Doctoral School on Engineering Sciences
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Extended summary

Stand-alone solar systems for the cold chain

Curriculum: Energetica

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Abstract.

The present work aims to make a comparison between different sun's cold technologies "Ice maker "; These machines could be thermally powered by (solar thermal energy adsorption or absorption) or electrically (FV- Vapor Compression).

The thesis begins with an introduction that explains the advantages of solar Ice maker: Self-sufficiency, Health and non-toxicity, Ecological sustainability, Social and Economic factors.
I mentioned at the beginning the topic of the PV and thermal solar collectors, which will be used to drive these machines, and then i illustrated the thermodynamic cycle of the machines mentioned above.
Then i studied the adsorption machine (methanol-activated charcoal) powered by a solar thermal Panel.
The second machine was the solar absorption (water-lithium bromide) powered by solar thermal Panel.
For the third machine the vapor compression (R-600a) powered by polycrystalline Panel and DC motor.
For all the three machine I Stared from a mathematical model and fixed and dynamic data (temperature and radiation) inserting them in a software that gives us the dynamic simulation results, then it i discussed the parametric analysis and sometimes the components design.
The final comparison between these three machines was done based on comparing index (Ice quantity per day/Panel surface, STR, Lowers temperatures reached ...).

Keywords. Absorption cooling, Adsorption cooling, Ice maker, Solar Refrigeration

1 Problem statement and objectives

This thesis is a comparison of different cold technologies "Ice maker", an intermittent stand-alone solar powered where the ice acts as a cold storage.
A study of each technology and to arrive at a final confrontation between them.
These cold machines technologies can be divided into two categories, electrically or thermally powered by the sun (electromagnetic waves).
In the first category (Thermally driven) is based on the adsorption and refrigeration Absorption powered by solar panels.
While in the second (Electrically driven) is based on a compression refrigeration of steam powered by photovoltaic solar panels.

These technologies are useful for the following reasons:
• For energy Self-sufficiency: (not grid connected)
• For health
• Why Are Eco (environment friendly)
• For Socio-economic reasons and for agriculture

The purpose of this thesis is:
• To study the principle from a physical and chemistry point of view.
• To mention the most widely used solar collectors.
• To analyze their thermodynamic cycle.
• To study their dynamic mathematical model, that simulates their behavior.
• To put in 'data' and 'parameters', are both constants (dynamic) variables in the model above.
• To have a results or comparing indices: [COP, DIP, Surface ice Panel Quantity per day), minimum temperatures reached ...] all useful after for the final comparison.
• Parametric analysis of results (in some cases) for designing.
• Final comparison between these technologies.

2 Research planning and activities

2.1. Adsorptive Solar Ice Maker design

General description and dynamic simulation Results
Before treating the dimensioning of design ' solar Ice maker [1], I would like to make a description of it and a brief mention on results generated by the dynamic simulation.
The machine is as follows: (solar collector System; Condenser-tank system; Refrigerator box system; Piping; Valves; Support structure; Tilt system of the solar collector; Drawer opening/closing system of the solar collector).

2.1.1. Dynamic Simulation results (Base case)

Both for the preliminary design of components and the dynamic simulation, i taken as reference this publications [16] [17].
These articles are presented the results of a dynamic simulation of an adsorption system powered by solar energy that works in an typically North Mediterranean climate area.
In which explain the starting hypothesis of thermal energy balance (in/out) in every component of the Ice Maker (collector, condenser, evaporator); in order to arrive at a mathematical model that simulates the operation ' solar Ice maker , just put in the data in the simulation to obtain the results.
<u>The data can be variables or constants:</u>
Variables data: Global Solar Radiation (max. 800-900 W/m2); Ambient temperature (max. 30-35° C).
Constants Data: 6 kg water, 24 Kg activated charcoal, 1 m2, 5 m2 collector ev/water, 1 m2 ev/amb., 2 m2 cond./amb…

2.1.2. results and parametric analysis:

The most important result is the COPs.

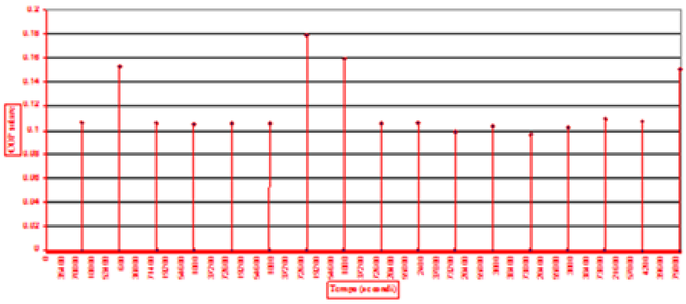
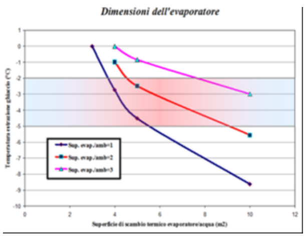
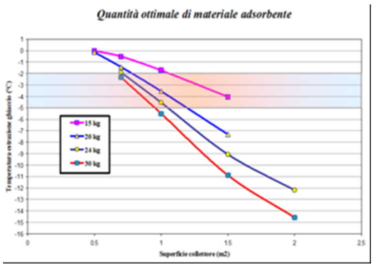


Fig.1: COP (7 July to 23 July), around 0.15 to 0.14 with peaks up to 0.16.

The parametric Analysis which will be used later to optimized the design:
evaporator design, the best adsorbent quantity; COP vs panel surface (see figure 2- a,b,c)



2-a)



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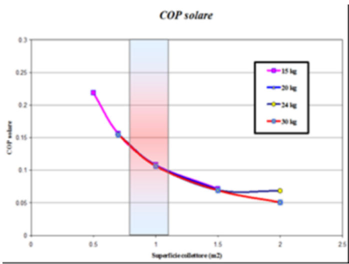


2-c)

2.1.3. The Design

<u>The solar collector:</u>

- Outer case;
- Insulating material: polyurethane foam
- Activated charcoal Tube: AISI 304 l (DN6 pipes, 5 3 cm x173cm + 5 hoses DN6, 3 cm x163cm) with activated charcoal thickness 1 cm for both.
- Selective Surface: Nickel sheet (SOLMAX); (α = 96%, ε = 7%)

- Reflective surfaces;
- Transparent Surfaces: glass with low iron content
- Sliding Drawer;
- Collector (active carbon tubes).

The condenser:

- 7 finned tubes: (DN 16x79cm) slanted towards the reservoir
- 1 connecting pipe DN 25;
- Fins (FIN Height, h = 1.5 cm; Fin thickness, thickness = 2 mm; Step-fins, p = 6 mm)
- tank: (10 cm x80cm)

The evaporator**:**

- box refrigerator: (The base container; The front door; The left side cover. The Center cover; The right side cover.
- Insulation: expanded polyurethane blocks 5;
- Evaporating Tubes: 2 files from 9 AISI 304 l steel pipes, DN 25, finned; 1 high, collector in stainless steel AISI 304 l, DN 63; 1 low, collector in stainless steel AISI 304 l, DN 63; 1 connection tubing in stainless steel AISI 304 l, DN 25; 2 output tubes in AISI 304 l, one 16 and the other DN DN 25.

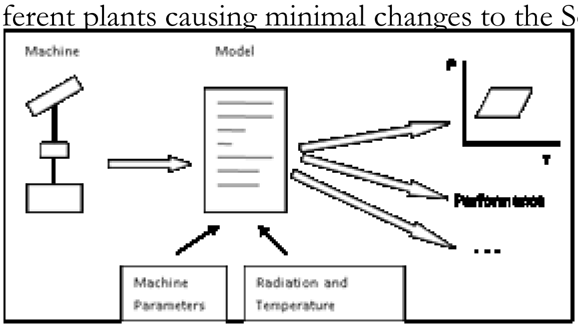
2.2. Absorptive Solar Ice Maker

2.2.1. General description

2.2.1.1. The mathematical model

This chapter contains a dynamic mathematical model capable of simulating the operation of an intermittent absorption refrigeration machine (water-lithium bromide) with the following features [2]:
• The refrigerant-absorbent pair used is water-lithium bromide, given the extensive documentation for the properties of the fluids [3][4] [5] [6];
• For the solar collector refers to a flat-plate collector, a single glass cover, with the solution contained in pipes and selective surface. [7].
• The condenser.
• The evaporator is rectangular/trapezoidal geometry, given the excellent heat transfer characteristics.

The design, drafting and implementation of the model were performed in order to obtain a flexible and modular structure offering, so it can be used in the design and the study of different plants causing minimal changes to the Solver algorithm (fig.3).



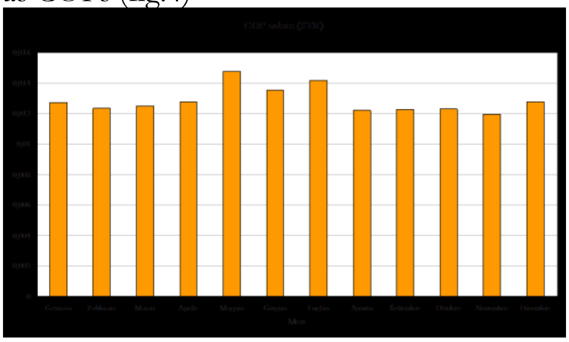
2.2.1.2. Assumptions

The main assumptions adopted herein are the following:
• The solution you consider spatially isotherm and Isobar.
• The solution is in equilibrium with the steam generated.
• Uniformity of the concentration of the solution.
• The cooling phase by condensing pressure to that of evaporation occurs at constant concentration.
• Steam generation generates pure refrigerant.
• Thermal dispersions in connections between components are considered negligible

<u>The quantity used (most significant) for the description of the installation are constants and variables:</u>
The constants:
• Masses of components;
• Specific heats, except that for the solution;
• Heat exchange Coefficients between components and the fluids concerned;
The variables are:
• Pressure and Temperature of the solution: $T_s(t)$ $p_s(t)$
• The refrigerant saturation temperature at pressure of solution: $T_{re}(t)$
• Salt solution concentration: $X(t) =$
• Tube collector Temperature: $T_t(t)$
• Temperature of the condenser and evaporator: $T_{co}(t)$ $T_{ev}(t)$
• Chilled water temperature: $T_w(t)$

2.2.3. Mathematical model and resolutions(Mathlabs 7.0-dae2):

2.2.4. Results:
as COPs (fig.4)



2.3. Photovoltaic Solar Ice Maker

2.3.1. General description

The study object model consists of three components: 1-Solar Panel (polycrystalline silicon), 2-box fridge, Compressor 3 DC steam [8].
1) solar panel SHARP ND-L3E6E model in multicrystalline silicon with a peak power 123W and the following characteristics (see table)

2) coolbox with a capacity of 140 litres and a thickness of insulation (polyurethane) 14 cm. Inside the cell there are two sections, one for food conservation/vaccines and one for the water that once frozen will act as thermal storage.
3) fully hermetic Danfoss R600a BD35K 10-45 V DC using the refrigerant fluid as R600a (Isobutane) and has the following performance (see table):

General observation.
The choice of compressor and of the PV module is dictated precisely by the absence of battery, also the compressor must have low starting current (start-up) (figure 5).

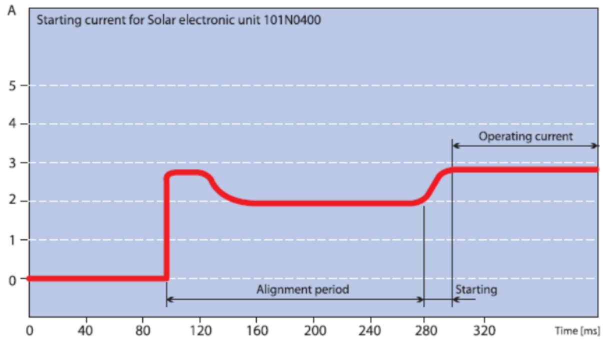


Fig. 5: progress of operating current of compressor

2.3.2. Assumptions

The process leading to the drafting of the equations that describe the physical phenomenon has two preliminary steps required:
• The formulation of hypotheses such simplification by making the system as much as possible, but at the same time easy resolution;
• Identification of descriptive parameters of the system.
The main assumptions adopted herein are the following:
• Heat transfer during off periods of compressor is rated non-permanent regime with the finite element method.
• The thermal load of the vaccines was not considered, because it is assumed that their temperature, into the cooler, is in the range of conservation and the temperature at which the cell is maintained.
• The thermal load for air infiltration was not considered.
• PV Panel efficiency was evaluated as a function of the reference yields.

Between the quantities used for description of the installation there are two types:
Constants: Masses of components; Specific heats; Heat exchange Coefficients;
Variables: cell temperature; water temperature in different phase; ice mass; nodes temperature; The power generated by the panel.

2.3.3. Instant global radiation

Incident on a surface still geared is sum of the direct component of the diffuse component from the portion of the sky "view" from the surface, the reflected component from the ground

$$G = I_{bn}\cos i + I_{do}\cos^2\left(\frac{\beta}{2}\right) + (I_{bn} sen\alpha + I_{do})\cdot \rho sen^2\left(\frac{\beta}{2}\right)$$

Where:

β: the pitch angle on horizontal plane Panel
ρ: reflection coefficient of the soil [0.2 (grass, concrete) to 0.75 (snow

2.3.4. thermal flow through the walls of the cold
The determination of the internal temperature of the cell, in the period in which the electrical power produced by photovoltaic system is not sufficient for the activation of the compressor, is a problem of periodic heat flux through walls.
Heat flow problems in non-permanent regime, temperature and time may be a function of space variable "x".
<u>The equation to describe the thermal flow system "wall of the cold room" is</u>

$$\mathrm{k}\frac{\partial T}{\partial x^2} = c\rho\frac{\partial T}{\partial \vartheta}$$

Where:
k is the conductivity coefficient;
ϱ is the density;
c is the specific heat.

To solve it numerically to transform it into an equation in finite differences. It begins by dividing the wall into thick layers Δx, then we fixe a time scale, as increments of time $\Delta\vartheta$.

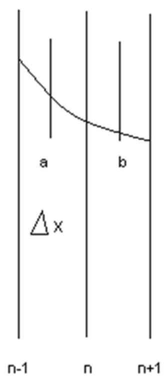


Fig.6: average temperature Gradient: in the cell wall.

At the end we arrive to this equation:

$$T_n^{t+1} = T_n^t\left(1 - 2\frac{\Delta\vartheta k}{c\rho\Delta x^2}\right) + \frac{\Delta\vartheta k}{c\rho\Delta x^2}\left(T^t_{n-1} - T^t_{n+1}\right)$$

Setting boundary conditions I could resolve it knowing moment to moment the temperature in the cell and his wall of the cell (in each section).
2.3.5. The final drafting of equations

The steps are basically five:
Stage 0: Power output Calculation of the panel
Phase I: Start compressor
Phase II: Ice formation
Phase III: Ice sub-cooling
Phase IV: Off of the compressor

2.3.6. Resolution (Mathematica 5.0)

To solve the various systems of equations by repeating the procedure with different input data every day, you need to implement the model in an appropriate algorithm solvable easily by a computer.
For this reasons we choose a suitable commercial software that would allow the resolution via numeric or symbolic method, and had management functions of logical structures similar to a programming language. The solution adopted is Mathematics 5.0 that although in this particular case requires a laborious programming regarding the variable flow control to give the entire algorithm a highly modular and flexible structure, it features powerful tools to find the equations solution .

2.3.7. Results
Instantaneous power:

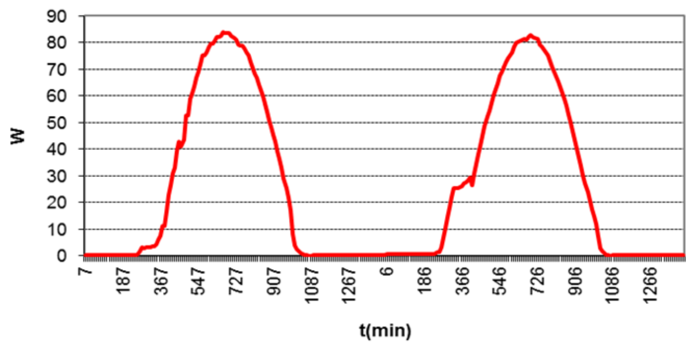


Fig. 7: power module Performance within two days of August.

The temperature inside the freezer box:

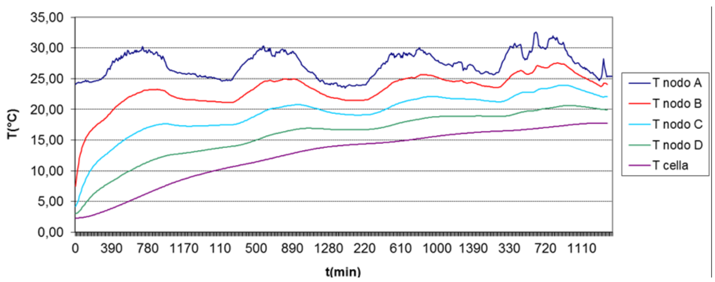
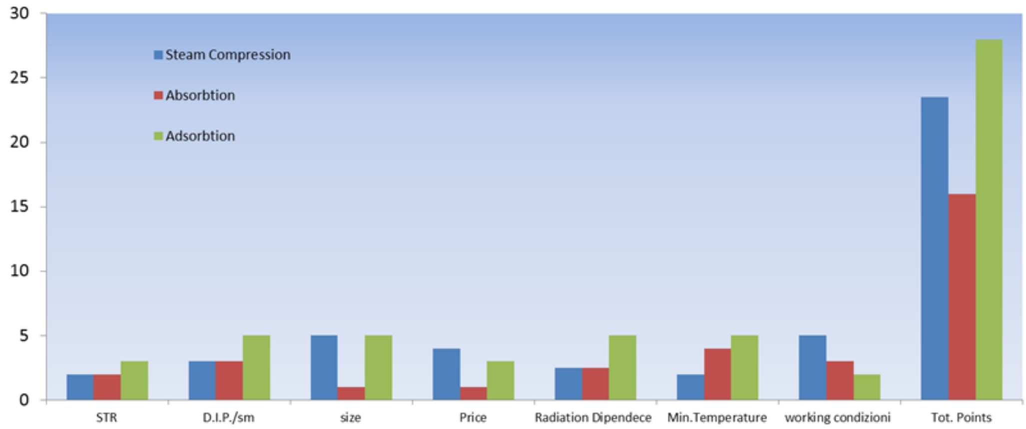


Fig.7: trend of temperatures calculated in 4 days of August with the compressor in the off status but with 5 kg of ice accretion (August).

3 Analysis and discussion of main results

Comparison



At the end you could deduce that the adsorption solar occupies in the first comparison (first place) and the second comparison (second place) and has good prospects for the future especially for small powers machines, and she deserves a greater attention both in research and in the production, and by the way she needs small maintenance.
Alternatively, always for small powers, we recommend the application of PV steam compression; in this technology there are mechanical and electrical parts so you need more maintenance.

4 Conclusions

We studied the three refrigeration machines:

The adsorption machine (active carbon-methanol) powered by a solar thermal Panel. Starting from mathematical model and fixed and dynamic data (temperature and radiation) at our disposal and placing them in an application which gave dynamic simulation results; then was treated parametric analysis and design of all components (solar collector, condenser, evaporator, ...)

The second machine was the solar absorption (water-lithium bromide) always powered by solar thermal Panel. Doing the same procedure of first mathematical model ➔ data ➔ dynamic simulation ➔results ➔ parametric analysis (without the design).

For the third car it is vapor compression (R-600a) powered by polycrystalline Panel and DC motor. Doing the same procedure just mentioned.

The final comparison is between these three machines was done based on comparison indices (ice quantity per day/Panel surface,STR, minimum temperatures reached,...) to find that the adsorption is the best.

The next step is to go beyond dynamic simulation, and to Design/install these three machines in the same climate zone (Mediterranean, sub-Saharan Africa) studying the effective machines run and to establish which one is the best in the same operating conditions.

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