Effect of Inlet and Outlet Configurations on Blow-Off and Flash Back with Premixed Combustion for High Hydrogen Content Fuels in a Generic Swirl Burner

Cardiff School of Engineering

Introduction

• The process industries are facing significant challenges in terms of both fuel and electricity:
  – Security
  – Cost
  – Environmental impact

• In steel making, a process gas of high calorific value is produced in the coke oven
Research Justification

• To help address these challenges the Coke Oven Gas (COG) can be utilised to produce thermal reduce dependence on external sources

• Combustors are being designed and converted to be fired on high hydrogen content fuels, including COG

• Also looks at application toward methane and Natural Gas
Modern industrial combustion methods

- Premixed Combustion
- Non-Premixed Combustion
- Partially Premixed Combustion
Combustion challenges: 1. Flashback

Occurs when the local flame speed exceeds the local flow speed, and the flame zone settles too close to or inside burner components.
Combustion challenges: 2. Blow-out

Occurs when the flame speed exceeds the flow speed and the flame zone is blown away

Lifted Flame
Research aims

• To define a flames stability range in terms of a variable that can be applied to multiple burner geometries

• To establish the effect of different fuels

• To establish why this variable is of importance and what it is dependant on
Generic Swirl Burner- Utilises different vane configurations to alter geometric swirl number (28mm exit diameter)

provides $0.8 \leq S_g \leq 1.5$ for thermal output up to 50 kW
No significant correlation when geometry is altered for COG or Methane

Blow Off data from generic swirl burner
Methane and COG for varying Sg, Open Flames, no air preheat

COG Gas – 65% H₂, 25% CH₄, 6% CO, 4% N₂
Blow Off Data from Belatgui and Maccallam (1986): Exit axial vel. v Equivalence ratio
Natural Gas and Town gas for varying vane angles, Open Flames, no air preheat

Town Gas - 49% H₂, 29% CH₄, 11% CO₂, 7% N₂, 2% O₂, 1% CO, 1% C₂H₆
- Good correlation with Tangential Velocity & Equivalence ratio,
Methane Blow Off: Generic Burner

- CH$_4$ $S_g$ = 1.2
- CH$_4$ $S_g$ = 1.5
- CH$_4$ $S_g$ = 0.8

Methane Flash Back: Burner Comparison

- CH$_4$ $S_g$ = 0.80 (Other)
- CH$_4$ $S_g$ = 0.86 (Generic)
- CH$_4$ $S_g$ = 1.04 (Other)
- CH$_4$ $S_g$ = 1.08 (Generic)

Good blow off correlation between $S_g$ = 1.2, 1.5 and 0.8 above $W_{in} > 25$ m/s

No flash back correlation on low turbulence generic burner

Good flash back correlation for high turbulence radial burner
Reinterpreted Town Gas Blow Off

Blow off results from Belatgui and MacCallam reinterpreted in terms of average tangential velocity leaving burner
• Good correlation for COG for both flash back and blow off

• Methane results seem highly dependant on turbulence

\[ S_T = S_L + K \cdot U' \]  (Cheng)

COG :
\[ S_L = 93.1 \text{ cm/s}* \]
\[ K = 2.73 \]

Methane :
\[ S_L = 36.8 \text{ cm/s}* \]
\[ K = 1.73 \]

\( S_T \) - Turbulent flame speed  
\( S_L \) - Laminar flame speed  
\( K \) - Fuel dependant constant  
\( U' \) - RMS Total Fluctuating Velocity

*measured stoichiometric 303K 0.1MPa
Correlation suggests both mechanisms are dependant on shear layers, and not exclusively the CRZ and recirculation.

Phase Locked PIV images in the $0^\circ$-$180^\circ$ Phase Plane of Axial Radial Velocities

- a) $\Phi = 0.99$
- b) $\Phi = 0.62$
- c) $\Phi = 0.45$
Correlation suggests both mechanisms are dependant on shear layers, and not exclusively the CRZ and recirculation.
Near Flash Back Limit
Lower Turbulence
Higher Laminar Flame Speed

Near Blow Off Limit
Higher Turbulence
Low Laminar Flame Speed
Conclusions

• The comparison between equivalence ratio and tangential inlet velocity offers the potential to define stability limits of a fuel for a non specific burner

• The most consistent results are achieved with COG gas, a fuel with a high hydrogen content and high laminar flame speed

• Results with methane depend on turbulence increasing flame speed

• The believed reason for this is the role of shear layers in stabilising the swirling flame
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\[ S_A = 1.47 \]

\[ S_B = 1.04 \]

\[ S_C = 0.8 \]
Radial swirl burner used to provide $0.56 \leq S_g \leq 4.46$ for thermal output up to 150 kW

Typical Isothermal Re ≈ 10,000

Test Burner 2- Utilises different sized inserts to alter geometric swirl number
(76mm exit diameter)