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Associazione Sezione Italiana del Combustion Institute ASICI

Università degli Studi di Firenze
Dipartimento di Ingegneria Industriale - DIEF

FGM vs ATFM: a comparative analysis in predicting the flame characteristics of an industrial swirler

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Introduction & Motivation

TRANSITION

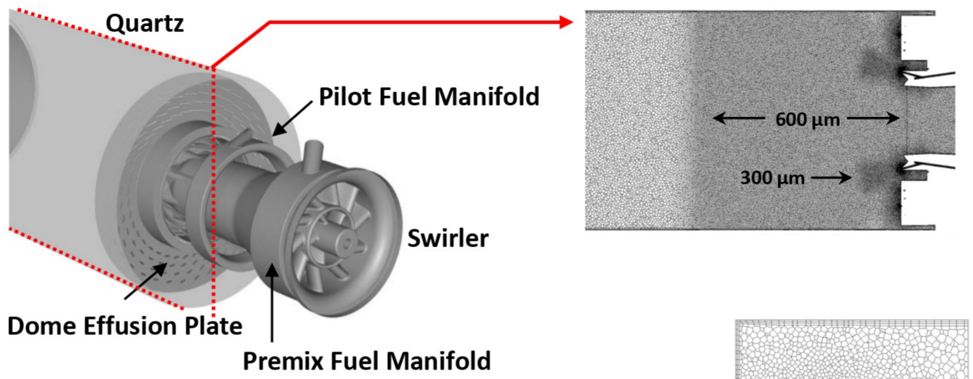
- ✓ *fuTure hydRogen Assisted gas turbiNeS for effective carbon capTure IntegratiON*
- ✓ Main objective: pave the way for the carbon-neutral energy generation from natural gas-fired power plants using GT
  - Efficient coupling of gas turbine generators with CO_2 capture and sequestration processes
    - employment of high percentage of EGR to maximize the CO_2 content at the inlet of the CC unit
      - ❖ Final objective: design of technical solutions for the extension of the operational limits at high EGR rates
- ✓ A significant number of CFD simulations are necessary to determine the flame stability limits at different EGR levels and burner designs:
  - It is mandatory to limit the computational cost while keeping a high accuracy

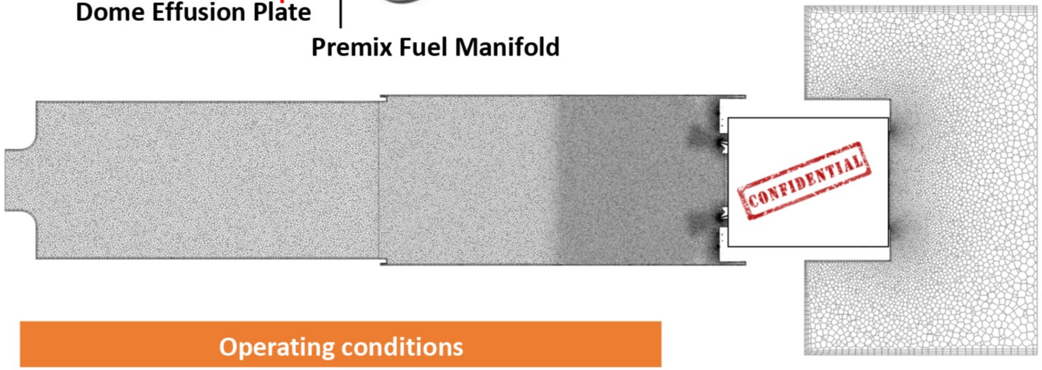
AIM OF THE WORK

- comparing the FGM and ATFM models in predicting the flame characteristics of an industrial swirler
- validate the suitability of the FGM model for future simulations in supporting burner design

Test Case & Numerical Setup

- ✓ THT test rig with Baker Hughes burner
  - Main premixer: uniform mixture through a counter-rotating swirler for fuel injection
  - Pilot lines for flame stabilization
- ✓ Fully unstructed polyhedral mesh
  - 13.5M polyhedral elements
  - Local refinements
    - Reaction zone (600 µm)
    - Pilots jet exit (300 µm)
- ✓ Simulations performed on ANSYS Fluent 2022R1
  - Turbulence model: LES-Dynamic Smagorinsky SGS model
  - Numerical schemes: 2nd order discretization
  - Combustion model & Turbulence-Chemistry Interaction:
    - FGM Finite-Rate (FR) – GRI Mech 3.0
    - Artificially Thickened Flame Model (ATFM) – Skeletal UCSD mech (19 species, 62 reactions)
- ✓ Fuel-Oxidizer: CH_4-air





Operating conditions	
Pressure	101325 Pa
Air Temperature	573 K
Fuel Temperature	343 K
Fuel	100% CH_4
φ	0.561
Pilot split	30%

THT lab – laboratory of Technology for High Temperature

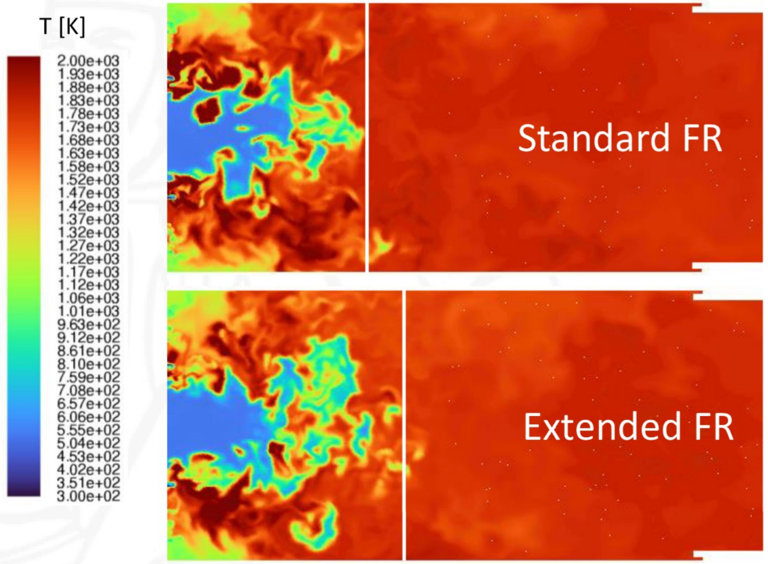
Baker Hughes

FGM-FR vs Extended FGM-FR: a thermal field comparison

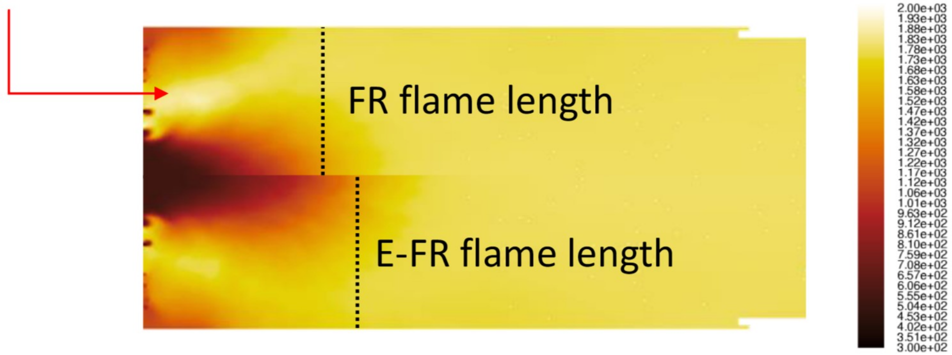
Standard FR $\widetilde{\dot{\omega}_c}(\tilde{Z},\tilde{c}) = \iint \dot{\omega}_c(Z,c)P(Z)P(c)dZdc$

Extended FR $\widetilde{\dot{\omega}_c}(\tilde{Z},\tilde{c},\psi,k) = \Gamma(\psi,k) \iint \dot{\omega}_c(Z,c)P(Z)P(c)dZdc$

$\Gamma(\psi,k) = \frac{\max \dot{\omega}_c(Z,c,\psi,k)}{\max \dot{\omega}_c^0(Z,c)}$ → Unstrained $k = 0$, Adiabatic $\psi = 1$

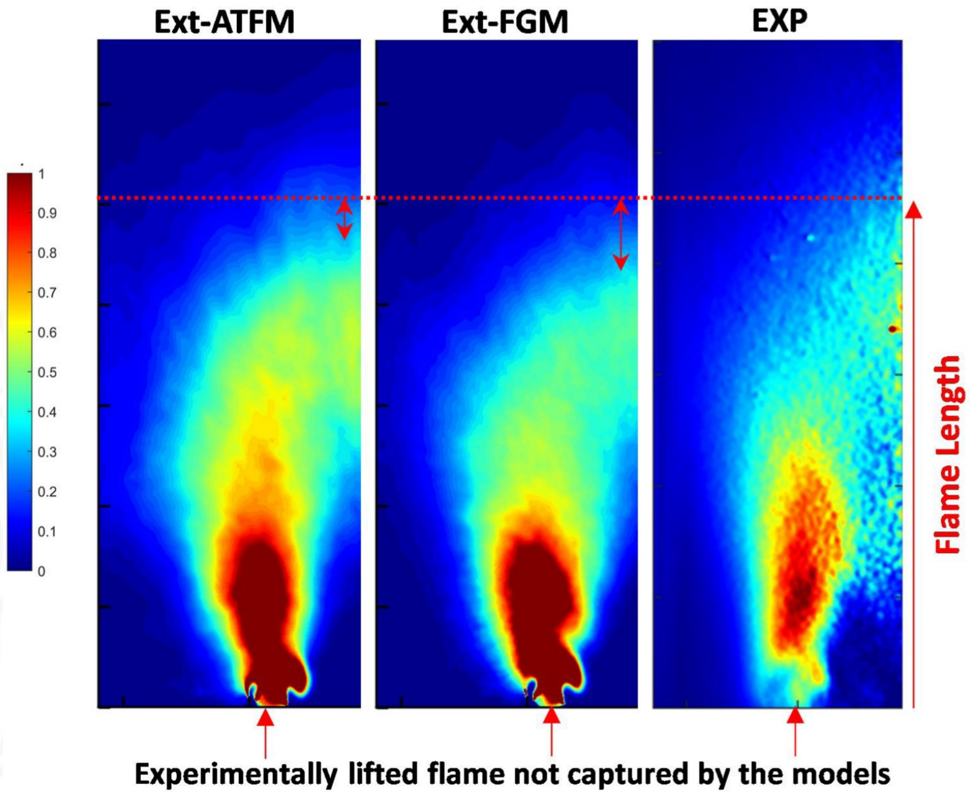


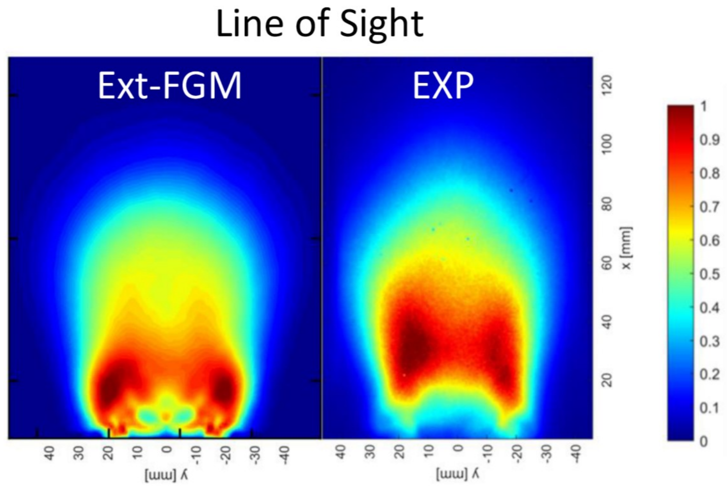
Higher temperature peak



- ✓ Higher reactivity for the Standard FR:
  - Shorter flame
  - Higher temperature peak around the pilot jet exit
- ✓ Adiabatic wall boundary condition
  - Limited heat loss effects
  - Reactivity differences mainly due to strain effects
    - The difference between FR & E-FR will rise when constant wall temperature is applied

ATF Vs FGM: Flame Morphology

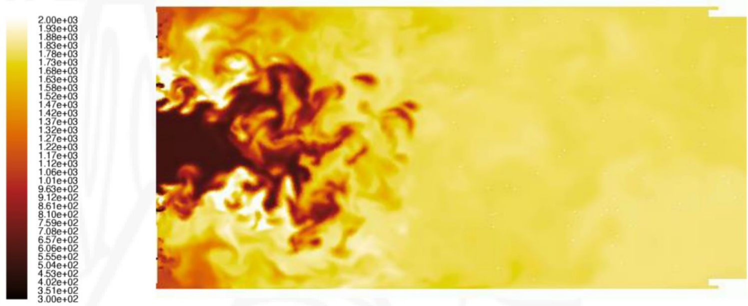


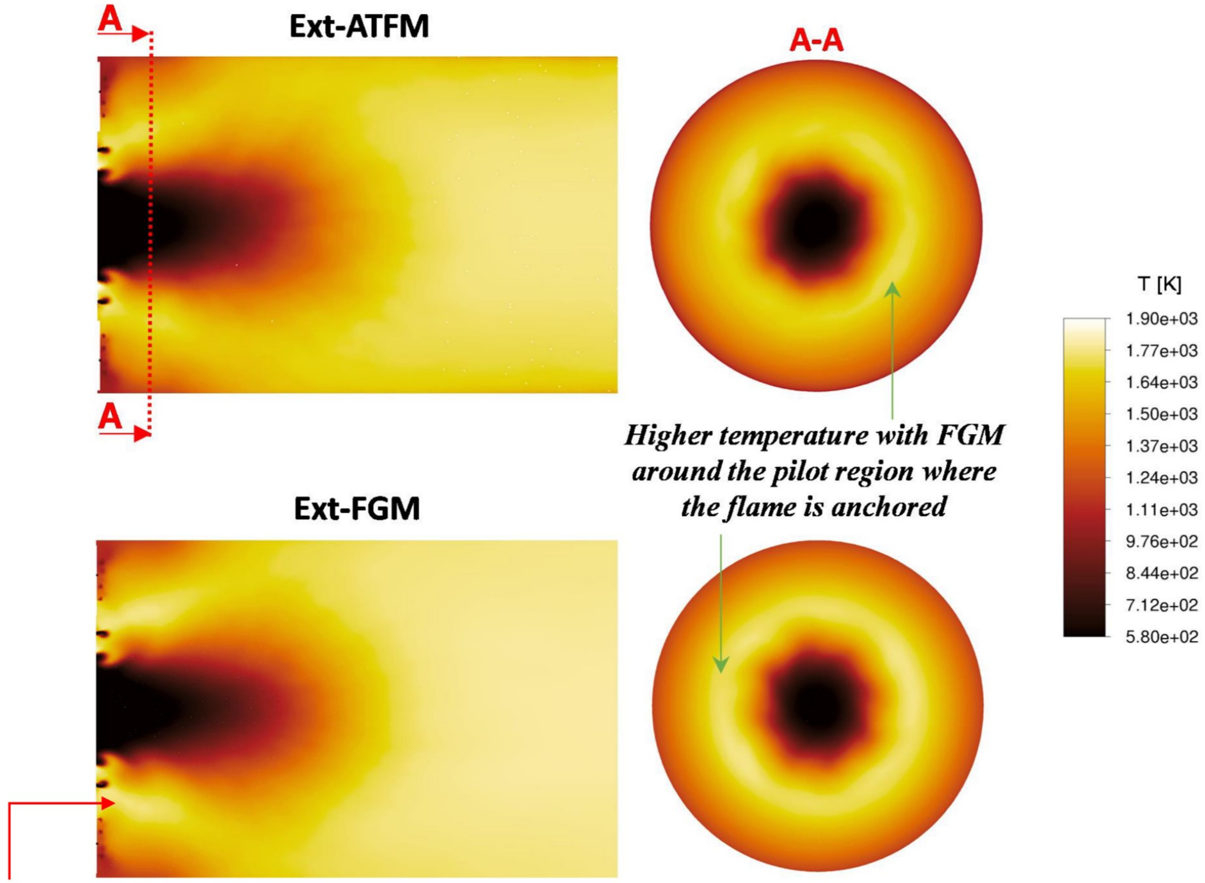


- ✓ Exp: OH∗ chemiluminescence
  - Abel-deconvoluted (Left), Line of Sight (Top)
- ✓ CFD: time-averaged contour plots of heat release
- ✓ Both models predict the flame length reasonably well
  - Ext-FGM affected by a higher reactivity
- ✓ EXP: lifted flame
- ✓ CFD: anchored flame (lift not captured by both models)
  - adiabatic thermal boundary condition on burner walls
  - New simulations currently ongoing

ATF Vs FGM: Thermal Field

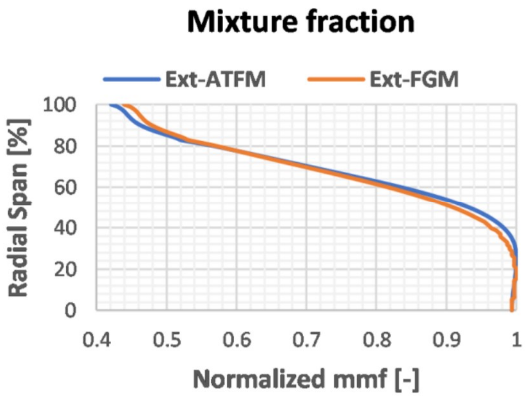
- ✓ The enhanced reactivity of the FGM has a direct impact on the thermal field
- ✓ Higher peak temperature for the FGM around the pilot region
- ✓ Potential impact on NOx emission prediction

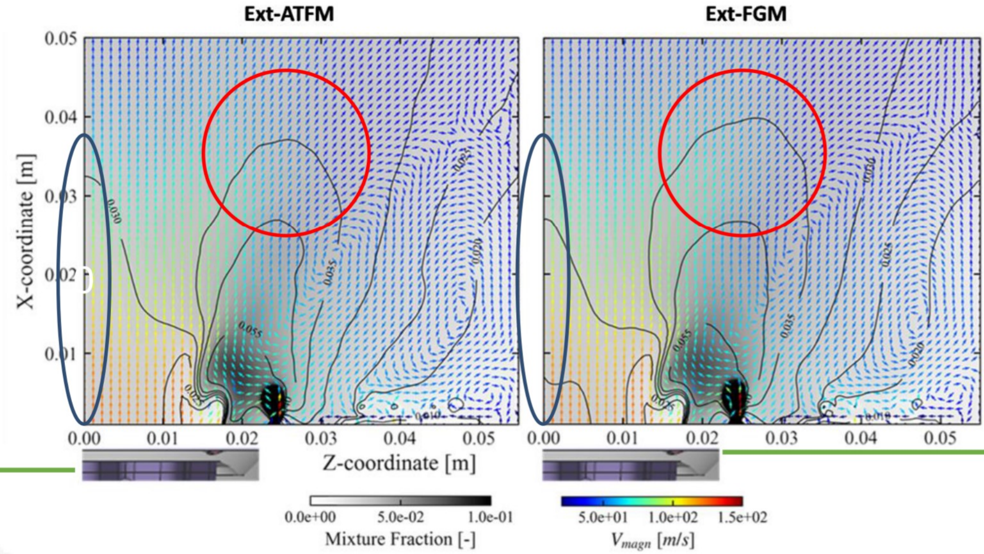


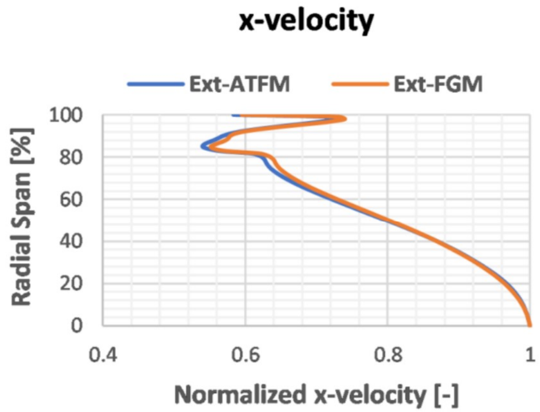


Higher temperature peak

ATF Vs FGM: Mixing and Velocity Field







- ✓ The minor differences in the flame shape prediction between the two models do not appear to significantly affect the flow field in the burner exit region
- ✓ Just a few discrepancies:
  - Along the centerline ($Z = 0$) the ATFM model exhibits a more axially developed fluid region outside the main burner characterized by higher Z values compared to the FGM model
  - Conversely, in the pilot region, the zone with higher mixture fraction values appears to be shorter for the ATFM model
  - These observations suggest that in the ATFM model, the pilot flame mainly enriches the main region rather than the recirculation zone.

Conclusions & Future Developments

- ✓ Both models are capable of accurately predicting the flame topology, with ATFM showing slightly higher accordance with the experimental data
  - FGM marginally underestimates the flame length, thus indicating a slightly higher reactivity affecting the approach
    - future test with USD instead of GRI
  - No substantial impact on the flow field
- ✓ the exclusion of wall heat losses from the analysis may impact the flame shape
  - further investigations for both models are currently ongoing
- ✓ the FGM shows suitability for design-phase simulations by reasonably replicating the results from more computationally intensive models, such as the ATFM.

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Thanks for your attention

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