New targets for laminar flame speed determination and kinetic schemes assessment

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full OPTical access Perfectly spheRical combustion chaMber (OPTIPRIM)
Experimental set-up

<table>
<thead>
<tr>
<th>Fuel</th>
<th>$T_0$ (K)</th>
<th>$P_0$ (bar)</th>
<th>$\phi$ (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$CH_4$</td>
<td>300</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$CH_4$</td>
<td>300</td>
<td>1</td>
<td>1.3</td>
</tr>
</tbody>
</table>
Flame propagation

CH_4/air at \( \phi = 1.0 \)
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Radiation and heat losses to the walls

**ADI-wall** adiabatic walls

**ADI** adiabatic model with no radiative loss

**OTM** optically thin model considering emission but no absorption

**SNB** statistical narrow band model with both radiation emission and absorption
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**Stretch effect**

<table>
<thead>
<tr>
<th>Fuel</th>
<th>( T_0 ) (K)</th>
<th>( P_0 ) (bar)</th>
<th>( \phi ) (-)</th>
<th>( S_{u0} ) (m/s)</th>
<th>( L_u ) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( CH_4 )</td>
<td>300</td>
<td>1</td>
<td>1</td>
<td>0.36</td>
<td>-0.13</td>
</tr>
<tr>
<td>( CH_4 )</td>
<td>300</td>
<td>1</td>
<td>1.3</td>
<td>0.22</td>
<td>0.3</td>
</tr>
</tbody>
</table>

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\[ K \text{ [s}^{-1} \] \]
Flame speed evaluation

\[ S_u = \frac{dR_f}{dt} - \frac{(R_c^3 - R_f^3)}{3 \gamma_u R_f^2 P} \frac{dP}{dt} \]

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Species</th>
<th>Reactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRI Mech 3.0 [1]</td>
<td>53</td>
<td>325</td>
</tr>
<tr>
<td>USC Mech II [3]</td>
<td>111</td>
<td>784</td>
</tr>
<tr>
<td>DTU Mech [5]</td>
<td>68</td>
<td>631</td>
</tr>
<tr>
<td>HP Mech [6]</td>
<td>92</td>
<td>625</td>
</tr>
</tbody>
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Alternative method

\[ S_u = \frac{dR_f}{dt} - \frac{(R_c^3 - R_f^3)}{3\gamma_u R_f^2 P} \frac{dP}{dt} \]

\[ S_{u,n} = \frac{R_{f,n+1} - R_{f,n}}{t_{n+1} - t_n} - \frac{R_c^3 - R_{f,n}^3}{3\gamma_u P_n R_{f,n}^2} \frac{P_{n+1} - P_n}{t_{n+1} - t_n} \]

\[ R_{f,n+1} = R_{f,n} + S_{u,n}(t_{n+1} - t_n) + \frac{R_c^3 - R_{f,n}^3}{3\gamma_u P_n R_{f,n}^2} (P_{n+1} - P_n) \]

\[ P_{n+1} = P_n + \left((R_{f,n+1} - R_{f,n}) - S_{u,n}(t_{n+1} - t_n)\right) \cdot \frac{3\gamma_u P_n R_{f,n}^2}{R_c^3 - R_{f,n}^3} \]
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\[
\begin{align*}
    P_{n+1} &= P_n + \left( (R_{f,n+1} - R_{f,n}) - S_{u,n} \cdot (t_{n+1} - t_n) \right) \cdot \frac{3 \gamma_{u,n} P_n R_{f,n}^2}{R_c^3 - R_{f,n}^3} \\
    T_{n+1} &= T_n \left( \frac{P_n}{P_{n+1}} \right)^{1-\gamma_{u,n}}/\gamma_{u,n}
\end{align*}
\]
Flame speed as a function of pressure

\[ P_{n+1} = P_n + \left( R_{f,n+1} - R_{f,n} \right) - S_{u,n} \cdot (t_{n+1} - t_n) \cdot \frac{3 \gamma_{u,n} P_n R_{f,n}^2}{R_c - R_{f,n}^3} + S_u = f(P, T) \]
Conclusions

- full OPTIcal access Perfectly spheRical combustIon chaMber
- **Simultaneous** recording of the pressure inside the chamber and, fully innovative, of the flame radius until the walls
- Accurate flame speed as a function of pressure/temperature evolution
- **Pressure** is the correct target to assess the accuracy of a kinetic mechanism
- A relative error lower than ±5 % over almost the entire pressure range was obtained

- The unmatched accuracy allows to optimize kinetic schemes