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Research Article

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Effect of Density on the Thermal Impedance of the Kapok Material in Frequential Dynamic Regime

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Abstract In this article, we have proposed a study of the behavior of the thermal impedance of the Kapok material. From the electrical-thermal equivalence, we establish the expression of thermal impedance. We can vary the density to highlight their influences on the behavior of thermal impedance. We focus this work on the lateral x axis and the depth z of the material.

Keywords Density, Thermal Impedance, Kapok material , Frequential dynamic

Introduction

Within the framework of this thermally sound insulating materials, not very generous and external studies the thermal exchanges with the outside; we propose a use of KAPOK [1] which is a renewable resource, naturally biodegradable, neutral in terms of CO_2 emissions into the atmosphere, and requiring little energy for its production. In fact, Kapok is a plant fiber whose mechanical properties allow it to perform thermal insulation functions with low thermal conductivity.

In this work, we propose a study of heat transfer through the kapok material by the thermal impedance method [2]. In this case, we establish the expression of thermal impedance by the electric-thermal analogy [3]. We then propose a study of the thermal behavior of the Kapok material by highlighting the influences of density [4], excitatory pulsation [5]and the heat exchange coefficients [6] according to the position in the material.

Materials and Methods

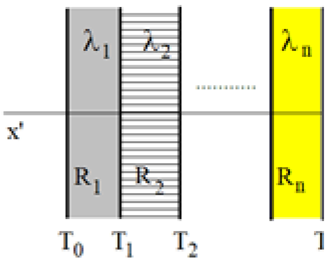

Figure 1: Diagrams of the study model in 1-D

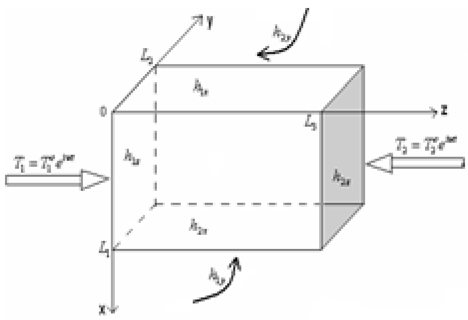

Figure 2: Diagrams of the study model in 3-D

In steady state, the same power crosses any surface S normal to x'x :

$$P = \frac{T_0 - T_1}{R_1} = \frac{T_1 - T_2}{R_2} = \ldots = \frac{T_{n-1} - T_n}{R_n} = \frac{T_0 - T_n}{\sum R_i}. \quad (1)$$

The conductors are equivalent to a single conductor whose faces risk at T0 and Tn, of thermal resistance R such that:

$P = \frac{T_0 - T_n}{R}$. (2)

Thus R = R1 + R2 +...+ Rn. (3)

By analogy with electricity, we have an analogy relationship to ohm's law:

$\Delta T = T_{a1} - T_{a2} = R_{eq1}.\phi$ (4)

Where,

R_{eq1} is the equivalent resistance of the material,

ϕ The heat flow through the wall.

Thus, by generalizing in dynamic frequency regime, one can define the thermal impedance.

We summarize in the following table the correspondence between certain electrical and thermal quantities.

Table 1: Thermal electric equivalent [7]

Electrical Quantities			Equivalent Thermal Quantities		
Electric current intensity	$I = \frac{dq}{dt}$	(A)	Flux	$\phi = -\lambda \frac{\partial T}{\partial x} = -\frac{\partial(\lambda T)}{\partial x}$	(w)
Electric potential	V	(V)	Temperature	T	(K)
Electrical impedance	$Z = \frac{\Delta V}{I}$	(Ω)	Thermal impedance	$Ze = \frac{\Delta T}{\phi}$	(K.w^{-1})

For a material depth $M(x,y,z)$, we have :

$$\Delta T(x,y,z,t) = Z(x,y,z)\cdot\phi(x,y,z,t) \quad (5)$$

With the temperature variation between the points $M_0(x,y,0)$ and $M(x,y,z)$ in the material and, $\phi(x,y,z)$ the heat flux density transmitted between these two points.

$$\Delta T = \sum_{m=1}^{+\infty}\sum_{n=1}^{+\infty}\left\{\begin{array}{l}\left[\cos(\beta_m x) + \frac{h_{1x}}{\lambda\beta_m}\sin(\beta_m x)\right]\left[\cos(\gamma_n y) + \frac{h_{1y}}{\lambda\gamma_n}\sin(\gamma_n y)\right] \\ \times\left[A_{mn}\left(1-\cosh(L_{mn}z)\right) - B_{mn}\sinh(L_{mn}z)\right]\end{array}\right\}e^{i\omega t} \quad (6)$$

Where the impedance is: $$Z(x,y,z) = \frac{\Delta T(x,y,z,t)}{\phi(x,y,z,t)}$$

Finally the thermal impedance is written:

$$Z(x,y,z) = \frac{\sum_{m=1}^{+\infty}\sum_{n=1}^{+\infty}\left\{\begin{array}{l}\left[\cos(\beta_m x) + \frac{h_{1x}}{\lambda\beta_m}\sin(\beta_m x)\right]\left[\cos(\gamma_n y) + \frac{h_{1y}}{\lambda\gamma_n}\sin(\gamma_n y)\right] \\ \times\left[A_{mn}\left(1-\cosh(L_{mn}z)\right) - B_{mn}\sinh(L_{mn}z)\right]\end{array}\right\}e^{i\omega t}}{\sqrt{\phi_1(x,y,z,t)^2 + \phi_2(x,y,z,t)^2 + \phi_3(x,y,z,t)^2}} \quad (7)$$

Results & Discussion

In figures (1) and (2); we present the evolution of the thermal impedance of the Kapok material as a function of its density. We study the thermal behavior of the material at different points in the direction (oz) and by varying the heat exchange coefficient.

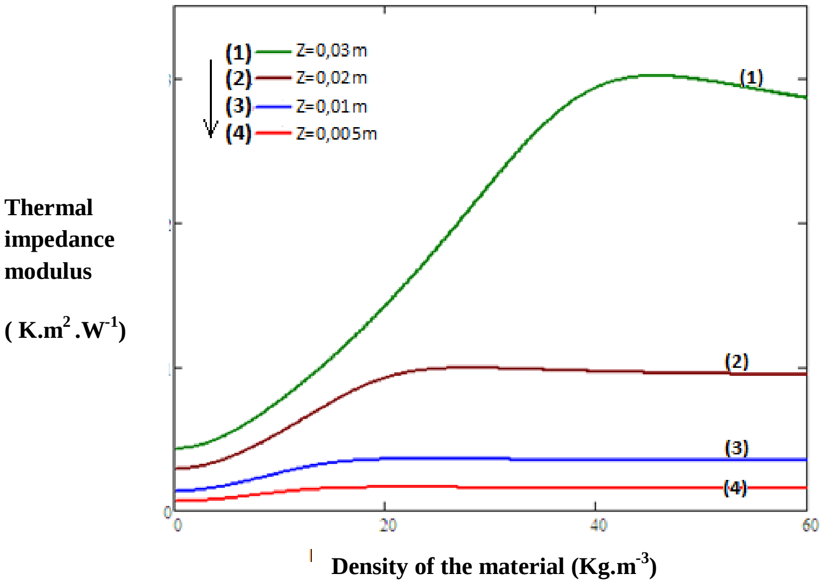

Figure 3: Variation of the thermal impedance of the material as a function of its density for different values of z. x = 0,02m ; y = 0,01m ; ω = 0,001rad/s ; h_{1Z}= 30w.m^{-2}.K^{-1} et h_{2Z} = 0,05w.m^{-2}.K^{-1}

Table 2: Density and thermal impedance modulus values for different depth values for h_{1Z} = 30w.m^{-2}.K^{-1} et h_{2Z} = 0,05w.m^{-2}.K^{-1}

Depthz (m)	Density of the material ρ (kg/m^3)	Impedance modulus $(K.m^2.w^{-1})$
0.005	0.1	0.064
	22.1	0.1614
0.01	0.1	0.135
	22.6	0.357
0.02	0.1	0.289
	28.3	0.989
0.03	0.1	0.430
	45.6	3.015

The curves in this figure (3) have the same profile; they increase to reach a maximum before decreasing slightly. We note at the level of the curves that the thermal impedance increases when we go deep into the material. The modulus of the thermal impedance of the material is important when the density is low for a low thickness. And that for a great thickness, the thermal impedance modulus is important when the density of the material is high [8] [9].

It can be seen that the maximum value of the impedance is reached faster if the position considered is close to the front face where the exchange coefficient h_{1z} is high for a low rear face exchange coefficient h_{2Z}.

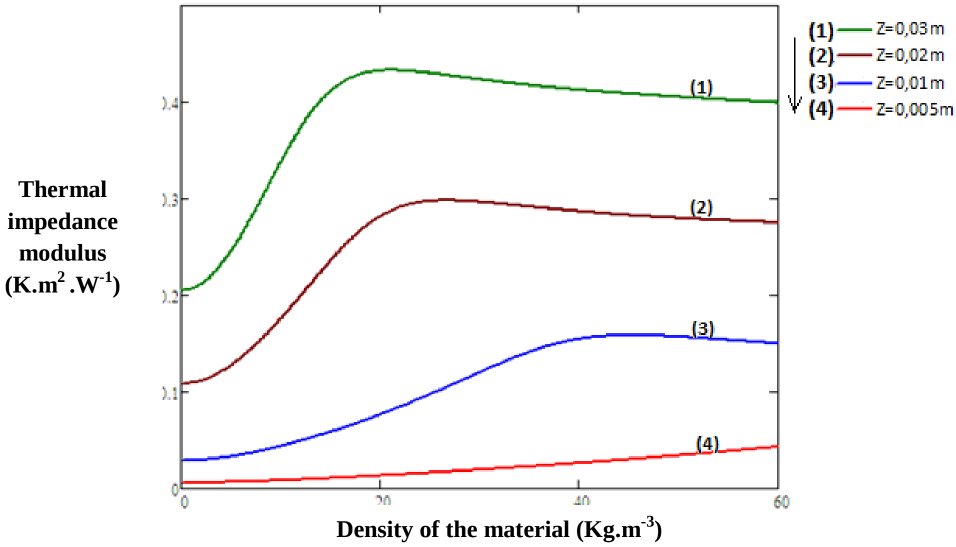

Figure 4: Variation of the thermal impedance of the material as a function of its density ρ.
x = 0,02m ; y = 0,01m ; ω = 0,001rad/s ; h_{1Z} *= 0,05w.m*$^{-2}$*.K*$^{-1}$ *et* h_{2Z} *= 30w.m*$^{-2}$*.K*$^{-1}$

The curves in this figure (4) increase to reach a maximum before decreasing slightly. We note at the level of the curves that the thermal impedance increases when we go deep into the material. The modulus of the thermal impedance of the material is important when the density is low for a high thickness. For a low thickness, the thermal impedance modulus is important when the density of the material is height. This is confirmed in the following table (3).

Table 3: Density and thermal impedance modulus values for different depth values for h_{1Z} = 0,05w.m^{-2}.K^{-1} et h_{2Z} = 30w.m^{-2}.K^{-1}

Depthz (m)	**Density of the material** ρ **(kg/m^3)**	**Impedance modulus** $(K.m^2.w^{-1})$
0.005	0.1	0.006
	60	0.043
0.01	0.1	0.028
	45	0,158
0.02	0.1	0.108
	26.7	0.298
0.03	0.1	0.205
	21.3	0.433

In this figure (4), the maximum of the thermal impedance is reached faster when the position considered is close to the rear face where the exchange coefficient h2Z is high for low h1Z.

Through these two figures, it can be seen that the positions close to the face expose to external thermal stresses are more resistant to these stresses.

In figures (5) and (6); we present the evolution of the thermal impedance of the Kapok material as a function of the density of the material. We study the thermal behavior of the material at different points of the material along the lateral axis (ox), then we vary the heat exchange coefficient

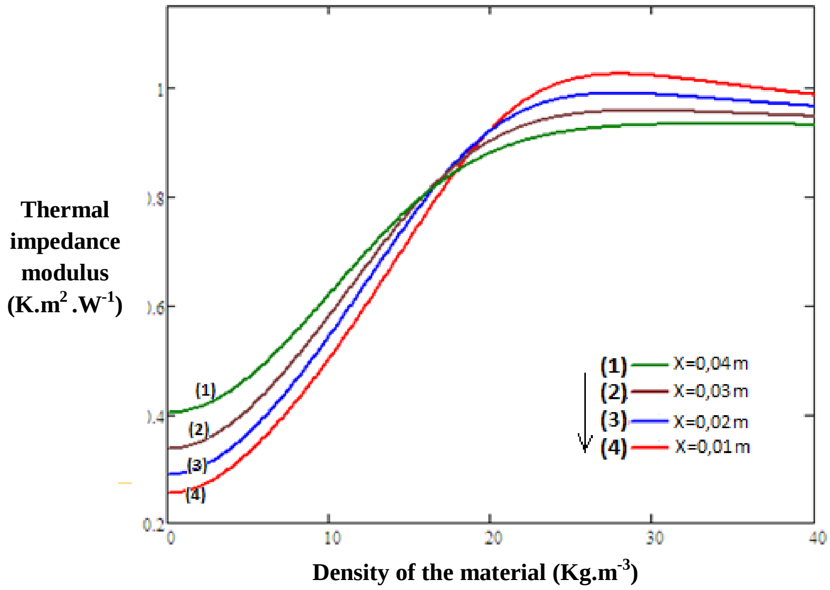

Figure 5: *Variation of the thermal impedance of the material as a function of its density for different values of x.*
z = 0,02m ; y = 0,01m ; ω = 0,001rad/s ; h_{1Z} *= 30w.m*$^{-2}$*.K*$^{-1}$ *et* h_{2Z} *= 0,05w.m*$^{-2}$*.K*$^{-1}$

Table 4: Density and thermal impedance modulus values for different values of x on the lateral axis for h_{1Z} = 30w.m^{-2}.K^{-1} et h_{2Z} = 0,05w.m^{-2}.K^{-1}

Depthz (m)	**Density of the material ρ (kg/m^3)**	**Impedance modulus ($K.m^2.w^{-1}$)**
0.01	0.1	0.254
	27.8	1.025
0.02	0.1	0.289
	28.3	0.989
0.03	0.1	0,336
	29,6	0.958
0.04	0.1	0.403
	34.3	0.933

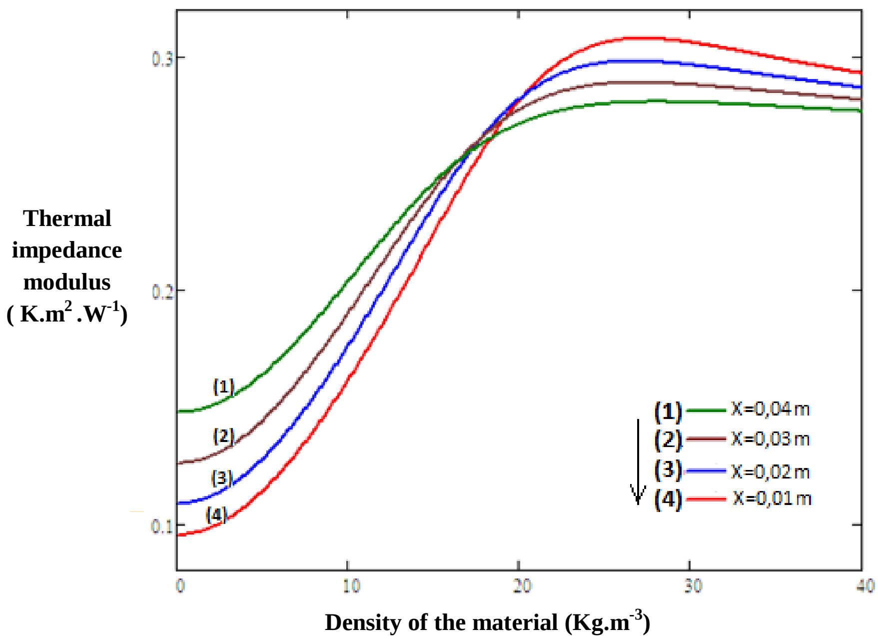

Figure 6: Variation of the thermal impedance of the material as a function of its density for different values of x.

z = 0,02m ; y = 0,01m ; ω = 0,001rad/s ; h_{1Z} = 0,05w.m^{-2}.K^{-1} et h_{2Z} = 30w.m^{-2}.K^{-1}

We see that in figures (5) and (6); the curves look the same. The modulus of thermal impedance increases considerably with density, reaching a maximum before decreasing slightly. The maximum of the thermal impedance modulus reflects a loss of heat flow density in the material, that is, a large temperature difference between the faces perpendicular to the axis (oz). The phenomenon of energy storage is important at this level. Then the impedance decreases as a function of the density; therefore we observe a drop in impedance at this level.

Along the lateral x axis, we see that for a thin material, the modulus of the impedance increases as a function of the value of x. On the other hand, from the value of ρ = 20 kg / m^3, we observe the reverse and the positions corresponding to large values of x first reach the maximum of the modulus of the impedance. This inversion is due to the fact that the Kapok material tends to store thermal energy in a thin layer or thickness when its density is high.

Through the curves of these figures, it can be seen that a drop in the modulus of thermal impedance from a certain value of the density equal to 30 kg.m^{-3} corresponding to the critical density ρo (ρo = 30 kg.m^{-3}).

Conclusion

In this article, we have studied the evolution of the modulus of the thermal impedance of the Kapok material as a function of the density and specific heat. Through this study, we have identified an area of variation in density and specific heat in which we can achieve good thermal insulation of the Kapok material. We have shown that the thermal impedance of the material also depends on the thickness of the material:

- The modulus of the thermal impedance of the material is important when the density is low for a high thickness.
- For a great thickness, the thermal impedance modulus is important when the density of the material is high.

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