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Portable Vapor-Compression Solar Refrigeration System for use in the Agricultural Harvesting Site

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There is a growing interest in implementing sustainable technologies within reach of the population to cover the need for the rational energy consumption of refrigeration systems. Therefore, this work shows the design and simulation of a cooling chamber, which will be part of a vapor-compression solar cooling system, useful for the agro-industrial sector to conserve perishable products directly at the harvesting site. This portable system uses photovoltaic panels as a source of motive power. The above was developed from the knowledge of the fruit to be conserved for its modeling and subsequent simulation. In this case the fruit is guava. Also, a photovoltaic analysis was carried out. It is possible to obtain a cooling capacity for the chamber of 183.10 W and a heat loss of 6.85 W. Detailed data of the formulas used for designing and simulating the chamber, its isolation calculus, the guavas and their wooden boxes, and the Photovoltaic panels, were provided to clarify the procedure for the proposed prototype.

Keywords: Cooling chamber, Guava, Organic Rankine Cycle, Photovoltaic, R-134a

Introduction

The agro-industrial sector[1–3] is one of the sectors with the highest possibility of development and competitiveness in many developing countries, where part of the population is dedicated to agricultural activities, and those related industries that are part of processing, distribution, and commercialization of fruits[4] and vegetables.[5,6]

Agribusiness generates demand for agricultural product conservation during shelf life and at the harvest site, where there are important post-harvest losses.[7] Portable refrigeration has enormous potential for rural non-farm employment.[8] Also, it adds an important value to agricultural production, both for the national and export markets. It is estimated that the worldwide commercialization of these products continues growing, even considering special circumstances, such as that of COVID-19.(9) Refrigeration is an essential service directly related to supplying food in all its stages, including food production, transport, storage, and commercialization. Also, refrigeration is directly associated with medicines, vaccines, and health care equipment in hospitals.[9,10]

Given the importance of this industry, the search for alternatives becomes a priority to provide solutions to the lack of technologies, materials, and procedures that sustainably maintain its products and optimal conditions. Another factor of interest that today affects the population is the rational consumption of energy and the lack of disposal in large areas. There is a growing concern to implement technologies within reach of the people, and sustainable, whose operation is free of anomalies and degradations with an energy-efficient operation, maintaining the quality of production conditions.

Refrigeration with solar power presents a favorable scenario for research and development in countries with high solar irradiation. So, it is likely to be adaptable to different productive sectors, such as agro-industry, meat, dairy, derivatives industries, etc.

Jacob Perkins in 1834 patented the fundamental basis of vapor-compression cold production systems. They have come to the present day with design improvements.[11–13] These systems have been a significant part of our current lifestyle. Nowadays, the vapor-compression system is the most widespread method in the world for the production of cooling, being used in large part of domestic, commercial, industrial, air conditioning[14], and automotive (Evans-Perkins process[15]) refrigeration applications. Cooling

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systems are the convergence of multidisciplinary researches, which includes areas such as nanotechnology.[16] Nonetheless, the refrigeration facilities imply a high percentage of energy consumption and represent high environmental and economic impacts. These are reasons for the high interest in waste heat recovery by the Organic Rankine Cycle (ORC).[17] There is a part of the global population that cannot access refrigeration because of such energy costs.

The type of refrigerant gas to use is tetrafluoroethane (CF_3-CH_2F), commercially known as R-134a.[18,19] Hydrofluorocarbons (HFCs) are considered environmentally safe and harmless to the ozone layer, as they indirectly contribute to global warming by reducing CO_2 emissions. They are not flammable, have very low toxicity, and can be recycled. Technically, and according to end-users, they are the best refrigerants available for most applications.

This work is mainly focused on the study and application of technologies that use the solar resource as the primary energy source, for the conservation of perishable foods, aimed at the agro-industrial sector. Especially, this work is focused on designing the cooling chamber for wooden boxes with guavas for intended use in rural areas and harvesting sites, which is a gap to cover.

Materials and Methods

Analysis of the Energy Capacity of Photovoltaic Panels

A photovoltaic cell[20,21] is a device capable of transforming incident radiation from the sun into electrical energy. Efficiency is defined as the ratio of energy production from the solar panel to the input energy from the sun.

During the experimental development, the photovoltaic system was read on a semi-cloudy day of insolation, the objective of which was to determine the capacity at which the system can operate and, in this way, adapt a device with similar characteristics for the proposed equipment. The system comprises three panels whose dimensions are 0.98 m × 1.6 m, each having a theoretical power of 1 kW. Both are connected in parallel to a 24 V storage system corresponding to each battery.

Obtaining Information on the Guava Fruit for the Sizing of the Cooling Chamber

Guava is a tropical fruit that belongs to the *Mirtáceas* family.[22–26] The characteristics of the fruit to be preserved were determined. For this, a random sample of 10 of them was considered. This was possible with the help of a 5 kg scale and a 500 mL burette. An amount of 400 mL of water was taken in the burette and the volume of the sample was obtained, using the following formula:

$$V_f - V_i = V_{real\ of\ each\ guava} \qquad \ldots(1)$$

where, V_f is the final volume; V_i is the initial volume. To obtain the average density of guava(mL/g):

$$\frac{Mass_{guava}}{Volume_{real\ of\ each\ guava}} = Density \qquad \ldots(2)$$

$$\sum_1^{10} \frac{n_{Density}}{n} = Average\ density\ of\ guava \qquad \ldots(3)$$

Sizing of the Cooling Chamber

A cooling chamber is a thermally insulated enclosure within which matter is contained to extract its thermal energy. This energy extraction is carried out by means of a refrigeration system. Therefore, particular aspects, such as the type of product to be conserved, should be considered to define the size of the unit, the storage, and conservation capacity. The capacity is directly proportional to the size of the cooling unit since it is the point from which to start for the calculation and development of the proposed equipment. Other important points to consider are the location, arrangement of the facility, and selection of construction material.

Based on the above, to carry out this stage, a supply center was visited and the different containers for the transportation of guava were verified. Data collection was acquired from the measurement of the box containing the described fruit (Fig. 1). It should be noted that the chamber may vary depending on the evaporator and depending on the type of system. Once having the necessary data, it was modeled in *SolidWorks*®.

Modeling and Simulation of the Refrigeration Chamber

Simulation allows studying a system without having to carry out experimentation on the real

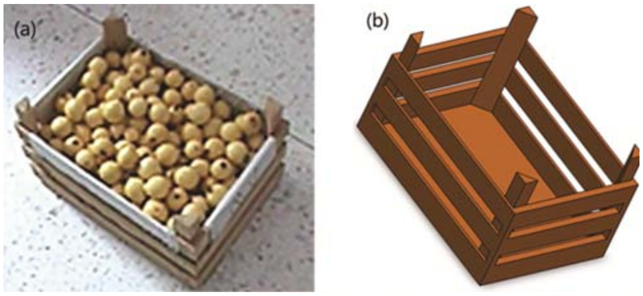

Fig. 1 — A) Image of the fruit wooden box (guava), B) CAD design of the container

system. Furthermore, simulations are an essential part of decision-making in a given process. Considering its importance, the storage chamber in cooling systems has been of high interest for modeling and simulation.[27] The kinetic cooling rates during different fruits, vegetables, or other foods have been investigated.[28,29]

For the modeling, the measurements obtained from the wooden box for guava were considered. Once the above was obtained, the area and its respective volume were calculated. A criterion of 2” of space between the walls was assigned for airflow to determine the cooling chamber size (Fig. 2).

COMSOL Multiphysics® software main window. The input data used were cross-sectional areas, thicknesses, and conductivities of the materials corresponding to the walls, floor, and ceiling. In this case, polyurethane with a value of (0.02 Kcal/m.h.ºC), for stainless steel 16/16´´ gauge (27 Kcal / m.h.ºC). For the thermodynamic simulation (heat transfer from the exterior to the interior), the external temperatures (35°C and 20°C) and conservation temperatures of 4°C were considered.

There are many reported studies with 4-6 °C for storing guavas and there are others even with lower temperatures, such as −20°C. Patthamakanokporn *et al.*[30] reported that using 5°C “*The ORAC and FRAP antioxidant activity in guava tended to increase with a storage of 10 days…*”, which is a reason to use such temperature (Oxygen radical absorbance capacity, ORAC; Ferric reducing antioxidant power, FRAP).

The behavior of the interior of the cooling chamber was observed through the captures obtained by the software. The ambient temperature considered was 20°C corresponding to the exterior (ambient temperature) and 4°C for the internal case (storage temperature).

In the images presented in Fig. 3(a–d), the colors indicate the temperature at which the interior of the cooling chamber is located. The red color indicates excess heat, blue the cold, orange, and green represent the outside temperature of it. The four images show the cooling process of guava containers, which vary according to the initial product temperature. The surrounding environment temperature contributes depending on the insulation. In a previous study, there was a proposal of directly acquiring the 3D geometry of each piece of the refrigerator.[31]

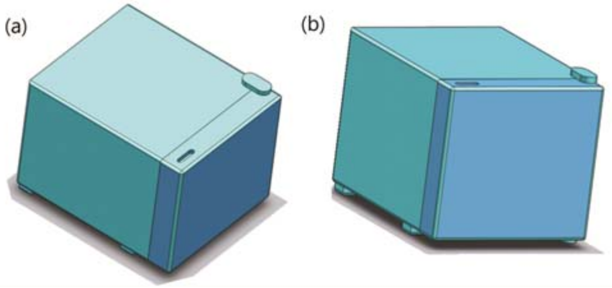

Fig. 2 —The 3D views of the walls of the cooling chamber

Cooling Power and Heat Loss

The cooling power is the nominal power of the energy supplied in Watts so that the camera operates and manages to stay at the programmed temperature. In comparison, heat loss is the amount of heat removed in watts.

The calculations obtained were made using a spreadsheet once the necessary data is available. The thermal load to be evacuated from the treated space must be estimated or calculated to select the appropriate refrigeration equipment. Therefore, the heat gains that form the total thermal load can be classified into four main areas:

1) Transmission or transfer through the external surfaces.
2) Heat associated with air, which enters the refrigerated space.
3) Gains from the heat contained in the refrigerated and stored product.
4) Load corresponding to the heat given off by the workers inside the chamber. Lighting, electric motors. The total load under design conditions is the sum of these four components.

The data and formulas for calculating the cooling chamber power for 30 kg are shown below (Table 1 and Table 2).

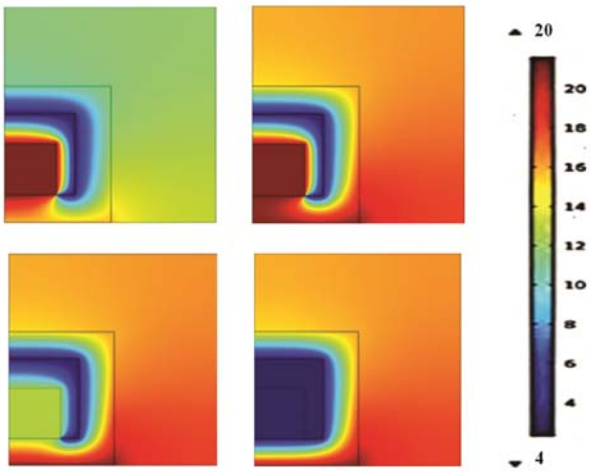

Fig. 3 — Simulated temperature profiles for the cooling chamber: a) initial temperature 20°C, b) temperature 15°C, c) temperature 10°C, c) temperature 4°C

Formulas:

a) Calculating the resistance of walls 1 and 2.

$$q1 = LAW(Te - Ti) \quad \ldots (4)$$

$$R1 = \frac{SC}{Css} \quad \ldots (5)$$

$$R2 = \frac{Pu}{Cpu} \quad \ldots (6)$$

$$R3 = \frac{SC}{Css} \quad \ldots (7)$$

$$qt1 = R1 + R2 + R3 \quad \ldots (8)$$

$$Q1 = \frac{q1}{qt1} \quad \ldots (9)$$

b) Calculating the resistance of walls 3 and 4.

$$q2 = qt1 \quad \ldots (10)$$

$$Q2 = \frac{(FA)(Te-Ti)}{q2} \quad \ldots (11)$$

$$QT2 = 2Q2 \quad \ldots (12)$$

c) Calculating the resistance of walls 5 and 6.

$$q3 = qt1 \quad \ldots (13)$$

$$Q3 = \frac{(Aul)(Te-Ti)}{q3} \quad \ldots (14)$$

$$QT3 = 2Q3 \quad \ldots (15)$$

d) Calculating the total loss of heat for the chamber.

$$QTC = QT1 + QT2 + QT3 \quad \ldots (16)$$

$$QTC = (QTC)(1.16) \quad \ldots (17)$$

Formulasfor obtaining refrigeration:

$$\text{Lsc1} = (\text{Fs} * Cp_{\text{fuf}})\,(\text{Tfamb} - \text{Tff}) \quad \ldots (18)$$

$$\text{Llf} = \text{Fs*Q*Lsc2} = (\text{Fs*}Cp_{\text{fuf}})(\text{Tfc*Tff}) \quad \ldots (19)$$

$$\text{Cb} = (\text{NC *Wb * }Cp_{\text{b}})(\text{Tfamb} - \text{Tff}) \quad \ldots (20)$$

$$\text{Cap} = \text{Npw * Top * Lv} \quad \ldots (21)$$

$$\text{Hrva} = (24 * \text{Aa(Ha - Hcc)}) * 0.252 \quad \ldots (22)$$

$$\text{Lcfw} = \text{Lcfw} * 0.252 \quad \ldots (23)$$

$$\text{Hlb} = \text{Hlb} * 0.252 \quad \ldots (24)$$

Total Power:

$$\text{Ptot} = \text{Lsc1+Llf+Lsc2+Cb+Cap+Hrya+Hlb+Lcfw [W]} \quad \ldots (25)$$

Nomenclature

LAW: Lateral area of walls.
FA: Frontal areas.
Aul: Upper and lower areas.
Te: External temperature.
Ti: Interior temperature.
L: Length.
W: Width:
H: Height.
SC: Sheet caliber.
Pu: Polyurethane.
C_{SS}: Conductivity of stainless steel.
AC: Air conductivity.
Cpu: Conductivity of polyurethane.
q1: Wall load 1 and 2.
R1: Resistance 1.
R2: Resistance 2.
R3: Resistance 3.
qt1: Sum of resistances.

Lsc1: Load of sensitive cooling 1 [kcal].
Llf: Load of Latent Freezing [kcal].
Lsc2: Load of sensitive cooling 2 [kcal].
Cb: Cooling of boxes [kcal].
Fs: Fruit to store [kg].
Cp_{fuf}: Cp of fruit under freezing [kcal/kg °C].
Tfamb: Temperature of fruits at ambient [°C].
Tff: Temperature of fruit to be frozen [°C].
Q: Latent heat of fusion [kcal/kg].
Cp_{fsc}: freezing fruit Cp [kcal/kg °C].
Tf c: Fruit temperature to preserve [°C].
Bc: Box cooling [kcal].
NC: Number of boxes [pcs].
Wb: Weight of boxes [kg].
Cp_b: Cp of boxes [kcal/°C kg].
Ca p: Charge for personnel [kcal].
Npw: Number of people to work.
Top: Operation time [h].

Table 1 — Parameters considered for heat loss

Areas	Side (LAW)	0.19 m^2
	Frontal (FA)	0.12 m^2
	Upper and lower (ASI)	0.25 m^2
Chamber dimensions	Length	0.52 m
	Width	0.4 m
	Height	0.3 m
Temperatures	Exterior	35ºC
	Interior	4ºC
Thermal conductivities of materials	Polyurethane	0.017 Kcal/mhºC
	Stainless steel	27 Kcal/mhºC
	Air	0.019 Kcal/mhºC
Materials thickness	Sheet 16/16”	0.00152 m
	Polyurethane	0.1 m

Table 2 — Input data for calculating cooling power

	Value		Value
Fruit to store	30.0 kg	Ambient Fruit Temperature	35.0°C
Guava	1.25 kg/h	Fruit to Freeze Temperature	4.0°C
Time	24.0 h	Cp Guava Fruit	1.46 Kcal/kg °C
Guava density	1.06 kg/L	Cp fruit under Freezing	0.94 Kcal/kg °C
Exterior Ambient Temperature	35°C	Cp fruit over Freezing	0.50 Kcal/kg °C
Cooling Temperature	4°C	Optimal Relative Humidity	80.0%
Sensible Cooling Charge	874.2 Kcal	Dry Bulb Temperature	36.0°C

Q1: Heat loss wall, 1 and 2 [kcal / h].
QT1: Total heat loss wall 1 and 2 [kcal/h].
q2: Wall load 3 and 4.
Q2: Loss of heat wall, 3 and 4 [kcal/h].
QT2: Total loss of heat, wall 3 and 4 [kcal / h].
Q3: Loss of heat wall, 5 and 6 [kcal/h].
QT3: Total loss of heat wall 5 and 6 [kcal/h].
QTC: Total loss of the cooling chamber [W].
Lv: Losses due to ventilation [kcal].
Hrva: Heat removed by ventilated air [kal].
Hlb: Heat per light bulb [kcal].
Aa: Air amount [kg].
Ha: Heat of air [kcal / kg].
Hcc: Heat of cellar conditions [kcal / kg].
Lcfw: Load due to ceiling, floor, and walls [kcal].
Ptot: Total power [W]

Design and Preliminary Analysis of the Solar Refrigeration System and Cycle Vapor- Compression

Solar energy in refrigeration[15] can be used in two routes that can be combined with each other: solar thermodynamics and it is based on the photoelectric effect. The first uses thermal radiation and converts it to work to move a compression cycle. The second is the conversion of light energy from the sun (photons) into electrical energy. The performance index of a refrigeration system is the ratio between the refrigeration load (amount of heat removed) and the amount of energy invested from the outside to make it work.

It receives the name of solar vapor-compression refrigeration because a photovoltaic installation provides the main source of energy for the operation of its components.

Vapor-compression refrigeration systems are the most commonly used. The principle of this system is to cool a refrigerant liquid by evaporation. This is maintained under pressure conditions such that its evaporation occurs at temperatures lower than those of the environment to be cooled. The fluid used as a refrigerant, which is in the vapor phase, returns to the liquid phase expelling heat, thereby completing the cycle.[25–34] For the gas to condense to deliver heat to the environment, the temperature at which this process occurs must be higher than that of the environment and much higher than that of the liquid that is evaporating. The condensation temperature is achieved by increasing the gas pressure.

Refrigeration cycles allow us to calculate the powers or capacities of the elements and the detection of possible anomalies. The enthalpy diagram (p-h) is the most used for the representation of the different refrigeration cycles.

Refrigerant Gas R-134a

Refrigerants are the transport fluids that carry heat energy from the low-temperature level (evaporator) to the high-temperature level (condenser), where they can give up their heat. The R-134a has been predominantly used in the industry but others have been investigated.[12]

The preliminary design was carried out through prior knowledge of the components that make up a solar cooling system. Such a system is still in the process of improving its implementation. In Fig. 4 a design of the proposed solar cooling system is shown.

Results and Discussion

This work is focused on the design and construction of a cooling chamber for its subsequent adaptation to a vapor-compression solar refrigeration system applicable to the agro-industrial sector. Among the results obtained there is the photovoltaic analysis (Table 3). In Fig. 5 one

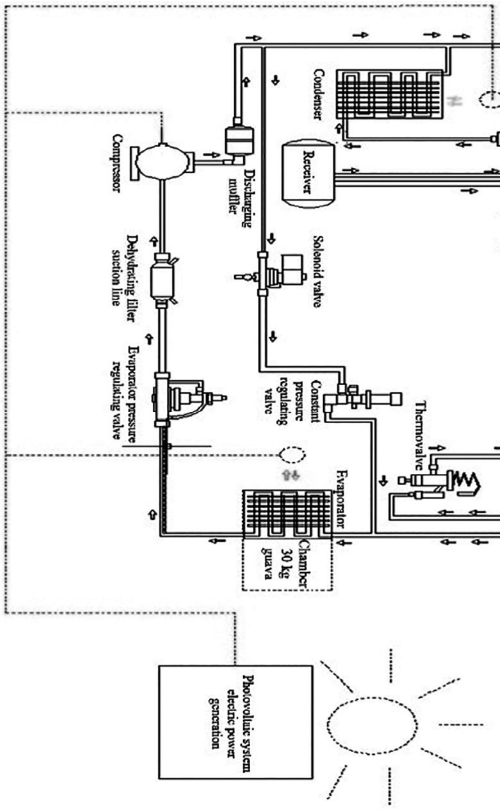

Fig. 4 — Computer-aided design of the cooling system (vapor-compression)

Table 3 — Readings obtained from the energy efficiency of photovoltaic panels

Reading	Input (V)	Input (A)	Output (V)	Output (A)	Input Power (kW)	Output Power (kW)
1	33.4	3.0	27.9	3.8	0.10	0.10
2	29.4	7.6	27.3	8.0	0.22	0.5
3	29.2	6.1	27.3	6.6	0.18	0.5

Fig. 5 — Photovoltaic panel, control panel, and battery bank

of the panels, the control board, and the batteries are shown.

For the second step of the methodology, in the experimental measurements carried out through the guava fruit sampling, it was possible to obtain an average density of 1.06 g/mL. This is close to the bibliography consulted, which mentions a close value to water. In addition, it was possible to verify that the storage capacity of the box is less, that is, from 30 kg to 10.39 kg. The cooling chamber was designed for 30 kg, which means that it can have three wooden boxes with fruits. The average weight of single guava is about 31 g, having a length of about 4.65 cm, and the total occupied volume was about 100 cm^3, including surrounding empty spaces. Then, there were about 300 pieces of guavas in a wooden box.

In the third step, the dimensions to which the cooling chamber will be available at the laboratory level, the volume obtained was 0.0315 m^3. Regarding the criterion of spaces assigned for the cooling of the chamber, the volume was 0.0624 m^3.

In the fourth step, through the modeling in SolidWorks®, a design of the proposed equipment was obtained. Furthermore, thanks to the simulation in *COMSOL Multiphysics*®, the thermodynamic behavior (heat transfer and loss) was observed through the walls, floor, and ceiling of the chamber.

In the fifth step of the methodology, the results obtained for the total pressure drop of the chamber are shown in Table 4.

In the sixth and final step, through modeling in *AutoCAD*®, a preliminary design of the proposed equipment was obtained for its subsequent assembly and implementation in the sector of interest (Table 5). Furthermore, it was possible to analyze the vapor-compression refrigeration cycle using refrigerant gas R-134a.

For the analysis of the photovoltaic system, the purpose was to acquire and check the power at which it can be working under normal insolation conditions. In this way, knowing the possible variations that may arise during the adaptation of this technology to the complete solar cooling system proposed.

Table 4 — Heat removed through chamber walls, ceiling, and floor

Total load of walls 1 and 2	−2.00	kcal/h
Total load of side walls 3 and 4	−1.26	kcal/h
Total load of bottom/rear walls 5 and 6	−1.32	kcal/h
Total load of chamber 30 kg	−2.63	kcal/h
Total heat loss in chamber 30 kg	−5.90	kcal/h
	−6.85 W	

Table 5 — Results obtained for the cooling power

Total	3770.56	kcal/h	183.10	W

To obtain the guava average density, it was not necessary to carry out an exhaustive measurement since, from its random sample, it was possible to obtain its average density. Furthermore, the knowledge of the characteristics, mainly the fruit storage temperature, allowed adjusting the capacities and characteristics at which the cooling chamber will be operating. On the other hand, according to the results obtained from the quantity of fruit that a wooden box stores, it will be necessary to consider the following considerations in the future for the proposed system at the field level (200 kg). A) The number of boxes that will be stacked inside the chamber. B). In the case that there is a lower capacity, than 30 kg of fruit in each wooden box, the number of boxes will increase and, therefore, the refrigeration requirements may vary.

For the prototype camera modeling at the laboratory level (30 kg), the measurements obtained from the wooden box (0.42 m × 0.30 m × 0.25 m) were considered. Therefore, a criterion of 2´´ of space was assigned between the walls for the airflow in the chamber and the coupling of the box (0.52 m × 0.40 m × 0.30 m), that is, in such a way that the entrance of the wooden box does not damage its walls and surface.

The modeling in *SolidWorks*® represents support to have a preliminary approach to the physical appearance of the proposed equipment. In addition, thanks to the previous simulation in *COMSOL Multiphysics*®, it reflects how important it is to consider the conductivity coefficients of the materials that comprise it, being these (stainless steel, polyurethane) on walls, floor, and ceiling, as well as the characteristics of the fruit to preserve, the size of the chamber and the environmental conditions of its operation. Furthermore, such software is usually very noble in optimizing, obtaining, and analyzing capabilities for the prototype at the laboratory level.

According to the values obtained in the amount of heat removed and the cooling power, it corresponds only to the 30 kg cooling chamber at the laboratory level. This implies that the nominal power of energy supplied only in the refrigeration chamber was 183.10 W, whereas the amount of heat removed was 6.85 W. It is recommended to perform a more precise quantification of the coefficient of performance (CoP) for the proposed system, which could be calculated placing the cooling element in a cold room and stabilizing it at a temperature below room temperature. Then, adjusting the system power input until getting offset the simulated load and keeping the camera at the original temperature. The relationship between simulated load and power increase can be used as CoP. Therefore, 200 W of cooling is then required for the system at the laboratory level.

Finally, for *AutoCAD*® modeling of the complete cooling system (laboratory level with 30 kg), it is necessary to determine the capacities of the comprising components, since the selection of the photovoltaic system (panels or concentrators) will depend on it. Therefore, it is necessary to conduct an in-depth analysis of the ideal and real vapor-compression refrigeration cycle, with its respective refrigerant gas R-134a[12], to avoid damage and imperfections.

Conclusions

A vapor-compression solar refrigeration system powered by photovoltaic panels has been designed using the adjusted R-134a tetrafluoroethane refrigerant to preserve fruits (guavas).

An energy efficiency analysis was performed on the photovoltaic system comparing with the solar concentrator for the incorporation and/or adaptation of the proposed cooling system.

Data were obtained to carry out calculations of power and energy loss from the physical properties of the fruit to be preserved, as well as from the materials, walls, and ceilings that compose it.

Modeling of the refrigeration chamber to be used for the preservation of fruit (guava) was developed.

It is concluded that the product contained in the box is 10.39 kg, requiring three containers of guava to complete the pre-established load at the pilot level of 30 kg. Likewise, the average density of the sample was 1.06 g/mL. Also, there was an energy variation depending on the climatic conditions. However, they approached the theoretical data of the photovoltaic panels.

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References

1 Augustin-Jean L & Xie L, Food safety, agro-industries, and China's international trade: A standard-based approach, *China Inf*, **32** (2018) 400–422.

2 Gardas B, Raut R, Jagtap A H & Narkhede B, Exploring the key performance indicators of green supply chain management in agro-industry, *J Modell Manage*, **14** (2019) 260–283.

3 Sharma V K, Chandna P&Bhardwaj A, Bhardwaj, A Green supply chain management related performance indicators in agro industry: A review, *J Cleaner Prod*, **141** (2017) 1194–1208.

4 Wenten I G, Khoiruddin K, Reynard R, Lugito G & Julian H, Advancement of forward osmosis (FO) membrane for fruit juice concentration, *J Food Eng*, **290** (2021) 110216.

5 Tadić Đ, Bleda Hernandez M J, Cerqueira F, Matamoros V, Piña B & Bayona J M, Occurrence and human health risk assessment of antibiotics and their metabolites in vegetables grown in field-scale agricultural systems, *J Hazard Mater*, **401** (2021) 123424.

6 Zhang B H, Xu X, Lu H, Wang L & Yang Q, Removal of phoxim, chlorothalonil and Cr^{3+} from vegetable using bubble flow, *J Food Eng*, **291** (2021) 110217.

7 Minten B, Tamru S & Reardon T, Post-harvest losses in rural-urban value chains: Evidence from Ethiopia, *Food Policy*, **98** (2021) 101860.

8 Chattopadhyay S & Ghosh S, Techno-economic assessment of a biomass-based combined power and cooling plant for rural

application, *Clean Technol Environ Policy*, **22** (2020) 907–922.

9 Coulomb D, COVID-19 and refrigeration, *Int J Refrig*, **116** (2020) iv.

10 Hossain A, Saha S & Rahman M A, Low power consuming solar assisted vapor compression refrigerator to preserve emergency medicines and vaccines in rural areas, *1st Int Conf Adv Sci, Eng Robot Technol*, 2019, 8934783.

11 Anand B & Murugavelh S, Performance analysis of a novel augmented desalination and cooling system using modified vapor compression refrigeration integrated with humidification-dehumidification desalination, *J Cleaner Prod*, **255** (2020) 120224.

12 de Paula C H, Duarte W M, Rocha T T M, de Oliveira R N & Maia A A T, Optimal design and environmental, energy and exergy analysis of a vapor compression refrigeration system using R290, R1234yf, and R744 as alternatives to replace R134a, *Int J Refrig*, **113** (2020) 10–20.

13 Halpern A M & Noll R J, That's so cool. Using a flame to freeze water. The vapor-absorption refrigerator and how it works, *J Chem Educ*, **97** (2020) 726–735.

14 Abubaker A M, Najjar Y S H & Ahmad A D, Uniquely finned tube heat exchanger design of a condenser for heavy-duty air conditioning systems, *Int J Air-Condit Refrig*, **28** (2020) 2050004.

15 Westerloh M, Twenhövel S, Koehler J & Schumacher W, *SAE Tech Pap*, **2018-April** (2018) 134884.

16 Subhedar D G, Patel J Z & Ramani B M, Experimental studies on vapour compression refrigeration system using Al_2O_3/mineral oil nano-lubricant, *Aust J Mech Eng*, DOI: 10.1080/14484846.2020.1784558.

17 Seyedkavoosi S, Javan S & Kota K, Exergy-based optimization of an organic Rankine cycle (ORC) for waste heat recovery from an internal combustion engine (ICE), *Appl Therm Eng*, **126** (2017) 447–457.

18 Bell I H, Domanski P A, Mc Linden M O & Linteris G T, The hunt for nonflammable refrigerant blends to replace R-134a, *Int J Refrig*, **104** (2019) 484–495.

19 Kim D, Lee D, Jang D S, Jeon Y & Kim Y, Comparative evaluation of flow boiling heat transfer characteristics of R-1234ze (E) and R-134a in plate heat exchangers with different Chevron angles, *Appl Therm Eng*, **132** (2018) 719–729.

20 Klugmann-Radziemska E & Kuczyńska-Łażewska A, The use of recycled semiconductor material in crystalline siliconphotovoltaic modules production - A life cycle assessment of environmental impacts, *Sol Energy Mater Sol Cells*, **205** (2020) 110259.

21 Ndagijimana P, Tech M & Kunjithapathan B, Design and implementation PV energy system for electrification rural areas, *Int J Eng Adv Technol*, **8** (2019) 2340–2352.

22 Arroyo B J, Bezerra A C, Oliveira L L, Arroyo S J, Melo E A D & Santos A M P, Antimicrobial active edible coating of alginate and chitosan add ZnO nanoparticles applied in guavas (Psidium guajava L.), *Food Chem*, **309** (2020) 125566.

23 Lin G, Tang Y, Zou X, Xiong J & Li J, Guava detection and pose estimation using a low-cost RGB-D sensor in the field, *Sensors (Switzerland)*, **19** (2019) 428.

24 Lima R D S, Ferreira S R S, Vitali L & Block J M, May the superfruit red guava and its processing waste be a potential ingredient in functional foods?, *Food Res Int*, **115** (2019) 451–459.

25 Nair M S, Saxena A & Kaur C, Effect of chitosan and alginate based coatings enriched with pomegranate peel extract to extend the postharvest quality of guava, *Food Chem*, **240** (2018) 245–252.

26 Murmu S B & Mishra H N, The effect of edible coating based on Arabic gum, sodium caseinate and essential oil of cinnamon and lemon grass on guava, *Food Chem*, **245** (2018) 820–828.

27 Ccalli Pacco H, Temperature simulation and control in refrigerated storage chambers for fruit, *Procedia Manuf*, **42** (2020) 35–40.

28 Narasimha Rao K V, Devarakonda S & Ramesh Babu D, Mathematical modeling of pre-cooling kinetic rates during artificial ripening of banana fruits under refrigerated conditions, *Test Eng Manage*, **83** (2020) 6872–6879.

29 Narasimha Rao K V, Shareef S & Ramesh Babu D, Mathematical modeling of cooling rates of mango fruits during unsteady state cooling in an artificial ripening chamber, *Test Eng Manage*, **83** (2020) 6862–6871.

30 Patthamakanokporn O, Puwastien P, Nitithamyong A & Sirichakwal P P, Changes of antioxidant activity and total phenolic compounds during storage of selected fruits, *J Food Compos Anal*, **21** (2008) 241–248.

31 Obregón Morales E, Perez Bueno J J, Moctezuma Esparza J C, Marroquín García D, Trejo Perez A, Flores Romero R C, Olivares Ramírez J M, Mendoza López M L, Solís Ulloa J C, MeasVong Y & Rodríguez Obregón V H, Portable hybrid refrigerator prototype for agribusiness with its 3D real physical geometry scanned and transferred for simulation software, *Int J Hyperconnect Internet Things*, **5** (2021) 78–97.