Experimental Determination of the Thermal Properties of a Local Solar Energy Storage Material

Pius Ezeali Okpani

Abstract— In Abakaliki, a common local material that is used in building construction is quarry dust mixed with cement and water. For this material to be used in the thermal storage wall or Trombe wall system there is need to determine its thermal properties which includes thermal conductivity, specific heat capacity and thermal density. This research work is undertaken to determine these properties experimentally. The thermal conductivity was found to be 0.6 W/mK, the specific heat capacity, 0.57 KJ/kgK and the thermal density 1311KJ/m^{3}K. These results compare favorably with values found in literature for similar materials.

Index Terms— Trombe wall, thermal conductivity, specific heat capacity, thermal density.

1 INTRODUCTION

The quest for alternative forms of energy has been greatly accelerated in recent years because of the increasing awareness of the problems of total dependence on fossil fuels. This energy source is not only harmful to the environment but also non renewable [1]. One source of renewable energy that has attracted much attention is solar energy. But a great impediment to large scale utilization of this energy source is its intermittency. This has necessitated the search for ways of taping it when the Sun is shinning and storing it for use when sunshine is not available [2], [3].

The thermal storage wall or Trombe wall is one of such findings. The passive solar thermal storage (Trombe) wall system was invented and patented by Edward L. S. Morse in the USA in 1881(US Patent 246626), but it was ignored for decades. In the 1960's the idea was revived, developed and popularized by Engineer Felix Trombe of France in collaboration with Architect Jacques Michael following the construction of a passive solar house using the principle in Odeilo, France [4], [5].

A typical Trombe wall consists basically of a south facing 200 – 450mm thick adobe, masonry or concrete wall coated with a dark heat absorbing material and faced with a single or double layer of glass placed 20 to 50mm from the wall to create a small sunspace.

But before a building material can be used for the construction of a Trombe wall, its thermal properties which include thermal conductivity, specific heat capacity and thermal density must be known [6], [7], [8].

The building material under investigation in this work is a mixture of quarry dust and cement. Quarry dust is abundant in Abakaliki, in Ebonyi State of Nigeria because it is a bye product of quarrying activities which constitute the main industry of the town.

2 MATERIALS AND METHODSINTRODUCTION

The composition by mass of the material used in this work was 75% quarry dust, 15% cement and 10% water.

To determine the specific heat capacity and thermal density of the material, 10 very thin slabs of various sizes were made and sun-dried for 30 days. After that each slab was weighed in air and in water. It was then put in boiling water of known temperature for about 30mins to attain the temperature of the boiling water. After that it was the quickly and gently transferred to a well-lagged calorimeter containing water of known mass. The temperature of the calorimeter was taken at 5-minute intervals until it rises to a maximum and begins to fall. A temperature-time graph was drawn from which the correction factor to compensate for radiation was determined. The mass density of the slab ρ_s was calculated from the formula [9], [10]:

$$\rho_s = \frac{w_{sa}}{w_{sa} - w_{sw}} \rho_w \quad (1)$$

where w_{sa} is the weight of the slab in air , w_{sw} is the weight in water and ρ_w is the density of water.

The specific heat capacity of the material c_s was calculated using the formula [10], [11], [12]:

$$c_s = \frac{(m_w c_w + m_c c_c)(T_c - T_i)}{m_s (T_b - T_c)} \quad (2)$$

where m_w is the mass of the water in the calorimeter, c_w is the

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specific heat capacity of water, m_c is the mass of the calorimeter, c_c is the specific heat capacity of the calorimeter, m_s is the mass of the slab, T_b is the temperature of the boiling water, T_i is the initial temperature of the calorimeter and T_c is the compensated final temperature of the calorimeter.

The thermal density of the material τ_D is calculated from the formula [6]:

$$\tau_D = \rho_s c_s \quad (3)$$

Since the material is a poor conductor of heat, the pipe method [13] is used determine its thermal conductivity. This method takes advantage of a radial heat flow in a cylindrical specimen. A core heater, which is a tube, rod, or wire, is inserted into the central axis of the pipe-shaped specimen. There are heaters at both ends of the specimen. The combination of the specimen and heaters is surrounded by thermal insulation and then a water jacket or a liquid-cooled heat sink.

For this purpose 10 hollow cylinders each with length at least twice the diameter were cast in molds of various sizes and sun-dried for 30 days. A heater assembly of tungsten filament was inserted into the hollow of each cast and 8 thermocouples were positioned at radii r_1 and r_2. The longitudinal and transverse cross- sections of one sample are shown in fig. 1.

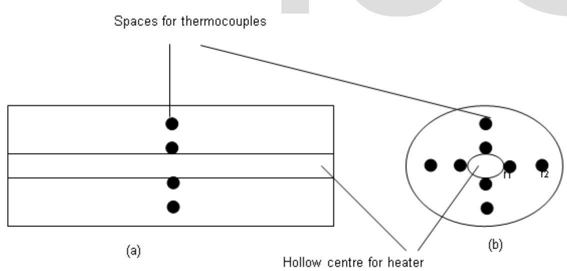

Fig. 1 (a) Longitudinal cross- section (b) Transverse cross- section

The thermal conductivity of the material is calculated from the formula [6], [8], [13]:

$$\kappa_m = \frac{Q \ln\left(r_2 / r_1 \right)}{2\pi L \left(T_1 - T_2 \right)} \quad (4)$$

where Q is the total heat supplied during the period, L is the length of the cylinder, and T_1 and T_2 are the temperatures of the thermocouples at the positions r_1 and r_2 respectively.

3 RESULTS AND DISCUSSION

The results of the experiments are shown in table 1.

Table 1: Results of the Experimental Investigation

Exp. No.	Mass density Kgm^{-3}	Specific heat capacity $KJkg^{-1}K^{-1}$	Thermal density $KJm^{-3}K^{-1}$	Thermal conductivity $Wm^{-1}K^{-1}$
1	2265	0.574	1300	0.65
2	2315	0.568	1315	0.58
3	2288	0.570	1304	0.56
4	2297	0.565	1301	0.63
5	2312	0.571	1320	0.62
6	2280	0.572	1304	0.64
7	2300	0.573	1318	0.55
8	2300	0.566	1302	0.62
9	2322	0.569	1321	0.58
10	2311	0.572	1322	0.57
Avg	2300	0.570	1311	0.60

For comparison the values of thermal properties of some building materials are shown in table 2 [6], [11].

Table 2: Thermal Properties of Building Materials

Material	Mass density Kgm^{-3}	Specific heat capacity $KJkg^{-1}K^{-1}$	Thermal density $KJm^{-3}K^{-1}$	Thermal conductivity $Wm^{-1}K^{-1}$
Granite	2720	0.88	2394	2.85
Concrete	2360	0.88	2082	1.30
Brick	1840	0.84	1699	0.75
Adobe	1700	1.00	1700	0.52

From tables 1 and 2 we can see that the thermal properties of quarry dust compares favorably with those of similar building materials like granite, concrete, brick and adobe since their values are in the same order. Hence these results are reliable enough to be used in the design of solar energy storage device such as the Trombe wall. Knowledge of the specific heat capacity, thermal density and thermal conductivity helps to determine the size and temperature range of the device. In view of these knowledge of these values for the local solar energy storage material is indispensable in the design of such devices [3], [6], [11], [12].

4 CONCLUSION

The experimental investigations reported in this paper show that for a local solar energy storage material made up of 75% by mass of quarry dust 15% of cement and 10% of water has a specific heat capacity of 0.57 $KJkg^{-1}K^{-1}$, a thermal density of 1311 $KJm^{-3}K^{-1}$ and a thermal conductivity of 0.6 $Wm^{-1}K^{-1}$. These results will assist greatly in the design of solar energy storage devices such as the Trombe wall which can make use of this material.

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