Numerical Simulation of the Laminar Hydrogen Flame in the Presence of a Quenching Mesh

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Introduction.

Severe accident

\[ \text{Zr} + 2\text{H}_2\text{O} \rightarrow \text{ZrO}_2 + 2\text{H}_2 \]

Release of steam and hydrogen into the reactor building, forming an explosive mixture

\[ \text{H}_2 + \frac{1}{2}\text{O}_2 \]
Introduction.

There is a need for mitigation measures against hydrogen risk in a nuclear power plant.

In a number of NPP Passive Autocatalytic Recombiners (PAR) are installed.

The installation of a quenching mesh between the compartments or the enclosure of equipment by the quenching mesh has been suggested [1] as a measure to prevent flame propagation.

Typical situations studied in the past

- Head-on quenching
- Side-wall quenching
- Tube quenching
Flame-Mesh interaction is a combination of the above situations.

We assume

- Two-dimensional laminar flame
- Stoichiometric H₂-Air mixture
- Initial T=300 K, P=1 atm
- Mesh temperature is constant in time

D = 0.3 mm (MESG)
### Governing Equations

\[
\begin{align*}
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{u}) &= 0 \\
\frac{\partial \rho y_i}{\partial t} + \nabla \cdot (\rho \vec{u} y_i) &= \nabla \cdot \{ D_i \nabla (y_i) \} + \dot{\omega}_i \\
\frac{\partial \rho \vec{u}}{\partial t} + \nabla \cdot (\rho \vec{u} \otimes \vec{u} + pI) &= \nabla \cdot \vec{\tau} + \rho \vec{g} \\
\frac{\partial \rho e}{\partial t} + \nabla \cdot (\rho \vec{u} h) &= \nabla \cdot (\vec{\tau} \cdot \vec{u} - \vec{q}) + \rho \vec{g} \cdot \vec{u} - \dot{\omega}_r
\end{align*}
\]

where

\[
\begin{align*}
p &= \rho \frac{R_u}{W} T \\
\dot{\omega}_r &= \sum_{i=1}^{N} \Delta h_{f,i} \dot{\omega}_i \\
e(T) &= \int_{0}^{T} c_v dT + \frac{1}{2} \vec{u} \cdot \vec{u}
\end{align*}
\]
One Step Global Reaction Mechanism

\[ 2H_2 + O_2 \rightarrow 2H_2O \]

Laminar ‘Arrhenius’ rate:

\[ \dot{\omega}_{Arr} = C_f \left( \frac{\rho_{H_2}}{W_{H_2}} \right) \left( \frac{\rho_{O_2}}{W_{O_2}} \right) \exp \left( -\frac{\omega}{T_a} \right) \]

Quenching Criterion:

\[ T_q = T_{adiab} - \frac{T_{adiab}^2}{T_a} \]

\[ \dot{\omega} = \dot{\omega}_{Arr} H(T - T_q) \]
Numerical method and grids used for computation

- Finite Volume discretisation
- Shock-Shock approximate Riemann Solver (convective)
- “Diamond” method (diffusive terms)

1134 elem., $dx=0.02$ mm

4548 elem., $dx=0.014$ mm

10354 elem., $dx=0.0092$ mm
Temperature contours on the

coarse mesh

medium mesh

$t=45\,\mu s$

$t=85\,\mu s$

$t=125\,\mu s$

$t=165\,\mu s$

$t=205\,\mu s$
Numerical results

\[
\frac{Q_{\text{gener}} - Q_{\text{lost}}}{Q_{\text{gener}}} \times 100\%
\]
Temperature evolution with time
Conclusions.

- **Thermal criterion is used for flame quenching**

- **Quenching Peclet number**

\[ Pe = \frac{S_L D}{\alpha} \approx 25 \]

- **Which role is played by active radicals recombination during diffusion near wall is not clear**

- **Turbulent flame quenching studies are suggested as a future work**