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

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Consideration</th>
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</thead>
<tbody>
<tr>
<td>Material</td>
<td>Melting temperature, corrosion or wear resistance, mechanical properties, vibration resistance, optical properties, thermal properties</td>
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<tr>
<td>Porosity</td>
<td>Gas or liquid permeability, weight</td>
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<tr>
<td>Geometry</td>
<td>Application, performance</td>
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Radiative Properties

Transmission

Absorption

Scattering

incident light

• 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

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.
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 (NN) model of transmitted power, $T$ as a function of:

1. Emissivity, $\epsilon$
2. Particle radius, $r$
3. Bed height, $L$
Results - Transmissivity

EXPERIMENT [3]  
RTMC [6]  
RTMC (PRESENT STUDY)  

POLISHED CARBON STEEL  
$\epsilon = 0.4$  $D = 0.47625$ cm
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

- As the bed depth increases, the total amount of energy that 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

Overlapping Spheres

\[ \text{NOP} = 0.0004 \]
\[ r_{\text{mean}} = 0.05 \]
\[ \phi = 0.8 \]
\[ A_s = 0.6 \]

Random Packed Bed

\[ \text{NOP} = 0.07 \]
\[ r_{\text{mean}} = 0.47625 \]
\[ \phi = 0.4 \]
\[ A_s = 1.2598 \]
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

  Powder response

  Metal pool characterization

  Build quality prediction