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# Ignition delay study of liquid nano-fuels for application in pulse detonation engines using a shock tube

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## Abstract

The ignition delay of various nano-fuels was compared with the base fuel (i.e. aircraft turbine engine fuel) to study the feasibility of use in high-speed aerospace applications (i.e. pulse detonation engines). The base fuel was mixed with two different nano-particles, titanium dioxide (TiO2) and multi-walled carbon nanotube (MWCNT), to develop a nano-fuel that can be employed for regenerative cooling of combustor walls before injection. A shock tube was employed to carry out the experiments where the liquid fuel was introduced in the test section as a wall droplet. From the experiments, an increase in the ignition delay was observed for the titanium dioxide nano-fuel whereas a slight reduction in the ignition delay was observed for the MWCNT nano-fuel.

**Keywords**: *Ignition delay, pulse detonation, nano-fuel, alternative fuel*

## Nomenclature

$S_1$ – Pressure transducer 1.

$S_2$ – Pressure transducer 2.

$M_s$ – Incident Mach number.

$P_5/T_5$ – Pressure/temperature behind the reflected shock wave.

$\phi$ - Equivalence ratio

## 1. Introduction

Ignition delay defines the residence time of a fuel in the combustion chamber of a high-speed engine. It is a useful parameter that defines the ignition capability as well as the flame sustainability in any engine. Further this parameter is a much more important parameter for the cases where the packet of air-fuel mixture resides within the combustion chamber for a few milliseconds [1]. To avoid fluctuations in specific impulses and energy release, testing the ignition delay of any new fuel developed for high-speed applications is necessary.

The use of nano-fuels can be advantageous as they can serve an alternate purpose i.e. cooling of the combustion chamber. This removal of heat from the combustion chamber, further pre-heats the fuel before it is injected into the combustion chamber thus reducing the ignition delay. Heat transfer studies indicate an increase in the heat transfer coefficient when nano-fuel was employed instead of the base

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fuel (ATF) [2]. Thus nano-fuels have a probable application in high-speed engines, such as pulse detonation engines [3,4,5].

In the work carried out previously [1], the effect on the ignition delay of the airplane turbine fuel (ATF) was measured when aluminium oxide ($Al_2O_3$) nano-particles were added to ATF. This comparison pointed out that a reduction of ~11% is observed in the value ignition delay when the nano-fuel ($ATF+Al_2O_3$) is used instead of ATF. In the current work, this study is further extended to test the effect on ignition delay of two different nano-fuels, i.e., ($ATF+TiO_2$ and ATF+MWCNT). The volume fraction loading of the nano-particles is 0.3%.

## 2. Experimental Setup

The experiments in this study were carried out using a shock tube of variable inner diameter, where the inner diameter and length of the driver and driven sections of the tube were 51 mm, 37 mm, and 2.5 m, 3 m respectively. Fig. 1 presents a schematic of the experimental setup employed in the current study. The capability of shock tubes to create high pressure and temperature within a fraction of a second (around ~2-5 ms), makes them an ideal instrument for combustion testing. Nowadays many researchers are using this technique to measure the ignition delay of various fuels [1,6,7].

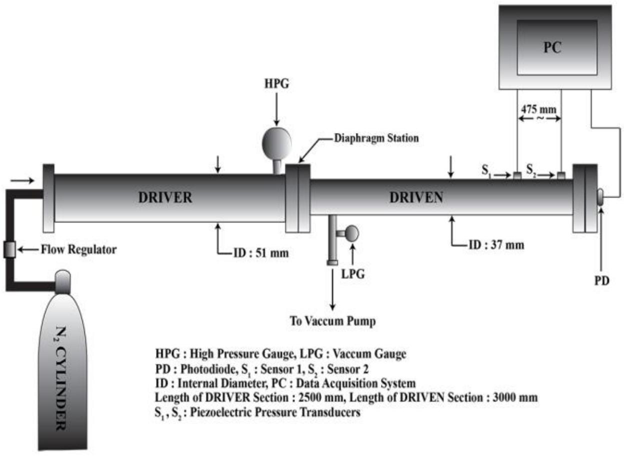


**Fig 1.** Schematic of the shock tube used for ignition delay studies.

**Table 1.** Ignition conditions in the shock tube for base and nano-fuels.

| Fuel | Equivalence Ratio | $P_5$ (bar) | $T_5$ (K) |
|---|---|---|---|
| ATF | 2.0 | 9.66 ± 1.42% | 1152 |
| ATF+MWCNT | 2.0 | 10.09 ± 6.87% | 1161 |
| $ATF+TiO_2$ | 2.0 | 8.89 ± 9.13% | 1128 |
| ATF | 3.0 | 12.3 ± 4.93% | 805 |
| ATF+MWCNT | 3.0 | 11.08 ± 8.11% | 790 |
| $ATF+TiO_2$ | 3.0 | 11.78 ± 6.45% | 788 |

The gas in the test section is air and the liquid fuel to be tested was preloaded into the end of the driven section as a wall droplet. This droplet atomizes on collision with the propagating shock waves accomplishing the function of a fuel injector [8]. A photodiode was fixed at the test section to measure the line emissions of CH* chemiluminescence of 430±5 nm wavelength ($A^2\Delta \rightarrow X^2\Pi$). These emissions are observed as soon as pre-dominant combustion is initiated by the conditions behind the reflected shock wave. Table 1 presents the details of simulations carried out in the current work.

## 3. Results

The ignition delay for the present study is defined as the time between the pressure jump due to the first reflection of the shock wave and the point of intersection of the line of extrapolation of the maximum slope of the photodiode trace with the baseline (x-axis) [9]. The results obtained for the fuelled runs for both ATF+MWCNT and ATF+$TiO_2$ (here the ignition delay for each case are compared with the base fuel i.e. ATF) are presented in Fig. 2 and 3 respectively.

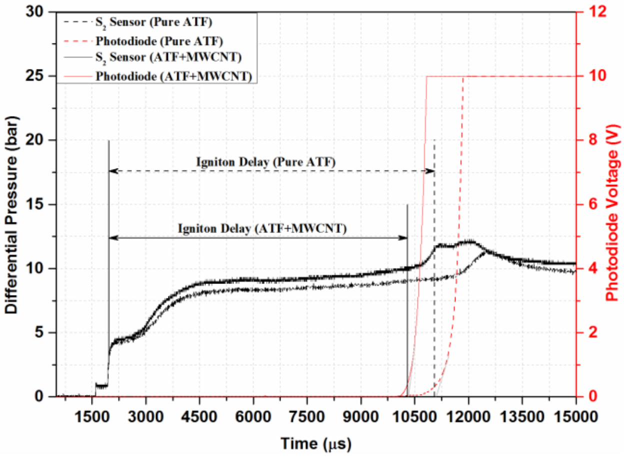


**Fig 2.** Comparative plots of data acquired for sensor $S_2$ and photodiode for the fuelled run ($\varphi$= 2) for MWCNT nano-fuel and pure ATF.

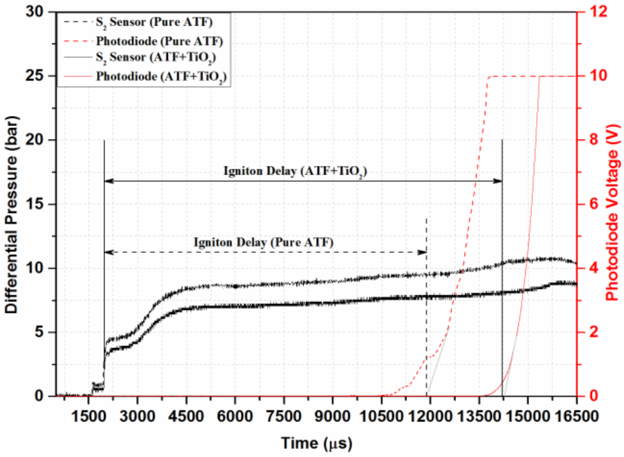


**Fig 3.** Comparative plots of data acquired for sensor $S_2$ and photodiode for the fuelled run ($\varphi$= 2) for $TiO_2$ nano-fuel and pure ATF.

**Table 2.** Experimentally measured values of ignition delay.

| Fuel | Equivalence Ratio | Ignition Delay (ms) |
|---|---|---|
| ATF | 2.0 | 10.35 ± 6% |
| ATF+MWCNT | 2.0 | 9.02 ± 7.68% |
| ATF+$TiO_2$ | 2.0 | 12.8 ± 3.04% |
| ATF | 3.0 | 8.95 ± 10.56% |
| ATF+MWCNT | 3.0 | 8.8 ± 20.04% |
| ATF+$TiO_2$ | 3.0 | 8.08 ± 18.5% |

From the results presented in Table 2, it can be observed that for the ATF+MWCNT a reduction in the ignition delay (~9%) is observed (for both equivalence ratios 2 and 3). For the ATF+$TiO_2$ fuel, an enhancement in the ignition delay values is observed (~7%) when the equivalence ratio is 2 but a reduction in the value of ignition delay is observed when the equivalence ratio increases to 3 (~9%).

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