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Characterization of the Thermophysical Properties of Kapok

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Abstract: This research report to the thermophysical characterization of the kapok and the kapok-plaster mixture. To carry out this characterization, we used the method off limp in permanent given to mode the conductivity and also the Degiovanni model. This study shows that the kapok's conductivity dregs between 0.03 and 0.04 W/m.°K for density which varies between 5 and 40 kg/m^3. Taking also into account year average diffusivity of 17.1x10^{-7} m^2/s, kapok has good heat insulator. Associated with the plaster, it makes it possible to improve the thermophysical characteristics off the plaster.

Keywords: Conductivity, degiovanni model, diffusivity, flash, thermal insulation, kapok and permanent mode

INTRODUCTION

The worldwide consumption of energy records very a strong growth. The thermo isolation is an important factor as well for the countries with climate moderated to protect itself from the cold as for the tropical to secure heat and to preserve certain food products and pharmaceutical countries using the cold.

Endogenous materials good selected would make it possible to reduce in a very significant way the manufacturing costs of the apparatuses and to practically divide by three the consumption of electricity for the refrigeration.

Within the framework of this study, we chose the characterization of a material very little used in Africa and in the majority of the Asian countries which produce it: kapok or called the wool of kapok.

The object of this study is to characterize from the point of view thermo isolation, a neglected local material and less expensive in order to show than it shows characteristics better than the other heat insulators.

The characterization of the thermophysical properties of this material would make it possible to facilitate its choice as an insulating material following the example glass wool and also to solve a problem encountered by the farmers in the fields invaded by this resource, that of uncontrolled fires, kapok being very flammable.

Kapok resulting from the silky sleeping bag, which surrounds seeds of the kapok trees or cheesemongers, tree of the family of is bombacées which one finds in the tropical zone (Manohar *et al*., 2006).

In kapok, *Ceiba pentandra* (L.) Gaertn or *Eriodendron anfractuosa* cd., (Bombacaceae), it is the capsule which provides a light sleeping bag around seeds. The tree is the kapok tree; he pushes in the Indies, in Java, in Africa and South America.

Kapok is a single natural fiber from its characteristics. It consists of unicellular fibers, like cotton, but they are seven times less dense (Manohar *et al*., 2006) that those of this last and have buoyancy being able to carry up to twenty times its weight. It presents advantageous properties: hydrophobic subject, resistant to the fungic and bacterial attacks, little snuffed rodents and it is also very soft.

Its main difficulty of use resides is its inflammability or in even more exactly of dust than it generates during its handling. Kapok is distinguished from cotton by the fact that its fiber, very short, is of 10 with 23 mm, is cylindrical and nontwisted.

The notorious lightness of kapok offers the characteristics hereafter to him:

Buoyancy: clothing and material of survival were manufactured starting from kapok before the arrival of polystyrene and foams expanded which are used in this field currently.

Capacity insulating: thanks to its form, kapok is the best insulating among the natural fibers which can compete

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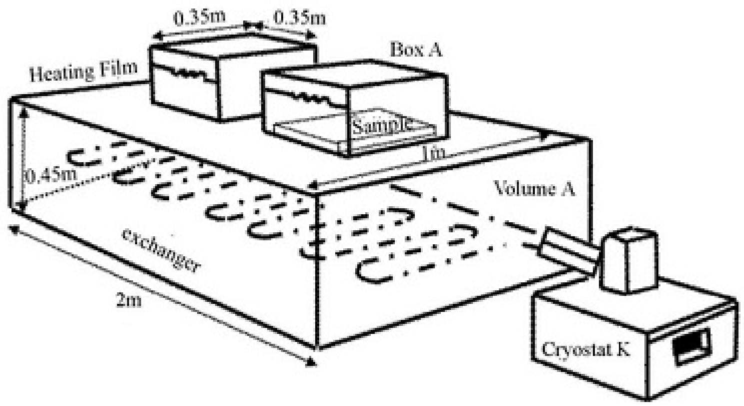

Fig. 1: Diagrammatic sight of the measuring cell

with manmade fibers such as polyester as regards thermal comfort.

Softness: Possibly due to the presence of the waxy cuticle;

Absorption: As regards absorption, kapok can compete with polypropylene and absorbent cotton.
The major disadvantage of kapok is its excessive inflammability.

MATERIALS AND METHODS

This study was led to the laboratory of energetics applied of the Ecole Polytechnique to the University Cheikh Anta Diop of Dakar of Senegal between 2005 and 2008 to samples of kapok of Burkina Faso.

By assimilating the porous environment, heterogeneous by nature, to a homogeneous continuous medium "are equivalent", and by neglecting the influence of the phase shift on the thermal field, at the low temperatures, the phenomena of heat transfer within a porous material saturated by a motionless fluid are described by the fundamental equation:

$$div(\lambda \, gr\vec{a}d \, T) = \rho . C_P \frac{\partial T}{\partial t} \qquad (1)$$

with

λ : Thermal conductivity of the medium, C_P: thermal conductivity.

In general, conductivity is a tensor of order 2. This last is reduced to a scalar for a homogeneous medium, isotropic and of which the thermal characteristics are independent of the space coordinates and of the temperature. The Eq. (1) takes the form:

$$\frac{\lambda}{\rho C_P} \Delta T = \frac{\partial T}{\partial t} \qquad (2)$$

The ratio $\frac{\lambda}{\rho C_P} = a$ defines the thermal diffusivity of the medium and it is expressed in $m^2.s^{-1}$.
Measure of thermal conductivity

Thermal conductivity is an intrinsic property of material; it characterizes the diffusion of heat in the material (Murdocco, 1999). The propagation velocity of heat in a body thus makes it possible to distinguish the drivers and insulators.

There exist several methods of measurement of apparent thermal conductivity in permanent mode. One can quote:

- Method of the kept hot plate (Tye, 1969; Clark and Taylor, 1975)
- Method of radial flow (Maillet *et al.*, 1993)
- Method of the coaxial cylinders
- The method of limp (Tye, 1969)

These methods call upon a transfer of heat in permanent mode, the sample constitutes a system in thermal balance then. These methods allow obtaining thermal conductivity with a good precision. On the other hand, they require a very long time of experimentation.

The method of limp, developed at the university Claude Bernard of Lyon, allows determining apparent thermal conductivity in permanent mode with a time of experimentation much less long and a precision comparable with the other methods is 6%.

It is a question of carrying out a known heat flow one-way, through the sample to test then to take the temperature measurements after obtaining the permanent mode. While cooling A and by heating B, one creates a variation in temperature between two environments so that the convective exchanges on the two faces of the sample are negligible. With this intention one uses the assembly of Fig. 1.

All the samples studied must be a parallelepipedic form 27 cm dimensioned and a thickness of 2 to 7 cm.

They are placed between the box and the isothermal capacity.

By analogy with the walls of a habitat, the sample presents a hot face and a cold face. The hot face is side of the interior of limps and the cold one on the side of the isothermal capacity.

We made so that the heat gradient is in this direction in order to eliminate the phenomena of convection on the two faces.

The acquisition of measurements is done through a power station of measurements HP 34970A having a multiplexer with reinforcement with 20 ways HP 34901A. With this chart and the power station of measurement, one as well measures the terminal voltage of heating film as the various temperatures.

The system of acquisition of measurements is managed by a microcomputer using an application, which was worked out to control the power station of measurement and to calculate diffusivity or conductivity. Apparent thermal conductivity in permanent mode is given by:

$$\lambda = \frac{qe}{S\Delta T} = \frac{e\left(\frac{U^2}{R}\right) + C.\Delta T'}{S\Delta T} \tag{3}$$

where:

E: Thickness of the sample
S: Useful surface of the sample
U: Tension applied at the boundaries of heating resistance
R: Value of heating resistance
DT: Variation in temperature enters the two faces heat and cold
DT': Variation in temperature enters the interior and the outside of the box

$$\Delta T = T_C - T_F \tag{4}$$

$$\Delta T' = T_a - T_B \tag{5}$$

Measure of thermal diffusivity: Thermal diffusivity is the most important parameter, which makes it possible to characterize the propagation velocity of a periodic thermal wave through a given wall. Its knowledge is paramount in all the problems of thermal inertia.

Its measurement results from the resolution of the equation of transfer of heat in transitory mode, by an analytical method. This one is used as support for the settling of experimental methods, which can lead to the measurement of thermal diffusivity while being based on the recordings of the change of the temperature in transitory mode. Its measurement is delicate and there does not exist universal device allowing its measure to all temperature ranges.

Several methods were worked out to measure thermal diffusivity. For a one-way heat transfer and when the thermal parameters are independent of the temperature, the equation of FOURIER, in transitory mode, is written in the form:

$$\rho_c \frac{\partial T}{\partial t} = \lambda \frac{\partial^2 T}{\partial x^2} \text{ or } \frac{\partial T}{\partial t} = a \frac{\partial^2 T}{\partial x^2} \tag{6}$$

$a = \frac{\lambda}{\rho_c}$ is thermal diffusivity ($m^2.s^{-1}$) correspondent in an isotropic homogeneous medium.

Where λ is Thermal conductivity ($W.m^{-1}.K^{-1}$) and ρ_c is Voluminal heat ($J.m^{-3}.K^{-1}$).

In the case of bi or three-dimensional, the preceding equation is written according to the Laplacian ΔT, that is to say:

$$\frac{\partial T}{\partial t} = a\Delta T \tag{7}$$

In a more general way, when thermal conductivity depends at the same time, of the coordinates of space and the temperature, the equation of generalized heat is written:

$$\rho c \frac{\partial T}{\partial t} = div(\lambda\, \overrightarrow{gradT}) \tag{8}$$

There exist several methods allowing direct measurement of thermal diffusivity. Although using all the same principle, founded on the answer in temperature in a point of a sample, of which one of the faces is subjected to a condition of temperature or heat flow.

They can nevertheless be classified in two categories, according to the nature of the request applied. One distinguishes the methods of the periodic signal and the methods impulse.

Contrary to the stationary method, which requires times of setting in very long mode to measure thermal conductivity, the nonstationary or periodic methods, for the measurement of thermal diffusivity, have the advantage of being fast.

Periodic method with the advantage of allowing to calculate the thermal diffusivity in two different ways; however, it is valid only for one perfectly sinusoidal thermal excitation and an one-way flow. Thus, we rather used the method “flash”.

Parker *et al.* (1961) proposed impulse methods or “Flash” present many advantages whose principal ones are the speed, the simplicity of implementation and the suppression of the systematic errors (Degiovanni, 1997). It was the object of many developments related to the methods of calculating and estimates of parameters, with the sensors, the devices of acquisition and data processing.

The principle consists in tackling a thermal system by a disturbance more or less localized in time and space and, to raise, on the not irradiated face, the evolutions of

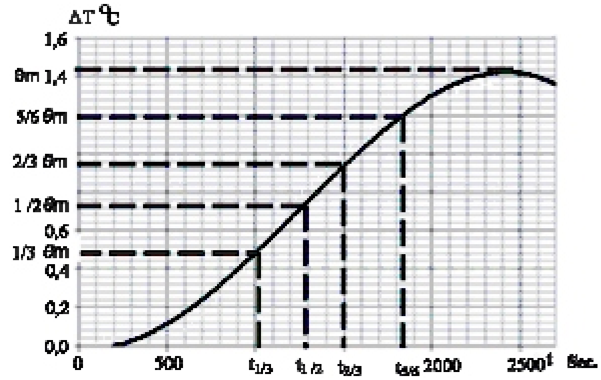

Fig. 2: Thermogram for the measurement of diffusivity

temperature according to time, i.e. the thermograms. From these data, one determines diffusivity by the method of part times.

The method of part times exclusively uses the ascending part of the thermogram, for which the sensitivity of diffusivity is most important.

In practice, Degiovanni (1997) introduces particular time t^*_a corresponding to α time of the maximum rise $\frac{t^*_\alpha}{t^*_{5/6}}$ in temperature, reduced (θ^*_{max}) and starting from ratio of times calculated starting from the model and of the ratios of experimental times $\frac{t_\alpha}{t_{5/6}}$, as shown in the Fig. 2.

We have:

$$t'_{1/3} = \frac{t^*_{1/3}}{t^*_{5/6}} = \frac{t_{1/3}}{t_{5/6}} f(t^*_{5/6}) \quad (9)$$

$$t'_{1/2} = \frac{t^*_{1/2}}{t^*_{5/6}} = \frac{t_{1/2}}{t_{5/6}} f(t^*_{5/6}) \quad (10)$$

$$t'_{2/3} = \frac{t^*_{2/3}}{t^*_{5/6}} = \frac{t_{2/3}}{t_{5/6}} f(t^*_{5/6}) \quad (11)$$

With the standardized experimental thermograms:

$$\frac{T - T_0}{T_{\max} - T0} = f(t) \quad (12)$$

Where T_{max} is the maximum temperature reached? Diffusivity is then given by:

$$a = \frac{a_1 + a_2 + a_3}{3}$$

With:

$$a_1 = \frac{e^2}{t^2_{5/6}}(1{,}15t_{5/6} - 1{,}25t_{2/3}) \quad (13)$$

$$a_2 = \frac{e^2}{t^2_{5/6}}(0{,}761t_{5/6} - 0{,}926t_{1/2}) \quad (14)$$

$$a_3 = \frac{e^2}{t^2_{5/6}}(0{,}618t_{5/6} - 0{,}862t_{1/3}) \quad (15)$$

RESULTS AND DISCUSSION

Measurements of the thermophysical properties were carried out on samples of kapok of Burkina Faso and a combination of the plaster like binder with kapok. In the case of the samples of kapok + plaster, we manufactured plates of 27cmx27cmx5.2cm.

To measure the thermal characteristics of kapok in a fibrous state, we used a special framework having the shape of a test-tube, making 27 on 27 cm side and 5 cm height. With dimensions ones of the framework are out of plexiglass 1 cm thickness, whereas the faces are formed by two aluminum plates of 1.5 mm, which one can screw by the edges on the framework. The unit is a sandwich metal-fiber-metal, easily adaptable to our experimental device as shown in the Fig. 3.

The choice of the plates - aluminum support is justified by the value of the coefficient of the thermal conductivity of the aluminum, which is very high in front of that of the fibrous mediums considered. Indeed, a study former with copper plates showed that all occurs as if the heat flow were directly applied to material and that the taking of temperature is also carried out it, directly on fibers.

We studied the influence of the apparent bulk density on thermal conductivity with average temperatures close to the room temperature. After measurements, one obtains the results hereafter.

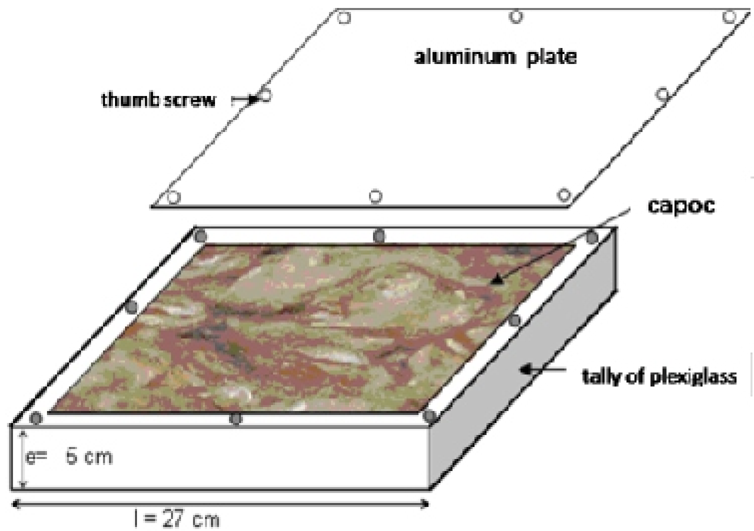

Fig. 3: Elements of the framework used for fibrous materials

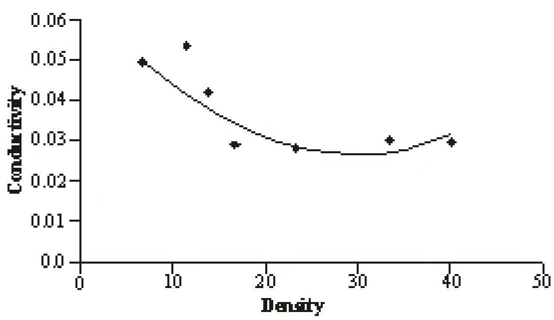

Fig. 4: Variation of the conductivity (W/m.K) of kapok according to the density (kg/m^3)

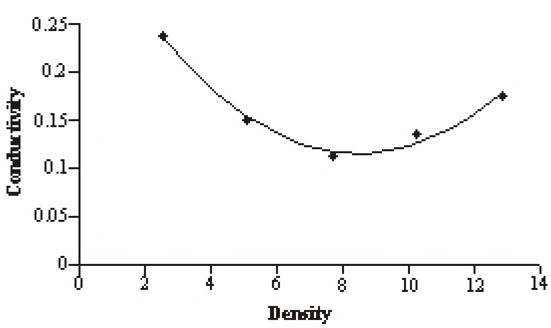

Fig. 5: Conductivity (W/m.K) of the kapok mixture + plaster according to the density of kapok (kg/m^3)

It is noticed that the conductivity of kapok and kapok mixture + plaster presents an optimum point where it is weakest according to the mass of kapok contained in the support i.e. according to the density as Fig. 4 and 5.

As in the case of the measurement of the conductivity of all alone kapok without binder, one notices that here also that the conductivity of the mixture presents a minimum.

Table 1: Diffusivity of the samples of kapok

Density of kapok in kg/m^3	Diffusivity has in m²/s
6.66	1.81×10^{-6}
13.73	1.65×10^{-6}
16.66	1.65×10^{-6}

What gives us an average diffusivity of the kapok of 17.1.10^{-7} m ² /s.

Table 2: Diffusivity of the samples of kapok + plaster

Density of kapok in the mixture in kg/m^3	Diffusivity has in m²/s
2.56	2.77.10^{-7}
7.68	1.10.10^{-6}
10.25	2.67.10-7
12.81	2.46.10^{-7}

One finds a diffusivity average of kapok + plaster equal to 4.73.10^{-7} m²/s.

The diffusivity measured by the method of limp is summarized in the Table 1 and 2.

CONCLUSION

Taking into consideration result obtained, kapok has a very good conductivity. It can then be used as insulator in the systems of production or of conservation of cold in particular compared to the polystyrene or glass wool which has an average conductivity of 0.04 W/m.K.

Moreover, the measurement of its diffusivity shows that it is clearly with the top of insulating materials having the same order of conductivity.

It has should be noted as kapok allows improves, into weak quantity, the thermophysical characteristics of the plaster.

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