Fabrication and Experimental Study of New Zero Energy Cooling Chamber with a Solar-Driven Adsorption Refrigerator

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***Abstract*— A New Zero Energy Cool Chamber (ZECC) consisting of two cooling systems, a solar-driven adsorption refrigerator and an evaporative cooling system, was developed and then evaluated as low-cost and eco-friendly cooling storage for storing fruit with moderate respiration rates. The solar-driven adsorption refrigerator, consisting of a solar collector containing activated carbon as an adsorbent, a condenser and an evaporator, cools water based by evaporating methanol and adsorbing it on activated carbon, and then makes ice. The methanol adsorbed on the activated carbon is desorbed by applying solar heat. The ice is then used to cool the storage space, which can be done for a long time without the need for electricity. The evaporative cooling system also cools the storage space by evaporating water from the wet walls containing wet filler. The combined use of two cooling systems reduced the average inside temperature of the new ZECC to 12.07^{0}C compared with an average outside temperature of 31.5^{0}C and extended the shelf life of tomatoes from 7 to 16 days. These results suggest that the new ZECC proposed here is low cost and energy-saving and is useful for storing fruit and vegetables in areas where electricity is unavailable.**

***Keywords:* Solar-driven Adsorption Refrigerator, Evaporative Cooling, Storage, Eco-friendly.**

I. INTRODUCTION

Energy is integral to almost every aspect of modern life. It is used for transportation, communication, industrial and domestic purposes like heating, cooling, cooking, lighting as well as other appliances Both economic growth and technological advancement of a country depends on it.

Cooling is required to maintain the freshness of fruit and vegetables during storage. Conventional vapor compression cooling systems that use chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) contribute to ozone depletion and global warming. The International Institute of Refrigeration in Paris (IIF/IIR) has estimated that approximately 15% of all the electricity produced in the world is employed for refrigeration and air-conditioning processes of various kinds, and the energy consumption for air-conditioning systems has recently been estimated at 45% for all households and commercial buildings. Therefore, an eco-friendly refrigerant with a newer refrigeration system is required to reduce the emissions of harmful gases.

In recent years, adsorption refrigerators driven by solar energy have been receiving much attention as a replacement for conventional vapor compression refrigeration cycles driven by electricity. In the adsorption system we are proposing, methanol is used as a refrigerant instead of harmful CFCs, HCFCs or HFCs, and solar energy is used to drive the refrigerant (methanol) without electricity.

Adsorbent (activated carbon) is used to adsorb the methanol and promote its evaporation. The storage space is cooled using ice made by the adsorption refrigerator. Solar energy is safe, environmentally friendly and abundant. Therefore, a solar-driven adsorption refrigerator is low cost, eco-friendly, energy-saving and simple in structure. Several noiseless and non-corrosive solar refrigeration systems such as liquid/vapor, solid/vapor absorption, adsorption, vapor compression and photovoltaic-vapor/compression systems have been developed. However, the most promising method of producing ice by using solar energy is with an activated carbon (adsorbent)-methanol (adsorbate) pair, which could be driven by relatively low heat temperatures and is less expensive. The cooling load of such a system is generally high when solar radiation is high.

In developing countries, most agricultural areas do not have a grid electricity supply. As a result, large quantities of fruit decay due to the unavailability of electric-powered vapor compression refrigeration systems. This lack of refrigeration also causes sharp differences in food supplies between the harvest and off harvest periods. Using an evaporative cooling technique is effective in overcoming this problem. We have developed a zero-energy cooling chamber (ZECC) using an evaporative cooling technique.

1.1 Global Energy Demand

Nowadays, there is an significant increase of energy demand due to three vital factors -population, per capita energy consumption and economic growth. Global energy demand will grow by more than one-third up to 2035, with China, India and the countries of the Middle East being responsible for more than 60% of that increase. Energy demand rises especially in OECD countries, although there is a pronounced shift away from carbon sources like oil or coal towards natural gas and renewables.

Currently, despite the growth in alternative sources of energy, most of the energy needs are met by coal, oil, natural gas, and uranium. Thus, fossil fuels remain dominant in the global energy mix.

Because of the constant increase in the energy demand and the limited resources of fossil fuels, there is an imperative need to shift towards renewable energy sources. This shift is also reinforced by the fact that fossil fuel resources have negative environmental impacts. Many efforts from both the United Nations (UN) and the European Union (EU) in the form of policies were implemented for the reduction of greenhouse gas emissions and the promotion of renewable resources. The most important directive is Directive 2009/28/EC, requiring EU member states to produce a pre-agreed portion of their energy consumption from renewable sources in order that the EU as a whole shall obtain at least 20% of total energy consumption from renewable by 2020.

Another important Directive is European Directive 2006/32/EC on energy end-use efficiency and energy services, which states that Member States must adopt and achieve an indicative energy saving target of 9 % by 2016 in the framework of a national energy efficiency action plan [NEEAP]. The EU Member States should establish indicative targets and incentives so as to achieve this target. Some of the main areas for potential energy conservation are the building sector and especially energy end-use efficiency in the public sector, promotion of energy end-use efficiency and energy services.

1.2 Types of Solar Collector

The solar collector is the major component of any solar system since it absorbs solar radiation, converts it into heat and transfers it to a medium (usually water). There are two types of solar collectors:

Non- concentrating and concentrating collectors. In the non-concentrating type, the collector area is the same as the absorber area.

Concentrating solar collectors concentrate solar energy onto a small area. The collectors which are used in solar combo plus systems are usually stationary (non- concentrating) collectors.

There are three collector technologies available on the market:

1. Flat plate collectors (FPC);
2. Evacuated tube collectors (ETC).
3. Stationary compound parabolic collectors (CPC);

Flat-plate collectors are the most common solar collectors used in solar systems. A flat-plate collector is an insulated metal box with a glass or plastic cover on the top (the glazing) and a dark-colored absorber plate on the bottom. Solar radiation is absorbed by the absorber plate and is transferred to a medium that circulates through the collector in tubes.

Evacuated tube collectors consist of a large number of glass tubes. Each evacuated tube consists of 2 layers of glass with a vacuum layer between them, providing large insulation. Evacuated tubes have a special coating on the inner tube layer which absorbs radiation from the sun. The evacuated tube is heated by the sun and the liquid in the heat pipe changes state (gas). The gas rising to the top of each pipe carries the heat to the top of the collector. The cold water in the tank is circulated through the top of the collector and absorbs this heat.

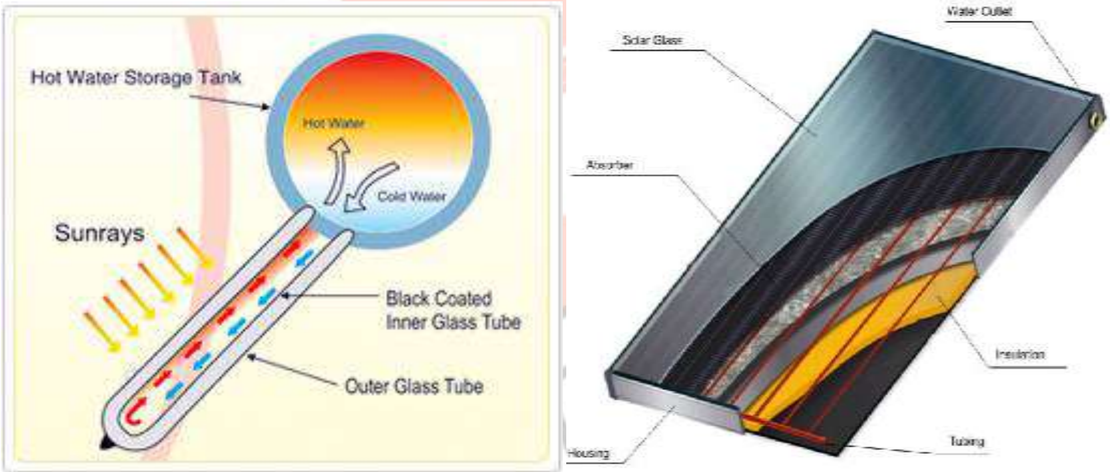


Figure 1.2 Evacuated tube collectors and flat plate collectors

Compound Parabolic Concentrator (CPC) is a special non-imaging type of solar collector, having the highest possible concentrating ratio. It is fabricated in the shape of two meeting parabolas. The appropriate technology for each application depends on the needed operational temperature. Generally, there are four different temperature levels, in solar combi plus systems.

- 40°C for a low temperature space heating system
- 60°C for domestic hot water production
- 70°C typical driving temperature for adsorption chillers
- 90°C typical driving temperature for absorption chillers

Flat-plate solar collectors were designed for use in sunny and warm climates. From the other side, evacuated tube collectors perform better in colder and cloudier conditions than the flat plate collectors. This is due to the fact that there is vacuum between the tube glasses, which minimizes heat losses to the environment. On the other hand, condensation and moisture problems can cause deterioration of internal materials resulting in reduced performance and system failure in the case of flat plate collectors. Furthermore, since the evacuated tube collectors are more efficient than flat plate collectors, they require less space. In some cases, it may be worth to install a larger surface area of flat plate collectors instead of evacuated tube collectors since they are much more expensive.

1.3 Solar-Driven Adsorption Refrigerator

This system is cooled in two ways: one is a solar-driven adsorption refrigerator which evaporates methanol and adsorbs methanol on active carbon and the other is evaporative cooling of water from a wet wall containing wet filler between inner and outer walls. The fig.1.3 shows the solar driven adsorption system.

Adsorption Cooling is a thermally driven refrigeration system, which can be powered by solar energy as well as waste heat. The use of thermal driven systems helps to reduce the carbon dioxide emission from combustion of fossil fuels in power plants.

Another advantage for adsorption systems compared with conventional vapor compression systems is the working fluid used. Adsorption systems mainly use a natural working fluid such as water which has zero ozone depletion potential.

Like in a vapour compression system, the adsorption refrigeration system also consists of a compressor, a condenser, an expansion valve, and an evaporator. However, the compressor in an adsorption system is replaced by a thermal compressor which is operated by heat instead of mechanical energy. The vaporised refrigerant is adsorbed in the pores of the adsorbent in the reaction chamber. Due to the loading of the adsorbent, the thermal compressor is operated intermittently. During the first phase of the operation the refrigerant is evaporated at a low pressure and low temperature in the evaporator and is adsorbed by refrigerant under isobaric conditions. In the next phase, the charged refrigerant is regenerated by heating up the adsorbers (temperature swing). A two-chamber adsorption cooling system, described in the figure below enables continuous operation.

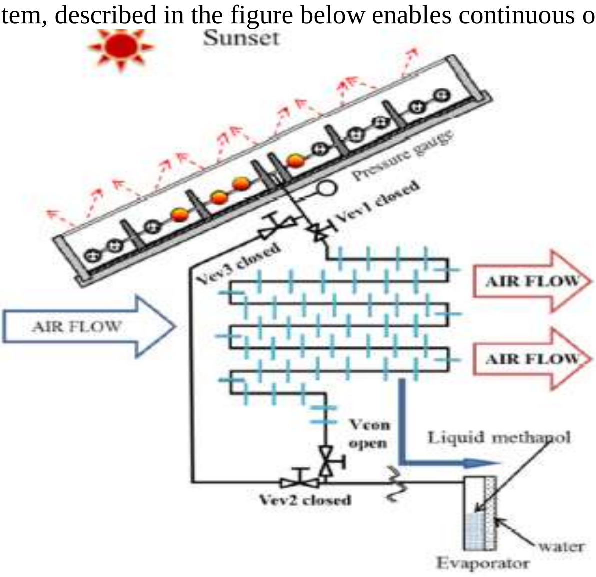


Figure 1.3 Isosteric Cooling

II. EXPERIMENTAL SET UP

2.1. Design Strategy

The solar flat plate collector plays vital role in the operation of solar driven adsorption system. In this research the solar driven cooling system. The following strategy is used in the design of the cooling system.

- Gather meteorological data and describe the sun radiation resource on site.
- Define the objective function (state the most important design criteria).
- List the parameters encountered in the design procedure. This is a mean of defining the level of detail in the analysis.
- Fix some parameters to simplify and shorten the amount of time needed for the design process.
- Based on the solar energy resource on site and performance data of earlier designs find a first tentative design fulfilling the power demand. Refine the tentative design using a design tool to ensure that all parts in the objective function are achieved.
- To further simplify the design process, it is performed assuming fixed output from the system.

2.2 Experimental Set-up and its components

The experimental set-up consisting of the following parts

a. **Solar Flat Plate Collector**
b. **Condenser**
c. **Evaporating Box**
d. **Dryer Filter**

a. Solar Flat Plate Collector

Solar flat plate collector is consisting of the copper tubes of diameter 1.25 cm drilled into the 2.5 cm copper tubes. The inner copper tubes drilled with 10 mm diameter hole for soaking of working fluids when it is not in working conditions. The solar flat plate collector's riser tube of 2.5 cm diameter is filled with granular activated carbon for soaking the fluid methanol during the non-working condition. The methanol fluids charging in the solar panel. The construction of solar flat collector. The transparent sheet is used to maximizes the radiation over the solar flat plate collector. The solar flat plate collector is made up with the plywood in order to make the insulation form boundary.

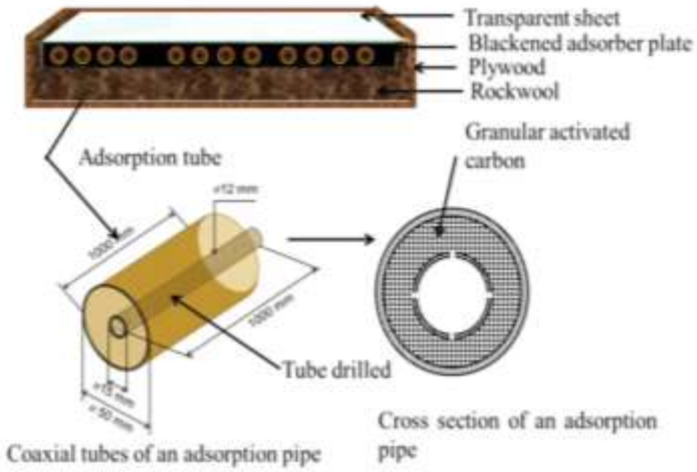


Figure 2.1 Solar Flat Plate Collector

The construction of coaxial riser tubes is packed with the box structured with layering of rockwool and glass wool. The aluminium foil is also used to cover base. The granular activated carbon sintered packed with tubes, the cross section of adsorption tubes shows in figure above. The length of riser tube is taken as 1000mm for better evaporation of methanol and achieving proper cooling.

b. Condenser

It is consist of small tubing over which the fins are provided. The condenser is connected at the exit of the solar flat plate collector. The continuous air flow made in contact over the condenser so that the it can be condensed the methanol liquids easily. The condenser of 3x2 feet is used for the experimentation. The exit of the condenser attached with the evaporative box for collecting the condensed methanol.

c. Evaporating Box

The evaporative box of conventional refrigerator is used for the experimentation. It is connected at the exit end of the condenser. The evaporative box is fitted within the insulated chamber and also use as storage for vegetables and fruits. It is also continuously cooled with water evaporation techniques. The wood wool and thermocol sheet is employed at the outer surface of evaporating box. The evaporative box exit is connected to the inlet of solar flat plate collector so that the working fluid can be returned to the collector in order to complete the cycle.

d. Dryer Filter

It is connected at the exit of the evaporator box and the inlet of solar flat plate collector. During the continues condensation and evaporation, it is necessary to dry and filter the refrigerant before entering into the solar flat plate collector. It removes impurities from the refringent.

Data Unit

The data unit is employed for the recording the temperature of evaporative chamber. The glass tube thermometer is used for recording the temperature. The flow of the methanol within solar flat plate collector is controlled manually in order to make system zero system.

2.3 Structure of the new ZECC

A new zero energy fruit-storage chamber with two eco-friendly cooling systems, a solar-driven adsorption refrigerator and an evaporative cooling system, was set up at the premises of K.D.K College of Engineering, Umred, as shown in Fig. 2.2.

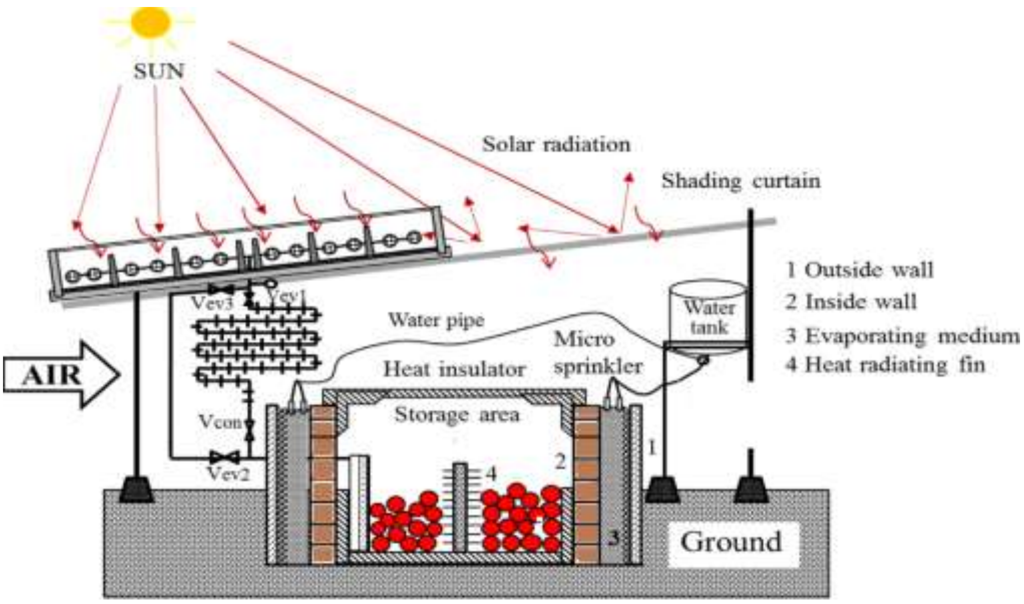


Figure 2.2 Zero Energy Cooling Chamber

The chamber consists of a double wall (inner and outer walls), a filler (evaporating medium) inside the double wall, a storage space for fruit and vegetables, two cooling systems, and a shading curtain. The outer and inner walls of the zero-energy storage chamber were made of solid clay bricks and wooden box filled with wood wool respectively. The storage space is about 1300 mm long x 800 mm wide x 800 mm high. The evaporating medium between the walls consisted of two layers of evaporative box and its chamber is maintained cooled by continuous spraying of water. The gap between the outside and inside wall was 65 mm,55 mm of which was packed with filler consisting of a mixture of sand (80%) and natural zeolite and the remaining 10 mm was packed with filler consisting of gravel stone (2 mm). The natural zeolite was added to the sand to increase the water retention capacity and gravel stone was used to enhance the evapotranspiration rate. Tap water from an overhead water tank (100 mm wide,30 mm deep; at a height of 200 mm) was supplied to the filler material through a low-pressure micro sprinkler tap in stream pattern. The amount of watering was set to 0.40 ml per second. The inside wall and bottom of the storage area was covered with 5 mm thick polystyrene (expanded type) heat insulation board. A shading curtain that reduces solar radiation by 60% was also used. A replaceable aluminium made ice box (evaporator box) used for the solar driven adsorption refrigerator was set up at the centre of the storage space. Field testing of the new zero energy fruit-storage chamber was done continuously from 1 to 27 Feb.2017 during summer. The experimental prototype was positioned north-south, which was the average frequent air direction at the location during the experiment period. The average total solar radiation was 14.25 MJm^2 during the experiment period. The cooling performance of the new prototype was tested under a load condition with 5 kg of tomatoes to determine stored fruit qualities.

2.4 Working of new Design ZECC

he solar-driven adsorption refrigerator was designed and fabricated based on the solid adsorption refrigerator Fig.4.5 shows a schematic view of the solar adsorption system. The flat type solar collector containing the adsorbent bed consisted of 5 copper tubes 25 mm in diameter and 1 m long with an effective exposed area of 1.2 m^2 and each copper tube was loaded with 1.6 kg of activated carbon. Activated carbon (F13 1.5mmin grain size, Sanei Kako Co. Ltd., Osaka, Japan) was selected to be used with methanol (Nacalai Tesque Inc., Kyoto, Japan). During day time, the solar radiation passes through a transparent cover of the solar collector, and impinges on the blackened adsorbers plate and copper tube surface. The transparent cover is used to reduce convection losses from the copper tube through the restraint of the stagnant air layer between copper tube and the transparent cover. It also reduces radiation losses from the collector as the short-wave radiation from the sun passes through the transparent cover but it is nearly opaque to long -wave thermal radiation emitted by the blackened adsorbers plate and copper tube (greenhouse effect). A large portion of the adsorbed heat energy by adsorber plate transferred it to the cooper tube, while losing as little heat as possible upward to the atmosphere and downward through the back of the casing. Because underside of the adsorber plate and the side casing are well insulated using rockwool to reduce conduction losses. The advantage of this configuration is the compactness of the components and the reduction of heat transfer resistance from the solar collector to the activated carbon. The tilt angle of the solar collector was adjusted to 30-40 degree to set its optimal value based on BRI. The air-cooled condenser consisted of seven copper tubes and the outer condenser's heat transfer area was 0.70 m2. Forty-seven square copper fins 0.3 mm thick and 80 mm long 80 mm wide were used to enhance the cooling process. The refrigerant flow through the condenser was controlled by two valves (Vev1 for gaseous methanol after Isosteric heating; Vcon for liquid methanol after cooling).

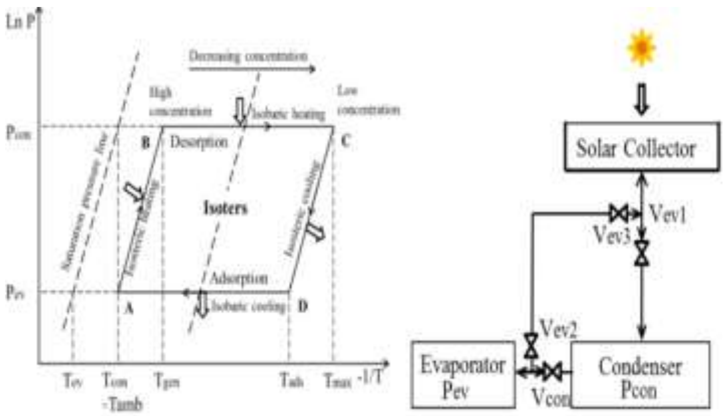
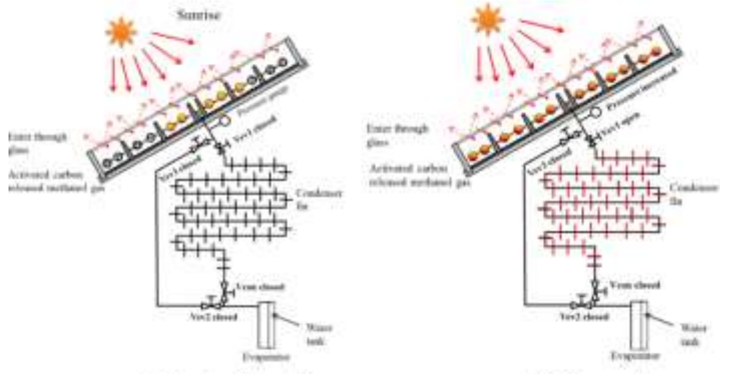
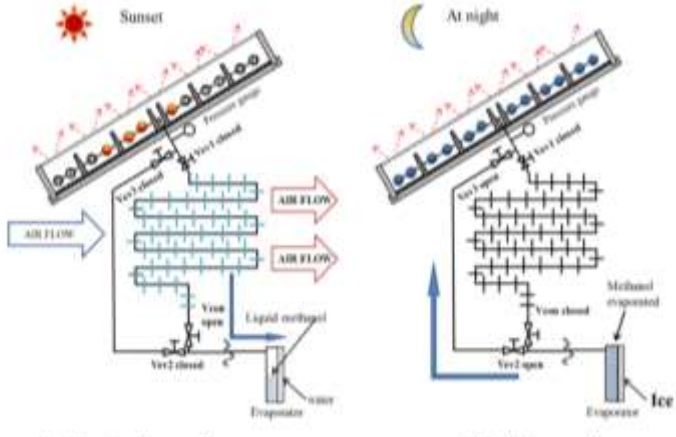


Figure 2.3 Experimental method of a solar-driven adsorption refrigerator



(a) Isosteric heating **(b) Desorption**



(c) Isosteric cooling **(d) Adsorption**

Figure 2.4 Solar-driven adsorption refrigeration system

a. Isosteric Heating Process of the Adsorbent

The adsorbent (activated carbon inside the copper tube) is heated up together with adsorbate (methanol) that was trapped in the micro pores of activated carbon particles. During this phase, the solar collector is not connected to the condenser and the pressure increases from Pev to Pcon. Concentration of methanol inside the activated carbon in this process remains changed. Energy input (energy losses are not taken into account) to heat activated carbon and methanol can be calculated by Eq. (1), as shown below:

$$Q_{A-B} = (C_{ac}M_{ac} + C_M M_M)(T_{gen} - T_{con}) \qquad (1)$$

$Q_{A\text{-}B}$ is heat supplied to heat activated carbon and methanol from point A to point B in Fig. 2.4 (a);
C_{ac} and C_M represent heat capacities of activated carbon and methanol, respectively;
M_{ac} and M_M are masses of activated carbon and methanol adsorbed (M_M=xAM_{ac}), respectively;
and T_{con} and T_{gen} are activated carbon and methanol-activated carbon temperature at points A and B, respectively.

b. BC is the isobaric heating process of the fluid (decreasing the fluid concentration shown in fig.2.4 b)

The activated carbon releases the methanol to the condenser and decreases with heating; therefore, concentration of methanol (x) is no longer a constant in this process. Energy input for desorption of methanol from activated carbon is shown in Eq. (2):

$$Q_{B-C} = (C_{ac}M_{ac} + C_M M_M)(T_{gen} - T_{con}) + \Delta_x M_{ac} H_d \qquad (2)$$

where
$Q_{B\text{-}C}$ is heat supplied to heat activated carbon and methanol, leading to desorption;
M_M is the average mass of methanol, which can be calculated approximately using $M_M=(M_{MB}+M_{MC})/2$;

T_{gen} and T_{max} are the temperature of points B and C, respectively; Δx is concentrated variation that is calculated by $\Delta x = x_B - x_C$;and H_d is desorption heat constant for a given pair.

III. MATERIALS AND METHODOLOGY

- The solar refrigerator consists of a solar collector, a condenser and an evaporator coupled by means of a structure and connected in series through a copper tube
- The solar collector has the dimensions 1 m x 1 m stainless steel plates. Internally the collector has eight copper tubes 1 m long and 40mm in diameter, containing activated carbon, covered with copper mesh into a tube of 15 mm in diameter, allowing access of methanol in gas phase for adsorption. The collector has a tempered glass dimensions 1 m x 1 m, which determines the catchment area of solar radiation
- The condenser is made of copper tube 66, 48 mm in diameter and 0.7 m long of heat exchange area 1.02 m^2.
- The evaporator made, 1.5 inches in diameter and 0.5 m^2 of heat exchange area, is located at the bottom of the system.
- To determine the dimensions of the exchanger, collector-condenser-evaporator, mass amount of methanol and activated carbon is used the following design conditions:
    a. Flow of methanol vapor is assumed laminar.
    b. Coefficient of heat transfer between the condenser tubes and air is assumed 350 w/m^2K.
    c. Coefficient of heat transfer between the evaporator tubes and the medium is assumed 100 w/m^2K.

For the condenser would remain the following arguments: Considering a condensation time of 4 hours, and knowing that the latent heat of condensation of methanol is 1160 kJ/kg, we have:

$$Q_c = \frac{(1160\ \text{kJ/kg x } 2.62\ \text{kg})}{(4 \text{ x } 3600\ \text{s})} = 281.04\ \text{w}$$

$$Q_c = h \text{ x } A_{sc} \text{ x } \Delta T$$

$$A_{sc} = \frac{(281.04\text{w})}{\left(350\ \frac{\text{w}}{\text{m2}} * \text{K}\right) \text{x } (1\ \text{K})}$$

$$A_{sc} = 0.8096\ m^2$$

i. Area of copper tube = 0.7 m^2 which consists of 66 copper tube of diameter 2.06 mm and 7 m long.
ii. Area of fins = 0.3136 m^2 which consists 66 circular fins of dimension 80 mm (W) x 800mm (L) x 0.3mm (T).

- Taking the mass of methanol may result in the amount of activated carbon that is required in the system by Raduskevich Dubinin equation, which consists of:

$$X=0.316 \text{ Exp}\left[-1.12 \text{ x } 10-6 \text{ x } \left(\text{T} \ln\left(\frac{P_s}{P}\right)\right)^2\right]$$

Where x represents the mass of methanol per unit mass of activated carbon, T is temperature in degrees Kelvin activated carbon, P the vapour pressure of methanol in the system, and P_s the saturation pressure of methanol at the temperature of the activated carbon. Referencing the saturation pressure of methanol as a function of temperature with the following equation.

$$\text{Log}_{10} \text{P mmHg} = 7.87863 - \left(\frac{1473.11}{230+T}\right)$$

By assuming a temperature of 80°C on activated carbon, it has a saturation pressure of 1338.63 mmHg taking a pressure of 21 mmHg for -5ºC would give a value of X = 0.28 indicating that for every kilogram of activated carbon will 0.28 kilograms of methanol. Knowing that they chose to use 5 liters of methanol 2.74 kg was calculated 17.8571 kg of activated carbon. As the uncertainty of the activated carbon that was used is significant, since the activation technique is emerging, apply 20 kg of charcoal. These fairly Iran organized in copper pipe, nominal diameter 50mm and a length of 1 meters so entangled that methanol has a good flow area. The collector tubes are painted black for better uptake of radiation. The solar collector has a tempered glass 1.32 m^2 to retain heat radiation, thus giving an area of 1.32 m^2 incident radiation.

- The lowest temperature was stable for a considerable time is maintained between 9 and 11 degrees, so the calculation of COP reduction estimated temperature from 26ºC to 11ºC. Taking an amount of 7 litres of water in the evaporator, is necessary:

$Q_{c.agua}$ = (4.18 kJ/kg*K) x (7 kg) x (15 K) = 438.9 KJ
$Q_{c.agua}$: power removed from the water to reach the minimum temperature
COP = ($Q_{c.agua}$)/ (solar radiation during time of insolation).

Solar energy Q_{in} received corresponds to the area where incident. On the horizontal the slope in the solar collector to facilitate calculations, the Q_{in} obtained is calculated:

$$Q_{in} = H_{prom} \text{ x } A_{incidencia}$$

The H_{prom} = 3577 Wh/m^2 will be converted to Joules MJ/m^2 12.88, taking the respective exposure time as 5 hours. Moreover, as has a tempered glass dimensions 1.25 x 1.08 m, the area of sunlight will be 1.36 m^2. Therefore, the Q_{in} will be:

Qin = (12.88 MJ/m^2) x (1.36 m^2)
Qin = 17.52 MJ

After the calculation the COP will be:

$$\text{COP} = \frac{313.50\ \text{kJ}}{17.52\ \text{MJ}}$$

COP = 0.018

Since it is not producing ice reached the desired amount, the solar coefficient of behavior is very low. When compared with the desired scope in the design is the production of ice, would theoretically produce energy 2209.15 kJ and is associated with the measurement of heat stroke. The ideal range would be:

$$COP_{ideal} = \frac{2209.15\ \text{kJ}}{17.52\ \text{MJ}}$$

$COP_{ideal} = 0.13$

Given the same conditions shows that the cycle had a:

$$\eta = \frac{COP}{COP_{ideal}} \times 100$$

$\eta = 14.28\ \%$

IV. RESULTS

- The mass of tomato loss in ZECC is 0.01 to 0.05 % by mass per hour.
- In atmosphere condition, the mass of tomato loss is nearly 0.1 % to 0.6 %.
- This study is related to 5 kg of tomato and at two different condition i.e.
    i. At open atmospheric condition.
    ii. At ZECC Condition.
- In ZECC, the mass of tomato reduces is 0.12 kg/10 days.
- In open atmospheric condition, the loss of mass by weight is 3 to 4 kg. (All observation for 16 days).
- In ZECC system, the tomato life is increase for 7 to 16 days.

V. CONCLUSION

The solar flat plate collector seems to be an interesting option as a collection system or the driven for cooling system and for solar adsorptive refrigerators. Our primary object of the design ZECC prototype uses the activated carbon–methanol pair and was used tested at KDK College of Engineering, Umred. The unit also includes a air cooled condenser, where condensation takes place outside an array of horizontal tubes. The evaporator is a grid of vertical tubes and is directly connected to the condenser.

In his study, a new ZECC with two types of cooling system, a solar-driven adsorption refrigerator and an evaporative cooling system, was developed. The solar-driven adsorption refrigerator produced about 3.5 kg of ice per day with a solar COP of 0.018. Both cooling systems allowed lowering of the inside temperature of the new ZECC without any electricity. The inside temperature during the diurnal change was lowered to 21.9^0C by watering and then further reduced to 13.6^0C by applying the solar-driven adsorption refrigerator, while the ambient outside temperature was 32.6^0C. The shelf life of tomatoes was extended from 7 to 16 days. Physiological loss in weight (PLW) of 3.6%. Thus, the new ZECC proposed here is very effective in lowering the storage temperature and expanding the shelf life of fruit and vegetables in an area without electricity. This system can help to store medicine and vaccine in the remote areas of the developing countries.

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