

On non-dimensionalized DDT distances and limits

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Understanding the transition from deflagration to detonation in tubes is one of the oldest motivations for studying quasi-sonic and supersonic combustion waves. The main phenomena that participate in the deflagration and detonation processes, and the transitions from the former to the latter, are qualitatively well understood today [1]. However, each remains a numerical challenge and predicting how they combine in complex reactive flows is currently out of reach. One possibility is to approach particular DDT configurations with simplified macroscopic analyses that aim at bringing out relevant non-dimensional parameters for predicting DDT distances and boundaries.

We thus consider the DDT process generated by jets of hot gases uniformly distributed over the cross section of a smooth-walls square tube. This surface ignition ensures a simpler hydrodynamic field ahead of the subsonic flame front and, therefore, a better reproducibility of the transition limits and lengths. The hot jets were obtained from the impact of a CJ detonation on a multi-perforated plate. The detonation tube consists of two main elements, namely the driver section and the re-ignition section, separated from each other by the multi-perforated plate. The methodology was to generate the detonation at one end of the driver section, to quench it through the plate, and to study the conditions for re-ignition depending on the properties of the plate, the composition of the mixture and the initial pressure p_0 . The driver and re-ignition sections are 2.25 and 1-m long, respectively, with the same 40×40 -mm² square cross section. Soot foils positioned on the bottom walls of the driver and re-ignition sections were used to record the structure of the detonation cells upstream and downstream the plate. We considered the stoichiometric compositions of hydrogen, methane and oxygen $(1-x)_2 + xCH_4 + 1/2(1+3x)O_2 \rightarrow xCO_2 + (1+x)H_2O$. We varied the composition parameter x from 0 to 1, namely $x=0, 0.25, 0.5, 0.75$ and 1, to generate detonation cells ranging from regular to irregular, as defined from the soot recordings. We varied the initial pressure p_0 from 12 to 35 kPa, and the initial temperature was about 294 K. We chose plates with diameters of holes d smaller than the cell widths, so the detonation quenched through the plate [2]. We considered the values $d=2$ and 3 mm, the hole numbers $N=64$ and 144, and the plate thicknesses $e=7, 14$ and 21 mm.

Our analysis considers dimensionless ratios that use the cell mean width λ_{CJ} as the reference length for representing the effect of heat production by evolution of chemical composition. These ratios are Nd^2/λ_{CJ}^2 for the relative effects of surface re-ignition resulting from the interaction of the jets coming out of the holes, and Ned/λ_{CJ}^2 for the relative effects of the surface-dissipation phenomenon.

Figure 1 shows the DDT limits for the mixture $H_2 + 1/2 O_2$ ($x=0$). A unique value of Nd^2/λ_{CJ}^2 thus separates the re-ignition and non-re-ignition domains, which appear to be independent of Ned/λ_{CJ}^2 . Figure 2 shows that the non-dimensional DDT distances well correlate with Nd^2/λ_{CJ}^2 regardless of the plates and the mixture compositions.

In general, DDT dynamics depends on the ignition mode, the set-up geometry and dimensions, and the mixture composition, so only high-resolution numerical simulations based on Navier-Stokes reactive equations will be capable of predicting this complex phenomenon when the necessary computations capacities are available. To date, given an industrial system, the DDT risk must be assessed with large-scale model experiments. Our analysis suggests that non-dimensional numbers built from the system characteristics can help in anticipating its DDT limits and distances. Additionally, our non-dimensionalization appears to be independent of the regularity of the detonation cell, as defined by soot recordings at walls. This indicates that this regularity criterion may not always be relevant for interpreting dynamical behaviours of deflagration and detonation [3].

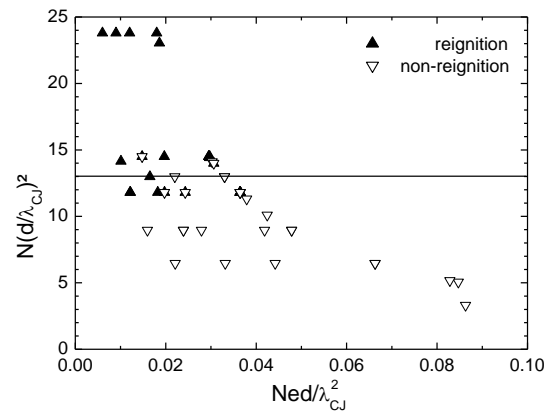


Figure 1. Re-ignition and non-re-ignition domains for the mixture $H_2 + 1/2 O_2$ ($x=0$)

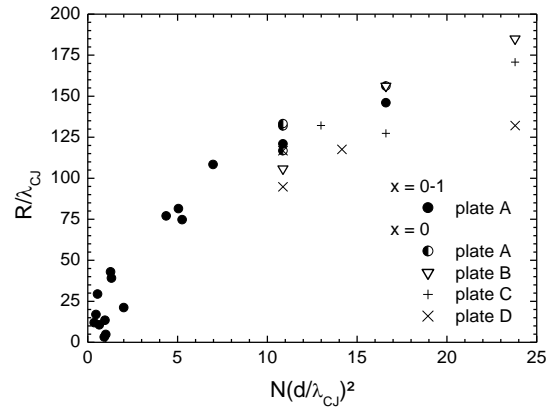


Figure 2. Non-dimensional re-ignition distance for the mixture $(1-x)H_2 + xCH_4 + 1/2(1+3x)O_2 \rightarrow xCO_2 + (1+x)H_2O$.

[1] Ciccarelli G., Dorofeev S., Flame acceleration and transition to detonation in ducts, Progress in Energy and Combustion Science, 34, 499-550 (2008)

[2] Khomik S.V., Medvedev S.P., Veyssiere B., Olivier H., Maksimova O.G., Silnikov M.V., Initiation and suppression of explosive processes in hydrogen-containing mixtures by means of permeable barriers, Russian Chemical Bulletin, International Edition, 63, 1666-1676 (2014)

[3] Monnier V., Rodriguez V., Vidal P., Zitoun R., On the relevance of detonation cell regularity and width, extended abstract submitted to the 13th ICPCD, Saint Petersburg, Russia, 18-21 April, 2022