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Experimental characterization of ignition events in CVC-like conditions

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Introduction and objectives

This work focuses on investigating the sensitivity of the minimum ignition energy (MIE) to both mixture (C3H8/air) and flow properties in a constant volume chamber (CVC), Tumble 2. The study involves analyzing the flow average velocity using high-speed PIV, starting from inert mixtures. Additionally, experiments are conducted in the reactive case using coupled PIV/OH PLIF techniques to measure, identify, and follow the fresh gas velocity and the contour of the ignition kernel in propane/air mixtures.

The research aims to determine the MIE while controlling the mixtures and flow properties in the CVC chamber, using time-resolved high-speed PIV to determine the velocity field in the chamber, and PLIF to measure the turbulence intensity of the fresh gas velocity and the contour of the ignition kernel in propane/air reactive mixtures.

Methodology

To study the effects of turbulence and flow velocity on MIE, a square-shaped combustion chamber (66 cm x 66 cm x 66 cm, Fig. 1) with a pin-to-pin electrode spark ignitor (Fig 2.) and a designed grid set of perforated plates was used. The setup allowed for a well-controlled flow with the ability to vary pressure, mean velocity, turbulence intensity, and integral length scales. The ignition system provided a short-duration spark between 100 µs and 500 µs triggered at different delays after the end of the injection. The field 1 is used for the inert case and measuring the overall velocity measurement. The field 2 is used for the reactive case and will be used for the turbulence characteristics measurements.

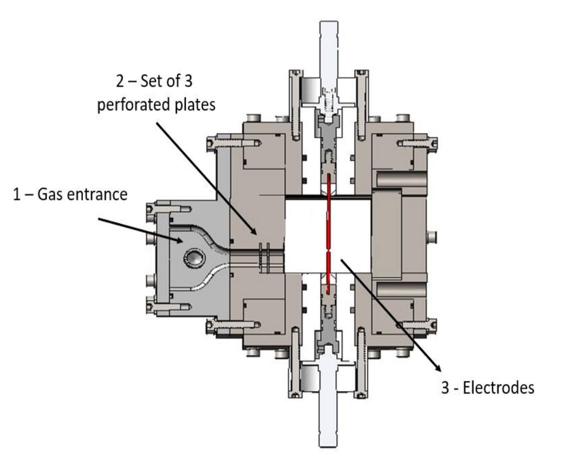

Figure 1: TUMBLE 2 chamber schematic design.

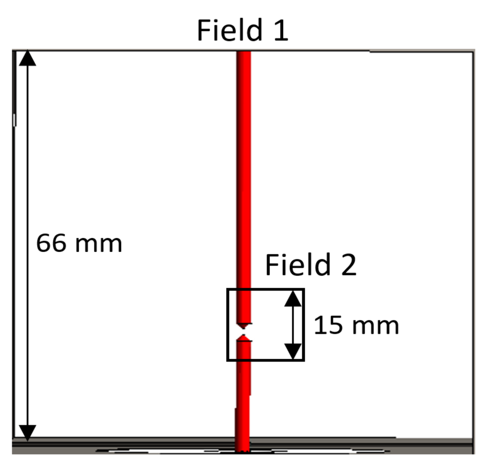

Figure 2: TUMBLE 2 chamber Representation for the zoomed area of 15x15 mm.

- Experimental design: two sets of experiments, different resolution and scale factor;
- PIV cross-correlation files: processing in different window sizes and multi-pass interactions;
- Utilization of high-speed OH PLIF to detect the fluorescence emission from OH radical as an ideal tracer for combustion chemistry;
- Conducting high-speed 2D PIV and PLIF combined to analyze the kernel trace generated in the TUMBLE 2 chamber;
- Filter with 90% transmission at 308 nm and a 2 mm filter WG305 to reduce scattered stray light and eliminate laser excitation wavelength contributions;
- Use of dichroic mirror to align both sheets;
- Data processing using Davis 10;
- Schematic design of the combined PIV and LIF systems in Fig. 3.

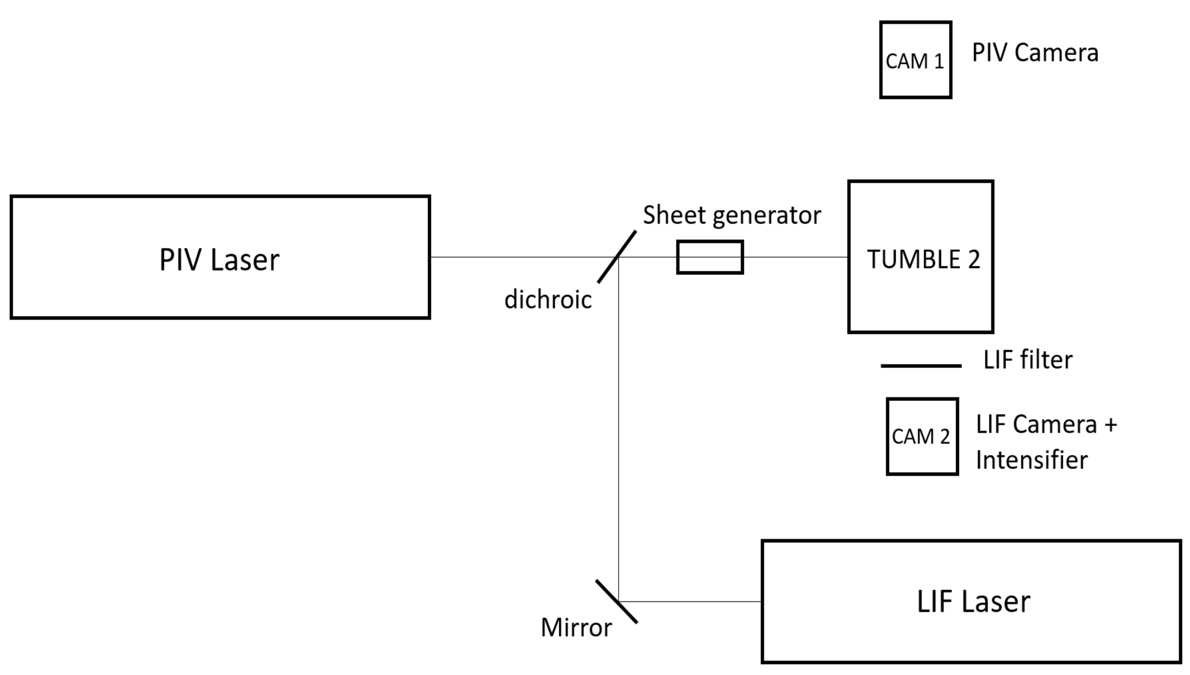

Figure 3: Combined laser diagnostics of PIV and LIF schematic design.

Aknowledgements

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Results

The study began with inert mixtures at 1 bar of pressure, and time-resolved high-speed PIV was used to study the chamber's overall flow velocity and velocity fluctuations. The study progressed to propane and air reactive mixtures, and the high-speed PIV and PLIF measurements were combined in a 4 cm2 region near the electrode gap to measure and identify the fresh gas velocity, turbulence intensity, and ignition kernel contour. The study also considered different ignition timing to vary the flow properties under the same pressure conditions as the inert case. The results obtained from this study will help in understanding the effects of turbulence and flow velocity on MIE in CVC systems.

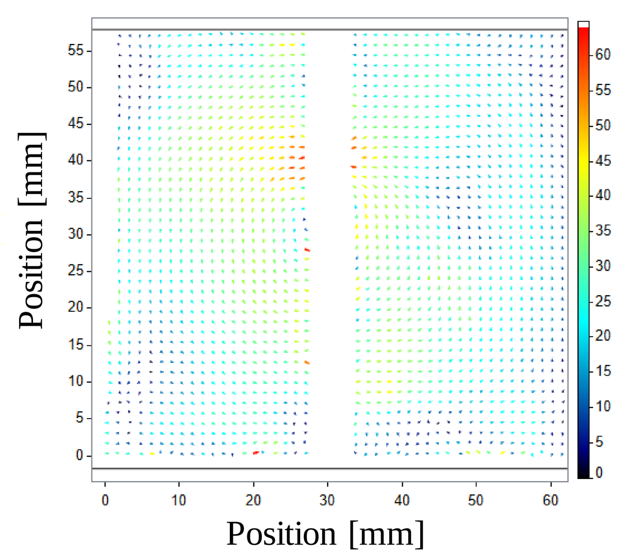

Figure 4: The averaged flow fields (from 20 shots) at 0 ms after the end of injection. Test conditions: inert air, ambient temperature, 1 bar of fresh gas pressure. Using field 1.

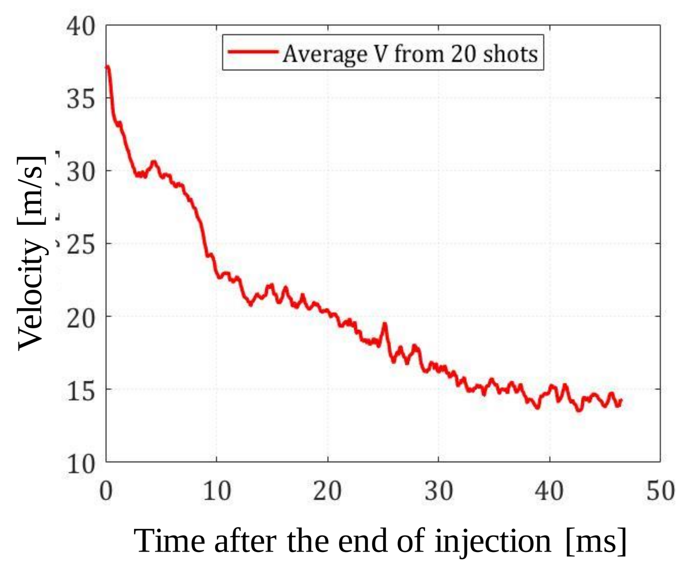

Figure 5: The averaged flow velocity (from 20 shots) temporal evolution. Test conditions: inert AIR, ambient temperature, 1 bar of fresh gas pressure. Using field 1.

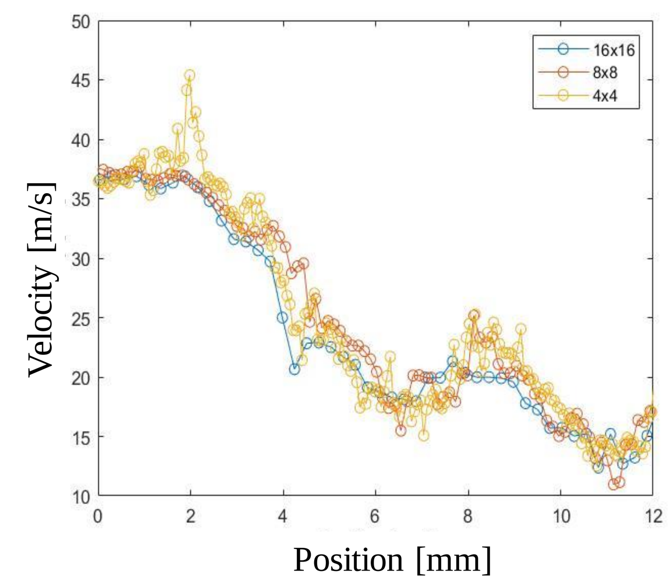

Figure 6: Velocity profile as a function of the position for three different processing window sizes: 4x4, 8x8, and 16x16, all of them with 25% of overlap. The measurements were taken from a horizontal line (shown in Figure 10) in the middle of the gap at 0 ms. Using field 1.

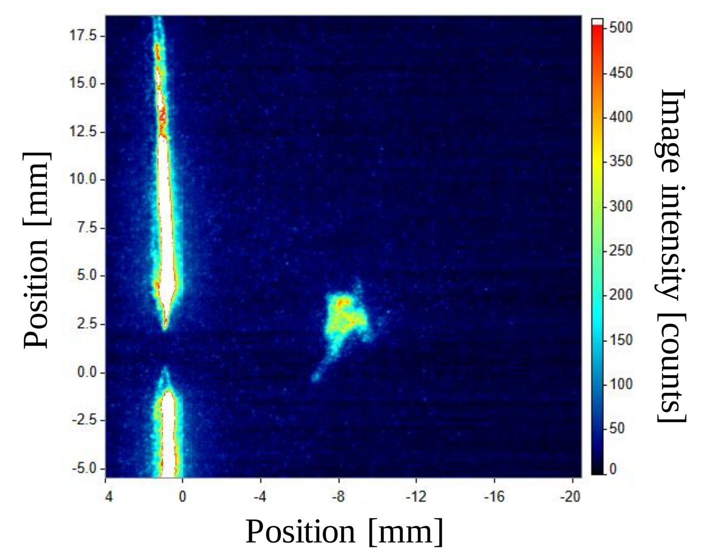

Figure 7: PLIF measurements for a C_3H_8/air mixture. Coil charge: 200 µs. Spark duration: 424 µs. Ignition delay time of 10 ms. Using field 2.

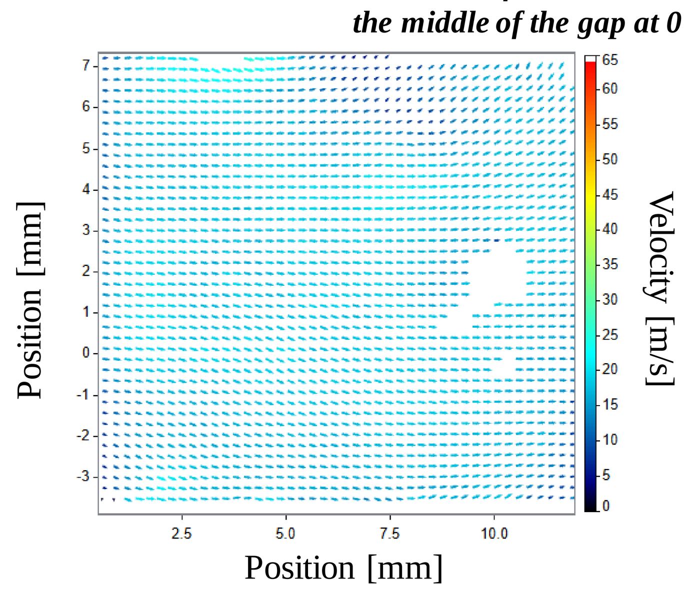

Figure 8: PIV velocity vector field for a C_3H_8/air mixture. Coil charge: 200 µs. Spark duration: 424 µs. Ignition delay time of 10 ms. Using field 2.

In this study, the minimum ignition energy (MIE) is determined through a series of experiments involving misfiring and ignition events (as shown in Figure 9-a and Figure 10-a). The probability of ignition is 0 for misfires and 1 for successful ignitions. To calculate the probability of ignition, a statistical function called likelihood is utilized.

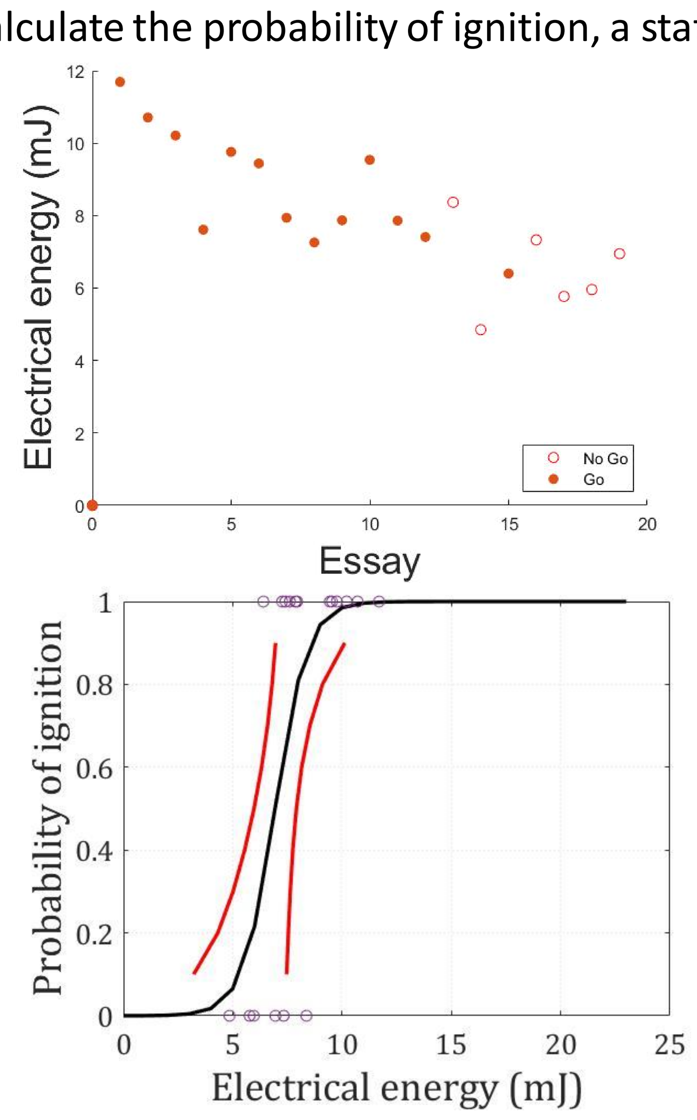

Figure 9: The results of the study conducted to investigate the probability of ignition in stoichiometric propane/air mixture at initial ambient pressure and temperatures. (a) Set of experiments carried out to distinguish ignition from misfire at various electrical energies. (b) Probability of ignition for a 95% confidence interval. The experiments were conducted using 20 shots at a velocity of V = 37 m/s.

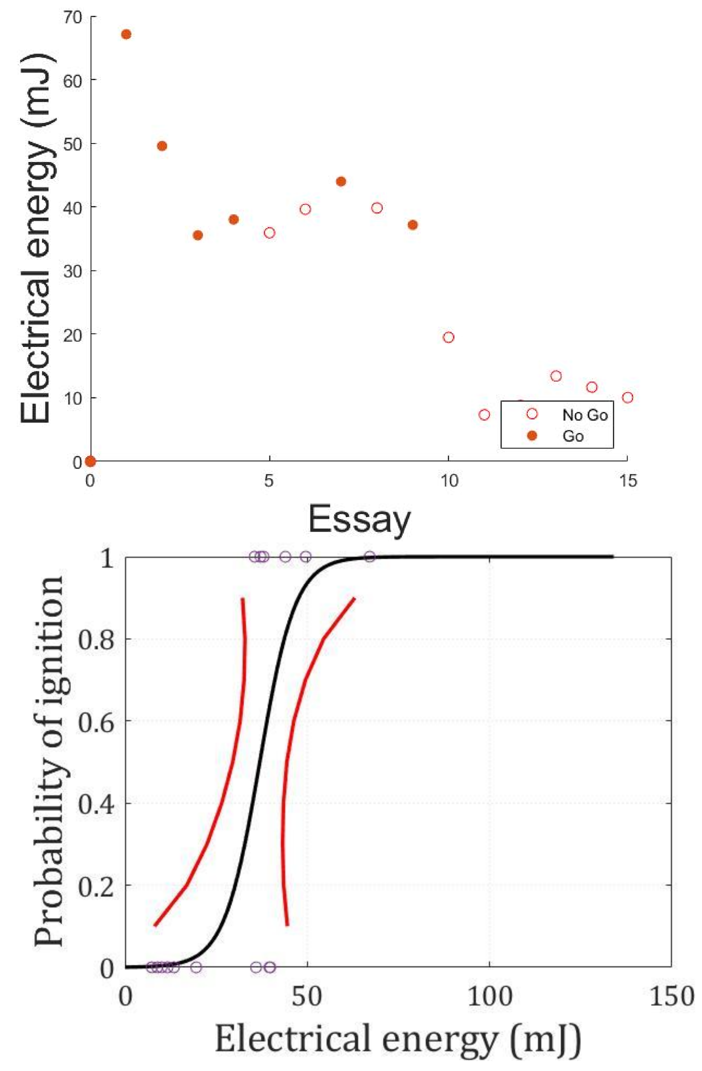

Figure 10: The results of the study conducted to investigate the probability of ignition in stoichiometric propane/air with 10% dilution (95% N_2 + 10% He) at initial ambient pressure and temperatures. (a) Set of experiments carried out to distinguish ignition from misfire at various electrical energies. (b) Probability of ignition for a 95% confidence interval. The experiments were conducted using 15 shots at a velocity of V = 37 m/s.

Conclusion and perspectives

In this study, the internal aerodynamics of Tumble 2 chamber were investigated using high-speed PIV and PLIF. The findings exhibit the time-dependent velocity decay. The subsequent phase involves the analysis of turbulence characteristics and calculation of turbulence length scales. The probability of ignition in a CVC chamber for short-duration sparks is influenced by turbulence, mean velocity and dilution effect, which affect the mixing and distribution of fuel and oxidizer as well as spark energy dissipation. Hence, understanding these factors is crucial for optimizing the design and operation of CVC systems. The analysis of turbulence intensity and length scales will be the next step.

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