

Effect of an Axial Electric Field on Detonations

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1 Introduction

The interaction of an electric field with a detonation wave is an interesting topic because of the possibility that the electric field can influence the charged particles in the reaction zone of the detonation plasma. One of the early studies on interaction of detonation and electric field was conducted by Bone and Wheeler [2]. They reported a significant dampening effect (40% velocity deficit) on the detonation when an axial electric field was applied. However this dampening effect was observed only with a single mixture: 2CO+O₂ (saturated with water) at atmospheric pressure. Moreover, this effect was not reproduced in all of their experiments. A high speed streak camera was the only diagnostic used in their work. Thus, the results of the study are inconclusive and it is not clear whether or not an axial electric field can have a significant influence on the detonation. Since the time of Bone's experiment a number of researchers have studied the interaction of detonation and an electromagnetic field. Kelly and Toong [3] studied the propagation of detonation waves in a transverse magnetic and electric field. They observed only a slight (10%) velocity deficit in unseeded oxyacetylene detonations at 30-100 Torr when a detonation passed through a region of high magnetic and electric field. They attributed this velocity deficit to Hall effect that altered the current distribution in the ionized gas behind the detonation. They stated that the increased turbulence of the boundary layer at the electrode surface due to development of arc discharges contributed to the velocity deficit. A more recent study by G.O. Thomas and coworkers [4] investigated the enhancement of the detonation wave in oxyacetylene mixtures at 100-200 Torr by large energy deposition in the reaction zone. However, the enhancement of the detonation wave was small since the ratio of ohmic heating to combustion chemical energy release was small (0.01). The main reason for low energy conversion potential of the detonation plasma is due to low electrical conductivity ($\sim 10^{-3} - 10^{-4}$ mhos/cm) (when no discharges are present). The measurements of electrical conductivity, degree of ionization as well as ion and electron densities were performed by various researchers [6,7,8]. Most of these studies show a decreasing gradient in these properties from the chemi-ionization zone behind the detonation to the equilibrium products. However, even in the chemi-ionization zone the electron and ion densities are small and the body force associated with an external electric field ($F = EeN_e A_{cube} L_{test\ section} \approx 0.03N$) is negligible as compared to the dynamic pressure forces of the detonation. In summary, most of the studies on the interaction

of electromagnetic field and detonation wave do not show a significant influence of the field on the detonation. The study by Bone and co-workers [2] is the only one that shows a large velocity deficit. Therefore it is of interest to revisit the study by Bone and Wheeler [2] and confirm whether or not axial electric field has a significant influence on the detonation.

The main objectives of the current study is to reproduce the previous experiments of Bone and Wheeler [2] and confirm the observations reported by them. Apart from streak photography, the variations of voltage and current are monitored as the detonation traverses the field region permitting a more detailed description of the interaction process.

2 Experimental Setup

The experiments were conducted in a detonation tube consisting of two sections – the driver and the test section (Figure. 1). The driver section is a 50.8mm diameter steel tube, 1.2 m long.

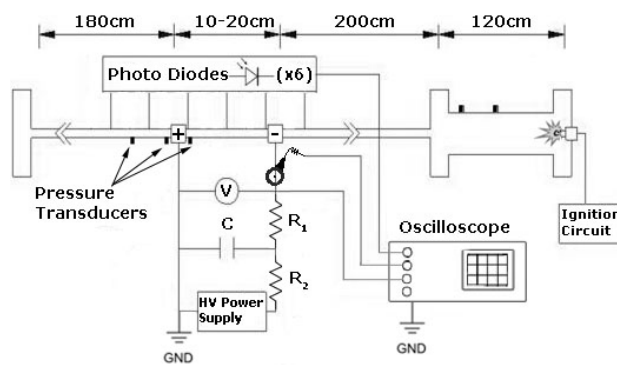


Figure 1. Experimental Setup

The detonation is initiated in the driver section by a spark discharge from a 2uF HV capacitor bank. Two pressure transducers are mounted in the driver section to make sure there is a steady CJ detonation is initiated prior to entering the test section. Three pressure transducers were mounted near the grounded electrode to monitor the pressure upstream of the detonation as the it traversed the electric field. The test section consists of a polycarbonate tube 12.7 mm in diameter with a total length of 4 m. Two polished

stainless steel cylinders were used as electrodes in the test section. These electrodes (marked “-“ and “+“ in Fig.1) were inserted in series with the polycarbonate tube to form a continuous detonation tube. The spacing between the electrodes was varied from 10-20cm. The live electrode was connected to a HV capacitor ($C=0.005\mu\text{F}$) which was charged by a HVDC power supply through a charging resistor $R_1=2\text{M}\Omega$ to a specified initial voltage. An optional $R_2=1\text{M}\Omega$ resistor was inserted in series with the capacitor to limit the current in the field section as the detonation traversed between the two electrodes. The second electrode was grounded. The electrode configuration is similar to that used by Bone et al. [2]. A Pearson VD-305A capacitive voltage divider was connected across the electrodes to monitor the voltage drop as the detonation traversed the field. A Pearson 1025 current transformer was used to simultaneously monitor the current. Six photo diodes were spaced regularly along the tube to monitor the detonation velocity as it traversed the field section. A rotating drum streak camera pointed at test section was also used for observing the change in the spinning structure as well as the detonation velocity. The electric field strength between the two electrodes was varied from 200 V/cm to 8000V/cm. In order to prevent arcing between the two electrodes the voltage applied between the two electrodes was always kept below the breakdown value. Smoked foils were not used as a diagnostic in this experiment since the natural conductivity of the soot promoted arcing and did not allow for the use of high electric fields.

3 Results and Discussion

Figure 1 shows a typical streak photograph of a detonation in 2CO+O2 mixture (saturated with water) at an initial pressure of 1atm propagating in a 12.5mm diameter tube containing two collar electrodes. No electric field is applied. The spinning structure of the detonation is clearly evident. The luminous regions downstream of the electrodes are due to combustion of soot particles ablated from the metal electrode surfaces. As seen in Figure 2, the detonation propagates through the test section without suffering any change in structure or velocity. Figure 3 shows the result of a similar experiment with the same initial conditions; however, in this case an electric field gradient of 5kV/cm was applied.

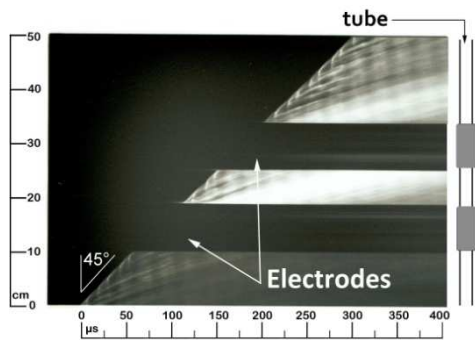


Figure 2.# 111 2CO+O2+H2O, 1atm, no field

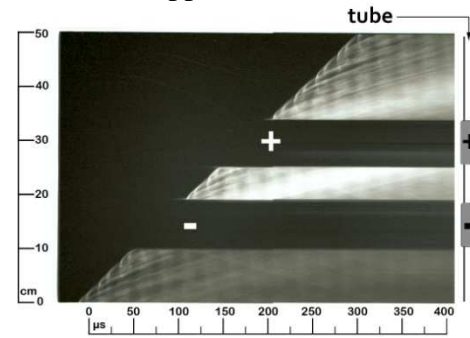


Figure 3.# 114 2CO+O2+H2O, 1atm, 5kV/cm, R=1MΩ

As can be observed in Figure 3 the electric field appears to have no effect on either the detonation structure or velocity. Numerous experiments were carried out, varying the electric field from 4 to 7kV/cm, and no effect on the detonation due to electric field was observed in all the experiments. Thus, the present finding is in contrast to what Bone and co-workers [2] observed. In their study they reported a significant velocity deficit when an electric field of 5kV/cm was applied. The fact that we observed no discernable change in the detonation velocity due to the electric field, is due to the very low ion concentration due to chemi-ionization in the reaction zone. Measurements of ion concentrations, conducted using a

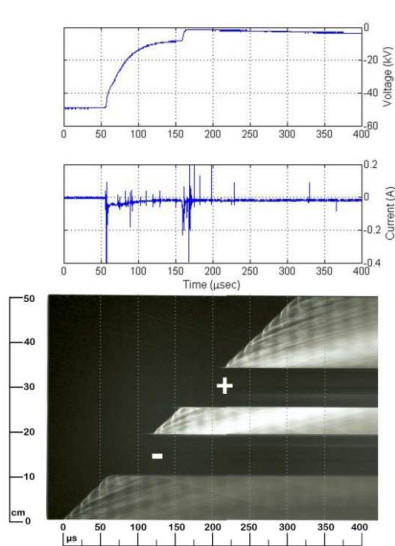


Figure 4. #114 2CO+O2+H2O 1atm, 5kV/cm, R=1MΩ

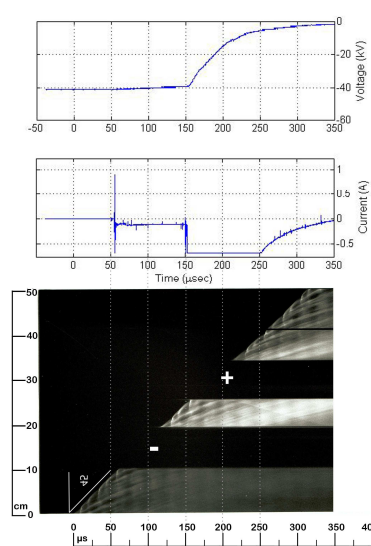


Figure 5. #116_2CO+O2+H2O 1atm, 4kV/cm, R=0Ω

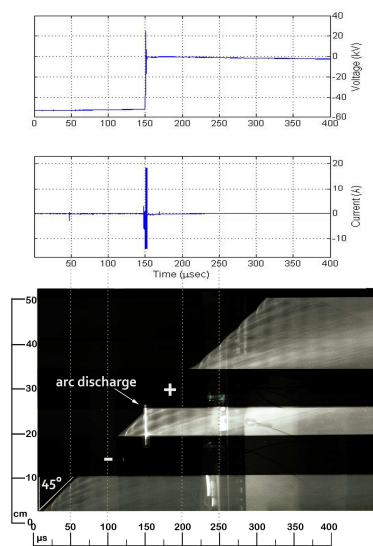


Figure 6. #115 2CO+O2+H2O, 0.9atm, 5.6kV/cm, R=0Ω

symmetrical double Langmuir probe, indicate ion densities of the order of $\sim 3 \times 10^{12} \text{cm}^{-3}$ and $\sim 4 \times 10^{11} \text{cm}^{-3}$ in the reaction zone and in the equilibrium product gases, respectively. These concentrations are in agreement with the ionization levels reported by Basu and Fay [3] for oxyacetylene detonations at atmospheric pressure. As a result of the low ion concentration, the body force due to the electric field is negligibly small as compared to the dynamic pressure forces of the detonation. The body force due to the electric field acting on a volume of charged particles is found to be very small, ie $F = EeN_i A_{\text{tube}} L_{\text{test section}} \approx 0.03N$.

In an effort to elucidate the interaction process, measurement of the time variation of the electric field and current between the electrodes were carried out. The time scale is synchronized with that of the streak photograph so that electric field and current can be correlated with the position of the detonation wave. Figure 4 shows the simultaneous streak, voltage across the electrodes and current measurements. A $1\text{M}\Omega$ current limiting resistor is inserted in series with the capacitor bank to limit the current between the electrodes. The detonation propagates from negative to positive electrode. An electric field of 5kV/cm is initially applied between the electrodes. The streak photograph at the bottom of the figure illustrates the same behavior as Figures 2 and 3 with no observable changes in velocity and structure. However, the voltage and current traces indicate the variation of voltage and current across the electrodes as the detonation traverses the test section between the electrodes. The voltage trace indicates a steady drop in magnitude of voltage across the electrodes (from -50kV to -10kV) as the detonation enters the electrode (at $57\mu\text{s}$) and traverses the 10cm length of the steel electrode. Upon exiting from the negative electrode (at $125\mu\text{s}$) into the insulated region, the magnitude of the voltage continues to drop, but now at a slower rate. As the detonation enters the positive electrode (at $157\mu\text{s}$) an abrupt drop in the magnitude of the voltage occurs as the region between the electrodes is essentially shorted out. The current trace indicates a sudden rise in current of the order of 400mA when the detonation is just about to enter the electrode. The current then decreases slowly as the detonation traverses the length of the negative electrode. The current drawn in by the negative electrode is governed by interaction of the detonation with the electrode sheath. The negatively biased electrode repels electrons and attracts positive ions from the reaction zone. The maximum amount of ions drawn in by the electrode is limited by the ion saturation current. Due to low ion concentration in the reaction zone, the ion current to the electrode is small. In the presence of a $1\text{M}\Omega$ resistor (as is the case in Figure 4) this current is even further reduced.

In order to determine if the ion current can, in fact, influence the detonation velocity, as suggested by Bone and co-workers [2] the current limiting resistor was removed. The result is shown in Figure 5. Similar to the previous streak photographs (Figures 2-4), there is no observable change in detonation structure or velocity. However, the voltage and current traces are different from the ones shown in Figure 4. As seen in Figure 5, the voltage remains at a relatively constant value (-40kV) as the detonation enters the negative electrode and traverses the distance between the electrodes. The current trace shows a quick spike as the detonation first enters the negative electrode. After this initial spike, the current maintains a constant value, which is of the order of the maximum ion saturation current ($\sim 100\text{mA}$). Thus, a constant ion current is drawn from the combustion products behind the detonation as it passes the negative electrode and traverses most of the field section. Another change in voltage and current occurs when the detonation approaches the positive electrode at about $150\mu\text{s}$. At this

point the detonation essentially shorts out the capacitor and it discharges through a slug of ionized gas between the electrodes.

In order to determine if the discharge can significantly perturb the detonation as it approaches the positive electrode, the initial electric field was increased to 5.6kV/cm and the pressure was reduced to 0.9atm to achieve an arc discharge conditions. The result is shown in Figure 6. However, similar to the previous results, the detonation does not appear to suffer any changes in either its structure or velocity. The voltage trace shows a very fast drop and the current trace is reduced to a very fast spike, indicative of an arc discharge. Moreover, the a luminous line (due to a bright arc) connecting the two electrodes is clearly seen in the streak photograph in Figure 6. The discharge has the potential to significantly change both the structure and the propagation velocity of the detonation by igniting the mixture ahead of the detonation. However, this effect is highly dependent on the location of the discharge which is a function of initial pressure. For the case of the 2CO+O₂ mixture at 1atm (as seen in Figure 5-6) the discharge occurs only when the detonation reaches the second electrode with a discharge occurring in the combustion products behind the detonation. In order to investigate the effect of the discharge occurring ahead of the detonation (before the second electrode) a mixture of C₂H₂+O₂+85% Ar at a lower initial pressure of 28kPa was used.

In the case of C₂H₂+O₂+85% Ar mixture at 28 kPa the discharge occurs before the detonation reaches the second electrode. As seen in Figure 7 the discharge occurs at about 150μs when the detonation is about 5cm before reaching the negative electrode. The discharge ignites the mixture ahead of the detonation. The lack of fresh mixture causes failure of the detonation, which becomes a shock wave. The shock wave is transmitted through the region of the burnt gas and meets the flame that was ignited by the discharge. The shock-flame interaction promotes the development of instabilities and increased surface area of the flame, resulting in DDT at 340μs. In summary, the discharge occurring ahead of the detonation can significantly perturb its structure and velocity by igniting the mixture ahead of the detonation leading to failure of the detonation.

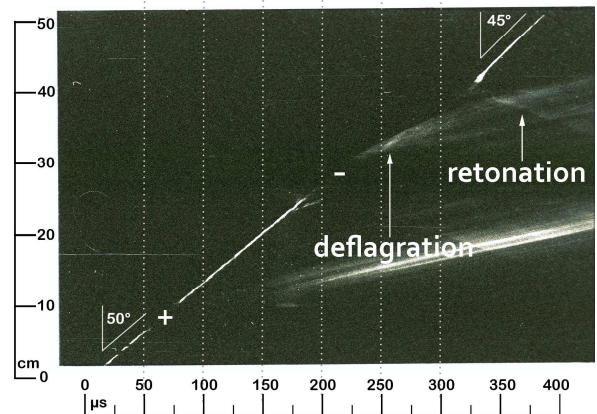
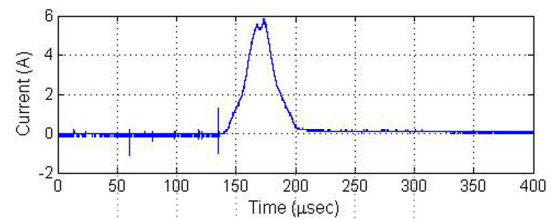


Figure 7.# 207 C₂H₂ O₂ 85%Ar 28kPa, 0.95kV/cm

4 Conclusion

The current study investigated the effect of an axial electric field on detonations in 2CO+O₂ mixture at 1atm and C₂H₂+O₂+85% Ar mixture at 28kPa. The experimental setup and initial conditions were similar to the previous experiment conducted by Bone and Wheeler [2]. However, no significant perturbation of the detonation travelling through the region of high electric field was observed. In the present experiments in the case of 2CO+O₂ mixture at 1atm neither the extraction of ions at the electrode nor the discharge ahead of the detonation had any influence on detonation structure and velocity. In the case of C₂H₂+O₂+85% Ar

mixture at low initial pressure of 28kPa we observed an arc discharge ahead of the detonation. This arc discharge significantly perturbed the detonation by igniting the mixture upstream of the detonation.

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