Deflagration to Detonation Transition in mixtures of Ethanol and Acetone Sprays with Gaseous Oxygen

Hertzel Kadosh and Dan Michaels
Faculty of Aerospace Engineering, Technion – Israel Institute of Technology
Haifa, Israel

Deflagration to detonation transition (DDT) of a heterogeneous mixture is more challenging. The time scales required for atomization, mixing, and vaporization of the fuel are longer, which results in a wider reaction zone than in a gaseous mixture [1]. However, facing these challenges is inevitable in airborne propulsion devices, which are volume limited, and the use of liquid fuel is preferred. Research has shown that heterogeneous mixture detonation is governed by the presence of a fuel vapor [2-5]; therefore, higher vapor pressure fuel can support detonation initiation.

Ethanol (C_2H_6O) is an alcohol that is liquid at room temperature and has a high vapor pressure of 5.95 kPa at 293 K (relative to 5.33 kPa of Heptane at the same temperature and 18 Pa of Dodecane at 298 K). Acetone (C_3H_6O) has even higher vapor pressure of 30.6 kPa at 298 K. For that reason, ethanol and acetone are potential candidates for usage as a fuel for detonation based propulsion devices; however, there is limited information on deflagration to detonation transition of heterogeneous mixtures of liquid ethanol or liquid acetone with gaseous oxygen.

The objective of our studies is to measure key parameters such as deflagration to detonation transition length and the effect of DDT enhancement methods and to measure the detonation cell size for different mixtures [6-7].

The experimental apparatus was based on a modular pulse detonation engine made of four stainless-steel flange sections with a diameter of 10 mm and an overall length of 60 cm. Twelve flush-mounted piezoelectric pressure transducers with a response time of 1 μs were equally spaced along the engine and enabled to track the pressure wave during its transition from deflagration to detonation. A data acquisition and analysis interface was designed, and the engine was controlled and monitored from it.

Correspondence to: khertzel@campus.technion.ac.il

Figure 1 shows the experimental setup. Single-cycle tests were taken for different fuels, equivalence ratios, and DDT enhancement methods. The mixture's initial conditions inside the engine were 298 K and 101 kPa and it was monitored before each experiment.

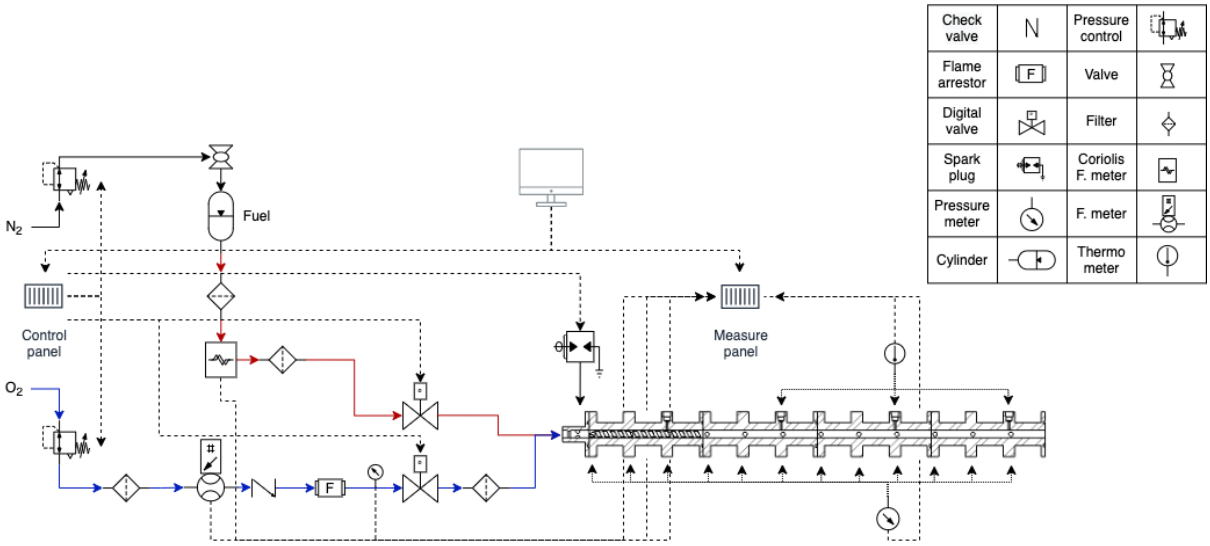

Figure 1: The experimental setup.

The liquid fuel was injected from the engine head end by a two-fluid oxygen-assisted atomizer, and the spray was characterized with a laser diffraction system for different equivalence ratios.

The ethanol spray has a bimodal distribution with a high volume of small droplets, and the acetone spray has a regular polydisperse distribution of relatively larger droplets. The Sauter mean diameter (SMD) measured at the atomizer exit at an equivalence ratio $\phi \approx 1.1$ is 30 μm for ethanol spray and roughly 385 μm for acetone spray. The measured SMD at the engine exit at the same equivalence ratio is 119 μm for ethanol and 464 μm for acetone. The droplet size distribution of both fuels at an equivalence ratio $\phi \approx 1.1$ is shown in Fig. 2.

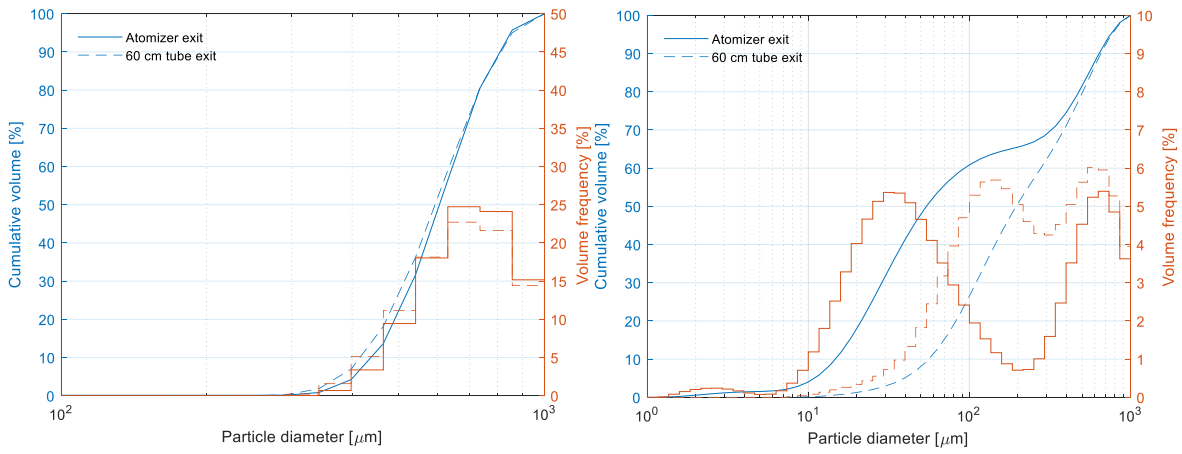

Figure 2: Droplet size distribution of acetone (left) and ethanol (right) at an equivalence ratio $\phi \approx 1.1$.

The droplet size distribution of the ethanol spray at the engine exit (dashed orange line on the right side of Fig. 2) has shifted toward a larger droplet diameter. This could be a result of droplet coalescence and a wall film breakup [6]. We assume that the high evaporation rate of acetone has led to a shift toward a smaller droplet diameter at the engine exit (dashed orange line on the left side of Fig. 2).

The detonation velocity was measured at the engine exit, between the two most downstream pressure transducers, for ethanol and acetone at various equivalence ratios. A lower velocity deficit relative to the theoretical Chapman-Jouguet (CJ) detonation velocity was measured for the acetone-oxygen mixtures, and this behavior is related to the higher amount of fuel vapor that existed in these mixtures.

Ten piezoelectric pressure transducers monitored the deflagration to detonation progress. The results shown in Fig. 3 are based on data from at least 15 experiments for each equivalence ratio. The wide variance of the results is due to the variation in the flame acceleration and DDT completion distances between the different experiments.

The DDT progress for the acetone-oxygen mixture is rapid compared to that of the ethanol-oxygen mixture. In the ethanol-oxygen mixture, the flame accelerated first to the choked flame regime with a velocity between 600-1000 m/s [8]. When the flame reached a speed close to the sound speed of the combustion products, the pressure wave became a strong shock wave and further developed to a detonation. The fuel-rich acetone-oxygen mixture tends to develop more easily to detonation.

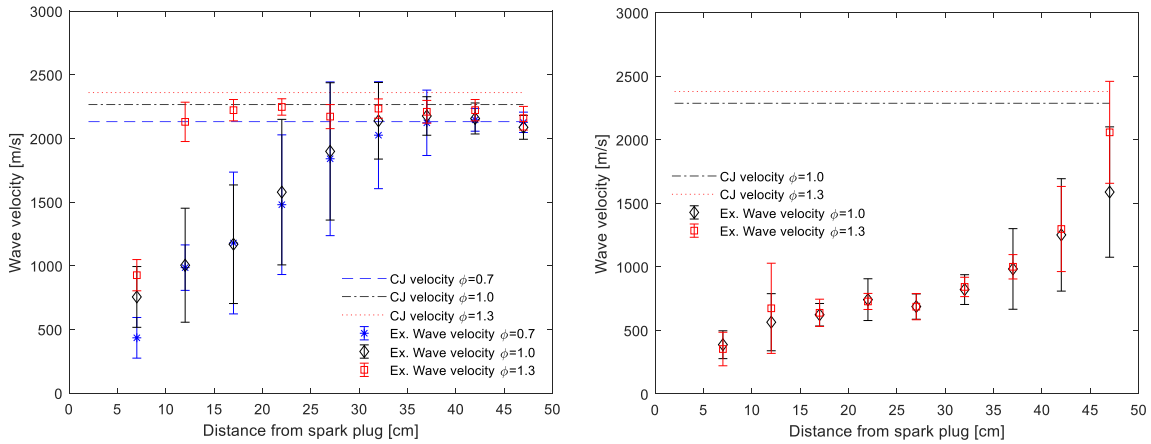

Figure 3: Wave velocity during DDT of acetone (left) and ethanol (right).

The detonation cell size of the heterogeneous mixtures was measured. A rectangular chamber (45 cm long, 10 mm height, and 40 mm wide) was attached to the exit of the pulse detonation engine. The trace of the detonation wave was captured by using the soot-foil technique. Some samples of soot traces are shown if Fig. 4. The measured detonation cell size for equivalence ratio $\phi \approx 1.0$ was $\lambda = 3$ mm for the

ethanol-oxygen mixture and λ=2 mm for the acetone-oxygen mixture. This may explain the higher detonability of the acetone-oxygen mixture. The theoretical estimations of detonation cell size for homogeneous mixtures are based on ZND one-dimensional calculations, and empirical constants that relate the induction length and the detonation cell size. The models of Ng et al. [9] and Westbrook et al. [10] were used. Figure 5 shows a summary of the measured cell size and theoretical estimations. As reported in our previous report [7], there are opposite trends in the models and the experiments for fuel-rich mixtures. This change is probably related to the atomizer in use, for which there is an increase in droplet size with the equivalence ratio. We assume that the increase in cell size for the fuel-rich mixture is a result of longer physical processes that characterize a larger droplet.

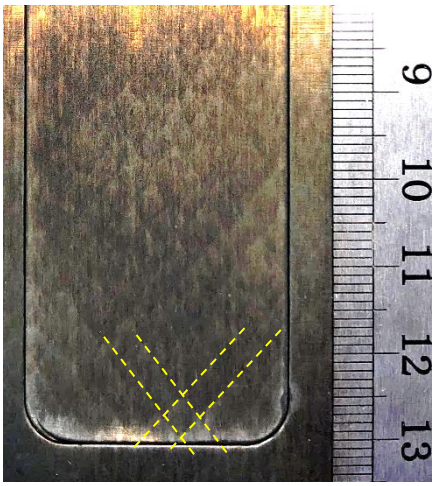

Figure 4: Detonaiton cell traces for heterogeneous ethanol-oxygen mixture, ϕ≈1.0.

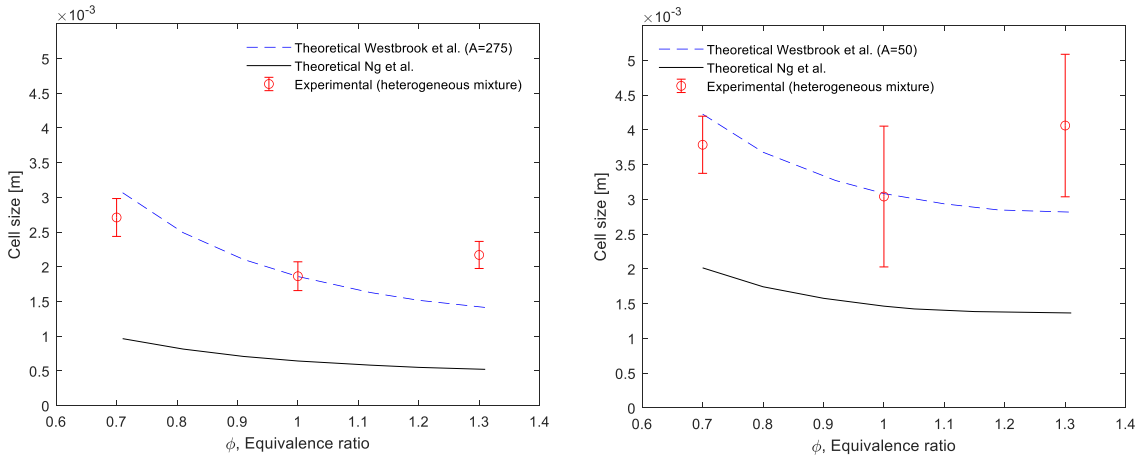

Figure 5: Measured cell size for heterogeneous acetone-oxygen (left) and ethanol-oxygen (right) mixtures and chemical kinetics estimations.

Both mixtures exhibited larger cell size than the estimated cell size for the same gaseous mixtures and an order of magnitude smaller cell size than a mixture with air instead of oxygen.

The full presentation will include a detailed introduction, a description of the experimental setups, and a thorough report of the results.

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