Research Article

Solar cooling system by absorption in areas of high irradiation in Colombia

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ABSTRACT:
This paper examines the potential of a solar refrigeration system by absorption in areas of high irradiation in Colombia for the conservation of food and medicine, through the analysis of Servel refrigeration characterized by a Domestic RH 131 refrigerator. For this analysis, real data was taken from the operation of the equipment, with input and output temperatures of each element of the system, in order to verify its cooling capacity. In this way, the working conditions were determined, as well as the heat required by the generator in which the chemical compression of the substance used to determine the solar collector will take place. For the simulation, the system is assembled in Trnsys coupled to thermal collectors and photovoltaic panels to simulate the real conditions of this, thus seeking to make an analysis of the behavior of the equipment and determine the viability of the system supported by solar energy.

KEYWORDS: absorption cooling, solar energy, generator thermal panels.

I. INTRODUCTION

Colombia is country rich in natural resources, even for their wealth today there are difficulties in some territories, among these, the lack of electricity in non-interconnected zones (NIZ) included in 52% of the Colombian territory [1], since being difficult to access, they lack physical structures, public services, education and communication [2]. Given Colombia's potential to generate energy from non-conventional sources of alternative energy [3] in this case the sun, its inhabitants still suffer the consequences of limited access to it, leading to not being able to use food and drug preservation devices through refrigeration, which would guarantee an im-proved quality of life [4]. The lack of electrical energy services has been evidenced in the impact caused in the indexes of suffering from ETA diseases. In the same way, departments like La Guajira, Atlántico and Barranquilla have presented increases in deaths due to malnutrition in children under 5 years old [5]. Thus, it is desired to seek solutions that, according to law 9 of 1979 [6], where the need to preserve food and medicines through adequate refrigeration systems is expressed, guaranteeing the necessary conditions for human consumption.

This article studies the potential of a solar cooling system by absorption in areas of high irradiation in Colombia, since the Caribbean Region and sectors of the Orinoquia and Inter-Andean Valleys [7], do not have electric energy, seeking to promote an improvement in the preservation of food and medicine. According to the above, absorption cooling is a system that works through the use of residual vapors, electrical resistances and hot water, with solar energy being an alternative for the cooling system [8]. Solar radiation is understood as the density of solar radiant flux [9] that radiates an energy of 4x1026 Joule which is a total power of all the power plants [10].

Due to the above mentioned, the purpose of this study is to show solar energy as an alternative to improve the social conditions of the less favored departments in Colombia, hoping to diminish problems related to the conservation of food and medicines, avoiding the proliferation of infections, since the use of solar energy presents an important reduction of costs thanks to the constant advances in technology, thus allowing an increase in the demand [11], hoping in the same way, to be the basis for future research using the solar potential as an energy source, also, to look for alternative cooling ways requiring a compression system that changes the state of the refrigerant gas.

Different studies have provided a clear idea of how this alternative has been used, to determine what type of absorption system is appropriate for cooling by means of solar energy, starting with [12], the one that presents an electrical characterization of a photovoltaic system to determine the electrical parameters under conditions of global solar irradiance and environment. In the same way [13], in its research, obtained results on the use of photovoltaic energy and its impact on rural development in the municipality of Tauramena.

The authors [14] implemented a PV system to generate energy in the homes of the municipality of Arbeláez Cundinamarca, installed in a hybrid way with solar cells and a bank of batteries as a backup system; [15] established the procedure for the determination of the thermodynamic parameters in the components in an absorption cooling system through the mass and energy balance of house one with ammonia/water refrigerant; [16] designed an absorption cooling system applying Matlab system determining the necessary load in the generator, absorber, condenser, ex-changer and evaporator for the selection of the components that integrate it.

A. THEORETICAL BASES

Photovoltaic solar energy generates direct current by means of semiconductors, which have electrons. While the light falls on the photovoltaic element, electrical power is generated and when this is extinguished, it disappears. According to [17], solar radiation can be used in two ways: by the transformation of solar radiation into heat in which it can be used to produce hot water, also to produce mechanical energy through a thermodynamic cycle and through an alternator generate electric energy, and by the transformation of solar radiation into electricity carried out by the semi-conductor elements that make up the panels, can be stored in batteries [18]. The photovoltaic system consists of a generator, a regulator and a battery bank [19].

Among the solar collectors adopted in this scheme is the flat collector, being used in this type of installations, another possibility is the collectors with vacuum tubes or concentration [20]. The efficiency of solar operated absorption cooling cycles basically depends on the efficiency of the solar collectors and the performance of the absorption cooling system used [21]. The electrical consumption of an absorption system is reduced as the solar capture area increases. For these systems, the most commonly used refrigerants are water/lithium bromide (H_2O/LiBr) and ammonia/water (NH_3/H_2O) [22], the Water Ammonia cycle is suitable for the use of energy as a heat source. It uses a liquid pump to differentiate the pressures in the evaporator and the condenser [23]. Ammonia is a naturally occurring substance, which is a colorless, low-density gas with a strong odor [24]; the lithium bromide water system uses R-718 (water) as the refrigerant, with lithium bromide as the absorbent. Servel absorption systems are a type of refrigeration that does not require pumping system because it is replaced with the use of hydrogen, which allows substances to cycle in the pipes of the refrigerator. In this way, the ammonia condenses at a temperature and evaporates at a lower one, achieving refrigeration without the use of a compressor or pump [25].

II. METHODOLOGY

It was necessary to characterize the Servel system, which consists of taking the cooling temperature to determine the thermodynamic states and its efficiency. A code is made in the EES software to describe the behavior of the refrigerator and the parameters of each system of the refrigerator.

The amount of heat energy is determined, starting with the intake of one Kg of water equivalent to 19.6°C, entering the fluid to the refrigerator to take the time required to reduce the temperature by 1°C, see Table 1.

Table 1. Data collection of temperatures with respect to one kilogram of water to be cooled.

Time of the experiment	**Kg of water to be cooled**	**Initial temperature**	**Experimental Temperature Delta**	**Time required in hours**
1	1	Environment	1 °C	12.01 minutes
	1	Environment	1 °C	12.5 minutes
	1	Environment	1 °C	11.58 minutes
	1	Environment	1 °C	12.0 minutes

Since the time in which the temperature decreases within two days is between 11.58 min to 12.1 min, a thermal balance is performed since there is no significant change.

Thermal load calculation: The first law of thermodynamics is used, **Q_R=m˙_agua/T×C_p×ΔT**

Data are taken from Table 1 to replace the equation

$$Q\_R = (1\ Kg)^{\dot{}}/(12.01 * 60) \times 4.18\ \ KJ/(Kg \times °C) \times (19°C - 18°C)$$
$$Q_p = 0.0058\ kW$$
$$Q_p = 5{,}80\ W \quad (1)$$

The same equation is performed in each time, reaching the conclusion that the thermal loads for the product are very similar, throwing the cooling load of the product Q_R,

$$Q\_R = (5.80 + 5.78 + 6.02 + 5{,}80)/4$$
$$Q_R = 5{,}85\ W \quad (2)$$

Heat transfer calculation by walls: Solar radiation is taken into account as the refrigerator will be in outdoor environments, the walls are composed of galvanized sheets, polystyrene 1-inch-thick to dissipate solar heat.

To find the load, take the area of the four faces plus the ceiling

$$A = 2(0.401 \times 0.554) + 2(0.446 \times 0.554) + (0.446 \times 0.401)\ m^2$$
$$A = 1.117\ m^2 \quad (3)$$

Initially, the area obtained from the four sides and the ceiling is converted to $\boldsymbol{pie^2}$

$$1m^2 - - - - - 10.763\ pie^2 \quad (4)$$

Where the area of the system in pie^2 is: $= 12.03\ pie^2$

The table asks for the temperature differential in °F, using the equation.

$$°F = 1.8 \times 31.2°C + 32$$
$$°F = 88.16°F$$
$$°F = 1.8 \times 5°C + 32$$
$$°F = 41\ °F \quad (5)$$

In order to find the room temperature differential (Guajira temperature) with the refrigerator temperature (5°C according to thermostat) the heat gain is calculated.

$$\Delta t = 88.16°F - 41°F$$
$$\Delta t = 47.16\ °F \quad (6)$$

With the formula $\boldsymbol{Q_{Irradiación\,solar} = U \times A \times \Delta T}$ the solar radiation is found and the global U and the area is replaced by the four sides of the refrigerator plus the roof.

$$Q\_(Irradiación\,solar)$$
$$= (0{,}033\ Btu/(\ 〚pie〛\ \text{^}2 \times °F)) \times 12.03\ \ 〚pie〛\ \text{^}2 \times 47.17°F$$
$$Q_{Irradiación\,solar} = 16{,}34\ Btu \quad (7)$$
$$1\ W\ equivale\ a\ 3.412\ Btu$$

The heat gain by transfer is: $Q_{Irradiación\,solar} = 4{,}79\ W$

Infiltration: This occurs when outside air enters the refrigerator, either through openings in the refrigerator or through the opening of doors. With the infiltration equation the sensitive load is calculated.

$$Q_{IS} = 1.1 \times CFM \times \Delta T \quad (8)$$

The use of the air psychometric chart to find the amount of water grains to be removed by the amount of moisture entering the refrigerator.

$$Q_{IL} = 0{,}68 \times CFM \times \Delta H_{gh20} \quad (9)$$

The CFM must be found, to do so, the equation (9) is used.

$$V_{Nevera} = 0{,}401\ m\ \times 0{,}054\ m\ \times 0{,}446\ m$$
$$V_{Nevera} = 0{,}099\ m^3 \quad (10)$$

As the tables are in the English system, the conversion of $\boldsymbol{m^3}$ to $\boldsymbol{pie^3}$

$$1\ m^3\ \leftrightarrow 35{,}32\ Pie^3$$
$$0{,}099\ m^3\ \leftrightarrow V \quad (11)$$
$$V_{Nevera} = 3.5\ Pie^3$$

The value one (1) taken in the formula described is taken from the book Principles and Systems of Refrigeration [26].

$$CFM = 1 \times V/60$$
$$CFM = 1 \times (3{,}5\ \ 〚pie〛\ \text{^}3)/60 \quad (12)$$
$$CFM = 0.0583\ \ 〚pie〛\ \text{^}3/min$$

Having the CFM, the calculation of sensible heat that enters the refrigerator with the use of the equation is carried out, obtaining the heat gain.

$$Q_{IS} = 1.1 \times CFM \times \Delta T \quad (13)$$

$Q\_IS = 1.1 \times 0{,}0583 \quad 〚Pie〛 \,\hat{}3/minuto$
$\times (47{,}16\ °F)$
$Q_{IS} = 3{,}024\ Btu$
$Q_{IS} = 0{,}885\ W$

For the Calculation of Latent Heat by Infiltration, the previously calculated CFMs are taken and replaced in the formula. To determine the $\Delta \boldsymbol{H}_{\boldsymbol{gh20}}$, is done through the use of the psychrometric chart:

$$Q_{IL} = 0{,}68 \times CFM \times \Delta H_{gh20}$$
$$Q\_IL = 0{,}68 \times 0{,}0583 \quad 〚Pie〛 \,\hat{}3/minuto \times (175\ - 135)$$
$$Q_{IL} = 1{,}586\ Btu$$
$$Q_{IL} = 0{,}464\ W \qquad (14)$$

The total heat gain by infiltration is the result of the sum of the sensible and latent heat gain.

$$Q_{TI} = Q_{IS} + Q_{IL}$$
$$Q_{TI} = 0{,}885\ W + 0{,}464\ W \qquad (15)$$
$$Q_{TI} = 1{,}349\ W$$

The refrigerator has a 10W consumption LED bulb, the heat gain by lights inside the refrigerator is:

$$Q_{Luces} = 10\ W \times 0{,}2$$
$$Q_{Luces} = 2\ W \qquad (16)$$

The sum of all heat gains results in the refrigerator's cooling capacity.

$$Q_L = Q_P + Q_R + Q_{IT} + Q_{Luces}$$
$$Q_L = 5{,}85\ W + 4{,}79\ W + 1{,}35\ W + 2W \qquad (17)$$

The cooling capacity of the Dominic system is 40 liters: $\boldsymbol{Q_R = 14\ W}$

Energy capacity of the generator: The 40-liter Dominic refrigerator has a heating element inside the generator to heat the ammonia water mixture. To determine the consumption in amps, a datalogger is used, which records current results with respect to time.

The behavior of the refrigerator is measured with the product load inside, as the temperature of the generator increases, the conservation temperature decreases, the minimum recorded is 5°C.

Solar installation: The Siemens pumping system is used, with a flow capacity of 10 lt/min, which determines the amount of mass per second that runs through the solar thermal panel.

Solar Collector Selection: Depending on the energy demand of the generator of the absorption unit, the capacity required by the generator is taken, which is 66.67. The efficiency depends on the average, ambient temperature of the area and the characterization points of the panel.

Collector selection: The behavior of the thermal collector is represented by the following equation which can establish the performance.

$$\eta\_C = \eta\_0 - ((k\_1 \times (T\_m - T\_a\ ))/I) - ((k\_2 \times (T\_m - T\_a\ )\hat{}2)/I) \qquad \textbf{\textit{(18)}}$$

The values of η_0, which is the optical performance of the solar collector, k_1 heat loss coefficient given in W⁄(m^2 K) and k_2, heat loss coefficient given in W⁄(m^2 K^2), are values given by the manufacturer in the data sheets.

Flat plate collector: The efficiency of the flat-plate collector is not appropriate under these characteristics; the low efficiency of the solar collectors is due to the fact that this type of collector is designed to heat domestic water at a maximum of about 80°C.

$$\eta\_C = 0{,}790 - ((2.414 \times (408.3\,K - 309{,}15\,K))/(780\,W/m\text{^}2\,)) - ((0.049 \times (408.3\,K - 309{,}15\,K)\text{^}2)/(780\,W/m\text{^}2\,)) \quad (19)$$

$$\eta_C = -0.12$$

For the absorption refrigerator, the temperature at which it must reach the generator output is 130 ℃.

Taking the Sunray Energy brand vacuum tube collector, the efficiency of the collector is:

$$\eta\_C = 0{,}79 - ((3.16 \times (408.3\,K - 309{,}15\,K))/(780\,W/m\text{^}2\,)) - ((0.009 \times (408.3\,K - 309{,}15\,K)\text{^}2)/(780\,W/m\text{^}2\,)) \quad (20)$$

$$\eta_C = 0.28$$

As the temperature range established in the table above and with the calculation of the collector efficiency, the panel selected is the vacuum tube panel.

The simulation was carried out in the area of Manaure Guajira, since it is one of the towns with more problems due to the lack of electric energy. Likewise, it is a privileged area for solar radiation, being this solar energy registered in 780 W/m^2 , sufficient for the use of energy generation, water heating and cold generation. Tansy's was used as a simulator, with the use of a black box called TYPE, containing the mathematical modeling of the system under investigation. For each of the components (heat pump, climatology, solar collectors, storage system, circulation pumps, support system) a type has been defined. Mathematical considerations, parameters, input variables and output variables that are required, in the use of the refrigerator in different climatic circumstances have been established.

III. RESULTS

The behavior of the thermal and photovoltaic installation that operated during one year was evaluated, using the Servel refrigerator with a capacity of 14 W of refrigeration and having as an energy source the solar radiation, supported by propane gas that is used in the moments of low radiation or when it cannot be supplied with the necessary energy for the activation of the refrigerator.

Likewise, an analysis of radiation and the solar behavior of Manaure was carried out, being this 780 W/m^2, in the month of December.

Manaure's meteorological data for one year corresponds to an average temperature of 27°C, with a relative humidity of 79.92% minimum radiation given in W-,-2.. was 780, it should be noted that these data are obtained by meteonor and simulated in Trnsys V17.

With the data obtained, the system is simulated, assuming that 3 thermal collectors of an area of 2.54 m^2 connected in parallel, to maintain the same temperature differential at the panel input and output, with a storage tank volumetric capacity of 0.40 m^3 and 9 photovoltaic cells

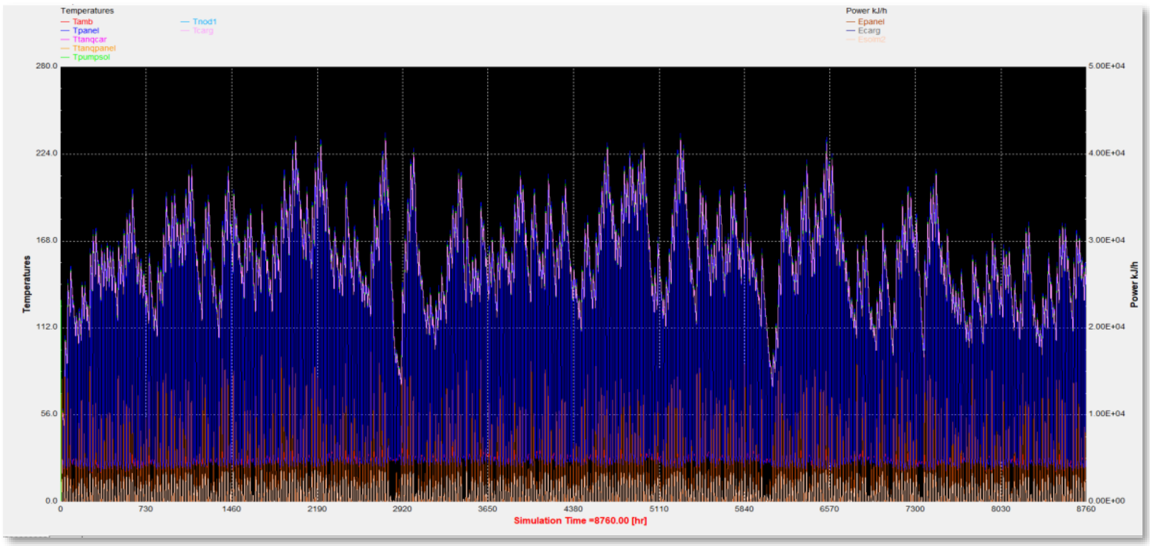

Fig. 1. Panel temperatures and energy demand.

connected in parallel to energize the pumping system. It uses oil as a working fluid in the thermal circuit. The pumping system in the first thermal circuit has a capacity of 10 l/min with a consumption of 60 W, for the second circuit a 4 l/min, with a consumption of 15 W. By means of meteonorm, the TYPE 109 is configured with all the climatic characteristics of the city of Manaure.

The thermal behavior of the proposed system working fluids is shown globally, achieving temperature ranges from 120°C to 175°C.

On the left side of the Y axis shown in Fig. 1, are the working temperatures at the generator output of the refrigerator. On the right side is the amount of energy that can be used by the solar collector, the blue color represents the temperature of the panel, associated with the energy that the solar collector delivers to the system, showing falls on certain days of the year, reaching 91.81 KJ/hr.

In the same way, the behavior of each of the panels and the systems of the refrigerator is evaluated, evidencing that sometimes the accumulator is not able to be activated, looking for an alternative solution maintaining the same scheme of collectors.

Servel System Operation Coefficient: One of the advantages of absorption systems is that they use energy sources such as steam, hot water and solar radiation. Their efficiency is measured by the condensation and the amount of energy absorbed by the conservation cellar, see Table 2.

Table 2. Temperature data of one year in Manaure Guajira.

<table>
<tr><td>Maximum Temperature</td><td>35.74 °C</td><td rowspan="4">evaporation temperature (W)</td><td>5°C</td></tr>
<tr><td>Medium High Temperature</td><td>29.38 °C</td><td>5°C</td></tr>
<tr><td>Medium-Low Temperature</td><td>27.60 °C</td><td>5°C</td></tr>
<tr><td>Low Temperature</td><td>24 °C</td><td>5°C</td></tr>
</table>

The panel generates a demand of energy to start the generator, this energy goes according to the temperature that delivers the panel, the relation is in Table 3.

Table 3. System efficiency in relation to cooling capacity.

Room temperature	**Panel output temperature**	**Panel Power**	**Calculated refrigeration demand**	**Refrigeration demand in real condition**	**Real COP**
34.9	172	0.319722222	0.014	0.02	0.0625543
29.3	158	0.22	0.014	0.01393	0.06331818
27	145	0.144444444	0.014	0.0091	0.063
24	137	0.105555556	0.014	0.0066	0.062522632

In this way, the room temperature is proportional to the temperature delivered by the solar collector. As the temperature given by the solar energy circuit increases, the cooling capacity changes, demanding more energy from the generator, with greater absorption of cooling by the cellar.

The behavior of the energetic efficiency in the refrigeration system compared to room temperature can be observed in Figure 2a.

The graph shows that the higher the temperature, the lower the efficiency because the equipment demands more energy, it should be noted that the COP only varies by 0.045%. Figure 2b shows the behavior of the COP of the system in relation to the energy of the panel. It can be noted that it is practically constant, as explained above, varying only by 0.045%.

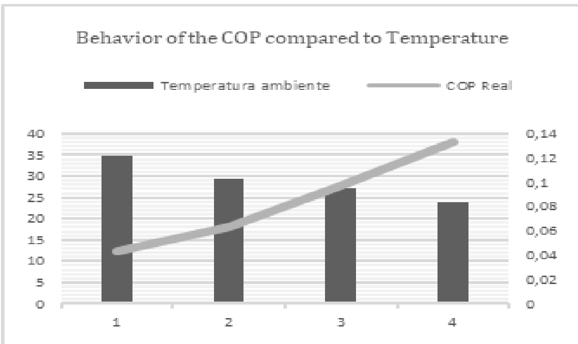

Fig. 2a. COP compared to room temperature.

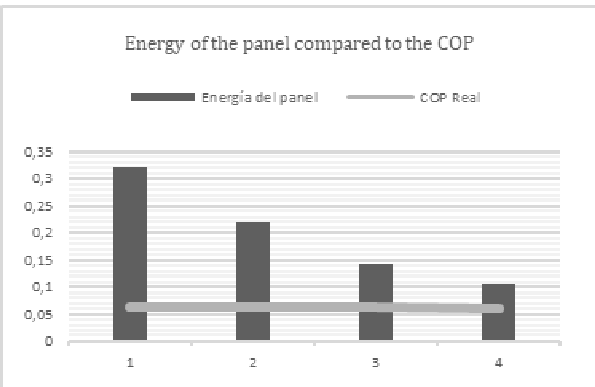

Fig. 2b. Energy delivered by the panel compared to the COP.

VI. CONCLUSIONS

Based on the analysis and results shown in this paper, it can be stated that the type of refrigerator selected, Servel shows that it does not require pumping equipment because it has hydrogen, this is in an atmosphere that allows the absorption of ammonia in the evaporator and balance pressure in the whole system, making the refrigerator autonomous with three working substances.

Absorption systems work with two types of refrigerants and absorbents, the first type is lithium bromide and water as a refrigerant. The second type is water and ammonia refrigerant, which is capable of lowering temperatures below 60°C. ℃. Therefore, this type of gas allows food to be properly preserved.

A Servel system is acquired, which is subjected to different types of measurement in the laboratory of the technologic. Peaks are measured on and off the cooler, measurements show that the system is kept on all the time, and the associated consumption is 78W, required, allowing to have a variable clearance in the cooling process. With the capacity of the system, the operating coefficient of the refrigerator is determined, which results in 0.17 W/W.

The solar thermal and photovoltaic installation has been modeled in TRNSYS, to validate the performance of the system, determining that the system works under normal operating conditions most of the year, but when the solar radiation at some times of the year is below 780 W/m^2 , leaving the cooling system inoperative for an interval of 9 days. For this particular case, a control system must be coupled to turn the primary pump on and off, where this system must be able to register the temperature entering the collector and when it exceeds the ignition temperature, turn off the primary pump, thus ensuring that the collector does not go into the vapor phase.

A minimum of 120 is required for the activation of the refrigerator ℃ at the generator output, i.e. it is below the operating temperature by 33.3 %. To compensate for this loss, a second backup is installed, a heater, with an energy source of propane gas. It was determined that the consumption is 13 kg per year. Being the most appropriate solution to work only with solar energy.

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