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Analysis of the use of aerogel as a thermal insulator in refrigerated containers for storing blood using a photovoltaic system

Análisis del uso de aerogel como aislante térmico en contenedores frigoríficos para almacenar sangre utilizando un sistema fotovoltaico

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Abstract

At the beginning of the present, a comparative analysis was carried out between polyurethane as a traditional thermal insulator and aerogel as an insulating material that has excellent thermal properties; the analysis is carried out through a container for storing blood, in which calculations of thermal loads were performed. In addition, a photovoltaic system is proposed to supply energy to the container. As a result, the energy consumption of the system is obtained, using the proposed insulators, resulting in lower consumption when aerogel is used.

Blood, Aerogel, Insulating

Resumen

Al inicio del presente, se realizó un análisis comparativo entre el poliuretano como aislante térmico tradicional y el aerogel como material aislante que posee excelentes propiedades térmicas; el análisis se realiza a través de un contenedor para almacenar sangre, en el cual se realizaron cálculos de cargas térmicas. Además, se propone un sistema fotovoltaico para suministrar energía al contenedor. Como resultado, se obtiene el consumo energético del sistema, utilizando los aislantes propuestos, resultando menor el consumo cuando se utiliza aerogel.

Sangre, Aerogel, Aislante

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Introduction

Blood allows nutrition, communication, protection and repair of the various tissues of the organism, being of vital importance in operations and medical treatments. This leads to the need for blood banks, where its correct storage and transport must cover special characteristics, being the temperature one of the most important parameters that must be maintained from the moment it is donated until its conservation at 4°C.

An important problem in the storage processes is to choose the appropriate insulators to consume the least amount of energy to ensure the safety of the product to be preserved; that is why the objective of this work is to develop an analysis of the use of aerogel as thermal insulation in refrigerated containers to store blood and compare it with a traditionally used insulator, such as polyurethane; analyzing its implementation in a blood container in a theoretical way; such that allows to determine the greatest energy savings.

Methodology

The methodology to achieve the objective of this work consisted of seven steps.

In the first step, the geographic location of the blood storage enclosure is proposed; with this, the solar radiation and the maximum temperature at which the system will operate are determined. Step two consists of proposing the design of the container; geometry, measurements, materials, etc. Subsequently, in step three, the characteristics of the insulators for the case studies are specified. In step four, an energy analysis is performed to calculate the thermal loads, taking into account the amount of blood, the thermal insulation, the type of container material and air infiltration. In the fifth step the cooling source is chosen from the conditions obtained in the previous step. Step six consists of calculating the energy consumed by the chosen cooling system. Finally, in step seven, the photovoltaic system that provides the energy is selected.

Development

Climatic operating conditions

In order to establish the operating conditions, it is necessary to define a geographical location for the analysis. Although this work proposes the central region of the state of Hidalgo, where there is an average maximum ambient temperature of 21°C and a solar resource of 6.3 hours, the methodology presented can be extrapolated to any location.

Container design

The size of the container was determined according to the amount of blood to be stored, which was 21 liters. Likewise, polypropylene was proposed as the material for its construction and for the insulating coating.

Table 1 shows the dimensions established for the container.

Dimension	Value
Height	0.4 m
Width	035 m
Long	0.27 m
Volume	0.04 m^3
Area	0.685 m^2
Material	**Thickness**
Polypropylene	0.254

Table 1 Container dimensions
Source: Own elaboration

Figure 1 shows the proposed design of the blood storage container.

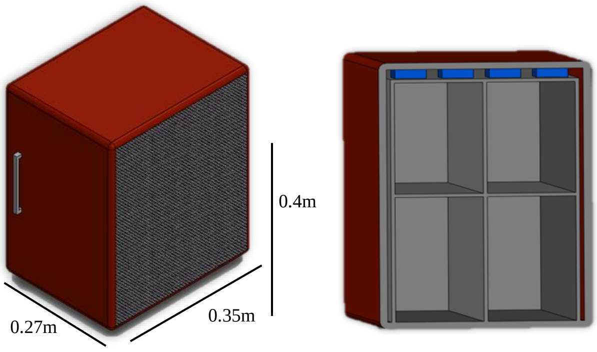


Figure 1 Design and dimensions of the blood storage container
Source: Own elaboration

The container material was polypropylene for universal use, since it has excellent chemical resistance, high purity, low water absorption and good electrical insulation properties.

Insulation characteristics

One of the main disadvantages when refrigerating products is the heat transmission losses through the walls. One of the ways to reduce this heat loss is to select materials with low thermal conductivity, allowing the difference between internal and external temperatures to be maximized (Incropera, 1999).

Rigid expanded polyurethane foam is a lightweight, strongly cross-linked, closed-cell synthetic material with good mechanical strength relative to its density. This is one of the most widely used insulating materials because it reduces the energy consumption of the premises it protects, due to its good thermal insulation capacity (Acevedo, 2016).

On the other hand, aerogel is considered as the perfect thermal insulator. The main reason is that it is practically made of gases and, therefore, it is a material with low heat conductivity. It is able to cancel or drastically minimize the three existing heat transmission methods: conduction, convection and radiation (Gonzales, 2022).

Table 2 shows some characteristics of the insulators analyzed.

Insulation	Thermal conductivity W/mK	Specific heat KJ/Kg*K	Density Kg/m^3
Polyurethane foam	0.028	1900	35
Silica aerogel	0.015	1.574	0.0004

Table 2 Insulation characteristics
Source: Own elaboration

Energy analysis

Thermal loads

The heat load is defined as the amount of heat that must be removed from the site to be cooled to reduce or maintain the desired temperature.

The total heat load results from the sum of the heat loads involved (HVACR, 2012). Based on the proposed design the thermal loads considered in this analysis are: by product, transmission through walls, and infiltration by outside air.

The temperature of the container must be maintained at 4ºC, considering a maximum temperature of 21ºC, corresponding to the case study.

Heat load per product

To calculate how much heat must be extracted from the device, the overall thermal load of the product is obtained as follows:

$$Q_{\text{prod}} = \left(\frac{m*Cp*\Delta T}{t}\right)$$

Where:

Q_{prod}= Heat extracted per product $[W]$.

m = Product mass $[kg]$.

Cp= Specific heat above freezing point $[KJ/kgK]$.

ΔT= Temperature difference $[K]$.

t = Time $[s]$.

Table 3 shows the parameters used to determine the thermal load per product.

Parameter	Value	Units
m	19.81	Kg
t	10800	S
Cp	3.8	kJ/kgK
ΔT	17	K

Table 3 Parameters to obtain the thermal load per blood product
Source: Own elaboration

Heat load generated by wall transfer

The thermal load generated by heat transfer through the walls of the container is calculated by the following equation:

$$Q_{walls} = A * U * \Delta T$$

Where:

Q_{walls} = Total heat transmission through walls $[W]$.

A = Heat transfer area $[m^2]$.

ΔT = Temperature differential between indoor and outdoor temperature [K].

U = Overall heat transfer coefficient [〖W/m〗^2 K], calculated as:

$$U = \frac{1}{\frac{1}{h_i}+\frac{e_1}{k_1}+\frac{e_2}{k_2}+\frac{1}{h_e}}$$

Where:

h = Convection coefficient [W/m^{2}K].

e_n = Thickness [m].

k_n = Thermal conductivity [W/mK].

Table 4 shows the parameters used to determine the overall heat transfer coefficient.

Parameter	Value	Units
h_{inside}	10	W/m^{2}K
$h_{outside}$	15	W/m^{2}K
e_1	0.025	m
e_2	0.04	m
$k_{1polypropylene}$	0.2	W/mK
$k_{2polypropylene}$	0.028	W/mK
$k_{2aerogel}$	0.015	W/mK

Table 4 Parameters to determine U
Source: Own elaboration

Thermal load generated by air changes

The thermal load generated by air changes in the device is calculated by the following equation:

$$Q_{\text{changes}} = Q_2 = Q_{2.1} + Q_{2.2}$$

Where:

$Q_{2.1}$ = Heat load due to technical air renewal, [W] per day.

m_a= air mass [Kg/day].

V= Enclosure volume [m^3].

ρ= Average air density between indoor and outdoor conditions [Kg/m^3].

n = Number of technical renewals, renewals/day

Δh= Enthalpy difference between outside and inside air [W/kg]

$$Q_{2.2} = m_a * \Delta h$$

Being:

$$m_a = V * p * \theta$$

m_a= Infiltrated air mass, [Kg] per day.

V= Volume of infiltrated air [m^3].

ρ= Average air density between indoor and outdoor conditions [Kg/m^3].

θ= Door open time per day in seconds.

The volume of infiltrated air is a function of temperature and door dimensions:

$$V = \frac{a*H}{4}\sqrt{0.072 * H * \Delta T}$$

V = Air volume [m^3/s].

a = Door width [m].

H = Door height [m].

ΔT= Indoor/outdoor air temperature difference [K].

Total thermal load

The total thermal load is determined by the sum of the thermal loads considered, i.e. es:

$$Q_{total} = Q_{product} + Q_{walls} + Q_{changes}$$

Choice of cooling source

Once the total load that the system must remove to maintain operating temperatures has been calculated, a thermoelectric cooling system is chosen. This is because there is a small container and the volume can be cooled with a system of this type, which is environmentally friendly.

Table 5 shows the specifications of the Peltier cell chosen for the thermoelectric cooling system.

Specifications	
I max.	10 A
V max.	15.4 V
ΔT max.	150 °C
Q max.	89 W
Dimensions	40 x 40mm

Table 5 Specifications of a TEC-12710 Peltier cell
Source: Godoy, 2016

Energy consumed by the cooling system

With the universal performance graph it is possible to determine the current intensity at which the Peltier cell must operate in order to remove the heat from the system, and thus calculate the electrical power required to be supplied.

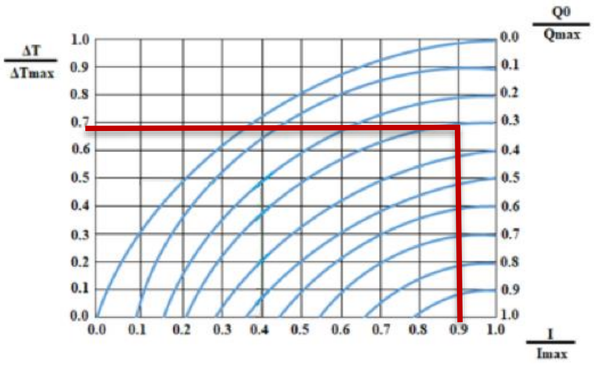


Figure 2 Universal yield curves
Source: Meerstetter Engineering, 2016

The Electrical Power required by the refrigeration system is calculated by the following equation:

$$P = V * I$$

Where:

P= Electrical power [W].

V= Maximum voltage [V].

I= Current intensity [A].

Choice of the photovoltaic panel

A light and flexible photovoltaic panel is proposed for quick installation and to provide the necessary energy for the operation of the system. Table 6 shows the specifications of the photovoltaic panel.

Parameter	Value	Units
Electrical power	250	W
Current	10	A
Voltage	12	V
Weight	0.862	Kg
Area	0.4	m^2

Table 6 Technical data sheet of the photovoltaic panel
Source: Own elaboration

To calculate the daily energy generated by the photovoltaic panel we have:

Energy = Panel power * Solar resource

Results

Table 7 shows the results of the thermal loads obtained for the container insulated with the two materials.

Parameter	Value	Units
$Q_{product}$	119	W
Q_{wall_P}	8.40	W
Q_{wall_A}	4.89	W
$Q_{changes}$	13	W
Q_{total_P}	140.4	W
Q_{total_A}	136.89	W

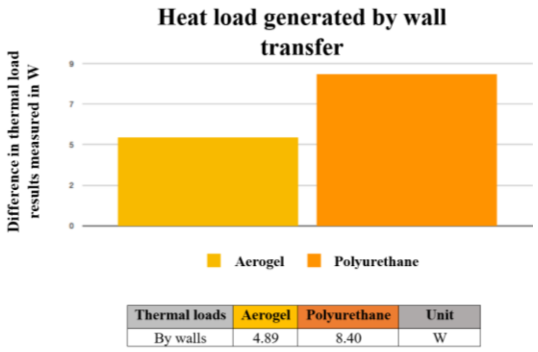
Table 7 Total thermal load
Source: Own elaboration

Where:

Q_{wall_P} = Heat transmission through walls, using polyurethane as a thermal insulator.

Q_{wall_A} = Heat transmission through walls, using aerogel as thermal insulation.

Figure 3 shows the comparison between thermal loads by wall transmission for both insulating materials. It can be seen that in the case of aerogel the heat transmission is lower, being almost half that of polyurethane.



Thermal loads	Aerogel	Polyurethane	Unit
By walls	4.89	8.40	W

Figure 3 Graph of thermal load generated by wall transmission
Source: Own elaboration

With the total thermal load and considering five thermoelectrics, as specified in Table 5, the operating current of each one of them is obtained from the values shown in Table 8.

Parameter	Value	Units
ΔT_{max}	150	K
ΔT	17	K
Q_{max}	89	W
Q_{0A}	136.9/5	W
I_{max}	10	A
I	**9**	**A**

Table 8 Parameters to find the value of current intensity
Source: Own elaboration

With the value of the current intensity and the potential difference supplied by the photovoltaic panel we have a consumption of 108 W per thermoelectric. This gives a total of 540 W for the refrigeration system.

To cool the product from 21°C to 4°C, storage temperature, 1620 Wh are required. While to maintain the temperature of 4°C, 1134 Wh of energy is needed, giving a total of 2754 Wh per day.

The energy generated by two 250W photovoltaic panels, such as the one specified in Table 6, is 3150 Wh, which more than satisfies the 24-hour supply.

Conclusions

From the results obtained, it can be considered that the performance of the container is acceptable for the two cases of study; with polyurethane and aerogel as insulators. The difference between total thermal loads does not change significantly; however, aerogel, due to its low thermal conductivity, shows a notable difference in the thermal load through walls, since it is the only calculated load that has a direct relationship with the insulation.

In conclusion, we could observe that the use of aerogel as an insulator is not very important in small capacity containers, such as the one analyzed in this work, but it could be adequate for large containers, where the thermal loads through walls are significant. In this case study, the best option is to opt for polyurethane as insulation because of its lower cost.

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