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The critical energy of direct initiation and detonation cell size in liquid hydrocarbon fuel/air mixtures

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HIGHLIGHTS

- New critical energy and detonation cell size for liquid hydrocarbon fuel/air mixtures are reported.
- Relationship between critical energy/detonation cell size and equivalence ratio are analyzed.
- Detonation sensitivity of the liquid hydrocarbon fuel/air mixtures is obtained.
- Results are useful for explosion safety assessment and hazard evaluation of liquid hydrocarbon fuels.

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ABSTRACT

Although the detonation phenomenon in liquid hydrocarbon fuel/air mixtures is a significant issue for chemical processing and development of propulsion materials, very limited amount of critical energy of direct initiation and detonation cell size – which provide a measure of detonability or sensitivity of an explosive mixture – are available in literature. In this study, the critical energies for direct initiation of planar detonations and detonation cell sizes in propylene oxide (PO), petroleum ether, isopropyl nitrate (IPN), n-hexane, n-heptane, n-decane and air mixtures are carried out in a vertical detonation tube with an inner diameter of 200 mm and a length of 6.5 m. In the experiment, direct initiation is achieved via #8 industrial electronic detonator associate with different amount of high explosive (i.e., Hexogen), the initiation energy is estimated accordingly to the amount of the explosive. Characteristic detonation cell sizes of those liquid hydrocarbon fuel/air mixtures are measured and obtained simultaneously. The experimental results show that the relationship between critical energy of direct detonation initiation and equivalence ratio is a 'U' shape behavior. For the alkane fuels, i.e., n-hexane, n-heptane, n-decane, the critical energy rises gradually with the increase of the carbon atom number of the liquid hydrocarbon fuel/air mixtures. By measuring the detonation cell size, it is found detonation cell sizes in the liquid hydrocarbon/air mixtures are very irregular, the behavior between cell size and equivalence is also a 'U' shaped curve. By the comparison of the critical energy and detonation cell size, it is shown PO/air and IPN/air are very sensitive to from a detonation, which followed by n-hexane/air and petroleum ether/air, the detonation sensitivity is relatively weak for n-heptane/air and n-decane/air.

1. Introduction

Liquid hydrocarbon fuels are energetic materials with a wide variety of applications, which include their usage as a liquid explosive, a solvent for chemical processing and analysis, and high-performance fuel additive for internal combustion engines. Those liquid hydrocarbon fuels are the choice for aviation propulsion systems, including the pulse detonation engine (PDE) concept [1]. Due to the difficulty of creating uniform fuel-oxidizer mixtures with liquid hydrocarbon fuels and initiating detonation in these mixtures, most of the present PDE research mainly focuses on gaseous fuels (i.e., C1–C3 hydrocarbons) [1]. As pointed out by Rocourt et al. [2], the choice of a fuel for PDEs applications must take into account two opposing criteria: (1) a good detonability with a high energetic content; (2) a low reactivity when ignited accidentally. It is thus much work has been carried out in the field of hydrocarbons to develop high density and energetic kerosene for aeronautical applications in safe conditions [3,4]. Among the kerosenes, JP-10 (*exo*-tetrahydrodicyclopentadiene, $C_{10}H_{16}$) is used more often in the field of the military aviation because of its heat of combustion (39.4 MJ/L) is substantially higher than

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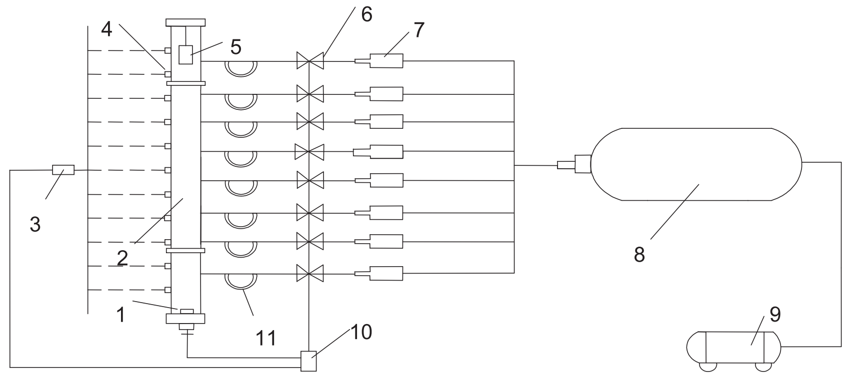

Fig. 1. Experimental setup. 1 – Ignition system, 2 – vertical detonation tube, 3 – data acquisition system, 4 – pressure transducers, 5 – smoked foil, 6 – solenoid valves, 7 – filter, 8 – air tank, 9 – air pump, 10 – controlling system, 11 – U-shaped sample can.

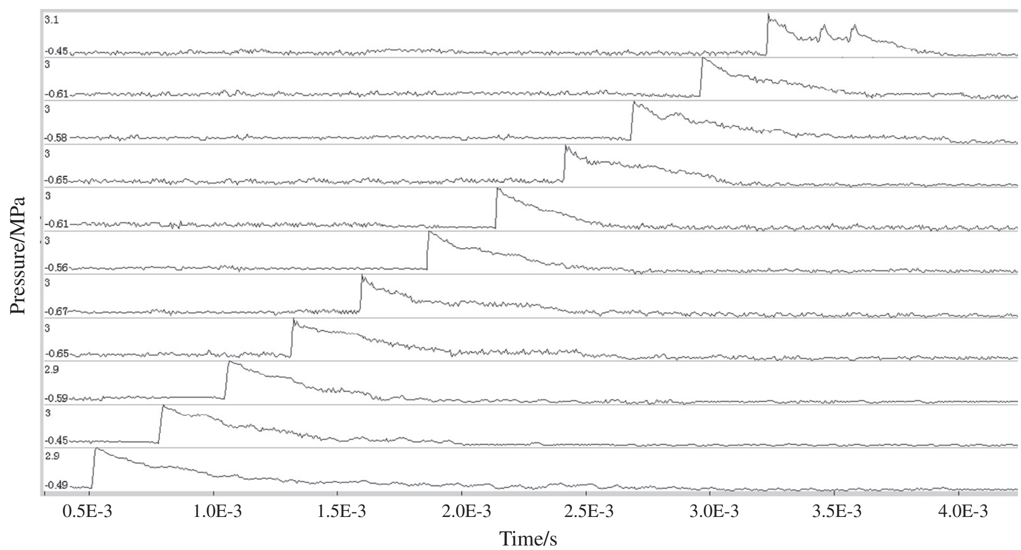

Fig. 2. Typical pressure wave history in PO/air mixture (p_0 = 0.11 MPa, φ = 1.06).

petroleum-based fuels such as JP-8 (34.5 MJ/L) [5], it thus receives considerable attention regarding to its combustion and detonation characteristics [1,6–10]. However, the detonation characteristics researches of liquid hydrocarbon fuels other than JP-10, for example, propylene oxide (PO), petroleum ether, isopropyl nitrate (IPN), n-hexane, n-heptane and n-decane have been seldom performed. In fact, those liquid hydrocarbon fuels have already been applied in various in chemical manufacturing industry, for example, petroleum ether is a group of various volatile, highly flammable, liquid hydrocarbon mixtures (i.e., n-pentane ~30%, n-hexane ~42%, n-heptane ~8%, dimethylbutane ~7%, cyclohexane ~6%, cyclopentane ~4%, benzene ~3%) used chiefly as nonpolar solvents. It is obtained from petroleum refineries as the portion of the distillate which is intermediate between the lighter naphtha and the heavier kerosene. It has a specific gravity of between 0.6 and 0.8 depending on its composition. Petroleum ether is mostly used by pharmaceutical companies and in the manufacturing process. Petroleum ether consists mainly of n-pentane and n-hexane, and is sometimes used instead of pentane due to its lower cost [11].

Due to the high reaction sensitivity and hazardous properties of liquid hydrocarbon fuels, these issues are of particular concerns in term of safety requirements in civil applications. It is highly recommended that the explosion/detonation characteristics should be investigated before its widely application. The explosion hazard of the fuels mainly depends on the relative ease with which a given mixture can be detonated. For the assessment of detonation hazards, measurement of dynamic detonation parameters such as critical energy of direct initiation and detonation cell sizes provides important information for the characterization of the explosion properties and the detonation sensitivity [12–14]. The critical energy for direct detonation initiation has long been considered as perhaps the most direct means of determining detonation hazard in gaseous explosive mixtures. 'Direct initiation', in contrast to the transition from deflagration to detonation, refers to the fast

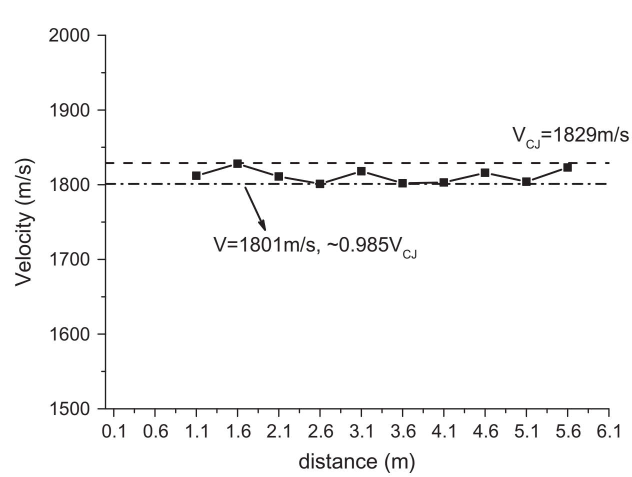

Fig. 3. Blast wave velocity versus CJ detonation velocity in PO/air mixture (p_0 = 0.11 MPa, φ = 1.06).