

Detonation Properties of Ethylene/Methane Blended Fuels

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1 Introduction

Biomass gas fuels are one of the most promising alternative fuels for combustion engines. As well as methane, ethylene can be produced from agricultural products and wastes through fermentation [1, 2]. Ethylene has higher deflagration to detonation transition (DDT) possibilities and substantially smaller detonation cell sizes. Higher thermal efficiencies can, therefore, be achieved when detonation engines are fueled with biomass gases containing ethylene. Deeper understanding of detonation properties for blended fuels would be needed for stable operation of detonation engines. Some researchers including one co-worker have studied detonation properties of blended fuels, such as DDT distance, propagation velocity and cell sizes [3-5]. In the present study, detonation properties of ethylene/methane blended fuels were experimentally examined using a detonation tube as a first step to utilizing biomass gas fuels.

2 Experimental apparatus

Figure 1 shows the schematic of the experimental apparatus. The detonation tube had a total length of 4913 mm and an inner diameter of 50 mm. The mixtures in the detonation tube were spark-ignited with a conventional plug for automobile engines. A Shchelkin spiral (pitch = 45 mm, blockage ratio = 0.44) with length of 1500 mm was inserted into the upstream part of the detonation tube for accelerating the transition from laminar to turbulent flame. Four ion probes were installed along the side wall of the detonation tube for measuring the detonation velocities. The soot foil technique was applied to record the cellular structure of the detonation waves. An aluminum sheet coated with soot was attached onto the inner wall of the downstream part of the detonation tube. In the present study, the blended fuels tested were the mixtures of ethylene and methane, and those blend ratio was varied as the experimental parameter. The equivalence ratio of the blended fuel/oxygen mixtures was kept constant to unity. The detonation tube was charged with the fuel/oxygen mixture, which diluted with 75 % argon for the convenience of an analysis, at an initial pressure of 30 kPa and an initial temperature of 293 K before each test run. Three tests were conducted at each experimental condition.

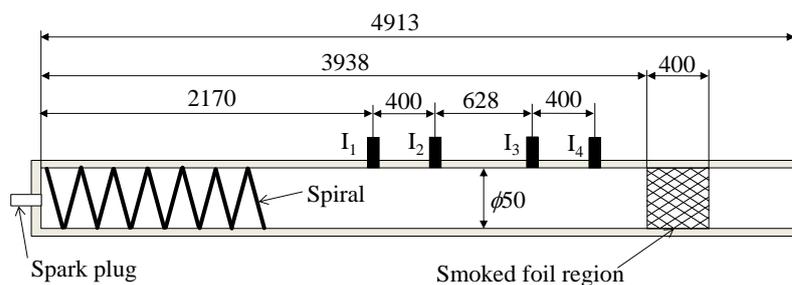


Figure 1. The schematic of the experimental apparatus.

Table 1 Success rate of detonation formation.

C ₂ H ₄ Vol.% in fuel	0	10	20	40	60	80	100
Success rate	0/3	1/3	3/3	3/3	3/3	3/3	3/3

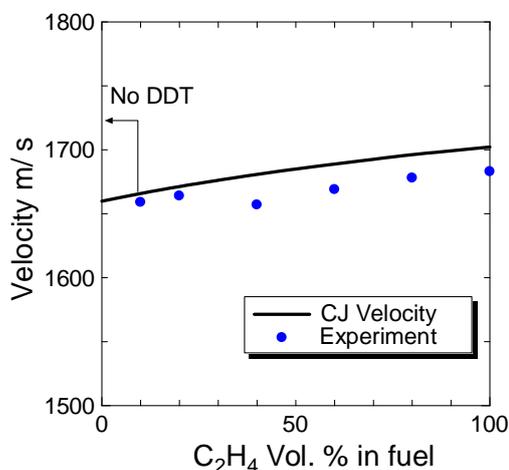


Figure 2. The averaged detonation velocities and the CJ velocities calculated using AISTJAN [6].

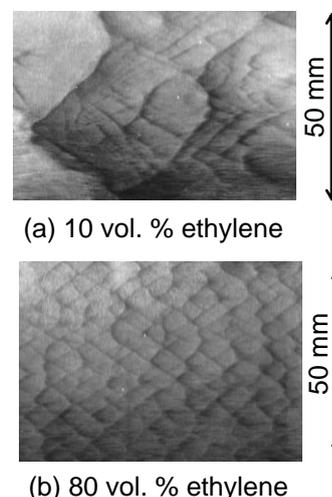


Figure 3. Typical examples of soot foil records.

3 Results and discussion

Table 1 shows the success rate of the detonation formation in this study. Formation of the detonation was determined from the measured velocities and the soot foil records. The detonation was observed once for the blended fuel with 10 vol. % ethylene, and no detonation for pure methane. Well-established detonations were observed in all test runs for the blended fuel containing 20 % or more ethylene in volume. Figure 2 shows the averaged detonation velocities and the CJ velocities calculated using AISTJAN [6]. The measured detonation velocities of the blended fuels were very close to the corresponding CJ velocities.

Figure 3 shows typical examples of soot foil records. In the present study, the observed cellular structures were multilevel detonation cellular structure (Fig. 3 (a)) [7-8] and simple single cellular structure (Fig. 3 (b)). When volume concentration of ethylene in blended fuel was less than 20 %, the multilevel detonation cellular structures were observed; secondary cells were arranged inside the primary detonation cells. These secondary cells can be one order of magnitude smaller than the primary cells, while the size of the secondary cells scattered rather largely.

Figure 4 shows the effects of the volume concentration of ethylene in the blended fuel on the measured cell width λ . The widths of the primary cells were less scattered, and those average was

defined as the cell width for the double cellular structures. The cell width monotonically increased with decrease in volume concentration of ethylene in the blended fuel, although no linear relationship was observed between the cell width and the ethylene concentration.

It has been found that the detonation cell width is well correlated with the chemical induction length and that the factor of the proportionality of the cell width to the chemical induction length $A = \lambda/L$ depends on the mixture content [9]. Figure 5 shows the effects of the volume concentration of ethylene in the blended fuel on the proportionality factor A , which was calculated from the measured cell width λ and the numerically derived chemical induction length L using Shepherd's algorithm for the Zel'dovich-von Neumann-Doring (ZND) detonations [10]. The Konnov model Release 0.4 [11] was used as a chemical reaction model. The distance between the leading shock and the location of the maximum rate of the temperature rise was defined as the chemical induction length. The induction length showed a decreasing trend with an increase in the ethylene concentration, but the decrease was gradual, and therefore, the proportionality factor decreased with higher ethylene content.

Secondary cell structures inside primary cells have been explained to be caused by two distinct stages

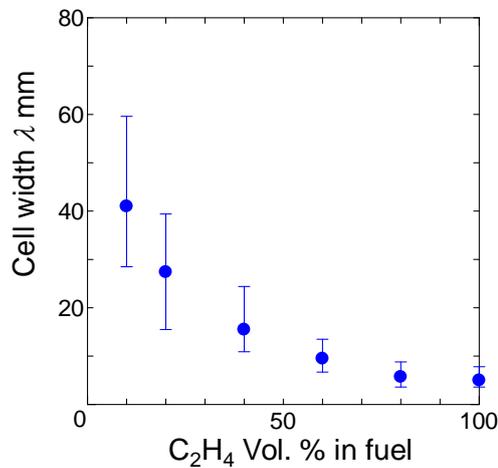


Figure 4. The effects of the volume concentration of ethylene in the blended fuel on the measured cell width λ .

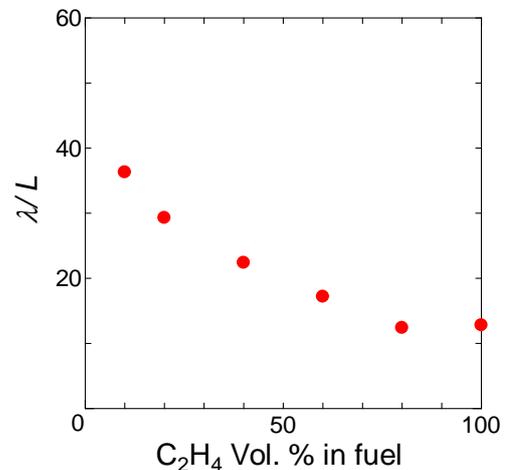


Figure 5. The Ratio of experimentally measured cell width, λ , to the characteristic reaction zone length, L .

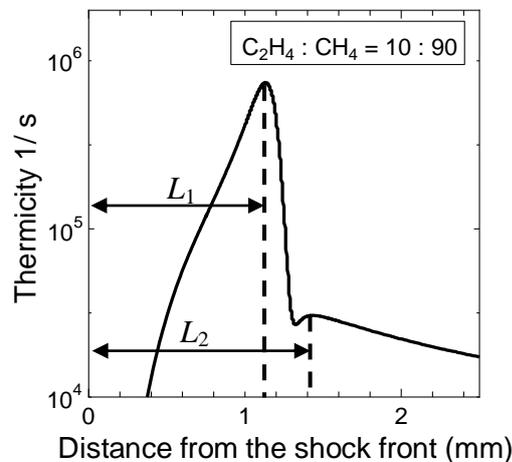


Figure 6. The calculated distributions of thermicity behind the leading shock front for the 10% ethylene case.

of energy release with different timescales [8, 12]. Figure 6 shows the calculated distributions of thermicity behind the leading shock front for the 10% ethylene case. Other induction lengths L_1 , L_2 and L_2-L_1 can be determined from the spatial distribution of thermicity. L_1 and L_2 were of the same order of magnitude, and therefore, L_2/L_1 was near unity; the ratios were 1.27 and 1.32 for 10 and 20% ethylene cases, respectively. The multilevel cellular structures have been explained by secondary instabilities of overdriven parts of the detonation front, which appear in systems with a one-step energy release and high E/RT_{ZND} , where R is the gas constant, E is the activation energy for the reaction, and T_{ZND} is the temperature behind the shock front propagating at the CJ velocity [7, 8]. More work is needed to identify the mechanism forming the multilevel detonation cellular structure in the present study.

4 Conclusions

Detonation properties of ethylene/methane blended fuel were experimentally investigated under the conditions that a total equivalence ratio is kept constant of 1.0. The detonation tube was charged with the fuel/oxygen mixture, which diluted with 75% argon, at an initial pressure of 30 kPa and an initial temperature of 293 K.

1. The measured detonation velocities of the blended fuels were very close to the corresponding CJ velocities.
2. The cell width monotonically increased with decrease in volume concentration of ethylene in the blended fuel, although no linear relationship was observed between the cell width and the ethylene concentration.

5 Acknowledgment

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References

- [1] Ishii T, Kadoya K. (1984). Ethylene evolution from organic materials applied to soil and its relation to the growth of grapevines. *J. Japan. Soc. Hort. Sci.* 53: 157.
- [2] Ochiai S, Ishii T. (2008). Production of bio-ethylene using dead grape leaf. *Journal of the Japan Institute of Energy* 87: 744.
- [3] Austion JM, Shepherd JE. (2003). Detonations in hydrocarbon fuel blends. *Combustion and Flame* 132:73.
- [4] Ishii K, Akiyoshi T, Takada T, Murayama M. (2008). Detonation properties of acetylene-air mixtures with additive of hydrocarbon. *Journal of the Combustion Society of Japan* 50: 152.
- [5] Medvedev SP, Polenov AN, Khomik SV, Gel'fand BE. (2010). Deflagration-to-detonation transition in air-binary fuel mixtures in an obstacle-laden channel. *Russian Journal of Physical Chemistry B* 4:70.
- [6] Tanaka K. (2006) The AISTJAN, detonation properties computer program. *Proceedings of the Forty-Fourth Symposium (Japanese) on Combustion*: 330.

- [7] Ng HD, Chao J, Yatsufusa T, Lee JHS. (2008). Measurement and chemical kinetic prediction of detonation sensitivity and cellular structure characteristics in dimethyl ether–oxygen mixtures. *Fuel* 88: 124.
- [8] Kessler DA, Gamezo VN, Oran ES. (2011). Multilevel detonation cell structures in methane-air mixtures. *Proceedings of the Combustion Institute* 33: 2211.
- [9] Lee JHS. (1984). Dynamic parameter of gaseous detonations. *Annual Review of Fluid Mechanics*. 16: 311
- [10] Shepherd JE. (1986). Chemical kinetics of hydrogen-air-diluent detonations. *Prog. Astronaut. Aeronaut.* 106: 263.
- [11] Konnov AA. (1998). Detailed reaction mechanism for small hydrocarbons combustion, Release 0.4, <http://homepages.vub.ac.be/~akonnov/> .
- [12] Presles HN, Desbordes D, Guirard M, Guerraud C. (1996). Gaseous nitromethane-oxygen mixtures: a new detonation structure. *Shock Waves* 6: 111.