STUDY OF THE IMPACT OF HEAT EXCHANGE ON THE DYNAMIC RESPONSE OF A FIBER-PLASTER COMPOSITE UNDER TRANSIENT CONDITIONS.

Abstract:

The Cartesian coordinate study of a material forming a simple wall made of tow-plaster. The hemp-plaster thermal insulation is characterized in transient dynamic regimes by its heat transfer coefficients. The wall is 5 cm thick and composed of the hemp-plaster thermal insulation material. This article is based on determining the different profiles of temperature and heat flux density as a function of depth and time, along with the heat transfer coefficient at the front face of the material.

Nomenclature

λ: Thermal conductivity ($W.m^{-1}.°C^{-1}$)
α: Thermal diffusivity coefficient ($m^2.s^{-1}$)
ϕ: Heat flux density ($W.m^{-2}$)
L: Length of the material (m)
h_1: Heat transfer coefficient at the front face ($W.m^{-2}.°C^{-1}$)
h_2: Heat transfer coefficient at the back face ($W.m^{-2}.°C^{-1}$)

Key words:-
Transient Dynamic Regime, Temperature, Heat Flux Density, tow-plaster.

…………………………………………………………………………………………………….....

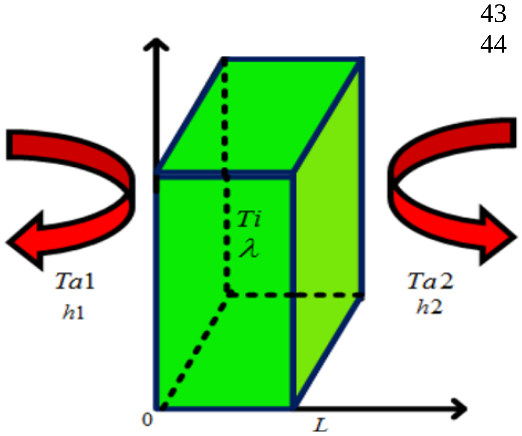
1) Introduction:

Energy efficiency in buildings and the rational use of materials are major current challenges. Some studies propose optimizing the thermal insulation materials used by determining the effective thermal insulation layer [1] or the optimal insulation thickness [2].This study falls within the framework of improving the use of local, natural products for thermal insulation [3,4].

The wall is 5 cm long and made of a hemp-plaster thermal insulation material. Hemp, a biodegradable natural product, is used as thermal insulation in combination with plaster as a binder [5]. The thermal conductivity λ = 0.15 $W.m^{-1}.°C^{-1}$and the thermal diffusivity coefficient α= 2.07$m^2.s^{-1}$ [6,7]. Hemp-plaster is of great interest for thermal comfort and contributes to the moderate regulation of the indoor climate of dwellings due to its thermal inertia [8].

2) Mathematical Model:

We will present a profile view of a gypsum-fiber brick subjected to an excitatory temperature in a transient dynamic regime.



<u>Figure 1:</u> Sample to be studied consisting of the thermal insulation tow-plaster

L = 0.05m, Ta=30°C and Ti=10°C.

$\mathbf{h_1}$ and $\mathbf{h_2}$ are the heat transfer coefficients at the front and rear faces, respectively.

Ta: the ambient temperature of the material.

Ti: the initial temperature of the material.

Equation (1), which governs heat transfer in the unidirectional hemp-plaster thermal insulation without internal energy input, is given by the expression below.

$$\frac{\partial^2 T(x,h_1,h_2,t)}{\partial x^2} - \frac{1}{\alpha}\frac{\partial T(x,h_1,h_2,t)}{\partial t} = 0 \qquad (1)$$

$T = T(x, h_1, h_2, t)$: is the temperature (°C) of the material at a depth x (m) and a time t (s) with heat transfer coefficients at the front and back faces. Equation (2) gives the relationship between diffusivity α, thermal conductivity λ, density ρ, and specific heat c for the gypsum fiber.

$$\alpha = \frac{\lambda}{\rho . C} \qquad (2)$$

α is the thermal diffusivity coefficient ($m^2.s^{-1}$)

λ is the thermal conductivity ($W.m^{-2}.°C^{-1}$)

ρ is the density of the material ($kg.m^{-2}$)

C is the specific heat capacity

Boundary conditions:

Equations (3) and (4) are the boundary conditions that express the conservation of heat flux at the interfaces of the tow-plaster material, and the initial condition is given by equation (5).

$$\begin{cases} \lambda \left.\frac{\partial T(x,h_1,h_2,t)}{\partial x}\right|_{x=0} = h_1[T(0,h_1,h_2,t) - Ta] & (3) \\ \lambda \left.\frac{\partial T(x,h_1,h_2,t)}{\partial x}\right|_{x=L} = -h_2[T(L,h_1,h_2,t) - Ta] & (4) \\ T(x,h_1,h_2,t=0) = T_i & (5) \end{cases}$$

To solve equation (1) we will perform the dimensionless decomposition of the heat equation by setting:

$$\theta(u,\tau) = \frac{T(x,h_1,h_2,t) - T_a}{T(x,h_1,h_2,t=0) - T_a} = \frac{T(x,h_1,h_2,t) - T_a}{T_i - T_a} \quad (6)$$

With $\theta(u, \tau)$: reduced temperature corresponding to the transient regime;

$u = \frac{x}{L}$; u is a reduced spatial variable

and $\tau = \frac{\alpha\, t}{L^2}$; $\tau = F_0$: is the reduced time variable (Fourier number).

The heat equation (1) becomes:

$$\frac{\partial^2\theta(u,\tau)}{\partial u^2} = \frac{\partial\theta(u,\tau)}{\partial\tau} \quad (7)$$

Boundary conditions (3) and (4) become (8) and (9):

$$\left.\frac{\partial\theta(u,\tau)}{\partial\tau}\right|_{u=0} = \frac{h_1.L}{\lambda}\theta(0,\tau) \quad (8)$$

$$\left.\frac{\partial\theta(u,\tau)}{\partial\tau}\right|_{u=1} = -\frac{h_2.L}{\lambda}\theta(1,\tau) \quad (9)$$

The boundary conditions allow us to find the transcendental equation (10):

$$\tan(\beta_n) = \frac{\frac{h_2.L}{\lambda}\beta_n + \beta_n\frac{h_1.L}{\lambda}}{\beta_n^2 - \frac{h_1.h_2.L^2}{\lambda^2}} \quad (10)$$

The transcendental equation is split into two functions:

-The trigonometric function denoted ft (βn)

$$ft(\beta_n) = \tan(\beta_n) \quad (11)$$

-The homogeneous function denoted fh (β_n)

$$fh(\beta_n) = \frac{\frac{h_2.L}{\lambda}\beta_n + \beta_n\frac{h_1.L}{\lambda}}{\beta_n^2 - \frac{h_1.h_2.L^2}{\lambda^2}} \quad (12)$$

We plot the transcendental curve for different values of the exchange coefficient at the front and rear faces.

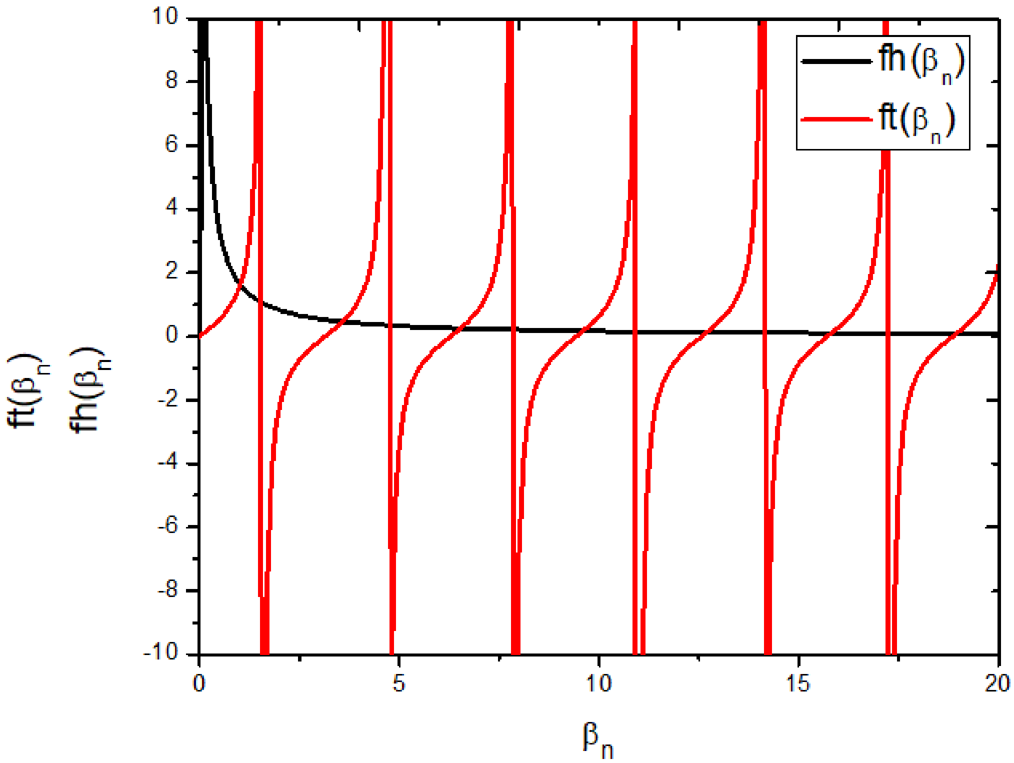


Figure 2: Graphical determination of the eigenvalues (βn) of the transcendental equation.

In this figure, we present the evolution of **ft(βn)** and **fh(βn)** as a function of the eigenvalues of the transcendental equation for different values of the coefficients.

Table 1 summarizes the eigenvalues found for β_n.

Table 1: Eigenvalues of βn of the equation

n	**1**	**2**	**3**	**4**	**5**
β_n	**1.2**	**3.5**	**6.5**	**9.6**	**12.7**

En utilisant les conditions aux limites et les intégrales d'Euler-Fourier. Nous avons détermines

$H_{1n}(0)$et $H_{2n}(0)$

$$H_{1n}(0)=\frac{\sqrt{\gamma}}{(\beta_n^2+\gamma)(\sqrt{\gamma}\cosh(\sqrt{\gamma})+\frac{h_2 L}{\lambda}\sinh(\sqrt{\gamma}))}\left\{(\sqrt{\gamma}\sinh(\sqrt{\gamma})+\beta_n\ \sin(\beta_n))+\frac{h_2 L}{\lambda}[\cos h(\sqrt{\gamma})-\cos(\beta_n)]\right\} \quad (13)$$

$$H_{2n}(0)=\frac{h_1 L}{\lambda(\beta_n^2+\gamma)(\sqrt{\gamma}\cosh(\sqrt{\gamma})+\frac{h_2 L}{\lambda}\sinh(\sqrt{\gamma}))}\left\{\sqrt{\gamma}[\cosh(\sqrt{\gamma})-\sin(\beta_n)]+\frac{h_2 L}{\lambda}\left[\sinh(\sqrt{\gamma})-\frac{\sqrt{\gamma}}{\beta_n}\cos(\beta_n)\right]\right\} (14)$$

$$\theta(u,\tau)=[a_n\cos(\beta_n u)+b_n\sin(\beta_n u)].T(0).e^{-\frac{\tau}{\tau_d}}$$

We obtain the expression for the reduced temperature of the heat diffusion equation and it is given by expression (15):

$$\theta\left(\frac{x}{L},\frac{\alpha.t}{L^2}\right)=\delta\theta_0\, a_n{}^2\left[\cos\left(\frac{x}{L}.\beta_n\right)+\frac{h1.L}{\lambda.\beta_n}.\sin\left(\frac{x}{L}.\beta_n\right)\right][H_{1n}\ (0)+H_{2n}\ (0)]e^{-\frac{\alpha\, t}{L^2}[\beta_n^2+\gamma]} \ (15)$$

By combining equations (6) and (31) we obtain the expression for the final temperature:

$$T(x,h_1,h_2,t) = Ta + (Ti - Ta).\delta\theta_0.a_n^2.\left[\cos\left(\frac{x}{L}.\beta_n\right) + \frac{h1.L}{\lambda.\beta_n}.\sin\left(\frac{x}{L}.\beta_n\right)\right]\left[H_{1n}\ (0) + H_{2n}\ (0)\right].e^{-\frac{\alpha\,t}{L^2}[\beta_n^2+\gamma]} \quad (16)$$

3) Thermal heat flux density:

The heat flux density [8], through the tow-gypsum material is obtained from the relation (17):

$$\Phi(x,h1,h2,t) = -\lambda\frac{\partial\, T(x,h1,h2,t)}{\partial\, x} \qquad (17)$$

By differentiating the temperature with respect to the next component x, we obtain expression (18):

$$\Phi(x,h1,h2,t) = \lambda(Ti - Ta).\delta\theta_0.a_n^2.\left[\frac{\beta_n}{L}.\sin\left(\frac{x}{L}.\beta_n\right) - \frac{h1}{\lambda}.\cos\left(\frac{x}{L}.\beta_n\right)\right]\left[H_{1n}\ (0) + H_{2n}\ (0)\right]e^{-\frac{\alpha\,t}{L^2}[\beta_n^2+\gamma]} (18)$$

4) Evolution of Temperature and Thermal Heat Flux Density as a Function of Different Parameters

41) Results:

Figures 1 and 2 show the temperature and heat flux density for different values of the heat transfer coefficient at the front face, setting a very low value for h2.

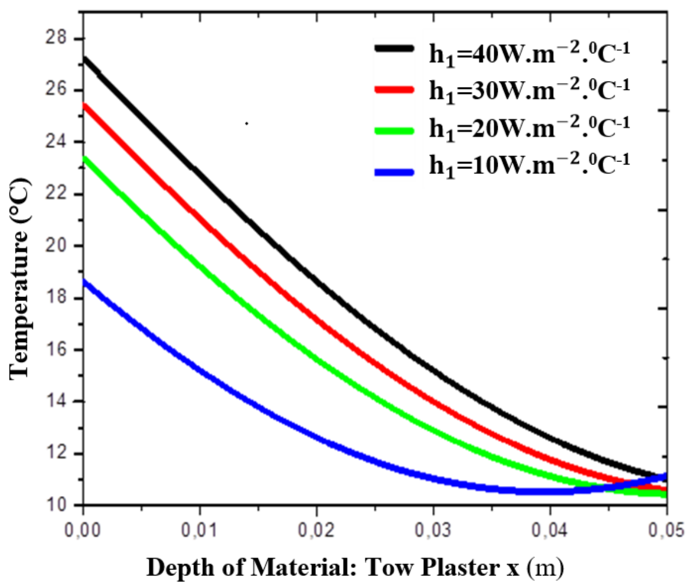


Figure 3: Temperature evolution as a function of material depth.t = 100 s, h_2 = 0.005 W.m^{-2}.°C^{-1}

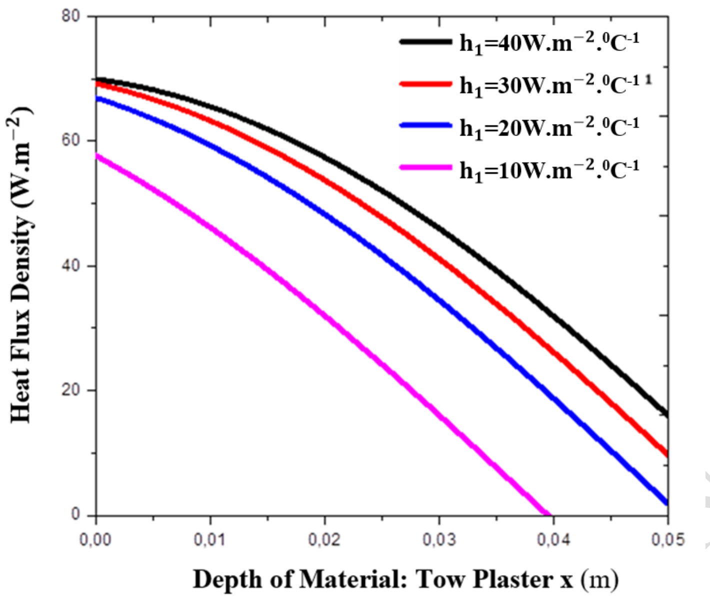


Figure 4: Evolution of heat flux density as a function of material depth. t=100s, h2 = 0.005 W.m⁻².°C⁻¹

In Figure 3, the temperature is maximum for x = 0 and begins to decrease when we move away from the front face of the material then we will reach the initial temperature Ti of the tow-plaster material when the depth becomes significant. We notice for x = 0 the quantity of heat exchanged at the front face is all the more important as the exchange coefficient at the front face is low. If the exchange coefficient on the front face decreases, we note a slight decrease in temperature.

The temperature curves show that the tow-gypsum insulating material tends to release heat to the interior environment.

In Figure 2 we have a decrease in the heat flow density as a function of depth under the influence of the exchange coefficient on the front face. We note a decrease which is less brutal on the curve where h1=25W.m⁻².°C⁻¹than on the others. Low depth values correspond to high heat flux density values. On these curves we see a slight decrease in the heat flux density for low depth values.

This results in a positive gradient in the heat flux density towards the interior face.

Table 2: The different values of the temperature and heat flux density of the tow-plaster material for t = 100s and h2 = 0.005W.m⁻².°C⁻¹

$\mathbf{h_1(W.m^{-2}.s^{-1})}$	25	15	10	5
X(m)	0.01	0.02	0.03	0.05
T (^{0}C)	22,7	17,1	12,9	10,6
Φ ($\mathbf{W.m^{-2}}$)	65,6	53,7	34,4	0

For different values of the depth, we obtain figures 5 and 6. The curves of temperature and heat flux density as a function of the coefficient a at the front face h1.

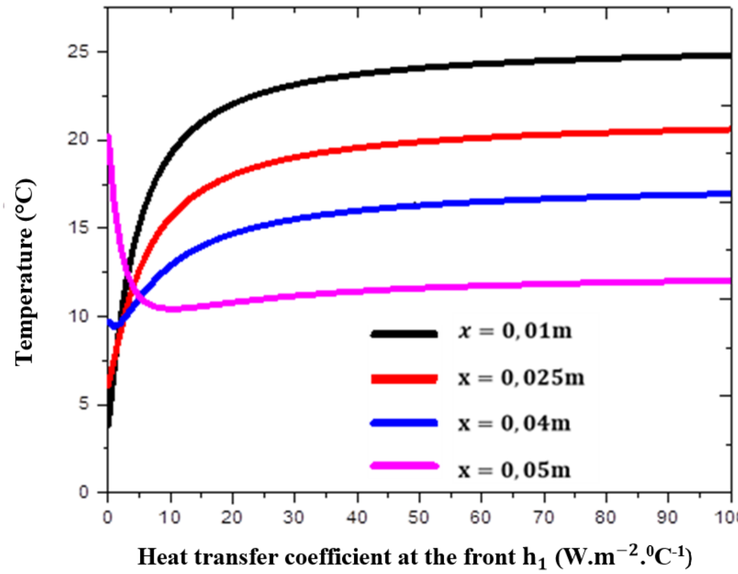


Figure 5: Temperature evolution as a function of the heat transfer coefficient a at the front face h1 of the material. t=100s, h2 = 0.005W.m^{-2}.°C^{-1}

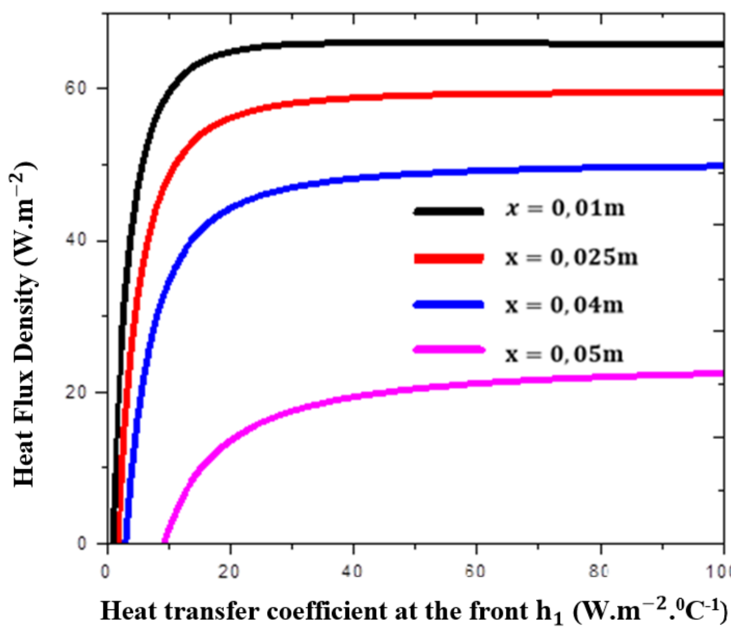


Figure 6: Evolution of the heat flux density as a function of the heat transfer coefficient a at the front face of the material h1. t=100s, h2 = 0.005W.m^{-2}.°C^{-1}

The temperature and heat flux density increase with the heat transfer coefficient at the front face, h1, and then become constant at high values of h1. Therefore, the gypsum-fiber material stores thermal energy.The temperature and heat flux density are higher when the heat transfer coefficient at the front face is greater. As the heat transfer coefficient at the front face increases, the temperature and heat flux density also increase. The temperature and heat flux density become constant beyond a certain depth.

Table 3: The different values of the temperature and heat flux density of the gypsum-fiber material for $t = 100$ s and $h2 = 0.005 W.m^{-2}.°C^{-1}$

X(m)	0.01	0.02	0.03	0.05
$\mathbf{h_1 (W.m^{-2}.s^{-1})}$	25	15	10	5
T (^{0}C)	22,7	17,1	12,9	11
Φ ($W.m^{-2}$)	65,5	53,8	34,6	0

In these figures we will plot the profiles of temperature and heat flux density as a function of time for different values of the front face heat transfer coefficient.

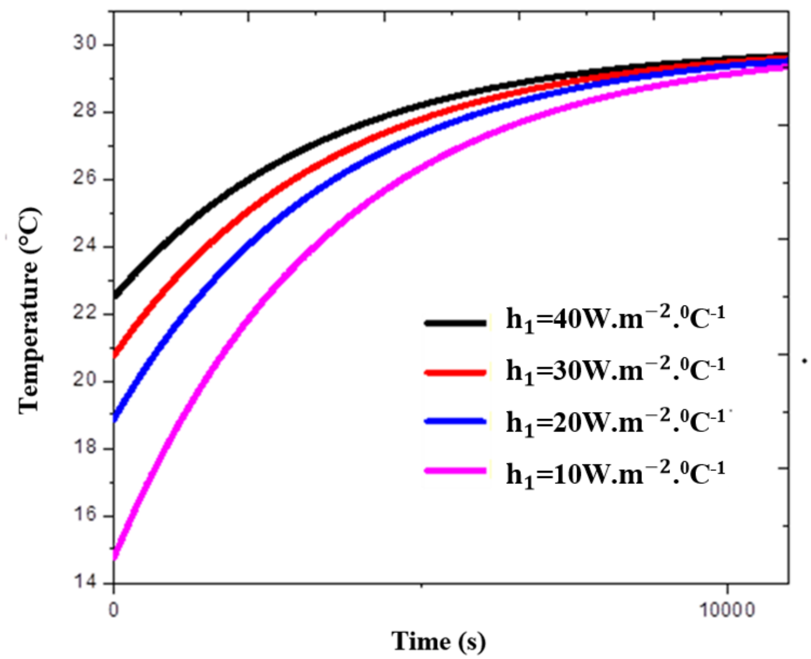


Figure 7: Temperature evolution as a function of time for the material. t=100s, $h2 = 0.005 W.m^{-2}.°C^{-1}$

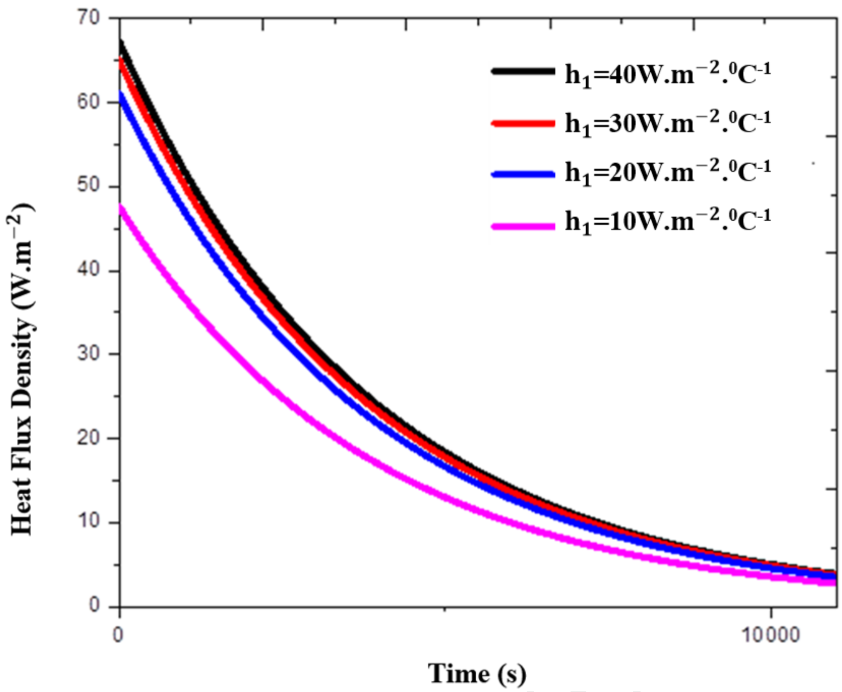


Figure 8: Evolution of heat flux density as a function of time. t=100s, h2 = 0.005 0.005 $W.m^{-2}.°C^{-1}$

In these two figures, we have plotted the temperature and heat flux density as a function of time under the influence of the heat transfer coefficient at the front surface.

We observe an increase and a decrease, respectively, in the temperature and heat flux density over time.

For high temperature values (Figure 7), we observe that each point in the gypsum-fiber material reaches a plateau. This increase occurs within the material. This is due to heat storage and the phenomenon of heat retention within the gypsum-fiber material.

In Figure 8, the heat flux density decreases over time for different values of the heat transfer coefficient at the front surface.This is due to the absorption and transfer of heat within the material, which leads to an increase in the heat transfer coefficient at the front surface. We observe a slight decrease in density.For each point in the material, the heat flux density is higher when the heat transfer coefficient is higher. When the heat transfer coefficient at the front face increases, the heat flux density decreases at a point deep within the material.

This decrease in heat flux density is due to a gradual loss of heat.

Conclusion:

The study shows that the thermal behavior or response of the material is highly dependent on the timing of external climatic stresses. The study of heat transfer in a simple wall highlighted the influence of the heat transfer coefficient at the front face of the gypsum-fiber material on temperature and heat flux density under transient dynamic conditions.

Gypsum-fiber plays an important role in thermal insulation and in maintaining air quality and thermal comfort.

BIBLIOGRAPHICAL REFERENCES:

[1] M.S. Ould Brahim, I. Diagne, S. Tamba, F. Niang and G. Sissoko.Characterization of the minimum effective layer of thermal insulation material tow-plaster from the method of thermal impedance. Research Journal of Applied Sciences, Engineering and Technology 3(4): 337-343, 2011. e-ISSN: 2040-7467.

[2] Abdoulaye Korka Diallo, Makinta Boukar, Mamadou Babacar Ndiaye, Alassane Diene, Paul Demba, Issa Diagne, Mohamed Sidya Ould Brahim and Grégoire Sissoko. Study of the Equivalent Electrical Capacity of a Thermal Insulating Kapok-plaster Material in Frequency Dynamic Regime Established. Research Journal of Applied Sciences, Engineering and Technology. 8(20): 2141-2145, 2014 e-ISSN: 2040-7467.

[3]G.Sissoko, M. Adj, D. Azilinon, V. Sambou, A. Wéreme. «Caractérisation par phénomènes thermiques transitoires d'une dalle en béton récupératrice d'énergie solaire». Journal des Sciences (2001), Vol.1, N°2, pp.

[4]Issa DIAGNE, Moussa DIENG, Mamadou L. SOW, Alhadi WEREME, Fadel NIANG, Grégoire SISSOKO .«Transfert de chaleur en régime dynamique fréquentiel dans un matériau a trois dimensions: Etude de l'impédance dynamique équivalente du matériau kapok » ART-Volume 4, N^0 134 CIFEM2010, pp. 36-45

[5]M. S. Ould Brahim, S.Tamba, M.Sarr, A. Diene, I. DIAGNE, F. NIANG, G. SISSOKO. « Caractérisation d'un matériau isolant thermique filasse-plâtre à partir de l'impédance thermique en régime dynamique fréquentiel» Journal des Sciences, Vol. 10, N° 3 (2010), pp. 30-40

[6]M. L. Voumbo. « Contribution à l'étude des caractéristiques thermo physiques des matériaux locaux: application au kapok », Thèse de Doctorat d'état, FST/UCAD, Février 2008, Sénégal.

[7]Y. Jannot, A.Degiovanni, G.Payet.«Thermal conductivity measurement of insulating materials with athree layers device» International Journal of Heat and Mass Transfer 52 (2009), 1105–1111 Vol.7, N°3, pp. 48 -52, 2007.

[8]El Hadji Abdoul Aziz Cisse* , Papa Touty Traore , Seydou Faye, Moussa Dieng, Mor Ndiaye, Issa Diagne"Thermomechanical Characterization and Numerical Modeling of Thermal Transfer of Plaster-based Insulating Composite Materials with Gradual Typha Contents"Science PG 2025, Vol. 14, No. 2, pp. 36-45 https://doi.org/10.11648/j.am.20251402.11