Particle size effects of solar absorbing dispersions in water and convergence of Mie solutions

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Introduction
Nano particle dispersions have been extensively studied in terms of solar collector applications to increase the absorption capability of the fluid. In addition, they can be tailored to suit specific requirements. Recently, they have also been studied to enhance the surface evaporation process and boiling applications for solar desalination purpose.

Dispersion systems
Dispersions floating on water help absorbing the incoming solar radiation. Specific uses in solar collectors have been studied by [1-2]. They have also been identified for use in solar water evaporation process [3]. The particles can be tuned to meet specific radiation properties: either to act as an absorber or a strong reflector [1]. These dispersions can be metallic plasmons or non-metallic particles. The radiative properties depend explicitly on the size of the suspension and the complex index of refraction.

Radiation consideration
The radiation properties are firstly calculated by determining the scattering and absorption efficiency. They are calculated by using three different models to account for size variations. The models considered are [4]:

1. Rayleigh scattering theory (X>>1).
2. Mie Theory (X=1), and
3. Geometric Optics (X<<1)

The size parameter ‘X’ quantifies the radiation model form to be used. It is given as

\[ X = \frac{\rho}{\lambda} \]

where \( \rho \) is the refractive index of water. Activated Carbon is selected as the absorbing material. For simplicity, and use of the radiation models described above, three different values for radius are considered: 40nm, 4μm and 40μm. The complex index of refraction are taken from [5].

Activated carbon is a low cost substitute for many commonly used nano-fluid dispersions for good solar absorptivity. Its inherent advantage is that, even at large scale, it tends to have higher efficiency than most of the other dispersion candidates in use. The other advantage comes from the fact that, the material doesn’t need to be ground or pulverized to extremely small scales. It can be used as is from the commercially available scale with no or very simple grinding to a few hundred micrometers.

Formulation
The input for the computations: 1. Wavelength (λ), 2. radius (r), 3. complex index of refraction: m = n + ik;

1. Efficiency
Based on the size (parameter) of the dispersion, the respective radiation model is selected and the absorption and scattering efficiency are firstly determined. They are given as

\[ Q_{abs} = 4\pi \int_0^\infty \left( \frac{m^2}{m^2+1} \right) \frac{d\omega}{\omega} \]

Rayleigh Scattering Theory
For extremely small particles, the scattering efficiency and absorption efficiency can be approximated as

\[ Q_{sc} = \frac{2}{3} \frac{m^2}{m^2+1} \frac{\pi}{\lambda^2} \rho^2 \]

\[ Q_{abs} = 1 - Q_{sc} \]

2. Coefficients
The coefficients are then calculated from the determined efficiencies as

\[ \sigma_e = 1.5 \frac{Q_{abs} m^2}{\rho^2} \]

\[ \sigma_a = 1 - \frac{Q_{abs} m^2}{\rho^2} \]

\[ \kappa_a = \frac{\rho_0 + \sigma_a + \sigma_e}{\rho} \]

Geometric Optics
The absorption and scattering efficiency are given in terms of hemispherical absorptivity and reflectivity of the particle as

\[ Q_{abs} = \rho \]

\[ Q_{sc} = \frac{2}{3} \frac{m^2}{m^2+1} \frac{\pi}{\lambda^2} \rho^2 \]

\[ Q_{ext} = Q_{abs} + Q_{sc} \]

For large particles (X>>1), the extinction efficiency \( Q_{ext} \) can be approximated as

2. Coefficients
The coefficients are then calculated from the determined efficiencies as

\[ \sigma_e = 1.5 \frac{Q_{abs} m^2}{\rho^2} \]

\[ \sigma_a = 1 - \frac{Q_{abs} m^2}{\rho^2} \]

\[ \kappa_a = \frac{\rho_0 + \sigma_a + \sigma_e}{\rho} \]

References