Radiative Transfer in a Free-Falling Particle Receiver

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In a free-falling particle receiver, freely-falling particles (e.g. ceramics, sand) form a curtain heated to high temperatures under direct high-flux solar irradiation. First proposed by Sandia National Laboratories in the 1980s [1], falling-particle receivers have been investigated using experimental and numerical techniques. The majority of work has focused on thermal performance of particle receivers with monodisperse particles as the working medium. To elucidate effects of particle size distribution in polydisperse curtains on radiative absorption and radiation confinement in a particle receiver, we numerically investigate radiative transfer in a simple free-falling particle receiver system as shown in Fig. 1. The model receiver contains polydisperse particles suspended between the aperture and the back wall, which are subject to external concentrated solar flux q''_{solar}. The Monte-Carlo ray-tracing method [2] is applied. The absorption and scattering coefficients are obtained using

$$\kappa_{\text{abs}} = \int_0^\infty \pi Q_{\text{abs}} a^2 n(a)\text{d}a = 3\int_0^\infty Q_{\text{abs}} \frac{g(a)}{4a}\text{d}a, \qquad Q_{\text{abs}} = 1-\rho, \qquad g(a) = \frac{4\pi}{3}a^3 n(a) \tag{1}$$

$$\sigma_{\text{sca}} = \int_0^\infty \pi Q_{\text{sca}} a^2 n(a)\text{d}a = 3\int_0^\infty Q_{\text{sca}} \frac{g(a)}{4a}\text{d}a, \qquad Q_{\text{sca}} = \rho \tag{2}$$

where Q_{abs}, Q_{sca} are the absorption and scattering efficiency factors evaluated assuming geometric optics is valid for all particles considered in this study. $n(a)$ is the particle size distribution function,

$$f(a) = \lim_{\Delta a \to 0} \frac{\tilde{f}(a)}{\Delta a} = \lim_{\Delta a \to 0} \frac{\int_{a-\frac{\Delta a}{2}}^{a+\frac{\Delta a}{2}} g(a)\text{d}a}{\Delta a \int_0^\infty g(a)\text{d}a} \tag{3}$$

where $f(a)$ is the continuous frequency function given by the Gauss distribution,

$$f(a) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{2(a-a_{\text{mean}})^2}{\sigma^2}} \tag{4}$$

a_{mean} and σ are the mean particle radius and standard deviation of the Gaussian distribution, respectively. Three particle curtain configurations are investigated (see Table I).

1. Particles with the Gaussian size distribution are uniformly distributed across the curtain. Four sub-cases with mean diameters and standard deviations are studied.
2. Particles of smaller and larger size distributions occupy central and outer curtain zones, respectively. The mean particle diameter is Gauss-distributed across the curtain, where *L and* z are the curtain thickness and spatial coordinate, respectively.
3. Particles of larger and smaller size distributions occupy central and outer curtain zones, respectively. The mean particle diameter is Gauss-distributed across the curtain.

Case (1) is studied to obtain basic understanding of radiative transfer in a particle curtain. Cases (2) and (3) are studied to mimic conditions at the top and bottom of a particle curtain in a receiver, respectively.

Table I. Parameters of particle size distribution in cases

Parameter	Case 1				Case 2	Case 3
$d_{mean}=2a_{mean}$ (μm)	**1.1**	**1.2**	**1.3**	**1.4**	$270L-100L^2 \times \dfrac{\exp\left[-\dfrac{(z-0.5L)^2}{2\times(0.15L)^2}\right]}{0.15L\times\sqrt{2\pi}}$	$100L^2 \times \dfrac{\exp\left[-\dfrac{(z-0.5L)^2}{2\times(0.15L)^2}\right]}{0.15L\times\sqrt{2\pi}}$
	300	300	700	700		
σ (μm)	10	80	10	80	10	10

Absorbed radiative power profiles across the curtain for cases (1)–(3) are shown in Figure 2. In case 1, particles with smaller mean diameter (d_{mean}=300 μm) have higher absorption. This is attributed to a larger absorption coefficient of small particles than that of larger particles with the same particle volume fraction. By comparing the absorption profiles for cases 2 and 3, we find that the profile for case 3 is wider than for case 2 but with a significantly reduced peak of the absorbed power. Both profiles have peaks in the first half of the curtain, at locations $z < L/2$.

Future work includes spectral radiative properties of particles and temperature effect (self-emissions) of particles and the back wall of receiver.

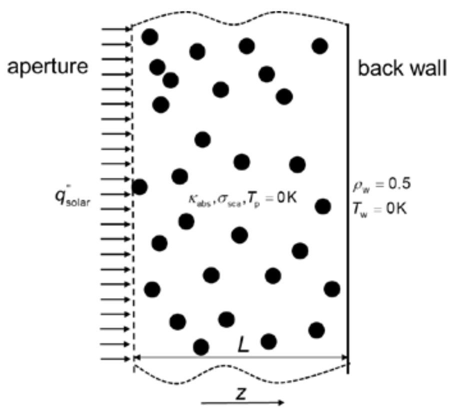

Figure 1. One-dimensional model system containing suspernsion of particles

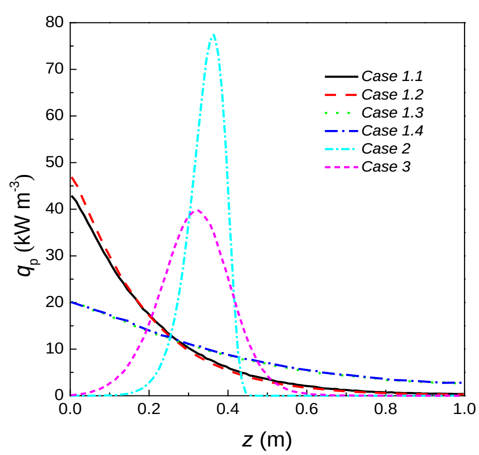

Figure 2. Radiative absorption profiles in the curtain

References

[1] Hruby, J.M. and Steele, B.R., 1986, ‘A solid particle central receiver for solar energy‘, *Chem. Eng. Prog. (United States),* 82(2).

[2] Modest, M.F., 2013, Radiative heat transfer’, Academic press.