Study of Flame Flashback Phenomena for the Safety of Hydrogen-Rich Fuel Burners

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With financial support from the BIGCCS Centre
Background and Motivation

• Pre-combustion CO₂-capture
  → hydrogen-rich fuels

• NOₓ ↓ → Lean premixed combustion

• Hydrogen is extremely reactive
  → Risk of flame flashback into premixing section

Industrial relevance: How to design safe and reliable burners for highly reactive fuels?
Overview

• Background and Motivation

• Boundary Layer Flashback – Theory and State of the Art

• High-Speed Flashback Movie

• Highlights of the Experimental Work

• Conclusions
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How Flashback is Initiated

Upstream flame propagation in low-velocity region close to the wall!
Flashback Limits of H₂-Air Flames – State of the Art

Velocity gradient as a measure of the flashback propensity!

H₂-air flames at ambient temperature / pressure

But: No interaction of flame and flow accounted for!
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High-Speed Flashback Movie

H₂-air flame, unconfined, \( \Phi = 0.57 \) („fuel-to-air ratio“)
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Flashback Limits for Confined and Unconfined Flames

- Literature results for unconfined tube flames reproduced well
  → Test rig suitable for flashback experiments!
- Flashback propensity for confined flames substantially higher!

Influence of Boundary Layer Air Injection

Influence of Swirl - Detail

High-Speed Flashback Movies
Velocity Field (High-Speed Micro-PIV)

Stable flame

Flame at flashback

→ Flow is retarded and deflected by flame!
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Conclusions

• Substitution of hydrocarbons for hydrogen
  → Increasing flashback (FB) propensity

• Flame confinement: Extremely negative influence on FB stability
  → FB limits from literature not reliable for safe gas turbine designs!

• Boundary layer air injection: Positive influence on FB propensity

• Swirling flow: Positive and negative effects on FB propensity

• Interaction between flow and flame during flashback
  → State-of-the-art model for flashback not satisfactory/applicable
  → Development of a new model necessary
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Additional Material
Microscopic Particle Image Velocimetry (PIV)

Small tracer particles are injected into the flow to measure the flow velocity!
Bacatec Study
Design of the Test Rig at TU München

- Fully turbulent flow conditions
- Air preheating up to ca. 450°C possible
- Optional flame confinement
- Optional swirl generator
Flashback in the Boundary Layer

Critical velocity gradient theory:

Flame speed outbalances flow velocity at certain vertical distance from wall ($\delta_b$)

$$g = \left( \frac{\partial u}{\partial y} \right)_w = \frac{\tau_w}{\eta} \leq g_{krit} \rightarrow \text{Flashback}$$

$S_f$: Flame speed (Burning velocity)

$\delta_q$: Quenching distance

$\eta$: Dynamic viscosity

Velocity gradient as a measure of the flashback propensity!
Possible Explanation for Deviations

Unconfined flame:
→ Radial leakage flow through quenching gap
→ Radial heat flow

Confined flame:
→ Radial leakage flow restricted
→ Radial heat flow restricted