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Shock Tube Study on Auto-ignition Delay of Kerosene Aerosol and Its Cracked Mixture

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Abstract

An aerosol shock tube with piston setup attached to reflection end is developed for ignition delay studies of liquid fuels. Piezoelectric gauge and photomultiplier with filter are used respectively to detect pressure and OH emission signals. Autoignition delay is obtained for kerosene aerosol and its cracked mixture at different temperature and pressure, equivalence ratios. The results show good linearity of ignition delay with temperature inversion at different pressure and equivalence ratio. At high pressure, data of delay is close for aerosol and heating kerosene. But difference is obviously at low temperature. During burning, local shock waves are generated and propagate into burnt and unburnt mixture.

Keywords: shock tube, ignition delay, shock waves, light emission

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1. Introduction

For combustion studies of scramjet and detonation, ignition delay of kerosene and its cracked mixture are important for combustor design. Also, in calibration of fuel chemistry elementary reaction models, ignition delay is used to judge chain reaction steps. Usually, shock tube is almost a unique facility to obtain delay of auto-ignition. In fact, industrial fuels are almost liquid, so, how to get liquid fuel ignition delay in shock tubes is still a challenge topic at present. Davison and Hanson[1] used ultrasonic nebulizer to produce kerosene aerosol in mixture of Argon and oxygen and got ignition delay for liquid fuels. Hydraulic assembly connected to shock tube end is used to inlet

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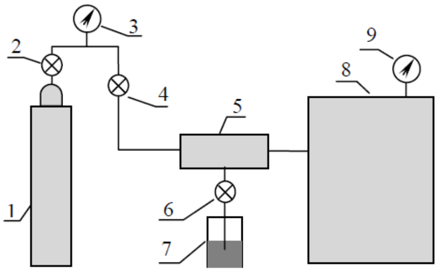
aerosol. In this paper, premixed kerosene aerosol in air mixture is formed outside shock tube and an aerosol shock tube is developed with piston assembly at reflection end for aerosol inlet. A tube with large inner and bend diameters are used to avoid droplets adsorption collision to tube walls during filling. In this shock tube, kerosene and its cracked mixture[2]are studied for obtaining ignition delay.

2.Experiments

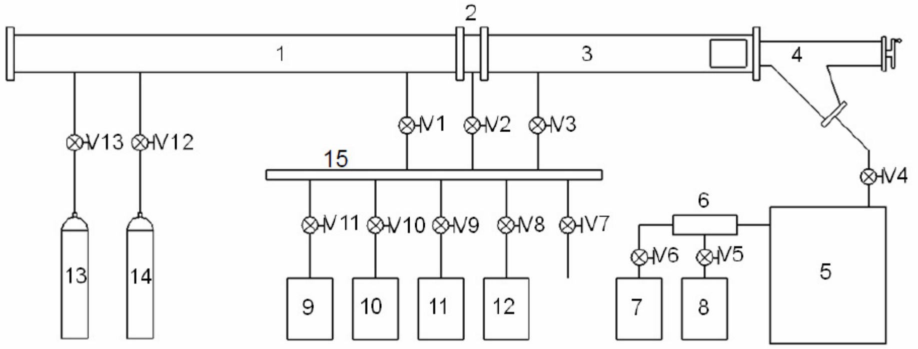
Fig 1 presents a schematic of set-up for aerosol forming. Tank is vaccumed and kerosene is sucked by a fuel nozzle at diameter 0.3mm in throat of Laval nozzle with constant throat. Air is inlet from a gas bottle at specified pressure by a regular meter. Equivalent ratio is predetermined by air mass in tank and metered volume of kerosene.

Fig 2 shows schematic of gas distributor for shock tube. Sections of high pressure(1), low pressure(3) and diaphragm(2) are conventional. But piston setup is attached to reflection end. Fig 3 presents picture and schematic of piston setup. When aerosol is filled into low pressure section, piston is opened and entered aerosol is vaccumed initially so that inner tube walls can be wetted. Then, piston is closed and aerosol filling is finished at specified pressure. By Mie scattering, SMD of droplet is ranged from 3μm to 4.5μm at tank pressure from 0.14MPa to 1.8MPa(Fig 4). No kerosene is condensed on quartz windows in shock tube test section due to low pressure. Fig 5 shows how to determine ignition delay by signal time histories of pressure gas and photomultiplier(PMT). Dispersed burning zones occur randomly in test section at low temperature. Therefore, it is difficult to determine auto-ignition delay because of several peaks of light signal(Fig 6). In our experiments, we neglect such paradox conditions and minimum temperature is found when unique peak appears in PMT signal(fig 5).



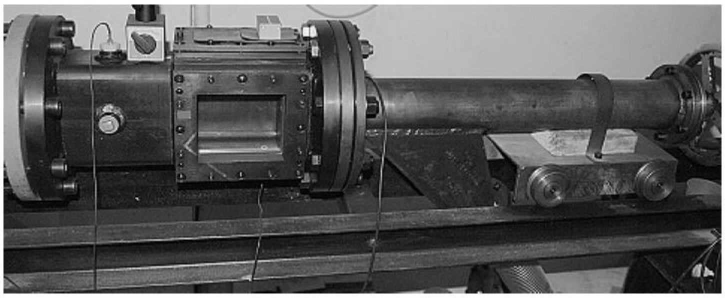
1 gas bottle 2 regulator 3 9pressure gauge 4 ball valve 5laval nozzle 6 fuel valve 7 kerosene 8 tank

Fig. 1.schematic of assembly for aerosol formation

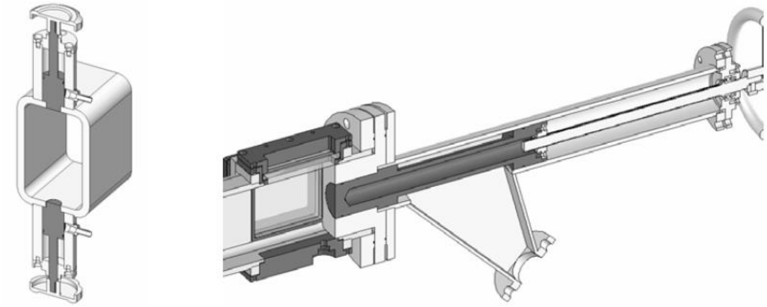


1 high pressure 2 diaphragm3low pressure 4piston setup 5tank 6 atomizer 7air bottle 8kerosene
9 10 11pressure gauge 12vaccum 13he bottle 14nitrogen bottle 15 gas distributor V1-V11valves

Fig. 2 .schematic of gas distribution system



(a)picture of piston setup



(b) vaccum valve (c)schematic of piston setup

Fig.3. picture and schematic of piston setup

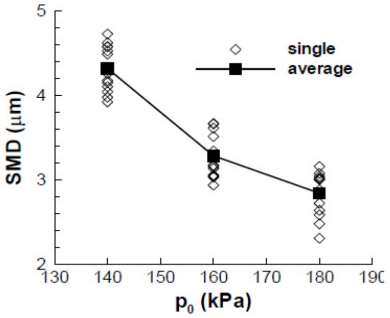


Fig .4. schematic of gas distribution

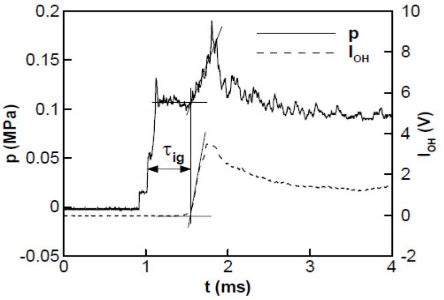


Fig .5.pressure and PMT signal time histories

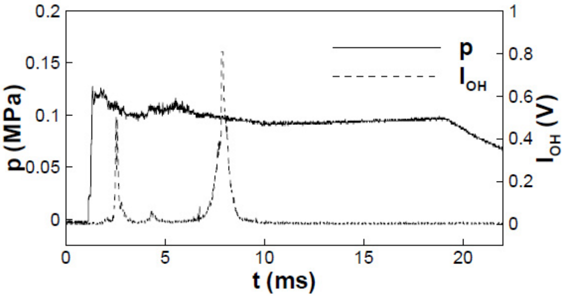


Fig.6. time histories of pressure and PMT at low temperature(T5=1119K)

3 Results and Discussions

Fig 7 and Fig 8 present ignition delay at different temperature and pressure. In Fig 7, ignition delays are in agreement with precious data but different at low temperature. Ignition delay is obtained in shock tube with heat tape in low pressure section. Complex decomposition and fractionation possibly occur while heating. In Fig 8, ignition delay is decreased when pressure is increased for the same temperature. The difference of ignition delay between our kerosene and JP-10 is possibly due to difference in species composition and different bath gas. Based on data in Fig 7, a correlation formula can be obtained as follows

$$\tau_{ig} = 4.75\times10^{-7} p^{-1.16} \exp\left(\frac{17360}{T}\right) \tag{1}$$

Where τig is time delay(ms), p is pressure(MPa) and T is temperature(K). In Ref[1], factor in term p is -0.56 but -1.16 in our paper. This means τig in our experiments depends more strongly on pressure than that in Ref[1] which mixture of oxygen and argon and JP-10 is used.

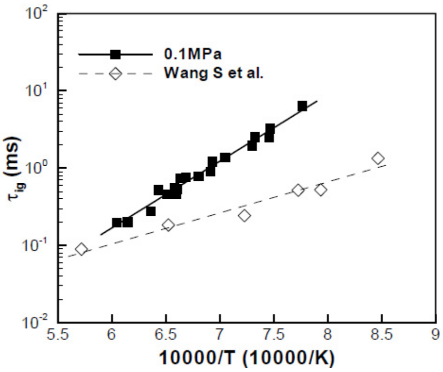


Fig.7. τig versus 1/T at 0.1MPa

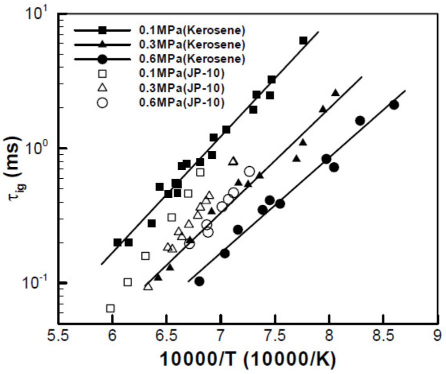


Fig.8. τig versus 1/T at different pressure

Normalized formula can be got based on data in Fig 8 and referred pressure 0.1MPa, i. e.

$$\tau_{ig} = 0.0692 p^{-1.16} \tau_{ig,\ 0.1\mathrm{MPa}} \tag{2}$$

Rearranging data in Fig 8, normalized τig are replotted in Fig 9 and good linearity is shown. In Ref[2], cracked kerosene is composed of species CH4(35%), C2H6(20%), C3H8(15%), C2H4(15%), C3H6(15%). The percentage in bracket is species molar fraction. By Dalton’s law, mixture is formed by listed species in our experiments. Fig 10 presents τig for different equivalence ratio Φ. For cracked kerosene, τig also shows good linearity. With increasing of Φ, τig also increases.

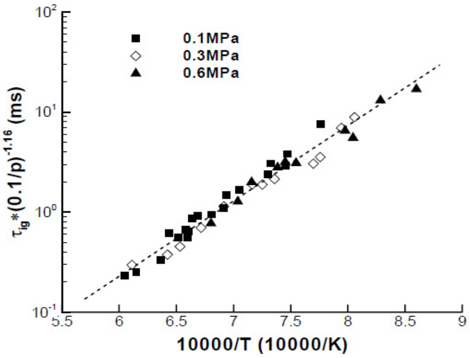


Fig.9. normalized τig versus 1/T referred to 0.1MPa

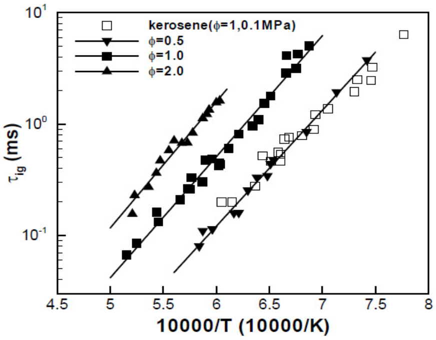


Fig.10. τig versus 1/T for cracked kerosene

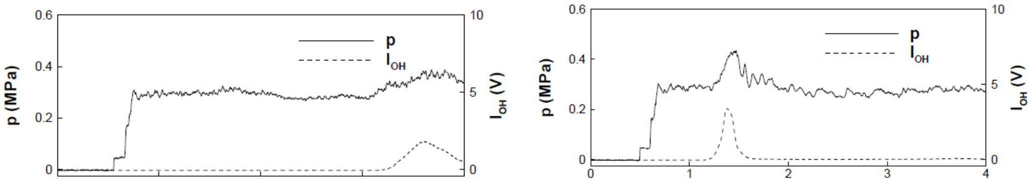
Based on data in Fig 10, an empirical formula can be correlated as follows

$$\tau_{ig} = 1.45 \times 10^{-7} \phi^{1.85} \exp\left(\frac{24950}{T}\right) \tag{3}$$

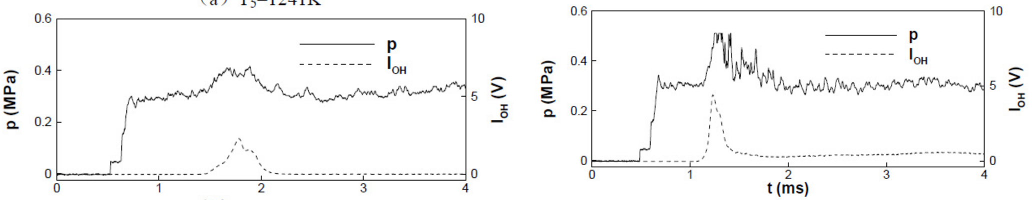
Where τig is time delay(ms), Φ is equivalence ratio and T is temperature(K). Comparing equations (1)and (3), equivalence ratio has strongly effects over pressure. Referring to Φ is unity, we can derive normalized equation as follows:

$$\tau_{ig} = \phi^{1.85} \tau_{ig,\ \phi=1} \tag{4}$$

Fig 11 gives time histories of pressure and OH intensity. In Fig 11, incident and reflected shock are clearly seen and shock bifurcation due to interaction between reflected shock and boundary layer induced by incident shock. Also, OH intensity becomes strong at high temperature. Accompany to burning, local shock is generated and propagates outwards to burned and unburned mixture. At high temperature, this local shock becomes strong either. This corresponds to DDT phenomena in premixed mixture. Similar phenomena are observed in different pressure and equivalence for kerosene and cracked kerosene mixture.



(a) T_5=1241K (c) T_5=1359K



(b) T_5=1299K (d) T_5=1379K

Fig.11. pressure and PMT signal time histories at 0.3MPa for kerosene

4 Concluding Remarks

(1)An aerosol shock tube is developed by attaching a piston setup for aerosol filling. Premixed aerosol is formed outside shock tube and SMD ranged from 3 to 4.5 μm.

(2)Ignition delay of kerosene and its cracked mixture are obtained in shock tube. These datum are air mixture but not mixture of fuel, oxygen and Argon.

(3)Formulas of ignition delay correlated to pressure and equivalence ratio are obtained so that comparison can be made for datum obtained at different test condition such as different pressure, equivalence ratio and size of shock tube.

Reference

[1]Davidson D F, Horning D C, Herbon J T, et al. Shock tube measurements of JP-10 ignition. Proceedings of the Combustion Institute, 2000, 28(2):1687-1692

[2] Fan X J, Yu G, Li J G, et al. Combustion and ignition of thermally cracked kerosene in supersonic model combustors. Journal of Propulsion and Power, 2007, 23(2):317-324