Mathematical Model of Sun oriented Coefficient of Performance of an Intermittent Adsorption Refrigeration System with Silica Gel &Activated Carbon

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Abstract

The sun is a heavenly vitality hotspot for us. It is spotless and safe goes to the earth for nothing. The gadgets need to assemble its vitality is basic, calm and non - dirtying. Worldwide condition assurance activities have prompted the heightening of research endeavors on advancement of ozone layer and a worldwide temperature alteration safe refrigeration innovation. Lately, more consideration is being given to the utilization of waste warmth and sunlight based vitality in the field of building refrigerating frameworks. Sun powered fueled refrigeration and air - molding framework have been extremely alluring amid the most recent twenty years, since the accessibility of daylight and the requirement for refrigeration both achieve greatest levels in the late spring season. The ordinary cooling innovations are for the most part in view of the electrically determined refrigeration framework. These frameworks require large amounts of essential vitality utilization, causing power top loads and utilize refrigerants which cause ecological contamination. Sun powered adsorption refrigeration is a choice to pick up on the downsides of the customary cooling framework.

The target of this venture is to set down an option eco - cordial refrigeration cycle for delivering a temperature more often than not happens upon in an ordinary cooler. By assembling such kind of fridge adds new significance to the universe of refrigeration. This cooler gives some measure of alleviation to the refrigeration world by making it freewheeling from electric power supply and zero running expense. This work aims to model numerically the adsorption process of an adsorber bed by using activated carbon &Silica Gel pairs in order to evaluate the performances of different elements that influence the operation of adsorption refrigeration machine.

Keywords - *Adsorption, Adsorbent, activated carbon & Silica Gel pairs, COP.*

1.INTRODUCTION

The challenge caused by greenhouse gases effects in the Globe has driven researches in the direction to decrease mitigation these emitted gases by exploiting alternative and clean energy. Since the Montreal Protocol that prohibits the CFC gases, the research efforts focused on the development of refrigeration technologies that address more environmental preoccupations to the ozone layer and global warming. However the adsorption machines had more advantages than the heat pumps or air conditioning systems based-compression process, because they generate less noises and more environmental friendly.

2. THE THEORETICAL ADSORPTION COOLING CYCLE

The theoretical adsorption cooling cycle in the (Ln P versus – 1/T) diagram, as indicated in figure 1 below. Theoretically, the cycle consists of two isosteres and two isobars that intersect at points defined by the temperatures and boundaries in the processes: adsorption temperature, condensation temperature, maximum generation temperature and evaporation temperature. The operating principle of an adsorption cooling machine is analyzed by dividing the cycle into four different operational stages, which can be outlined as follows:

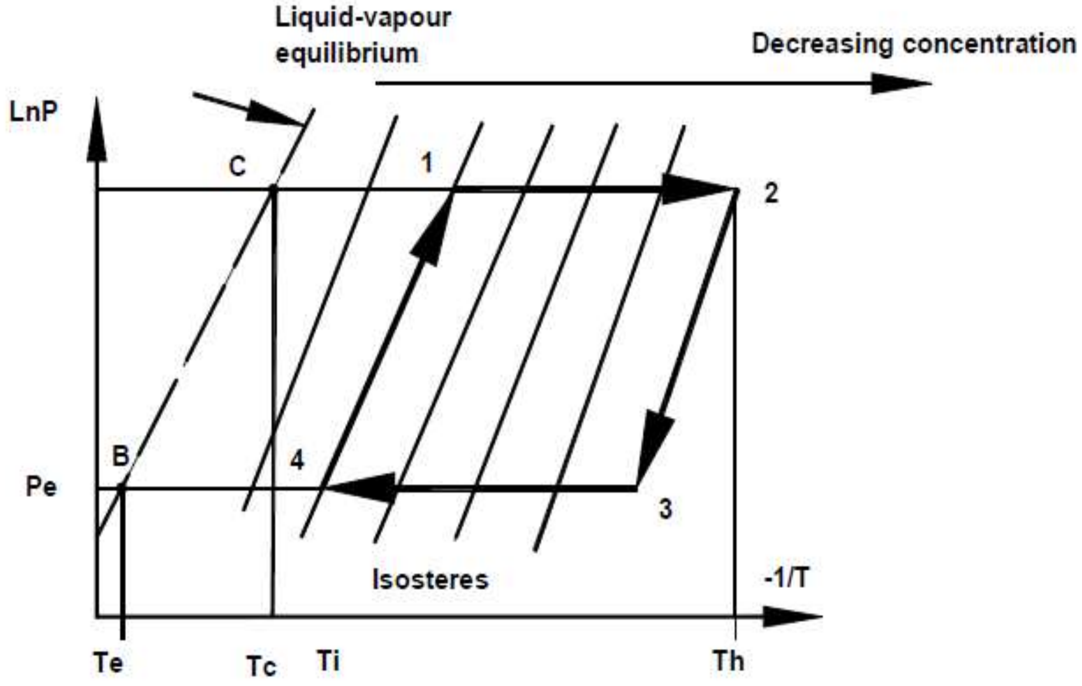

Figure 1:The theoretical adsorption cooling cycle

Heating periods: 4 - 1 & 1 – 2, Cooling periods: 2 – 3 & 3 – 4

Process 1: ($T_4 – T_1$) Isosteric heating

In the morning, the first stage of the cycle is isosteric heating (i.e. heating with constant mass transfer, line 4–1). The solar heating makes the temperature of the collector/adsorber increase from T_4 to T_1. At this stage the connection between the adsorber and evaporator is closed.

Process 2: ($T_1 – T_2$) Isobaric desorption and condensation

From T_1 to T_2, the pressure is kept constant at condenser pressure*Pc*, while the temperature is raised to temperature T_2, the maximum temperature attainable in the system. When the vapour pressure in the collector/adsorber equals condenser pressure, the connection between the adsorber and the condenser is opened and the vapour released from the adsorber is cooled to near ambient temperature and condensed. The liquid from the condensed vapour at temperature T_2 can be collected for recording.

Process 3: ($T_2 – T_3$) Isosteric cooling

After noon solar irradiance are decreases with time. The adsorber starts to cool down. To increase the rate of cooling in the adsorber, insulators are removed to allow ambient air moved by natural convection to flow along the adsorber and cool it more efficiently. This is the beginning of the cooling period, the temperature of the adsorber decrease from $T_2$to T_3 without any mass transfer. The temperature decrease of the adsorber induces an internal pressure decrease. At this time the connection between the condenser and the evaporator is opened and the condensate is allowed into the evaporator.

Process 4: ($T_3 – T_4$) Isobaric adsorption and cooling

From $T_3 – T_4$, the pressure of the adsorber decrease until it equals that of the evaporator (Pe). At this point, the connection between the adsorber and the evaporator is opened and the liquid in the evaporator boils at low temperature and extracts heat in the cooling cabinet. The vapour produced is then adsorbed by the adsorbent at constant pressure until the adsorbent is saturated. This is the end of the cycle.

3. MATHEMATICAL MODEL

3.1 The overall Heat and Mass Transfer Equation in the Adsorber Bed

The following assumption are made in the development of model

i. In absorbent bed the pressure is uniform.
ii. Conduction heat transfer can be characterized by an equivalent thermal conductivity in adsorbent bed and considered as a continuous medium.
iii. Headers provide uniform flow to and from the adsorber tubes.
iv. The process is an isobaric during the adsorption/desorption process.
v. All phases are continuous in thermal and chemical equilibrium.
vi. The thermophysical properties of the adsorbate are those of the bulk liquid and the gaseous phase behaves as an ideal gas.
vii. The condenser and evaporator processes are ideal; $Tcon$ and Tev are constant during the isobaric phases.
viii. The heat transfer in the adsorbent is radial and the convection heat transfer due to radial mass transfer is neglected.

Assuming negligible heat losses from the tank due to insulation.

The useful heat from the collector Qu is supplied as input heat required heating up:-

i. The water in the tank (Q1)
ii. The metallic storage tank (Q2)
iii. Adsorber tubes and adsorbent mass (Q3)
iv. The adsorbate mass before desorption (Q4) i.e. sensible heat ofadsorbate
v. Desorb a differential amount of adsorbate (Q5)
vi. The adsorbate mass as desorption starts (Q6), i.e. sensible heatof the adsorbate left in the adsorbent.

$$Q_u = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 \qquad (3.1)$$

But,

$$Q_1 = \int_{T_1}^{T_3} m_w Cp_w \, dT \qquad (3.2)$$

m_w Is mass of water in tank (kg), Cp_w is the specific heat capacity of water (kJ/kgK)

$$Q_2 = \int_{T_1}^{T_3} m_{wt} Cp_{wt} \, dT \qquad (3.3)$$

m_{wt}Is mass of water tank (kg), Cp_{wt} is the specific heat capacity of water tank (kJ/kgK)

$$Q_3 = \int_{T_1}^{T_3} (m_{ad} Cp_{ad} + m_{ac} C_{P_{ac}}) \, dT \qquad (3.4)$$

m_{ad} Is the mass of adsorber tube (kg), m_{ac} is the mass of activated carbon&silica gel in adsorber tube (kg), Cp_{ad} is the specific heat of adsorber tube (kJ/kgK), and $C_{P_{ac}}$is the combined specific heat capacity of activated carbon & silica gel.

$$Q_4 = \int_{T_1}^{T_2} x_{max} m_{ac} Cv_m \, dT \tag{3.5}$$

x_{max} Is maximum quantity of water adsorbed (kg) per kg of activated carbon & silica gel and Cv_m is the specific heat at constant volume of water (kJ/kgK).

$$Q_5 = \int_{T_1}^{T_3} m_{ac} h_d \frac{dx}{dT} dT \tag{3.6}$$

h_d Is heat of sorption (kJ/kgK) for activated carbon& silica gel-water pair is calculated from the Clausius-Clapeyron equation as,

$$H = R\, A \frac{T}{T_s} \mathrm{R\ AT/T\_s} \tag{3.7}$$

Where R is the gas constant for water with a value of 287 J/kg.K, T is the sample temperature K, T_s is the saturation temperature corresponding to the gas pressure P. A is aconstant corresponding to the slope of the saturation curve on a plot of lnP vs. (-1/Ts).

$$Q_6 = \int_{T_1}^{T_3} x(T, P_c) m_{ac} C_{P_{mw}} \, dT \tag{3.8}$$

$C_{P_{mw}}$ Is the specific heat of water vapor (kJ/kgK).

$$Q_u = \int_{T_1}^{T_3} m_w Cp_w \, dT + \int_{T_1}^{T_3} m_{wt} Cp_{wt} \, dT + \int_{T_1}^{T_3} (m_{ad} Cp_{ad} + m_{ac} C_{P_{ac}}) \, dT + \int_{T_1}^{T_2} x_{max} m_{ac} Cv_m \, dT + \int_{T_1}^{T_3} m_{ac} h_d \frac{dx}{dT} dT + \int_{T_1}^{T_3} x(T, P_c) m_{ac} C_{P_{mw}} dT \tag{3.9}$$

The adsorption equation of activated carbon& silica gel –water is calculated from the Dubnin-Astakhov equation.

$$x = x_o \exp[-K \left(\frac{T}{T_s} - 1\right)^n] \tag{3.10}$$

The useful energy in equation (1) can also be expressed as

$$\left(m_w C_{P_w} + m_{wt} C_{P_{wt}}\right) \frac{dT}{dt} = Q_u - h_{C_{w-ad}} (T_w - T_{ad}) A_{ad} \tag{3.11}$$

Where$h_{C_{w-ad}}$is the heat transfer coefficient between water and adsorber tubes of diameter d, and can be evaluated using the following correlation given byDeaver as

$$h_{C_{w-ad}} = Nu_d \frac{K_1}{d} \tag{3.12}$$

And$N_{u_d} = 0.48\, Ra_d^{0.23} \quad \text{for } 10^4 < Ra_d < 10^7$ (3.13)

The Raleigh number

$$Ra_d = \frac{\mathcal{G} \beta' d^3 (T_w - T_{ad}) \mu C_p}{\nu^2 k_1} \tag{3.14}$$

Then the energy balance between the hot water in the tank, adsorber tubes and content is

$$(m_{ad} C_{P_{ad}} + m_{ac} C_{p_{ac}} + x_{max} m_{ac} C_{v_m}) \frac{dT_{ad}}{dt} = h_{C_{w-ad}} (T_w - T_{ad}) A_{ad} - m_{ac} h_d \frac{dx}{dt} \tag{3.15}$$

In the evening, the hot water is drained and replaced with cold which cools the adsorber. The sensible heat of the adsorber and heat of adsorption rejected from the adsorbent bed will cause the temperature of the water in the tank to rise by a few degrees.

Heat rejected from the adsorbent bed into the water tank and heat recovered by the water can be expressed with the following heat balance equation:

$$Q_{ct} = \int_{T_0}^{T_1} m_w C_{P_w}$$

$$= \int_{T_1}^{T_3} \left(m_{ad} C_{P_{ad}} + m_{ac} C_{P_{ac}}\right) dT + \int_{T_4}^{T_3} x_{min} m_{ac} C_{v_m} dT + \int_{T_1}^{T_4} m_{ac} h_a \frac{dx}{dT} dT + \int_{T_1}^{T_4} x(T, P_e) m_{ac} C_{P_m} dT \tag{3.16}$$

x_{min} Is the adsorption capacity after desorption (kg/kg) and ha is the heat of sorption.

The cold water to fill the tank in the evening enters at a temperature T_0, which can be expressed as

$$T_1 = T_0 + \frac{Q_{ct}}{m_w C_{P_w}} \tag{3.17}$$

3.2 Refrigeration Effect and System Efficiency

The desorbed refrigerant collects and is condensed in the condenser from where it flows into the evaporator. At night, with the introduction of cold water into the water tank, the temperature and subsequently the pressure of the adsorbent bed drops to below the evaporation pressure, causing the refrigerant liquid in the evaporator to vaporize resulting in the refrigeration effect. The refrigeration effect is measured by the system performance efficiency. It is described by the coefficient of performance (COP) as

$COP = \frac{Q_{ref}-Q_{cc}}{Q_g}$P=Q_ref-Q_cc/Q_g (3.18)

The amount of refrigeration is calculated as

$Q_{ref} = \Delta x m_{ac} L_e$ (3.19)

Le is the latent heat of vaporization of the adsorbate.

Q_{cc} Is the amount of energy assumed to be utilized in cooling the refrigerant liquid from the condensing temperature Tc to the evaporation temperature $Te. Q_{cc}$.Q_cc is estimated as

$Q_{cc} = m_{ac} C_{p_{ac}} \Delta T$ (3.20)

QgIs the heat required for the regeneration of the adsorption bed and it is calculated in the equation below;

$Qg = \mathrm{Qu} - (Q_1 + Q_2)$=-(Q_1+Q_2) (3.21)

$\Rightarrow Q_g = Q_3 + Q_4 + Q_5 + Q_6$

$Q_g =$

$\int_{T_1}^{T_3} \left(m_{ad} C_{P_{ad}} + m_{ac} C_{P_{ac}}\right) dT + \int_{T_1}^{T_2} x_{max} m_{ac} C_{v_m} dT + \int_{T_2}^{T_3} m_{ac} h_d \frac{dx}{dT} dT + \int_{T_2}^{T_3} x(T, P_c) m_{ac} C_{P_{mv}} dT$ (3.22)

The specific cooling power

$SCP = \frac{Q_{ref}-Q_{CC}}{t_{cycle} \cdot m_{ac}}$P=Q_ref-Q_CC/t_cycle.m_ac (3.23)

The gross solar coefficient of performance is

$$COP_s = \frac{Q_{ref} - Q_{cc}}{\int A_c I(t) \partial t}$$

4. CONCLUSIONS

This paper describes the overall Heat and Mass Transfer Equation in the Adsorber Bed, Refrigeration Effect & System Efficiency. However the numerical resolution of the differential equation will help to develop the mathematical model for the Intermittent Adsorption Refrigeration System

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