Experimental characterization of ignition events in CVC like conditions

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Introduction

- Since early development, the thermodynamic cycle used in gas turbines has undergone little change. Over the last decades, an effort has been put into increasing efficiency by reducing losses and raising the overall pressure ratio and peak temperature. One of the most promising new types of cycles is the case where a pressure rise across the combustion process is allowed (CVC). In this case, an ignition in each cycle will be considered and also diluted mixtures with high mean velocities and turbulent flows. The main objective of this work is to experimentally investigate the different phenomena involved in the ignition stage in a CVC application, such as the effect of the dilution by a residual burned gas (RBG), the turbulence intensity, and turbulence length scales.
- For this purpose, a lab-scale facility was developed to generate turbulent flow and to allow electrical energy measurements. The setup will allow a well-controlled flow, with the possibility to vary the mean velocity and turbulent scales. The ignition system's energy and power effects on the ignition process will be studied.

Concepts and project overview

Definition of RBG composition

- In order to define the composition of the synthetic RBG, the main flame properties were analyzed (T_b, S_L, δ)
- Mixture: Propane/air - $\phi = 0{,}7$, P = 1 bar and 2 bar and ambient temperature.
- The calculations were made using Cantera with the San Diego chemical mechanism [1].
- The mixture chosen was so that the heat release from the RBG produced would be the same.
- Synthetic RBG dilution mixture chosen: 5% He + 95% N2 (without H2O).

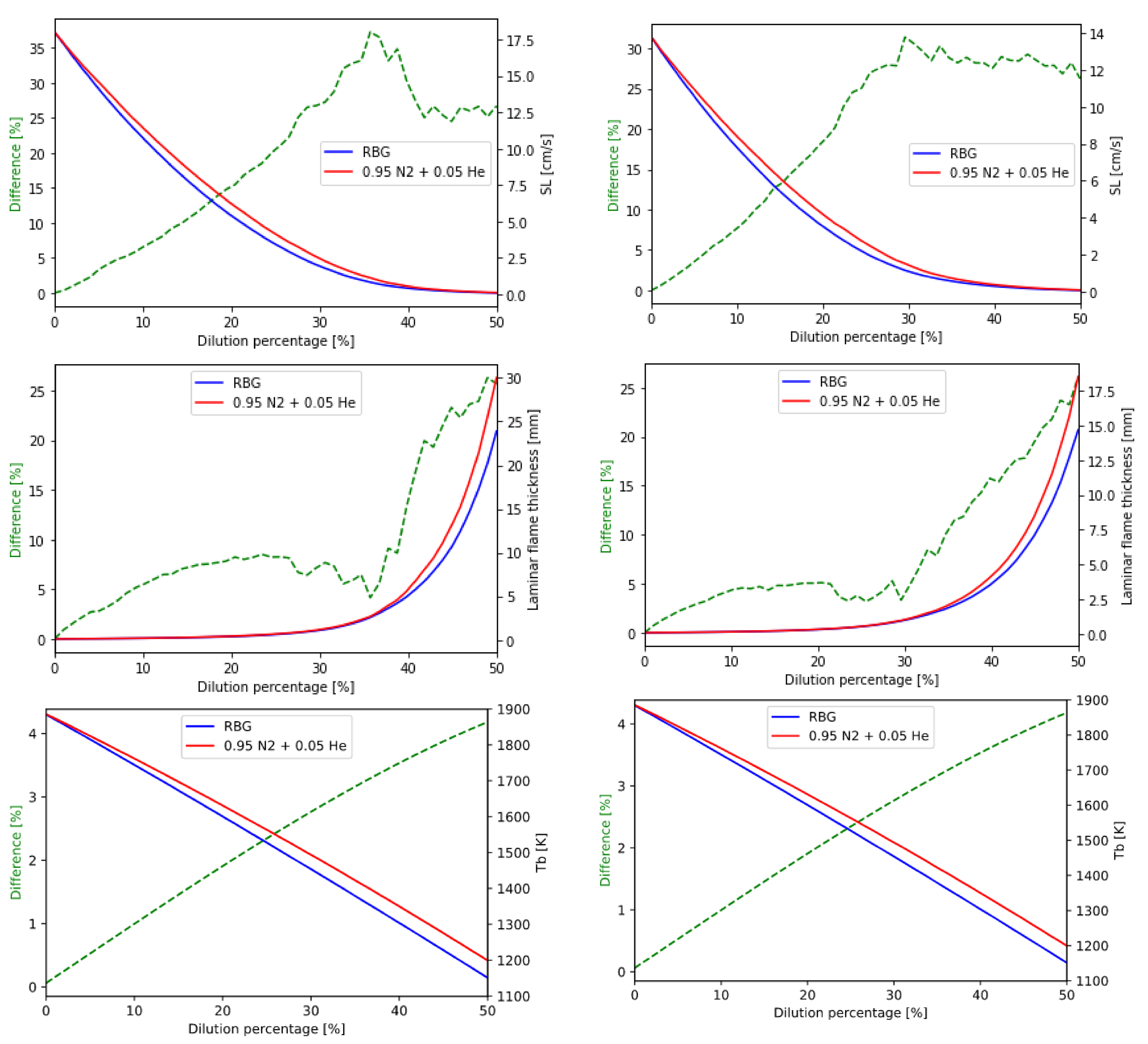

Fig. 1: Flame properties (S_L, δ and T_b) calculated for a mixture of propane/air/RBG with equivalence ratio 0.7 for pressures of 1 and 2 bar. Blue: RBG, red: synthetic RBG.

Design of the TUMBLE chamber's turbulence generator

- The chamber TUMBLE studied by Le Dortz [2] was modified in order to be able to control the turbulence intensities and the turbulent length scales.
- Based on literature review [3], a set of 3 perforated plates were chosen.

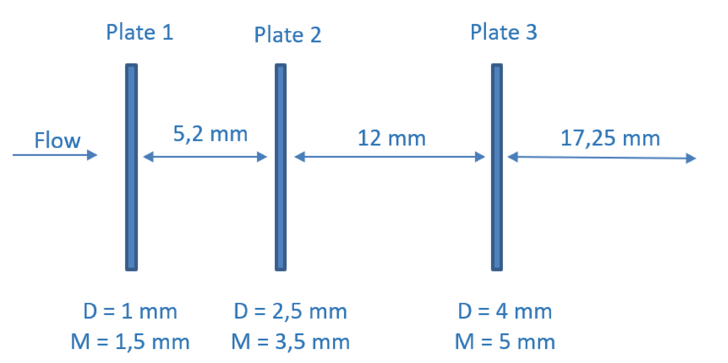

Fig. 2: Perforated plates first configuration for a 3-plate grid. Including the length between the plates, the distance to develop the turbulence and the values for diameter and mesh size chosen..

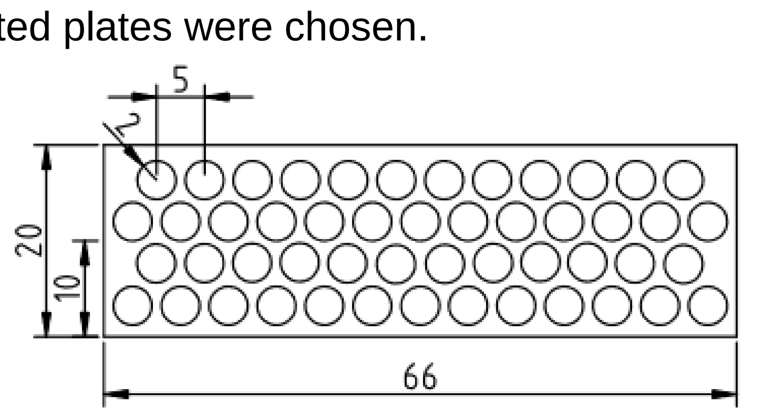

Fig. 3: Detailed design of the 4 mm diameter perforated plate with a mesh of 5 mm.

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Concepts and project overview

Design of the TUMBLE chamber's turbulence generator

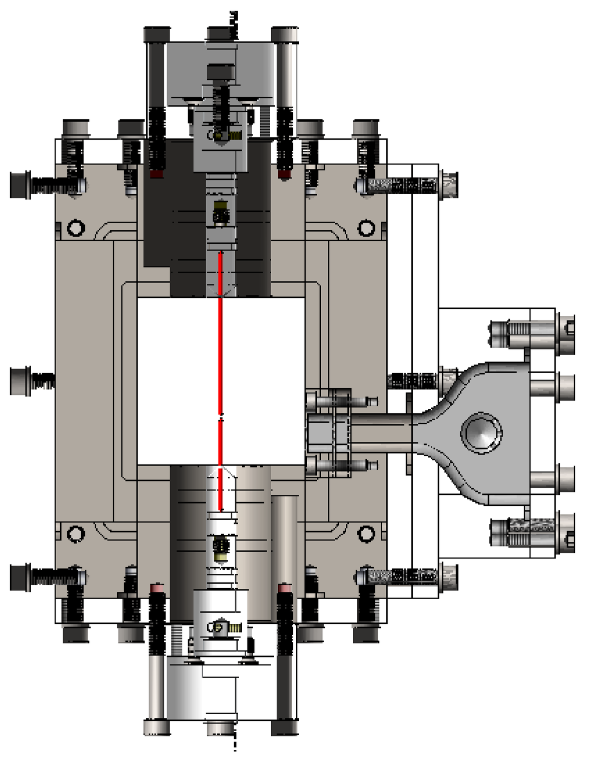
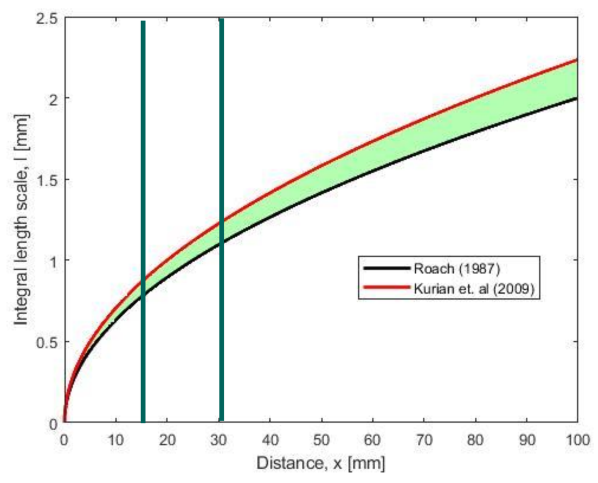


Fig. 4: Turbulence generator design for the TUMBLE chamber.

Chamber ignition system configuration:
Pin to pin electrodes of 1 mm diameter. Gap = 2 mm.
Ignition: Automotive inductive type NRJ with varied primary coil charge (τ_p) and voltage (V_p)



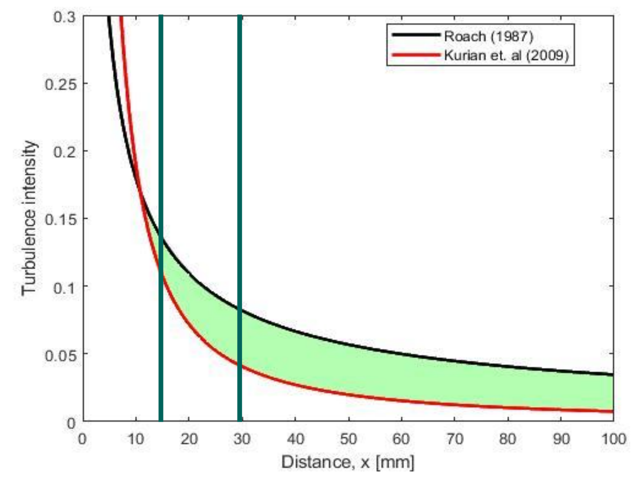


Fig. 5: Integral length scale and turbulence intensity as a function of the distance from the grid to the electrodes, calculated for the 3-plate design developed. Dark green: zone of interest.

Electrical energy measurements

- The amount of energy sufficient to provide a 50% ignition probability is called minimum ignition energy (MIE) [4].
- Measurements made with the previous configuration, for quiescent air mixture.

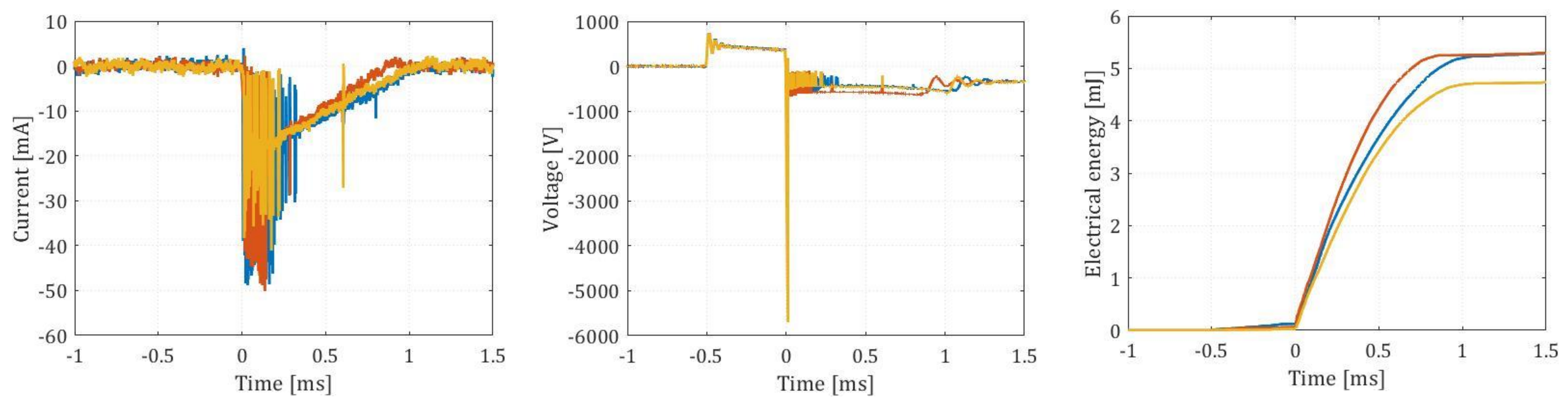


Fig. 6: Current, voltage and electrical energy measurements made in the TUMBLE chamber with the previous turbulence generator. Air at atmospheric pressure. V_p = 12V.

Minimum thermal energy and calorimetry

- A 3D printed calorimetric chamber with two electrodes is also under study to measure the electrical and thermal energy deposit and the ratio (efficiency) between them.
- Energy efficiency [5]: $\eta = \frac{E_{th}}{E_{el}}$
- The maximum chamber volume is decided by the highest acceptable uncertainty in the experiment, on the other hand the lower limit of volume is set by ensuring that the volume of spark should be negligible compared to the chamber volume.

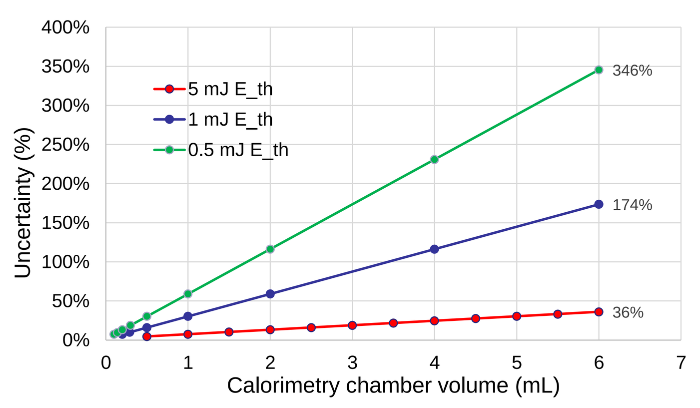


Fig. 9: Thermal energy uncertainty estimation as a function of the chamber volume.

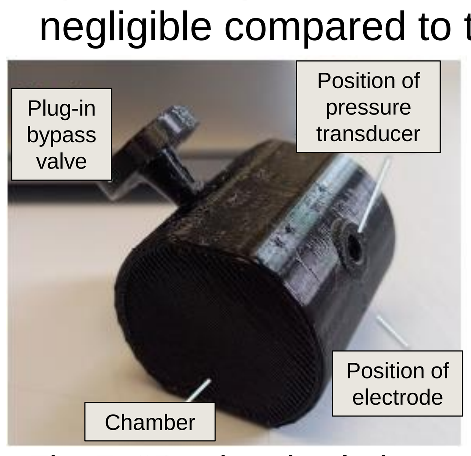
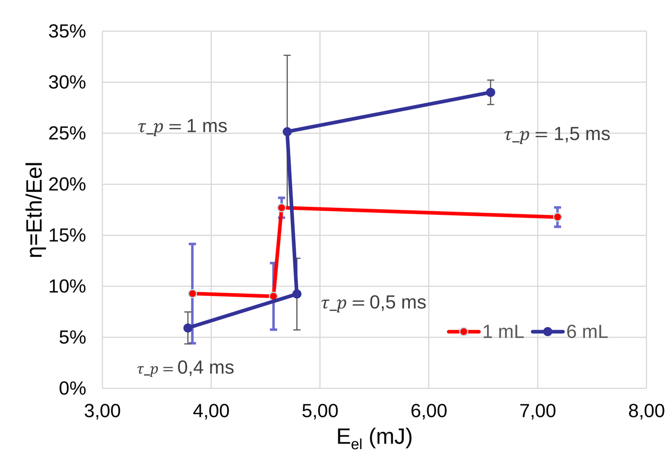


Fig. 7: 3D printed calorimetry chamber used for thermal energy measurements. Volume of 1 mL.

Fig. 8: Thermal efficiency obtained in the 1 mL chamber compared with the 6 mL for V_p = 6 V.



Conclusion and perspectives

- A mixture of 5% He + 95% N2 is adequate and behaves as a residual burned gas.
- The perforated plate design describes the desired turbulence intensity profile.
- Optical diagnostics will be made to characterize the turbulence and ignition in the chamber.
- MIE [1] measurements will be performed for a propane/air mixture with synthetic RBG dilution with the new turbulence generator.
- For spark duration lower than 0.4 ms, a smaller calorimetry chamber could be used.

References

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