Solid Adsorption based Solar Powered Ice Maker

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Abstract: - **Everywhere in our world, refrigeration is a major energy user. In poor areas, “off grid” refrigeration is a critically important need. Both of these considerations point the way toward refrigeration using renewable energy, as part of a sustainable way of life. Solar-powered refrigeration is a real and exciting possibility. The interest in adsorption system started to increase, firstly due to the oil crisis in the 1970s that lead to concern about the energy shortage, and then later, in the 1990s, because of ecological problems related to use of CFCs and HCFCs as refrigerants. Such refrigerants, when released into the atmosphere deplete the ozone layer and contribute to the greenhouse effect.**

*Keywords:-***Solar adsorption, activated charcoal, icemaker, methanol refrigerant, ozone layer.**

I INTRODUCTION.

In simple words an “Adsorption is the process that occurs when a gas or liquid accumulates on the surface of solid”. The gas or liquid which is been accumulated is known as adsorbate. The solid substance on which adsorbate accumulates is known as adsorbent.

In simple terms, adsorption is "the collection of a substance onto the surface of adsorbent solids." It is a heat removal process where certain particles are bound to an adsorbent particle surface by either chemical or physical attraction. Adsorption is often confused with absorption, where the substance being collected or removed actually penetrates into the other substance

Adsorption is the accumulation of atoms or molecules on the surface of a material. This process creates a film of the adsorbate (the molecules or atoms being accumulated) on the adsorbent's surface. It is different from absorption, in which a substance diffuses into a liquid or solid to form a solution. The term sorption encompasses both processes, while desorption is the reverse process.

Adsorption is present in many natural physical, biological, and chemical systems, and is widely used in industrial applications such as activated charcoal, capturing and using waste heat to provide cold water for air conditioning and other process requirements (adsorption chillers),synthetic resins, and water purification.(e.g.[1]) Adsorption, ion exchange, and chromatography are sorption processes in which certain adsorbates are selectively transferred from the fluid phase to the surface of insoluble, rigid particles suspended in a vessel or packed in a column.

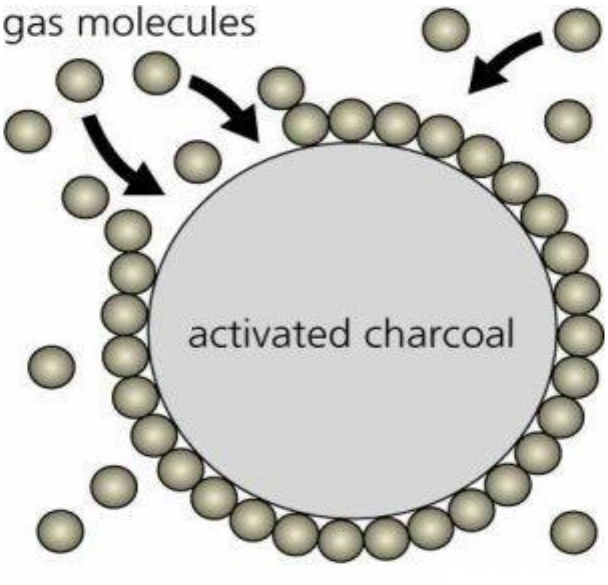


Fig. 1. Adsorption by activated charcoal

DIFFERENCE BETWEEN ADSORPTION AND ABSORPTION

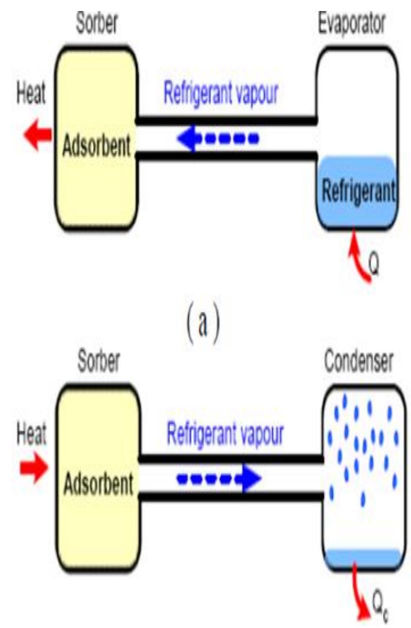
Adsorption is a phenomenon which takes place at the external surfaces and, in case of a porous solid, at the internal surface formed by the walls of the pores as well. It is a surface phenomenon that does not involve any changes in the chemical or lattice structure of the solid. Absorption occurs if the molecules of adsorbate do not remain on the surface but penetrate into the structure of the solid. In some cases both adsorption and absorption can take place simultaneously. The general term for the latter process, irrespective of the mechanism, is sorption. The solid in this case is termed as sorbent while, according to some definitions, the adsorbed molecules may be considered as a separate adsorbed phase

. PRINCIPLE OF ADSORPTION

Adsorption constitutes a solid sorption process by which the binding forces between fluid molecules (adsorbate) and the solid medium (adsorbent) derive from an electrostatic origin or from dispersion-repulsion forces. It is an exothermic and reversible process as a result of the gas-liquid phase change without modification of the solid itself. The liberated energy during the adsorption is called isosteric heat of adsorption and its intensity depends on the nature of the adsorbent/adsorbate pair, the adsorbed mass and the latent heat.

ADSORPTION REFRIGERATION PROCESS

The adsorption process is caused by the Van der Vaals force between adsorbate and atoms or molecules at the adsorbent surface. The adsorbent is characterized by the surface and porosity. In the adsorption refrigeration cycle, refrigerant vapor is not be compressed to a higher temperature and pressure by the compressor but it is absorbed by a solid with a very high microscopic porosity. This process requires only thermal energy, no mechanical energy requirement. The principles of the adsorption process provide two main processes, adsorption or refrigeration and desorption or regeneration.



(b)

Fig. 2 (a) Adsorption (refrigeration) process

(b) Desorption (regeneration) process.

The operation principle of the solid adsorption refrigeration system utilizing solar heat is shown in above figure. The system is composed of a container of adsorbents, which serves as a solar collector, a condenser and an evaporator which acts as a refrigerator and an ice-box. A combination of adsorbent and adsorbate is confined in a closed system where no carrier gas exists. (e.g. [2]) The collector is supplied with adsorbent which is adsorbed with adsorbate. During the day-

During the day-time the adsorbent along with the refrigerant is heated in the collector. As the temperature in collector increases, refrigerant evaporates from the adsorbent bed and then is cooled by the condenser and stored in the evaporator. During the night-time, the collector is cooled by ambient air and the temperature of the bed reaches a minimum. In this period, refrigerant begins to evaporate by absorbing heat from the water to be frozen and is adsorbed by the adsorbent. As the evaporation of the refrigerant continues, the water temperature decreases until it reaches 0 _C, where starts forming

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II DESIGN

The system of solar powered adsorption icemaker is composed of bed which acts as thermal collector, a condenser, evaporator and an ice box. Design of each parameter is explained in detail below.

DESIGN OF ADSORBENT BED

Design of Solar collector

Aspect ratio = $\frac{H}{L} = \frac{0.976}{0.075} = 13$

Adsorber temperature = 100°C

Ambient temperature = 30°C

Film temperature = 65°C

Air properties at 65°C

R_{aD} = Grashoff no. × Prandtl no.

$= \frac{\beta \Delta T g D^3}{\upsilon^2} \times P_r$

$= 166.44 \times 10^4$

Nusselt Number

$N_{uD} = 1 + [\,1 - \frac{1708}{RaCos\theta}\,][1 - \frac{1708(sin 1.5\theta)^{1.6}}{RaCos\theta}\,] + [[\frac{RaCos\theta}{5830}]^{1/3} - 1]$

$= 7.712$

Conductive Heat coefficient

$N_{uD} = \frac{h_c \times L}{k}$

$h_c = 2.99 W/m^2K$

Collector area exposed to solar radiation

Area = 0.976 × 0.976

$= 0.9526\ m^2$

Energy absorbed by adsorber

$Q_{plate} = IA\ (\,T_G \alpha s + \alpha_G) / 7$

Where

I = intensity of solar radiation = $6.448 Kwh/m^2$

A = $0.9526 m^2$

$T_G \alpha s = 0.92 \times 0.92 = 0.846$

α_G = Absorptivity of glass = 0.105

Q_{plate} = 834.48 W

Solar energy losses through radiation and convection

Film temperature $(T_f) = \frac{(373+303)}{2} = 338K$

Where

Adsorber temp = 373K

Ambient temp = 303K

Properties of air at 338K

K = 0.0291 W/m.k

C_p = 1.005 KJ/kgk

$\upsilon = 18.85 \times 10^{-6}\ Ns/m^2$

$\beta = 1/T_f = 1/338\ K^{-1}$

Solar energy loss by radiation and convection

$Q_{loss} = [\,h_c - (\,T_g - T_o) + \sigma\varepsilon(Tg^4 - To^4)]\,A$

Where

σ = Stefan boltzman constant
ε = emissivity of fiber glass = 0.75
T_G = temperature of glass = 50°C (Assumed) = 323K
T_o = Ambient temperature = 303K
A = 0.976 m^2
Q_{loss} = 160.285W
Available heat for heating absorber
$Q_{avail} = Q_{plate} - Q_{loss}$
= 674.199W

Total heat in Joules require for system

Q_{gross} = Heat to activated carbon + Heat to warm & evaporate methanol + Heat to glazing
+ Heat to adsorption

Total heat required to system of activated carbon
$Q_1 = mC_p\Delta T$
= 1432.2 KJ

Heat to warm & evaporate methanol
$Q_2 = mC_p\Delta T$
= 246.267 K

Heat of adsorption
$h_d = L\times\frac{T_a}{T_{co}}$

Where
L = Latent heat of vaporization of adsorbate = 1007.5 KJ/kg
T_{co} = Condensing temperature = 35°C = 308K
T_a = Adsobent temperature = 100°C = 373K
h_d = 1220.121 KJ/kg
Methanol used = 1.3575 Kg
$\therefore Q_3 = 1220.121 \times 1.3575 = 1656.31$ KJ

Heat to glazing
$Q_4 = mC_p\Delta T$

Where
m = mass of glass = 3kg
C_p = Specific heat of fiber glass = 844 J/kgK
$Q_4 = 3\times844\times(50-30)$
= 50.64 KJ

Total heat required for system
$Q_{gross} = Q_1 + Q_2 + Q_3 + Q_4$
= 3385.42 KJ

For heating period of 7 hours, total heat required for system is
$Q_{gross} = \frac{3385.42\times10^3}{7\times3600}$
= 134.34 W

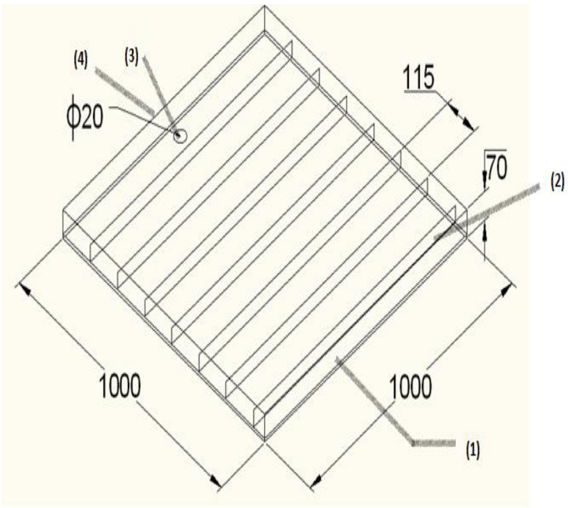

Fig. 3 (1) Adsorbent bed, (2) Supporting plate and fins, (3) Hole for flow of methanol vapour, (4) Extension for temperature measuremen

Actual photo of adsorbent bed without fiber plastic glass and insulation is as shown below.

Fig. 4 Actual photo of adsorbent bed

During night activated carbon loses heat to atmosphere(exothermic reaction) thus affinity between activated carbon and methanol is gained back thus activated carbon from bed will adsorb methanol at night.(e.g.[3]) Thus adsorbent bed is heart of system and it works similar to compressor in basic refrigerator so as to circulate methanol in system.

DESIGN OF CONDENSER:

Condensing temperature (T_{con}) = 35°C

Adsorber desorption temperature = 100°C

Ambient temperature = 30°C

Film temperature (T_{av}) = 65°C

Pipe diameter = 9.5 mm

Condenser we have used is readymade condenser and specifications of the same are as below:

- Manufacturer : 'Shreya' manufacturing pvt.ltd.
- Dimensions of condenser :355.6* 368.3*129mm
- Tube material : copper material
- Tube diameter(inlet / outlet) : 12.50 mm
- Tube diameter(condenser) : 9.525 mm
- Total length of one tube : 5337.048mm
- Number of tubes used : 4
- Fin material : Aluminum
- Total number of fins : 165

DESIGN OF EVAPORATOR

Determination of evaporator cooling load.

Load = Water

Quantity = 4. 5 liters

Entry temperature = 30°C

Exit temperature = −6°C

Duration = 12 Hours

Specific heat capacity of fresh water = 4.19 KJ/Kg K

To cool 4.5 liters of water from 30°C to −6°C heat removed (Q_{ev}) is given by

$Q_{ev} = M_w \times C_{pw} \times (T_i - T_0)$

$= 0.678780$ MJ

Assume the Q_{ev} = 1.2MJ with the various losses like the heat loss in the cabinet and heat loss during opening the ice box.

$Q_{ref} = \frac{1.2\times10^6}{12\times3600}$

$= 27.778$W

Determination of adsorption rate of refrigerant.

Q_{ref} must be supplied during evaporation of refrigerant.

$27.778 = \dot{M}_m (h_{fg} - 6°C)$

$= \dot{M}_m (1180) \times 1000$

$\dot{M}_m = 203540 \times 10^{-5}$ Kg/Sec

Therefore mass of methanol adsorbed in 12 hours

$M_m = 1.016$ kg

Thus we use the total methanol $M_m = 1.3575$ kg

Determination of evaporation area required

Film temperature = $\frac{30+(-6)}{2}$ = 12°C = 285K

Properties of air at 285K

K = 0.02504 W/m.k

p = 1.10678 kg/m^3

υ = 13.63 × 10^{-6} Ns/m^2 P_r = 0.7122

ΔT = [30− (−6)] = 36°C

Rayleigh's number

R_a = Grashoff no. × Prandtl no.

$= \frac{\beta \Delta T g D^3}{\upsilon^2} \times P_r$

$= 128.26 \times 10^6$

Nusselt's number

$$N_{uD} = 0.36 + \frac{0.518\,(128.26\times10^6)^{1/4}}{\left[1+\left(\frac{0.559}{0.7122}\right)^{\frac{9}{16}}\right]^{4/9}}$$

$= 92.07216$

$N_{uD} = \frac{h_{cond}\, L}{k}$

$h_{cond} = 3.5116$ W/m^2

$Q_{ref} = hA(\Delta T)$

$27.778 = 3.5116 \times A \times 36$

$A = 0.2197\ m^2$

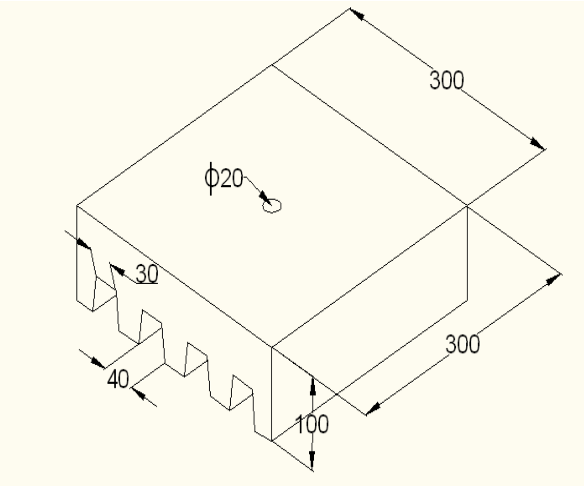

Fig. 5. Design of evaporator

DESIGN OF ICE-BOX

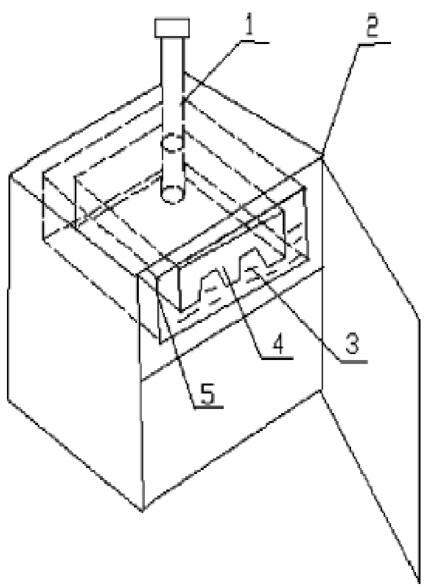

Fig.6 Icebox with evaporator and water container

The diagram shown is the ice-box along with water container and an evaporator. Where,

1- Stainless steel tube of evaporator

2- Ice-box of wood

3- Water in container

4- Evaporator

5- Water container

Icebox of system is made so as to insulate the water container. It is made up of wood. Dimension of ice-box made is 406mm*355mm*508m, it is situated in lower-most position. It is provided with handle and hinges on one side just as door of a box, so as to open the box and remove the container from the box when ice is formed. It is provided with hole on upper side of box from where copper tube of evaporator passes. Actual ice box of icemaker is as shown in figure below.

Fig. 7 . Integrated system of ice-maker

III. EXPERIMENTAL RESULTS:

ADSORPTION ICE-MAKER SYSTEM'S CYCLE

The cycle for adsorption refrigeration of AC-methanol can explained by Clapeyron diagram (in P versus _1=T). (e.g. [4], [5])

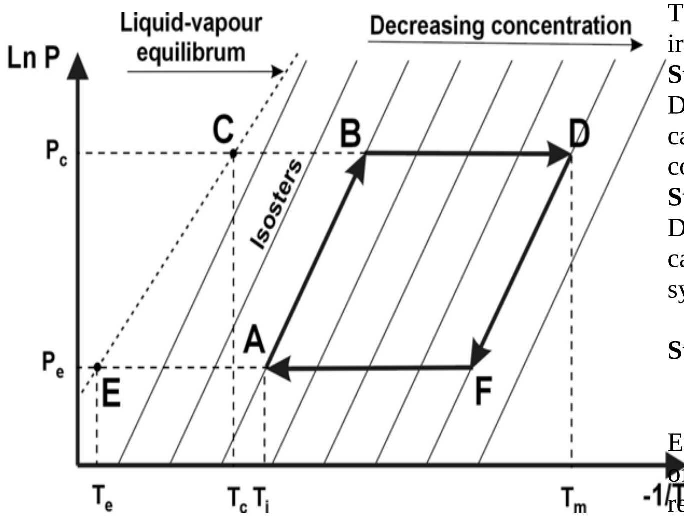

Fig. 9 An ideal adsorption cooling cycle in the claperyon diagram.
a.m.→4 p.m.) ; Cooling period: step DF (4p.m.→7 p.m.) and step FA (7 p.m.-7a.m).

Tbdes = TEMPERATURE BEFORE DESORPTION

This temperature is taken before the desorption process starts i.e. during morning session measured at adsorbent bed.

Tades = TEMPERATURE AFTER DESORPTION

This temperature is taken after desorption completes i.e. at the end of day during evening session at adsorbent bed.

Ta = TEMPERATURE AT POINT

This temperature is taken before afternoon session at the start of isosteric heating at adsorbent bed.

Tb = TEMPERATURE AT POINT B

Tb --This temperature is taken at afternoon time of the day and at the end of isosteric heating and start of desorption process at adsorbent bed.

Td = TEMPERATURE AT POINT D

This temperature is taken during evening session after desorption completes at adsorbent bed.

Heating period:step AB(7a.m. **→10a.m.)& step BD(10**

Step 1: Isosteric heating (A→B):

The system temperature and pressure increase due to solar irradiance.

Step 2: Desorption + condensation (B→D):

Desorption of the methanol vapors contained in the activated carbon bed; condensation of the methanol steam in the condenser.

Step 3: Isosteric cooling (D→F):

Decrease of the period of sunshine; cooling of the activated carbon; decrease of the pressure and the temperature in the system

Step 4: Adsorption + evaporation (F→A):

Evaporation of methanol contained in the evaporator; cooling of the cold cabinet; production of ice in the evaporator; readsorption of methanol steam by the activated carbon.

Tcc = TEMPERATURE OF CONDENSATE

This is temperature of condensate measured by measuring water/ice temperature at ice box during early morning session.

Tee = TEMPERATURE OF EVAPORATE

This is temperature of evaporate measured by measuring water/ice temperature at ice box during early morning session. By Clapeyron theory the mass of methanol at point A and D is

Let, Mm = 1.3575 KG, mass of total methanol in system.

Mma = Mm*(75/100), mass of methanol at point A
= 1.3575*0.75
= 1.018125 KG

Mmd = Mm*(25/100), mass of methanol at point D
= 1.3575*0.25
= 0.339375 K

TABLE I

OBSERVATION `S

DATEs --------------------- TEMPERATUREs (K)	1st 23/03/13	2nd 24/03/13	3rd 02/04/13	4th 05/04/13	5th 07/04/13
Tbdes	30+273	29+273	30+273	31+273	30+273
Tades	65+273	65+273	66+273	65+273	65+273
Ta	35+273	37+273	36+273	35+273	37+273
Tb	43+273	45+273	45+273	44+273	45+273
Td	53+273	55+273	54+273	55+273	53+273
Tcc	8+273	7+273	5+273	5+273	5+273
Tee	7+273	6+273	4+273	4+273	4+273

TABLE II

RESULT TABLE FOR PERFORMANCE ESTIMATES OF THE SOLID ADSORPTION SOLAR POWERED ICE-MAKER

DATEs → ------------------ PERFORMANCE PARAMETERs	1st 23/03/13	2nd 24/03/13	3rd 02/04/13	4th 05/04/13
η1	0.0292	0.0294	0.0295	0.0320
η2	0.8415	0.8896	0.8655	0.8415
COP cycle	1.6505	1.6444	1.6383	1.5095
COPsolar	0.0174	0.0174	0.0174	0.0174

IV CONCLUSION

- **A solar powered solid adsorption icemaker using an activated carbon/methanol adsorbent pair has been successfully designed, constructed, and tested.**
- **C.O.P of system is 0.12, which is comparatively low but as system works on solar energy it is ecofriendly system.**

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