A Comprehensive 3-D Bed Model

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Outline of Presentation

- Objectives
- General application
- Flow through porous media
- Heat and mass transfer
- Chemical kinetics
- Results
- Future work

Objectives

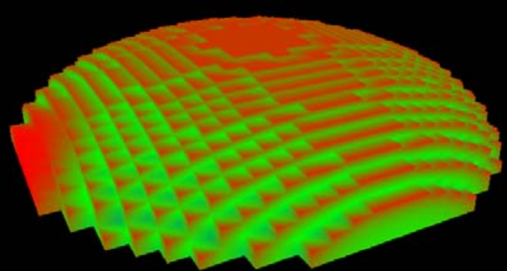
- Have a comprehensive, general bed model that can be applied to range of boiler beds
- Integrate results with other CFD models
- Compare model with experimental data

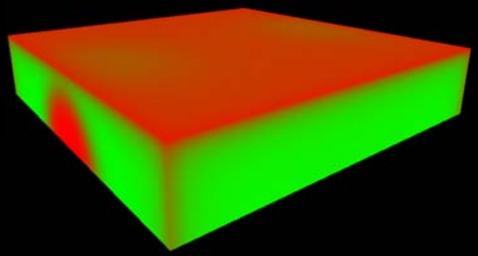
Desired Model Output

- Gas Phase
  - Fluid flows
  - Temperature
  - Composition
- Solid Phase
  - Temperature
  - Composition
  - Bed Shape
- Currently no consideration of liquid phase
- Chemical reactions
  - Heterogeneous
  - Homogeneous

General Application

- Generalized input of boundary conditions
- Variable bed shape



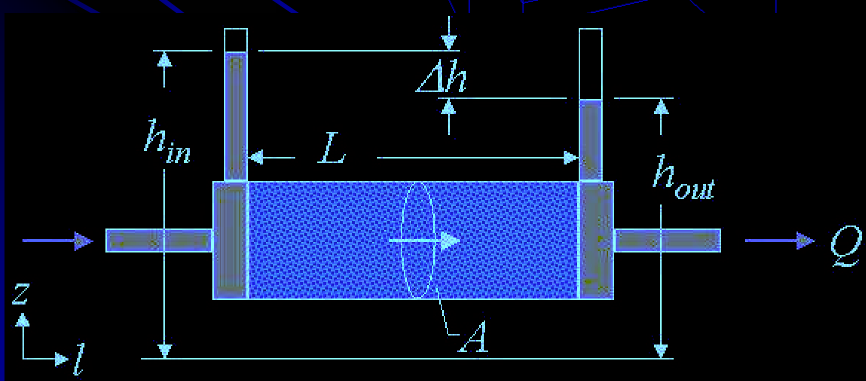


Model Fundamentals

- Finite Volume Method
- Darcy's Law (Ergun Equation)
- General Transport Equations
  - Mass
  - Energy
- Global kinetic rates
- Other sub-models

Darcy's Law

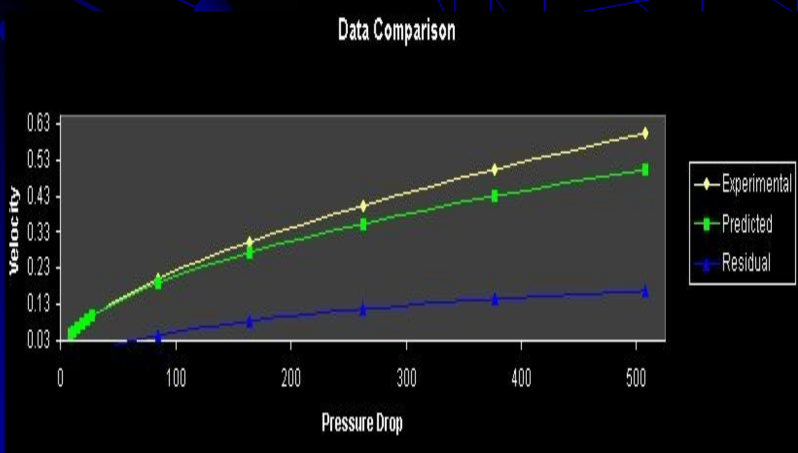
- Models flow through porous media
- More appropriate to bed conditions
- Similar to oil reservoir modeling



$$\nabla P = \frac{\mu}{\alpha} \cdot v_{\infty}$$

Ergun Equation

- Semi-empirical model based on Darcy's law
- Transitional flow
- Continuity equation



$$\nabla P = 150 \cdot \left(\frac{\mu \cdot \upsilon}{D_p^{\;2}} \right) \cdot \frac{(1-\varepsilon)^2}{\varepsilon^3} + \frac{7}{4} \cdot \left(\frac{\rho \cdot \upsilon^2}{D_p} \right) \cdot \frac{1-\varepsilon}{\varepsilon^3}$$

Ergun Equation

Energy/Mass

- General Transport Equation
- Energy Source Terms
  - ΔH_{rxn}
  - Inter-phase convection
- Mass Source Terms
  - Reaction rate (both phases)
  - Feed

$$\frac{\partial(\rho\phi)}{\partial t} + div(\rho\,\vec{u}\,\phi) = div(\Gamma\, grad\phi) + S$$

General Transport Equation

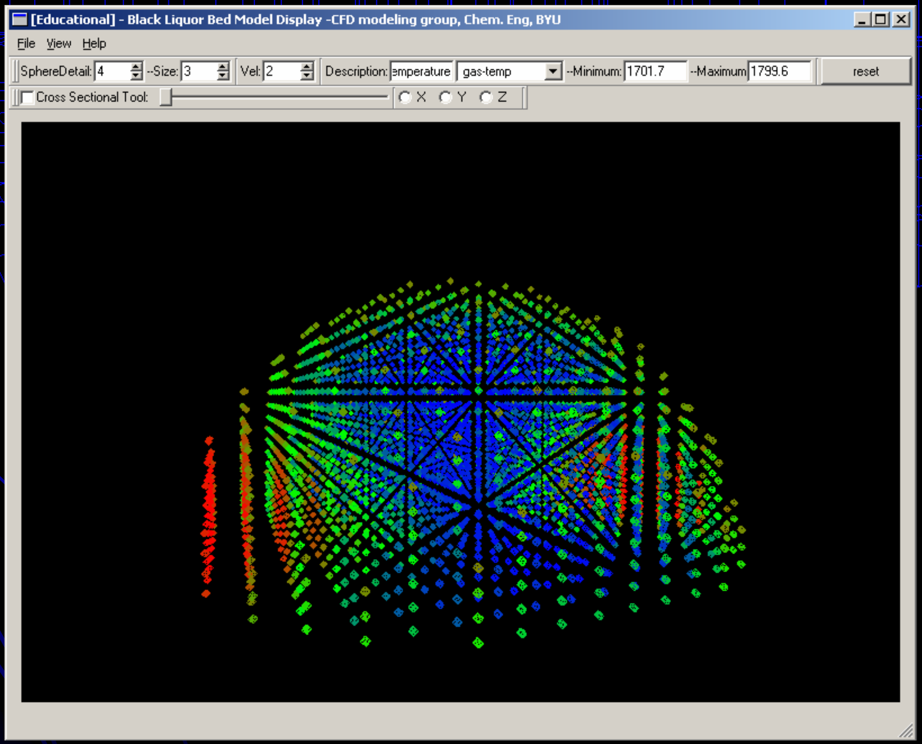
Reactions

Simple global reactions

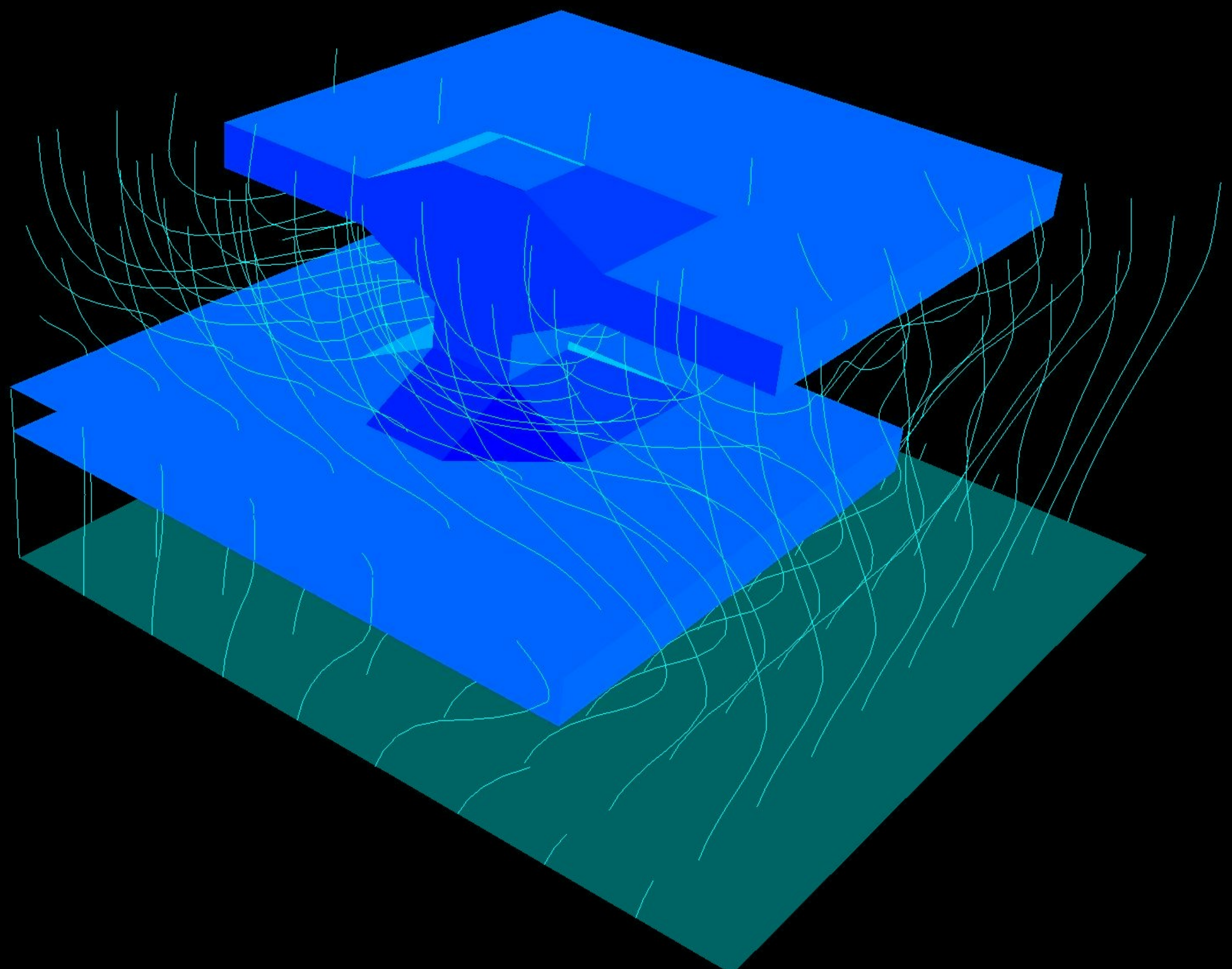
- Char reaction
  - Oxidation
  - Gasification (CO_2, H_2O)
  - Diffusion/Rate limited model
- Gas phase reactions

Visualization of Results

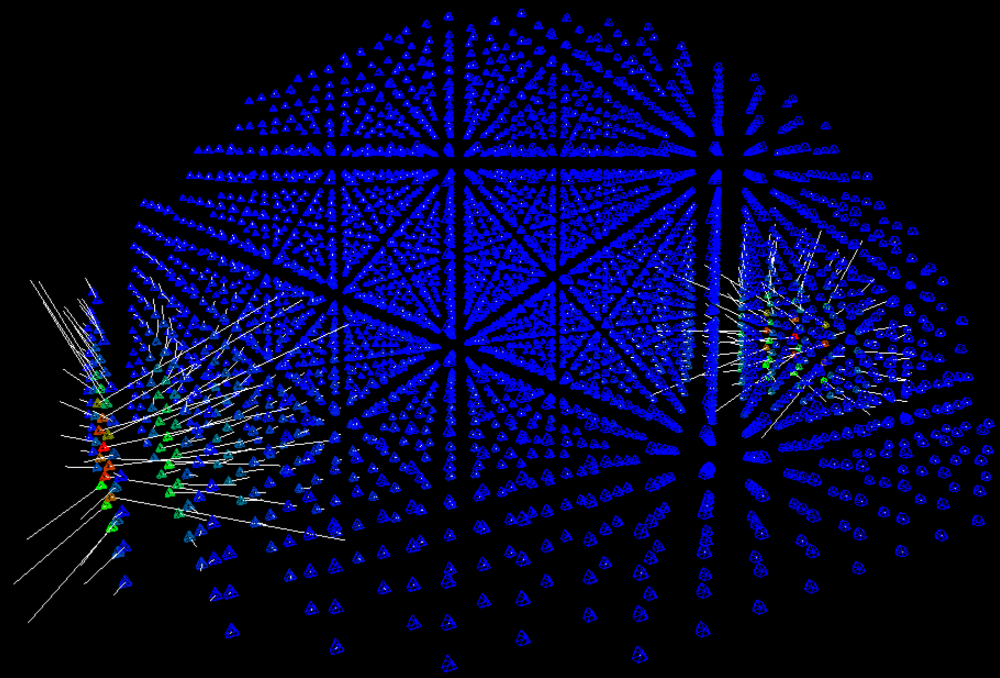
- Ensight
- Visual C++ with OpenGL



Results – Gas Flow



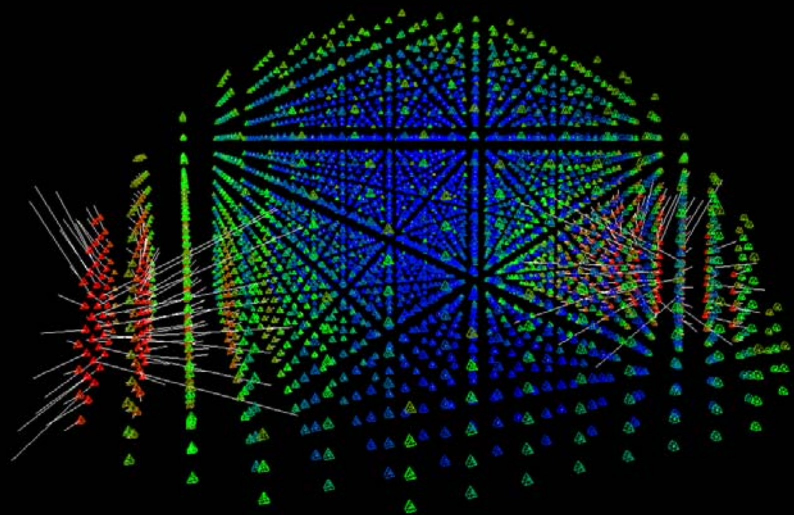
Results – Air Penetration

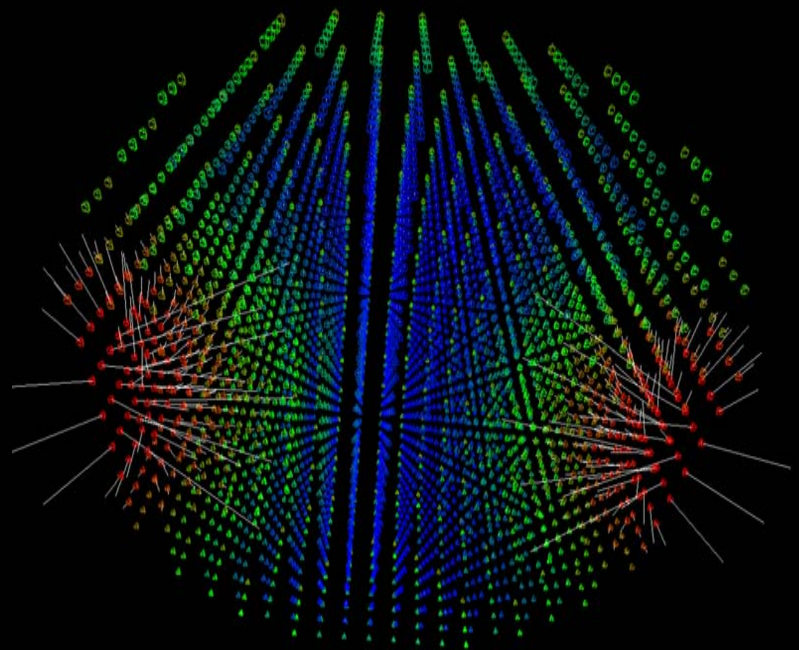


Prediction of pressure drop and gas velocity through the porous bed
Boundary Conditions

- jet pressure of 1015.25kPa and pressure of 1012.25kPa elsewhere
- bed size: 3m x 3m x 1.5m
- no flow boundary condition on the bottom of the bed and constant value boundary condition elsewhere
- simple gas phase reaction incorporated ($CO + ½ O_2 \rightarrow CO_2$)

Results – Gas Temperature

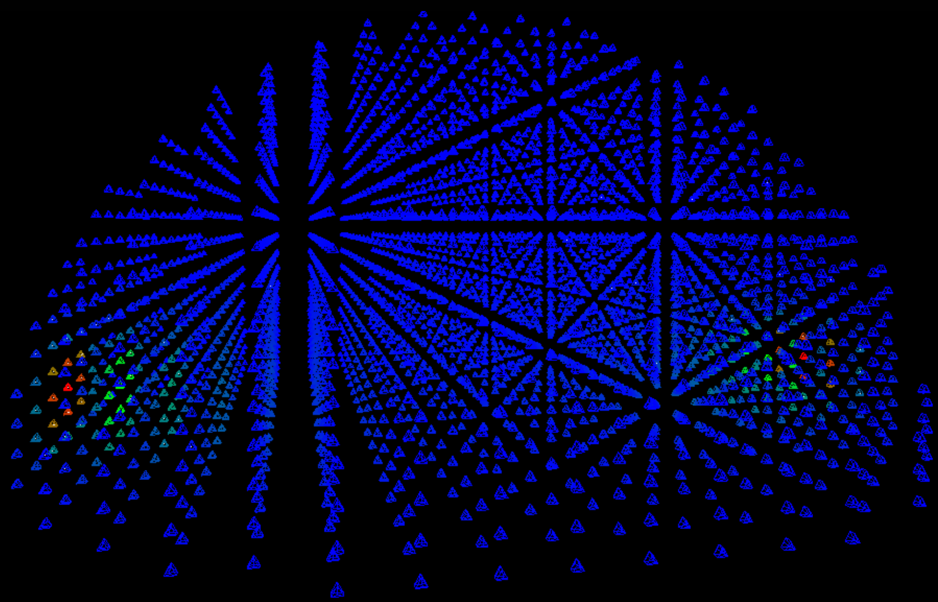




Gas at high temperature entering the solid char bed of lower temperature
Boundary Conditions

• outside temperature of 1800K, constant solid bed temperature of 1750K
• jet pressure of 1019.25kPa and outside pressure of 1012.25kPa elsewhere
• bed size: 3m x 3m x 1.5m
• no flow boundary condition on the bottom of the bed and constant value boundary condition elsewhere
• no reaction in the solid or the gas phase

Results – Species Concentration



Prediction of pressure drop and gas velocity through the porous bed
Boundary Conditions

- simple gas phase reaction incorporated ($CO + \frac{1}{2} O_2 \rightarrow CO_2$)
- constant gas concentration of CO and CO2 outside (set as 5%). The oxygen concentration of 21% by the jet
- jet pressure of 1015.25kPa and pressure of 1012.25kPa elsewhere
- bed size: 3m x 3m x 1.5m
- no flow boundary condition on the bottom of the bed and constant value boundary condition elsewhere

Summary

- The current model
  - Pressure drop
  - Airflow through porous medium
  - Heat transfer (solid and gas)
  - Gas global kinetics

Future Work

- Smelt (liquid phase)
- Self-adjusting bed shape
- Fluent
  - Boundary conditions
  - Incorporate other models
- Comparisons with experimental data
  - Adriaan van Heiningen (University of Maine)
  - Other literature values

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