Detonability of simple and representative components of pyrolysis products of kerosene Pulsed Detonation Engine Application

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1. Introduction

Because of the necessity of developing limited volume systems, utilizing liquid fuels in pulsed detonation engine (PDE) could be a key issue. The use of liquid fuels, especially kerosene, would be very interesting. Unfortunately for this application, it is difficult to initiate a detonation with such fuel. Thus, several studies aimed at determining the proper conditions for detonating fuel spray (Brophy et al. 1998). However, detonation has been obtained for JP10/O_2. The detonation of JP10/air and JetA/air mixtures has been obtained with and without nitrate sensitization (Akbar et al. 2000). In this case, to initiate the detonation, the experiments were performed at 1 atm and 135°C in a 32 cm diameter, 24 m long heated test section and a 4 m long H_2/O_2 driver. The detonation cell size for stoechiometric JP10/air is about 4.7 cm (comparable to C_3H_8/air mixture). A tube of several tens meters in length cannot be used directly for industrial applications. Hence, we investigate if the kerosene can be substituted by a more simple combustible and easier to detonate. We have pyrolysized a kerosene to identify the light hydrocarbon molecules produced via Pyrolysis/GC/MS experiments and we have retained a representative mixture of the lighter products of the decomposition. The results of our first experiments show that the products are hydrogen, ethylene, methane, benzene, butadiene and propylene. In a first time of this study, to obtain a representative and a detonable mixture in oxygen and air from these compounds, we retain H_2, C_2H_4 and C_3H_6 gaseous products for the tests. The mixtures $H_2/O_2/N_2$ are recognized to be easier to detonate. The detonability of C_3H_6 is comparable to C_2H_4 (Bull 1983), and consequently it appears as an interesting product. In our knowledge, the detonability of $C_6H_6/O_2/N_2$ and $C_4H_6/O_2/N_2$ mixtures is not well recognized. The methane is not selected by reason of the difficulty to detonate in air. Hence, we select H_2, C_2H_4 and C_3H_6. In this study we characterize the detonability of ethylene and propylene in oxygen diluted in nitrogen, using a detonation tube. This device has a length compatible with aircraft industry applications of PDE. We report here the experimental results obtained for ethylene and propylene.

2. Experimental set-up

The experiments were performed in a stainless steel 304L detonation tube (Fig. 1) of 2.5 m long, with a 50 mm inner diameter and 13 mm thickness. The device consisted of two tubes connected by a sleeve, one being 0.5 m long and the other 2 m.

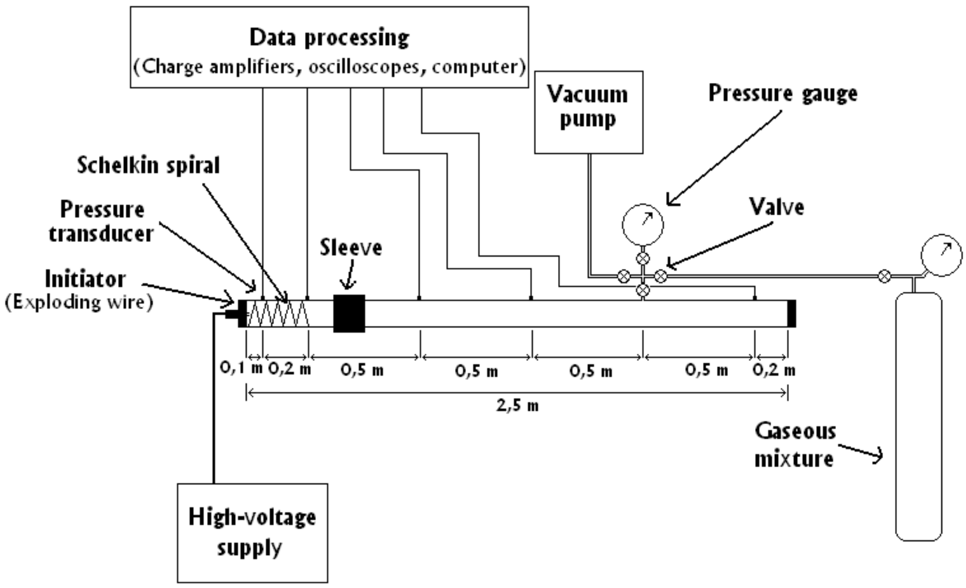

Figure 1 : Detonation tube facility

The ignition source (IS) of the reacting mixture is obtained with an exploding wire delivering a nominal energy of 265 J. We have studied the influence of three Schelkin spirals on the detonability of the different gas mixtures. The spirals have varying blockage ratio (BR) and lengths. We call spiral 1 : BR=0.37, l=0.32 m ; spiral 2 : BR=0.37, l=0.64 m ; spiral 3 : BR=0.55, l=0.64 m. We have tested two positions of the spirals : one against the initiation source (location 1: L1) and the other one located 0.18 m from the latter (location 2: L2). The shots are carried out with an initial temperature of about 295 K.

3. Detonability of C_2H_4 and C_3H_6 /O_2/N_2

3.1. Detonation limits: effect of N_2 dilution

We investigate the detonation limits of stoechiometric mixtures as a function of nitrogen dilution: $C_2H_4 + 3(O_2 + \beta\ N_2)$ and $C_3H_6 + 4.5(O_2 + \beta\ N_2)$ mixtures. The results are reported on the following diagram:

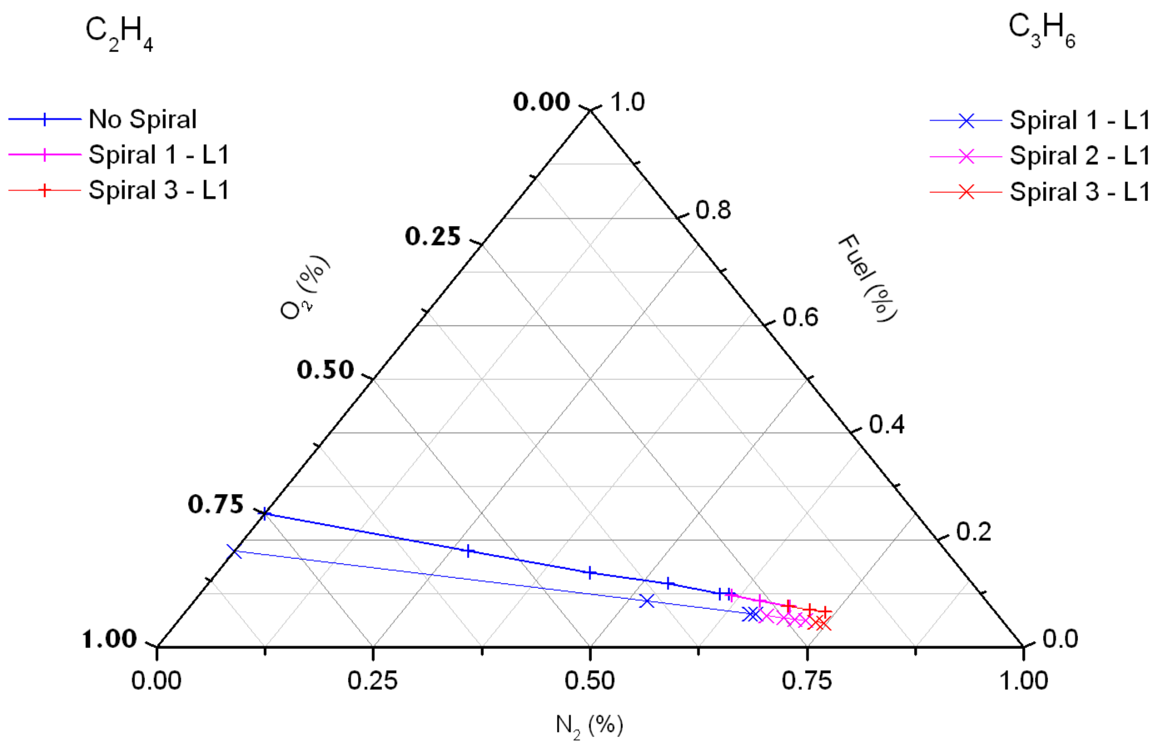

Figure 2 – Detonation limits – P_0 = 0.1 MPa – T_0 = 295 K

In the case of $C_2H_4/O_2/N_2$, the detonation limit in air is reached by using spiral 3 (L1). In our experimental conditions (tube, IS, Schelkin spiral) the dilution limit can not be obtained with C_3H_6/O_2. The maximum dilution compatible with detonation in nitrogen is reached for $C_3H_6 + 4.5(O_2 + 3.6\ N_2)$ with spiral 3 (L1).

3.2. Detonation limits: effect of initial pressure

In the case of stoechiometric C_2H_4/O_2 mixture diluted by nitrogen of ($\beta = 2.5$), the detonation can be observed only if the pressure is higher than 0.05 MPa for a configuration of Schelkin spiral 1 located at 0.18 m of the IS. A detonation of the $C_3H_6 + 4.5(O_2 + 3\ N_2)$ mixture is obtained for an initial pressure equal or higher than 0.08 MPa in the case of Schelkin spiral 3 at L1.

4. Evolution of pressure in the tube: effect of Schelkin spiral

In the case of $C_2H_4/O_2/N_2$ mixture the P_{CJ} values have been calculated by means of the Chemkin software. The detonation of $C_2H_4 + 3(O_2 + \beta\ N_2)$ mixture can be obtained via direct initiation for $\beta \le 2.7$. The stationary state CJ is observed between the two first transducers (about 0.2 m from the ignition source). Spiral 1 at L2 allows to increase the nitrogen dilution at $\beta = 3$. In this case, the detonation is not directly created and results from a deflagration-to-detonation transition which occurs at about 0.8 m. Spiral 3 located against the IS is very efficient to reach the detonation limit with a dilution by nitrogen corresponding to air.

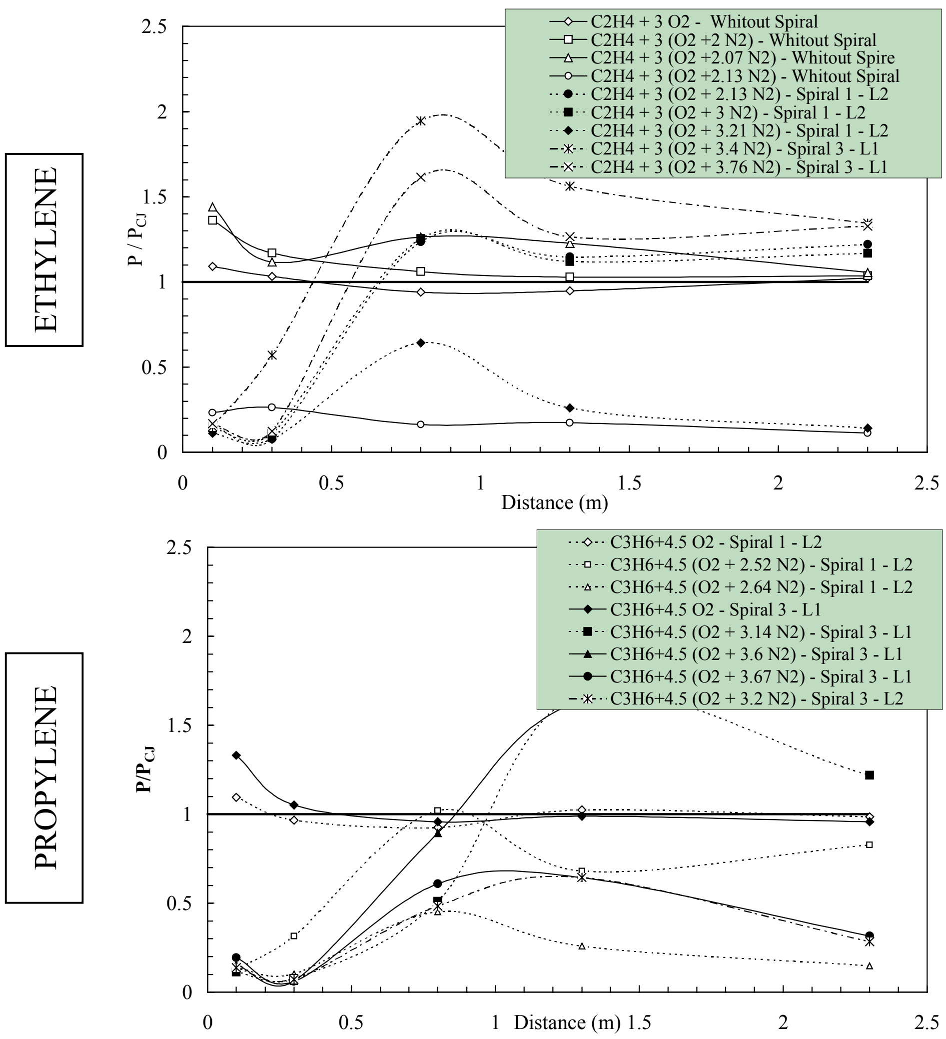

Figure 3 – P/P_{CJ} versus the distance along the tube – T_0 = 295 K – P_0 = 0.1Mpa

The maximum pressure obtained is more important than with the previous spiral and for $\beta = 3.4$ and a non-stationary state ZND is obtained. The overdriven detonation rapidly decreases, reaching a stronger state than CJ conditions. The more the BR increases, the more the dilution limit in N_2 can be extended. The more the distance between the spiral and the IS decreases, the more the distance of DDT decreases. The evolution of pressure for $C_3H_6/O_2/N_2$ shows that a stationary propagation of detonation converges at a pressure of around 3 MPa by upper values for $\beta = 0$ and by lower values for $\beta = 3.6$. The position of spiral 3 has not a positive effect on the DDT if we compare the results obtained for $\beta = 3.13$ and $\beta = 3.2$. The larger detonability domain for these two gases is obtained with the spiral of BR=0.55 located against the ignition source.

5. Conclusion

The first experiments of a kerosene pyrolysis have revealed the presence of C_2H_4 and C_3H_6 among various gases. The detonability limits of stoechiometric $C_2H_4/O_2+\beta N_2$ and $C_3H_6/O_2+\beta N_2$ mixtures have been investigated for various nitrogen dilution β. The effect of initial pressure and geometry of the DDT device (Schelkin spiral) was reached. The best results have been obtained with the Schelkin spiral which has a blockage ratio of 0.55, located against the ignition source. In this configuration, the detonability limit of ethylene corresponds to the air composition (β=3.76), whereas the nitrogen dilution limit for C_3H_6 is lower (β=3.6).

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References

Akbar R, Thibault PA, Harris PG, Lussier LS, Zhang F, Murray SB, Gerrad K (2000), AIAA paper 2000-3592.
Brophy CM, Netzer D, Forster LTD (1998), AIAA paper 98-4003.
Bull D.C. (1983), Gas detonation hazards, Symposium International "The control and prevention of gas explosions".
Matsui H, Lee JH (1978) 17th Symp. (Int.) on Comb, pp.1909-1915.
Peraldi O., Knystautas R., Lee JH (1986), 21^{st} Symp. (Int.) on Comb., pp. 1629-1637.