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Thermal Insulating Properties of Carbonized Corkboard and Layered Metal Sheets at Low Temperatures*

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I. Introduction

Lately carbonized corkboard has very frequently been used for a thermal insulating material at subzero range of temperature and more recently layered metal sheet has been adopted for the same purpose. Provided the thermal conductivity is the same for two kinds of materials cited above, the latter is rather superior to the former since the metal sheet shows a smaller detrimental influence on the insulating power due to the condensation of water vapour and the facility in the removal of moisture by either warming up or desiccation. The conductivity of heat of carbonized corkboard(1) and layered aluminium sheets(2) has been measured at temperature ranges of 20°~150° and 0°~500° respectively, while so far as the writer is aware no systematic observation has been undertaken to extend the said range lower than an ice point, excepting the allied study on the chromium steel plates insulator that is called "Ferro-Therm" by Macormack(3).

The present study was made to fulfil the above mentioned requirement to know the thermal data that are necessary for the practical design of cold storage constructions.

II. Methods and Procedures

In order to measure the thermal conductivity, Niven's cylindrical method(4) was adopted principally, however, the comparison method which will be described below was also employed owing to the benefit of simplicity and the economy of material.

(i). *Niven's method applied on carbonized corkboard:* As shown in Fig. 1, the heater at the central core of the cylinder was made by winding densely constantan wire No. 30 gauge on a porcelain tube of 12mm in diameter and 304mm in length, the electric resistance of which is about 96 Ω at room temperature, and it was lapped with a thin asbestine sheet and coated with alumina powder and then inserted in a copper tube of 22 mm in diameter and 305mm in length. Both ends of the constantan wire just mentioned were equipped with two pairs of terminal, one pair was used for supplying the electric current and the other for measuring the potential drop at both ends of the heater. The heat energy developed in the heater was about 0.3~0.7 watt in total length. Four disciform blocks, each 110 mm in diameter, were cut from an adequately carbonized corkboard of 3 inches thick and the heater stated above was pierced through the holes perforated in their centres. Both ends of the specimen and heater system are covered by two disks of corkboard 1.5 inches thick and 110 mm in diameter, with the view to preventing the heat dissipation from the ends of the heater

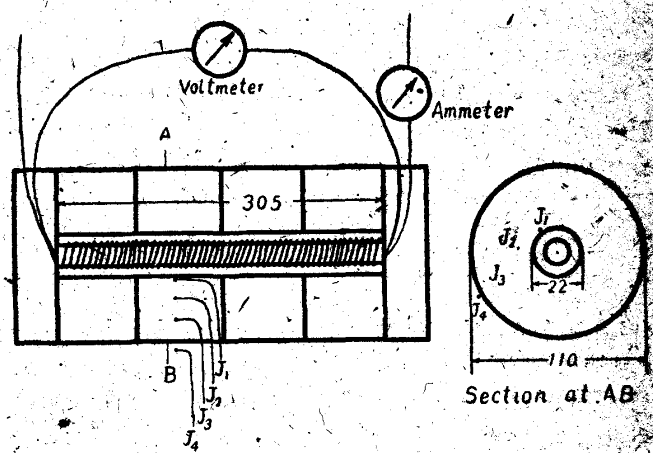

Fig. 1. Apparatus for Niven's method applied on carbonized corkboard.

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and thereby to render the heat flow in radial direction of the cylinder.

The temperature gradient in the specimen was measured by the copper-constantan (No. 35 wire gauge) thermojunctions J_1, J_2, and J_3, which were inserted in the pin holes bored in a side of the middle corkboard viewed from the lateral side. The extremities of J_1, J_2, and J_3 were fixed just in contact with as well as 10 and 20 mm apart from the surface of the heater respectively. One more junction, J_4, was put in contact with the outside surface of the specimen. The electromotive force of these thermojunctions was measured to an accuracy of 1 μ V by means of a Leeds and Northrup's type potentiometer. And the electromotive forces of every thermojunction were calibrated at an interval of 5° in the temperature range of 46° and −60° in a cryostat, by comparing with a standard thermocouple and a resistance thermometer.

In order to determine the thermal conductivity, it is a matter of prime importance that the thermal stationary condition should be maintained satisfactorily and that the heat flow should have radial and uniform distribution in the specimen. Therefore, the specimen in question was contained in a cryostat which was described elsewhere[5], the temperature of which, i. e. the reading of J_4, can be kept within ±0.1° in the temperature range from room temperature to −150° by the aid of liquid nitrogen, and the temperature of the heater, i. e. the reading of J_1, was kept about 5° higher than that of the cryostat, and eventually the temperature distribution in the specimen usually attains to a final stationary state 6～7 hours after commencement of an experiment.

Under the above-mentioned conditions, the thermal conductivity is given by the expression:

$$\lambda = \frac{IV}{4.19\times 2\pi l}\cdot\frac{\ln r_2 - \ln r_1}{\theta_1-\theta_2}, \text{ cal/cm sec °C} \tag{1}$$

where I is the current through the heater (amp), V the potential drop on both ends of the heater (volt), l the length of the heater (cm), r_1 and r_2 the distances from the centre of cylinder (cm) and θ_1 and θ_2 the corresponding readings of temperature.

(ii) *Niven's method applied on layered aluminium sheets:* The same heater described above was also used and three sheets of aluminium foil, 0.2 mm thick, were lapped cylindrically in three layers as shown in Fig. 2 in which asbestine strips of about 4 mm thick and 4 mm wide were used as separators between successive metal sheet layers. In one layer of 305 mm in total length, 10 rings of such separators were arranged making equal gaps of 29 mm. The outermost diameter of the specimen was about 46 mm, i. e. about 1/7 of the length, so the end effect on the heat flow was also very small in this case. The thermojunctions J_1, J_2, J_3 and J_4 were equipped at the middle portion of the cylinder in contact with the surface of the heater and the successive layers of aluminium sheet, and the readings of them were obtained after their electromotive forces maintained at constant values for more than a few hours. The conductivity of heat is also given by (1).

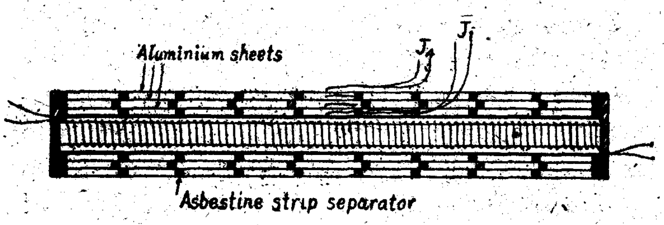

Fig. 2. Apparatus for Niven's method applied on layered aluminium sheets.

(iii) *Comparison method applied on carbonized corkboard:* As shown in Fig. 3, a square block of carbonized cork 200×200×80 mm in dimension was cut out and a square hole of 100×100 mm was bored through its central position. A square disc-shaped heater was made, winding a square sheet of mica having 100 mm sides with a constantan wire of No. 35 gauge by 5 mm intervals 2 metres in total length, both ends of which were attached two pairs of terminals that were intended for current and potential leads respectively, and then it was sheltered with two sheets of mica and covered with two copper plates of the same dimension on both sides. Next the heater in question was put between two pieces of corkboard, one of which was cut from the board whose conductivity was already known by means of the aforesaid method and the other one was taken from the board whose conductivity was under investigation. Then this specimen as a whole was inserted in the square hole bored in cork referred to above in

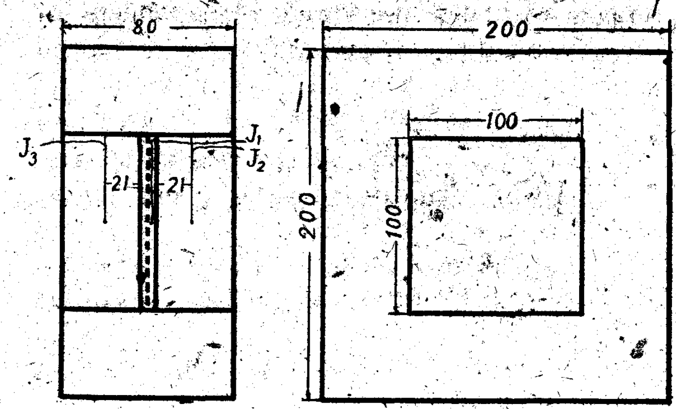

Fig. 3. Apparatus for comparison method applied on carbonized corkboard.

order to lessen the lateral dispersion of heat. Three thermojunctions were provided, one of which (J_1) was in contact with the heater's surface and the other two (J_2, J_3) at symmetrical positions with regard to the heater, i. e. each 21 mm apart from the heater's surfaces into the corkboards whose conductivities were to be compared. The thermal conductivity of the specimen is expressed by

$$\lambda=\frac{\lambda_3(\theta_1-\theta_3)}{\theta_1-\theta_2}, \qquad (2)$$

where λ_3 is the thermal conductivity of the standard sample and θ_1, θ_2 and θ_3 correspond to the temperature readings of J_1, J_2 and J_3 respectively.

By means of the comparison method, one can measure the thermal conductivity with regard to the various kinds or states of specimens easier than Niven's method in addition to the saving of materials, for instance, it can be applied when the specimen of the best condition in the degree of carbonization is searched for.

III. Experimental Results

(A) *Carbonized corkboard:* The corkboard examined first by Niven's method has been supplied from "A" company, which was principally made from the cork-texture of the wood called *Quercus variabilis*, and it is a uniformly carbonized one, made by compression at elevated temperatures, which has a bulk density of 0.208 gr/cm³. The results are given in Table 1.

Table 1. Corkboard from "A" company.

Temperatures (°C)	λ (cal/cm sec °C)	A (kcal/m h °C)
26~32	1.43×10^{-4}	5.15×10^{-2}
19~23	1.40×10^{-4}	5.04×10^{-2}
−23~−30	9.27×10^{-5}	3.34×10^{-2}
−46~−57	6.47×10^{-5}	2.33×10^{-2}
15~19	1.47×10^{-4}	5.30×10^{-2}

In the above table the stated temperatures correspond to the readings of J_1 and J_4 in Fig. 1 respectively, and the augumentation in the value of λ in the undermost row may perhaps be ascribed to the influence of moisture absorbed at low temperatures.

The materials supplied from "B" company having the same density and the lighter one due to over-carbonization gave the results in Table 2 by means of the comparison method.

Table 2. Corkboards from "B" company.

Bulk density (gr/cm³)	Temperatures (°C)	λ (cal/cm sec °C)	A (kcal/m h °C)
0.208	21~24	1.42×10^{-4}	5.12×10^{-2}
〃	−47~−60	6.16×10^{-5}	2.22×10^{-2}
0.138	20~24	1.58×10^{-4}	5.70×10^{-2}

(B) *Layered aluminium sheets:* The results of measurement on the layered aluminium sheets are shown in Table 3, in which the data that were obtained when the specimen was kept in hydrogen gas at normal pressure are also given.

Table 3. Layered aluminium sheets. (IV=0.21~0.26 watt)

Atmosphere	Temperatures (°C)	λ (cal/cm sec °C)	A (kcal/m h °C)
Air (1 atm)	12~14	1.43×10^{-4}	5.16×10^{-2}
〃	−20~−23	9.35×10^{-5}	3.37×10^{-2}
〃	−39~−42	7.71×10^{-5}	2.77×10^{-2}
〃	−56~−61	5.70×10^{-5}	2.05×10^{-2}
H_2 (1 atm)	11~12	8.39×10^{-4}	3.02×10^{-1}
〃	−62~−64	3.41×10^{-4}	1.23×10^{-1}

In the data shown in Table 3, they contain the part of heat transmitted through asbestine separators in addition to the heat carried by conduction and convection through the gas phase, of course, including radiation.

IV. Resumé

(1) Thermal conductivity of carbonized corkboard and layered aluminium sheets

has been measured at the temperature range from room temperature to $-60°$.

(2) The conductivities of both materials cited above show remarkable monotonous decrease as the temperature is lowered.

(3) If the similar construction of the aluminium sheets layer as that cited in this paper is adopted, the heat insulating property of that layer will be almost the same as that of carbonized corkboard., as it is easily apprehended by comparing the data given in Tables 1 and 3.

(4) When tin sheets have been used in place of aluminium sheets almost the same results could be obtained.

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