CFD–SIMULATION OF NATURAL GAS COMBUSTION
AND IST APPLICATION TO TUNNEL KILN FIRING
Contents

1. Introduction to combustion models in OpenFOAM
2. The Flamelet-Model
3. Tunnel kiln firing
4. Outlook
1. Introduction to combustion models in OpenFOAM

Simple flame – Reactions and species

CH₄ + 2 O₂ → CO₂ + 2 H₂O

CH₄ + 1½ O₂ → CO + 2 H₂O

CO + ½ O₂ ↔ CO₂

CH₄ + Air

1. Introduction to combustion models in OpenFOAM

Simple flame – Reaction Model

**Chemical Reaction:**

\[ \text{CH}_4 + 2 \text{O}_2 \rightarrow \ldots \rightarrow \text{CO}_2 + 2 \text{H}_2\text{O} \]

**GRI22 reaction mechanism:**
- 22 species (+ N\textsubscript{2}, Ar)
- 104 reactions

**Reaction Model:**
- Equilibrium calculation for each cell
  - Easy implementation
  - (Very) slow calculation
2. Flamelet model

Simplified model description

\[
\text{CH}_4 + 2 \text{O}_2 \rightarrow \ldots \rightarrow \text{CO}_2 + 2 \text{H}_2\text{O}
\]

GRI22 reaction mechanism:
- 22 species (+ N₂, Ar)
- 104 reactions

Flamelet Model:
- Pre-calculation of possible reactions
- Generation of lookup-tables
  - 😊 Fast calculation
  - 😞 High memory consumption
  - 😞 More difficult implementation

\[
\text{CH}_4 + \text{Air}
\]
2. Flamelet model
Simplified model description – Lookup-tables

\[ \text{CH}_4 + 2 \text{O}_2 \rightarrow \ldots \rightarrow \text{CO}_2 + 2 \text{H}_2\text{O} \]

GRI22 reaction mechanism:
22 species (+ N\textsubscript{2}, Ar)
104 reactions

**Flamelet Model:**
- Pre-calculation of possible reactions
- Generation of lookup-tables
  - 😊 Fast calculation
  - 😞 High memory consumption
  - 😞 More difficult implementation

scalar Dissipation \( \chi \) [s\(^{-1}\)]

\[ \text{Fuel + Oxidizer} \rightarrow \text{Fuel fraction} \ z \ldots \ [0\ldots1] \]
2. Flamelet model
Implementation issues

- Only one type of fuel
- More burners with different Fuel/Oxidizer ratios → Adjustment of lookup-tables
- Heat exchange gas/solid needs to be treated additionally for transient simulations

\[ \lambda_A \quad \text{Fuel A + Oxidizer} \quad \lambda_B \quad \text{Fuel B + Oxidizer} \]

\[ T_{\text{wall}} \text{ not taken into account} \]
Similar to \( \text{grad}(T) = 0 \)
cold solids don’t cool gas
3. Tunnel kiln firing
Overview
3. Tunnel kiln firing

Mesh generation – SnappyHexMesh
3. Tunnel kiln firing

Mesh generation – SnappyHexMesh
3. Tunnel kiln firing

Extended burning zone model – Overview

- **Dimensions:**
  - Gas: 2,5M cells
  - Solid: 1,5M cells

- **Simulation time:** ~ 6d for 1s of gas flow on 4 (older) processors

- **Solver specifications:**
  - Transported species: steady-state
  - Gas: transient
  - Solid: transient with speed-up factor $10^4 \rightarrow \sim 2.8$ h
3. Tunnel kiln firing

Extended burning zone model – Overview
3. Tunnel kiln firing

Extended burning zone model – Results after 1s of gas flow
3. Tunnel kiln firing

Extended burning zone model – Results after 1s of gas flow
3. Tunnel kiln firing

Extended burning zone model – Results after 1s of gas flow
4. Outlook

- Further modifications of the model
  - Fine-tuning of the mesh on the burner patches
  - Mesh refinement in the flame region

- Implementation of a total kiln model
  - Kiln dimensions and setup
  - Process parameters
  - Data for the initialization
  - Transient simulations according to kiln car pushing sequence