

Numerical characterization of premixed methane flames in vitiated atmosphere at supercritical conditions

Citation for published version (APA):

Lo Presti, F., Post, P., di Mare, F., & van Oijen, J. A. (2020). *Numerical characterization of premixed methane flames in vitiated atmosphere at supercritical conditions*. 3rd International Seminar on Non-Ideal Compressible-Fluid Dynamics for Propulsion & Power (NICFD 2020), Delft, Netherlands.

Document status and date:

Published: 29/10/2020

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
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3rd International Seminar on Non-Ideal Compressible-Fluid Dynamics for Propulsion & Power

Delft, 29th - 30th October 2020

Numerical characterization of premixed methane flames in vitiated atmosphere at supercritical conditions

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² *Department of Mechanical Engineering, Eindhoven University of Technology*

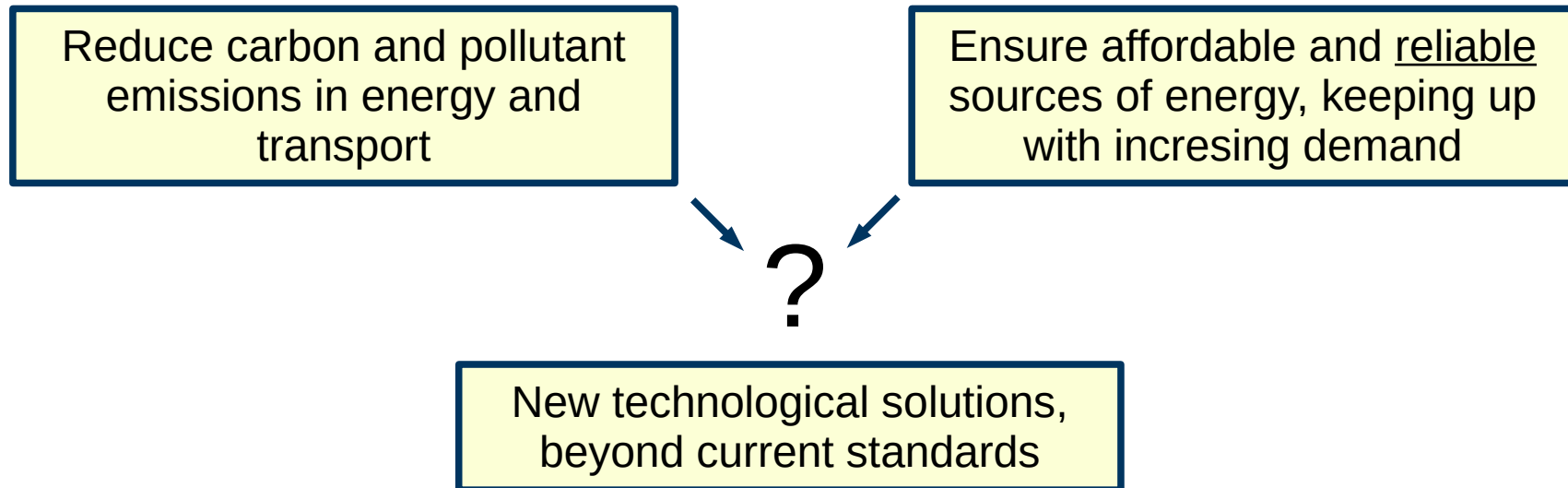


RUHR-UNIVERSITÄT BOCHUM

CHAIR OF THERMAL TURBOMACHINES AND AEROENGINES

Introduction and motivation

Fundamental technological challenges in the next future

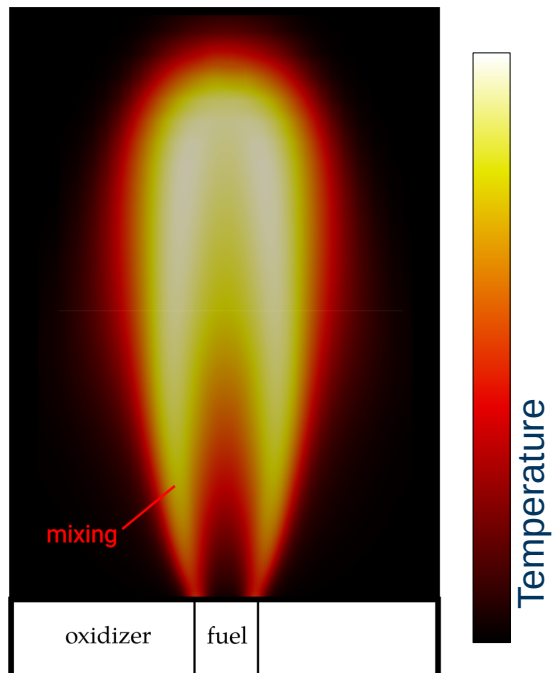


Some research trends in gas turbines:

- Hydrogen combustion
 - Carbon Capture and Sequestration
e. g. in directly fired supercritical CO₂ power cycles
- reduce CO₂ emissions
• oxyfuel: no NO_x
• higher density: lower size

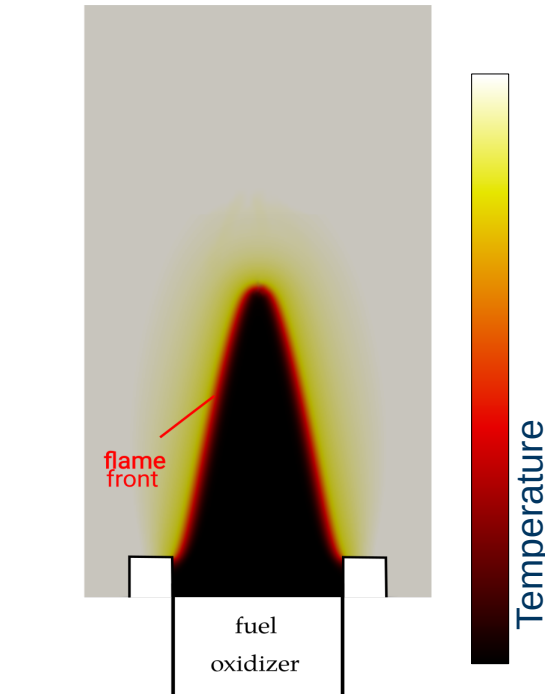
Introduction and motivation

Non-premixed



Most application of supercritical combustion

Premixed



Unexplored field at very high pressures

Stability critical issue

Purpose:

Characterize flame properties

Develop numerical model for stability studies

Outline

- Introduction and Motivation
- One dimensional flames:
 - Chemistry solver
 - Chemistry mechanisms
 - Equation of state, thermodynamics and transport
- Two dimensional application
 - Coupling CFD and chemistry solver
 - Bunsen flames results
- Conclusions and outlook

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One dimensional flames

Chemistry solver

CHEM1D¹

- One-dimensional laminar flame code
- Complex chemistry reaction mechanisms

Extended with

- Peng Robinson EOS with consistent thermodynamics
- High pressure Chung's method for mixture transport properties

¹CHEM1D, A one-dimensional laminar flame code, Eindhoven University of Technology. <http://www.combustion.tue.nl/chem1d>

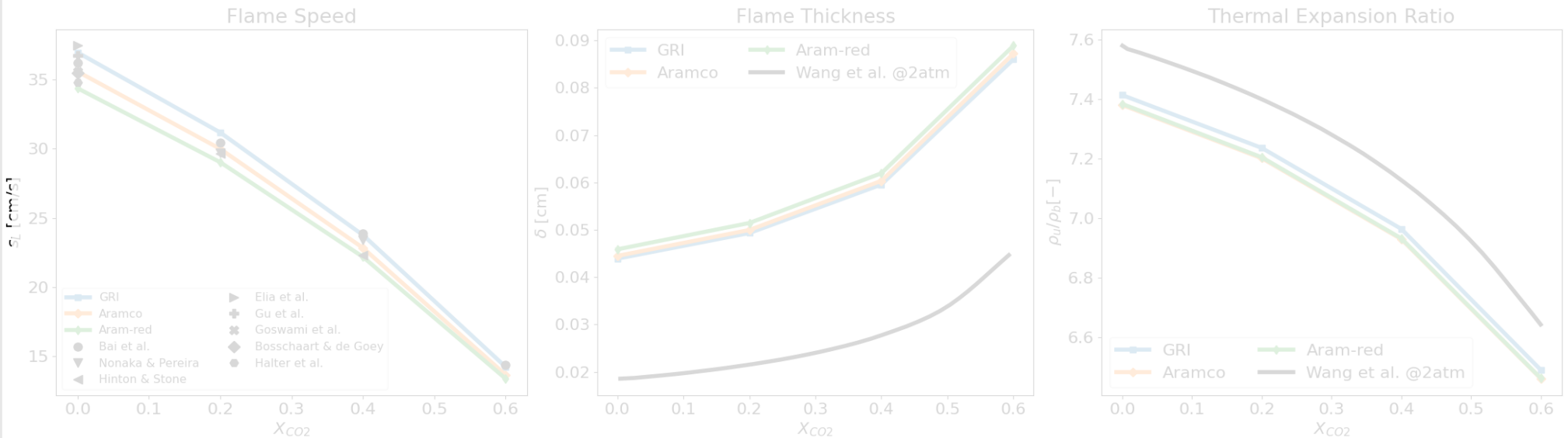
One dimensional flames

Biogas mixtures

Φ	Fuel		Oxidizer		
	CH ₄	CO ₂	N ₂	O ₂	Ar
1.0	1.0	0.0	0.781	0.21	0.009
1.0	0.8	0.2	0.781	0.21	0.009
1.0	0.6	0.4	0.781	0.21	0.009
1.0	0.4	0.6	0.781	0.21	0.009

Unburnt mixture T=300K

Validation at low pressure



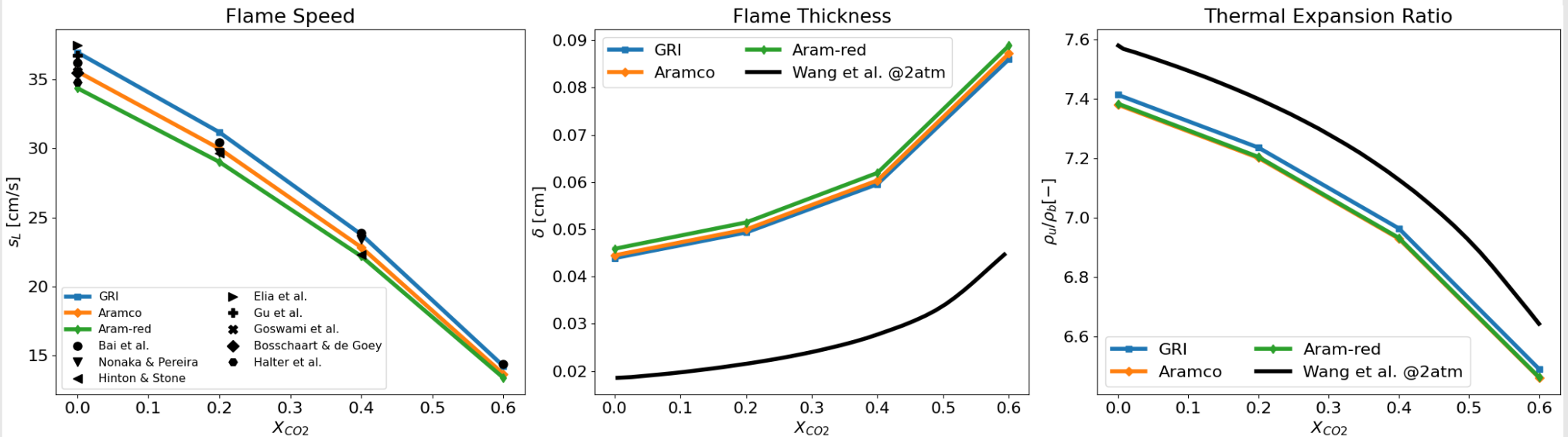
One dimensional flames

Biogas mixtures

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1.0	0.6	0.4	0.781	0.21	0.009
1.0	0.4	0.6	0.781	0.21	0.009

Unburnt mixture T=300K

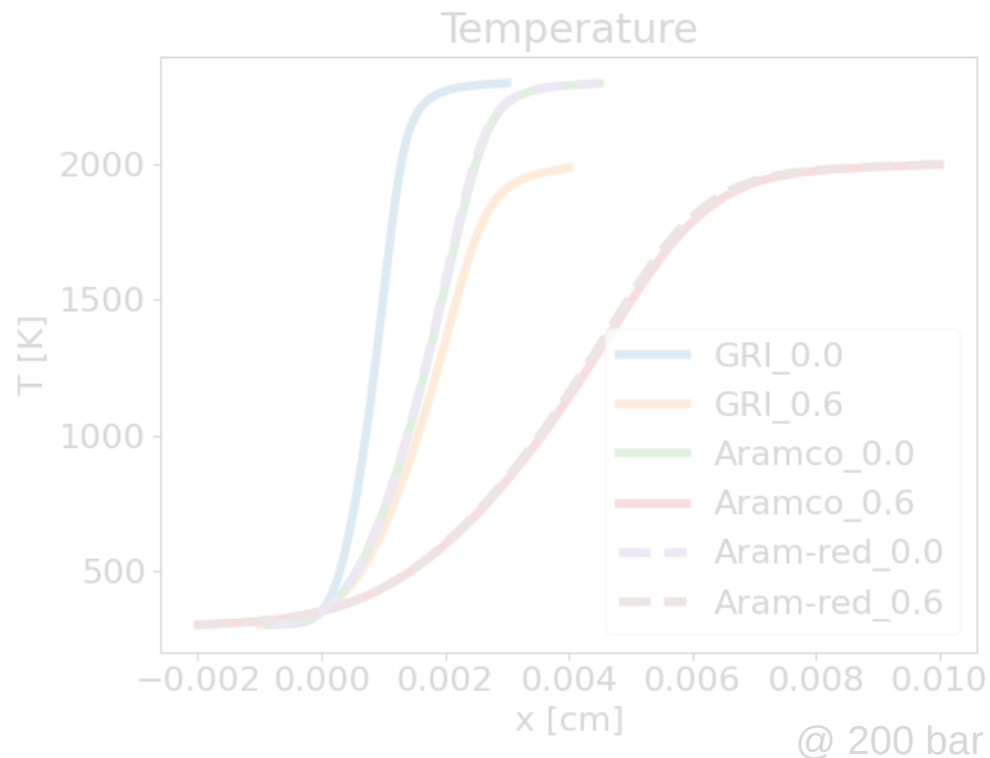
Validation at low pressure



One dimensional flames

Chemistry mechanism

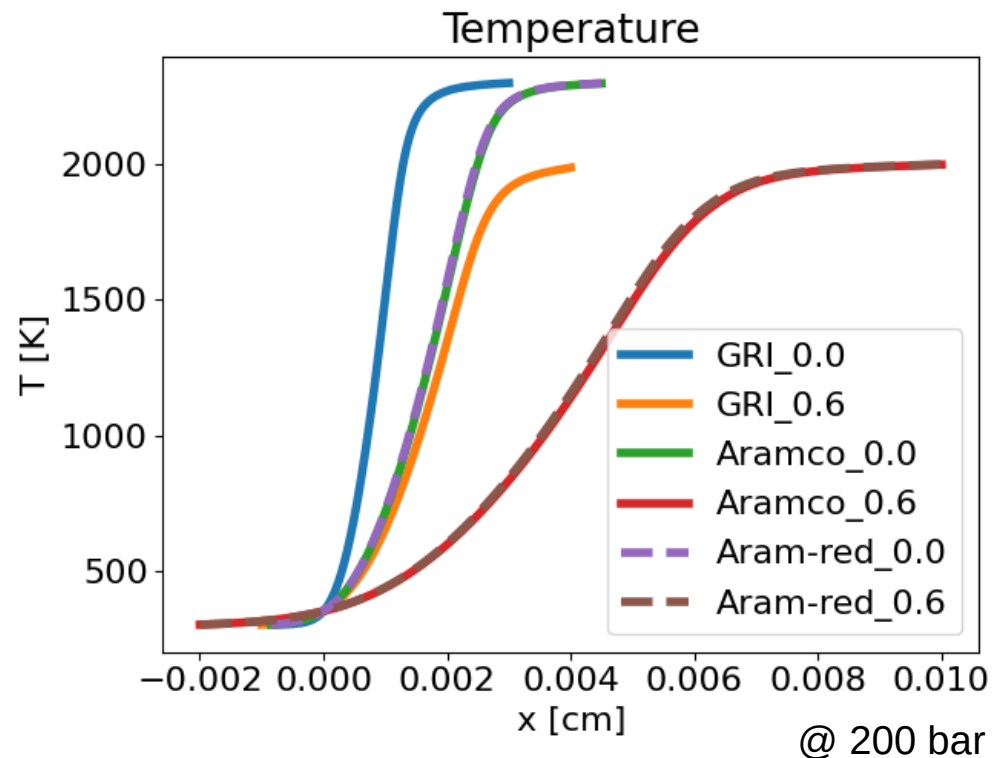
- GRI 3.0 (53 species and 255 reactions, not validated for high p)
- AramcoMech2.0 (493 species and 2716 reactions, computationally expensive)
- AramcoMech2.0 – reduced (37 species and 223 reactions)



One dimensional flames

Chemistry mechanism

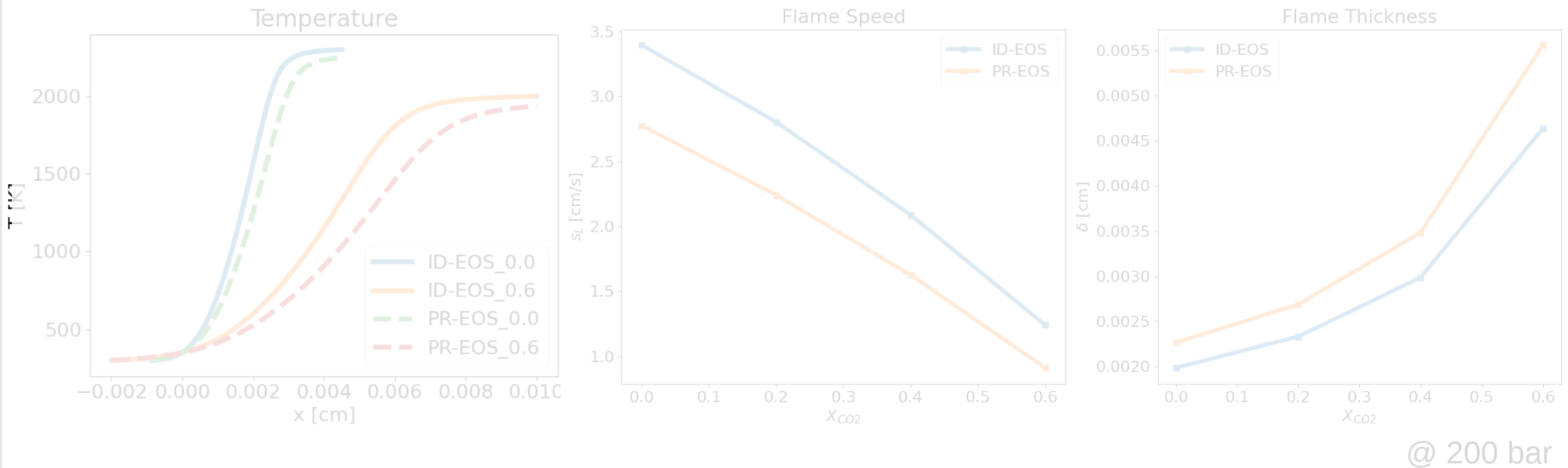
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One dimensional flames

EOS, thermodynamics and transport

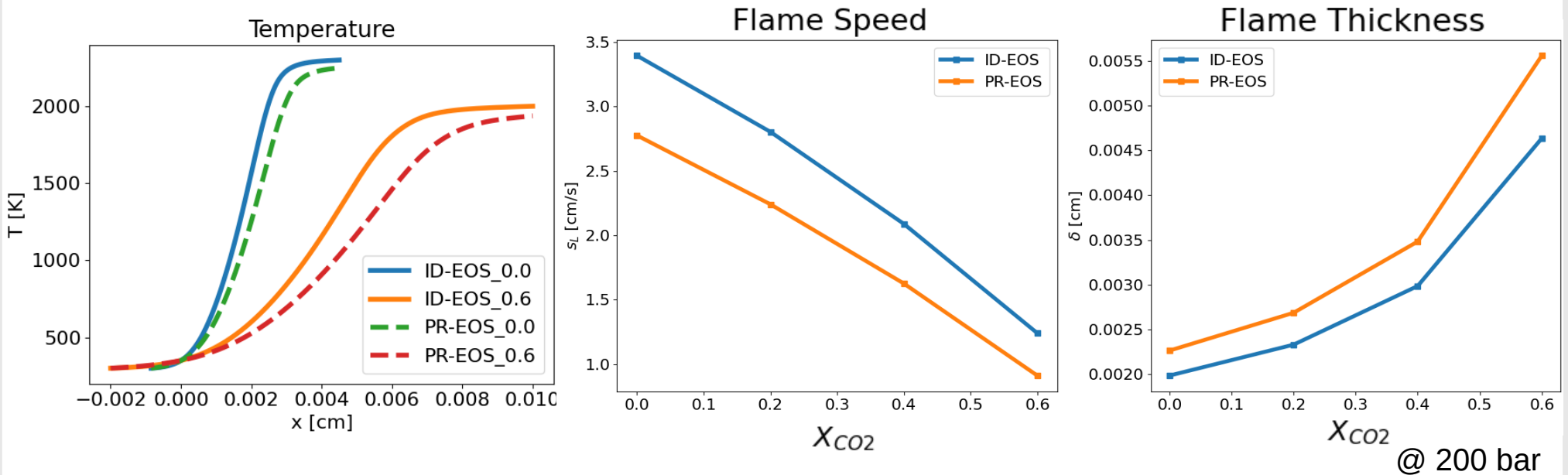
- ID: Ideal Gas EOS, Nasa Polynomials, Power Law
- PR: Peng Robinson EOS, NASA Polynomials + correction, Chung's method



One dimensional flames

EOS, thermodynamics and transport

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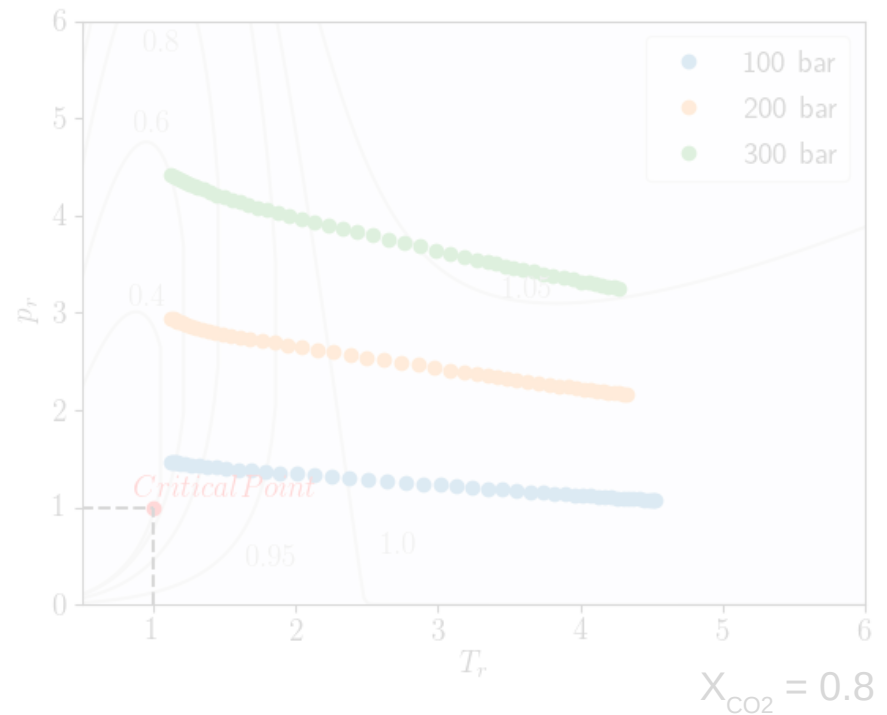
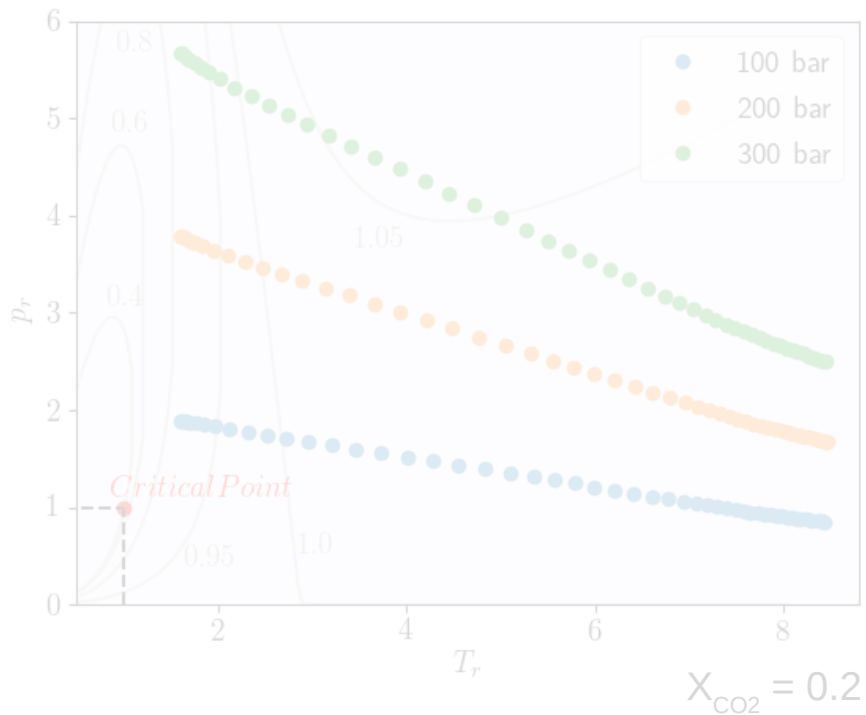


One dimensional flames

OxyFuel combustion

	Fuel		Oxidizer	
Φ	CH ₄	CO ₂	O ₂	
1.0	1.0	0.2	0.8	
1.0	1.0	0.4	0.6	
1.0	1.0	0.6	0.4	
1.0	1.0	0.8	0.2	

Unburnt mixture T=300K

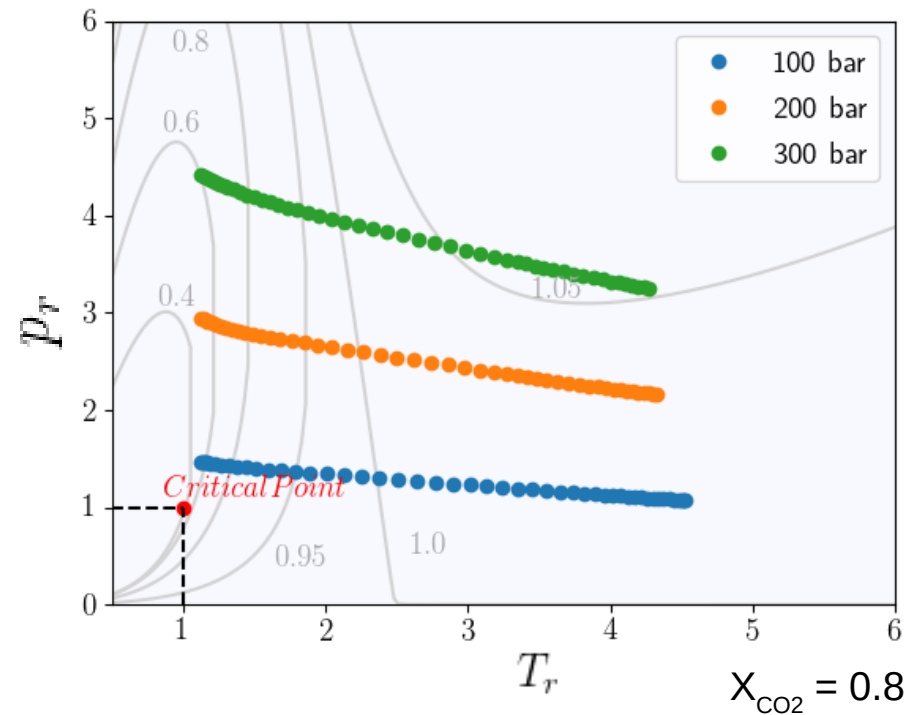
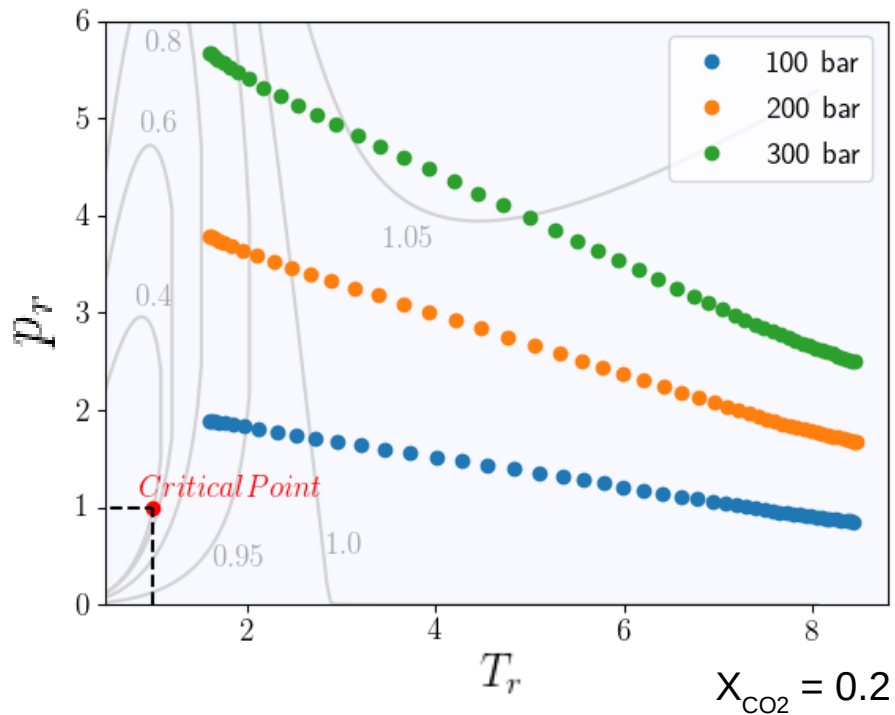


One dimensional flames

OxyFuel combustion

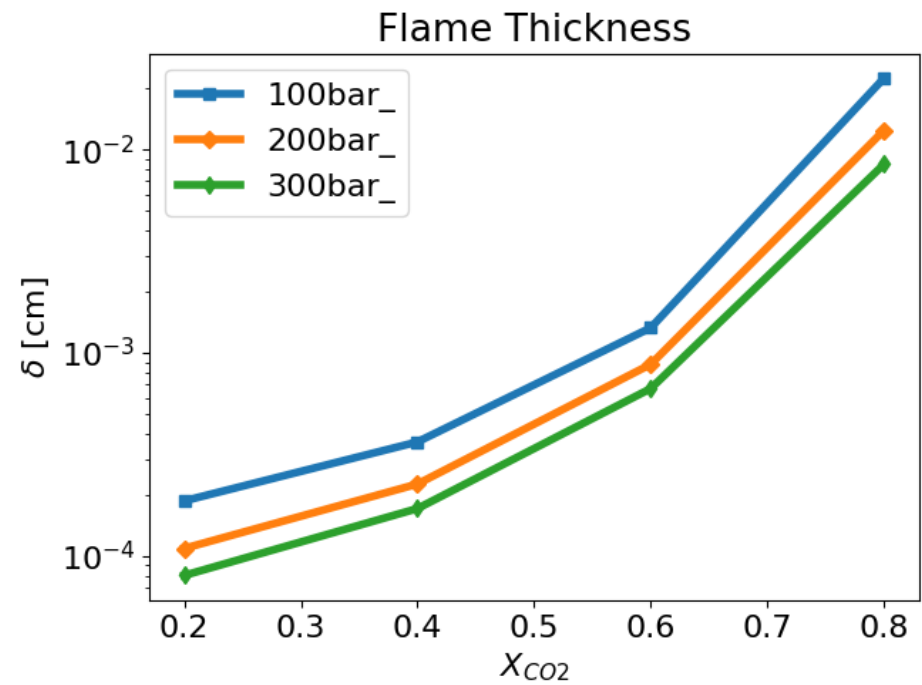
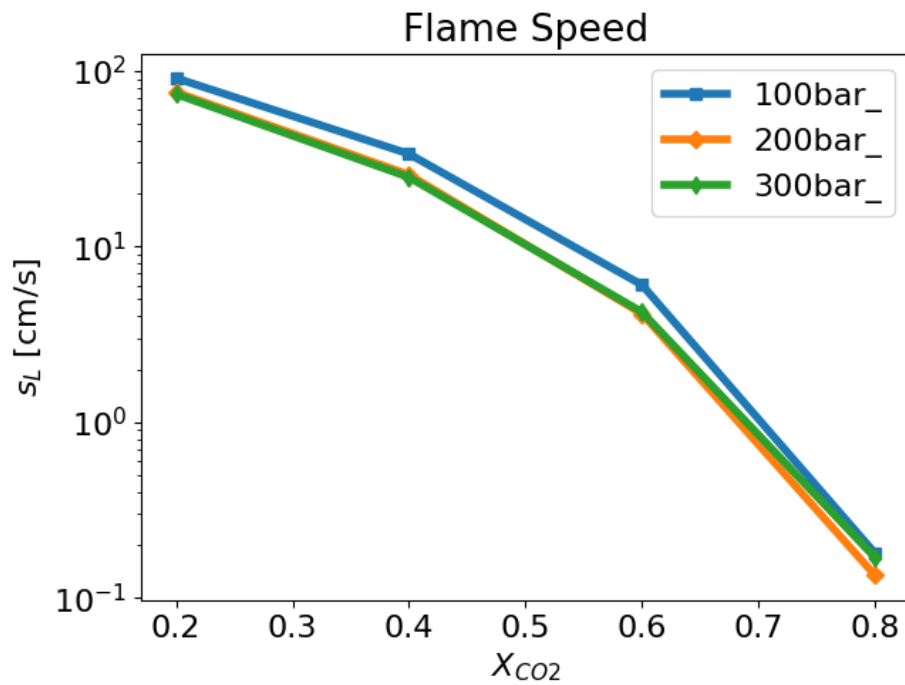
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1.0	1.0	0.8	0.2	

Unburnt mixture T=300K



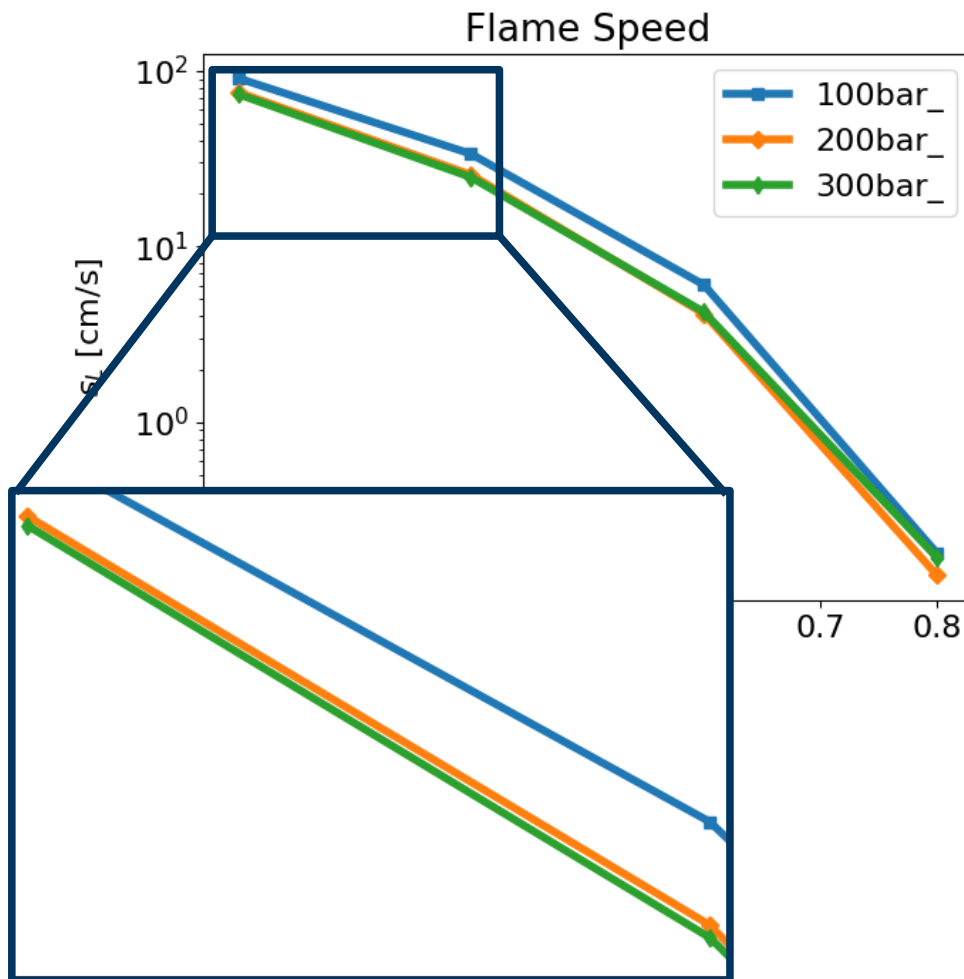
One dimensional flames

OxyFuel combustion



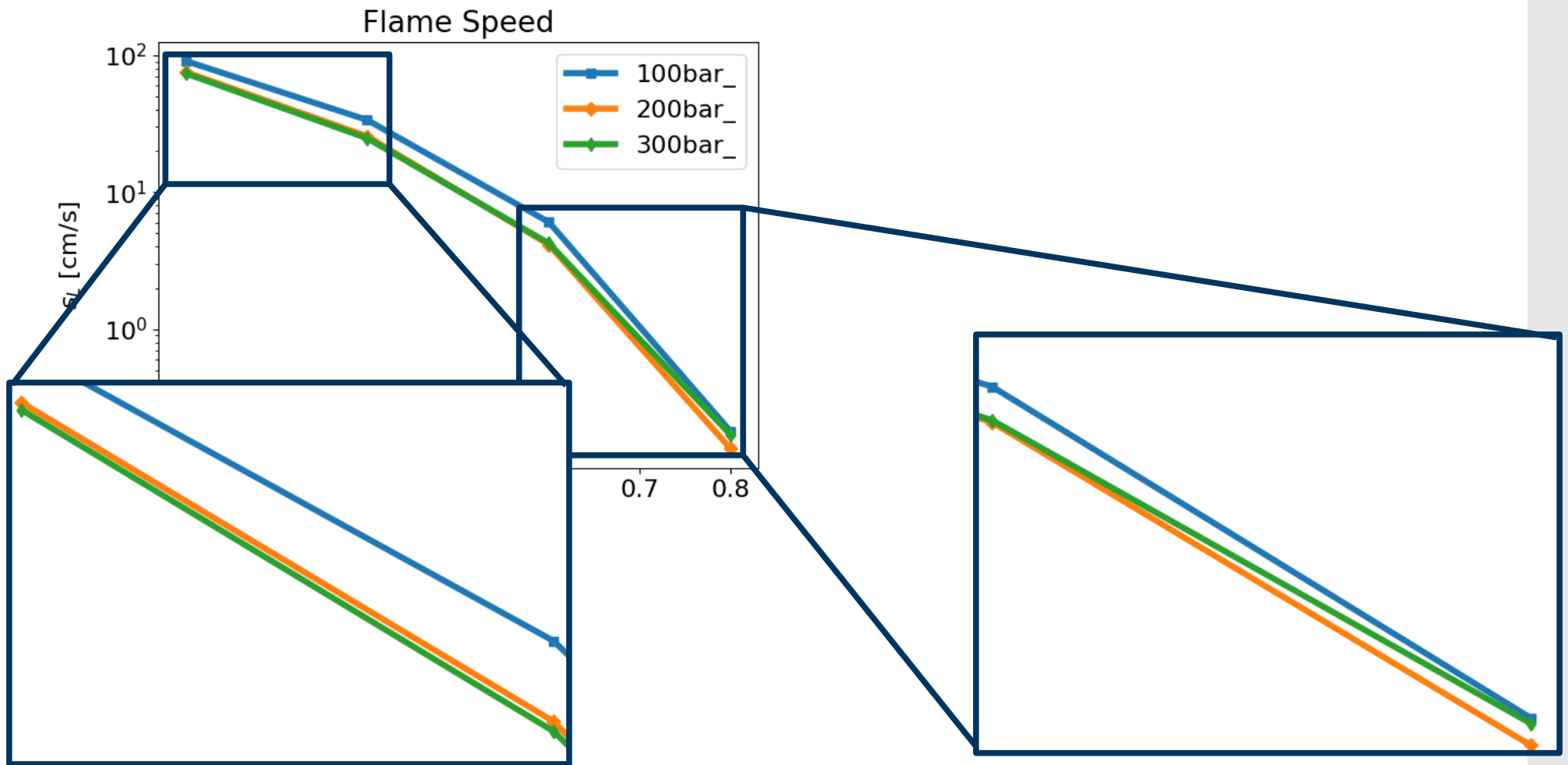
One dimensional flames

OxyFuel combustion



One dimensional flames

OxyFuel combustion

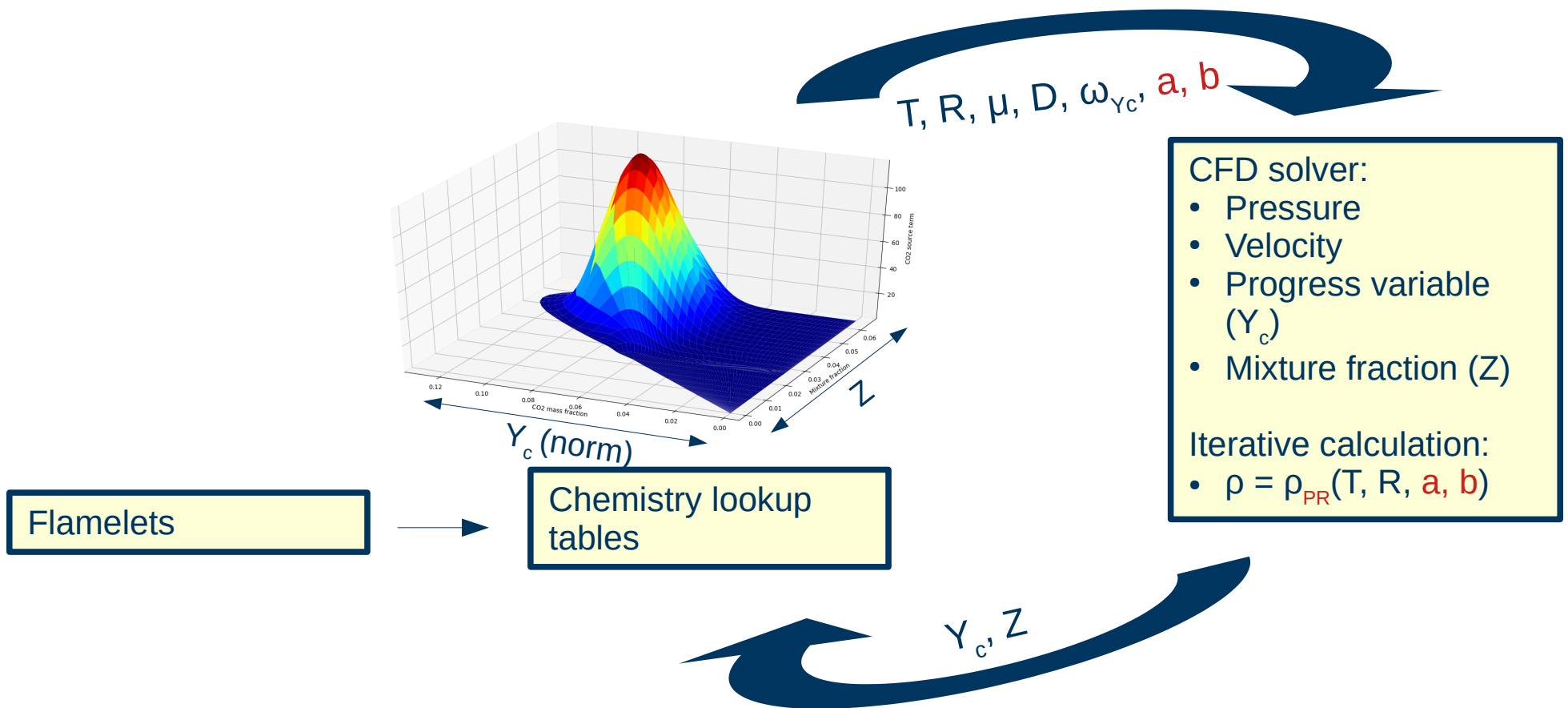


Outline

- Introduction and Motivation
- One dimensional flames:
 - Chemistry solver
 - Chemistry mechanisms
 - Equation of state, thermodynamics and transport
- Two dimensional application
 - Coupling CFD and chemistry solver
 - Bunsen flames results
- Conclusions and outlook

Two dimensional flames

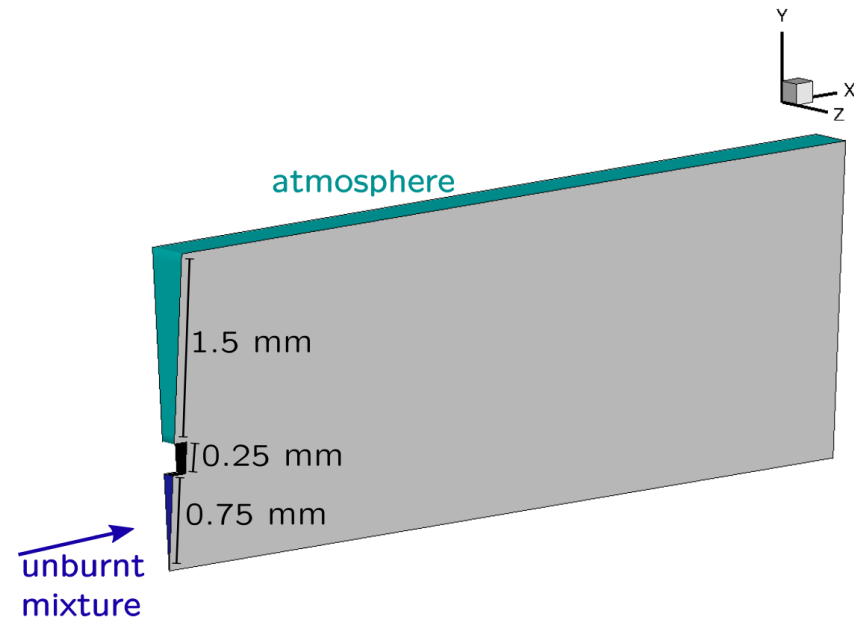
Coupling CFD solver with chemistry tables



Two dimensional flames

Results

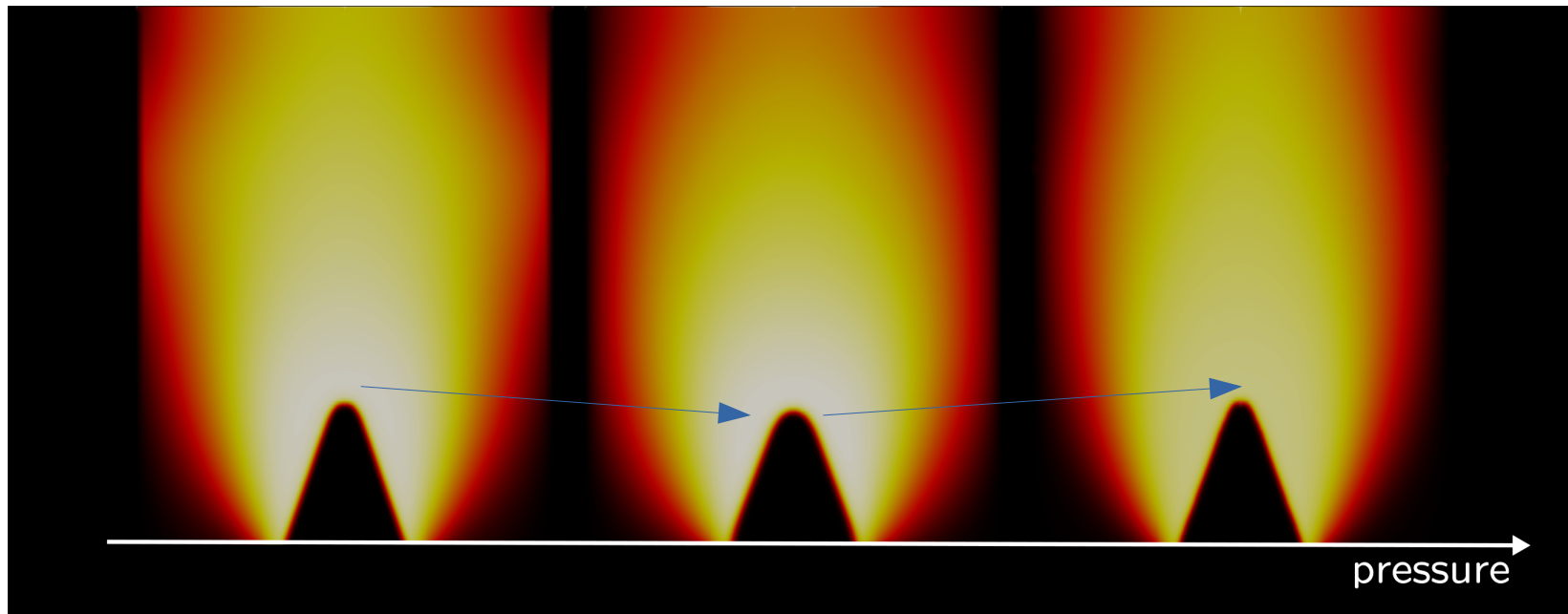
- OpenFOAM + CHEM1D tables
- Unconfined Bunsen configuration
- Fuel: CH₄, Oxidizer: 80% CO₂, 20% O₂
- Pressure: 100/200/300 bar
- Re = 47 - 206



Two dimensional flames

Results

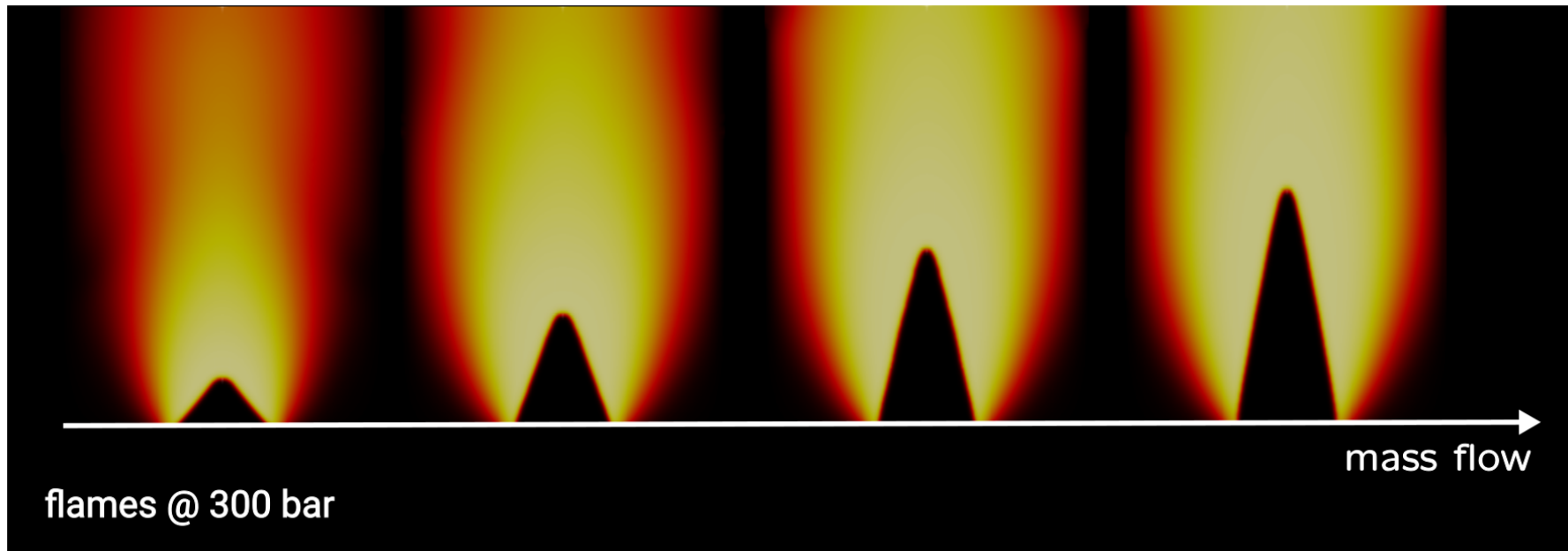
Pressure	Laminar Flame Speed	Unburnt Mixture Velocity
100 bar	1.6926 mm/s	6.7704 mm/s ($4 s_L$)
200 bar	1.2691 mm/s	5.0764 mm/s ($4 s_L$)
300 bar	1.5988 mm/s	6.3925 mm/s ($4 s_L$)



Two dimensional flames

Results

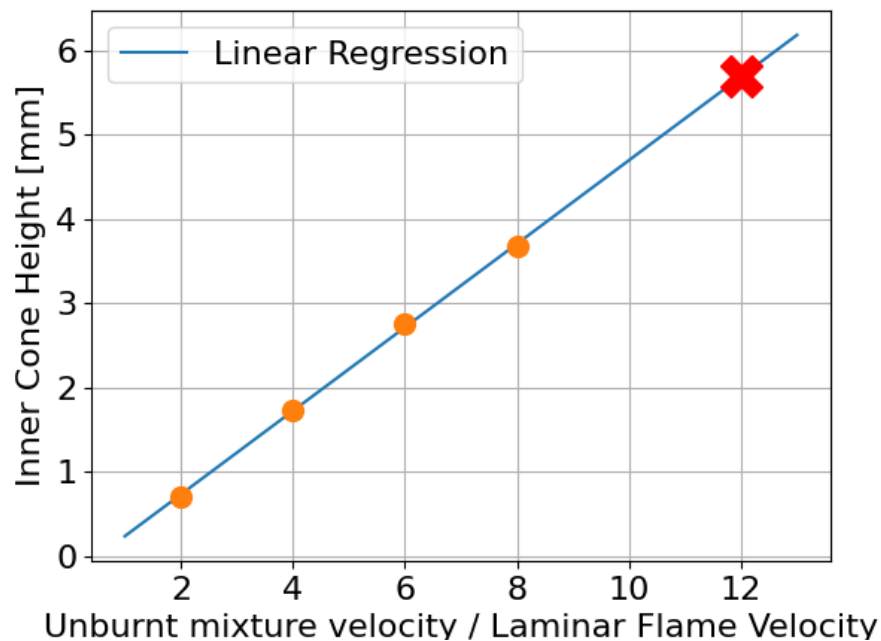
Pressure	Unburnt Mixture Velocity
300 bar	3.1976 mm/s ($2 s_L$)
300 bar	6.3925 mm/s ($4 s_L$)
300 bar	9.5928 mm/s ($6 s_L$)
300 bar	12.7904 mm/s ($8 s_L$)
300 bar	19.1856 mm/s ($12 s_L$)



Two dimensional flames

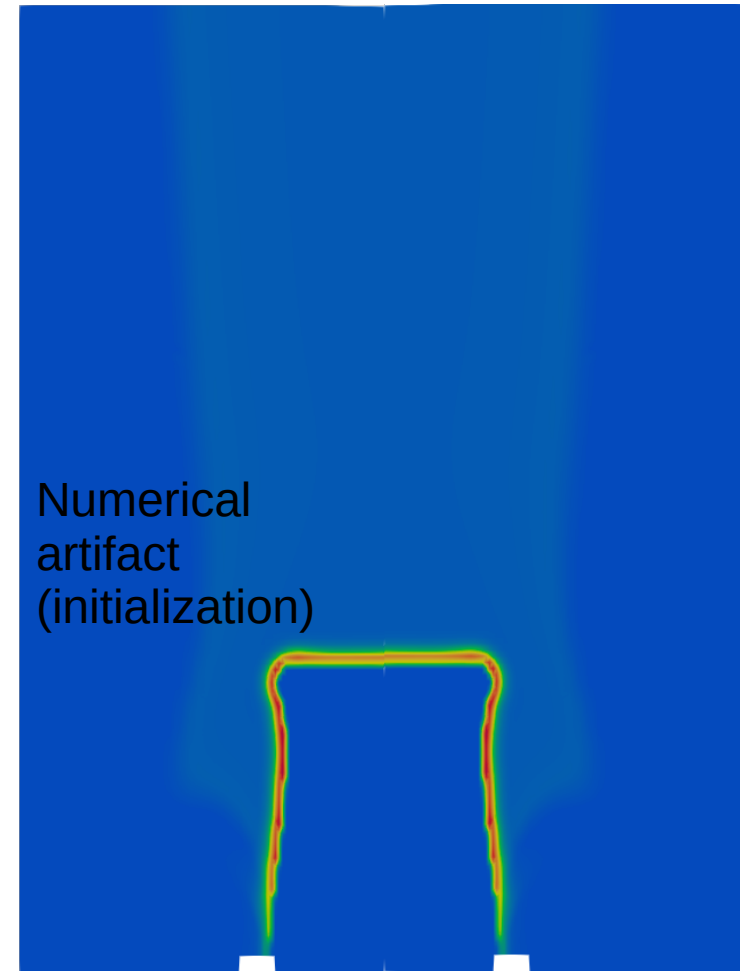
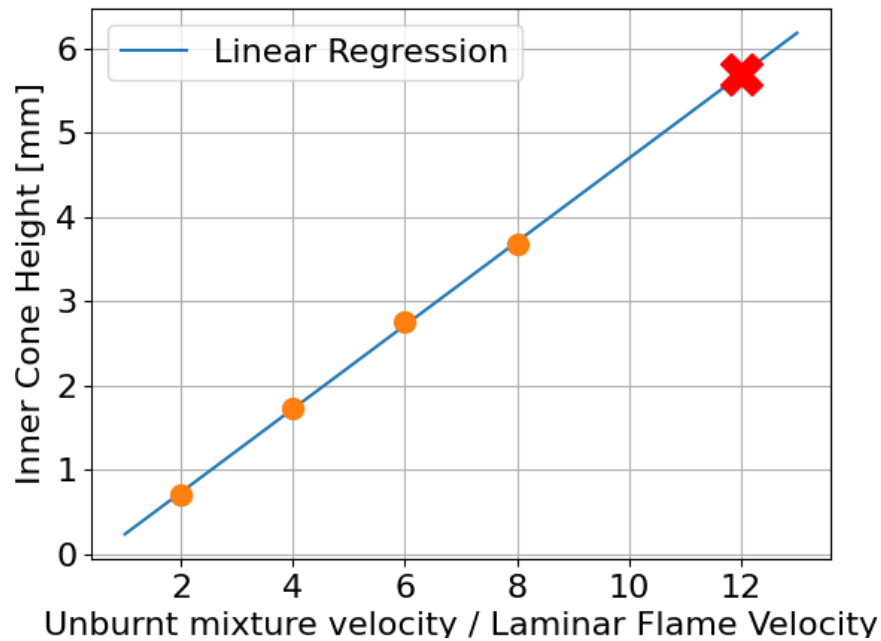
Results

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Two dimensional flames

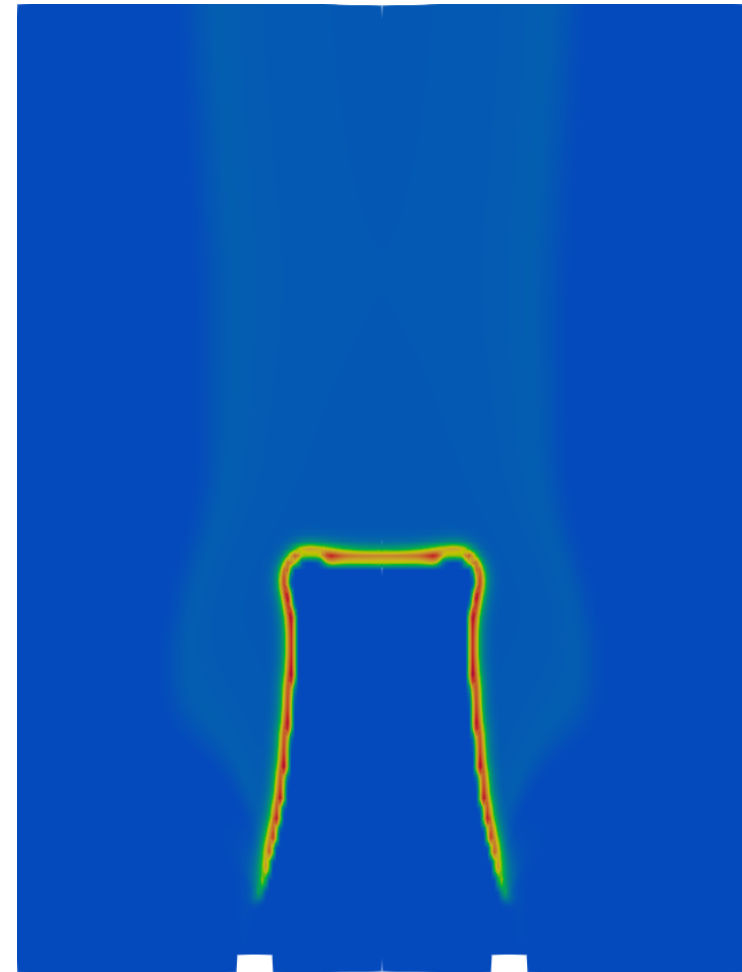
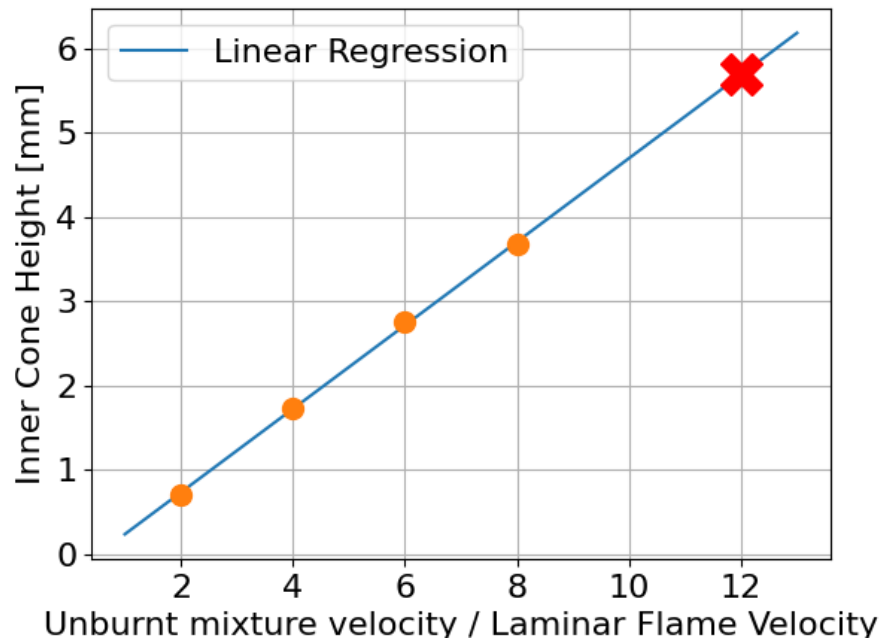
Results



Progress variable reaction rate
@ $t = 0.15s$

Two dimensional flames

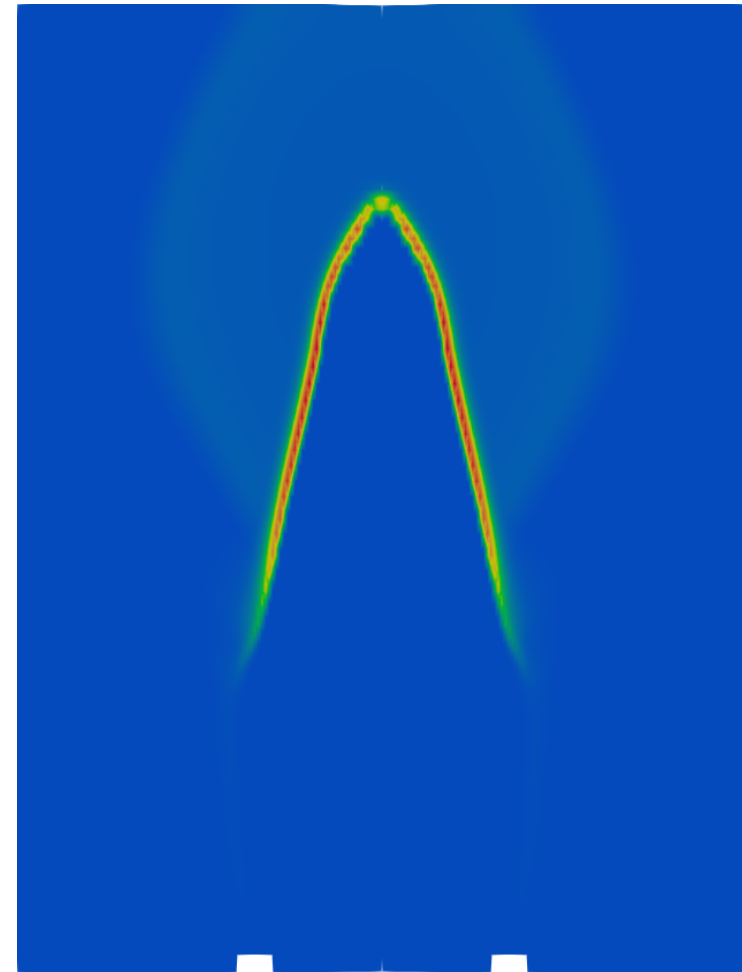
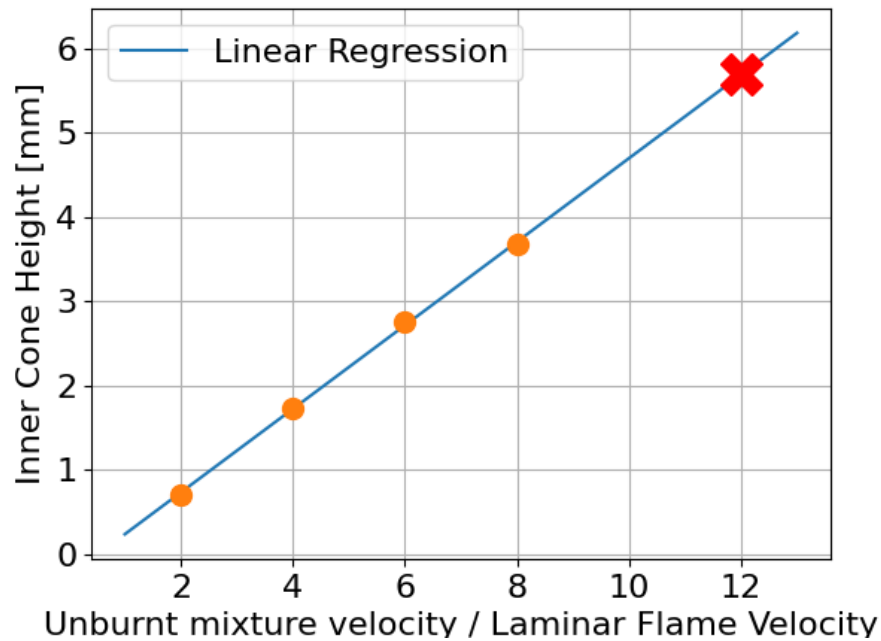
Results



Progress variable reaction rate
@ t = 0.20s

Two dimensional flames

Results



Progress variable reaction rate
@ $t = 0.46s$

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- **Conclusions and outlook**

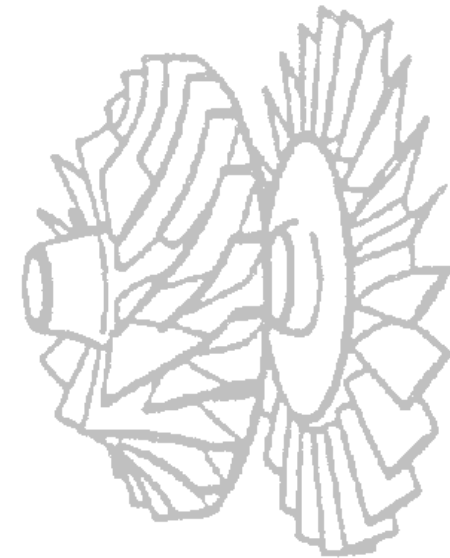
Conclusions and outlook

- Non ideal equation of state, thermodynamics and transport integrated in detailed chemistry solver
- Reduced detailed chemistry mechanism
- Characterization of 1D premixed flames at very high pressure
- Chemistry lookup tables
- Coupled CFD and detailed chemistry solver taking care of new EOS
- Ongoing study on parameters influencing stability of laminar flames
- Future work:
 - Further validation of results
 - Turbulent flames

Thank you for your attention.

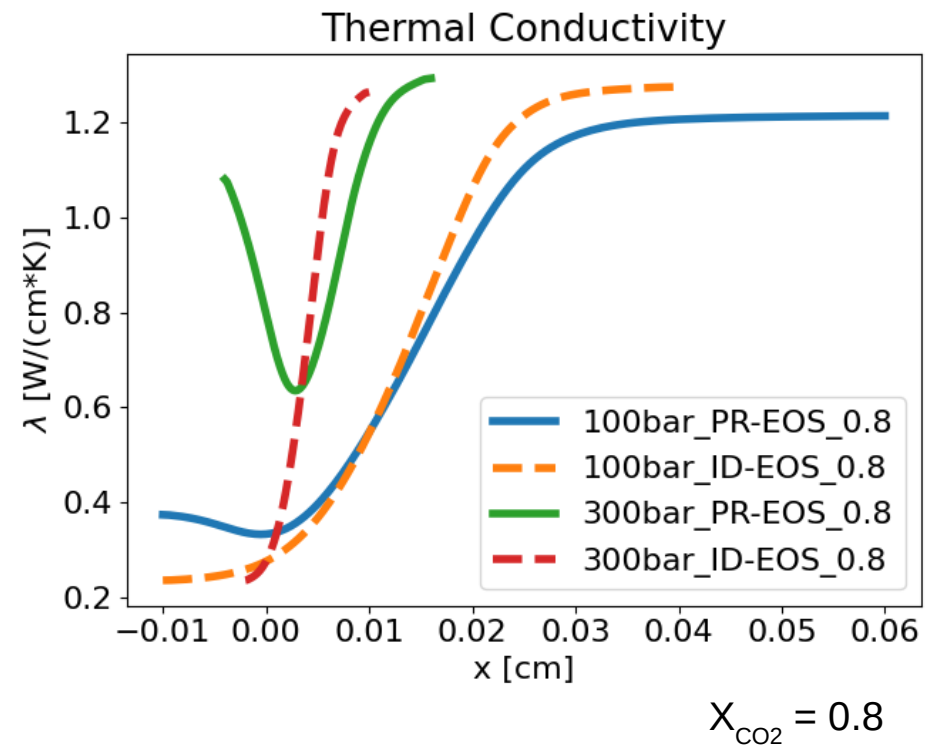
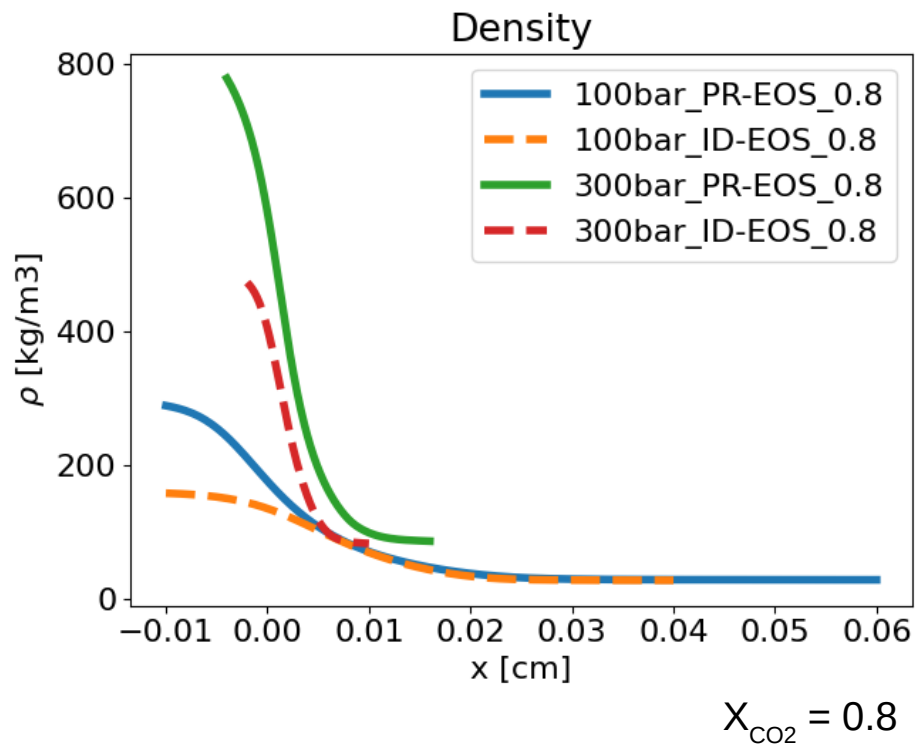
Federico Lo Presti

federico.lopresti@rub.de



One dimensional flames

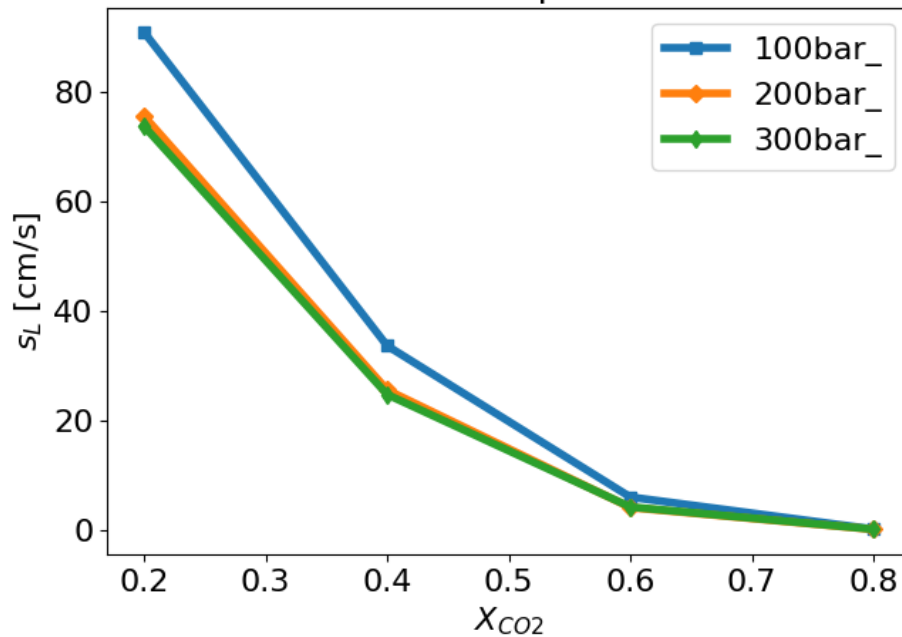
OxyFuel combustion



One dimensional flames

OxyFuel combustion

Flame Speed



Flame Thickness

