MODELING MULTI-PARAMETERS RADIATION IN POROUS METAL VIA MACHINE LEARNING

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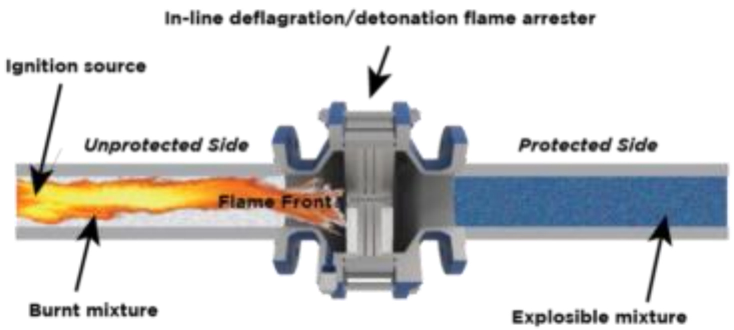
Thermal Radiation in Porous Media

- Thermal radiation is an important heat transfer mechanism in many engineering applications involving dispersed media operating at elevated temperatures such as:
  - Porous metal components in engine or thrust system
  - Additive manufacturing / 3D printing



[1] Flame arrestor

[2] Selective Laser Melting process on metal powder bed

[1] RAMEN Industrial Control Valves and Regulators
[2] GE additive

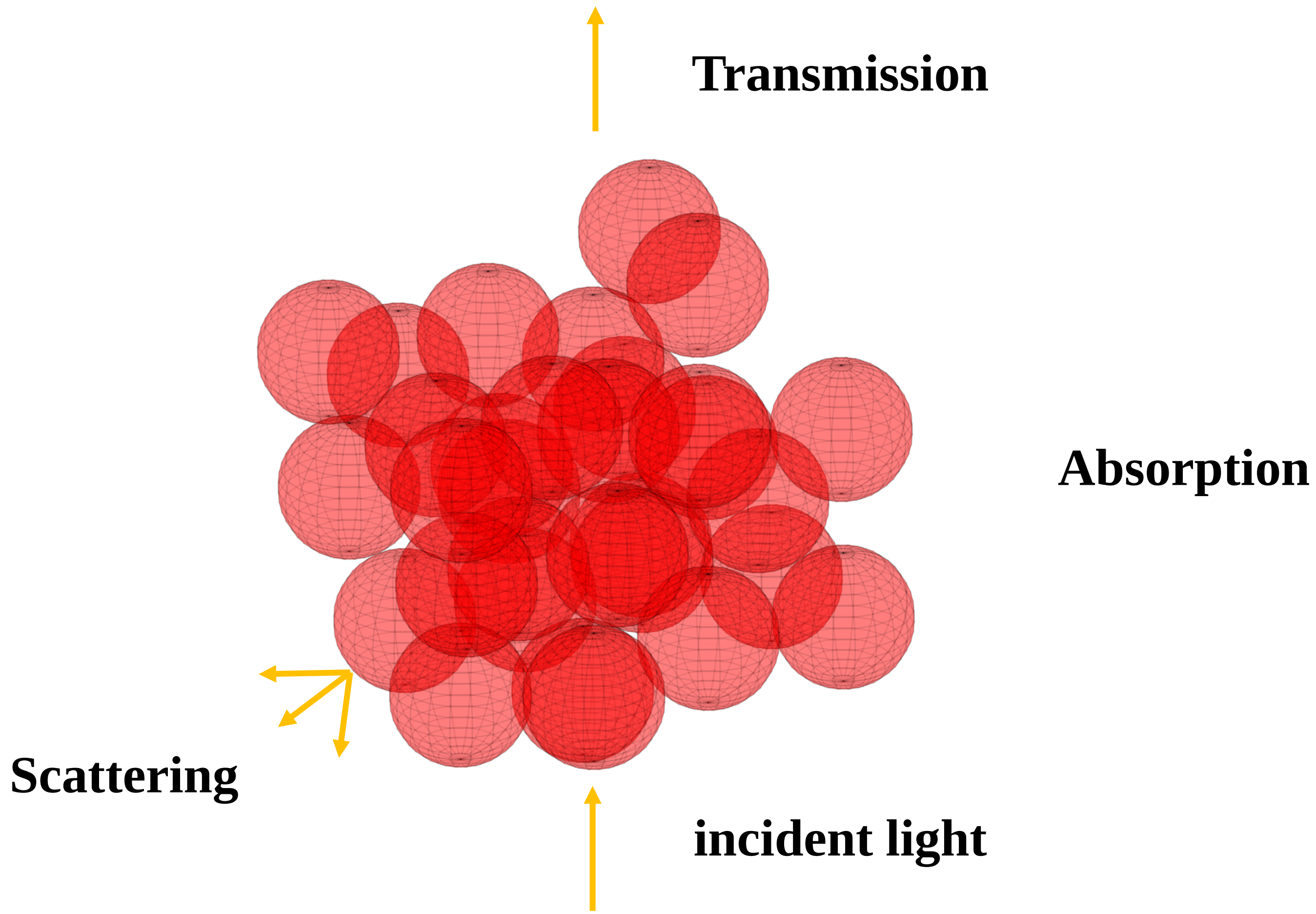
Porous Metal Applications

- Applications

  Filter, Flame arrestor, Flow control, Thermal management

- Features

Parameters	Consideration
Material	Melting temperature, corrosion or wear resistance, mechanical properties, vibration resistance, optical properties, thermal properties
Porosity	Gas or liquid permeability, weight
Geometry	Application, performance



- Extinction = Absorption + Scattering

Objective

- To efficiently and accurately predict the radiative properties of metal packed bed using neural networks based on RTMC simulation data.

- The resulting predictive model to be used in:
  - Sensitivity analysis,
  - Optimal design of heterogeneous structures,
  - Process control (3d printing, laser cleaning,…)
  - Multi-objective analysis with other engineering system

Dependency

- Powder

  size distribution, porosity, bed height

- Temperature

  radiative conductivity tends to increase with temperature

- Wavelength

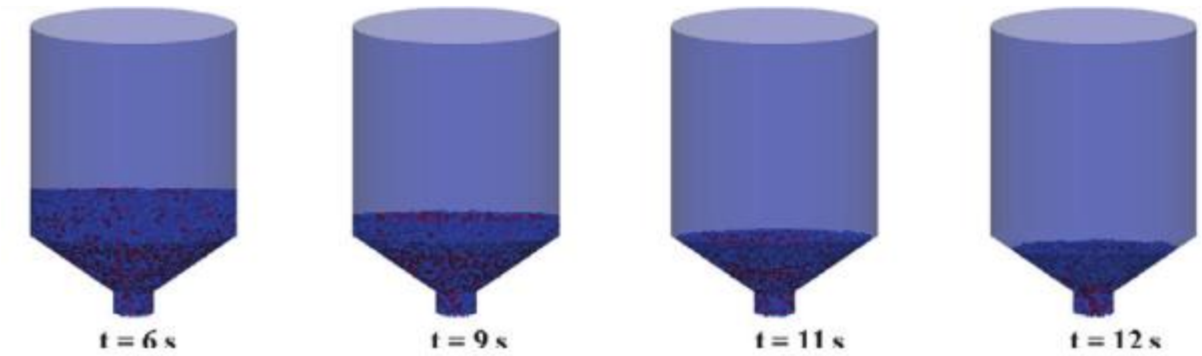
  Optical properties of a material change with wavelength of light source

- Optical thickness

  Different approximation model should be used depending on optical thickness of porous media

Powder Bed Geometry

- MFIX from the National Energy Technology laboratory (NETL) of the Department of Energy
  - simulate the motion and effect of small particles (Lagrangian)
  - provide the final position and size of small particles in a packed bed
  - Capable of handling particle size poly-dispersity

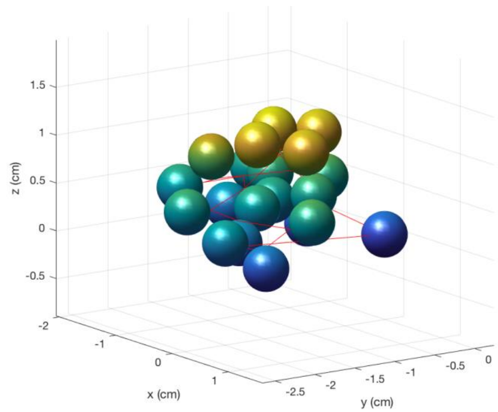


Chen, S., Adepu, M., Emady, H., Jiao, Y., & Gel, A. (2017). Enhancing the physical modeling capability of open-source MFIX-DEM software for handling particle size polydispersity: Implementation and validation. *Powder Technology*, *317*, 117-125.

Monte Carlo Ray Tracing (MCRT)

- Monte Carlo ray tracing (RTMC) methods are popular in solving radiative heat transfer equation
- A RTMC simulation observes repeated light travels in random packed beds to approximate radiative properties of porous media
- Result of RTMC is the probability distribution of extinction coefficient and the transmissivity of a random packed bed

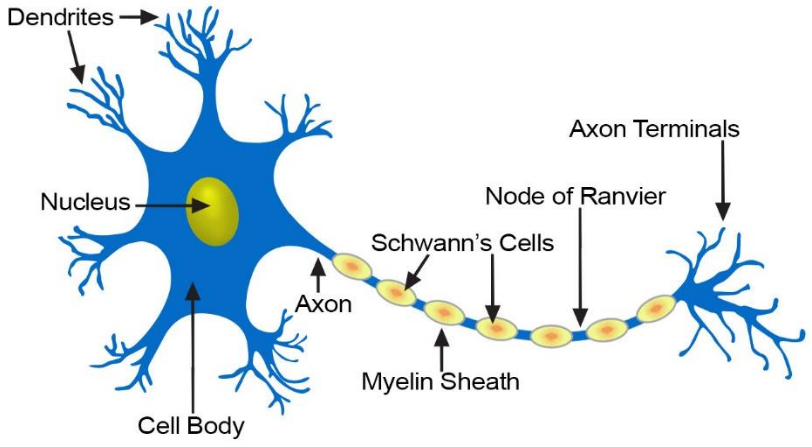
Radiative properties



Repeated random sampling

Neural Network Principle

- Can be used for regression, classification, and clustering
- It can be thought as a function approximator which finds relationship between input and output by adjusting the weight of neurons and threshold of learning curve



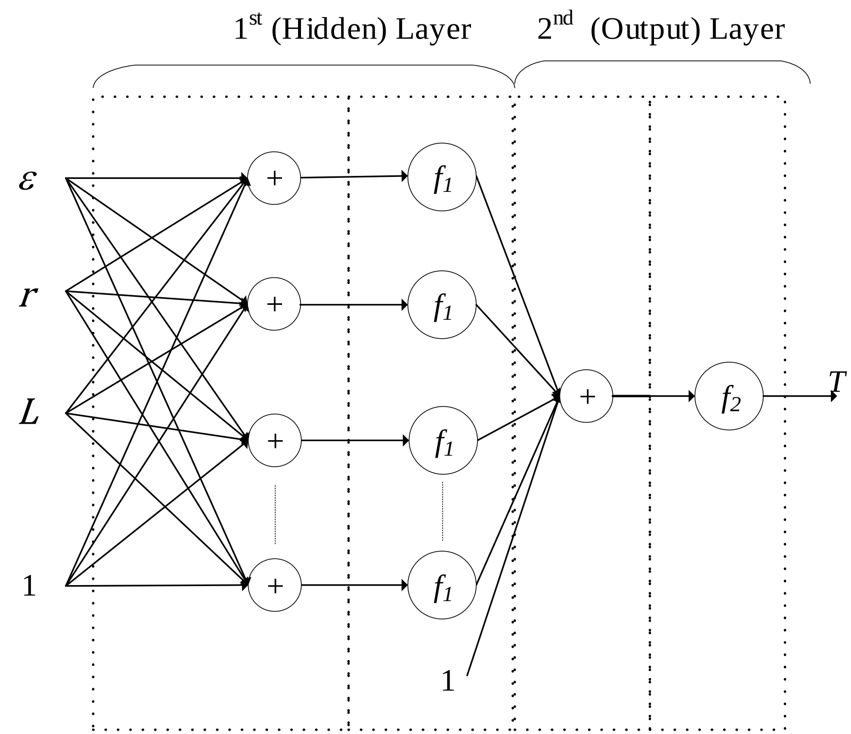
[1] National Cancer Institute

Neural Network Model

NN Model of Transmissivity

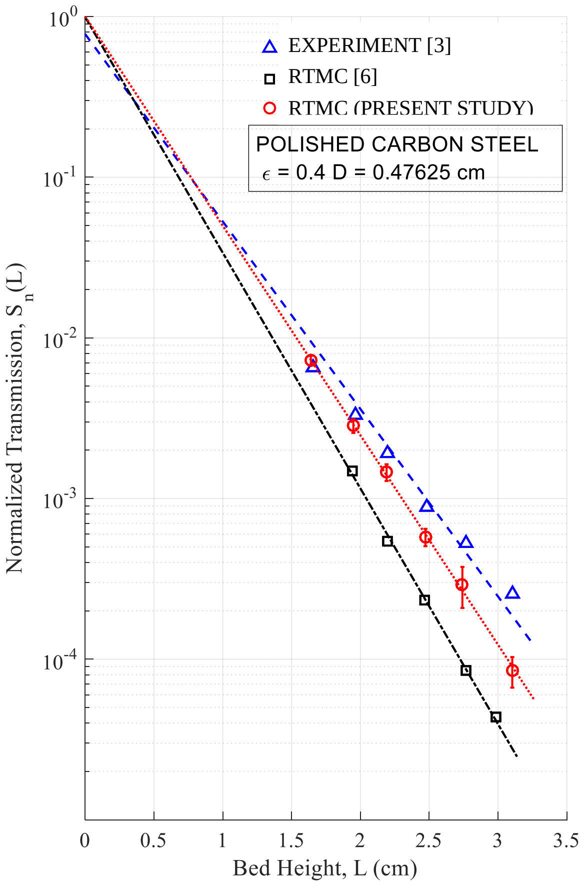
Neural network (NN) model of transmitted power, T as a function of:

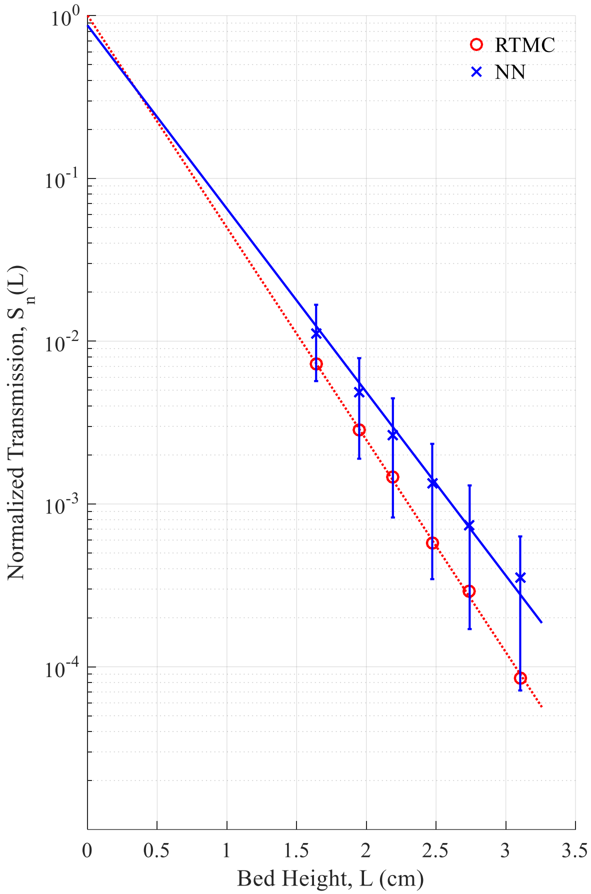
1. Emissivity, ε
2. Particle radius, r
3. Bed height, L



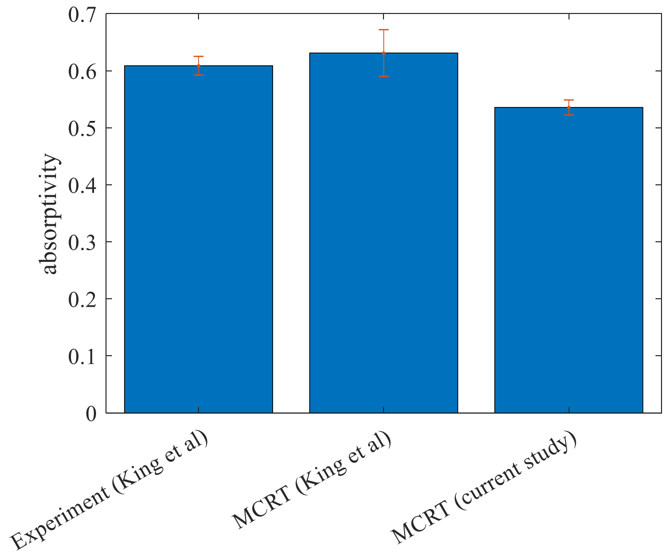
$$\mathbf{y_0} = [\varepsilon \quad r \quad L \quad 1]^T \qquad \mathbf{y}_1 = f_1(W_1\mathbf{y}_0) \qquad \mathbf{y}_2 = f_2(W_2\mathbf{y}_1)$$

Results - Transmissivity



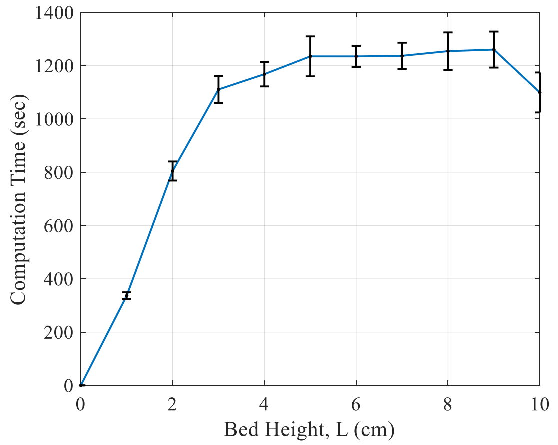


Results - Absorptivity

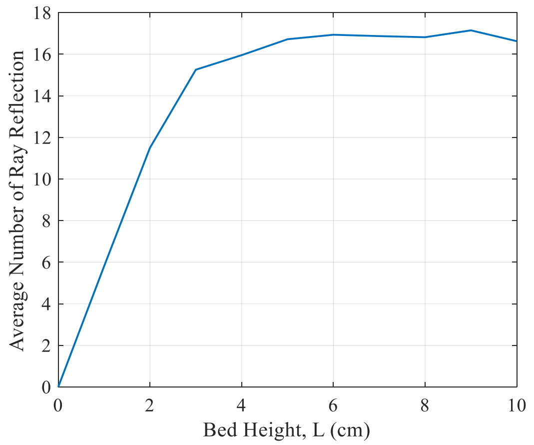


- 316L stainless steel absorptivity
  - fluctuate along the beam path
  - Fluctuation becomes more significant with smaller beam spot size
  - discrepancy coming from different powder geometry, laser specification

Results – Computational performance



Average MCRT computation time with respect to bed height (3 samples).

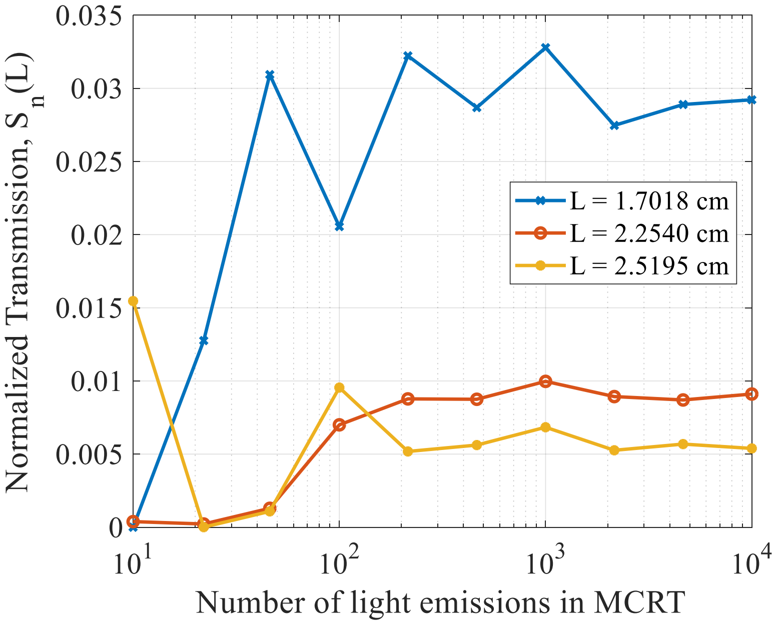


Mean frequency of particle-light reflection experienced by 5000 rays in MCRT simulation with varying bed heights.

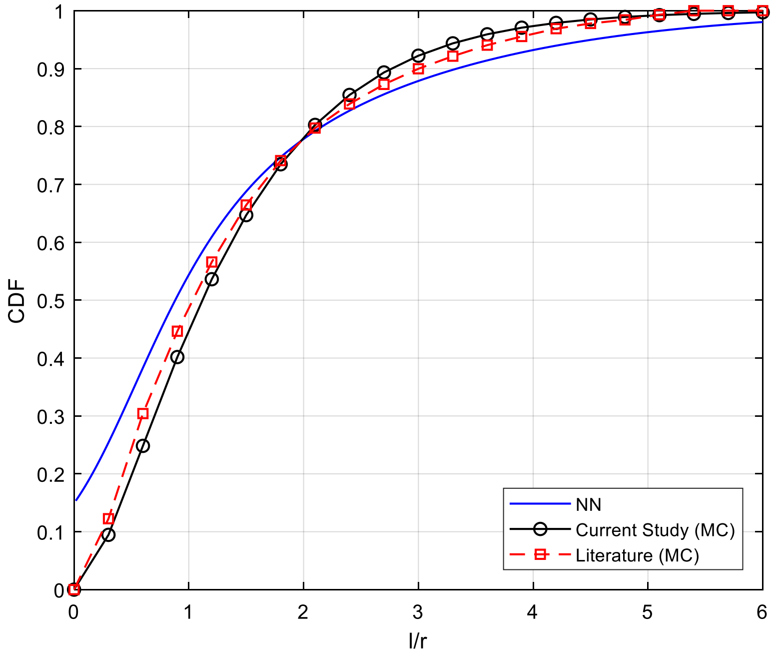
- As the bed depth increases, the total amount of energy transmits the packed bed becomes negligible. Instead, most energy in ray bundles is either scattered or absorbed by particles
- The neural networks based surrogate modelling takes generally less than 10 seconds with 200 transmission output, and its output can be generated instantaneously

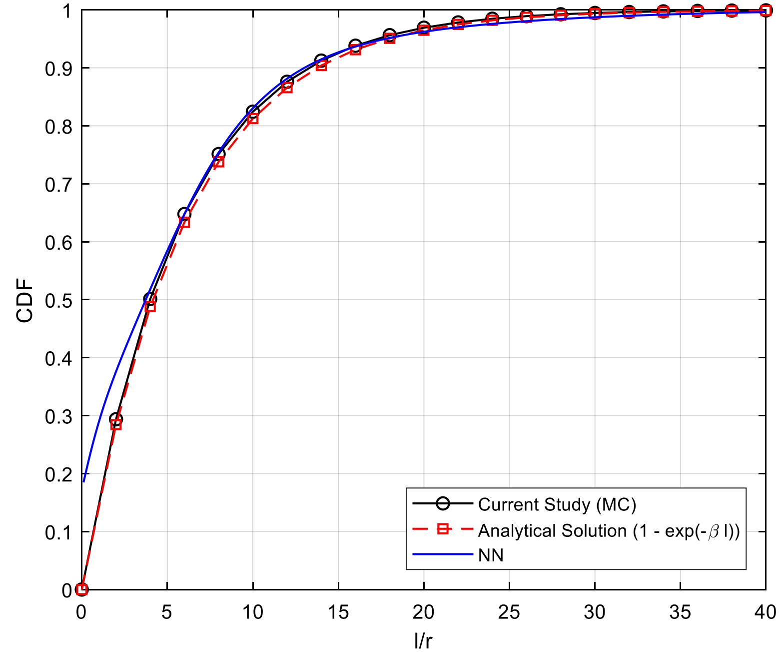
Convergence Study

- law of large numbers
- require enough light emission to generate stable long-term results
- effect of light numbers in simulation is investigated
- 5000 number of light is concluded to guarantee good efficiency and accuracy



Results – Extinction distribution





Random Packed Bed

$NOP = 0.07$

$r_{mean} = 0.47625$

$\phi = 0.4$

$A_s = 1.2598$

Overlapping Spheres

$NOP = 0.0004$

$r_{mean} = 0.05$

$\phi = 0.8$

$A_s = 0.6$

Conclusion

- NN modeling has promising capabilities when it is desired to be used in porous structure design,
- The importance of microstructure parameters on radiative properties can easily be explored using feature selection provided by machine learning,
- The NN prediction modeling can be applied to various engineering application with great advantages

Future plan

- Quality control in 3D metal printing

Laser interaction with the powder bed

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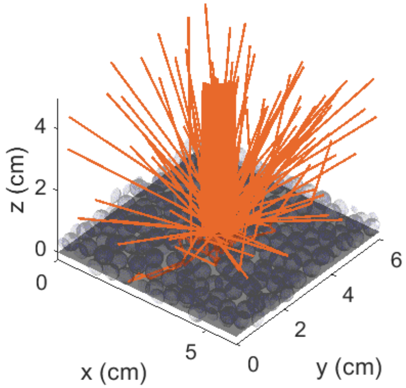
Powder response

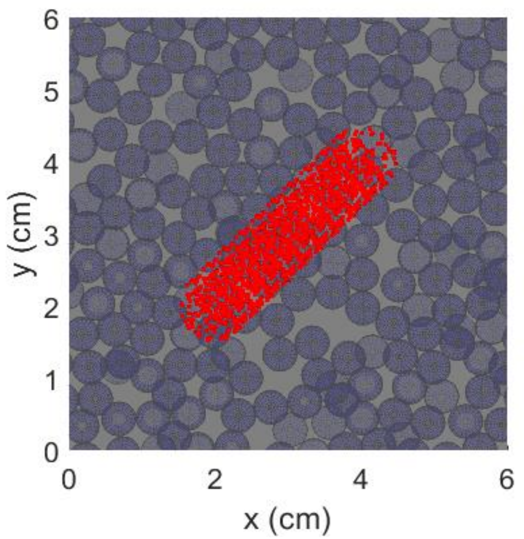
↓

Metal pool characterization

↓

Build quality prediction





Publication

1. Kaya, M., & Kang, H. and Hajimirza, S. (2018). "A machine learning approach for modeling radiation in packed beds ". Eurotherm Seminar 110-*Computational Thermal Radiation in Participating Media-VI, April 11-13,2018 Cascais, Portugal*

2. Kang, H. and Hajimirza, S. (2018). "Modeling multi-parameters radiation in packed beds via machine learning". *International Mechanical Engineering Congress and Exposition(IMECE 2018), November 9-15,2018,Pittsburgh, PA*