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A new model for gas radiative properties applicable to oxy-fuel combustion modelling

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Introduction
Radiation is the principal mode of heat transfer in furnaces. Modeling of radiation heat transfer in combustion systems is very complicated. There are two key issues, i.e., how to calculate radiation intensity at different locations along different directions from radiative transfer equations and how to evaluate radiation properties at different locations. Different combustion environments (air-fuel or oxy-fuel) make no difference to the 1st key issue; they will only affect the gaseous radiative properties.

Models for gaseous radiative properties have been well established for air combustion. However, there is uncertainty regarding their applicability to oxy-fuel conditions. In this paper, a new and complete set of models for gaseous radiative properties is derived. In this paper, a new and complete set of models for gaseous radiative properties is derived. Which is applicable to CFD modeling of both air-fuel and oxy-fuel conditions. The derivation, calibration and implementation of the new model are given.

Method

- First, a computer code is developed to evaluate the emissivity of any gas mixture at any condition using the exponential wide band model (EWBM), and the calculated results are calibrated in very details by data in literature.
- Then, the calculated emissivities are used to generate emissivity databases for representative air-firing and oxy-firing conditions, for each of which a new weighted-sum-of-gray-gases model (WSGGM) with new parameters is derived. The way to implement the new models into CFD simulations of combustion systems is given.
- Finally, as a demonstration, the new models are applied to CFD modeling of a 0.8MW oxy-natural gas flame furnace. The CFD results are compared with those based on the widely used WSGGMS in literature. Based on that, some useful guidelines on oxy-fuel modeling are recommended.

Result 1: Calibration of EWBM code

Based on “almost exact analytical expressions”, a computer code in C++ is developed to evaluate the emissivity of any gas mixture that may consist of H2O, CO2, CO, CH4, NO and SO2, at any condition using the EWBM. The application of this code to any gas mixture is shown below, with almost all the values here calibrated with a reference example.

\[ \varepsilon = \sum_{i=0}^{l} c_i(T_g) \left( 1 - e^{-b_i P_L} \right) \]

Where, the emissivity \( \varepsilon \) of a gas mixture that may consist of \( \varepsilon_{\text{air}} = 0.35 \) is shown below, with almost all the values here calibrated with a reference example.

Table 1: New parameters for the WSGGM, applicable to oxy-fuel flames

<table>
<thead>
<tr>
<th>T [K]</th>
<th>c1</th>
<th>c2</th>
<th>c3</th>
<th>( \varepsilon_{\text{air}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>0.125</td>
<td>0.14</td>
<td>0.15</td>
<td>0.35</td>
</tr>
<tr>
<td>1500</td>
<td>0.125</td>
<td>0.14</td>
<td>0.15</td>
<td>0.35</td>
</tr>
<tr>
<td>2000</td>
<td>0.125</td>
<td>0.14</td>
<td>0.15</td>
<td>0.35</td>
</tr>
<tr>
<td>2500</td>
<td>0.125</td>
<td>0.14</td>
<td>0.15</td>
<td>0.35</td>
</tr>
<tr>
<td>3000</td>
<td>0.125</td>
<td>0.14</td>
<td>0.15</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Result 2: The new models

The complete set of new models consists of the following equations and new parameters for a number of representative air-fuel and oxy-fuel conditions, and the way to implement them into CFD modeling. Here, only the new WSGGM parameters for the representative oxy-fuel conditions are listed, as seen in Table 1.

Result 3: Demonstration

The new models have been applied to CFD modeling of a 0.8MW IFRF oxy-natural gas flame furnace.

Conclusions

The new WSGGMS need to be used in CFD modeling of large-scale oxy-fuel furnaces. For small-scale facilities, they do not make remarkable difference. Combustion chemistry also plays a key role in oxy-firing modelling.

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