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An estimation of correlation on thermo-acoustic properties of mineral wool

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Paper presents thermal and acoustical properties of mineral wool, a class of building material available in the form of blankets and acoustical tiles. Thermal conductivity and sound absorption coefficient of materials have been determined at CBRI, Roorkee. For measurement of sound absorption coefficient, Standing Wave Method is used and for thermal conductivity, Guarded Hot Plate Apparatus is used. Paper describes regression equations correlation between noise reduction coefficient (NRC) and thermal conductivity (*K*) for mineral wool material. The equation is useful to determine NRC value by knowing the *K*-value and vice versa for indoor design purposes.

Keywords: Mineral wool, Noise reduction coefficient, Thermal conductivity, Thermo-acoustic properties

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Introduction

Porous acoustical materials with intercommunicating pores form an important class of sound absorbing materials[1]. In these materials, dissipation of sound energy takes place by the action of thermal and viscous processes. Due to wide range of available thicknesses and densities of mineral wool materials, these have wider application as sound absorbers. Therefore, evaluation of acoustical performances of sound absorption coefficient values has been studied by standing wave apparatus in the laboratory. The absorption characteristics are governed by their physical properties. In general, porous material with rigid backing absorbs[2,3] more at middle and high frequencies than at low frequencies of sound. The pores of fibrous material must be intercommunicating so that sound wave can easily penetrate[4] into the material and attenuation of sound energy takes place by multiple reflections inside the material. There has been attempt to theoretically predict the acoustical behavior of fibrous material starting from its basic physical properties, which have been determined by sound absorption coefficient.

When sound waves are incident on the surface of a material, some of the sound energy is reflected back while some is absorbed in the material and some of sound energy transmitted on the other side of the material. The reduction in sound energy reflected would give the idea of sound energy absorbed by the surface of the material. Sound absorption coefficient 'α' of a material is the ratio of sound energy absorbed to the total energy incident. It depends on the nature of material, the frequency of sound and the angle at which sound waves strikes on the surface of the material. The overall sound absorption of different materials can be compared through noise reduction coefficient (NRC) values. It is the average of coefficients at four different frequencies 250, 500, 1000 and 2000 Hz.

Thermal performance of a space is dependent on the amount of heat flowing from outside to the inside and vice versa through various building components. Building material is characterized by thermal conductivity (*K*) to evaluate its ability to transfer heat by conduction through a homogeneous layer of material. Mineral wool is a good thermal insulating material. Its *K* value is higher[5] for low densities and as the density increases, *K* value decreases in the beginning and then establishes. In the present study, *K* value of mineral wool has been determined using Guarded Hot Plate Apparatus (GHP). Thus as density changes, the thermal and acoustical behaviour changes causing variation in thermo-acoustic (TA) environment indoors.

Thermo – Acoustic Behavior of Materials in Buildings

TA indoor environment of a space depends much on thermal and acoustical performance of fibrous mineral wool material when used as lining material on

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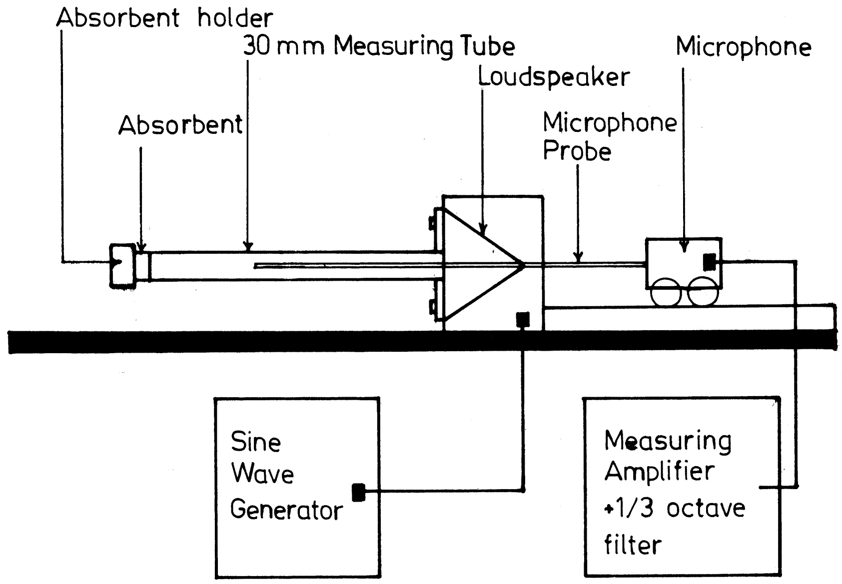

Fig. 1—Experimental setup on standing wave tube

indoor walls, whereas a lower value of $K^{6,7}$ of material helps resisting outside heat being transmitted into the building during summers and reverse in winters. Thus improving the thermal efficiency of indoor space results in comfortable living conditions. Application of mineral wool also improves indoor acoustical environment by cutting down excessive reverberation within the space. Thus the need of correlation between K and α is an important parameter to assess TA environment when such materials are applied in building. An attempt has been made in this study to establish a correlation between these two physical parameters of different densities of mineral wool available in market.

Materials and Methods

(a) Measurement of α

Measurement of α is done by standing wave tube method (Fig. 1). The sound waves are generated from beat frequency oscillator. As per ASTM C-384-1977 measurement, 6 frequencies (125, 250, 500, 1000, 2000 and 4000 Hz) were chosen. The material is cut in a circular shape of given thickness and fitted in different sample holders. The sample holder is tightened by bolts at the one end of the tube with rigid backing. The loudspeaker is fitted at the other end of this tube. The sound waves of selected frequencies generated from the beat frequency oscillator is reinforced by the loudspeaker and passes through the tube and falls on the sample normally. Some sound energy will be absorbed in the sample whereas some is reflected back. The reflected wave and the incident wave form a system of standing wave inside the tube, which will depend on the absorption properties of the material. The ratio of maxima (A+B) and minima (A-B) of the sound pressure along the tube is measured by moving the probe attached with a microphone, and recorded by frequency analyzer. With the help of this analyzer, α is calculated.

For low frequencies (125, 250 and 500 Hz), larger tube and for high frequencies (1000, 2000 and 4000 Hz.) smaller tube is used. This method is very convenient for the measurement of α at normal incident for fibrous material. Thus,

$$\alpha = 1-(B/A)^2 \quad \dots (1)$$

where A=amplitude of reflected wave, and B=amplitude of incident wave.

The ratio of maxima (A+B) and minima (A-B) is maximum pressure/minimum pressure=P_{max}/P_{min}= $A+B/A-B$. Now let $n = A+B/A-B$, then

$$\alpha = 4n / n^2 + 2n + 1 \quad \dots (2)$$

The sound absorption behaviour of mineral wool is dependent upon its packing density. More precisely, it is related with the resistance offered to the movement of air through the material called flow resistance.

(b) Measurement of *K*

Measurement of K of these fibrous materials has been determined by GHP as per IS: 3346 at mean temperatures of 50°C and 10°C. Hot plates tempera-

Table 1—Thermo-acoustical behavior of mineral wool at 50°C

S No	Density kg/m^3	NRC	K W/mk
1	48	0.852	0.0302
2	80	0.832	0.0292
3	96	0.776	0.0286
4	120	0.781	0.0283
5	150	0.757	0.0279

Table 2—Thermo-acoustical behavior of mineral wool at 10°C

S No	Density kg/m^3	NRC	K W/mk
1	48	0.852	0.0279
2	80	0.832	0.0272
3	96	0.776	0.0270
4	120	0.781	0.0270
5	150	0.757	0.0267

Table 3—Thermo-acoustical behavior of mineral wool at normal temperature

S No.	Density kg/m^3	NRC	K W/mk
1	48	0.852	0.0325
2	80	0.832	0.0312
3	96	0.776	0.0301
4	120	0.781	0.0295
5	150	0.757	0.0289

tures were maintained at 70°C and 30°C by voltage stabilized temperature controller and cold plates temperatures were maintained at 30°C and –10°C respectively by a refrigerated thermostat. K was determined as:

$$K = Q \cdot d / A\, dt \qquad \ldots (3)$$

where Q is the thermal power required to maintain the steady state heat flow between hot and cold plate through materials, d is thickness of the material, A is the area of central hot plate and dt is the temperature difference between hot and cold plate.

K, NRC and density of the materials (thickness 50 mm) were measured at 50°C (Table 1), 10°C (Table 2) and at normal temperature (Table 3).

Results and Discussion

With increase in frequency, NRC has been found maximum when material has density of 96 kg/m^3 (Fig. 2). NRC versus K has been plotted at 50°C (Fig. 3), 10°C (Fig. 4) and at room temperature (Fig. 5). The dependency of NRC on temperature is not very meaningful. For all practical purposes under the present study, the NRC may be assumed to be independent of temperature in the range of 10-50°C i.e. room temperature for mineral wool[8]. The correlation between NRC and K has been explored using regression least square method and the final equations are shown as Eq. (4), Eq. (5) and Eq. (6) along with their correlation factor. The trend line

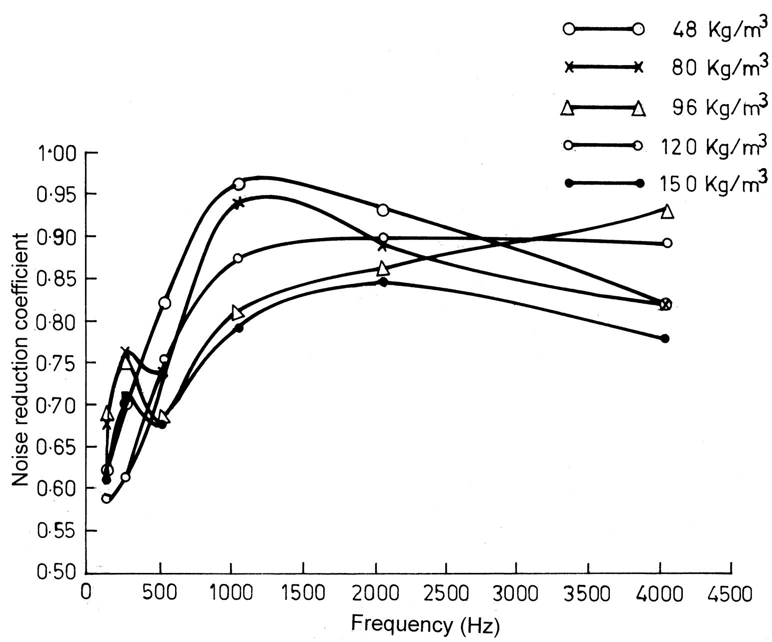

Fig. 2—Frequency vs Noise Reduction Coefficient (NRC)

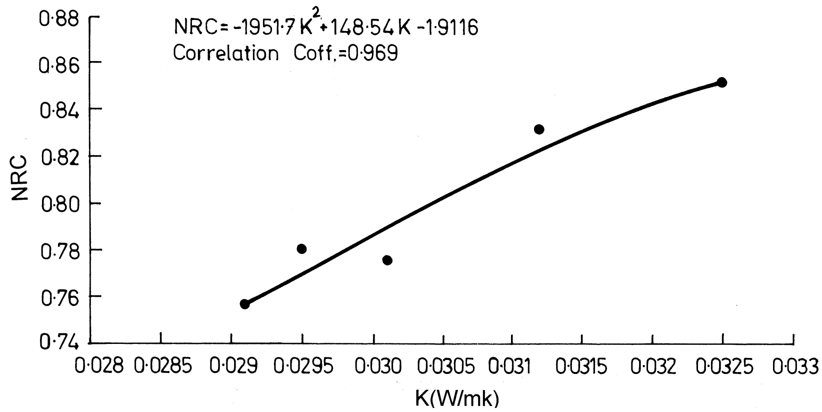

Fig. 3—NRC vs *K* at mean temperature 50°

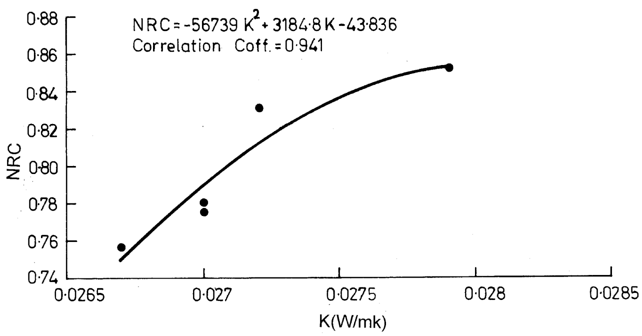

Fig. 4—NRC vs *K* at mean temperature 10°

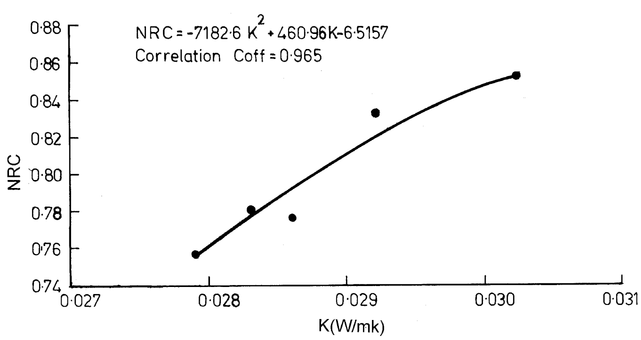

Fig. 5—NRC vs *K* for normal temperature

equation (correlation factor, 0.969) for Fig. 3 is represented by

$$NRC = -1951.7K^2 + 148.54K - 1.9116 \quad \ldots (4)$$

The trend line equation (correlation factor, 0.941) for Fig. 4 is represented by

$$NRC = -1951.7K^2 + 148.54K - 1.9116 \quad \ldots (5)$$

The trend line equation (correlation factor, 0.965) for Fig. 5 is represented by

$$NRC = -7182.6K^2 + 460.96K - 6.5157 \quad \ldots (6)$$

Eq. (6) is useful to find out values of NRC or *K* for design purpose if one variable is known at normal temperature. Eq. (4) and Eq. (5) are used for the temperatures about 50°C and 10°C, respectively. These equations are useful for predicting acoustical and thermal properties of mineral wool with in acceptable accuracy and are in good agreement with experimental measurement.

Conclusions

Study describes about a correlation between NRC and *K* for mineral wool. As it is time consuming and laborious process to find out NRC and *K* experimentally, one can theoretically determine approx NRC value by knowing the *K*-value and vice versa by applying these equations, which are very useful for different climatic conditions. For acoustical and thermal relief in hilly areas where the weather remains cold about 5°C, Eq. (4) is useful, Eq. (5) is useful for hot areas where temperature is about 45°C and Eq. (6) can be used for general climatic condition, however mineral wool can also be used for isolation of vibrations and sound insulation.

Acknowledgement

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