ISSN 2395-1621

Research Paper on

Design, Construction of Solar Assisted Adsorption Refrigerating Machine with Composite Adsorbent

#1Sfurti Chavan, #2Prof.S.Y.Bhosale

1 sfurtichavan@gmail.com
2sybmodern@gmail.com

#1Mechanical Engineering Department, Mechanical Engineering Department
PES Modern College of Engineering, Pune

ABSTRACT

A flat plate solar adsorber machine is developed on the basis of previous research achievements of a large number experiments and theory analysis. There are no moving parts on this device, Silica gel (75%) and calcium chloride (25%) and NH3 as refrigerant. This work showed that design of each subsystem, such as adsorbent bed, condenser, evaporator, cooling chamber. This adsorption refrigeration machine prototype is approached to practical application of mass production from view of cost and techniques. Good design of an adsorber and improvement of the thermal conductivity of the adsorbent are the means to reduce the cycle time, while treatment of adsorbent to increase its adsorbent capacity for a refrigerant could increase the refrigeration capacity of adsorbent per unit mass and also the COP of the cycle.

Keywords— Design, Solar Adsorption Machine, Adsorbent bed, Evaporator, Condenser, Cooling Chamber.

ARTICLE INFO

Article History

Received : 8th June, 2015

Received in revised form : 9^{th} June , 2015

Accepted : 12^{th} June, 2015

Published online :

14th June 2015

I. INTRODUCTION

Environmental-friendly means of air-conditioning and refrigeration are attracting a lot of attention nowadays since traditional methods such as vapour compression cycles require consumption of expensive electric energy and are responsible for emission of green house gases. Adsorption air-conditioning is an attractive alternative to the latter-mentioned methods. The emphasis when reviewing the research was on the design, evaluation and cost effectiveness of the prototypes.

The introduction of adsorption refrigeration, a new application for adsorption technology, necessitated the need for the development of new adsorbents. Physical adsorption is caused mainly by van der Waals force and electrostatic force between adsorbent molecules and the atoms of the adsorbent surface. The renewed interest on the studies of adsorption refrigeration is based upon the various advantages of the system, such as non chlorofluorocarbon (non-CFC) problems, cost effectiveness, simplicity in construction and lack of need for solution pumps. Besides, they can be driven by low grade energy. Solar solid adsorption refrigerator can be built on a small scale, and can be operated with no moving parts.

There are several working pairs for solid adsorption. For the successful operation of a solid adsorption system, careful selection of the working medium is important. For any refrigerating application, the adsorbent must have high adsorptive capacity at ambient temperatures and low pressures, but less adsorptive capacity at high temperatures and high pressures. Thus, adsorbents are first characterized by surface properties such as surface area and polarity. A large specific surface area is preferable for providing large adsorption capacity.

From literature, the composite adsorption-refrigeration pair is selected. Adsorbing material is Silica gel (75%) and calcium chloride (25%) and NH3 as refrigerant.

II. LITERATURE REVIEW

M. Li. et. al. [1] The adsorbent bed was composed in two flat plate collectors, with a total surface area of 1.5 m2, activated carbon and methanol was used as working pair. Each subsystem, such as adsorbent bed, condenser, evaporator was connected with valve for ideal operation; also thermocouples and pressure gauges were installed within each subsystem for measuring temperature and pressure parameters of that solar ice maker. The indoor experiments with quartz lamps instead of real solar radiation showed that that solar ice maker can produce 7–10 kg ice when the total insolation accepted by 1.5 m2 collector was 28–30 MJ. However experiments were not conducted outdoor under real solar conditions. However experiments were not conducted outdoor under real solar conditions. On the basis of successful experiments, a heat and mass transfer model of solar flat plate ice maker was established [2], and the effects of solar collector and environment on the performance of a solar powered solid adsorption refrigerator was analyzed using this model [3]. Above mentioned experience has helped us in designing a no valve solar ice maker which was tested for the performance in real solar radiation condition. In this paper, we focus on the design of no valve solar solid adsorption ice maker, also the typical performance of the no valve solar ice maker valve was given according to the experiments both under indoor and outdoor conditions.

Zhai and Wang et al [4] designed a solar adsorption cooling system which can be switched between a system with heat storage and a system without heat storage. Furthermore, experiments were carried out to compare the operating characteristics of the system under these two operating modes.

Solmus et al. [5] investigated experimen- 120 tally the adsorption capacity of water on natural zeolite at several zeolite temperatures and water vapor pressures for adsorption and desorption processes. Mateus and Oliveira et. al. [6] evaluated the potential of integrated solar absorption cooling and heating systems for building applications.

Huizhong Z. et. al. stated that Solar adsorption refrigeration machine constitutes a very attractive solution for both industrial waste heat recovery as well as the exploitation of renewable energy. It enables the realization of refrigeration cycles that make use of the characteristic of sorbents for which the adsorption ability varies with temperature and pressure. The heat transfer in the adsorber is poor and influences strongly the performance of the system [7].

Abdulateef et. al. [8] stated that, An alternative solution for this problem is to make use of solar energy which is available in most areas and represents a good source of thermal energy. Traditional refrigeration cycles are driven by electricity or heat, which strongly increases the consumption of fossil fuels. The International Institute of Refrigeration in Paris (IIF/IIR) has estimated that approximately 15% of all the electricity produced in the whole world is employed for refrigeration and air-conditioning processes.

III.EXPERIMENTAL SETUP LAYOUT

The adsorption refrigerating machines (Fig. 2) consist essentially of an evaporator, a condenser and an adsorber (purpose of this paper) containing a porous medium, that is assumed to be in this work the Silica gel and $CaCl_2$ reacting by adsorption with ammonia. The operation of the adsorber can be described as follows. When the adsorbent (at temperature T) is in contact with the vapor of the refrigerant (at pressure P), an amount ma of refrigerant is trapped inside the pores in an adsorbate state. This adsorbed mass depends on T and P according to a bi variant equilibrium ma = f (T, P). Moreover, for a fixed pressure, the trend of ma decreases as T increases, while for a fixed adsorbed mass, the pressure P increases with T. It results the possibility to make up an ideal refrigerating cycle consisting of a phase of heating/desorption/condensation followed by a phase of cooling/adsorption/ evaporation. At the initial time of the cycle, the adsorber reaches its minimal temperature, whereas the adsorbed mass of ammonia attains its maximum, so this time period corresponds to the sunrise where the sun starts gradually the heating of the adsorber. In the case where all the valves are closed, the temperature increases. The pressure inside the adsorber will raise, while the mass adsorbed remains almost constant, thus, the evolution is isosteric. When the pressure in the adsorber reaches the pressure of the condenser, which is the saturation pressure of ammonia at the operating temperature of the condenser, the valve V2 (Fig. 1) between the adsorber and the condenser opens, so, the desorption begins and the ammonia vapor condenses in the condenser during an isobaric heating phase. When the sun goes down, the heating phase ends and the adsorber enters the cooling phase. The valve V3 (Fig. 1) between the condenser and evaporator is opened, so, the condensate enters in the evaporator where it expands to the saturation pressure of ammonia at the temperature of the evaporator, thus the pressure in the adsorber decreases. When the pressure in the adsorber reaches the pressure of the evaporator, the ammonia evaporates in the evaporator producing the cold. The valve V1 (Fig. 1) between the evaporator and the adsorber opens and the ammonia vapor is adsorbed in the activated carbon contained in the adsorber. When the adsorber reaches its minimum temperature, the valves V1 and V3 close and the new cycle begins.

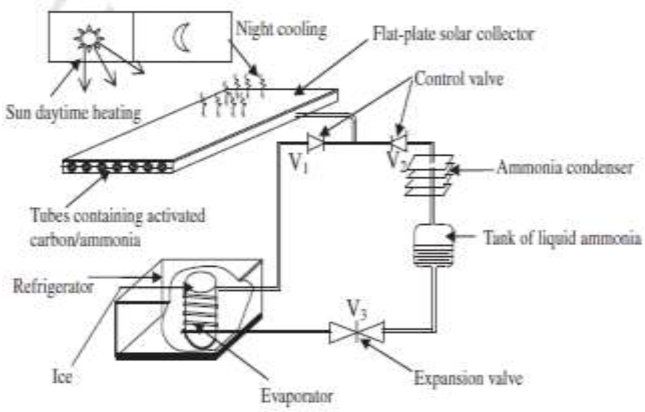

FIG.1 LAYOUT OF SOLAR ADSORPTION SYSTEM.

the solar powered Adsorption Refrigeration system with composite adsorbent is to be designed ,fabricated tested and compared with existing vapour compression system. The components is to be selected/designed includes,

- Choice of Working Pair (Composite adsorbent and refrigerant)
- Design of Cooling Cabinet
- Design of Evaporator
- Design of Condenser
- Design of Adsorber bed and Solar Collector

3.1: Design of cooling cabinet

A cooling cabinet is a space where evaporation of water vapour and cooling takes place. A well-insulated chest type cabinet can be chosen to save material and simplify construction. The cabinet is large enough to contain ten litre containers and to avoid too much change of temperature during the day. The cabinet can be insulated by 50 mm Energylite, and covered by 3 mm white Perspex at the inside and outside. The dimensions are based on required capacity, convenience factors, and economical use of materials.

Cabinet specifications

- Interior dimensions: 0.30 m x 0.30 m x 0.30 m deep.
- Usable capacity: 0.027 m3 or 27 litres.
- Exterior dimensions: 0.34 m x 0.34 m x 0.34 m high.
- Cabinet construction: 3 mm Perspex sheeting lined interior and exterior.
- Insulation: 40 mm thick Energylite on all sides.

Fig 2: The chest type cooling cabinet

Determination of the heat loss due to air infiltration into the cabinet during opening and Heat loss due to temperature difference across the walls of the cooling cabinet can be calculated by using the properties of the material and the heat transfer correlations.

Determination of the heat loss due to air infiltration into the cabinet

Qair = m.Cp(Ta - Tev)

= 0.005 MJ.

The rate of heat leakage (QL) by the following expression

QL= [ΔT] / [1/hc1.A1+ tPE /kPE A+ tFB/kFB A+ tPE/kPE A+ 1/hc2.A 2]

QL = 2 .256W.

For six sides, QL = 2 . 256 x 6= 3.536 W

This can be converted to cooling load in Joules per 24 hours:

QL=13.536 x 24 x3600 = 1.169MJ

3.2 Design of Evaporator

The function of an evaporator is to absorb heat from the surrounding air and moves it outside the refrigerated area by means of a refrigerant. The evaporator is made of a number of pipes. Inside these pipes the refrigerant is allowed to boil under very low pressure conditions, hence absorbing heat from the warm cabinet and transferring it to the adsorber.

3.2.1 Evaporator specifications

1) Outside pipe diameter : 16 mm.
2) Wall thickness : 1.5 mm.
3) Usable capacity : 0.01 m3 or 10 litres.
4) Construction material : Copper.
5) Film temperature : 17oC.
6) Evaporation temperature : 7oC.

To cool 10liters of water from 35˚C to 7˚C, heat removed (Qev) is given by:

Qev = Mw x Cpw x (T_i- T_0)
= 1.1732 MJ.

The total load on the refrigerator (Qrefr) is therefore = Heat required to cool water + Heat due to air infiltration + Heat leaking in through cabinet walls.

QRefri = 1.1732 +0.0053 + 1.169
= 2.3475 MJ.

But cooling period is from 6 P.M to 6 A.M or 12 hours. In 12 hours,

QRefri = (2.3472* 10^6) / (12*3600)
= 54.33W

To find length of Evaporator tube when Diameter is 16mm.

Qrefr= $h_{conv}A(T_a - T_{evap})$
54.33 = 7.2408* A (35-7)
A= 0.2680 m^2

Now, Area A = πDL
0.2680 = π 0.016*L
L = 5.33 m.

3.3 Design of Condenser

The purpose of the condenser is to dissipate heat from the vapour so that the vapour can condense back into a liquid during the process of desorption.

- Condensing temperature: 35˚C. Condensation of water vapour at 5˚C above ambient temperature.
- Ambient temperature: 30˚C.
- Pipe diameter: 12 mm

The rate of condenser cooling load (Qcon) equals the sum of heat rate required to condense the vapour and heat rate required to cool the liquid.

At entry to the condenser, the vapour temperature is assumed to be 65^{o}C and to condense at 35^{o}C.

$$Q_{cond} = M_w[h_{fg(65^\circ C)} + C_p(T_f - T_{cond})]$$
$$= 55.61W$$

To find length of Condenser tube when Diameter is 16mm.

$$Q_{cond} = hc\ .A.(T_{av} - T_{cond})$$
$$= 6.408\ m.$$

3.4: Design of Adsorber Bed and Solar Collector

3.4.1 Determination of the adsorption rate of the refrigerant :

The Q_{refr} of 54.33W, must be supplied during evaporation of the refrigerant. Therefore:

$$54.33 = M_{water}\ (hfg, 7^oC)$$
$$M_{water} = 2.1863*10^{-5}\ kg/s$$

Therefore the mass of water adsorbed in 12 hours is:

12 x 3600 X 0.00002186 = 0.94kg

3.4.2 Determination of the quantity of Adsorbent required

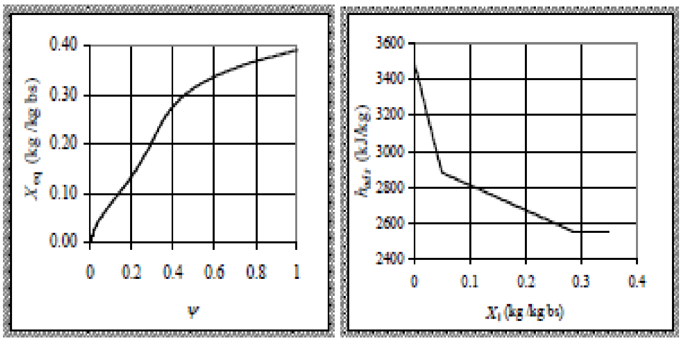

Figure 3.1: Curves for water-blue silica gel and Calcium Chloride

Using curve (b) above, the mass of silica gel ($M_{sil+CaCl2}$) required to adsorb 0.94 kg of water (M_{water}) with heat of adsorption of 2800 kJ, is estimated as:

$$M_{ads} = M_{water}/\Delta X$$
$$= 0.94/0.1$$
$$= 9.4\ kg$$

Where ΔX = the change in water vapour adsorbed.

Adsorbing material of mass 10 kg was used to compensate for some of the adsorbing material damaged during heating and brazing of the tubes.

3.4.3 Design of the Adsorber Bed:

15 copper tubes of dimension 33 mm OD × 30 mm ID × 1265 mm and 2 copper header tubes of 40 mm ID x 43 mm OD x 1464 mm long were chosen.

3.4.4 The volume of silica gel required

The volume of adsorbing material (V_{ad}) required can be calculated. The bulk density of adsorbing material is given as 700 kg/m3. 10 kg mass of silica gel calculated in article 3.4.2

$$V_{sg} = \frac{\text{mass of silica gel reqiured}}{\text{Bulk density of silica gel}}$$
$$= 0.0142\ m3$$

Inside volume of copper tubes

$$= \{ [\ \pi * D^2 * L] / 4\} * \text{Number of Copper pipes.}$$
$$= 0.0172\ m3$$

Thus, the adsorber is composed of copper pipes of volume 0.0172 m^3. Corresponding to a space of 17.2 liters of adsorbing material in the container. This volume contains (700 kg/m^3 x 0.0172 m3) or 12 kg adsorbing material, about 1.2 times the calculated 10 kg.

3.4.5 Choosing a solar collector

For the present study, a flat plate solar collector is chosen for the following reasons

- It is simple in design.
- It is easy to operate and install.
- It is a cost effective solution.

IV. CONCLUSION

A solar powered adsorption-cooling fridge employing silica gel-water vapour pair was designed, developed and evaluated.

REFRENCES

[1] M. Li, R.Z. Wang, Y.X. Xu, J.Y. Wu, A.O. Dieng, Experimental study on dynamic performance analysis of a flat plate solar solid-adsorption refrigeration for ice maker, Renew. Energy 27 (2002) 211–221.

[2] M. Li, R.Z. Wang, Heat and mass transfer in a flat plate solar solid adsorption, Renew. Energy 28 (2003) 613–622.

[3] M. Li, R.Z. Wang, A study of the effects of collector and environment parameters on the performance of a solar powered solid adsorption refrigerator, Renew. Energy 27 (2002) 369–382.

[4] Zhai XQ, Wang RZ. Experimental investigation and performance analysis on a solar adsorption cooling system with/without heat storage. Appl Energy 2010;87:824 – 35.

[5] Solmus I, Yamal1C, Kaftanoglu B, Baker D, Caglar A. Adsorption properties of a natural zeolite – water pair for use in adsorption cooling cycles. Appl Energy 2010;87:2062-7.

[6] Mateus T, Oliveira AC. Energy and economic analysis of an integrated solar absorption cooling and heating system in different building types and climates. Appl Energy 2009;86:949 – 57.

[7] Huizhong Z, Min Z, Jing L, Guoqing Y, Zhijun Z. Thermal conductivities study of new types of compound adsorbents used in solar adsorption refrigeration. Energy Convers Manage 2009;50:1244 – 8.

[8] Abdulateef JM, Sopian K, Alghoul MA, Sulaiman MY. Review on solar-driven ejector refrigeration technologies. Renewable Sustainable Energy Rev 2009;13:1338 – 49.