Efficiencies of Honeycomb Absorbers of Solar Radiation

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Theme

THE utilization of solar energy for certain space applications (e.g., solar thermo-electric converters, thermal control) requires a method for absorbing and retaining a large fraction of the incident solar radiation. In this paper, a solar energy absorber consisting of a honeycomb structure affixed to a collecting base surface is analyzed. Such a honeycomb would be designed to allow solar radiation to pass through to the base surface and to limit energy losses from the base due to emission and reflection. The primary objective of the analysis is to obtain results for the absorption efficiency, which is the ratio of the net rate of energy gain by the base surface to the rate of arriving solar radiation. Also included for comparison are efficiency results for plane plate absorber surfaces which, when coated with radiatively selective films (high solar absorptance, low infrared emittance), are often considered in spacecraft designs where solar radiation is to be utilized.

Contents

The geometrical aspects of the problem are illustrated in Fig. 1. The left-hand diagram, Fig. 1a, shows a typical element of the honeycomb in top and sectional views. Owing to symmetry, there is no heat transfer across the dashed lines, so that any cell of the honeycomb can be analyzed without involvement of the neighboring cells. The solar radiation is assumed to consist of a parallel ray bundle which is perfectly aligned along the axis of the cell, and, as a consequence, the incoming solar radiation impinges directly on the base surface. To facilitate the computations, the hexagonal cell was replaced by the circular cylindrical cavity shown in Fig. 1b. The cavity has diameter d, wall thickness t, length L, and the thermal conductivity of the cavity wall is k. The solar energy entering the cavity opening per unit time and unit area is denoted by q^s, while the temperature of the base surface is T_b.

The radiant transfer problem was treated using the so-called band model. The solar radiation was assumed to be confined to a distinct wavelength band, with radiation properties designated by a superscript s. The radiation emitted from the cylindrical wall and the base was assumed to be in the infrared band, with radiation properties designated by superscript ir. The relevant radiation surface properties are the emittance ε, absorptance α, and reflectance ρ. In general, $\rho = 1 - \alpha$. Furthermore, within the infrared band, the radiation properties were assumed to be gray, so that $\varepsilon = 1 - \rho$. The radiation properties of the cylindrical and base surfaces can, in general, be different, and subscripts c and b were respectively employed to designate the surface.

Received July 2, 1971; revision received October 7, 1971. Full paper (author's Rept. NASA TN D-6337) available from National Technical Information Service, Springfield, Va. 22151 as N71-25466 at the standard price (available upon request).

Index categories: Spacecraft Temperature Control Systems; Spacecraft Electric Power Systems.

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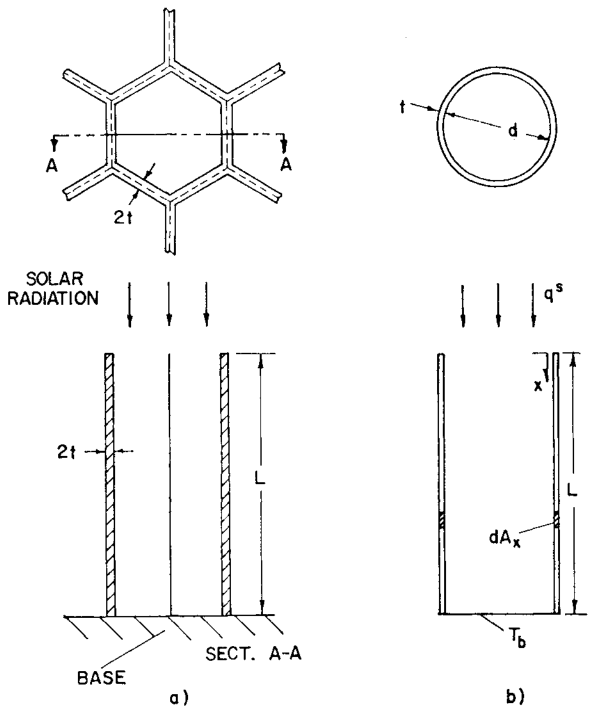

Fig. 1 Schematic of a typical element of a honeycomb absorber.

The radiation surface properties for which computations were performed are listed in Table 1. Cases 1 and 2 are, respectively, black- and gray-walled cavities. The third case has a black base surface and a gray cylindrical wall. Cases 4, 5, and 6 are characterized by a selective base surface whose solar absorptance of 0.8 and infrared emittance of 0.2 represent reasonable objectives of a coating development program. These cases have cylindrical walls that are, respectively, black, gray, and selective. The selective base surface properties of cases 7 and 8($\alpha_b^s = 1.0$ and $\varepsilon_b^{ir} = 0.2$), although not likely to be realized by present day technology, are included to permit a wide-ranging parametric study.

The analysis takes account of two-band radiant transfer between the walls of the cavity, which gives rise to a pair of integral equations, and axial heat conduction in the cylindrical wall, which is represented by a second order non-linear

Table 1 Radiation surface properties

Case	α_b^s	ϵ_b^{ir}	α_c^s	ε_c^{ir}
1	1.0	1.0	1.0	1.0
2	0.5	0.5	0.5	0.5
3	1.0	1.0	0.5	0.5
4	0.8	0.2	1.0	1.0
5	0.8	0.2	0.5	0.5
6	0.8	0.2	0.8	0.2
7	1.0	0.2	1.0	1.0
8	1.0	0.2	0.5	0.5

differential equation. The differential and integral equations form a nonlinear coupled mathematical system, and numerical solutions are appropriate. In addition to the radiation surface properties (Table 1), the following dimensionless groups appear as assignable parameters:

$$N = \sigma T_b{}^3 d^2/kt, \quad L/d, \quad q^s/\sigma T_b{}^4 \qquad (1)$$

where σ is the Stefan-Boltzmann coefficient, $\sigma = 5.67 \times 10^{-12}$ w/cm^2 °K^4. The main end product of the numerical solutions is the absorption efficiency η defined as

$$\eta = \frac{\text{net rate of energy gain by base}}{\text{rate of arriving solar radiation}} \qquad (2)$$

The presentation of results given here is illustrative and is directed toward identifying trends. In Fig. 2, the solid lines give the efficiency η of the honeycomb absorber as a function of the solar energy parameter $q^s/\sigma T_b{}^4$ for fixed typical values of N and L/d ($N = 20$, $L/d = 5$). The various curves are identified by the numbers of the cases listed in Table 1. The dashed lines give the efficiency for plane plate absorbers whose radiation properties correspond to those of the honeycomb base surfaces listed in Table 1.

The efficiency is seen to increase monotonically with the solar energy parameter $q^s/\sigma T_b{}^4$. For the honeycomb absorber, efficiencies on the order of 80% and greater are generally attained for $q^s/\sigma T_b{}^4 > 1$ (except for the gray cavity, case 2). If the gray cavity (case 2) is excluded, then it is seen that the efficiency results for all of the other honeycomb absorbers fall within a rather narrow band. That is, the efficiency is relatively insensitive to the specifics of the radiation surface properties within the range considered, especially at higher efficiencies ($\eta > 0.50$), which is the regime of greatest interest.

The aforementioned insensitivity of the efficiency of the honeycomb absorber to the radiation surface properties is of practical significance. Thus, if degradation of the cavity surfaces were to occur under spaceflight conditions, the absorption would not be seriously affected. Furthermore, it would appear unnecessary to strive to achieve a high degree of uniformity of the coatings applied to cavity surfaces. In contrast, as is shown by the spread among the dashed lines, the efficiency of a plane plate absorber is drastically influenced by the specifics of the radiation surface properties and would,

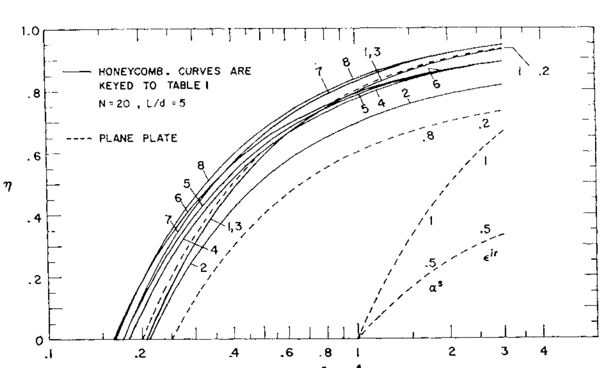

Fig. 2 Effect of radiation surface properties on absorption efficiency.

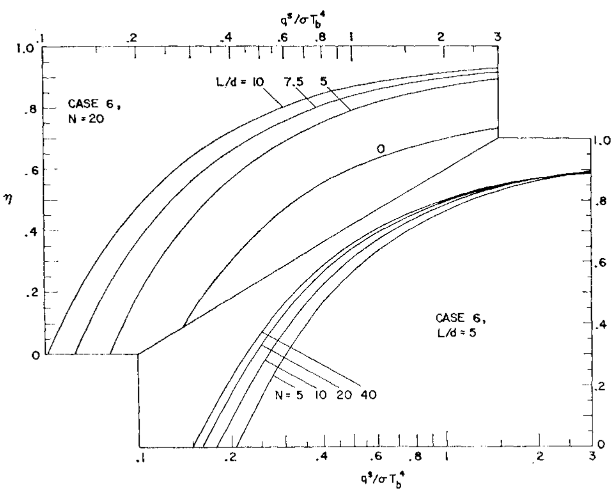

Fig. 3 a)—(Top) Effect of cavity depth-diameter ratio on the efficiency of a honeycomb absorber; b)—(Bottom) effect of radiation-conduction parameter N on the efficiency of a honeycomb absorber.

therefore, be affected by surface degradation. It can also be seen that the efficiency of a honeycomb absorber is generally higher than that of a corresponding plane plate absorber. Only if the radiation surface properties of the plate absorber are very highly selective (e.g., $\alpha^s = 1$, $\epsilon^{ir} = 0.2$) are the efficiencies of the honeycomb and plate absorbers comparable.

The influence of the cavity depth-diameter ratio on the efficiency is illustrated in Fig. 3a. The specific results apply to case 6 and to $N = 20$. The $L/d = 0$ curve is identical to that for a plane plate absorber. As seen in the figure, the efficiency increases with increasing L/d. However, in the range of higher efficiencies, η is relatively insensitive to L/d, provided that L/d is not too close to zero. The effect of the radiation-conduction parameter N is illustrated in Fig. 3b, which applies to case 6 and to $L/d = 5$. The efficiency is seen to increase with increasing N in the range of low efficiencies. However, when the efficiency is high, the N parameter has almost no influence.

A generalization which emerges from Figs. 2–3 is that in the range of higher efficiencies, the efficiency is very little affected by the radiation surface properties, by the radiation-conduction parameter N, and by L/d (as long as L/d is not too near zero). This finding permits considerable latitude in the selection of design parameters. In the range of lower efficiencies, the efficiency results are somewhat more sensitive.

In Ref. 1, consideration was also given to the effect of the boundary condition at the exposed tip of the cylindrical wall, of severing conductive contact between the honeycomb structure and the base surface, and of nonuniform base surface radiosity.

Reference

[1] Sparrow, E. M., Bifano, W. J., and Healy, J. A., "Efficiencies of Honeycomb Absorbers of Solar Radiation," TN D-6337, May 1971, NASA.