Estimation of Thermal and Kinetic Parameters to Model Coal Dust Ignition

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Coal Dust Ignition in a Silo

- Dust deposit
- Beam
- CO and other combustible vapors
- Growing
- Smoldering Nest
- Silo
Standard Hot Plate Ignition Test
ASTM E2021

\[ T_\infty = \text{Ambient Temperature} \]

\[ \dot{Q}'' = A e^{-\frac{E}{RT}} \]

\[ k \frac{d^2 T}{dx^2} + \dot{Q}'' = 0 \]

\[ T = T_p \quad \text{at} \quad x = 0 \]

\[ -k \frac{dT}{dx} = h(T_s - T_o) \quad \text{at} \quad x = H \]
Standard Hot Plate Ignition Test
ASTM E2021

- Dust ring
- Grove for thermocouple
- Hot plate
- Pittsburgh seam coal dust
Property Estimation

Chemical reaction

Reactant consumption zone

\[ \dot{Q}'' \rightarrow 0 \]
### Parameters Necessary to Model Ignition

<table>
<thead>
<tr>
<th>Current Approach</th>
<th>ASTM Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Thermal conductivity</td>
<td>- Ignition temperature</td>
</tr>
<tr>
<td>- Specific heat</td>
<td></td>
</tr>
<tr>
<td>- An expression for Q (energy release rate)</td>
<td></td>
</tr>
</tbody>
</table>

Other parameters, such as influence of particle size, packing density, and moisture content on the above parameters.
Numerical estimation

Inert case

Experiments at $T_p=210^\circ C$

$E=83.1 \text{kJ/mole}$

$E=61.7 \text{kJ/mole}$
## Comparison with Prior Research

<table>
<thead>
<tr>
<th>Investigators</th>
<th>$E$(kJ/mol)</th>
<th>$Q$(J/kg)</th>
<th>$A$(1/s)</th>
<th>$k$(W/m-K)</th>
<th>$\rho$(kg/m³)</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Howard and Essenhigh[[i]]</td>
<td>115.9</td>
<td></td>
<td>4.92×10⁴</td>
<td></td>
<td></td>
<td>Flame furnace</td>
</tr>
<tr>
<td>Stone et al.[16]</td>
<td>102~114</td>
<td></td>
<td>1.1×10⁵</td>
<td>~5.41×10⁶</td>
<td></td>
<td>Fluidized bed</td>
</tr>
<tr>
<td>Anthony et al. [16]</td>
<td>49.4</td>
<td></td>
<td>706</td>
<td></td>
<td></td>
<td>Electric grid</td>
</tr>
<tr>
<td>Kobayashi et al. [16]</td>
<td>104.6</td>
<td></td>
<td>6.6×10⁴</td>
<td></td>
<td></td>
<td>Entrained flow</td>
</tr>
<tr>
<td>Yuan and smith[[ii]]</td>
<td>89.9</td>
<td></td>
<td>6×10⁴</td>
<td>0.2</td>
<td>1300</td>
<td></td>
</tr>
<tr>
<td>Singer and Tye[[iii]]</td>
<td></td>
<td></td>
<td></td>
<td>0.19~0.21</td>
<td>1060~1297</td>
<td>Comparative slab</td>
</tr>
<tr>
<td>Herrin and Deming[[iv]]</td>
<td></td>
<td></td>
<td></td>
<td>0.27</td>
<td>1340~1370</td>
<td>Cell technique</td>
</tr>
<tr>
<td>Reddy et al.[[v]]</td>
<td>65.4</td>
<td>$QA = 3.04 \times 10^9$</td>
<td>0.1</td>
<td>492</td>
<td></td>
<td>Hot plate</td>
</tr>
</tbody>
</table>
Influence of Scale

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**Estimated Tp3 (°C)**

- **Experiment**
- □ E of 61.7 kJ/mole
- ○ E of 72.4 kJ/mole
- ◦ E of 83.1 kJ/mole

**Dust layer thickness (mm)**

- 6.4
- 19.1
- 25.4
Conclusion

- Ignition temperature criteria of ASTM E2021 is dependent on thickness of dust layer
- $T_p$ is not a fundamental ignition parameter
- First step – obtain kinetic parameters $A$ and $E$ from current test procedure
Future Work

❖ Apply results to more a realistic geometry such as a wedge and corner

❖ Analyze influence of moisture content, and particle size