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RESEARCH ARTICLE

STUDY OF THE THERMAL RESISTANCE OF HEAT TRANSFER IN TRANSIENT DYNAMIC REGIME IN AN INSULATING MATERIAL BASED ON TYPHA AND TWO-DIMENSIONAL (2D) CLAY: INFLUENCE OF THE HEAT EXCHANGE COEFFICIENT ON THE FRONT FACE

Seydou Faye[1], Mame Fadiamé Thiam[2] and Fatimata Ba[1]

1. Laboratory of Semiconductors and Solar Energy, Physics Department, Faculty of Science and Technology, University Cheikh Anta Diop, Dakar, Senegal.
2. The Higher Institute of Professional Education (ISEP) of Matam.

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Abstract

The objective of this study is to focus on the influence of local insulating materials in thermal insulation for a well-defined period. The material is a wall consisting of typha and clay. The main objective of this study is to see the behavior of the thermal resistance of the material as a function of the heat exchange coefficient at the front face. The typha and clay wall is modeled by applying the transient analytical method with the two-dimensional heat equation. This analytical resolution of the heat equation allows us to determine the detailed expression of the thermal resistance but also to visualize the curves of evolution of this resistance according to the depth under the influence of the heat exchange coefficient at the front side.

Introduction:-

The conductive thermal resistance can be defined as the conductive thermal resistance. It expresses its resistance to the passage of a flow of thermal conduction. Indeed, this resistance applies to solids, liquids and gases. In the international system of units, it is expressed in Kelvin per Watt (K/W or °C/W) **[1].** The thermal resistance Rth

[2-5], measures the resistance that a thickness of material opposes to the passage of heat. The thermal resistance Rth depends on the (lambda) and the thickness of the material. The types of synthesis used are generally imported from Europe or Asia, hence the need to find alternatives locally. However, several characterization studies **[6,7]** on various local materials, such as tow, kapok, kenaf..., have shown that these can be used for effective thermal insulation of buildings **[8-9]** and refrigeration equipment**.[10]** It is in this spirit that we choose to study the material of typha and clay for thermal insulation but precisely to study thermal resistance.

The biodegradable natural product such as typha **[11-13]** used as thermal insulation in combination with clay as a binder. Several methods in static regime **[14,15]** and in transient dynamics **[16, 17]** are proposed. We study the thermal and relative resistance as a function of the depth under the influence of the heat exchange coefficient at the front face.

Corresponding Author:- Seydou Faye
Address**:-** Laboratory of Semiconductors and Solar Energy, Physics Department, Faculty of Science and Technology, University Cheikh Anta Diop, Dakar, Senegal.

Study model

Study device

The tow-plaster material is assumed to be homogeneous and parallelepipedic in shape. The depth of the material is L=0,05m. The initial temperature of the material Ti=10^0C and that of the external ambient mediaTa1=Ta2=30^0C. The heat exchange coefficients on the front face and on the rear face along x and y are respectively h1, h2, h3and h4 . The average thermal diffusivity is α and the thermal conductivity is λ.

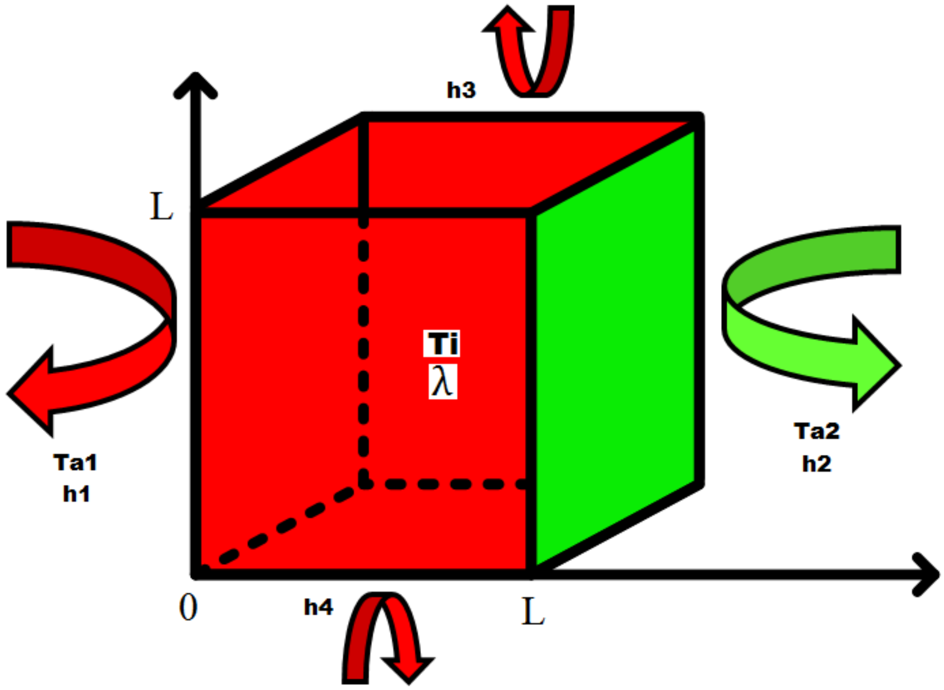

Figure 1:- Sample to be studied consisting of typha-clay thermal insulation.

The thermal resistance Rth is given by the following expression:

$$Rth = \frac{1}{S}\left[\frac{1}{h_1} + \frac{L}{\lambda} + \frac{1}{h_2}\right]; (1)$$

With

$R_{cv1} = \dfrac{1}{h_1 S}$ **:** The thermal resistance of a plane wall at the front face.

$R_{cd} = \dfrac{L}{\lambda S}$ **:**appears as the thermal resistance of a plane wall of thickness L, thermal conductivity λ and lateral surface S.

$R_{cv2} = \dfrac{1}{h_2 S}$ **:** The thermal resistance of a flat wall at the rear face.

The surface S=1m² ;

$Rth = \left[\dfrac{1}{h_1} + \dfrac{L}{\lambda} + \dfrac{1}{h_2}\right]$:The expression of the thermal resistance of a wall subjected to external climatic stresses in steady state.

$$Rth = R_{cv1} + R_{cd} + R_{cv2}; (2)$$

Theory

The unidirectional heat transfer in the yarn-plaster thermal insulation is governed by equation (1) below:

$$\frac{\partial^2 T(x,y,h_1,h_2,h_3,h_4,t)}{\partial x^2}+\frac{\partial^2 T(x,y,h_1,h_2,h_3,h_4,t)}{\partial y^2}-\frac{1}{\alpha}\frac{\partial T(x,y,h_1,h_2,h_3,h_4,t)}{\partial t}=0;(3)$$

$T = T(x,y,h_1,h_2,h_3,h_4,t)$ is the temperature inside the material; x the depth and t the time t. Equation (2) gives the expression of the diffusivity α

$$\alpha=\frac{\lambda}{\rho c};(4)$$

α is the coefficient of thermal diffusivity ($m^2.s^{-1}$)
λ is the thermal conductivity ($W.m^{-2}.c^{-1}$)
ρ is the density of the material ($kg.m^{-2}$)
Boundary conditions

$$\begin{cases}\lambda\left.\dfrac{\partial T(x,y,h_1,h_2,h_3,h_4,t)}{\partial x}\right|_{x\equiv 0}=h_1\left[T(0,y,t)-T_a\right];(5)\\ \lambda\left.\dfrac{\partial T(x,y,h_1,h_2,h_3,h_4,t)}{\partial x}\right|_{x\equiv L}=-h_2\left[T(L,y,t)-T_a\right];(6)\\ \lambda\left.\dfrac{\partial T(x,y,h_1,h_2,h_3,h_4,t)}{\partial y}\right|_{y\equiv 0}=h_3\left[T(x,0,t)-T_a\right];(7)\\ \lambda\left.\dfrac{\partial T(x,y,h_1,h_2,h_3,h_4,t)}{\partial y}\right|_{y\equiv L}=-h_4\left[T(x,L,t)-T_a\right];(8)\\ T(x,y,h_1,h_2,h_3,h_4,t=0)=T_i\,(9)\end{cases}$$

Dimensionless heat equation

$$\theta(u,v,\tau)=\frac{T(x,y,t)-T_a}{T_i-T_a};(10)$$

with $\theta(u,v,\tau)$: reduced temperature;

$u=\dfrac{x}{L}$; is a space reduced variable

$v=\dfrac{y}{L}$; is a space reduced variable

and $\tau=\dfrac{\alpha t}{L^2}=F_0$

F_0 : Reduced time variable or Fourier number
The heat equation (1) becomes:

$$\frac{\partial^2\theta(u,v,\tau)}{\partial u^2}+\frac{\partial^2\theta(u,v,\tau)}{\partial v^2}=\frac{\partial\theta(u,v,\tau)}{\partial\tau};(11)$$

The boundary conditions (5), (6), (7) and (8) become (12), (13), (14) and (15):

$$\begin{cases} \left.\dfrac{\partial\theta(u,v)}{\partial\tau}\right|_{u=0} = \dfrac{h_{1.}L}{\lambda}\theta(0,\tau);(12) \\ \left.\dfrac{\partial\theta(u,v)}{\partial\tau}\right|_{u=1} = -\dfrac{h_{2.}L}{\lambda}\theta(1,\tau);(13) \\ \left.\dfrac{\partial\theta(u,v)}{\partial\tau}\right|_{u=0} = \dfrac{h_{3.}L}{\lambda}\theta(0,\tau);(14) \\ \left.\dfrac{\partial\theta(u,v)}{\partial\tau}\right|_{u=1} = \dfrac{h_{4.}L}{\lambda}\theta(1,\tau);(15) \end{cases}$$

Let us find the solution of equation (13) in the form of reduced variables separable in space and time given by relation (16):

$$\theta(u,v,\tau) = U(u)V(v)W(\tau);(16)$$

Using the relations (13) and (16) we obtain that of (17)

$$\frac{1}{U(u)}\frac{\partial^2 U(u)}{\partial u} + \frac{1}{V(v)}\frac{\partial^2 V(v)}{\partial v} + \frac{1}{W(\tau)}\frac{\partial W(\tau)}{\partial\tau} = -\gamma^2;(17)$$

γ is a positive constant.

From relation (17) we obtain two differential equations:

- The differential equation in time is given by (18):

$$\frac{1}{W(\tau)}\frac{\partial W(\tau)}{\partial\tau} = -\gamma^2;(18)$$

- The differential equation in space (19) is written:

$$\frac{1}{U(u)}\frac{\partial^2 U(u)}{\partial u} = -\beta^2;(19)$$

The boundary conditions space:

$$\begin{cases} \left.\dfrac{\partial\theta(0,\tau)}{\partial\tau}\right|_{u=0} = B_{i1}\theta(0,\tau);(20) \\ \left.\dfrac{\partial\theta(1,\tau)}{\partial\tau}\right|_{u=1} = -B_{i2}\theta(1,\tau);(21) \\ \left.\dfrac{\partial\theta(0,\tau)}{\partial\tau}\right|_{u=0} = B_{i3}\theta(0,\tau);(22) \\ \left.\dfrac{\partial\theta(1,\tau)}{\partial\tau}\right|_{u=1} = -B_{i4}\theta(1,\tau);(23) \end{cases}$$

With $B_{i1} = \dfrac{h_1.L}{\lambda}$; $B_{i2} = \dfrac{h_2.L}{\lambda}$; $B_{i3} = \dfrac{h_3.L}{\lambda}$ et $B_{i4} = \dfrac{h_4.L}{\lambda}$ respectively the Biot numbers on the front face and on the back face.

Temperature expression:

The general solution of the reduced temperature is in the form

$$\theta(u,v,\tau)=\sum_n\left[\left(a_n\cos(\beta_n u)+b_n\sin(\beta_n u)\right)\right]\left[c_n\cos(\mu_n v)+d_n\sin(\mu_n v)\right]e^{-\gamma^2\tau};(24)$$

$$\theta(u;v,\tau)=\frac{T(x,y,h_1,h_2,h_3,h_4,t)-T_a}{T_i-T_a};(25)$$

$$T(x,y,h_1,h_2,h_3,h_4,t)=T=T_a+(T_i-T_a)\theta(u;v,\tau);(26)$$

The general solution of temperature:

$$T=T_a+(T_i-T_a)\sum_n\left[a_n\left(\cos\left(\beta_n\frac{x}{L}\right)+\frac{\frac{h_{1x}L}{\lambda}}{\beta_n}\sin\left(\beta_n\frac{x}{L}\right)\right)c_n\left(\cos\left(\mu_n\frac{y}{L}\right)+\frac{\frac{h_{1y}L}{\lambda}}{\mu_n}\sin\left(\mu_n\frac{y}{L}\right)\right)\right]e^{-\frac{\alpha t}{L^2}\gamma^2};(27)$$

Expression of the heat flux density:

We get the expression of the density of the heat flow (or surface heat flow)
Which is the heat flux per unit area ($W.m^{-2}$) as follows:

$$\vec{\Phi}(x,y,h_1,h_2,h_3,h_4,t)=-\lambda\,\overrightarrow{grad}T(x,y,h_1,h_2,h_3,h_4,t);(28)$$

$$\vec{\Phi}(x,y,h_1,h_2,h_3,h_4,t)=\overrightarrow{\Phi_x}(x,y,h_1,h_2,h_3,h_4,t)+\overrightarrow{\Phi_y}(x,y,h_1,h_2,h_3,h_4,t);(29)$$

From these two expressions we get, the final expression of the heat flux density

$$\vec{\Phi}_x(x,y,h_1,h_2,h_3,h_4,t)=-\lambda\frac{\partial\vec{T}(x,y,h_1,h_2,h_3,h_4,t)}{\partial x};(30)$$

$$\vec{\Phi}_y(x,y,h_1,h_2,h_3,h_4,t)=-\lambda\frac{\partial\vec{T}(x,y,h_1,h_2,h_3,h_4,t)}{\partial y};(31)$$

$$\vec{\Phi}(x,y,h_1,h_2,h_3,h_4,t)=\sqrt{\left(\Phi_x(x,y,h_1,h_2,h_3,h_4,t)\right)^2+\left(\Phi_y(x,y,h_1,h_2,h_3,h_4,t)\right)^2};(32)$$

We obtain the expression of the temperature variation:

$$\Delta T(x,y,h_1,h_2,h_3,h_4,t)=T(0,y,h_1,h_2,h_3,h_4,t)-T(x,y,h_1,h_2,h_3,h_4,t);(33)$$

Thermal resistance expresses its resistance to the passage of a heat conduction flow ($W.m^{-1}.^0C^{-1}$).
The greater the thermal resistance, the more insulating the material.
Thermal resistance depends on thickness and thermal conductivity.
The thermal resistance, which is the ratio between the change in temperature and the heat flux density, is given by expression (34).

$$R_{th}(x,y,h_1,h_2,h_3,h_4,t)=\frac{\Delta T(x,y,h_1,h_2,h_3,h_4,t)}{\Phi(x,y,h_1,h_2,h_3,h_4,t)};(34)$$

$\Delta T(x,y,h_1,h_2,h_3,h_4,t)$ being the temperature difference between the two sides of the material.

$\Phi(x,y,h_1,h_2,h_3,h_4,t)$ the heat flow that passes through the yarn-plaster material.

This expression allows us to draw the curves of the thermal resistance according to the various thermophysical parameters.

Results:-

We are going to plot the evolution of the thermal resistance as a function of the depth under the influence of the exchange coefficient at the front face h1.

Figure 2 shows the evolution of the thermal resistance as a function of the depth of the material under the influence of the exchange coefficient at the front face h1. For thicknesses between 0 and 1cm, the thermal resistance of the material is very low, therefore the heat passes through these thicknesses due to the proximity of the outer wall of the cylinder which has the highest temperature.

Beyond 1cm, the resistance of the material increases and reaches a maximum. This phenomenon reflects the retention of heat. This shows the good thermal inertia of the typha-clay material.

This maximum corresponds to the zero gradient, i.e. the storage of heat. And finally we notice a decrease in the thermal resistance corresponding to the negative gradient. This decrease corresponds to the dissipation or restriction of heat in the typha-clay material. This decrease reflects the heat loss to the outside environment. It is due to the low exchanges between the outer wall and the material.

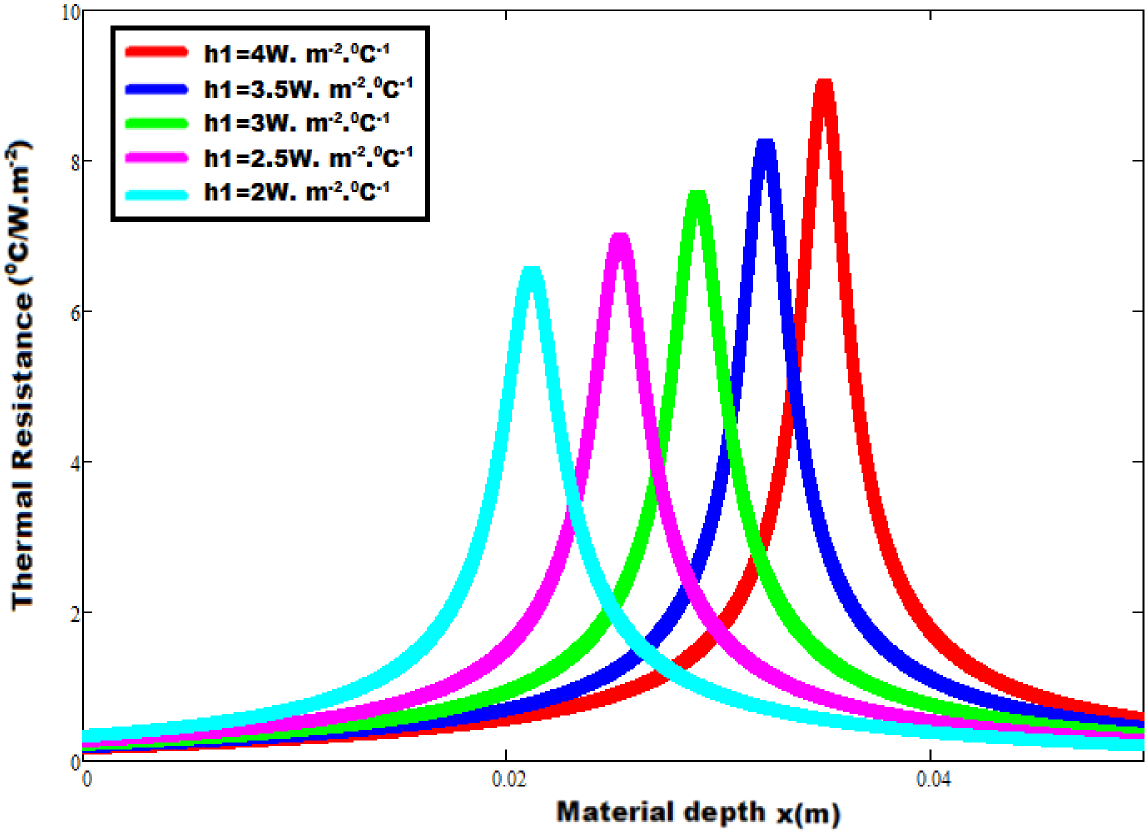

Figure 2:- Evolution of thermal resistance according to depth $h_2 = 0.005 \mathrm{W.m^{-2}.^0C^{-1}}$ et $t = 10s$.

Table 1:- Depth values for each maximum.

$h_1\left(W.m^{-2}.C^{-1}\right)$	2	2,5	3	3,5	4
Optimal insulation thickness $x(m)$	0.021	0.026	0.029	0.032	0.035

Evolution of the Relative Thermal Resistance as a function of the depth under the influence of the exchange coefficient at the front face.

For Figure 3 we have plotted the evolution of the Relative Thermal Resistance as a function of the depth under the influence of the exchange coefficient at the front face.

For low depth values, the relative thermal resistance gradually increases until it reaches a maximum, i.e. the positive gradient. This increase signifies the storage of heat inside the typha-clay material.

Then we have a maximum which corresponds to the zero gradient, i.e. the storage of heat. And finally we notice a decrease in the relative thermal resistance corresponding to the negative gradient. This decrease corresponds to the restriction of heat in the typha-clay material. We notice when the depth increases the maximum moves.

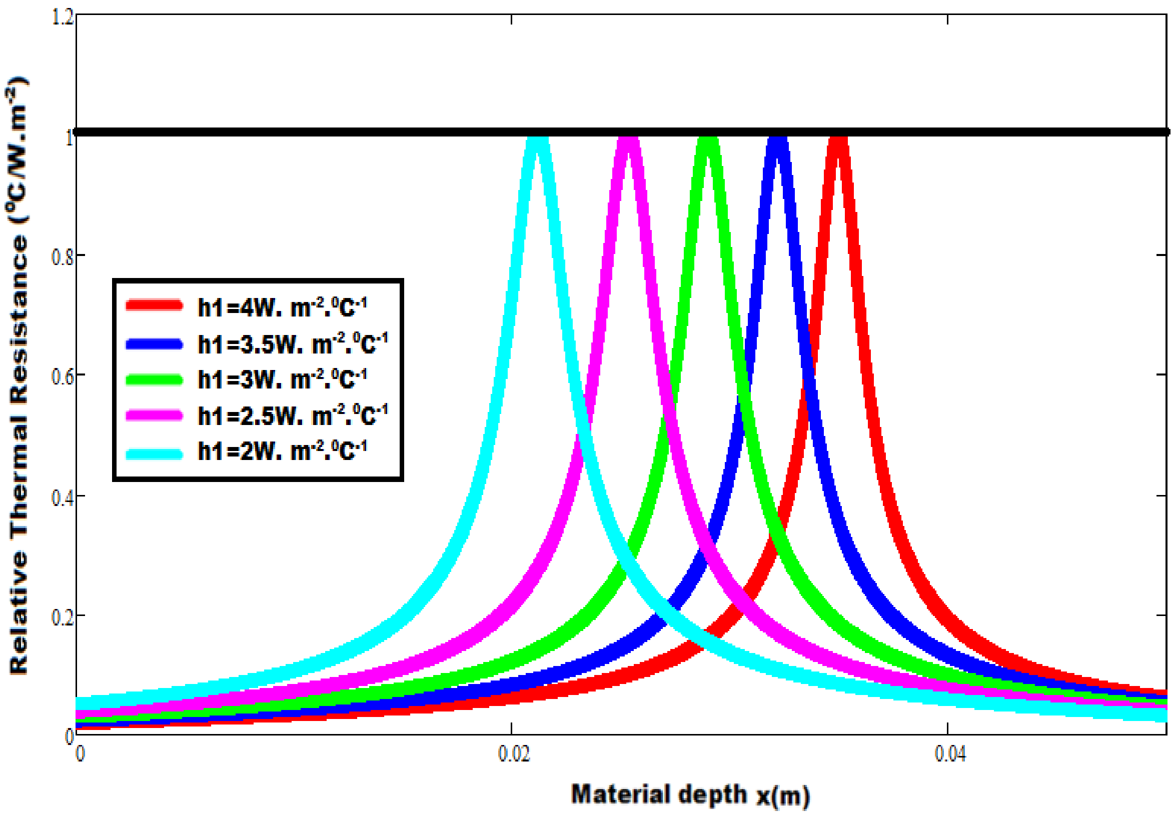

Figure 3:- Evolution of Relative Thermal Resistance as a function of depth $h_2 = 0.005\mathrm{W.m^{-2}.^0C^{-1}}$ et $t = 10s$.

Table 2:- Depth values for each maximum.

$h_1\left(W.m^{-2}.C^{-1}\right)$	2	2,5	3	3,5	4
Optimal insulation thickness $x(m)$	0.021	0.026	0.029	0.032	0.035

Evolution of thermal resistance as a function of the exchange coefficient at the front face under the influence of depth

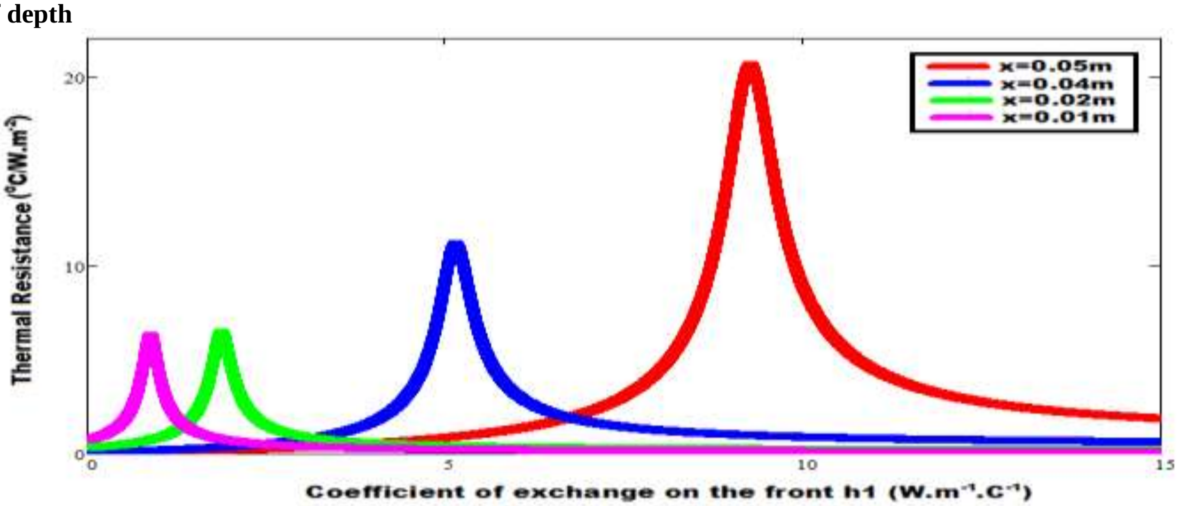

Figure 4:- Evolution of thermal resistance according to the exchange coefficient on the front face $h_2 = 0.005\mathrm{W.m^{-2}.^0C^{-1}}$ et $t = 10s$.

We have the same interpretations as Figure 2.

Table 3:- Depth values for each maximum.

Optimal insulation thickness $x(m)$	0.01	0.02	0.04	0.05
$h_1\left(W.m^{-2}.C^{-1}\right)$	0,92	1,82	5,20	9,34

3.4 Evolution of the Relative Thermal Resistance as a function of the exchange coefficient at the front face under the influence of depth

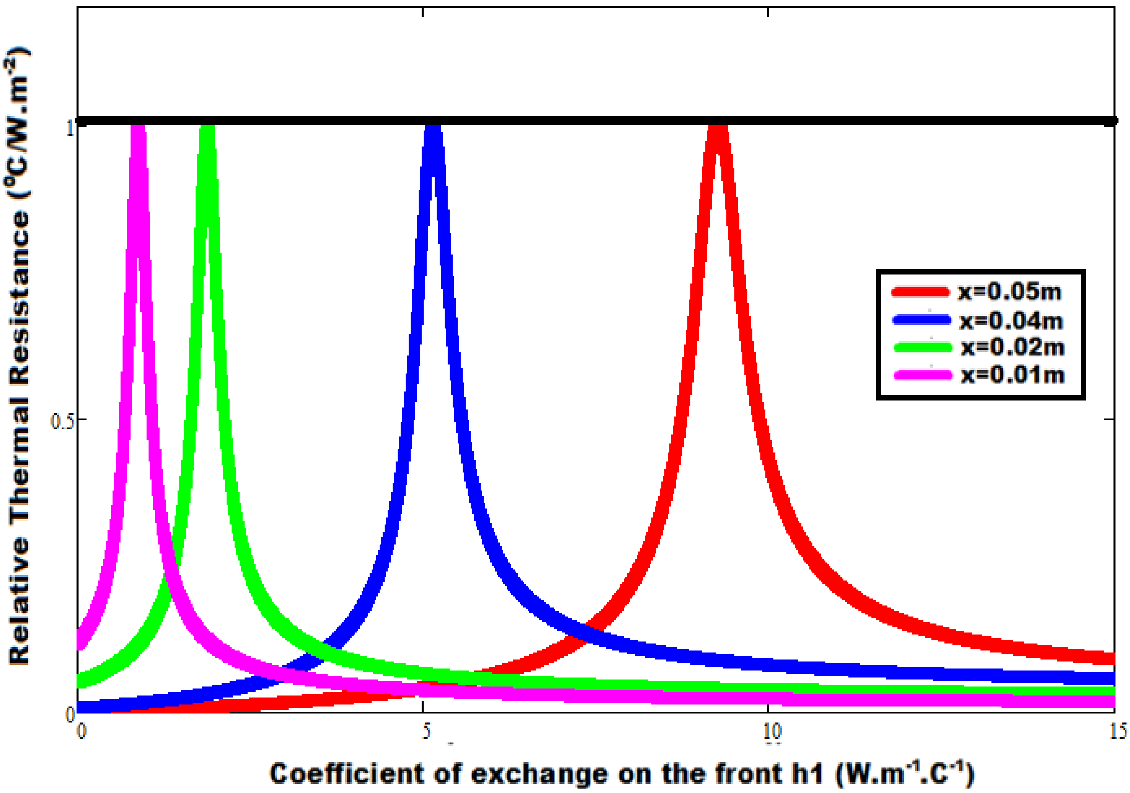

Figure 5:- Evolution of the Relative Thermal Resistance as a function of the exchange coefficient on the front face $h_2 = 0.005\text{W.m}^{-2}.^{0}\text{C}^{-1}$ et $t = 10s$.

Table 4:-Depth values for each maximum.

Optimal insulation thickness $x(m)$	0.01	0.02	0.04	0.05
$h_1\left(W.m^{-2}.C^{-1}\right)$	0,92	1,82	5,20	9,34

Conclusion:-

This work was devoted to the study of the behavior of the thermal resistance of the typha-clay material. We have managed to determine the optimum insulation thickness of the typha-clay material in which we can achieve good thermal insulation. Also, we demonstrated that the resistance depends on the thickness of the material. The influence of the heat exchange coefficient has been highlighted on the behavior of the material.

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