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Research Article

Effect of Cow's Dung on Thermophysical Characteristics of Building Materials Based on Clay

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Abstract: The excessive consumption of energy in the building sector weighs heavily on the energy bill of the developing countries. It is for this reason that several studies have been carried out at the international level, both at the level of building's envelope and equipments, in order to contribute to the control of energy. In this study, we are interested in studying the effect of cow's dung on the thermo-physical characteristics of materials based on clay in the region of Abeche (Chad). The goal is to obtain light weighs samples with better thermal performance, which can contribute to improve the thermal comfort in traditional constructions in Chad and to reduce the use of cereal's straw and pods. Since these are used to feed livestock. The experimental study that we have conducted has enabled us to determine the conductivity, the effusivity and the thermal diffusivity of our samples. Our experimental data show a good efficiency and a significant decrease in the thermal conductivity of material with cow's dung compared to simple clay material.

Keywords: Clay, cow's dung, thermal conductivity, thermal diffusivity, thermal effusivity

INTRODUCTION

Most of the African countries have a warm climate with high energy cost. The control of energy consumption in the building sector goes through a good choice of construction materials. The use of composite porous materials in wall's construction necessarily creates an energy economy.

Thermal characterization of a construction material constitutes a very crucial study for the assessment of the energy efficiency in buildings.

Thermal parameters such as conductivity, diffusivity and thermal effusivity permit to estimate the thermal behavior of construction materials.

The mixture of clay with cow's dung, just as the mixture of clay with straw or pods of cereals is traditionally used for the manufacture of bricks and the coating of the walls. These materials have ecological advantages and have a thermal conductivity relatively low.

The objective of this study is to enhance these local materials of construction in Chad for a better thermal performance in buildings.

We focus our choice on clay and cow's dung which are natural materials, ecological, low cost and available everywhere in the region of Abeche (Chad).

Several studies on the basical material of clay have been carried out by researchers, including (Charfadine, 2002) on clay mixture with straw, Meukam (2004) on compressed clay bricks, Bal (2001) on the laterite mixed with the pod of wheat, etc., which proves the interest of the construction material based on clay. But no study on thermal characterization has been carried out on this material.

So we have characterized this composite material by using the hot plate method in steady state regime for the determination of the thermal conductivity. The asymmetrical transient hot plate is used for the determination of the thermal effusivity and the flash method for the estimation of the thermal diffusivity.

MATERIALS AND METHODS

Materials used:

Cow's dung: It is the manure of cattle, used as fertilizer of the soil and is a good adjuvant with clay for the coating of mud walls. The sample used in this study comes from various cattle around the region of Abeche, city located at 900 km east of Ndjamena.

Clay: To prepare the samples of the bricks, we have taken clay from Abeche's brickworks career. The sieve

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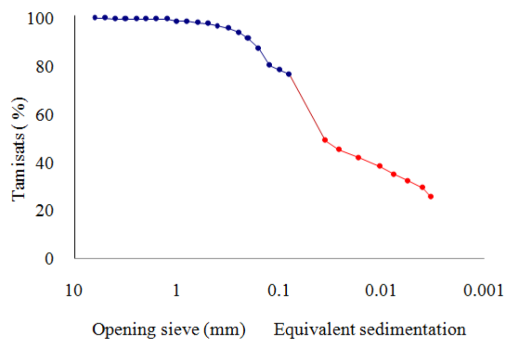

Fig. 1: Sieve and sedimentation analysis

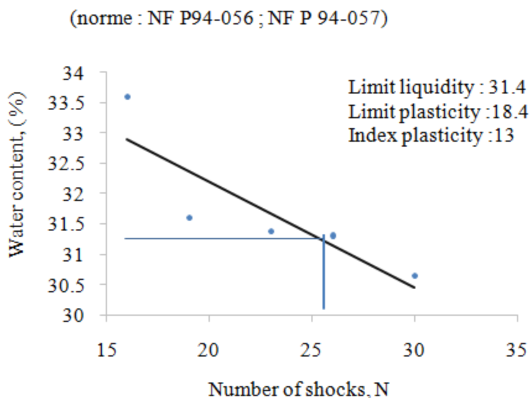

Fig. 2: Curve of casagrande

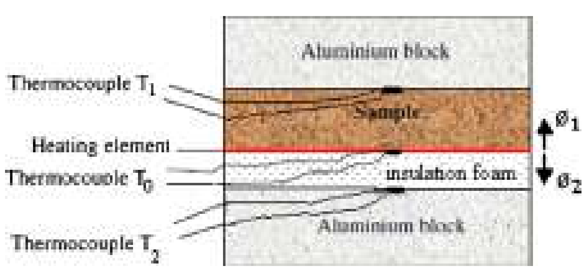

Fig. 3: Experimental device of the hot plate method in steady state regime

and sedimentation analysis of this soil shows 77.12% of grains mass passing through the sieve 80 µm and 0.75% of gravel, 22.75% of coarse sand, 27.24% of silt, 49.26% of clay. Thus the particle size has not an important influence on the behavior of this soil.

These limits results show that the clay used is little plastic with shrinkage and swelling less important during drying. Which is a considerable advantage in the construction work.

We chose traditional manufacturing method to realize our bricks samples. The mixture of clay with dry cow's dung is carried out by adding water (or 20% of the earth) until the whole is homogeneous and easily malleable. A mold of 100×100×30 mm^3 allows to give the parallelepiped shape of the brick and the drying is carried out in free air until total water evaporation.

Several samples of this dimension have been manufactured by adding a percentage of cow's dung weight ranging from 0 to 5%. Each sample was characterized in detail in order to determine its thermo-physical properties. The samples obtained are lightweight materials with a porous structure.

The experimental methods chosen for the thermal tests are the method of Hot Plate method in steady state regime and the Asymmetrical transient Hot Plate method (Khabbazi *et al*., 2013; Chekri *et al*., 2014).

Several authors have conducted studies following the different existing methods of characterization on composite porous materials. Including Jannot *et al*. (2010), Bal *et al*. (2012), Meukam (2004), Charfadine (2002), Chekri *et al*. (2013), Khabbazi *et al*. (2013) and Laaroussi *et al*. (2013).

Methods used:

Determination of the thermal conductivity by hot plate method in steady state regime: The thermal conductivity is the measurement of the heat faculty to easily more or less pass through a material in permanent regime. It depends essentially on the nature of the material and the temperature (Gaye, 2001). Figure 1 illustrates the schematic diagram of the asymmetrical method in permanent regime. The sample, of dimensions 30×100×100 mm^3 is placed on a heating element of section 100×100 mm² equal to that of the sample. The whole sample, heating plate and insulating block is then placed between two aluminum blocks of dimensions 50×100×100 mm^3. The latter rule is to bring as faster as possible the system toward the thermal equilibrium due to their high thermal conductivity (Fig. 2 and 3).

A thermocouple used to measure the temperature T_0 at the center of the heated face of the sample, a second thermocouple to measure the temperature T_1 of the non-heated face of the sample and then a third to measure the temperature T_2 of the non-heated face for the insulating foam. Based on these assumptions, we can write:

$$\phi = \phi_1 + \phi_2 \quad (1)$$

$$\phi_1 = \frac{\lambda_1}{e_1}(T_0 - T_1) \quad (2)$$

$$\phi_2 = \frac{\lambda_2}{e_2}(T_0 - T_2) \quad (3)$$

where, ϕ_1 is the heat flux through the sample, ϕ_2 is the heat flux through the insulation foam and ϕ the total flux emitted by the heating plate, λ_1 is the thermal conductivity of the sample that we are trying to determine, e_1 is the thickness of the sample and e_2 and λ_2 represent, respectively the thickness and the thermal conductivity of the insulating foam the heating

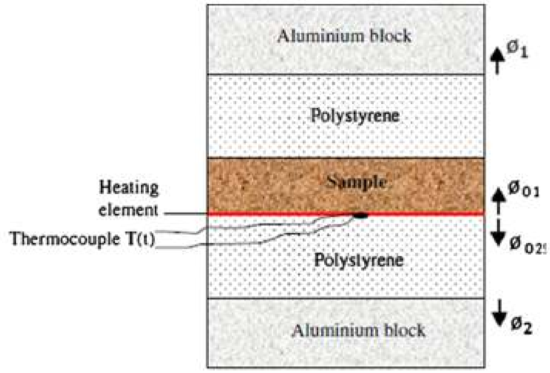

Fig. 4: View and schema of the experimental asymmetrical transient hot plate device

element is an electrical resistance R dissipating a stream by Joule. An electric current (I) which passed through the Resistance (R) under the effect of a voltage (U) imposed:

$$\phi_0 = \frac{U^2}{RS} \quad (4)$$

The combination of these equations gives us:

$$\lambda_1 = \frac{e_1}{(T_0 - T_1)}\left[\frac{U^2}{RS} - \frac{\lambda_2}{e_2}(T_0 - T_2)\right] \quad (5)$$

Knowing the thermal conductivity λ_2 of the polystyrene, this equation allows us to determine the thermal conductivity λ_1 of the sample when the permanent regime is reached.

The method of the asymmetrical transient hot plate method for the determination of the thermal effusively: The thermal effusively of a material characterized its ability to exchange thermal energy with its environment. It is proportional to the thermal conductivity and the inertia of the material (more precisely their square root). The effusively describes the speed with which a material absorbs or gives the heat away (Fig. 4).

The operative part of the standing hot plan is supplemented by a polystyrene block placed above the sample and the whole is placed between two aluminum blocks of 4 cm high of thickness. A level of flow is applied to the heating element and it saves the evolution of the temperature T (t) of the thermocouple.

This system is modeled on the assumption that the heat transfer is in one dimension at the center of the device during the time of the measure. We can check this assumption by the simulation in three dimensions with the Comsol tool and by analysis of the residues of estimation. This allows to write:

$$\begin{bmatrix}\theta \\ \Phi_{01}\end{bmatrix} = \begin{bmatrix}1 & 0 \\ c_h & 1\end{bmatrix}\begin{bmatrix}1 & R_c \\ 0 & 1\end{bmatrix}\begin{bmatrix}A & B \\ C & D\end{bmatrix}\begin{bmatrix}A_1 & B_1 \\ C_1 & D_1\end{bmatrix}\begin{bmatrix}0 \\ \Phi_1\end{bmatrix} \quad (6)$$

$$= \begin{bmatrix}A_1 & B_1 \\ C_1 & D_1\end{bmatrix}\begin{bmatrix}0 \\ \Phi_1\end{bmatrix} \quad (7)$$

$$\begin{bmatrix}\theta \\ \Phi_{02}\end{bmatrix} = \begin{bmatrix}A_1 & B_1 \\ C_1 & D_1\end{bmatrix}\begin{bmatrix}0 \\ \Phi_2\end{bmatrix} \quad (8)$$

with,

$$\Phi_0 = \Phi_{01} + \Phi_{02} = \frac{\phi}{P} \quad (9)$$

where,

- θ = The Laplace transform of the temperature T (t)
- Φ_{01} = The Laplace transform of the density of heat flow upstream of the heating plate
- Φ_{02} = The Laplace transform of the density of heat flow downstream of the heating plate
- Φ_0 = The Laplace transform of the flows of the total heat produced in the heating element
- ϕ = The flow of heat produced in the heating element:

$$A = D = cosh\left(\sqrt{\frac{P}{a}}\, e\right) \quad (10)$$

$$B = \frac{sinh\sqrt{\frac{P}{a}}e}{\lambda\sqrt{\frac{P}{a}}} \quad (11)$$

$$C = \lambda\sqrt{\frac{P}{a}}\, sinh\left(\sqrt{\frac{P}{a}}\, e\right) \quad (12)$$

$$A_i = D_i = cosh\left(\sqrt{\frac{P}{a_i}}\, e_i\right) \quad (13)$$

$$B_i = \frac{sinh\sqrt{\frac{P}{a_i}}e_i}{\lambda_i\sqrt{\frac{P}{a_i}}} \quad (14)$$

This system leads to:

$$\theta(P) = \frac{\Phi_0(p)}{\frac{D_1}{B_1} + \frac{D_i}{B_i}} \quad (15)$$

The principle of the method is to estimate the values of the parameters E, q, Rc and Ch which minimize the sum of quadratic differentials between the experimental curve and the curve calculated with the relationship (15) using the algorithm of Levenbeg-Marquart: (Marquart, 1963):

$$\Psi = \sum_{j=0}^{N} \left[T_{exp}(t_j) - T_{mod}(t_j) \right]^2 \quad (16)$$

The inverse Laplace transform is performed by use of the algorithm of De Hoog (1982). The value of the thermal capacity of the heating element is estimated by three measures of symmetrical hot plan (Jannot *et al*., 2010) carried out with two samples of polystyrene with 5 cm of thickness placed on both sides of the heating element.

Determination of the thermal diffusivity by the method of flash: This method permits to determine the thermal diffusivity in sending on top side of the sample a luminous flux of high power during a relatively short time. The thermocouple placed on the rear side allows collecting the increase of its temperature (Fig. 5).

Model of parker: The principle of the model of Parker consists, in a thermal system, to introduce a disturbance more or less localized in time and space and to raise in one or several places the evolutions of

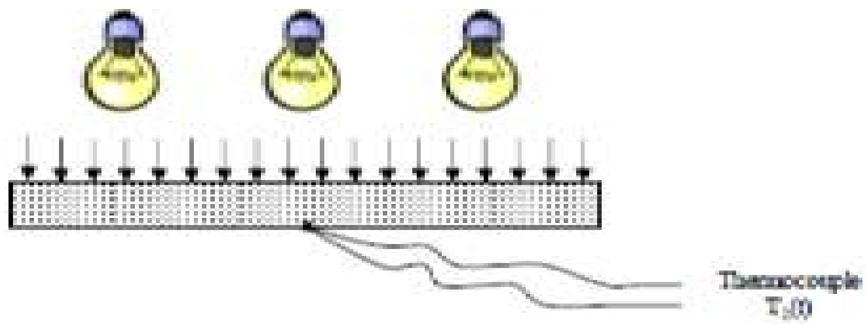

Fig. 5: Schematic diagram of the flash method

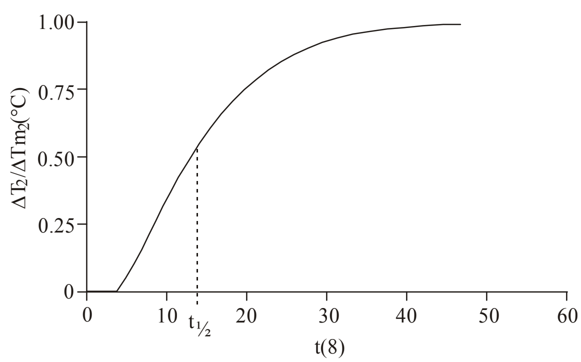

Fig. 6: Thermogramme of the face non enlightened

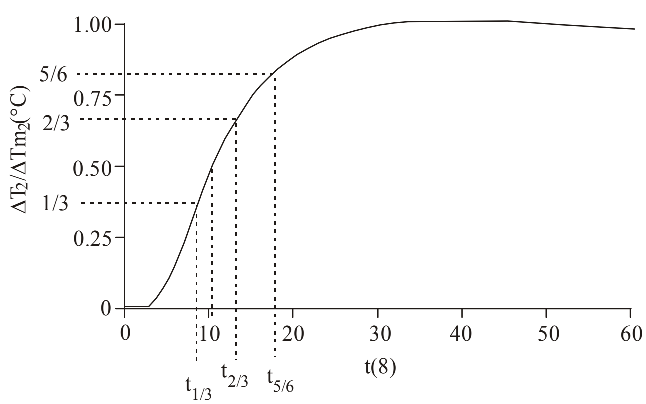

Fig. 7: Theoretical curve of the reduced temperature of the rear side

temperature as a function of time. From these thermograms depicted we will determine one or more characteristics of the system.

The thermal diffusivity is calculated from the time $t_{1/2}$ necessary for the temperature T_2 (t) of the rear side is equal to half the maximum temperature reached T_{2m} (Jannot, 2011):

$$a = \frac{1,38e^2}{\pi^2 t_{1/2}} \quad (17)$$

This method is applied only in cases where the duration of the flash is very small and where the thermal losses on the different sides of the sample are negligible (Fig. 6).

Model of Giovanni: This method takes into account the thermal losses but it is only applied in the case where the duration of the flash is very small.

The thermal diffusivity can be obtained from the following formulas (Jannot, 2011):

$$a_{2/3} = \frac{e^2}{t_{5/6}}\left(1,131 - 1,25\frac{t_{2/3}}{t_{5/6}}\right) \quad (18)$$

$$a_{1/2} = \frac{e^2}{t_{5/6}}\left(0,761 - 0,926\frac{t_{1/2}}{t_{5/6}}\right) \quad (19)$$

$$a_{1/3} = \frac{e^2}{t_{5/6}}\left(0,617 - 0,9626\frac{t_{1/3}}{t_{5/6}}\right) \quad (20)$$

where,

e = The thickness of the sample in meter

tp = The time elapsed since excitation for the temperature of the rear side to arise up to *p* times its maximum elevation, during the experiment

The principle is based on the use of four points thermogramme represented in the following Fig. 7.

In practice we take into consideration the average of three values obtained:

$$a = \frac{1}{3}(a_{2/3} + a_{1/2} + a_{1/3}) \quad (21)$$

EXPERIMENTAL RESULTS AND DISCUSSION

The experimental stage is to identify the material used and to perform the various tests to determine the thermal parameters such as conductivity, effusivity and thermal diffusivity. These tests are carried out at the Laboratory of Energy Materials and Environment, LEME, Salé, of the University Mohammed V Agdal Rabat (Morocco).

Determination of the thermal conductivity by the hot plate method in steady state regime: The thermal conductivities of the different samples are measured by the method of Hot Plate in steady state regime. The results of the tests are given in the following Fig. 8:

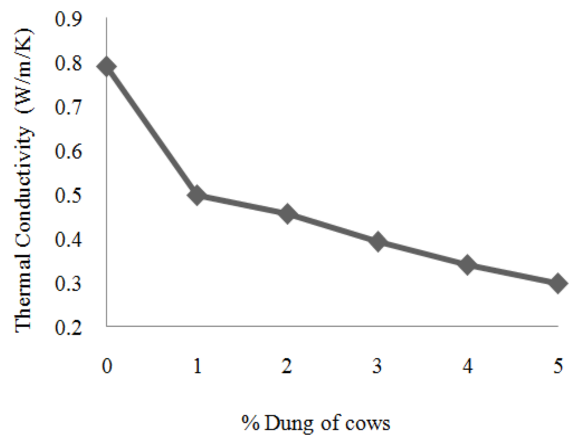

Fig. 8: Evolution of the conductivity as a function of cow's dung

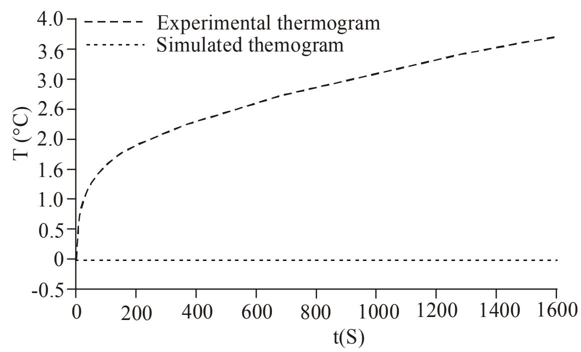

Fig. 9: Experimental and simulated hot plate thermograms

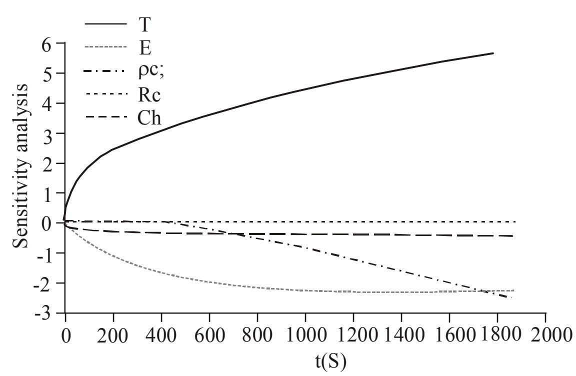

Fig. 10: Reduced sensitivity curves offitting Parameters

Figure 8 we can observe that the conductivity evolved in the opposite direction of the increase of the percentage by mass of the cow dung. This is explained by the fact that the increase of cow dung which has a porous structure engenders the multiplication of the porosity of the mixture. The pores promote the decrease of the thermal conductivity in a matrix. We note that the thermal conductivity varies in the same direction as the density, in this fact the mixture of clay with cow dung provides thermal conductivities lower than the

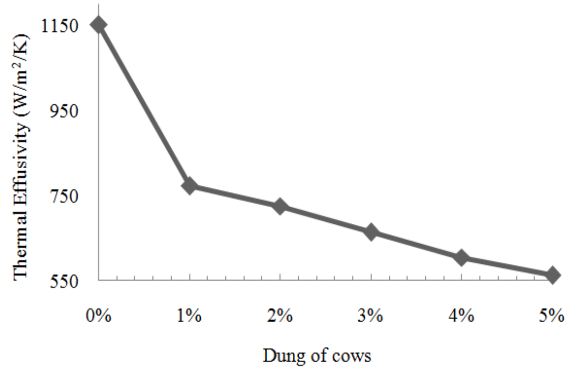

Fig. 11: Evolution of the thermal effusivity according to the percentage of cow's dung

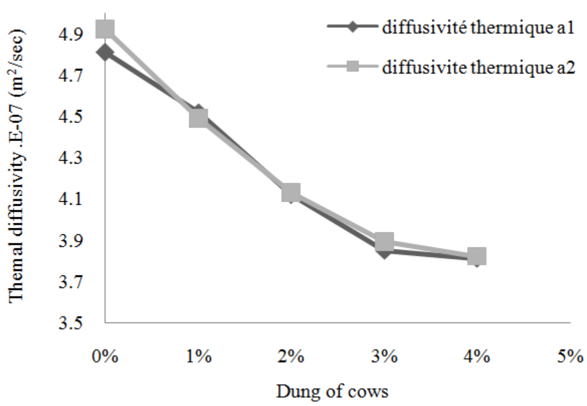

Fig. 12: Evolution of the thermal diffusivity as function of the addition of cow dung

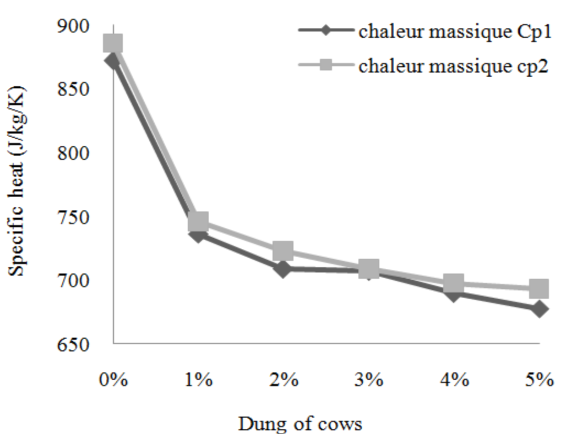

Fig. 13: Specific heat obtained from the diffusivity (C_{P1}) and the effusivity (C_{P2})

pure clay. This allows confirming that the cow dung is clearly favorable to the improvement of the thermal conductivity in the construction materials base on clay.

Determination of the thermal effusivity by the transient hot plate method regime: The algorithm of Levenberg-Marquard is used for the identification of the parameters (E, ρc, R_c and C_h) which allows us to obtain the thermogramme of each test (Cherki *et al*., 2013; Laaroussi *et al*., 2013). This method minimizes the sum of the quadratic error between the theoretical curve and the experimental curve (Fig. 9 and 10).

We note that the thermogramme is not sensitive to the parameter R_c, this implies that the contact resistance is so small that it has no significant influence on the thermogramme. Also, the sensitivity to the parameter C_h is very small; this means that its value has no influence on the calculation of other parameters.

We note that in the Fig. 11 decrease of the thermal effusivity in terms of the increase in the percentage of cow dung, this seems be much more logical because the increase of the cow dung contributed to the decrease of the density which is favorable to the decrease of the thermal effusivity.

Determination of the thermal diffusivity by the flash method: We used Parker and Degiovanni methods to determine the values of the thermal diffusivity in our samples (Fig. 12).

Actually the thermal diffusivity decreased as a function of percentage of cow's dung and of the density of the samples (Fig. 13).

Determination of the specific heat: We can deduce the specific heat through the following relations (Table 1):

$$E = \sqrt{\lambda \rho C_p} \quad (22)$$

$$a = \frac{\lambda}{\rho C_p} \quad (23)$$

Table 1: Values of the mass heat obtained by the relationship 22 (C_{P1}) and the relationship 23 (C_{P2})

Sample	Cow's dung (%)	C_{P1} (J/kg/K)	C_{P2} (J/kg/K)
E_0	0	871	885
E_1	1	736	745
E_2	2	708	723
E_3	3	707	708
E_4	4	689	697
E_5	5	677	693

We note that the values obtained by the two relations are almost the same, the two curves follow almost the same trajectory which confirms that the data obtained are fair and reliable (relative error of 1.9%).

CONCLUSION

In this study we determine the thermal properties of construction materials available locally in large quantities and which are used for a long time in the traditional constructions in Chad.

The Hot Plate method in steady state regime and transient Hot Plate method enable us to determine the thermal conductivity and the thermal effusivity. While the thermal diffusivity is determined by the flash method. The other thermal proprieties are deduced from these parameters.

The obtained results allow us to confirm, that this material presents very interesting thermal characteristics. The addition of the cow of dung to the clay improve its thermal conductivity which could contribute to the reduction of energy consumption by producing an ecological habitat with a good thermal performance.

The knowledge of these parameters will encourage its rational use to the detriment of the concrete, more expensive and less comfortable.

NOMENCLATURE

Latin letters:

a : Thermal diffusivity (m^2/sec)
C_p : Specific Heat (J/kg/K)
Ch : Thermal capacity of the heating element per area unit (J.m^2/K)
e : Thickness (mm)
S : Heat exchange surface between the heating element and the sample (m^2)
E : Thermal effusivity J/m^2/K/$s^{1/2}$
T : Temperature (°C)
t : Time (sec)
U : Voltage of the electric current (V)
h : Convection heat transfer coefficient (W/m^2/K)
p : Laplace parameter

Greek letters:

λ : Thermal conductivity (W/m/K)
ρ : Density (kg/m^3)
ρC : Thermal capacity (J/m^3/K)
ϕ : Heat flux density (W/m^2)
θ : Transforms Laplace transform of thermal flux
Ψ : Quadratic error between the curve experimental and theoretical

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