Evaluation of particle-scale radiative heat transfer in polydisperse beds

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Heat transfer in Particulate Systems

When radiation heat transfer matters?

Heat flux $W \propto T^3$

- At room temperature radiative heat fluxes are relatively negligible...
- ..but starting at temperature ≈ 800 K, radiative heat transfer becomes primary.
- External radiative heating (or heat loss) is also the case to consider.

Radiative Heat Transfer in DEM calculations: Available Techniques

Direct ray tracing (”shooting”) S.Amberger, S.Pirker, C.Kloss (JKU Linz)

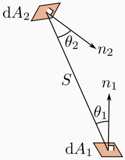
Local averaging of temperature (+ Stefan-Boltzmann’s law) (NSWU) Z.Y.Zhou and A. B. Yu (2009)

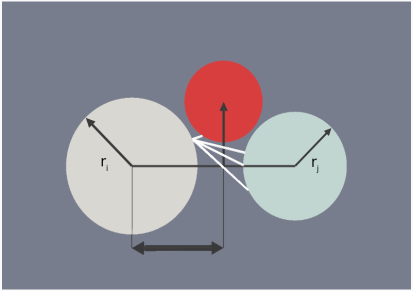
Simplified View Factors (uses Voronoi meshing)

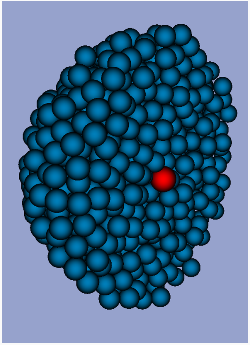
Projection Method Forgber, Radl (TU Graz)

Statistics distribution of view factors (Pitso(2009), South Afr.)

View factor: Definition Scheme

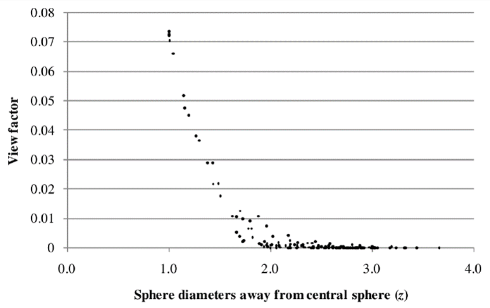






$$\Delta F_{ij} = \frac{\cos\theta_1 \cos\theta_2}{\pi s^2} dA_j; F_{ij} = \frac{1}{A_i} \int_{A_i} \int_{A_j} \frac{\cos\theta_1 \cos\theta_2}{\pi s^2} dA_j dA_i$$

View Factors Calculation



Proposed calculation technique is similar to one described in (Feng, 2012)

FENG, Y. T.; HAN, K. An accurate evaluation of geometric view factors for modelling radiative heat transfer in randomly packed beds of equally sized spheres. International Journal of Heat and Mass Transfer, 2012, 55. Jg., Nr. 23, S. 6374-6383.

View Factor results

View Factors: particle to particle

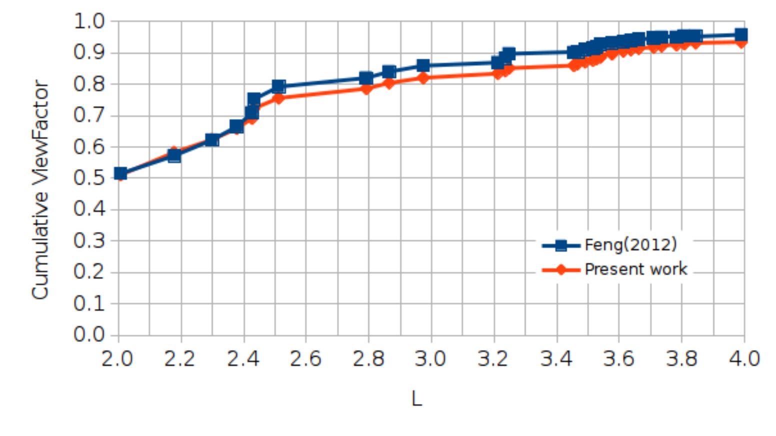
close random packing (porosity 0,37)

$F_{i-jdir} = 0.23(r_i/r_j + 0.8516)^{-1.8}$ for particles within direct contact,

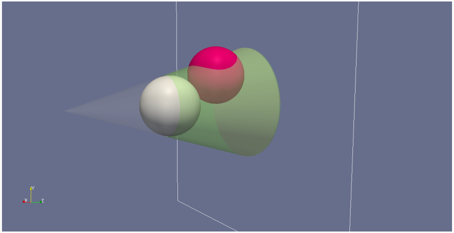
$F_{i-jind} = exp(1.5 - 1.9 r_{ij}/r)$ for all other then direct.

for polydisperse valid if $r_i \leqslant r_j$, in the opposite direction - inversely proportional to square of respective particle.

Verification: comparison with (Feng,2012)



View Factor: Particle to wall



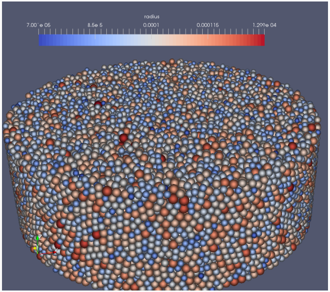
Monodisperse, close random packing. Cylinder wall radius is 50x of particle‘s.

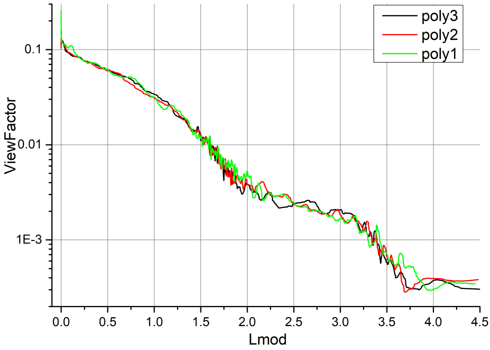
$$F = e^{-2.6-0.8{L^*}^2} + 0.12e^{-12{L^*}^2}$$

introducing nondimensional parameter

$L^* = s/r; [0, \infty\}$

View factor: polydisperse gaussian size distribution





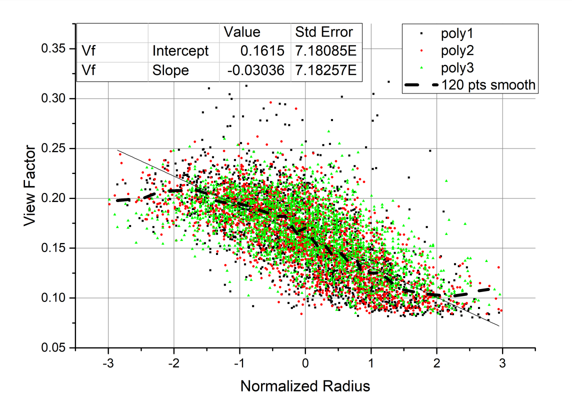
3 mixtures with the same average radius, and size $HLHW/ < r >$ 10%,5 %, and 3% respectively.

View Factor: Particle to wall polydisperse gaussian

for polydisperse mixtures with $r_{max}/r_{min} \leqslant 2.0$, parameter $L^* = s/<r>$ arises

$$VF|_{L^*<=2.5} = \left(e^{-2.6-0.8L^{*2}} + Fe^{-EL^*}\right) \qquad (1)$$

Calculation: Specific Results in 1st layer

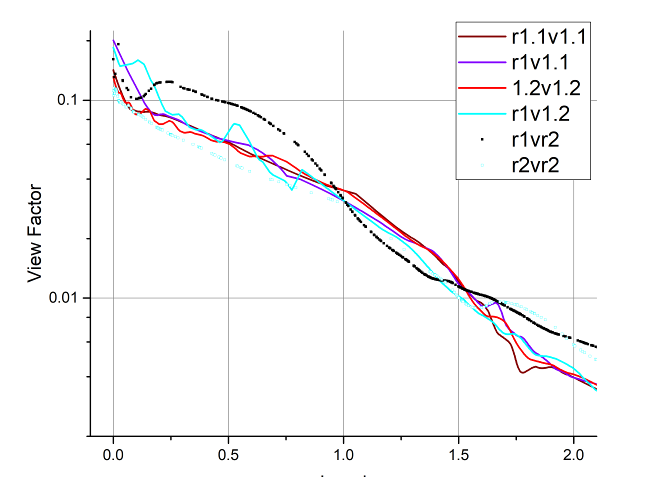


$$VF|_{L*=0} = (0.162 - 0.030r^*)$$

$$r^* = (r - <r>)/\Delta r$$

Calculation: Results bidisperse

View factors for distinct monodisperse fractions (r=X) in bidisperse mixture ($r_1/r_2 = Y$), in legend "XvY"



Statistical View factor Approach: Current Limitations

Porosity factor isn’t accounted for (yet);

high natural dispersion of data values;

assumption of isothermal particles;

emissivity = 1

Implementation in DEM

Idea...

is to make radiative heat transfer algorithm similar to conductive heat transfer

Heat transfer calculation requires at minimum:

- distance between particles,
- particle radii;

optional - particle size distribution bed-wise, emissivity, local porosity.

Algo map (based on heat conduction)

Iterate through particles

Iterate through neighbour list of specific particle

Calculate the distance, check whether there is direct contact

calculate heat conduction

evaluate view factor, write it to array and add to cumulative variable; evaluate view factor to boundary (if in range)

normalize cumulative variable to yield full solid angle 4π, iterate through neighbour particles again and assign heat fluxes

Proof of concept (verification)

Show CheckRadiat.mp4

Conclusions

- accounting for radiative heat transfer in DEM is viable
- ”raw” correlations for both particle-particle and particle-wall view factors suggested
- proposed nondimensional parameters enable single formulation for particle-wall view factors in polydisperse mixtures.

Finally...

Thank you for your attention!