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OPTICAL PROPERTIES OF SMALL PARTICLE SUSPENSIONS FOR SOLAR THERMAL COLLECTION

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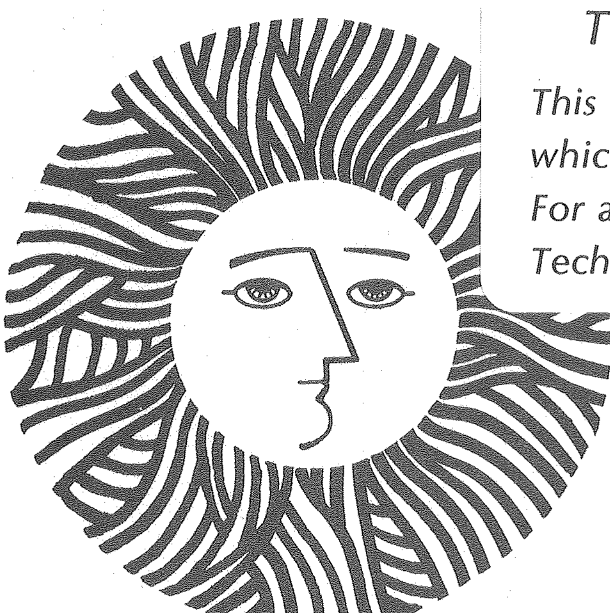

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Optical Properties of Small Particle Suspensions for Solar Thermal Collection*

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INTRODUCTION

A dispersion of very small absorbing particles forms an ideal medium to absorb radiant energy, transform it to sensible heat, and efficiently transfer the heat to a surrounding fluid. Because the absorption occurs within the fluid, the temperature drops that occur across the walls of conventional solar receivers are eliminated, resulting in higher efficiencies and lower operating temperatures. The optical properties of a Small Particle Suspension (SPS) may be tailored to the spectrum of the incoming radiation to maximize the absorption and minimize the reradiation of thermal energy. Thus a SPS offers the features of a selective surface absorber, but with the advantages of direct absorption within the fluid.

The technique has wide spread applicability, being suitable for gas or liquid media. Flat plate liquid collectors have been proposed to meet space heating requirements (1) and provide a combined collector and heat storage medium for passive solar applications (2). A liquid salt SPS has been investigated for use with highly concentrating collectors (3). Use of a SPS in a gaseous medium has been proposed for point focus applications including heating a gas to operate a turbine (4), providing industrial process heat (5,6), and using the sun to provide energy to operate a deep space rocket engine (7). A SPS may be used in a closed, recirculating system, and in an open system if the particles are discharged, or can be made to combine with the carrier fluid.

THE OPTICS OF RADIANT ENERGY COLLECTION BY PARTICLE SUSPENSIONS

The optical considerations for solar collection by a SPS may be divided into two broad areas: the effects of particle size, and the effects of the optical properties of the material comprising the particles. Each of these has an effect on the solar absorption and the IR emission. To minimize the losses due to sunlight scattered back out of the receiver, the ratio of the scattering efficiency, Q_{sca}, to the absorption efficiency, Q_{abs}, must be small. Rayleigh scattering theory describes small absorbing particles with this characteristic. In this case Q_{abs} is proportional to the size parameter $x = 2\pi r/\lambda$ and Q_{sca} is proportional to x^4. Thus the scattering losses are proportional to the cube of the particle radius, an important consideration for receiver efficiency.

The mass of particles required to provide a given absorption may be calculated using Beer's law and neglecting multiple scattering (a reasonable assumption since $Q_{abs} >> Q_{sca}$). The mass per unit surface area m_s, (defined by the product of the mass per unit volume and the distance for light to be attenuated by 1/e), is

$$m_s = \frac{4r\rho}{3\,Q_{abs}} \tag{1}$$

where r is the radius and ρ is the density of the particle. For small particles it was already noted that Q_{abs} is proportional to r, and it can be established that for increasing particle size Q_{abs} approaches a constant. The general behavior of m_s with particle size shown in Figure 1. This figure illustrates that for a given absorption, the required mass is minimized when the particles are in the Rayleigh size range. Setting aside temporarily the question of variation in the optical properties of the material, for a given particle size Q_{abs} is inversely proportional to the wavelength. This is a favorable condition to suppress IR emission.

The second important element in determining the performance of the SPS is the dielectric response function $N^2 = (n + ik)^2 = \epsilon_1 + i\epsilon_2$ that describes the material from which the particles are made. Again, the goal is to maximize Q_{abs} in the visible and minimize it in the IR. The absorption efficiency may be written:

$$Q_{abs} = 4x \ \mathrm{Im} \left[\frac{N^2 - 1}{N^2 + 2}\right] \quad (2)$$

The absolute maximum of the function in the braces is unbounded and occurs at $\epsilon_1 = -2$, $\epsilon_2 = 0$. The closer the dielectric function approaches this value, the larger Q_{abs} will become. This corresponds to the "resonant mode" for surface states in spherical particles.

To minimize Q_{abs} in the IR the values of ϵ_1 and ϵ_2 should be as large as possible. In real materials this occurs when ϵ_1 is large and negative and ϵ_2 is large and positive. This is just the description of a free electron metal using a Drude model.

ULTRAFINE CARBON PARTICLES AS A SOLAR ABSORBER

Carbon is an excellent choice of materials for SPS applications. In addition to its high visible absorptance it has a metallic optical behavior in the IR that suppresses its thermal emission. Figure 2 illustrates the wavelength dependence of the absorptance or emissivity of a SPS based on dielectric functions given in references 8 and 9. It can be seen that carbon has the desirable scattering characteristics mentioned earlier.

This brief discussion of the optical properties of SPS has indicated the importance of particle size and material properties to the efficient operation of a novel type of solar receiver. Other important factors that could not be treated here include the effect of particle shape, size distribution, multiple scattering, geometrical effects of the sunlight and receiver opening, and the influence of the optical properties of the carrier gas. Carbon was singled out as an outstanding candidate for particle composition but many other materials may find application to this solar absorber concept.

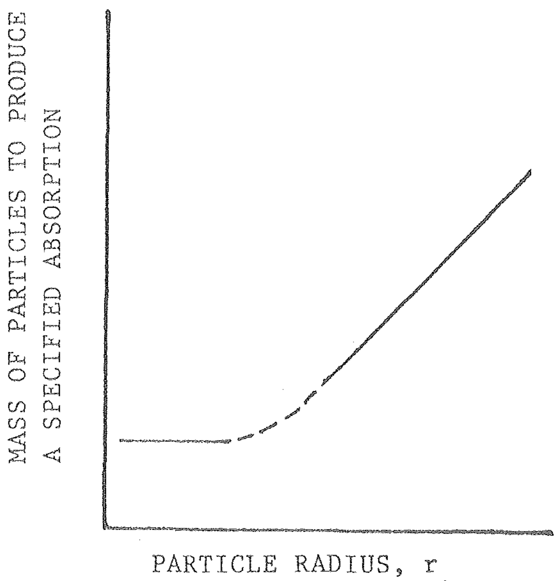

Figure 1. The effect of radius on the mass required to produce a given absorption.

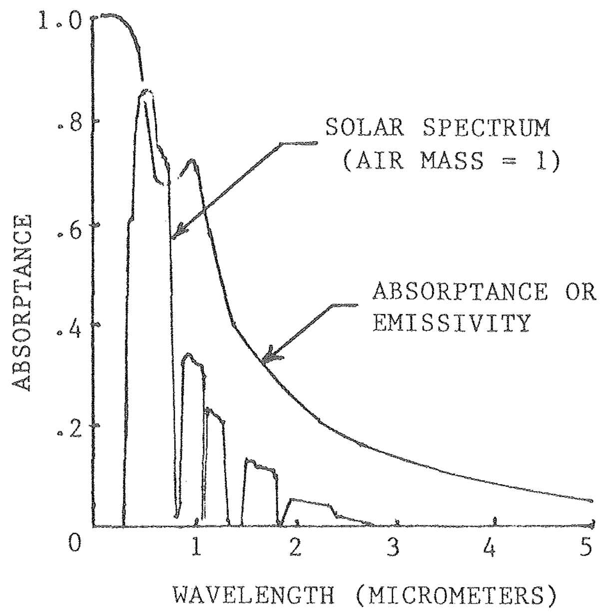

Figure 2. Wavelength dependence of the absorptance of a carbon SPS.

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