Humidification towards flashback prevention in an original H2 fuelled micro Gas Turbine — 0D/1D predeterminations and LES validation

Alessio Pappa[*,a], Laurent Bricteux[a], Ward De Paepe[a]

[a] *Université de Mons, UMONS, Faculté Polytechnique, B7000, Mons, Belgium*

Introduction

Aiming at stabilizing hydrogen combustion and to prevent flashback apparition in micro Gas Turbines without any redesign of the combustor, this work presents a parametric study over a specific range of operating conditions of the Turbec T100 [1] combustor to find the optimized humidification level of the combustion air for methane/hydrogen blends (at different hydrogen rate) leading to stable combustion.

First, using a hybrid model, combining a 0D Chemical Reactor Network (CRN) with 1D laminar flame calculations, the necessary minimal water amount is assessed and optimized to reach the same level of flame speed as reached in classical pure methane combustion. This methodology allows to predict the combustion temperature and emissions at reduced cost. Then Large Eddy Simulation (LES) of the actual combustor geometry of the T100 mGT are performed to validate the 0D/1D predetermination, by verifying if the predetermined conditions of humidified oxidizer help to stabilize the flame and reduce the reaction rate of hydrogen, and thus prevents flashback.

0D Chemical Reactor Network - 1D Laminar Flame model

Computation for both 0D CRN and 1D Flame are carried out using the CANTERA software [2] with the detailed GRIMech 3.0 (GRI 3.0) [3] mechanism (53 species and 325 reactions). A network of Continuously Stirred Reacor (CSR) is build to emulate the behaviour of the T100 combustor. During the 0D CRN simulation, the state of the flow in the premix chamber is calculated, and used to perform the 1D Flame calculation at the calculated operating conditions. The oxidizer and fuel temperatures have a major impact on the flame speed.

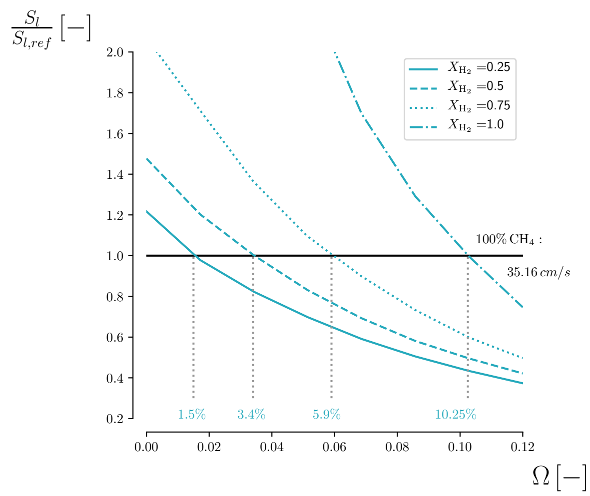

Figure 1: Predicted dimensionless laminar flame speed $S_l^0/S_{l,ref}^0$ compared with the reference case for several H_2/CH_4 blends (25/75, 50/50, 75/25 and 100/0) while the water-to-air ratio Ω is increased. To reach the same level of velocity as the reference case, hydrogen combustion requires respectively a Ω ratio of 1.5, 3.4, 5.9 and 10.25%.

Therefore, being able to accurately predict the temperature drop when water is added in the system would allow to optimize the water quantity, and thus reducing the operational cost of the mGT. A water-to-air mass ratio is considered to define the level of water dilution: $\Omega = \dot{m}_{water}/\dot{m}_{air,tot}$.

Figure 1 presents the operating range in which the flame velocity remains lower than the flame speed of pure methane case (considered as the reference case). It allows to determine the level of water dilution to avoid flashback apparition for various H_2/CH_4 blends. This quantitative analysis of $S_l^0/S_{l,ref}^0$ for a specific range of H_2/CH_4 blends (25/75, 50/50, 75/25 and 100/0), shows that the minimal necessary quantity of water to bring the flame velocity back to the reference level for these blends is respectively a Ω ratio of 1.5, 3.4, 5.9 and 10.25%. These predetermined conditions are validated in next section for the case $50\%_{vol}H_2/\Omega = 3.4\%$, using LES on the actual layout of the T100 combustor.

*Correspondence address: alessio.pappa@umons.ac.be.

Large Eddy Simulation of the T100 combustor

Numerical set-up

The LES, presented in this work, are performed using the massively parallel flow solver YALES2 [4]. Coupling finite-rate chemistry to a detailed chemical mechanism, the kinetic scheme DRM19 (21 species and 84 reactions) [5], the Dynamic Thickened Flames model (TFLES) [6] is considered as combustion model. In addition to this TFLES model, an Adaptive Mesh Refinement (AMR) algorithm is used for the LES simulation. By dynamically refining the mesh in the flame region, based on a combustion criterion using the flame sensor of the TFLES model, the mesh is optimized in terms of cell quantity and distribution. Based on a combustion criterion, the AMR algorithm dynamically refines the mesh all along the flow simulation to lead to the LES mesh. For the validation and the full details of the AMR methodology, the reader is invited to consult [7]. The automatically refined mesh obtained for the LES simulations (Figure 2 (a)) includes almost 83 million of tetrahedral cells where the cells size ranges from $\Delta = 700\,\mu\text{m}$ in the flame front region to $\Delta = 3\,\text{mm}$ in the domain.

Flame stability

In this part, the LES results for the case $50\%_{vol}H_2/\Omega = 3.4\%$ of the instantaneous reaction rate $\dot{\omega}_T$, highlighted on the dynamically adapted mesh (Figure 2 (a)), and the temperature (Figure 2 (b)) color fields are analysed. First, we can clearly observe that the mesh adaptation follows perfectly the flame in the combustor during the simulation (Figure 2 (a)). Then the instantaneous color field of the reaction rate (Figure 2 (a)), highlighting the flame front, clearly shows that the flame front is not going back in the main swirlers. Moreover, the instantaneous color field of the temperature (Figure 2 (b)) does not show either any temperature increase in the main injectors and swirlers. Hence, we can conclude that the LES results does not show any flashback apparition for the predetermined condition of dilution ($\Omega = 3.4\%$ for a 50/50 CH_4/H_2 mixture), validating the low cost 0D/1D predetermination approach.

Conclusion

Aiming at stabilizing hydrogen combustion in mGT without any redesign of the combustor, using 0D CRN/1D Flame predetermination and LES validation, 1D laminar flame calculations results show that the combustion, at nominal operating conditions of the Turbec

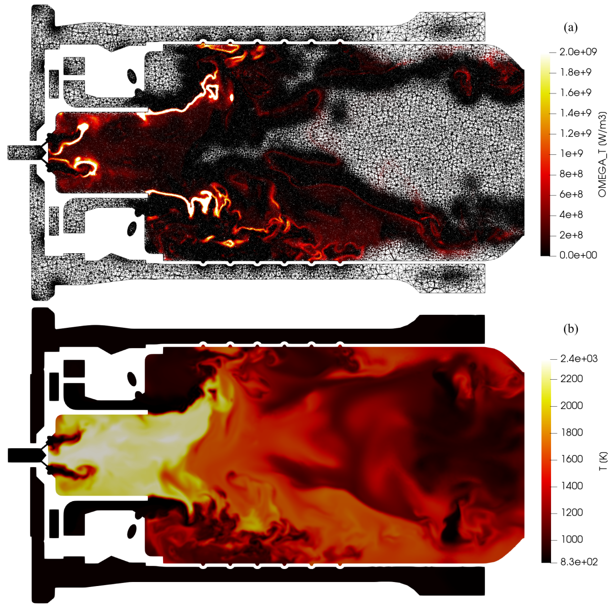

Figure 2: LES results for the case $50\%_{vol}H_2/\Omega = 3.4\%$ of the instantaneous reaction rate $\dot{\omega}_T$ on the dynamically adapted mesh (a) and the temperature (b) color fields showing no flashback apparition near the main flame swirler.

T100 mGT, fuelled with different H_2/CH_4 blends (25/75, 50/50, 75/25 and 100/0), can indeed reach the same level of flame speed as pure methane combustion by humidifying the combustion air (using a water-to-air ratio of 1.5, 3.4, 5.9 and 10.25% respectively). Moreover, LES results of the real combustor layout show stable combustion for the predetermined level of humidification when the combustor is fuelled by $50\,\%_{vol}$ of H_2. Similar temperature and reaction rate levels as those of pure methane combustion are reached in the combustor without flashback apparition. 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.

References

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