Evaluation of gas radiation modeling in oxy-fired furnaces

Robert Johansson

Department of Energy and Environment
Chalmers University of Technology
The oxy-fuel group at Chalmers

- Collaboration with Vattenfall, FLUENT and IVD (Uni-Stuttgart), Alstom and DOOSAN Babcock etc.

Missing on the picture: Daniel Fleig, Daniel Kühnemuth
Oxy-fuel research at Chalmers

Primary objective: Obtain knowledge of need for scaling of the process

Focus areas
- Combustion chemistry: nitrogen, sulphur
- Heat transfer
- Fluid mechanics

Propane and lignite fired tests: Identify and characterize differences between oxy-fuel and air combustion conditions

Modeling: - More detailed modeling of gas radiation, NOx chemistry and sulphur chemistry in connection to the experiments
- CFD-studies
Outline

• Introduction
• Modeling theory
• Experiments
• Results
• Conclusions
Background

Radiation heat transfer is of major importance in design of furnaces

Changed combustion conditions will affect the gas radiative heat transfer
  • Longer pressure path lengths
  • Different ratio of $\text{H}_2\text{O}/\text{CO}_2$
Purpose of the modeling work

Evaluate radiation models for conditions relevant to oxy-fired furnaces

Recommend models for CFD-calculations

Provide a tool that can be of help for evaluation of intensity measurements
Solve the radiative transfer equation (RTE) neglecting scattering

\[ \frac{dI_v}{dr} = \kappa_v I_{b,v} - \kappa_v I_v \]

Change of intensity

Increase of intensity due to emission

Decrease of intensity due to absorption

Discretization of a path in homogeneous cells

Modeling theory
Correlated formulation
formal solution
physically correct

$$I_{v,n} = I_{v,0} \tau_{v,0\rightarrow n} + \sum_i I_{bv,i+1/2} \left( \tau_{v,i+1\rightarrow n} - \tau_{v,i\rightarrow n} \right)$$

Wall

Non-correlated formulation
requires less calculations
the most commonly used approach in CFD

$$I_{v,n} = I_{v,n-1} \tau_{v,n-1\rightarrow n} + I_{bv,n-1/2} \left( 1 - \tau_{v,n-1\rightarrow n} \right)$$

Wall

Modeling theory

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### Tested models

<table>
<thead>
<tr>
<th>Transmissivity models</th>
<th>Model</th>
<th>Nr. of RTEs</th>
<th>Ranges of parameter validity</th>
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</thead>
<tbody>
<tr>
<td>Correlated formulation</td>
<td>SNBM Malkmus Soufiani and Taine, 1997</td>
<td>367</td>
<td>Cover conditions of interest</td>
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<td></td>
<td>SNBM Goody Leckner, 1972</td>
<td>686</td>
<td>Cover conditions of interest</td>
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<td>EWBM Edwards, 1976</td>
<td>21</td>
<td>Cover conditions of interest</td>
</tr>
<tr>
<td>Absorption coefficient models</td>
<td>SLW Denison and Webb, 1993</td>
<td>Optional, 121 are used in this work (10 for each species)</td>
<td>Cover conditions of interest</td>
</tr>
<tr>
<td>Non-correlated formulation</td>
<td>WSGG Smith et al.1982</td>
<td>4</td>
<td>$600 &lt; T &lt; 2400$ $0.001 &lt; PL &lt; 10$ $P_{H_2O}/P_{CO_2} = 1$ or $2$</td>
</tr>
<tr>
<td></td>
<td>WSGG Optimized this work</td>
<td>3 or 4</td>
<td>$500 &lt; T &lt; 2500$ $0.001 &lt; PL &lt; 40$ $P_{H_2O}/P_{CO_2} = 0.125$ or $1$</td>
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</table>
Theoretical cases

uniform and non-uniform paths
radiative source term (infinite plates)
wall fluxes (infinite plates)

Comparison with experiments
## Experimental cases

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<tbody>
<tr>
<td></td>
<td>In</td>
<td>Out</td>
<td>In</td>
<td>Out</td>
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<tr>
<td><strong>Propane</strong></td>
<td>Air</td>
<td>21</td>
<td>3.0</td>
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<td>12</td>
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<tr>
<td></td>
<td>OF 21</td>
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<td>3.0</td>
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<tr>
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<td>OF 27</td>
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<tr>
<td><strong>Lignite</strong></td>
<td>Air</td>
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<td>3.1</td>
<td>-</td>
<td>17</td>
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<td></td>
<td>OF 25</td>
<td>25</td>
<td>3.7</td>
<td>72</td>
<td>94</td>
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<tr>
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<td>OF 27</td>
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<td>3.9</td>
<td>71</td>
<td>94</td>
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<tr>
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<td>OF 29</td>
<td>29</td>
<td>4.2</td>
<td>69</td>
<td>94</td>
</tr>
</tbody>
</table>
Measurements

Intensity, temperature and gas concentrations measured along the cross section of several ports.

Intensity measurements
Narrow angle radiometer
Cold black background

Experiments
Evaluation of models: uniform paths

Results
Evaluation of models: wall fluxes (infinite plates)

Temperature given by a cosine profile: 1000-1800K

Results
Comparison with experiments

Propane flame
Port 3: 384mm from burner

Results
Comparison with experiments

Propane, Air  Propane, OF 21  Propane, OF 27

Results

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Comparison with experiments

Lignite flame, OF25

Results

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Conclusions

• The existing parameters of the WSGG model are intended for air fired conditions and often yield significant errors for conditions relevant for oxy-fired furnaces.

• The new WSGG parameters give results within 20% of the reference model.

• The WSGG model is suitable for CFD-calculations in terms of accuracy and computational cost.

• Conditions with significant amounts of soot and particles requires less accuracy of the gas radiation modeling.

• Modeling has confirmed the differences in soot concentration observed in the propane flames.
Thank you for your attention!