Ignition of Liquid and Dust Fuel Layer by Hydrogen-Oxygen Detonation

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Abstract

Ignition of the liquid layer and dust fuel layer by the detonation wave propagating in the hydrogen-oxygen mixture is reported. Experiments were carried out using shock tube equipped with optical quality observation windows. Schlieren system and high-speed camera were used for measurements of ignition delay, while pressure transducers provided data necessary for measurements of detonation wave velocity and pressure variation within the front of interacted detonation wave and fuel layer. Kerosene, nitroglycerine and pentryt were used as fuels. Investigation shows that the layer of liquid fuel can be efficiently ignited by detonation wave. It was found that the ignition delay of fuel layer depends primary on detonation wave velocity and sensitivity of igniting fuels and less on layer thickness. Knowledge of behaviour of fuel ignited by detonation can be useful for evaluation of explosion hazard associated with a spill of dangerous chemicals.

Introduction

Ignition of different fuels layers by a shock wave propagating in air, oxygen enriched air and in pure oxygen has been studied experimentally for may years [1÷5]. Such data are very useful for evaluation of kinetic data as well as for evaluation of the possibilities of detonation of the fuel layer [1,3]. This research is also focused on the development of simple techniques for obtaining data on high velocity dispersion and high temperature ignition of layered fuel.

The interaction between a detonation wave and a liquid or dust fuel layer may occur when fuel vapours from incidentally spilled chemical might explode and produce detonation wave which might ignite spilled fuel. Such problems concern mining where detonation front of a lean methane-air detonation can lift and ignite a coal dust. Similar scenarios can occur in petroleum, gas, power, chemical and process industries [6÷9].

Experiments

Experiments were conducted on the modified shock tube equipped with a special observation section for high speed Schlieren photography. The driven section has a square cross-section 35x35 mm and was 3.5 m long. The driving section of the shock tube was filled with stoichiometric hydrogen-oxygen mixture with 50% addition of helium. The driver section, separated from the driven section by the plastic diaphragm, was filled with mixture of oxygen and hydrogen, with hydrogen concentration changing from 25% to 66%. Initial pressure was always equal to 0.2 bar because of danger of breaking visualisation windows. The visualisation section is placed on the end of tube. Investigated fuel was placed in visualisation section at the bottom of the shock tube. Thickness of the layer is setting by changing special insets, which have different size. Kerosene, 1% solution of nitroglycerine in acetone and pentryt (PNT) were used as condensed fuels.

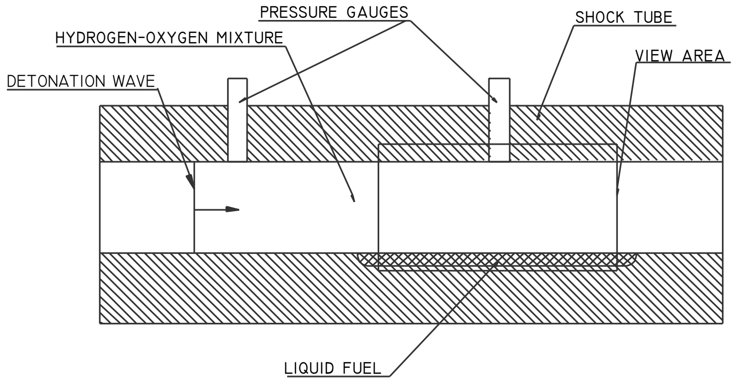

Fig 1. Schematic diagram of visualisation section.

Results

Ignition delay for tested fuel layers was determined by the Schlieren streak photographs (Fig. 2). The ignition delay was defined as a period between passing of the detonation wave and visible region of burning fuel. Propagating detonation wave is clearly visible on streak pictures, while ignition region is less sharp. Some time, accurate determination of the ignition moment is difficult. Measuring the distance between these two events one can calculate the ignition delay. Detonation speed was varied from 1700 m/s (for lean mixture) to almost 2750 m/s (for stoichiometric hydrogen-oxygen mixture). Investigation shows that ignition delay is changing between 61 μs and 111 μs for kerosene, from 21 μs up to 49 μs for nitroglycerine and from 33 μs up to 100 μs for PNT (pentryt). It depends on detonation velocity (composition of detonating mixture) and on thickness of fuel layer.

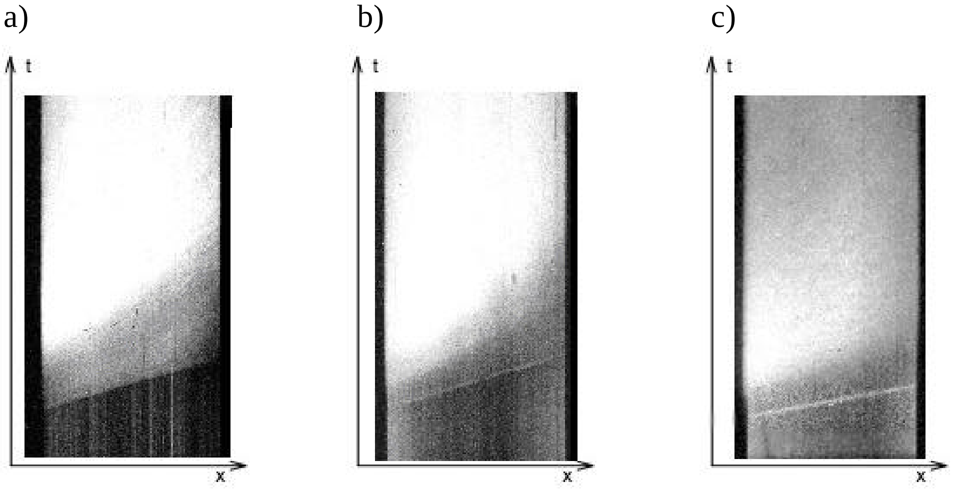

Fig 2. Streak photographs of ignition of: a) kerosene, b) nitroglycerine, c) PNT

The measured experimentally ignition delay time were plotted as a function of reciprocal temperature behind the detonation wave. This temperature and oxygen concentrations behind the detonation front were calculated using Gordon-McBride NASA computer code [10]. The ignition delay is a strong function of a temperature behind the detonation front and depends less on availability of free oxygen behind the detonation front. This relationship exists for all tested fuels, however it is strongest for nitroglycerine and pentryt. It is very well illustrated on logarithmic plots of τ (ignition delay) versus 1/T (reciprocal temperature) as seen on the Fig 3. It easy to notice that for thin layers of explosive materials, especially for nitroglycerine, experimental points are well correlated. It means that chemical processes occurring in the fuel layer are decided in ignition process. If layer of PNT is thick, dispersion of dust in gaseous products of detonation plays important role and results are more scattered. Dispersion and spray formation are also very important for ignition of kerosene [3]. These processes enable creating of fuel-oxidiser mixture. It is necessary in ignition of kerosene spray, which demand external oxidiser. Because of that ignition of liquid hydrocarbons is much more complicated phenomenon than ignition of explosives, which for ignition needs only temperature increase. Therefore experimental data for kerosene do not fit very well to simple Arrhenius equation.

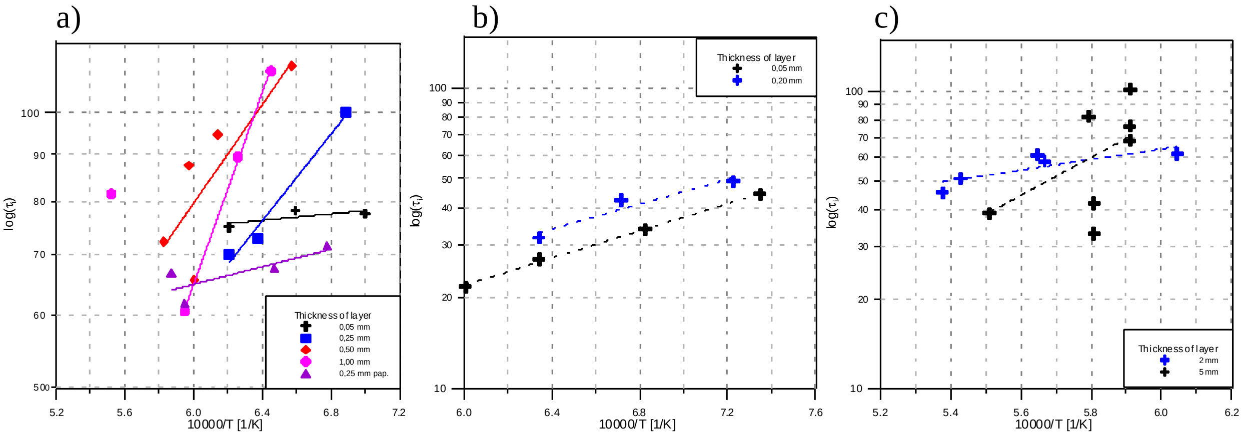

Fig 3. Ignition delay as a function of 1/T : a) kerosene, b) nitroglycerine, c) PNT

Dependence of ignition delay on layer thickness was also measured. There are, however, no clear relationship between layer thickness and measured ignition delay. For lean detonation mixtures (lower temperature behind the detonation front, but higher free oxygen concentration) ignition delay increases with increasing layer thickness, but if oxygen concentration is 50% (basically less free oxygen behind detonation front, but higher detonation speed and temperature behind shock) the ignition delay of kerosene can be even shorter for thicker layer.

During the experiment pressure was measured, too. First pressure gauge was placed before the layer, second above it. Differences between these three measurements don’t differ much for liquid fuels. Only for thicker layers of PNT pressure is slightly larger at layer location then before fuel layer. It was also found that the fuel poured into porous media (paper strip suck with nitroglycerine) ignites more easily and burns intensively.

Discussion

It was shown that detonation wave could be use to determine ignition delay of layered fuels and dependence of ignition delay versus temperature could be evaluated. Date on ignition of explosive material such as nitroglycerine and pentryt are well correlated while for kerosene more scattered results are obtained. This is due to complexity of ignition of kerosene as compare to explosives. For kerosene, ignition could occur only when appropriate mixture of fuel and oxidizer is form and temperature of this mixture is sufficiently high. Generally, smallest ignition delay was found for nitroglycerine, followed by pentryt dust and then kerosene. It was also found that for relatively thick pentryt dust layer slightly higher pressure is observed in layer vicinity. Some evidence also indicate that nitroglycerine placed in a porous media shows more intensive ignition and combustion after detonative wave ignition.

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