CFD with Combustion
using Fluent
PCGC-3
Coal Combustion

- Turbulence
- Gas Fluid Dynamics
- Gaseous Combustion
- Numerics
- Heat Transfer
- Particle Mechanics
- Particle Reactions
- Nitrogen Pollutants
General Procedure

- Pick geometry
- Pick variables
  - Turbulent vs laminar
  - Gaseous vs particle-laden
  - Adiabatic?
  - Reacting?
  - Steady-state?
  - Radiation?

- Set up grid system to solve basic equations
  - Cartesian, radial, or spherical?
  - Staggered vs collocated grid
  - “Stair-step” boundary vs. more complicated gridding
    - unstructured mesh, body-fitted coordinates, etc.
  - Finite difference, finite volume, finite element

Goal: Solve all conservation equations for continuum phase as painlessly as possible with one algorithm
\[
\frac{\partial (\rho \phi)}{\partial t} + \frac{\partial (\rho \phi \mathbf{v})}{\partial x} + \frac{\partial (\rho \phi \mathbf{w})}{\partial y} - \frac{\partial}{\partial x} \left( \Gamma \phi \frac{\partial\phi}{\partial x} \right) - \frac{\partial}{\partial y} \left( \Gamma \phi \frac{\partial\phi}{\partial y} \right) - \frac{\partial}{\partial z} \left( \Gamma \phi \frac{\partial\phi}{\partial z} \right) = S_\phi
\]

<table>
<thead>
<tr>
<th>Equation</th>
<th>( \phi )</th>
<th>( \Gamma \phi )</th>
<th>( S_\phi )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuity</td>
<td>1</td>
<td>0</td>
<td>( S_p^m )</td>
</tr>
<tr>
<td>X Momentum</td>
<td>( \mathbf{u} )</td>
<td>( \mu_e )</td>
<td>(-\frac{\partial p}{\partial x} + \frac{\partial}{\partial x} \left( \rho \mathbf{v} \phi \right) - \frac{\partial}{\partial y} \left( \Gamma \phi \frac{\partial\phi}{\partial y} \right) - \frac{\partial}{\partial z} \left( \Gamma \phi \frac{\partial\phi}{\partial z} \right) + \rho \frac{\partial \mathbf{u}}{\partial x} - \frac{2}{3} \frac{\partial p}{\partial x} + S_p^u + \mathbf{u} S_p^m )</td>
</tr>
<tr>
<td>Y Momentum</td>
<td>( \mathbf{v} )</td>
<td>( \mu_e )</td>
<td>(-\frac{\partial p}{\partial y} + \frac{\partial}{\partial x} \left( \rho \mathbf{v} \phi \right) + \frac{\partial}{\partial y} \left( \rho \mathbf{v} \phi \right) - \frac{\partial}{\partial z} \left( \Gamma \phi \frac{\partial\phi}{\partial z} \right) + \rho \frac{\partial \mathbf{v}}{\partial y} - \frac{2}{3} \frac{\partial p}{\partial y} + S_p^v + \mathbf{v} S_p^m )</td>
</tr>
<tr>
<td>Z Momentum</td>
<td>( \mathbf{w} )</td>
<td>( \mu_e )</td>
<td>(-\frac{\partial p}{\partial z} + \frac{\partial}{\partial x} \left( \rho \mathbf{v} \phi \right) + \frac{\partial}{\partial y} \left( \rho \mathbf{v} \phi \right) + \frac{\partial}{\partial z} \left( \Gamma \phi \frac{\partial\phi}{\partial z} \right) + \rho \frac{\partial \mathbf{w}}{\partial z} - \frac{2}{3} \frac{\partial p}{\partial z} + S_p^w + \mathbf{w} S_p^m )</td>
</tr>
<tr>
<td>Turbulent Energy</td>
<td>( \bar{k} )</td>
<td>( \mu_e )</td>
<td>( \frac{\partial^2 \bar{k}}{\partial x^2} + \frac{\partial^2 \bar{k}}{\partial y^2} + \frac{\partial^2 \bar{k}}{\partial z^2} - \frac{\partial \bar{u}}{\partial x} \frac{\partial \bar{u}}{\partial x} - \frac{\partial \bar{v}}{\partial y} \frac{\partial \bar{v}}{\partial y} - \frac{\partial \bar{w}}{\partial z} \frac{\partial \bar{w}}{\partial z} )</td>
</tr>
<tr>
<td>Dissipation Rate</td>
<td>( \bar{\varepsilon} )</td>
<td>( \mu_e )</td>
<td>( \frac{\partial \bar{k}}{\partial x} \frac{\partial \bar{k}}{\partial x} - \frac{\partial \bar{u}}{\partial x} \frac{\partial \bar{u}}{\partial x} - \frac{\partial \bar{v}}{\partial y} \frac{\partial \bar{v}}{\partial y} - \frac{\partial \bar{w}}{\partial z} \frac{\partial \bar{w}}{\partial z} )</td>
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<td>Mixture Fraction</td>
<td>( \bar{f} )</td>
<td>( \mu_e )</td>
<td>( \frac{\partial \bar{f}}{\partial x} + \frac{\partial \bar{f}}{\partial y} + \frac{\partial \bar{f}}{\partial z} - \frac{\partial \bar{u}}{\partial x} - \frac{\partial \bar{v}}{\partial y} - \frac{\partial \bar{w}}{\partial z} )</td>
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<td>Mixture Fraction Variance</td>
<td>( \bar{g} )</td>
<td>( \mu_e )</td>
<td>( \frac{\partial \bar{g}}{\partial x} + \frac{\partial \bar{g}}{\partial y} + \frac{\partial \bar{g}}{\partial z} - \frac{\partial \bar{u}^2}{\partial x} - \frac{\partial \bar{v}^2}{\partial y} - \frac{\partial \bar{w}^2}{\partial z} )</td>
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<tr>
<td>Coal Gas Mixture Fraction</td>
<td>( \bar{\eta} )</td>
<td>( \mu_e )</td>
<td>( \frac{\partial \bar{\eta}}{\partial x} + \frac{\partial \bar{\eta}}{\partial y} + \frac{\partial \bar{\eta}}{\partial z} - \frac{\partial \bar{u}}{\partial x} - \frac{\partial \bar{v}}{\partial y} - \frac{\partial \bar{w}}{\partial z} )</td>
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<td>Coal Gas Mixture Fraction Variance</td>
<td>( \bar{g}_{\eta} )</td>
<td>( \mu_e )</td>
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</tr>
<tr>
<td>Enthalpy</td>
<td>( \bar{h} )</td>
<td>( \mu_e )</td>
<td>( \bar{h} + \frac{\partial \bar{h}}{\partial x} + \frac{\partial \bar{h}}{\partial y} + \frac{\partial \bar{h}}{\partial z} + \frac{\partial \bar{P}}{\partial x} + \frac{\partial \bar{P}}{\partial y} + \frac{\partial \bar{P}}{\partial z} )</td>
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where:

\[ G = \mu_e \left\{ 2 \left[ \left( \frac{\partial \bar{u}}{\partial x} \right)^2 + \left( \frac{\partial \bar{v}}{\partial y} \right)^2 + \left( \frac{\partial \bar{w}}{\partial z} \right)^2 + \left( \frac{\partial \bar{v}}{\partial x} + \frac{\partial \bar{w}}{\partial y} \right)^2 + \left( \frac{\partial \bar{w}}{\partial x} + \frac{\partial \bar{u}}{\partial z} \right)^2 + \left( \frac{\partial \bar{u}}{\partial y} + \frac{\partial \bar{v}}{\partial z} \right)^2 \right] \right\} \]