OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 3, No. 1, January 2009, p. 75 - 76

Effect of porosity and grain size on heat storage coefficient of marble powder

A. K. SHROTRIYA, S. K. JAIN[a], RAMVIR SINGH[b], D. R.CHAUDHARY[b]
Department of Physics, SML(PG) College, Jhunjhunu, Rajasthan, India
[a]Department of Physics, Rajasthan Technical University, Kota, Rajasthan, India
[b]Department of Physics, University of Rajasthan, Jaipur, Rajasthan, India

An experiment was conducted to study the effect of porosity and grain size on thermo-physical parameter : heat storage coefficient of marble powder. Seven samples of marble powder having different grain size have been studied in the present paper. Sorting of different particle sizes were done through sieve analysis. The Heat storage coefficient (HSC) was measured by the plane heat source technique. It was possible to obtain a porosity range of 39 to 54 percent. For fine particles the HSC is low as compared with that for coarse particles. As the porosity increases the HSC decreases and beyond some larger values of porosity (say 54 percent) the change in value of HSC is less rapid.

(Received September 5, 2008; accepted January 21, 2009)

Keywords: Hheat storage coefficient, Marble powder, Plane heat source method

1. Introduction

The thermal characteristics of loose granular systems are extremely important in determining their ability to store heat. In case of loose granular materials, the solid particles are surrounded by fluid, or in the case of vacuum, by empty space. The thermal properties of such an unconsolidated system will depend on the conditions of loose granular system : porosity, temperature, grain size and structure of aggregate. To solve problems related to the energy status of loose granular system, a set of thermal parameters are needed. These are (a) the thermal conductivity λ, (b) the volumetric specific heat C which is the product of the specific heat c and the density ρ, (c) the thermal diffusivity α= λ/C and (d) the heat storage coefficient (HSC) β which is related to others by the relations

$$\beta = \sqrt{\lambda \rho c} = \sqrt{\lambda C} = \frac{\lambda}{\sqrt{\alpha}} \qquad \text{(i)}$$

In the literature [1-3] one finds very little importance attached to knowledge of the HSC of various materials. The heat storage coefficient characterizes a medium from the viewpoint of its heat storage ability. If we consider a section of the medium, then some of the heat entering is retained by it and the rest is transferred to subsequent layers. When the steady state is reached no heat is retained and all is transferred to the subsequent layers. It can be seen that during the transient state the heat retained by a particular layer is a function of its heat storage coefficient. It is well known that knowledge of the HSC is necessary in calculating the heat accumulating capability of a medium when in a transient state. A detailed account of the usefulness of knowledge of β is given in literature [4,5].

In terms of heat flow, it may be defined as the amount of flux flowing under unit temperature difference at an instant of $1/\sqrt{\pi}$ seconds. Its unit is $Jm^{-2}K^{-1}s^{-1/2}$ or $Wm^{-2}K^{-1}s^{1/2}$. Here we present an experimental study of the HSC (β) of marble powder with variation of grain size and porosity.

When insulation of a system in transient state is a matter of concern, it is an important parameter for deciding the insulating capability of a substance. For a good insulation envelope the amount of heat flowing through it should be small, which implies that the heat storage coefficient should be low.

In the present era of rapidly developing technology and energy economics, proper insulation is needed for devices such as solar ponds, space vehicles, underground structures, buildings etc. All such devices are heated periodically or for a short interval of time and steady state is not attained. Therefore for selection of suitable insulating material, the experimental determination of the heat storage coefficient becomes a basic requirement.

2. Experimental procedure

The HSC's of marble powders at different grain size and porosity were measured using the plane heat source method[4]. When a plane heat source is placed in an infinite medium, then the rise in temperature at a point *x* in the medium is given by

$$T = \frac{qx}{2\lambda\sqrt{\pi}} \int_{x\eta}^{\infty} \frac{\exp(-b^2)}{b^2} db$$

where q is the power per unit area of the source, λ is the thermal conductivity of the medium and $\eta = \frac{1}{\sqrt{4\alpha t}}$ and $b = \frac{x}{2\sqrt{\alpha(t-\tau)}}$ with α is the thermal diffusivity of the medium, t the time and τ the time variable within the interval 0 and t. For $x = 0$, this becomes $T = \frac{q}{2\lambda\eta\sqrt{\pi}}$. By putting $\eta = \frac{1}{\sqrt{4\alpha t}}$ we get $T = \frac{q}{\lambda/\sqrt{\alpha}}\sqrt{t/\pi}$

Using relation (i), we have

$$T = \frac{q}{\beta}\sqrt{t/\pi}$$

The rise in temperature at the centre of the source will be proportional to the square root of time. A graph of T versus √t will be a straight line. Its slope B will be given by the relation

$$B = q/\beta\sqrt{\pi}\,.$$

Therefore,

$$\beta = \frac{q}{B\sqrt{\pi}}. \qquad (2)$$

Thus, knowing the values of q and B the HSC can be determined.

This plane heat source method is quick, simple and suitable for the measurements of heat storage coefficients of loose granular materials. The experiment set up consisted mainly three units: (i) sample container, (ii) constant temperature bath and (iii) power and temperature measuring units

The sample container consists of a cylindrical copper vessel 15.5 cm long having a diameter of 7.3 cm. It is placed in a chamber at constant temperature. The temperature of the chamber can be kept constant between $\pm 1\,^{\circ}$C by circulating liquid from a constant temperature bath. The sample was put in the container and a little tapping was done so that the material settled uniformly in the container. The heat source was placed in the middle of the container with the sample on both sides.

After the current was switched on, the rise in temperature of the sample at centre of the heat source was recorded every 10 seconds. Each set of observations was recorded up to 200 seconds. The slope of the straight lines of the plot of temperature θ versus $\sqrt{t}$ was obtained by computer. The HSC was then determined by equation (2).

3. Measurements and results

The samples of marble powder were obtained from the local suppliers. Sieves were used to separate particle of different sizes. The materials were dried in an oven for 24 hr at $110\,^{0}$C. Some physical properties of the materials used are listed in Table 1. The plane heat sources which we used were initially tested by measuring the HSC of pure glycerine and found the value 821.6 $Wm^{-2}K^{-1}s^{1/2}$ at 20 ^{0} C. The value calculated from the literature [6] is 801.9 $Wm^{-2}K^{-1}s^{1/2}$ at 20 ^{0} C. The error in the measurement was not more than 3 %.

The Table 1 gives measured value of HSC of marble powder using plane heat source method. All these experiments were carried out at room temperature (about 25 $\pm$ 2 ^{0} C). Seven samples of marble powder having different grain sizes have been studied here. Sorting of different particle sizes was done through Sieve analysis.

Table 1. Physical properties of marble powder measured in the experiment.

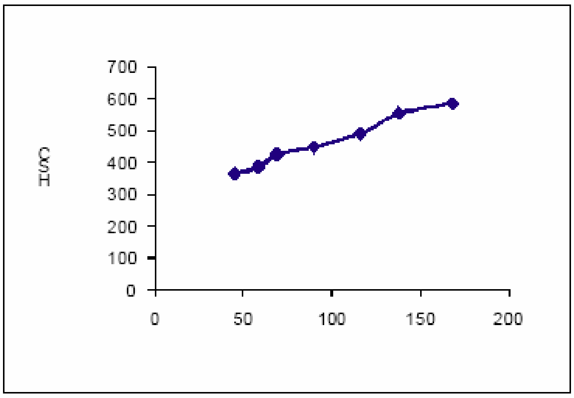
Bulk porosity φ	Average grain size (in micro metre) µm	HSC (β) $Wm^{-2}K^{-1}s^{1/2}$
0.540	45	364.1
0.510	58	385.6
0.490	69	424.8
0.471	90	448.5
0.443	116	490.2
0.404	138	552.9
0.390	168	585.1

4. Effect of the particle size

The variation of the HSC of these materials with particle size is listed in Table 1 and Fig. 1. From this Table 1 can observe that the particle size affects the HSC at room temperature. For fine particles the HSC at room temperature is low as compared with that for coarse particles. A thin air film around the grains turns the sample into a better insulator. Therefore there occurs a slight lowering of the HSC. This figure-1 also shows that there is a systematic variation in the HSC with the variation in particle size. When the particle size of the marble powder (Fig.1) is very small (45 µm), the HSC of the system becomes very small. This phenomenon is obvious, for the porosity and density of a sample has a strong influence on its HSC. The dry density γ_d of a sample is related to its porosity φ by the relation [7].

$$\gamma_d = (1-\varphi)\gamma_s$$

where γ_s is the solid density.



Average grain size(in µm)

Fig. 1. Variation of HSC (in $Wm^{-2}K^{-1}s^{1/2}$) with particle size.

A sample possesses a certain distribution of grain sizes which determines its density, porosity and pore-size distribution. A decrease in the particle size or an increase in porosity means a decrease in the dry density and more space between the solid particles. These properties, in turn, directly affect the HSC of the material.

5. Effect of porosity

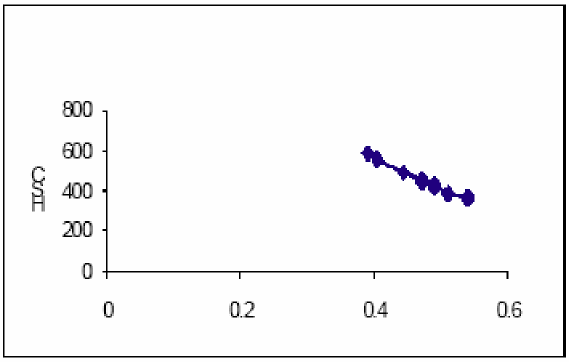
The marble powder has porosity range of 39 to 54 percent. Here porosity φ is defined[8] as the fraction of void (air) volume and it is a dimensionless quantity, because it is the ratio of air volume present in the substance to the total volume of substance. Such as

$$\varphi = 1 - \varphi_s$$

where

φ_s = fraction volume of solid

In Table 1 and Fig. 2 one finds that as porosity increases the HSC decreases and beyond some larger values of porosity (say 54 percent) the change in values of HSC is less increase, while in low porosity side the value of HSC has a greater increase. It seems that as long as porosity is small, the amount of air present within the sample is less and a further decrease in porosity will lead in bringing the particle still nearer.



Bulk Porosity (φ)

Fig. 2. Variation of HSC (in $Wm^{-2}K^{-1}s^{1/2}$) with bulk porosity.

This improves the contact between the particles which will enhance the over-all heat conduction. Therefore as the increases in porosity, it means the particles are separated appreciably. This separation has little effect on the conduction because contacts once broken are not further affected. This explains that after creation range of porosity, a further increase in porosity will not develop any marked change in conduction through the media. So there is a continuous decrease is found in the value of HSC of the marble powder with the increase in porosity.

Acknowledgements

The author thanks Mr. Munidra Jain Lecturer, Mr. Rajkumar Sahal, Lab Assistant, Department of Physics and Mr. Surendra Kumar Soni, Department of Computer Applications, Seth Motilal (P.G.) College , Jhunjhunu (Rajasthan) for help in preparation of the manuscript of the paper and their valuable suggestions.

References

[1] A. A. Babnov, Sov. Phys. Tech. Phys. **2** ,476 (1957).
[2] A. M. Luc, D. L. Balageas, Joint conf. On Thermophysical Properties, Gaithesrburg, MD 1-23, (Maryland : Onera,15-18 June (1981).
[3] S. V. Nerpin, A. F. Chudnovski, *Physics* of the Soil (Jerusalem : Israel Program for scientific Translation, 187 (1970).
[4] L. S. Verma, A. K. Shrotriya, U. Singh, D. R. Chaudhary, J. Phy. D. Appl. Phy. **23**, 1405(1990).
[5] A. K. Shrotriya, S. Jain, Indian J. Pure and Applied Phy. **41**, 700(2003).
[6] A. K. Shrotriya, L. S. Verma, R. Singh, Chaudhary, Heat Recovery Systems & CHP **11**, 423 (1991).
[7] O. T. Farouki, Thermal Properties of Soils (CRREL Monograph. 81-1), 12(1981)
[8] R. S. Beniwal, R. Singh, R. N. Pande, D. R. Chaudhary, P. V. Bakore, Heat Recovery Systems & CHP **7**, 139 (1987).

*Corresponding author: anilshrotriya@rediffmail.com