Fabrication and Experimental Study of Vapour Adsorption Refrigeration System

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Abstract- *Vapour Adsorption system (VAS) is the emerging technique in refrigeration which uses low grade energy like exhaust gases, solar energy etc. Inherently require large heat transfer surfaces to transfer heat to and from the adsorbent materials which automatically makes cost an issue. High efficiency systems require that heat of adsorption be recovered to provide part of the heat needed to regenerate the adsorbent. But on the other hand this system having lower COP as compare to existing systems which is due to lack of research and advancement in the system.*

The literature survey gives the information about selection of working pair. Activated carbon (adsorbent) and ammonia (refrigerant) are chosen as a working pair. The theoretical work gives the types, process and properties of adsorption refrigeration.

The adsorbent bed is the heart of the VAS in which compressor is replaced by adsorber bed in Vapour compression refrigeration. Here the heat input is given by generator. This work will give the fabrication and testing of the vapour adsorption system for finding the values of COP and SCP. The system has been evaluated for various operating temperatures for a cycle time of 42 minutes. Under the standard operating conditions the results shows that the system have low COP but there are no effects like depletion of Ozone layer and Global Warming due to emission of CFC`S ,HFC`S , CO_2.

Keywords- Adsorber bed, COP, Generator, SCP.

I. INTRODUCTION

Refrigeration is a process in which work is done to move heat from one location to another. The work of heat transport is traditionally driven by mechanical work with use of electricity. Refrigeration has many applications, including, but not limited to household refrigerators, industrial freezers, cryogenics and air-conditioning. Refrigeration has a large impact on industry, lifestyle, agriculture and settlement patterns.

A refrigeration cycle describes the changes that take place in the refrigerant as it alternately absorbs and rejects heat as it circulates through a refrigerator. It is also applied to heating, ventilation, and air conditioning HVACR work, when describing the "process" of refrigerant flow through an HVACR unit, whether it is a packaged or split system.

Classification of cyclic refrigeration

Vapour cycle refrigeration can be classified as:

1. Vapour-compression refrigeration cycle
2. Vapour-absorption refrigeration cycle
3. Vapour-adsorption refrigeration cycle

Vapour adsorption system:

When a solid surface is exposed to a gas or a liquid, molecules from the gas or the solution phase accumulate or concentrate at the surface. The phenomenon of concentration of molecules of a gas or liquid at a solid surface is called adsorption. “Adsorption” is a well-established and powerful technique for treating domestic and industrial effluents. In water treatment, the most widely method is “adsorption” onto the surface of activated carbon. The Vapour-adsorption refrigeration cycle as shown in figure-1

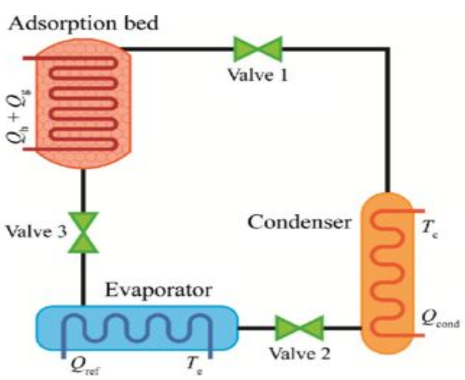

Figure-1 Vapour-adsorption refrigeration cycle

II. LITERATURE REVIEW

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This article reviews the adsorption refrigeration technologies. The increasing fossil fuel price and the awareness of environmental problems offer many potential applications to thermal powered adsorption cooling. However, the adsorption cooling machines still have some disadvantages that hinder their wide application.

After an introduction of basic principle, absorption refrigeration system research and development have been reported. Adsorption refrigeration system developed for transport refrigeration has been discussed and evaluated. Comparison with conventional vapour compression and absorption refrigeration system is given. An assessment is made about current and future development of adsorption refrigeration technologies.

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Energy conservation is an infinitum growing around the world and this situation yields research to find sustainable energy solutions. The increasing fossils fuel price and the consciousness of environmental problems recommend many potential applications to thermal powered adsorption cooling. Many of the conventional refrigeration systems use Chlorofluorocarbons (CFCs) as refrigerants, particularly in developing and under developed countries.

The ozone layer, which protects life on earth from the sun's ultra-violet radiation, is getting depleted due to use of chlorine containing chemicals in conventional refrigeration systems. The aim of study the design and fabrication of the experimental chamber, the experimental procedure and its feasibility towards development of an alternative eco friendly refrigeration cycle for replacement of chlorofluorocarbons. As solar power is freely accessible, solar adsorption refrigeration devices are of significance to meet the needs for cooling requirements such as air-conditioning, icemaking and food preservation in isolated areas. Various solar powered cooling system have been tested comprehensively; however these system are not yet ready to compete with the well-known vapour compression system. The objective of the work is to provide deep-seated knowledge on the adsorption systems and present a proposed model which will give refrigeration effect.

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An Adsorption refrigeration system are of significance to meet the need for cooling requirements such as ice making, food preservation and also it can work on solar energy or waste heat. Adsorption refrigeration system has various advantages over traditional refrigeration system. A model is constructed for the experimental investigation of single bed silica gel adsorption refrigerating system using silica gel – water as the adsorbent-adsorbate pair. These systems are attracting increasing attention because they can be activated by low-grade thermal energy and use refrigerants having zero ozone depletion potential and low global warming potential.

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In this present era more & more focus is to be given on energy conservation. Refrigeration & air conditioning is one of the growing field of engineering, the existing system are hampering the environment as they are suffering from various environmental problems such as depletion of ozone layer & global warming due to emission of harmful gases such as HFC's ,CFC's & CO_2 as they were using traditional refrigerants. Waste heat driven Vapour adsorption cooling system is eco-friendly, efficient, & reliable in nature. But on the other hand this system having lowers COP as compare to existing systems which is due to the lack of research and advancement in the system. By considering the environmental aspects & need of energy conservation it is necessary to design and developed the VAR's system which will successfully complete the existing systems.

This paper will give the idea about the Design of waste heat driven vapour adsorption system of 2KW capacity for vehicle air-conditioning & refrigeration application. The adsorber bed is the heart of the cooling system and it can affect the performance of the system to the greater extent. So that while designing the VAR cooling system more focused is given on design and selection of adsorber bed.

This article mainly focused on the various and important design parameters of the vapour adsorption cooling system Such as Adsorber bed design, adsorber and adsorbate mass, design of evaporator & condenser, Coefficient of performance(COP), Specific cooling power (SCP) and the other performance affecting parameters.

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Adsorption refrigeration system are of significance to meet the need for cooling requirements such as ice making, food preservation and also it can works on solar energy or waste heat. Adsorption refrigeration system has various advantages over traditional refrigeration system. This covers the performance of commonly used adsorption pair. A model is constructed for the experimental investigation of single bed silica gel/water adsorption chiller. This paper includes the working principles of the adsorption system and includes sorption refrigeration cycle; it also mentioned the properties of the adsorption pairs.

III. THEORETICAL WORK

Adsorption: Adsorption is the process by which molecules of a fluid are fixed on the walls of a solid material via connections of the Van der Waals type. The refrigeration circuit usually consists of three main components; a solid adsorbent bed, a condenser and an evaporator. Some system employ isolating valves between the various components and some utilize expansion valves between the condenser and the evaporator.

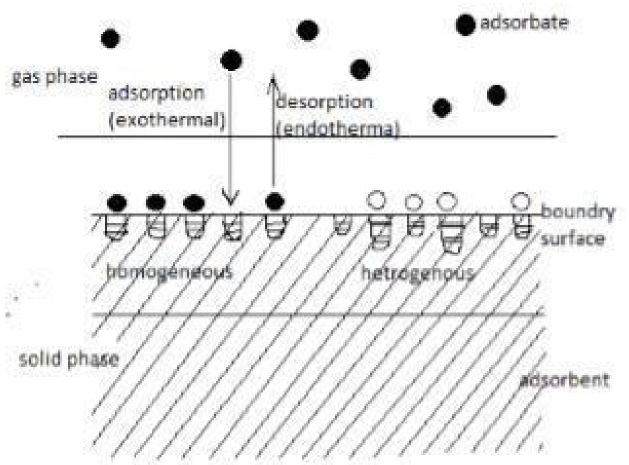

Figure-2 Adsorption and Desorption

Types of adsorption:

Depending on the type of attractions between adsorbate and adsorbent, the adsorption can be divided into two types. Forces of attraction exist between adsorbate and adsorbent. These forces of attraction can be due to Vanderwaal forces of attraction which are weak forces or due to chemical bond which are strong forces of attraction. On the basis of type of forces of attraction existing between adsorbate and adsorbent, adsorption can be classified into two types: Physical Adsorption or Chemical Adsorption.

Physical Adsorption or Physisorption:

When the force of attraction existing between adsorbate and adsorbent are weak Vanderwaal forces of attraction, the process is called Physical Adsorption or Physisorption. Physical Adsorption takes place with formation of multilayer of adsorbate on adsorbent. It has low enthalpy of adsorption i.e. adsorption is 20-40KJ/mol. takes place at low temperature below boiling point of adsorbate. As the temperature increases in, process of Physisorption decreases.

Chemical Adsorption or Chemisorption:

When the force of attraction existing between adsorbate and adsorbent are chemical forces of attraction or chemical bond, the process is called Chemical Adsorption or Chemisorptions. Chemisorptions take place with formation of unit-layer of adsorbate on adsorbent. It has high enthalpy of adsorption. It can take place at all temperature. With the increases in temperature, Chemisorptions first increases and then decreases.

Adsorbents:

Adsorbents can be classified into three categories, such as physical adsorbent, chemical adsorbent and composite adsorbent. In the following subsections, characteristics of each type of adsorbents are briefly presented.

Physical adsorbents:

Physical adsorption is occurred by an intermolecular force, namely van der Waals force between surface of adsorbent and adsorbate. The physical adsorbent preserves its true characteristics even though repetitive adsorption and desorption processes are occurred. The physical adsorbents which are commonly used in the adsorption cooling system are silica gel, activated carbon and zeolite.

Silica Gel:

The silica gel is a type of amorphous synthetic silica which consists of rigid and continuous net of colloidal silica connected to very small grains of hydrated SiO_4 as shown in Fig 3. Silica gel maintains chemically bonded traces of water about 2 - 3% and it loses adsorptivity by overheating temperature above 120˚C, thereby it is generally used in temperature system as low as 200˚C.Silica gel is divided into type A (2 to 3 nm of pore diameter) and B (about 0.7 nm of pore diameter) which are commonly used in the commercial application and they have 100 - 1000 m^2/g of specific surface area and about 2800 kJ/kg of adsorption heat. Type A can be used for general desiccant systems, however type B can be used in the higher relative humidity condition than 50 %.

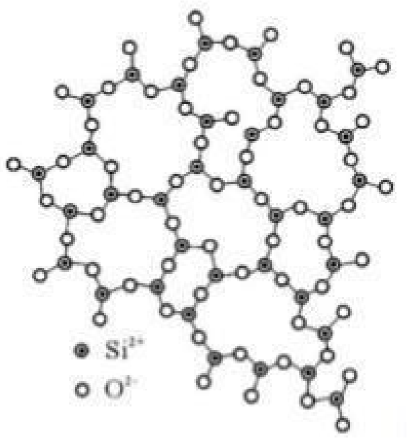

Figure-3 Structure of silica Gel

Activated carbon:

Activated carbon is prepared from various carbonaceous precursors containing coal, lignite, fossil fuel, char, peat, coconut shell, nut stone and bone which are carbonized, either by oxidization with CO_2 of stream, or by treatment with acids. Activated carbon can be made in many forms; powder, grain, molecular sieve and fiber, and used in liquid adsorption, air and water purification, gas separation and adsorption cooling system, and it has more than 1500 m^2/g of surface area. Structure of activated carbon is shown fig 4. The microcrystal for activated carbon produced hexagonal carbon-atomic ring, and adsorption performance is influenced by the functional groups which connected to the carbon-atomic ring. The activated carbon fiber has better performance in terms of mass and heat transfer with larger surface area and more uniformed pore size, where as it has anisotropic thermal conductivity and higher thermal resistance between the fiber and surface of heat exchanger compared with activated carbon.

Figure-4 Structure of Activated Carbon

Zeolite:

Zeolite is crystalline alumina silicate composed of alkali/alkali soil, namely molecular sieve, and alumina silicate skeletal has 0.2 - 0.5 cm^3/g of porosity. The adsorption capability of zeolite is related to the proportion between aluminum and silicon and it is higher in smaller proportion between aluminum and silicon. In the zeolite, there are 40 types of natural zeolite and 150 types of artificial zeolite regarding to synthesis method. Structure of Zeolite shown fig 5

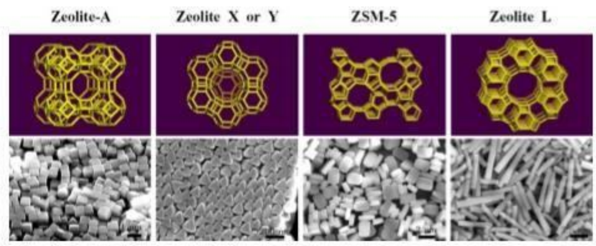

Figure-5 Structure of Zeolite

Chemical adsorbents:

Chemical adsorption is occurred by Valence force which is reaction between adsorbate and surface molecules of chemical adsorbent. Chemical adsorbents mainly divided into metal chlorides, metal hydrides and metal oxides. Chemical adsorbent has better adsorption performance while it has lower stability that cannot keep the original properties.

Metal chlorides:

Calcium chloride, strontium chloride, magnesium chloride and barium chloride are mainly used in the metal chloride adsorbents for adsorption cooling system. Metal chloride performs high adsorption capacity up to 1 kg ref/ kg ads whereas it influences negatively to heat and mass transfer with swelling and agglomeration during the adsorption. Methanol and ethanol are mainly employed as adsorbate for calcium chloride and ammonia is used as adsorbate for metal chloride.

Salt and metal hydrides:

Lithium hydrides, calcium hydrides and covalent high polymerized hydrides are promisingly used in the salt and metal hydrides for adsorption cooling system using hydrogen refrigerant.

Metal oxides:

The metal oxides are usually used in catalyst for oxidation and deoxidation reactions, they are employed as adsorbent for adsorption heat pump using oxygen as refrigerant Metal oxide/oxygen pair is suitable for cryogenic heat pump application of temperature below 120 K with large enthalpy of reaction between oxides and oxygen.

Composite adsorbents:

Physical adsorbent has higher thermal conductivity due to its uniform skeletal structure, while it has lower adsorption capacity than chemical adsorbent. On the other hand, chemical adsorbent has higher adsorption capacity, whilst it has poor heat and mass transfer caused by its swelling and agglomeration phenomena.

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The composite adsorbent is made from the combination of chemical sorbents and porous media to enhance adsorption performance of physical adsorbents and supplement drawback (poor thermal conductivity caused by swelling and agglomeration) of chemical adsorbents Typical composite adsorbents are metal chlorides and activated carbon/activated carbon fiber, or expanded graphite, silica gel or zeolite.

Adsorption working pairs:

.D.I. Tchernev mentioned that a naturally created mineral, namely zeolite adsorbs or desorbs large amounts of water vapour while it is being cooled or heated, thus providing a unique opportunity for its utilization in refrigeration applications. A demonstration unit of a refrigerator was first commercialized by Tchernev using zeolite water as the working pair

Zeolite/water working pair:

The zeolite/water pair can be utilized in dehumidification cooling system and adsorption cooling system. This pair has high adsorption heat about 3300 - 4200 kJ/kg and can be regenerated at high temperature over 200˚C. Tather et al. evaluated performances of zeolite 13X and 4A flake under different thickness. Zhu et al. developed medium size prototype of zeolite/water adsorption chiller using waste heat from diesel engine. Wang et al. investigated design and performance prediction of novel zeolite /water based two-bed type adsorption air conditioner.

Silica gel/water working pair:

Silica gel/water based adsorption system can be driven at heat source temperature as low as 50˚C and silica gel/water pair has about 2500 kJ/kg of adsorption heat. Silica gel/water based adsorption cooling system is better to be applied to air conditioning system where requires relatively higher evaporating temperature. Yeh et al. evaluated effects of regeneration temperatures and times on adsorption isotherm for water vapour onto silica gel

Activated carbon/ethanol working pair:

The performance of refrigeration system using activated carbon and ethanol was studied by many researchers. Using Maxsorb III introduced a solar powered adsorption cooling system.

The capacity of Maxsorb III was estimatedexperimentally to be1.2 g/g with an adsorption temperature from 20 to 60 °Cand the driving temperature was 80°C.The COP of the system was about 0.8 at evapourationtemperature of 15 °C. The specific cooling effect wasabout 420kJ/kg at an evapourator temperature of 7°C.Activated carbon fibers and ethanol as an adsorption pair was introduced by Saha et al. The driving temperature was in between 60 and 95 °C. The COP reached to about 0.6 with a cycle time of 600-700 s

Activated carbon/ammonia working pair:

Activated carbon-ammonia pairs for three cycles (single bed, two-bed and infinite number of beds) are presented at typical conditions for ice making, air conditioning and heat pumping applications. The driving temperature varies from 80 °C to 200 °C. The carbon absorbents investigated are mainly coconut shell and coal based types in multiple forms: monolithic, granular, compacted granular, fiber, compacted fiber, cloth, compacted cloth and powder. Considering a two-bed cycle, the best thermal performances based on power density are obtained with the monolithic carbon KOH-AC, with a driving temperature of 100 °C; the cooling production is about 66 MJ (COP = 0.45) and 151 MJ (COP = 0.61) for ice making and air conditioning respectively; the heating production is about 236 MJ (COP = 1.50).

Activated carbon/methanol working pair:

Activated carbon and methanol is one of the most common working pair due to the large adsorption quantity and lower adsorption heat, which is about 1800–2000 kJ/kg.However, activated carbon/methanol has the disadvantage of operating under sub-atmospheric pressure . The maximum adsorption quantity in activated carbon is 0.45g/g and the latent heat at -30°Cis about 1229.1 kJ/kg°C .

Vapour adsorption refrigeration cycle description:

Just like the Vapour Compression and Vapour Absorption refrigeration systems, Vapour Adsorption system also consists of four steps in a cycle as shown in fig 6

Heat and Pressurization

Heating and Desorption + Condensation

Cooling and Depressurization.

Cooling and Adsorption + Evaporation.

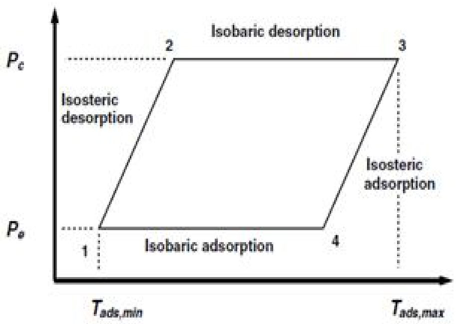

Figure-6Thermodynamic cycle of the adsorption refrigeration

Heat and pressurization:

During this period, the Adsorber receives heat while being closed. The Adsorbent temperature increases, which includes a pressure increase from the evapouration pressure up to the condensation pressure. This period is equivalent to the compression in Compression cycles.

Heating and Desorption + Condensation:

The Adsorbent temperature continues increasing, which induces Desorption of vapour. This Desorbed vapour is liquefied in the condenser. This is where condensation takes place just like in compression cycles

Cooling and Depressurization:

During this period the adsorber releases heat while being closed. The adsorbent temperature reduces which results in decrease in pressure from condensation pressure to evapourator pressure.

Cooling and Adsorption + Evapouration:

During this period, the adsorber continues releasing heat while being connected to the evapourator, which now superimposes its pressure. The evapouration heat is supplied by the heat source at low temperatures.

Performance of Evaluating Parameters of Adsorption Cooling System:

The performance of Vapour adsorption is evaluated by the determination of COP

Maximum Coefficient of Performance (COP $_{max}$)

In this COP is defined as the product of COP of refrigerator and thermal efficiency of heat engine.

$$COP_{max} = \mathrm{COP}_{ref} \times \eta_{HE}$$

$$= \frac{T_e}{T_c - T_c} \times \frac{T_g \quad T_c}{T_g}$$

Where,

T_e= Temperature of evaporator

T_c= Temperature of condenser

T_g = Temperature of generator

It also can be defined as the ratio of evaporative cooling power in (Kw) to the amount of waste heat supplied as input in (Kw).

$$COP = \frac{Q_{evap}(Kw)}{Q_{waste\ heat}(Kw)}$$

$Q_{waste\ heat}$ = power consumption

Specific Cooling Power (SCP):

It is defined as the ratio of evaporative cooling power in Kw to the mass of adsorbent in kg

$$SCP = \frac{Q_{evap}\,(Kw)}{m_{adsorbent}(Kg)} \text{ W/Kg of dry adsorbent}$$

$m_{adsorbent}$ = Mass of adsorbent in kgs

IV. EXPERIMENTAL WORK

The main parts of a refrigerator as shown in fig 8.

Adsorber, Condenser, Expansion valve, Evaporator and Generator. Here the adsorbent bed is cylindrical form having activated carbon as a adsorbent and ammonia as a refrigerant.

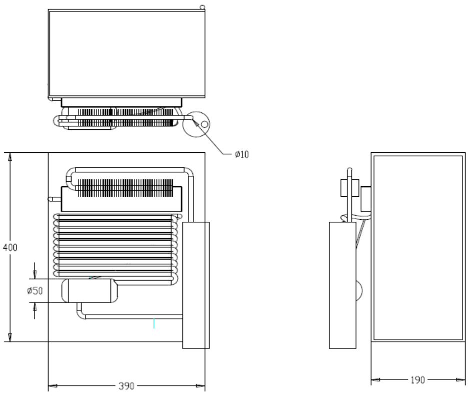

Figure-7 Vapour adsorption system outline view

Figure-8 Experimental set up of Vapour adsorption system

Figure-9 Evapourator temperature

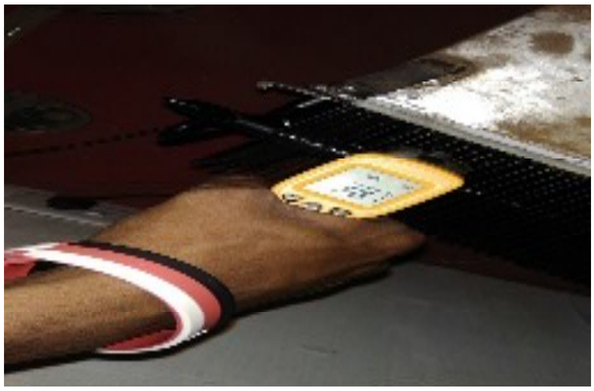

Figure-10 condenser temperature

Figure-11 Generator temperature

The adsorption refrigeration cycle is a heat powered cycle, where the adsorbent bed is the thermally driven compressor. The adsorption compressor operates in two modes adsorption and desorption when it is interconnected to the evaporator and condenser respectively. To switch between adsorption and desorption modes, an intermediate period is required to heat up the cold bed and cool down the hot bed and reverse their operating modes. In the simulated chiller, the switching period is two sequential processes.

The first is the mass recovery process where the refrigerant vapour in the high-pressure high temperature bed reactor moves towards the low pressure / low-temperature bed reactor until mechanical equilibrium. The second is the heat recovery process, where the cooling water flows through the hot bed and the heating water flows through the low temperature.

V. CALUCLATIONS, RESULTS & DISSCUSSIONS

Calculations:

For calculating maximum COP

$$COP_{max} = \frac{T_e}{T_c - T_e} \times \frac{T_g - T_c}{T_g}$$

The temperature values are shown in figures 9,10,11

T_e= - 8.5 °C = 264.5 K

T_c = 38.7 °C = 311.85 K

T_g= 63.5 °C = 336.65 K

$$COP_{max} = \frac{264.5}{311.85 - 264.5} \times \frac{336.65 - 311.85}{336.65}$$

$$= \frac{264.5}{47.35} \times \frac{24.8}{336.65}$$

$$= 5.58 \times 0.07366$$

$$= 0.411$$

Power consumption ($Q_{waste\ heat}$) = 0.065 KW

$$\therefore COP_{max} = \frac{Q_{evap}(Kw)}{Q_{waste\ heat}(Kw)} \quad (4)$$

$$Q_{evap} = COP_{max} \times Q_{waste\ heat}$$

= 0.411 × 0.065

= 0.026715 Kw

$$SCP = \frac{Q_{evap}(Kw)}{m_{adsorbent}(Kg)} \quad (4)$$

$$= \frac{0.026715}{0.2}$$

= 0.13357 Kw/Kg

= 133.57 W/Kg

Results & discussions:

We have demonstrated the theoretical and experimental way of understanding the adsorption cooling system. This project studied about the performance of activated carbon / ammonia adsorption cooling systems. An experimental test has been constructed to be used as performance evaluation tool.

It presents an overall review on the basic fundamental understanding on the adsorption refrigeration cycles and also performance (COP & SCP) of the test rig. These results can perform the important role for the further improvements in this sector. Experimentally the obtained values of COP and SCP are 0.411, 133.57 w/kg respectively.

VI. CONCLUSION

Adsorption systems can be an alternative to reduce the CO_2 emission and the electricity demand when they are driven by waste heat or solar energy. In comparison with the vapour compression refrigeration and absorption refrigeration systems, the adsorption refrigeration system has its drawbacks, such as low mass and heat transfer performance, low coefficient of performance (COP) and low specific cooling power. We got low COP for the model of vapour adsorption refrigeration system made by us, which is eco friendly and no harm full gases will emit into atmosphere there by it means no ozone layer depletion, in order to increase the COP composite adsorbents are suggested.

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