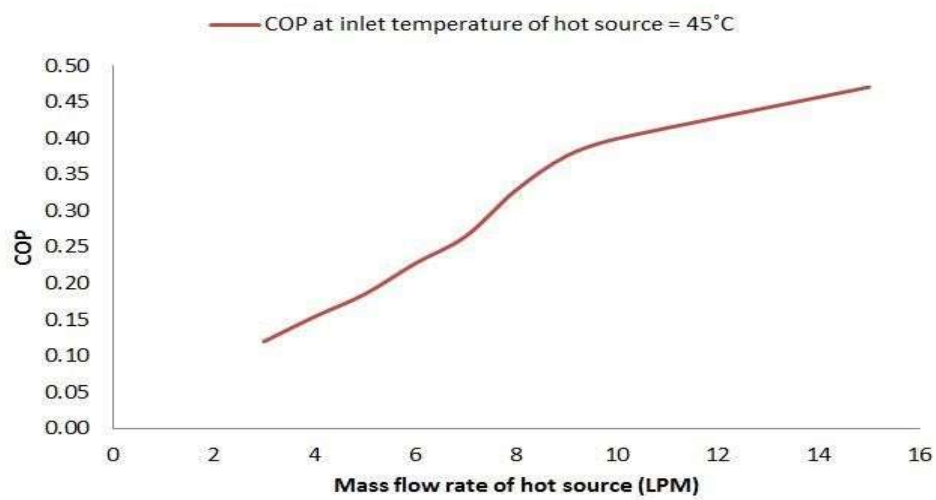



**Figure 5.2. Trend of COP for a different mass flow rate of hot and cold source at 55°C of hot source inlet temperature**

Mass stream rate is changed in the scope of 0 to 15 LPM of water. At the process duration of 15 min, the delta temperature of the hot source is kept consistent at 55 °C. As appeared in above figure, Very low COP's were accounted for lower mass stream rates; same as acquired when inlet temperature of the hot source is at 55°C. Be that as it may, an uneven example is watched when mass flow is expanded imperceptibly which demonstrates that bed is heated progressively and after each progressive process duration heat exchange increments however less and henceforth, COP increments hardly. In some cases, it remains practically consistent.

Most extreme COP is acquired at 15 LPM of water is around 0.49 which is higher than COP got at 55°C of hot source inlet temperature**.**

**5.2.3 At inlet temperature of hot source as 65 °C and constant Cycle time**

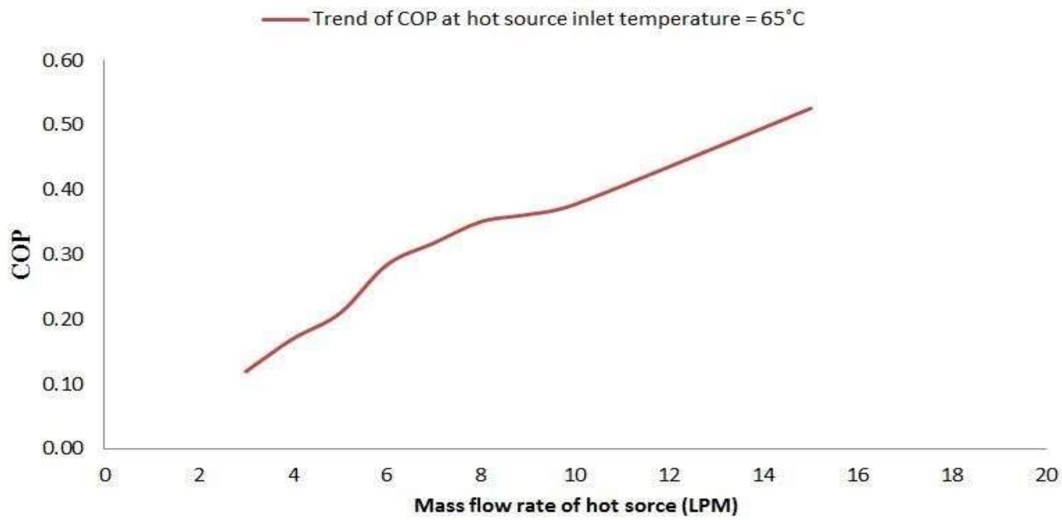



**Figure 5.3: Trend of COP for a different mass flow rate of the hot and cold source at 65°C of hot source inlet temperature**

As appeared in above figure, the pattern of COP is seen at 65°C of hot source temperature. At the beginning of the cycle, COP increments quick when the mass flow rate of hot source expanded insignificantly. Large heat is exchanged at this raised temperature. At the point when the mass flow rate of the hot source increments advances over 10 LPM of water, an immaterial increment in COP has been watched. Regardless of the possibility that the mass flow rate of the hot source is expanded slowly, no responsible increment in COP watched. COP remains partially steady past 15 LPM of water.

**5.2.4 Comparison of Trend of COP’s for varying mass flow rates of hot source at constant cycle time**

Analyze the impact of mass flow rate on COP of the cycle, patterns of COP are shown at 45°C, 55°C and at 65°C. These patterns are as appeared in figure 5. These patterns were dissected independently in before observation. Examination of the COP estimations of every operating condition has been shown down by watching nature of estimations of COP gathered for various operating condition run yet at single cycle of mass flow rate as appeared in figure 6.

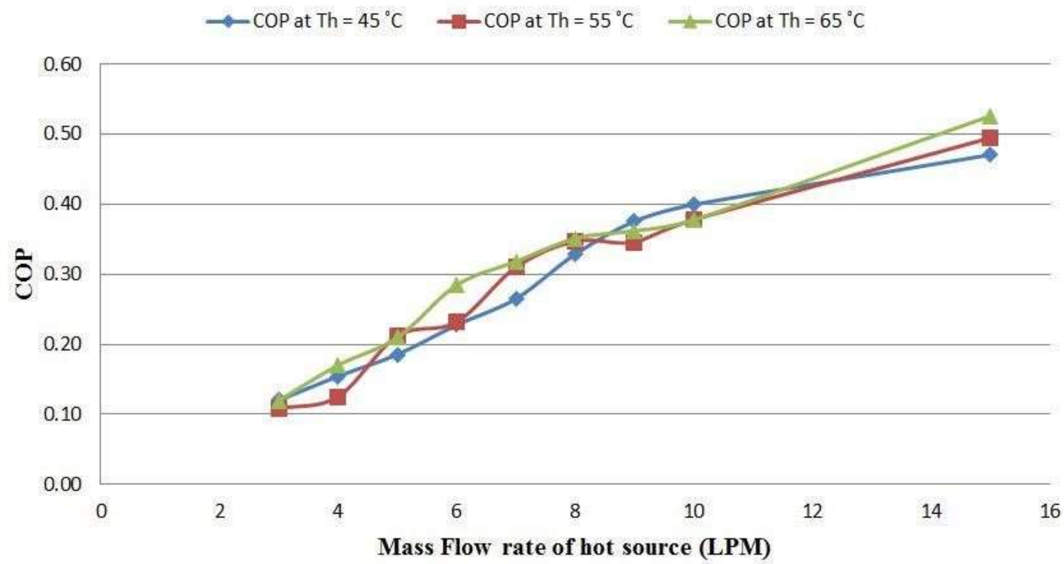
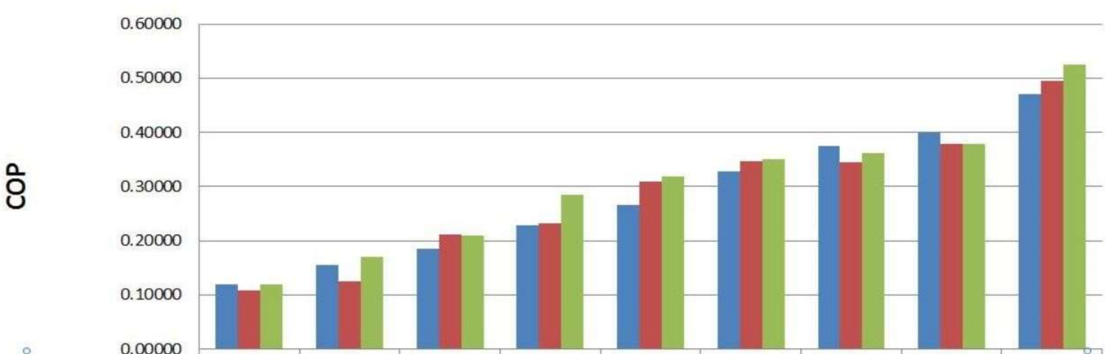



**Figure 5: Different COP Trends obtained at different inlet temperatures of hot source against mass flow rate of hot source at constant Cycle time.**

From the above figure, trend of COP follows the same trend at any operating condition when cycle time is constant. Smooth and hassle-free operations were observed at 45°C of the inlet temperature of the hot source. The range of COP values is maximum when the temperature is around 65°C but, the trend observed is uneven and unpredictable for earlier values of mass flow rates of hot source. Beyond 10 LPM of water, COP remains almost constant for all operating conditions. Nature of increase in COP is well predictable in the range of mass flow rate of the hot source of 10 to 15 LPM of water. It is well and good to keep mass flow rate of the hot source in the range of 10 to 15 LPM of water.




| | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 15 |
|---|---|---|---|---|---|---|---|---|---|
| Trend of COP at 45 °C | 0.12018 | 0.15428 | 0.18542 | 0.22764 | 0.26511 | 0.32872 | 0.37568 | 0.39945 | 0.47067 |
| Trend of COP at 55°C | 0.108160 | 0.125266 | 0.212089 | 0.231764 | 0.310081 | 0.347127 | 0.345718 | 0.377885 | 0.494874 |
| Trend of COP at 65°C | 0.11954 | 0.17016 | 0.20966 | 0.28455 | 0.31813 | 0.35112 | 0.36214 | 0.37792 | 0.52596 |

Mass flow rate of hot source (LPM)

**Figure 5.5: Comparison of COP values in the range of operating conditions for varying mass flow rate of hot source at constant Cycle time**

Above figure demonstrates a viable examination of three unique extents at same process duration. Same and low estimations of COP are acquired at the beginning of the system, for all the three working conditions. The reason is the low mass flow rate of heated water. For higher estimations of mass flow rate of hot source, COP increments, when inlet temperature of hot source provided is increased. At the beginning of the system, hot source inlet temperature of 66°C is well and sufficient to fabricate Adsorbate vapor in the framework in gave process duration. On the off chance that we analyze COP values at a higher mass stream rate, then COP around 0.53 got when hot source inlet temperature is around 65°C and COP acquired is 0.47 and 0.4 when the temperature of the hot source is 45°C and 55°C individually.

**5.**2.7 Effect of temperature of hot source on Coefficient of Performance when mass flow rate of hot and cold source kept constant at constant cycle time.

To assess the execution of Adsorption cooling system against the temperature of the hot source, a temperature scope of hot source from 45°C to 66°C is embraced. COP is computed for the mass flow rate of the hot source at 15 LPM of water. This estimation of mass flow rate of the hot source is embraced on the grounds that higher COP seen through before experimentation. For this situation, the system is made working constantly with an interim of process duration and Experimentation results are specified in Table 4 and results were said in table 9. The outcome is plotted and appeared as underneath.

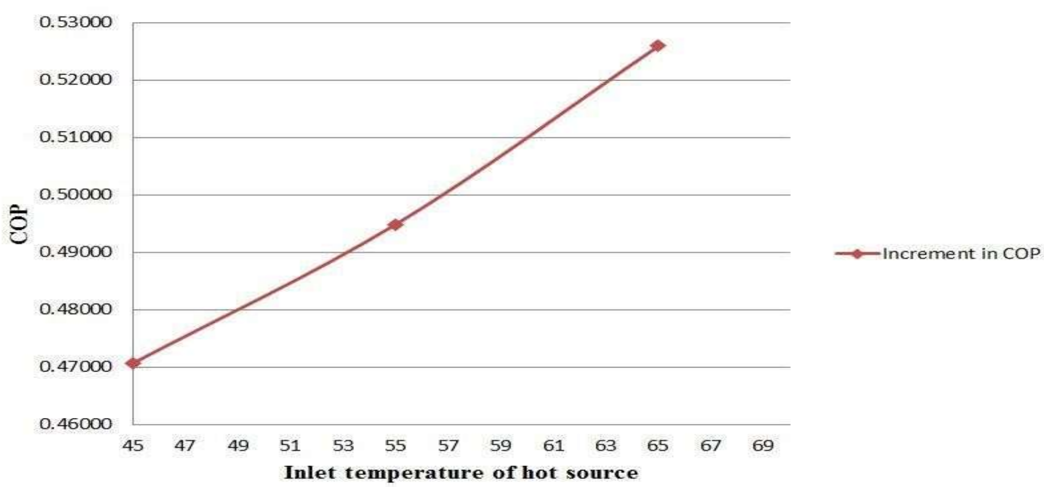



**Figure 5.6:- Variation in COP against the inlet temperature of hot source**

The pattern of COP acquired against the inlet temperature of the hot source is as appeared in above figure. Unmistakably COP is expanding with increment in the inlet temperature of the hot source in the scope of 45 °C to 65 °C. The channel temperature of the hot source is continue changing in the range while the mass flow rate of hot source and process duration is kept at 15

LPM of water and 15 min with the ADTR = 1. Because of the ethicalness of experimentation office, experimentation at a higher temperature of the hot source is impractical.

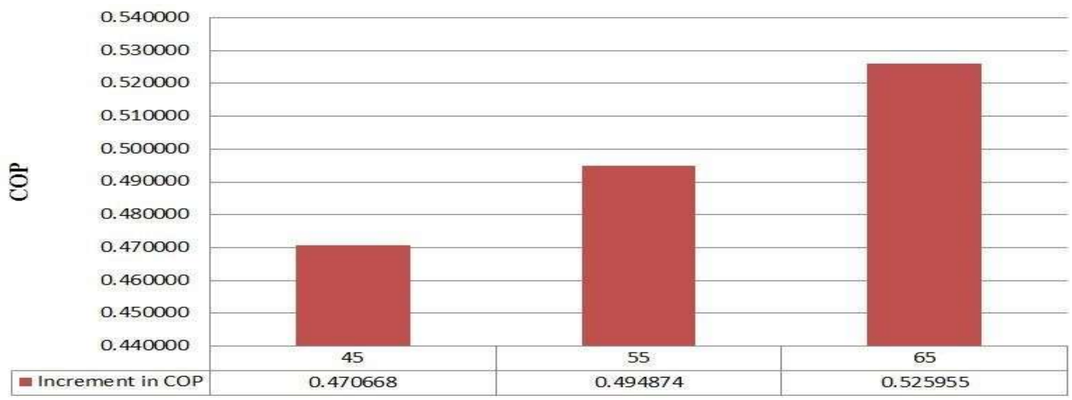



**Figure 5.7: Increment in COP at different temperature of hot source**

At the starting of system after completing the one-half cycle of 15 min, we get COP = 0.33, provided at 45 °C of the inlet temperature of the hot source, 30 °C of the inlet temperature of the cold source and chilled water inlet temperature, as shown in above figure. Flow rate of the hot and cold source is set at 15 LPM of water. As the temperature of hot source inlet temperature is increased at 55°C, we get an increase in COP for the same cycle time. Maximum COP is obtained around 0.53 at the 65 °C of hot source.

### 5.2.8 Utilization of energy

To assess the usage of energy in the system, Output from the system is contrasted against the input energy provided to the system. Input energy to the system is the energy provided to the Desorber bed to recover the bed for next cycle and yield got is the energy separated from the evaporator.

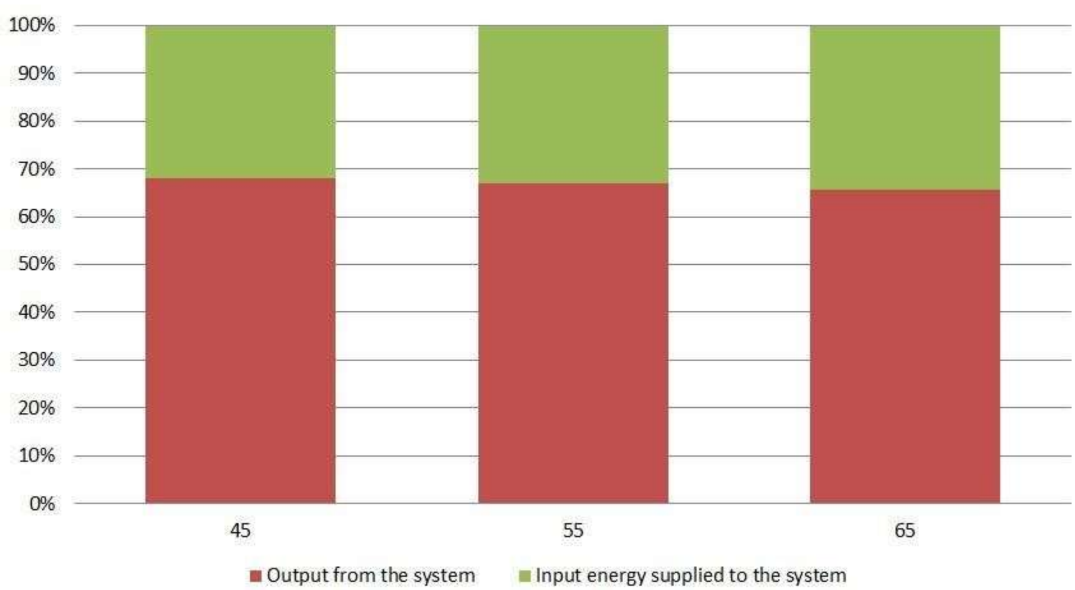


**Figure 5.8:- Utilization of energy**

As shown in above figure, at 45 °C; less output is obtained from the input energy supplied. The amount of output obtained is increasing the temperature of hot source increases. Maximum output is obtained at 65 °C. Around 37% output energy obtained against the input energy supplied. This would be the ideal operating condition in the desired temperature range.

**5..2.9 Effect of Mass flow rate of hot source on Specific Cooling Power (SCP)**

To assess the impact of mass flow rate of the hot source on SCP, experimentation is done at consistent process duration of 15 min and working conditions are changed in the scope of 50 to 60 °C. Experimentation parameters specified under case A. mass flow rate of the hot source is changed from 0 to 15 LPM of water. Because of the temperance of experimentation, the most extreme conceivable mass flow rate of the hot source is 15 LPM of water. The inlet temperature of the hot source is differed in the scope of 45 to 65 °C with the progression of 10°C and results are examined as appeared underneath in the sub-areas.

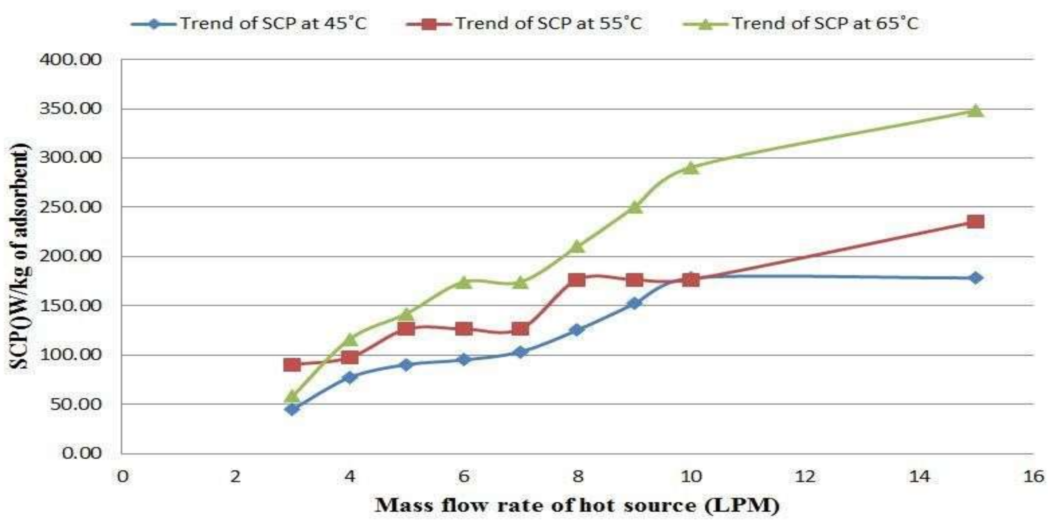



**Figure 5.9:- Trend of SCPs against varying Mass flow rate of the hot source in the range of operating conditions**

From all the three patterns, unmistakably SCP increments straightly with increment in mass flow rate as appeared in above figure. Low SCP seen at the lower mass flow rates of hot source. Up to mass flow rate of 10 LPM of water, it is hard to anticipate nature of the increment in SCP because of little variety of evaporative power. When the mass flow rate of the hot source increments past 10 LPM of water, more heat is exchanged to the bed. In the evaporator, we get substantial temperature drop and thus more evaporative cooling power. This infers increment in cooling power. Refrigeration system intended for 0.5 TR limit is well n great when it accomplishes SCP around 350 W/kg of adsorbent. At a mass flow rate of close around

15 LPM and hot source bay temperature of 65 °C, the system accomplishes SCP around 350 W/kg of the permeable. It is practical to work the system in this range to get successful SCP.

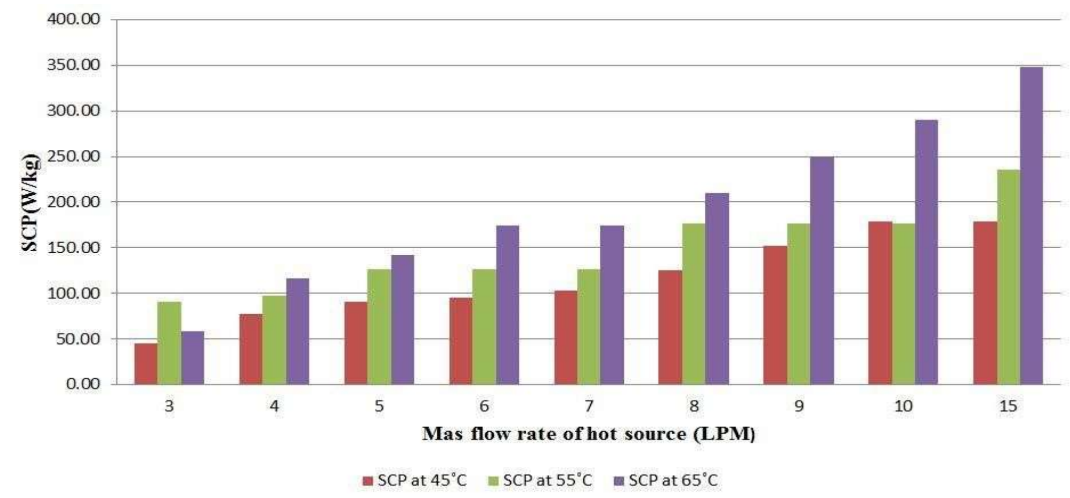
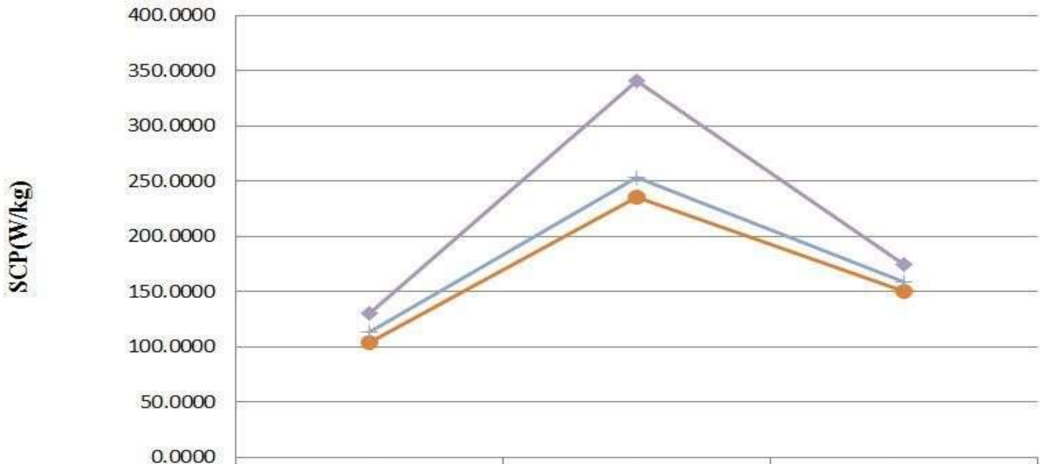



**Figure 5.10:- Comparison of SCP values in the range of operating conditions for varying the mass flow rate of the hot source.**

Low estimations of SCP are seen at the lower mass flow rate of the hot source. SCP of around 50 W/kg of adsorbent is accounted for at the mass stream rate of 3 LPM of water for all arrangement of working conditions in the working reach. It is not adequate to work the system at these low mass flow rates. As we require SCP cycle 350 W/kg of adsorbent. We ought to supply hot source in the scope of 45 to 65°C at 15 LPM of water as the mass stream rate of the hot source keeping in mind the end goal to acquire SCP around 350 W/kg of adsorbent. It is additionally seen from above assume that hot source temperature close around 45°C is not adequate to get coveted estimation of SCP because low heat exchange rates at lower temperatures.

**5.2.10 Effect of Cycle time on Specific Cooling Power**

To obtain the effect of cycle time on the SCP, the system is operated at a constant mass flow rate of 15 LPM of water as higher SCPs reported at higher mass flow rates. Operating conditions are set at 45 °C, 55 °C and 65 °C. Experimentation outcomes mentioned in table 5 under case C and results are mentioned in table 11. SCP trends for the different operating condition in the range are plotted against cycle time as shown in the following the figure.




| | 10 | 15 | 20 |
|---|---|---|---|
| scp trend at 45°C | 103.4535 | 235.5365 | 150.0339 |
| SCP trend at 55°C | 113.2739 | 253.5478 | 158.2739 |
| SCP trend at 65°C | 130.3605 | 340.7057 | 174.7807 |

**Figure 5.11: Trend of SCPs in the range of operating conditions against Cycle time at constant mass flow rate of hot and cold source**

It is essential to see that, SCP is expanding as process duration increments from 10 min to 15 min, it happens on the grounds that bed requires some more opportunity to accomplish the enough temperature at which Adsorbate vapor leaves the surface of Adsorbents. On the off chance that more vapor of Adsorbate goes into condenser then the all the more cooling impact is acquired in the evaporator. This infers vast temperature drop in the evaporator. At the process duration of 15 min., SCP around 350 W/kg of adsorbent is seen at the hot source temperature of 65 °C. SCP around 250 W/kg of adsorbent is seen at 55 °C, which is acknowledged when bring down temperature drop is required in the evaporator. As Cycle time increments past 15 min, SCP values fluctuate conversely with process duration. SCP values begin diminishing and again beginning qualities revealed. This happens because information vitality is utilized to build the temperature of metal present in the bed which is not in contact with the adsorbent material. Because of this measure of Adsorbate vapor diminishes. Less temperature drop in the evaporator suggests less estimations of SCP.

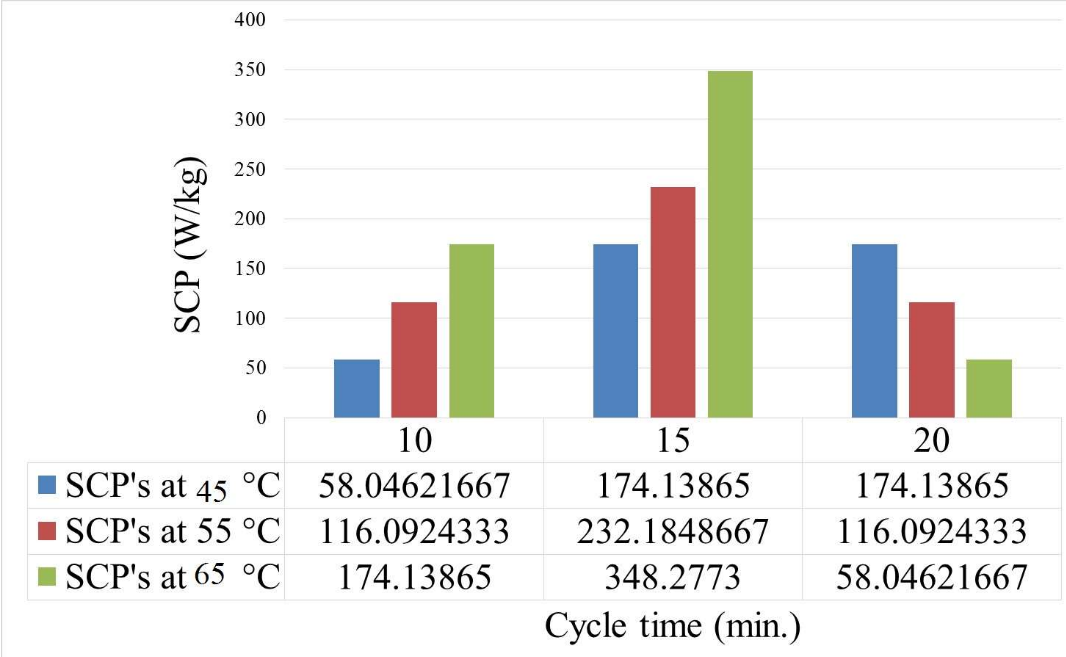



**Figure 5.12 :-Comparison of SCPs in the range of operating conditions against Cycle time at a constant mass flow rate of the hot source**

SCP values compared with each other in the operating range from 50 to 60 °C as shown in the interactive figure above. For the same cycle time, SCP values increase as hot source inlet temperature increases. Achieve sufficient cooling, SCP around 350 W/kg of adsorbent is our prime goal. Achieve that goal, it is mandatory to operate the system for 15 min. of cycle time and at an inlet temperature of hot source around 60 °C. SCP of 348 W/kg of adsorbent is observed at this operating condition.

**5.2.11 Effect of hot source inlet temperature on Specific Cooling Power (SCP)**

To acquire the impact of hot source inlet temperature on SCP, system is operated by keeping cycle time and mass flow rate of hot and cold source constant. Cycle time is kept consistent at 15 min and mass flow rate of the hot source at 15 LPM of water on the grounds that most noteworthy SCP is recorded. Presently, the temperature of the hot source is changed from 45 to 65 °C. Experimentation perceptions said, and graphical examination instruments were utilized to anticipate variety in SCP.

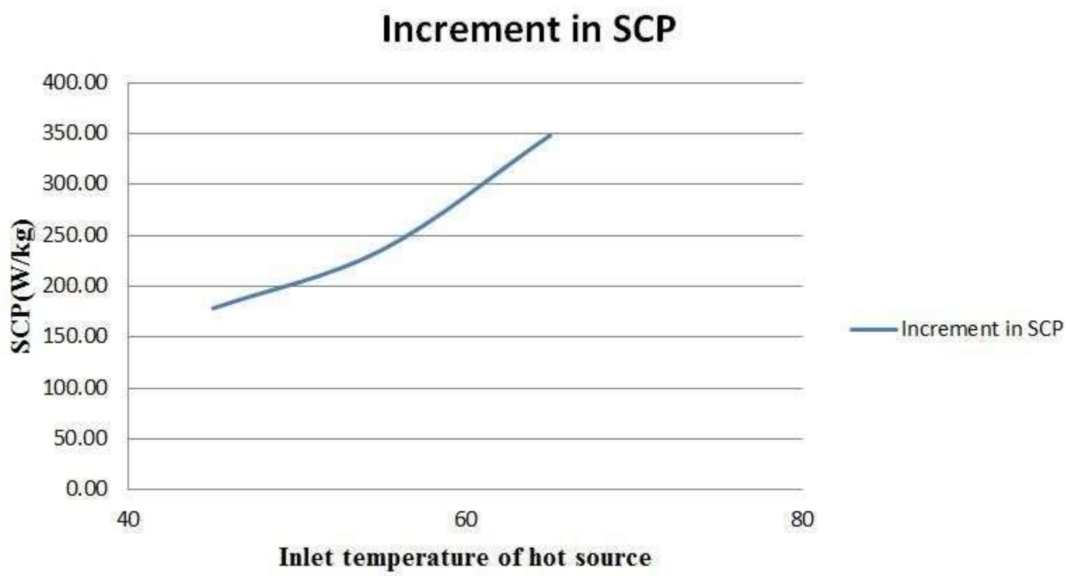



**Figure 5.13: Effect of the inlet temperature of the hot source on Specific Cooling Power (SCP)**

The value of SCP which is desired is 350 W/kg of adsorbent and this value is obtained at 65 °C of the inlet temperature of the hot source. From this temperature if we start reducing temperature up to 45 °C, then SCP also decreases linearly. This implies that less temperature drop is obtained in the evaporator due to less amount of Adsorbate vapor evaporates in the evaporator. The trend of SCP stabilizes at a lower temperature near 45 °C as at this temperature very less amount of Adsorbate vapor available which produces the very less cooling effect. It is well and good to operate the system at higher hot source temperatures as large temperature drop required at the starting of the vehicle.

# Chapter No. 6
# CONCLUSIONS AND FUTURE SCOPE OF WORK

## 6.1 Conclusions

This project explores tentatively the execution of cooling framework in view of the wonder of Adsorption. Execution parameters like SCP and COP are ascertained, in view of which test examination is finished. Taking after conclusions can be made through compelling work on the project,

**1. Experimentation reason model of Adsorption Cooling System has been produced.**

In this venture, Device and approach for the development and working of double bed Adsorption Refrigeration system operable with water as an eco-friendly Adsorbate and silica-gel as an adsorbent is developed. It comprises of Adsorber bed heat exchangers, Air cooled condenser, an Expansion gadget (Capillary tube) and an Evaporator as essential set up. Other supplementary setup comprises of parts as hot and cool water tank, Pumps, Inway and Out-way circuits, radiator, and so on.

### 2. Design and Fabrication of an Adsorber bed heat exchanger

The plan of Adsorber bed heat exchanger given at most significance since poor outline prompts low estimations of execution parameters. Here, more concentrate is made on the change in heat and in addition mass exchange rates. As per this, Adsorber bed is composed and manufactured. Heat exchange rate of the Heat exchanger is upgraded by expanding the heat exchange territory. Mass exchange rate is upgraded by diminishing the heat and mass resistance between Adsorbent-Adsorbate particles by using binder. Silica-gel (Adsorbent) material is filled legitimately in the middle of the circular fins with help of binder. Thus, creation of Adsorber bed heat exchanger is done to expand the execution of the work.

### 3.Specific Cooling Power (SCP) and Coefficient of Performance (COP) is straightforwardly corresponding to the mass flow rate of the hot source

As the mass flow rate of hot source builds, heat exchange rate inside the Adsorber bed heat exchanger increments. SCP and COP increment with increase in mass flow rates and gets settled after a few estimations of mass flow rates at specific process duration. At the process duration of 15 min, which is very much acknowledged time for cooling of the freezer, the mass flow rate of hot source embraced around 15 LPM of water. At this estimation of mass flow rate, most extreme COP's and SCPs are watched. Afterward, COP and SCP values stay consistent (exceptionally minimal change) regardless of the possibility that mass flow rate expanded. At around 65 °C of the gulf temperature of hot source and 15 min. of process duration, COP acquired is around 0.55 while, SCP is around 348 W/kg of adsorbent.

**4.Specific Cooling Power (SCP) and Coefficient of Performance (COP) is specifically corresponding to the Inlet temperature of the hot source**

As hot source input expands, COP and SCP increments. Desorption handle expands the convergence of Adsorbate particles in the framework which infers substantial temperature drop in the evaporator. Silica-gel received in the framework desorbs 40 % of Adsorbate while subjected to desorption temperature around 85°C. The framework displayed here is intended for utilization of vehicle ventilating, where the hot source is boiling point water accessible at the motor coolant circle around normal temperature 45 to 60°C. Consequently, Temperature range is chosen from 45 to 60 °C and execution parameters are assessed in this range as it were. In this range, no bigger temperature drop is seen at the beginning of the vehicle. As framework made running ceaselessly, the temperature drops.

**5. Best execution of the system at cycle time between 10 to 15 min**

Process duration is the most vital parameter to be chosen keeping in mind the end goal to get the cooling impact at the beginning of the vehicle. The process duration of 10 min is all around acknowledged planned time in vehicle cooling. Here, the cooling framework is intended for process duration of 10 min. after experimentation it has been found that COP boosts as process duration is expanded from 10 min to 15 min. after 15 min., COP and SCP begins diminishing considering transient conduct of Heat Exchanger. Greatest COP around 0.55 is gotten at process duration of 15 min. it is exceptionally close to the outlined process duration. Still a few varieties are watched because of faults in the creation of Adsorber bed warm exchanger. These issues need to unravel to get the cooling impact as quick as conceivable after the beginning of the vehicle.

**6. Less temperature drops in the evaporator**

It is seen through experimentation that, SCP of 348 W/kg of Adsorbents is seen at just some specific conditions. Regardless of the possibility that we perform tests at those conditions, still a few varieties are seen in the estimations of execution parameters. There is not enough temperature drop saw in only one cycle. It is not acknowledged in genuine application.

From this, it is reasoned that info parameters are not all that enough to modify varieties in the execution parameters. Execution improvements procedures to be utilized with a specific end goal to guarantee stable cooling power.

## 6.2 Future extension

**1.Heat and mass exchange improvement inside the Adsorber bed warm exchanger**

Low estimations of COP and SCP are the hindrances in the method for commercialization of cooling innovations which deals with the guideline of sorption. Poor heat and mass exchange rates are the purposes for this. More research is required to enhance COP and SCP estimations of ADCS. A few techniques are to be embraced to expand execution of ADCS as,

**a. Heat recuperation and mass recuperation prepare in ADCS**

Sharing of info heat source in the middle of beds is known as Heat recuperation and sharing of Adsorbate vapor in the middle of the bed is known as Mass recuperation. Both the wonder together can enhance the execution of the system as Heat recuperation deals with powerful usage temperature while Mass recuperation deals with Pressure varieties.

**b. Thermal wave (convective) and constrained convective cycle in ADCS**

The rule of the thermal wave is to incite a wave in the Adsorber bed by flowing any heat exchange liquid with well-pre-characterized speed in the shut circle containing radiator and cooler for the individual heat exchanger. By receiving this marvel, COP increments yet SCP diminishes.

**c. Cascading of ADCS**

Cascading is the blend of the fixing cycle which works at a high-temperature level and bottoming cycle which works at the low-temperature level. The standard of cascading is to utilize heat, after culmination of the Desorption procedure, in the bottoming cycle before the start of the Desorption procedure. Through this rule, powerful usage of heat increment which expands COP of the system.

**d. Multi-bed system**

More than two beds might be exchanged then again so that the constant cooling impact might be guaranteed. With the utilization of such multi-bed, the pinnacle temperatures in the evaporator and condenser diminish. The multi-bed system has higher efficiencies than single and double bed Adsorption cooling system.

**e. Coating of Adsorbent**

The adsorbent material is covered around the heat exchange tubes to decrease the heat resistance between the Adsorbent-Adsorbate combine. Mass exchange rate supported and COP increment.

**f. Use of composite Adsorbents**

Composite adsorbents are delivered by blending synthetic mixes in physical adsorbents in well pre-chosen extents. Adsorption rates are helped and warmth exchange rate increments.

**2.Use of nano-permeable material set up of an Adsorbent material**

A nano-permeable material has more no. of pores and more surface range than the ordinary Adsorbents. This new Adsorbent can trap the more measure of Adsorbate vapor than that of the physical Adsorbents. With this, size of the Adsorber bed warm exchanger will decrease.

**3.Use** of fluidized bed innovation

Fluidization of adsorbent material in the Adsorber bed warm exchanger could upgrade the execution of the framework.

**4.Evaluation of the impact of system segments or system parameters on SCP and COP**

Impact of condenser channel temperature, the impact of chilled water inlet temperature, the impact of icy water provided for Adsorption prepare, on execution parameters should be resolved to develop the system.

### 6.3 Program Outcomes (PO's)

**1. Engineering knowledge:** For fabrication of solar powered adsorption refrigeration system knowledge of mathematics , science, and fundamentals of Engineering are used to design, develop, and experiment on the system.

**2.Problem analysis:** by studying various research papers and articles the review is prepared for adsorption pairs and their applications

**3.Design/development of solutions:** Design of adsorption bed is created for maximum heat transfer during adsorption and desorption process from coolant to adsorbent.

**4.Conduct investigations of complex problems:** Investigations of cop and other parameters of adsorption refrigeration system are studied through data interpretation, from the research papers was studied

**5.Modern tool usage:** For designing adsorption refrigeration systems solid works software is used. And analysing the heat transfer of coolant solid works flow simulation extension is used.

**6.Environment and sustainability:** The electricity consumption of refrigeration and air condition system is huge which is produced by burning fossil fuels so sustainable environmentally friendly solar powered adsorption refrigeration system is created .

**7.Ethics:** This project provides an opportunity to understand professional responsibilities while representing the college in national student competitions.

**8.Individual and teamwork:** This project being a group activity, has taught to effectively work as an individual and as member /leader of team.

**19.Communication:** The project work has taught to understand the effective communication with engineering society like ISHRAE and involve in the activities and events conducted by ISHARE society .

**10.Project Management and Finance:** The project timeline is properly managed, and the finance is also properly managed by keeping the records in balance sheet.

**11.Life-long learning:** The project highlights the ability to identify the societal needs and professional requirements related to adsorption refrigeration, as well as being prepared to engage in lifelong learning to adapt to future technological advancements and trends.

# Chapter No. 7
# APPENDICES

## 7.1 Patent Acceptance

THE PATENT OFFICE
GOVT.OF INDIA

सत्यमेव जयते

**ORIGINAL**

मूल/No : 136780

भारत सरकार
GOVERNMENT OF INDIA
पेटेंट कार्यालय
THE PATENT OFFICE
डिजाइन के पंजीकरण का प्रमाणपत्र
CERTIFICATE OF REGISTRATION OF DESIGN

| | | |
|---|---|---|
| डिजाइन सं. / Design No. | : | 380793-001 |
| तारीख / Date | : | 03/03/2023 |
| पारस्परिकता तारीख / Reciprocity Date* | : | |
| देश / Country | : | |

प्रमाणित किया जाता है कि संलग्न प्रति में वर्णित डिजाइन जो **HEAT EXCHANGER TUBES** से संबंधित है, का पंजीकरण, श्रेणी **23-03** में 1.Himanshu D Wagh 2. Kunal Nimkar 3.Sudip Pidkalwar 4.Pankaj Jaiswal के नाम में उपर्युक्त संख्या और तारीख में कर लिया गया है।

Certified that the design of which a copy is annexed hereto has been registered as of the number and date given above in class **23-03** in respect of the application of such design to **HEAT EXCHANGER TUBES** in the name of 1.Himanshu D Wagh 2. Kunal Nimkar 3.Sudip Pidkalwar 4.Pankaj Jaiswal.

डिजाइन अधिनियम, 2000 तथा डिजाइन नियम, 2001 के अध्यधीन प्रावधानों के अनुसरण में।
In pursuance of and subject to the provisions of the Designs Act, 2000 and the Designs Rules, 2001.

INTELLECTUAL PROPERTY **INDIA**
PATENTS | DESIGNS | TRADE MARKS
GEOGRAPHICAL INDICATIONS

निर्गमन की तारीख/Date of Issue : 22/05/2023

महानियंत्रक पेटेंट डिजाइन और व्यापार चिह्न
Controller General of Patents, Designs and Trade Marks

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पारस्परिकता तारीख (यदि कोई हो) जिसकी अनुमति देश के नाम पर की गई है। डिजाइन का सत्त्वाधिकार पंजीकरण की तारीख से दस वर्षों के लिए होगा जिसका विस्तार, अधिनियम एवं नियम के निबंधनों के अधीन, पाँच वर्षों की अतिरिक्त अवधि के लिए किया जा सकेगा। इस प्रमाण पत्र का उपयोग विधिक कार्यवाहियों अथवा विदेश में पंजीकरण प्राप्त करने के लिए नहीं हो सकता है।

*The reciprocity date (if any) which has been allowed and the name of the country.Copyright in the design will subsist for ten years from the date of Registration, and may under the terms of the Act and Rules, be extended for a further period of five years.This Certificate is not for use in legal proceedings or for obtaining registration abroad.

**ORIGINAL**

मूल/No : 137911

सत्यमेव जयते

भारत सरकार
GOVERNMENT OF INDIA
पेटेंट कार्यालय
THE PATENT OFFICE

# डिजाइन के पंजीकरण का प्रमाणपत्र
# CERTIFICATE OF REGISTRATION OF DESIGN

| | | |
|---|---|---|
| डिजाइन सं. / Design No. | : | 380792-001 |
| तारीख / Date | : | 03/03/2023 |
| पारस्परिकता तारीख / Reciprocity Date* | : | |
| देश / Country | : | |

प्रमाणित किया जाता है कि संलग्न प्रति में वर्णित डिजाइन जो **HEAT EXCHANGER UNIT** से संबंधित है, का पंजीकरण, श्रेणी **23-03** में 1.Himanshu D Wagh 2. Kunal Nimkar 3.Sudip Pidkalwar के नाम में उपर्युक्त संख्या और तारीख में कर लिया गया है।

Certified that the design of which a copy is annexed hereto has been registered as of the number and date given above in class **23-03** in respect of the application of such design to **HEAT EXCHANGER UNIT** in the name of 1.Himanshu D Wagh 2. Kunal Nimkar 3.Sudip Pidkalwar.

डिजाइन अधिनियम, 2000 तथा डिजाइन नियम, 2001 के अध्यधीन प्रावधानों के अनुसरण में।
In pursuance of and subject to the provisions of the Designs Act, 2000 and the Designs Rules, 2001.

INTELLECTUAL
PROPERTY **INDIA**
PATENTS | DESIGNS | TRADE MARKS
GEOGRAPHICAL INDICATIONS

निर्गमन की तारीख/Date of Issue : 24/05/2023

महानियंत्रक पेटेंट डिजाइन और व्यापार चिह
Controller General of Patents, Designs and Trade Marks

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पारस्परिकता तारीख (यदि कोई हो) जिसकी अनुमति देश के नाम पर की गई है। डिजाइन का सत्त्वाधिकार पंजीकरण की तारीख से दस वर्षों के लिए होगा जिसका विस्तार, अधिनियम एवं नियम के निबंधनों के अधीन, पाँच वर्षों की अतिरिक्त अवधि के लिए किया जा सकेगा। इस प्रमाण पत्र का उपयोग विधिक कार्यवाहियों अथवा विदेश में पंजीकरण प्राप्त करने के लिए नहीं हो सकता है।

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## 7.2 ISHRAE SRPG GRANT Approval



Gmail **Kunal Nimkar <nimkark2@gmail.com>**

**SRPG UG - 2022-PROJECTS SELECTED FOR ISHRAE GRANTS**

2 messages

**Vikram** <v.thakur@ishraehq.in> Mon, Dec 26, 2022 at 1:48 PM
To: borris@student.tce.edu, ansarisalik0@gmail.com, saggurthiramadevi@gmail.com, nimkark2@gmail.com, "anshula.me@ghrce.raisoni.net" <gaurkar>, bhosalems19.mech@coep.ac.in, rohangawade2424@gmail.com, shreetamasahu@gmail.com, amruth.e@vvce.ac.in, sharathbabum27@gmail.com, amalshammy000@amail.com, kedharnathm20.m.000@gmail.com, sooryaraj1971@gmail.com

Kind Attn: **SRPG UG TEAMS SELECTED FOR PROJECT GRANTS**

Dear Team Leaders,

Congratulations!

Please find attached Results for the projects selected for funding under SRPG UG and have your name against the submission made for Project Grant.

Kindly note that we are initiating process for the release of your first instalment amount through the local ISHRAE Chapter.

You may please start working on your project.

Best Wishes.

Thanks & Regards,

Vikram Singh Thakur

Assistant Manager

Indian Society of Heating Refrigerating and Air-Conditioning Engineers

(ISHRAE)

1103-1104, 11th Floor,Chiranjiv Tower 43, Nehru Place,

New Delhi-110019

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# Engg students' solar fridge gets funding

TIMES NEWS NETWORK

**YOUNG INVENTORS:** The team from SB Jain Institute

**Nagpur:** Four final-year B.Tech mechanical engineering students of SB Jain Institute of Technology, Management and Research, Nagpur, have won a Students Research Project Grant (SRPG) of ₹50,000 sponsored by ISHRAE - Indian Society of Heating and Air Conditioning Engineers. The college too is funding ₹25,000 towards the eco-friendly project.

## ECOFRIENDLY

The technology is based on the concept of using solar energy to generate cooled space unlike the the domestic refrigerator running on electricity. A phase-change material and water as a refrigerant are used in the fridge. The fridge uses chlorofluro carbons which emit greenhouse gases. The design has been finalized and fabrication would be starting soon at the college.

The team is among 12 groups from across the country and one of the two from the western region to get the funding. The team made it after competing with several teams from across the world, including students and industry, in a technical hackathon held by ISHRAE.

The first contest was held at Nagpur level and progressed to regional level. They have been shortlisted for presentation in the final stage where the prize is ₹1.5 lakh.

ISHRAE is a non-government body working to promote new and innovative concepts in the field of refrigeration and air conditioning.

The team's mentor, assistant professor Himanshu Wagh, said, "An adsorption refrigeration system driven by solar energy is being developed for a cooling load of 0.5 TR that utilizes solar energy to power a refrigeration system. The developed system can efficiently convert low-grade heat into refrigerated space, making it a potentially cost-effective and environmentally friendly option for a wide range of applications," he said. The team includes Kunal Nimkar, Sudip Pidkalwar, Shreyash Vaidya and Sarvesh Neware.