The Effect of Ozone Addition on DDT for Ethylene-Oxygen Mixtures in Macro-Scale Tube

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1 Introduction

Deflagration-to-detonation transition (DDT) is one of considerably important topics in combustion and explosion science. After decades of experimental and numerical studies, the physical process of DDT by which a subsonic deflagration transforms into a supersonic detonation in distinct types of tube has received intense studies[1-3]. It is very important for a better understanding of DDT process and the full development of its potential applications.

A large number of works have investigated on DDTs in micro- and macro-scale channels, demonstrating that micro DDT depends on elongation of flame surface caused by diffusion[4], while turbulent combustion is more dominant for the occurrence of DDT in macro channel. Recently, Ju *et al*. [5] found that adding ozone in acetylene-oxygen system can promote significantly the appearance of DDT in micro-channel, showing that chemical kinetic effect is dominant for micro-scale DDT compared with thermal and viscous transportation. Wang *et al*. [6] studied the effect of ozone addition on cellular detonation for hydrogen-oxygen mixture, and found that cell size was influenced significantly by chemistry reactions caused from the ozone addition. Consequently, the run-up distance of DDT and the cell size of detonation are closely related to ozone kinetics. However, the study of DDT in macro-scale channel is few considering ozone addition and the kinetic effect of ozone addition in DDT with turbulent-combustion acceleration still needs to be identified. This study aims to examine the effect of ozone addition on DDT in macro-scale tube through experiments.

2 Experimental setup

Figure 1 illustrates the specific experimental setup. The experiment used a 1.5m stainless steel channel with a square of 20×20cm in cross section. One side is plexiglass for observation of flame propagation. An ignition source was installed at the end of channel, which utilizes electric spark ignition and possesses 40J energy. A high-speed camera was used to image the spark initiation and flame propagation. The manual trigger was used to control the spark ignition and the high speed camera to make the time accurate and consistent. The pressure controller is connected to the vacuum pump and the intake pipe. Ethylene and oxygen streams were regulated by pressure controller and mixed prior to flowing into the tube. An ozone

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generator was connected to the mixing stream so that it maintained at a fixed power setting; and the oxygen flow rate was varied to adjust the ozone concentration. Ozone concentrations determined from 1.5% to 6% mole fraction were used for the experiments. The images captured by the high-speed camera were placed in MATLAB for analysis to obtain a flame propagation position and velocity as a function of time.

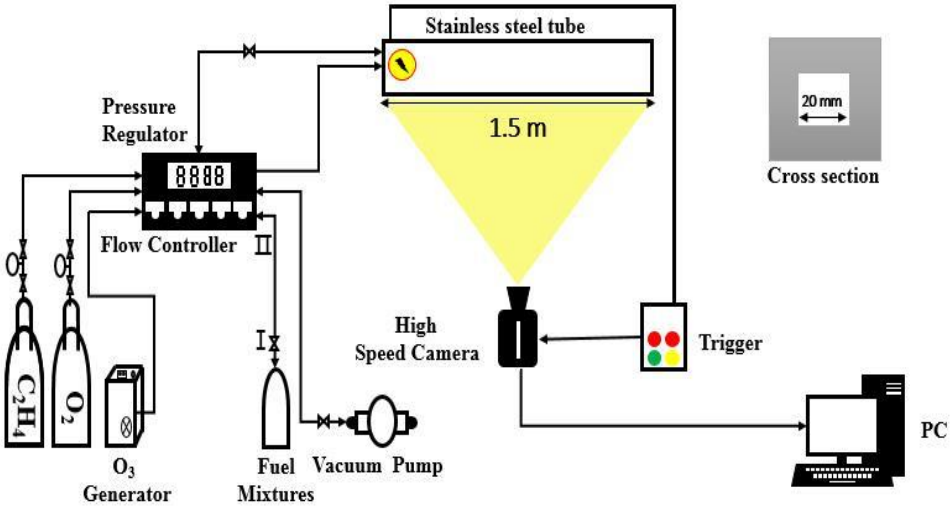


Figure 1 Schematic of experimental setup.

3 Results and discussions

3.1 Effect of ozone addition on DDT

Figure 2 shows a typical high speed image sequence of flame propagation for stoichiometric ethylene/oxygen mixtures with and without ozone addition. The visible flame were captured using the high speed camera with a frame rate of 150,000fps, the time interval between subsequent frames is 0.067ms. It can be seen that for both cases with and without ozone addition, the front part of flame exhibits blue, but the flame in downstream exhibits yellow. This is reasonable because flame takes on blue for the ethylene/oxygen mixtures with stoichiometric ratio and the yellow flame is led by the combustion of soot formed behind the front. The retonation wave observed in macro-channel differs from that in micro-channel. Furthermore, the chemical reaction luminous intensity with ozone addition is much stronger than that without ozone addition due to ozone kinetics.

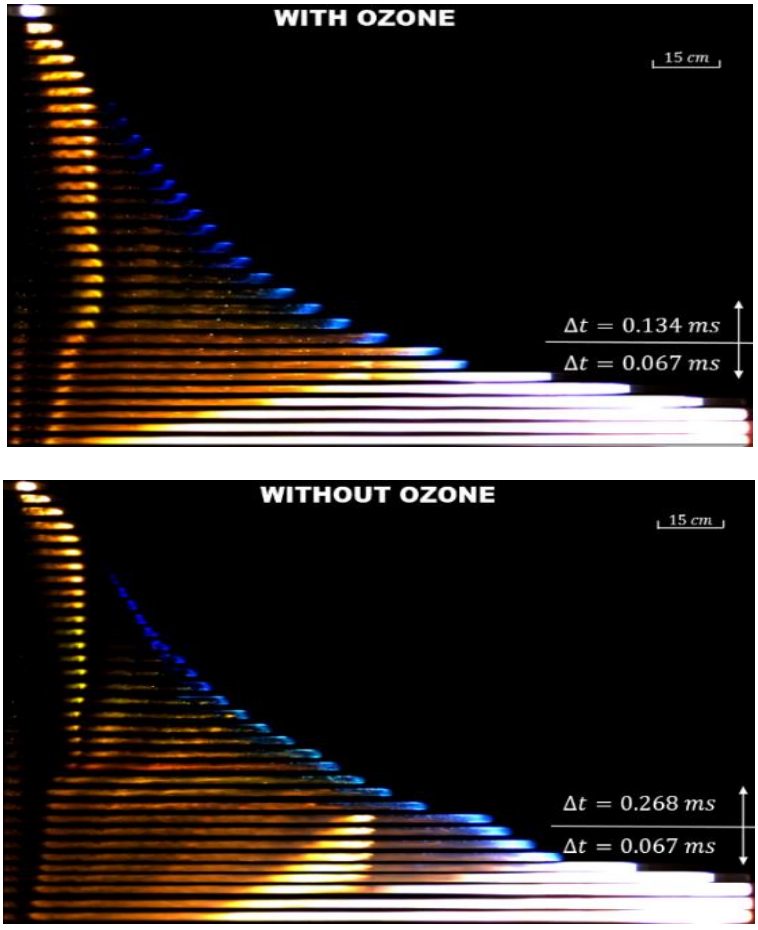


Figure 2 Image sequence showing DDT process with and without 1.5% ozone at p_0=10Kpa; the onset time is almost reduced to half for 1.5% ozone.

The flame position and velocity as a function of time for stoichiometric C_2H_4-O_2 mixture with and without 1.5% ozone are shown in Figure 3. The onset time of DDT with 1.5% O_3 is about 2 times faster than that without ozone (4.690ms versus 8.777ms), while the run-up distance of DDT is 95.36cm less than 112.92cm in the case without ozone. Adding ozone leads to the enhancement of flame velocity, while the detonation velocity keeps a constant of ~2175 m/s for both the cases with and without ozone addition. For large molecule hydrocarbon fuels, major chemical reactions during chain-initiation phase are H abstraction reaction: RH+ X=R+HX, X= H. OH. O.HO_2.CH_3 and so on. Note that, at a low temperature condition the reactions consuming H are very slow because of the extremely low concentration of radicals (X). Therefore, this reaction is a limiting step to produce initial hydrocarbon radicals [7]. Ozone can decompose spontaneously in a low temperature environment to produce a large amount of O radicals. In this experiment, the addition of ozone to generate O radicals increases the concentration of X radicals in the H abstraction reaction and shortens the ignition delay time, leading to the increase in flame speed. Since the detonation velocity depends on heat release rate, the slight difference of average velocities between the cases with and without ozone addition demonstrates that the heat release rate is not influenced substantially by the ozone addition. With a small amount of ozone addition, the DDT onset time was reduced by 77.5% (~39μs versus ~127μs) and the run-up distance is reduced to almost 60% (~6.3cm versus ~10.2cm) compared with that in micro-scale channel[5]. For micro-scale case, ozone addition drastically reduces the onset time and run-up

distance of DDT via kinetic enhancement, while for macro-scale case the DDT onset time is changed to half of no ozone case and the run-up distance almost unchanged. This shows that the ozone effect is weaker compared with that in micro-scale channel.

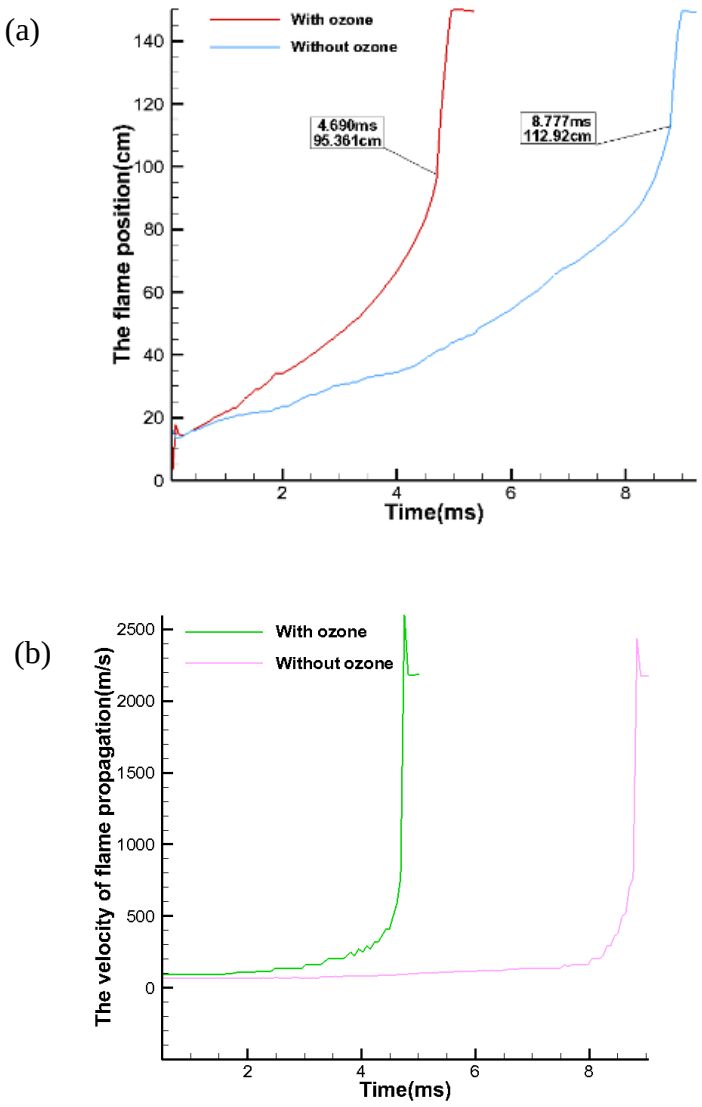


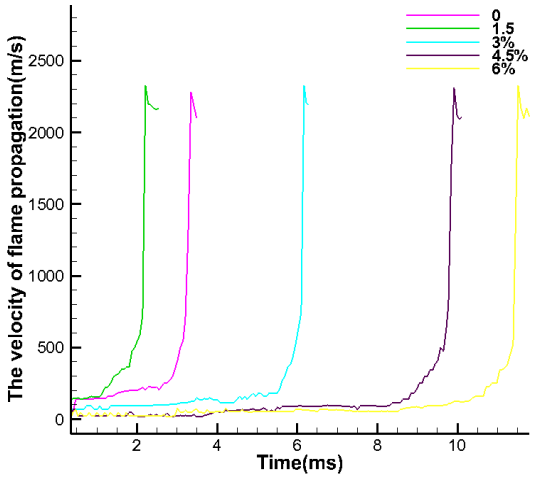
Figure 3 The flame position (a) and velocity (b) as a function of time showing DDT process with and without 1.5% ozone at stoichiometric ratio and the initial pressure is $P_0 = 10$Kpa.

3.2 DDT for different ozone concentrations

Figure 4 shows the flame position and velocities as a function of time for a range of ozone concentration from 1.5% to 6% as fixed p_0=20 Kpa. It is seen that ozone addition accelerates clearly the DDT onset time within a certain range. But if ozone concentration is higher than a certain value, the role of ozone addition

weakens and increasing ozone concentration has a negative effect on DDT. As shown in Table 1, when the ozone concentration is 1.5%, it promotes the occurrence of DDT, with shorter onset time than that without ozone by 67%; while ozone concentrations are 3%, 4.5% and 6%, the onset time of DDT increases considerably. With increasing ozone concentration, the run-up distance of DDT lengthens, while the trend is not obvious. It is interesting that for these three cases with 3%, 4.5% and 6% ozone, the run-up distances are 80.725cm, showing that viscosity friction plays the major role, meanwhile excessive ozone concentration dilutes the mixture and hence the promotion from the chemical kinetic no longer functions.

(a)



(b)

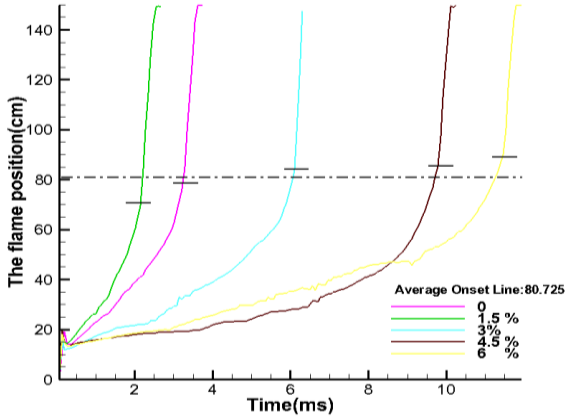


Figure 4 The flame velocity (a) and position (b) as a function of time for stoichiometric ratio at $P_0 = 20\text{Kpa}$ with different ozone concentration from 1.5% to 6%. The DDT onset distance under all conditions was approximately fitted to average onset line, and its value is 80.725cm.

Table 1: Detonation behavior of varying Ozone concentration

%O3	Onset time, ms	Distance, cm
0	3.216	75.916
1.5	2.144	69.326
3	6.030	78.560
4.5	9.782	85.068
6	11.457	89.761

4 Conclusion

The detonation time, distance, and velocities were gathered with and without ozone. This present experiment shows that the role of ozone kinetics on DDT in a macro-channel is weaker than that in micro-channel. DDT onset time is shortened with 1.5% ozone addition with as much as 50% reduction. However, the change in DDT onset distance and detonation velocities are minor. DDT trials conducted at varying ozone concentration displayed different influences: under the condition of adding a certain amount of ozone, the behavior of DDT will be strengthened, while after a certain amount, the weakening effect will be significantly enhanced.

The present experimental results indicate that the addition of a certain amount of ozone has an accelerating effect on DDT in macro-scale channel. However, compared with the micro-pipeline, its impact is relatively weaker. In the macro-scale channel, turbulence combustion has a major role on the detonation run-up distance, the effect of ozone kinetics on macro DDT is minor. The ozone addition changes slightly detonation velocity, showing that the addition of ozone hardly affects the rate of chemical reaction heat release during the detonation phase.

References

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