# DESIGN, CONSTRUCTION AND TESTING OF A COOLING SYSTEM OF SOLAR ADSORPTION

**Emil Hernández Arroyo, emil.hernandez@upb.edu.co**
Universidad Pontificia Bolivariana, Km 7 via Piedecuesta Bucaramanga-Colombia

***Abstract.*** *Design, construction and test run of a solid adsorption solar refrigerator are presented. It was used methanol/activated carbon as the adsorbate/adsorbent pair. The refrigerator has three major components: collector, condenser and evaporator. Its flat plate type collector/generator/adsorber used clear plane glass sheet of effective exposed area of 1.39 $m^2$. The steel condenser of 9 tubes, with transference area of 0.6 $m^2$ a square plan view was immersed in a pool of stagnant water contained in a tank. The evaporator of 9 steel tubes, with transference area of 0.51 $m^2$, immersed in stagnant water. Adsorbent cooling during the adsorption process is by natural convection of air over the collector plate. Ambient temperatures during the adsorbate generation and adsorption process varied 18.0 – 38.0 °C. The temperatures of refrigerator's evaporator ranging over 8 – 23 °C. According, the maximum daily useful cooling produced was 225.5 KJ/$m^2$ of collector area.*

***Keywords****: Solar; Solid adsorption; Refrigeration; Adsorbent; Condenser; Evaporator; Solar collector.*

## 1. INTRODUCTION

On this work has been developed a cooling system using solar energy as source. We have proposed a refrigerator design using the subsurface physical process called adsorption with methanol and activated carbon as a refrigerant and adsorbent, respectively, as well as building and testing the system collecting data with sensors that monitoring temperature and pressure in several points.

The cooler consists of a solar collector where the activated carbon is placed in contact with the sun whose presence and absence allowed the cycle [1]. Others important elements of the system are the condenser, working day, and the evaporator to cool water at night. The system is designed for cooling water at a temperature of 4 ° C but the ideal is to get ice.

The development of these systems is a great benefit because it eliminates the use of chlorofluorocarbons (CFCs), harmful to the ozone layer. Similarly there is a great economic benefit because these systems do not require connection to power grids.

## 2. STATE OF THE ART

### 2.1 Pons & Guilleminot Syistem

The development of solar refrigerators emerged in late 1970. One of the pioneers, Tchernev [1], studied the basic cycle of zeolite-water adsorption pairs. Pons & Guilleminot [1] developed a prototype working with activated carbon – methanol pairs producing 6 kg of ice per day with an irradiance of 20 MJ / day reaching a legendary COP of 0.12 [see Figure 1].

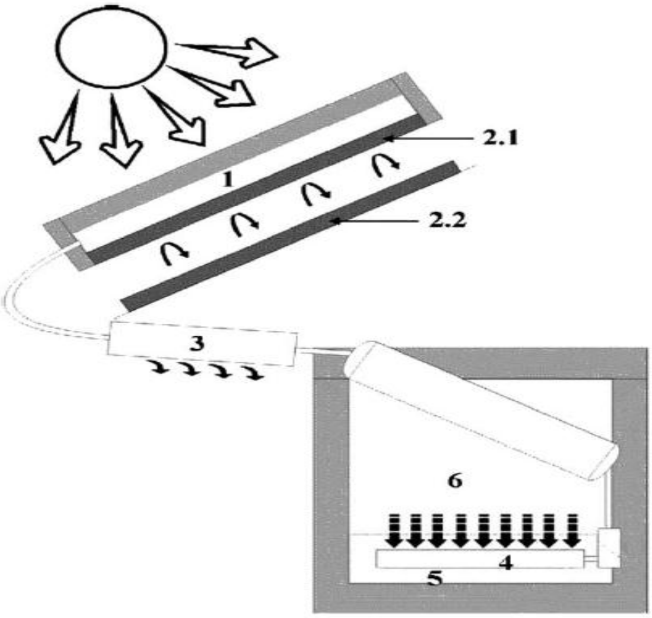


Figure 1. Diagram of Pons & Guilleminot system
Source: [2]

**2.2 Critoph System** [see Figure 2]

Hildbrand developed a system that worked with silica gel - water [2], producing ice in the evaporator, had a collector of 2 $m^2$ and kept in operation for 68 days showing a high influence of the environment (radiation and external temperature), for doses higher than 20 MJ/m2 COP occurred between 0.12 and 0.23, with an external temperature between 12 and 25° C.


Figure 2. Detail of solar collector in the Critoph system
Source: [5]

## 3. 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 stainless steel tube a quarter inch, as shown in Figure 3.


Figure 3. solar Refrigerator
Source: Autor

The solar collector has the dimensions 1.6 m * 0.8 m * 0.13 m stainless steel plates. Internally the collector has eight stainless steel tubes 1.6 m long and 1.5 inches in diameter, containing activated charcoal, covered with steel mesh into a tube of 2 cm in diameter, allowing access of methanol in gas phase for adsorption. The collector has a tempered glass dimensions 1.65 m * 0.82 m, which determines the catchment area of solar radiation (see Figure 4).

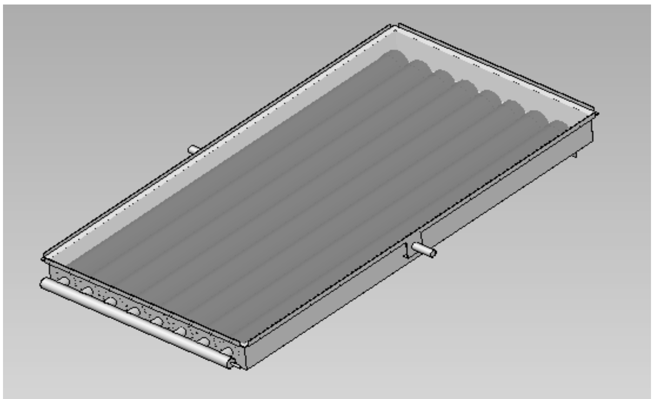

Figure 4. Solar Collector
Source: Author

The condenser was made of stainless steel tubing 18 gauge, 1.5 inches in diameter and 0.6 m 2 of heat exchange area. The structure is immersed in an aluminum box of dimensions 0.32 m * 0.80m * 0.45m which exchanges heat with water (see Figure 5).

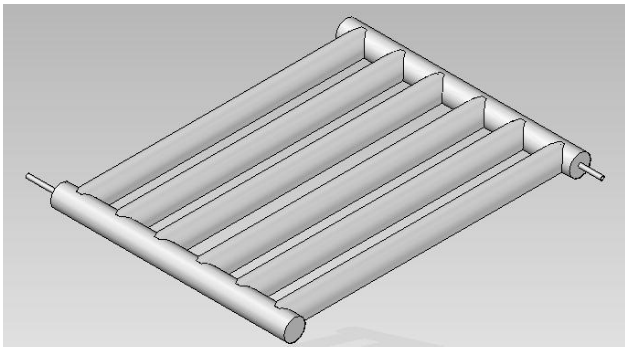

Figure 5. Condenser
Source: Author

The evaporator made of 18 gauge stainless steel, 1.5 inches in diameter and 0.5 m 2 of heat exchange area, is located at the bottom of the system (see Figure 6).

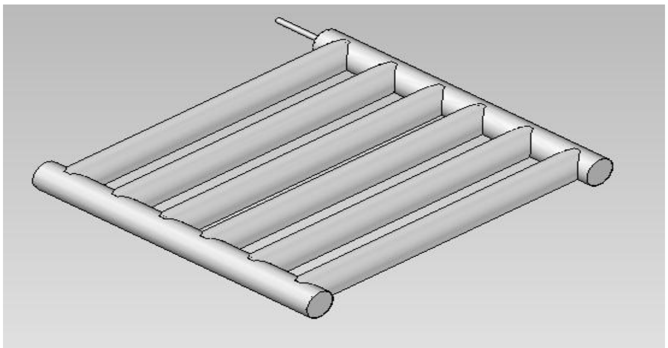

Figure 6. Evaporator
Source: Author

To determine the dimensions of the exchanger, collector-condenser-evaporator, mass amount of methanol and activated carbon is used the following design conditions:
* 5 kg of liquid water at 26 ° C which will become ice at 0 ° C.
* Flow of methanol vapor is assumed laminar.
* Coefficient of heat transfer between the condenser tubes and water is assumed 350 w / ($m^2$ K).
* Coefficient of heat transfer between the evaporator tubes and the medium is assumed 100 w / ($m^2$ K).

To calculate the mass of methanol used to obtain 5 kg of ice to be as follows [4]:

$$Q_T = Q_{c.agua} + Q_{s.agua} \quad (1)$$

$$Q_{c.agua} = C_{p.agua} * M_{agua} * \Delta T \quad (2)$$

$$Q_{c.agua} = (4.18 \text{ kJ/kg*K}) * (5 \text{ kg}) * (26 \text{ K}) = 543.40 \text{ kJ}$$

$$Q_{s.agua} = L_{f.agua} * M_{agua} \quad (3)$$

$$Q_{s.agua} = (333.15 \text{ kJ/kg}) * (5 \text{ kg}) = 1665.75 \text{ kJ}$$

$$Q_T = 543.40 \text{ kJ} + 1665.75 \text{ kJ} = 2209.15 \text{ kJ}$$

Taking the heat of vaporization of methanol and 1180 kJ / kg, is obtained:

$$Q_T = L_{e.met} * M_{met} \quad (4)$$

$$M_{met} = (2209.15 \text{ kJ}) / (1180 \text{ kJ/kg}) = 1.87 \text{ kg}$$

Taking an efficiency factor of 0.8 [5] has a mass of 2.34 kg and knowing that its density is about 0.79 kg / L will require a volume of $\approx$ 3 L.
For the condenser would remain the following arguments:
Considering a condensation time of 3 hours [6], and knowing that the latent heat of condensation of methanol is 1160 kJ / kg, we have:

$$Q_c = (1160 \text{ kJ/kg} * 1.87 \text{ kg})/(3 * 3600 \text{ s}) = 200.85 \text{ w}$$

$$Q_c = h * A_{sc} * \Delta T \quad (5)$$

$$A_{sc} = (200.85 \text{ w})/[(350 \text{ w/m}^2\text{*K})*(1^o\text{K})$$

$$A_{sc} = 0.57 \text{ m}^2$$

It would take a transfer area of 0.6 m2. This will have 9 tubes of 55 cm and a diameter of 1 ½ inches above. The condenser is tilted about 20 degrees to ensure the flow of methanol and then condense it will fall by gravity.

For the evaporator was estimated evaporation time of 4 hours [8] and considering a latent heat of evaporation of 1180 kJ / kg [11], we have:

$$Q_e = (1180 \text{ kJ/kg} * 1.87 \text{ kg})/(4 * 3600 \text{ s}) = 153.24 \text{ w}$$

$$Q_e = h * A_{se} * \Delta T \tag{6}$$

$$A_s = (153.24 \text{ w})/[(100 \text{ w/m}^2 * \text{K}) * (3^{o}\text{K})$$

$$A_s = 0.51 \text{ m}^2$$

To get an evaporation area of 0.51 m2. This will organize 9 tubes of 45 cm and a diameter of 1 ½ inches to exchange heat.

Taking the mass of methanol may result in the amount of activated carbon that is required in the system by Raduskevich Dubinin equation [7], which consists of:

$$x = 0,316\, e^{-1.12 \times 10^{-6} (T \ln(\frac{P_s}{P}))^2} \tag{7}$$

Where x represents the mass of methanol per unit mass of activated carbon, T is temperature in degrees Kelvin activated carbon, P the vapor pressure of methanol in the system, and Ps 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 [8]:

$$\text{Log}_{10} P_{mmHg} = 7.87863 - [(1473.11)/(230+T)] \tag{8}$$

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 -5 º C 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 3 liters of methanol (2.34 kg) was calculated 8.36 kg of charcoal. As the uncertainty of the activated carbon that was used is significant, since the activation technique is emerging, apply 15 kg of charcoal. These fairly Iran organized in 8 stainless steel pipe, nominal diameter 8.91 mm and a length of 1.57 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 [9] 1.62 * 0.86 m2 to retain heat radiation, thus giving an area of 1.39 m2 incident radiation. Figure 7 shows the solar refrigerator finally assembled with all components.

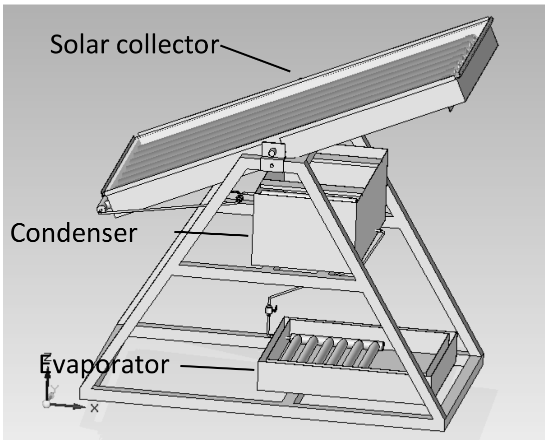


Figure 7. Solar Refrigerator, one way, accopled with all components.
Source: Autor

## 4. RESULTS AND DISCUSSIONS

as designed and built a solar refrigerator using activated carbon and methanol, as shown in Figure 1.

Methanol is injected into the evaporator which is insulated with polyurethane. Subsequently the activated carbon is introduced into the solar collector and a vacuum is created in the system. Parallel solar radiation is recorded with a pyranometer, yielding an average value of 777.8 W/m2.

The lowest temperature was stable for a considerable time is maintained between 8 and 10 degrees, so the calculation of COP reduction estimated temperature from 23 º C to 8 º C. Taking an amount of 5 liters of water in the evaporator, is necessary:

$$Q_{c.agua} = (4.18\ kJ/kg*K) * (5\ kg) * (15\ K) = 313.50\ Kj$$

$Q_{c.agua}$: power removed from the water to reach the minimum temperature.

COP = ($Q_{c.agua}$)/ (solar radiation during time of insolation).

Solar energy (Qin) received corresponds to the area where incident. On the horizontal the slope in the solar collector to facilitate calculations, the Qin obtained is calculated:

$$Q_{in} = H_{prom} * A_{incidencia} \tag{9}$$

The Hprom (3577 Wh/m2) will be converted to Joules MJ/m2 12.88, taking the respective exposure time as 5 hours. Moreover, as has a tempered glass dimensions 1.65 * 0.82 m, the area of sunlight will be 1.36 m2. Therefore, the Qin will be:

$$Q_{in} = (12.88\ MJ/m^2) * (1.36\ m^2)$$

$$Q_{in} = 17.52\ MJ$$

After the calculation the COP will be:

$$COP = (313.50\ kJ)/(17.52\ MJ)$$

$$COP = 0.018$$

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 [10]:

$$COP_{ideal} = (2209.15\ kJ) / (17.52\ MJ)$$

$$COP_{ideal} = 0.13$$

Given the same conditions shows that the cycle had a:

$$\eta = (COP/COP_{ideal}) * 100 \tag{10}$$

$$\eta = 14\%$$

By presenting this efficiency should look at various aspects. One of them, the most important and which generates more uncertainty, the activated carbon is not presented as an exact factor since its development at the regional level is emerging, companies do not have laboratories that provide better information on such minerals as its high adsorptive capacity at room temperature and low pressure as much as its low adsorptive capacity at high temperatures. Also consider that the environment is very variable in Bucaramanga, dates mitigation analysis showed precipitation during the day, the system cycle and the regeneration temperature was not high (average 61.17 ° C).

Other models showed coefficients of performance between 0.06 and 0.15 [12], [13] that range exceed the results of the review cycle. That is due to the achievement of getting lower the temperature below 0 º C and the solidification of water.

## 5. CONCLUSIONS

We built a solar cooling system consists of a solar collector, a condenser and an evaporator made of stainless steel. Due to radiation and the action of activated carbon, the system allows a refrigeration cycle established intermittent cooling at night [14].

The results of the experiment was obtained a minimum temperature in the evaporator 8 ° C, which was determined COP 0018 system with an efficiency of 14%.

## 6. ACKNOWLEDGEMENTS

The development of this research was supported financially by 100% by General Research Department (DGI) of the Universidad Pontificia Bolivariana, Bucaramanga and framed in a graduation project executed by students of Mechanical Engineering: Javier Bautista and Orlando Monsalve .

## 7. REFERENCES

[1] Pons M, Guilleminot JJ. Design of an experimental solarpowered, solid-adsorption ice maker. ASME 1986.

[2] Critoph RE. Laboratory testing of an ammonia carbon solar refrigerator. Hungría 1993.

[3] V. Passamai y M. Bernaski. Experiencias de refrigeración con una caja de heladera. Argentina 2002.

[4] Martínez J. Adsorción física de gases y vapores por carbones, Universidad de Alicante, España 1990.

[5] Tchernev DI. Solar energy application of natural zeolites, in natural zeolite: occurrence, properties and use. Oxford 1978.

[6] Zigler F. Recent developments and future prospects of sorption heat pump systems. International Journal of Thermals 38, 1990.

[7] E.E. Anyanwu. Review of solid adsorption solar refrigeration II: An overview of the principles and theory. Energy Conversion and Management 45, 2004.

[8] Hildbrand C, Dind P, Pons M, Buchter F. A new solar powered adsorption refrigerator with high performance. Sol Energy 2004.

[9] Li M, Wang RZ, Xu YX, Wu JY, Dieng AO. Experimental study on dynamic performance analysis of a flat-plate solar solid-adsorption refrigeration for ice maker. China 2002.

[10] Sergio Vera, Rodolfo Echarri, Andres Sartarelli, Ernesto Cyrulies, Inna Samson, Construcción de una Heladera Solar por Adsorción. Avances en Energías Renovables y Medio Ambiente, Vol. 12, Argentina 2008.

[11] Antonio Pralon Ferreira Leite, Refrigerador solar para producción de hielo usando carbón activado-metanol. Universidade Federal da Paraíba, Brazil 2000.

[12] F. Lemini, A. Errougani, F. Bentayeb. Realisation experimentale d'un refrigerateur solaire a adsorption à Rabat., FIER' 2002 Tetouan Maroc.

[13] R.Z. Wang, R.G. Oliveira, Adsorption refrigeration, An efficient way to make good use of waste heat and solar energy. Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, China 2006.

[14] John A. Dean. Lange's Handbook of Chemistry 10th ed.

[15] Leite, Antonio Pralon Ferreira, Michel Daguenetb. Performance of a new solid adsorption ice maker with solar energy regeneration. Energy Conversion & Management. Solar Energy Laboratory, Federal University of Paraiba, Brazil 2000