Towards flashback prevention in an original micro Gas Turbine combustor fueled by H_2 — 0D/1D predeterminations and LES validation

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Target? Flashback prevention without any redesign of the combustor

The absolute necessity to reduce carbon emissions has led to a significantly increase of the contribution of renewable energy, involving a strong trend towards storing the excess of electricity using **Power-to-Fuel**, i.e. production of the so-called green H_2. However, hydrogen combustion is well-known to lead to **flame instabilities**, and potentially to major facility damages. For full **flexibility**, stabilization must be achieved **without** any combustor redesign.

How? Using the diluted conditions from existing advanced cycles

Performing combustion air **humidification** or Exhaust Gas Recirculation (**EGR**) alters the combustor inlet conditions, enabling to slow down the reaction rate, temperature and flame speed. This work presents thus a parametric study to find the optimized dilution level leading to stable combustion, using a hybrid model, combining a 0D Chemical Reactor Network (CRN) with 1D laminar flame calculations. Finally, Large Eddy Simulation (LES) of the actual combustor geometry of the T100 mGT are performed to validate the 0D/1D predetermination.

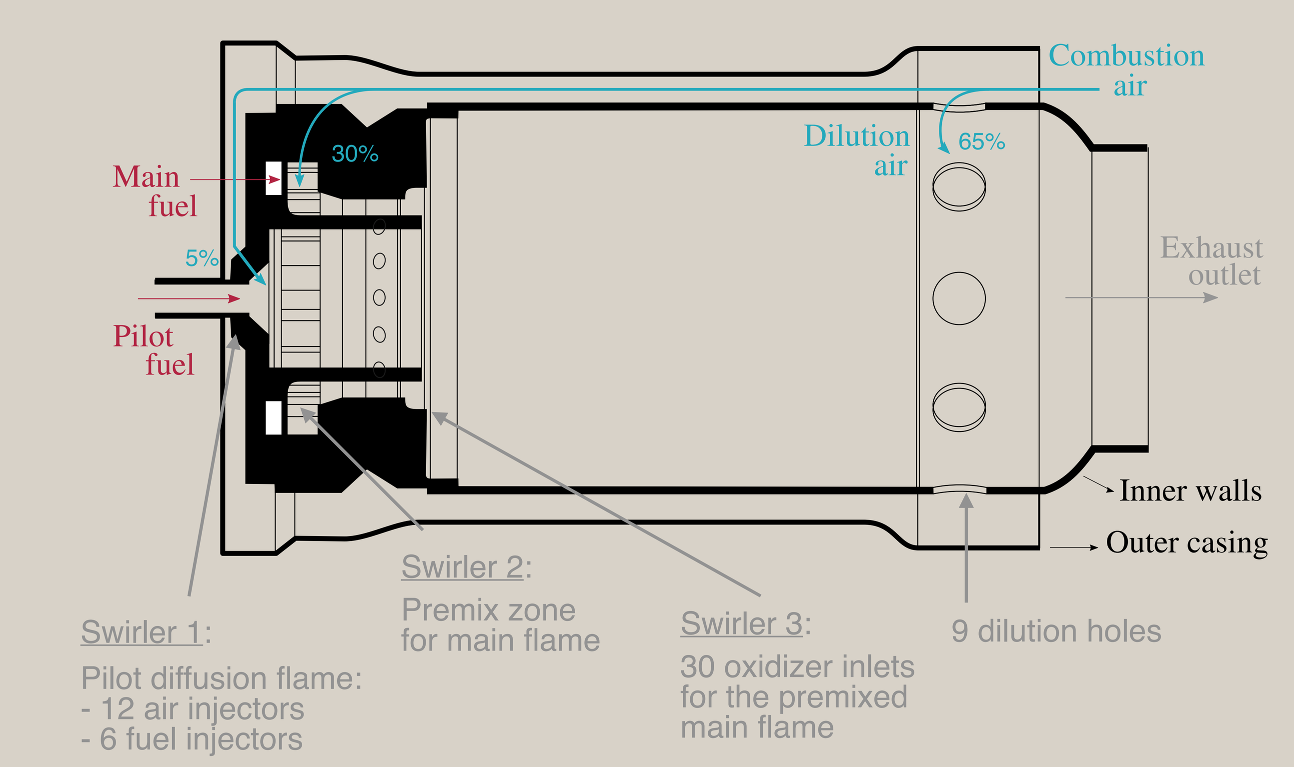
0D Chemical Reactor Network model to emulate the mGT combustor, humidification & EGR

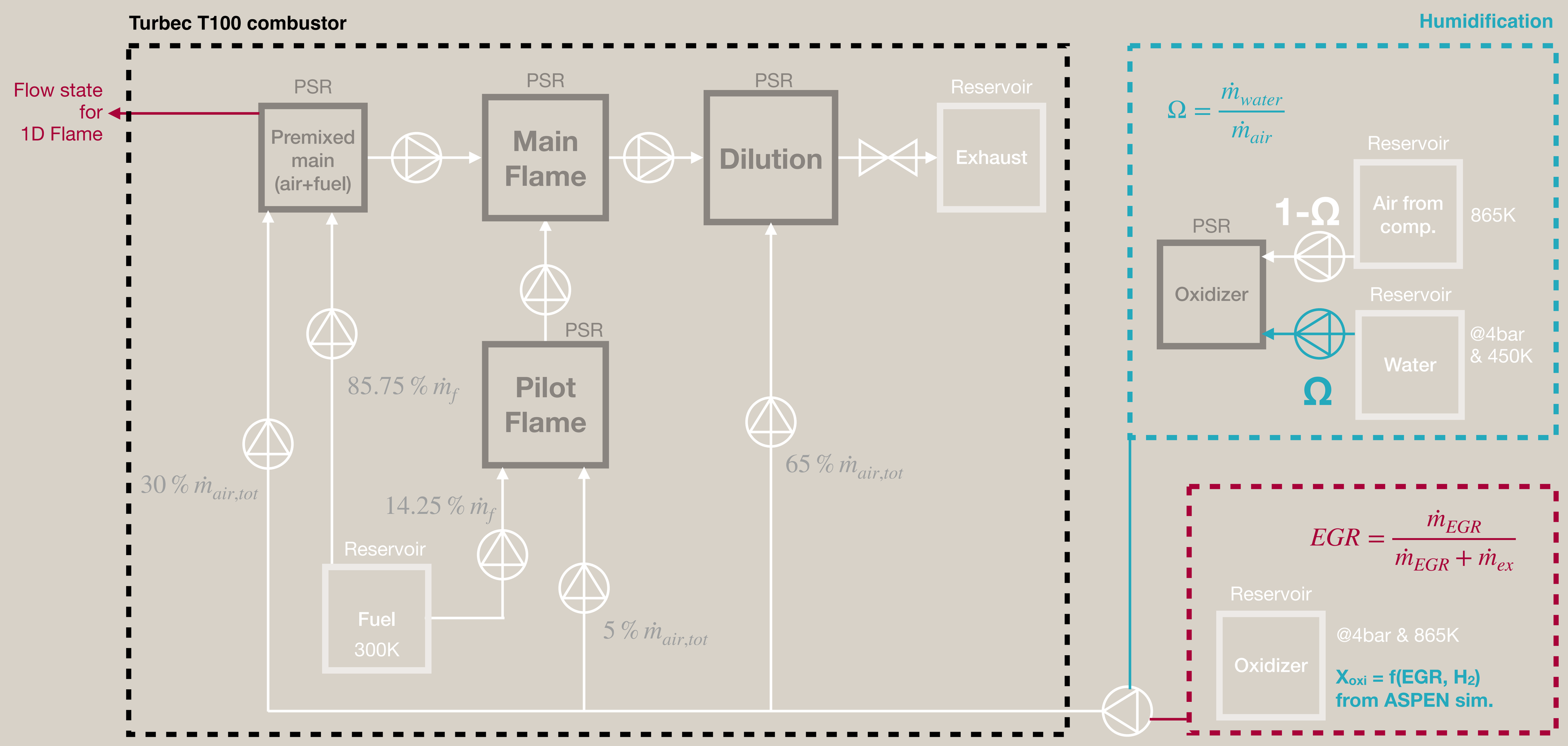
All simulations at **nominal conditions**:

P_{th} = 333 kW_{th}
$\dot{m}_{air}$ = 800 g/s
p = 4 bar
$T_{air,in}$ = 865 K
$T_{f,in}$ = 300 K

For REF case (100% CH_4):
ϕ_{global} ~0.14
$\phi_{local,main}$ ~0.41

Micro Gas Turbine Combustor of the Turbec T100





0D CRN/1D Flame model shows that humidification is more efficient to slow down hydrogen combustion

The 0D/1D calculations are performed using CANTERA

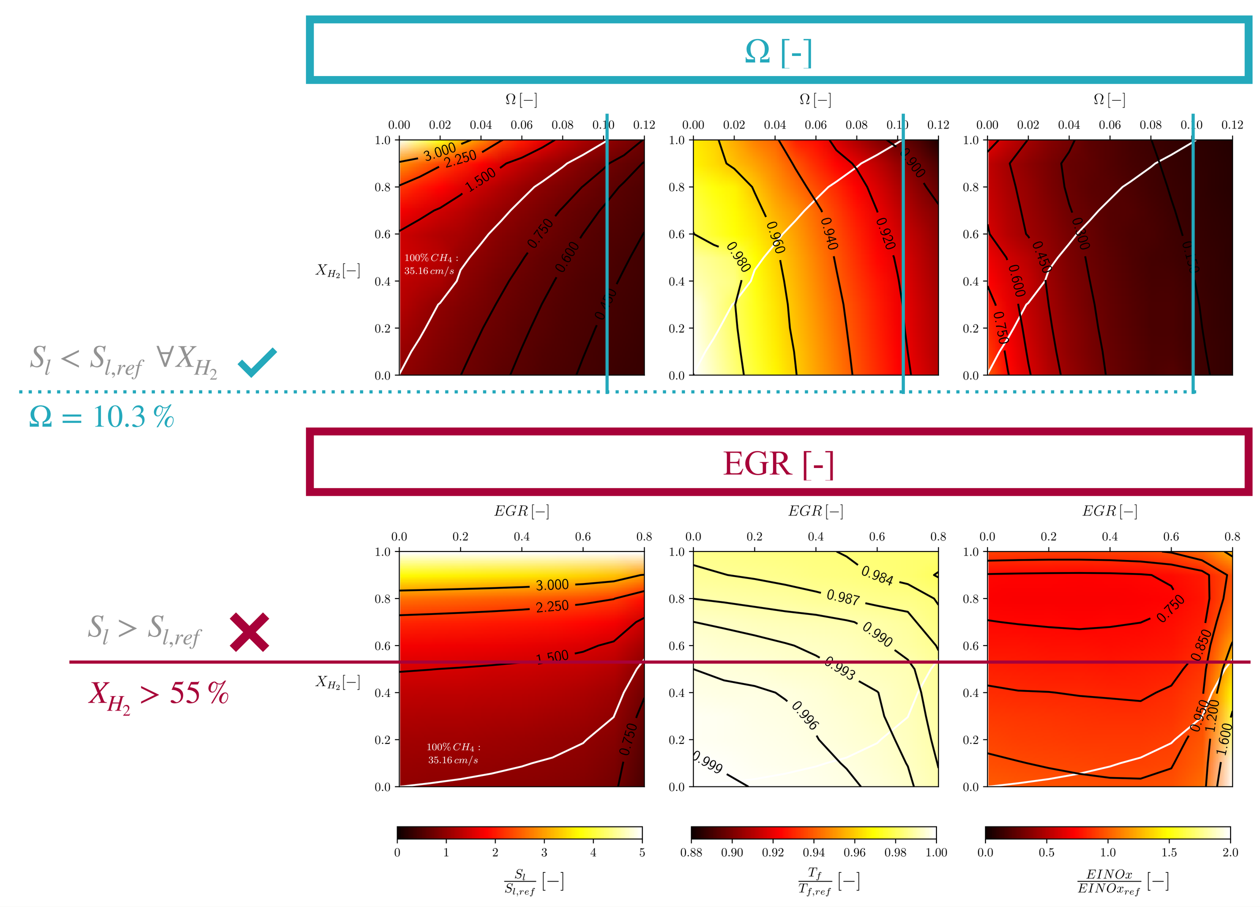
Low-cost prediction of the **minimal quantity** of water/EGR to reach same level of flame speed as pure CH_4 combustion (ref case).

0D CRN allows to take into account the **temperature drop** when water is added to the oxidizer.

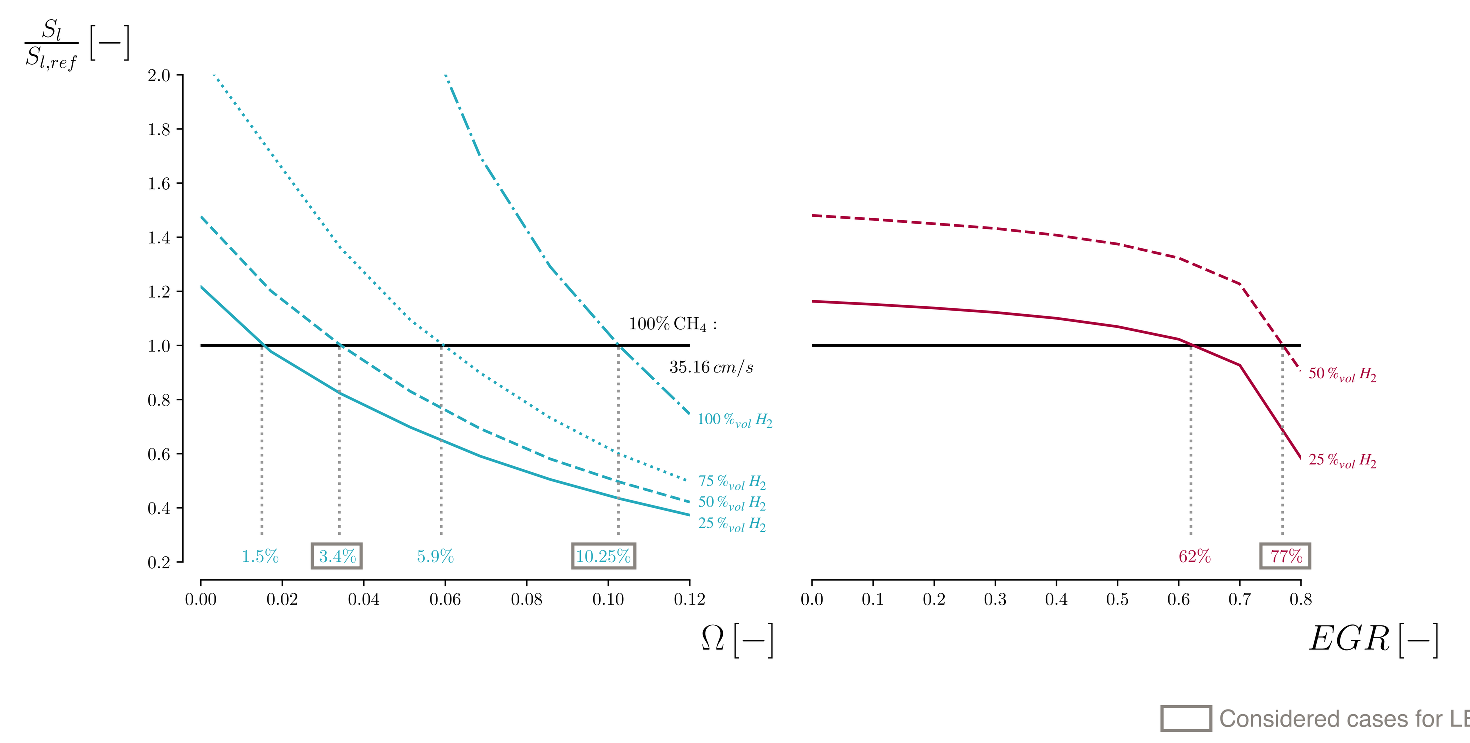
-> Optimize the water qty for the 1D flame calc.

Emission Index of NO_x in [g/kWh]

$$EINO_x = \frac{X_{NO_x} \cdot \dot{m}_{exi}}{P_{el}}$$



0D/1D benchmarking on specific H_2 blends: 100% H_2 case requires only Ω=10.3%



Temperature decrease of **~10%** with water addition, inducing a decrease of the NOx levels.

No significative **temperature** decrease (**~0.2%**) with EGR, while the **NOx** levels actually **increases (~30-60%)**.

Performing **EGR limits** the H_2 content at 50%$_{vol}$ since already 77% of EGR is required.

Numerical set-up

CFD code: YALES2

Sub-grid scale stresses model: Dynamic Smagorinsky

Wall model: Classical log-law
Re = 37500 y^+ = 38 (in the main swirler)

Heat losses: Adiabatic wall condition

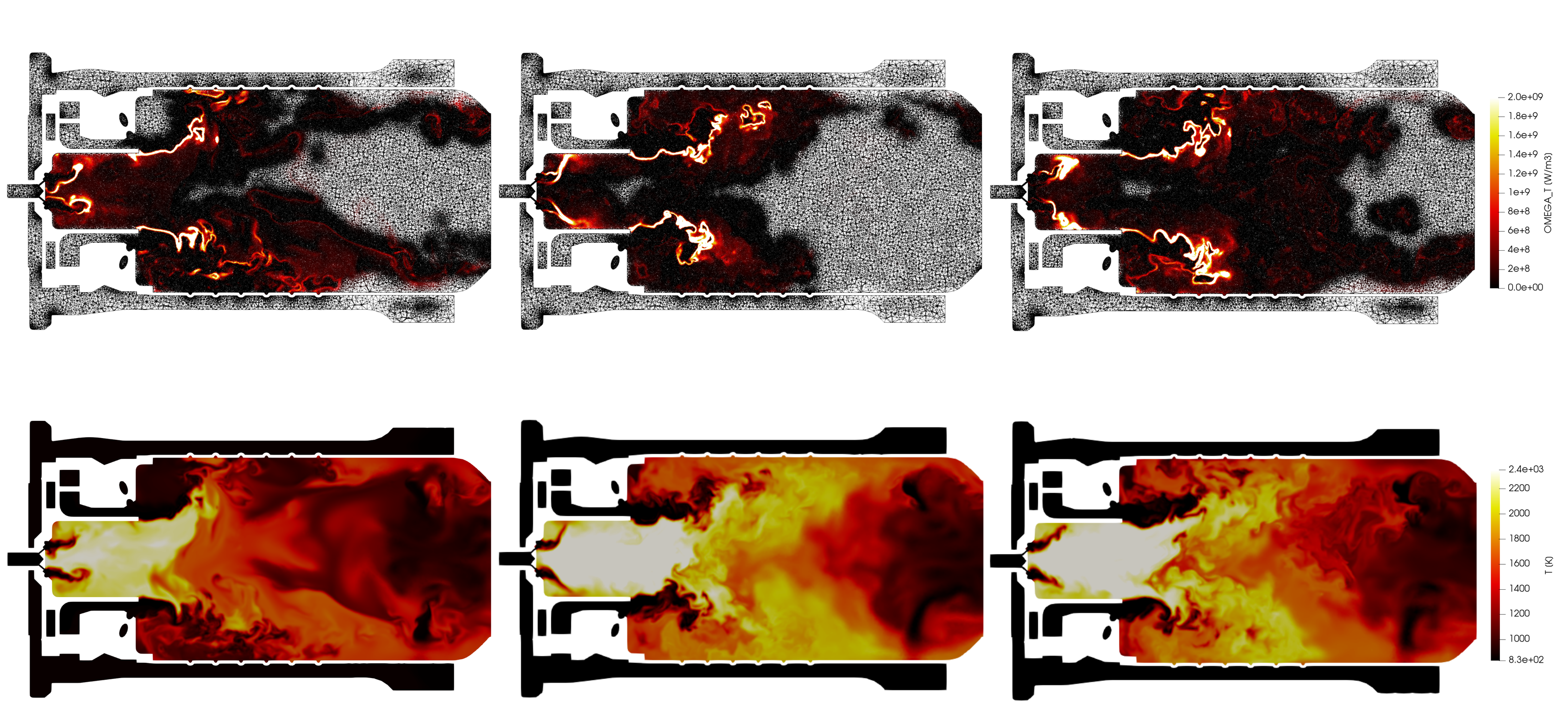
Complex chemistry + reduced kinetic scheme: DRM19

Combustion model: DTFLES

Dynamic Adaptive Mesh Refinement (AMR) to reach ±80.10⁶ tetrahedral cells (Δ_{min} = 0.7mm & Δ_{max} = 3mm)

LES results show no flashback apparition when the predetermined conditions of humidification and EGR

Case 1: 50%$_{vol}$ H_2 — Ω=3.4%   Case 2: 100%$_{vol}$ H_2 — Ω=10.25%   Case 3: 50%$_{vol}$ H_2 — EGR=77%



No flashback   No flashback   No flashback

The reaction rate fields show no flame front going back in the main injectors.

The mesh in the background shows that **AMR** follows the flame evolution **all along the simulation.**

Scan to discover!

Even though a higher temperature is reached in the reacting zone for cases 2 & 3, no temperature increase is observed in the main injectors.

Scan to discover!

Conclusion

Stabilizing hydrogen combustion in mGT **without any redesign** of the combustor is an important challenge. Using a hybrid 0D CRN/1D Flame model, we predetermined the **optimized quantity** of humidification/EGR to reach the same level of flame speed as pure methane combustion. These **low-cost predictions** are successfully validated using **LES simulations** of the real combustor layout of the Turbec T100. Results show stable combustion for the predetermined level of dilution **without any flashback apparition** for all considered cases. Hence we can conclude that this dilution method allows to stabilize H_2 combustion, and the 0D/1D approach provides accurate and low cost predetermination of the operating parameter to avoid flashback apparition.

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