DDT Properties of Hydrocarbon-Air Mixtures with Additive of Acetylene

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1. Introduction

Transition process of deflagration to detonation (DDT) has a close relation with reactivity of mixtures and has been intensively investigated for wide variety of mono-fuel mixtures. However detonation properties of binary fuel mixtures remains still unclear, in particular for combination of a reactive fuel and a less reactive one. In the present work, DDT process of hydrocarbon-air mixtures with additive of acetylene was experimentally studied to reveal controlling parameters of the DDT process.

2. Experimental Apparatus

The detonation tube has a total length of about 7 m and an inner diameter of 50 mm. A base mixture is a methane-air or a propane-air mixture to which acetylene is added to stimulate detonability of mixtures. Volumetric percentage of acetylene in the binary fuel ranges from 0 % to 100 % under the condition that a total equivalence ratio is kept constant of 1.0. To enhance initial development from laminar to turbulent flame a Shchelkin spiral(1) with length of 1.5 m was inserted into the detonation tube. Ignition of mixtures was done with a conventional spark plug used in automobile engines. Arrival of a shock and a flame front was detected individually with combination of pressure and ion probes. A photodiode was placed at the end flange to obtain DDT time, since a detonation wave emits much radiation than a deflagration wave.

3. Results

3.1 *Propagation behavior of shock and flame front*

Figure 1 and 2 show flame speed and corresponding *x*-*t* diagram of methane-acetylene-air mixtures. Steady detonation was obtained for the mixtures containing acetylene 50 % or more in volume and propagation velocities of detonation in these mixtures are almost the same value. It has been confirmed that the measured detonation velocities agree well with calculated Chapman-Jouguet velocities. In Fig. 2 horizontal lines denote time of sudden rise in a signal of the photodiode. Initial flame speed increases monotonically with volumetric percentage of acetylene and consequently DDT time decreases with the percentage of acetylene. In the mixtures containing acetylene 50 % or more, DDT can be achieved within 2 m from the ignition point, which means that onset of detonation occurs near the end of the Shchelkin spiral 1.5 m in length. Otherwise acceleration of flame once decays as shown in Fig. 1 and then flame needs longer traveling distance for re-acceleration.

Figure 3 and 4 show the flame behavior of propane-acetylene-air mixtures. Owing to higher reactivity of propane it is found that minimum volumetric ratio of acetylene to achieve DDT is 20 %, while methane-air mixtures needs 50 %. For the other two cases, namely

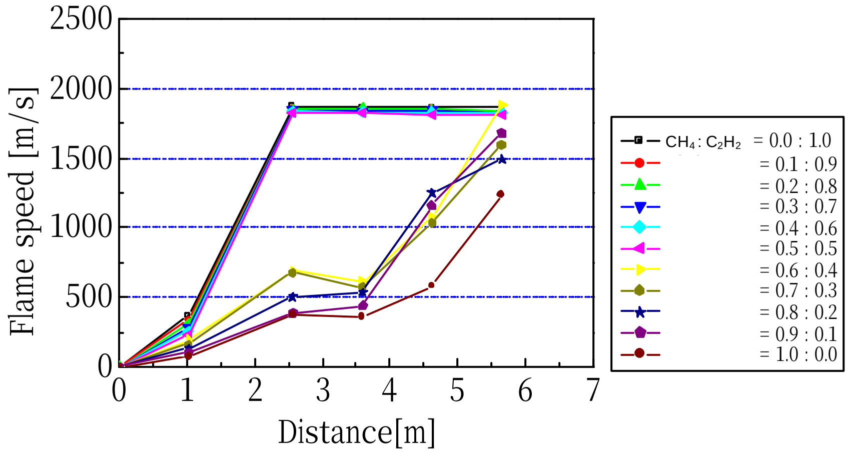

Fig. 1. Profiles of flame speed of methane-acetylene-air mixtures.

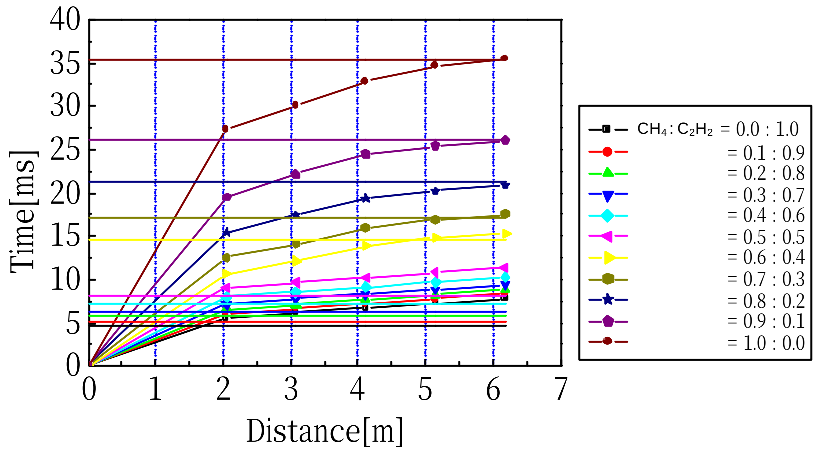

Fig. 2. X-*t* diagram of flame front of methane-acetylene-air mixtures.

propane-acetylene-air mixtures containing acetylene 0% or 10 %, the flame velocity and the photodiode signal indicate onset of detonation near the end flange. However, lower flame speed causes interaction between the flame and a precursor shock wave, which is generated at the initial stage of the flame acceleration and reflects at the end flange. This interaction promotes re-acceleration of the flame so that onset of detonation occurs.

3.2 *Cell size of binary fuel mixture*

Measured cell sizes for the mixtures containing various amount of acetylene are shown in Fig. 5. These data were obtained from smoked foils placed 6200 mm ~ 6400 mm downstream from the ignition point in the cases that propagation of steady detonations was confirmed. It is clearly found that cell size of the binary fuel mixtures monotonically decreases with increase

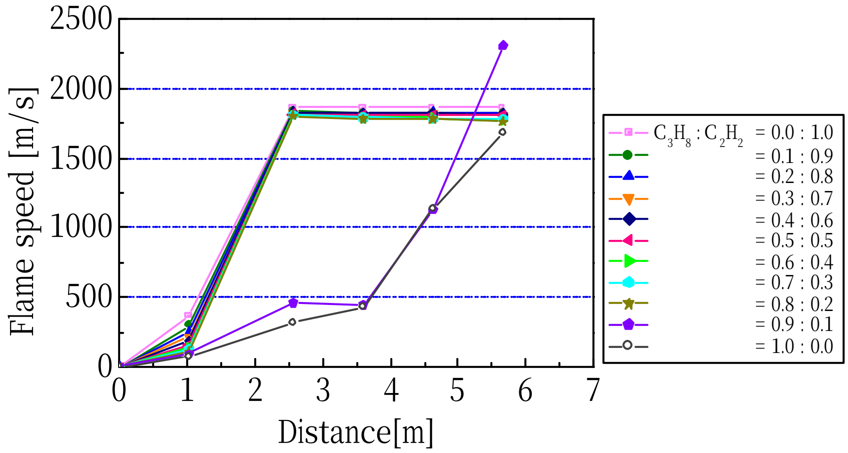

Fig. 3. Profiles of flame speed of propane-acetylene-air mixtures.

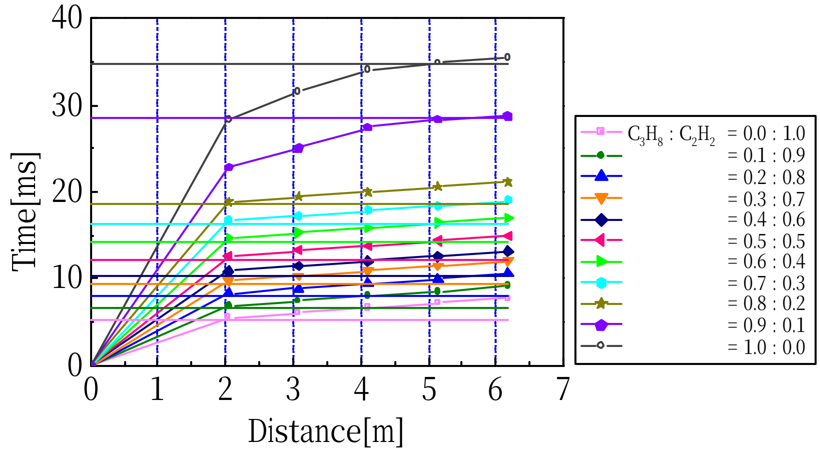

Fig. 4. X-*t* diagram of flame front of propane-acetylene-air mixtures.

in amount of acetylene. In terms of the mixtures with the same volumetric percentage of acetylene more than 60 %, methane-air-acetylene-mixtures have smaller cell size than propane-air-acetylene-mixtures. In the present work, total equivalence ratio is kept 1.0 and as a consequence absolute value of acetylene contained in the former is larger than that of the latter. It is also found that a methane-acetylene-air mixture with acetylene of 50 %, corresponding to a critical mixture for which detonation can be initiated, shows roughly a double cell size as compared to the mixture with acetylene of 60 %. This is consistent with large differences in flame speed and DDT time shown in Figs. 1-2.

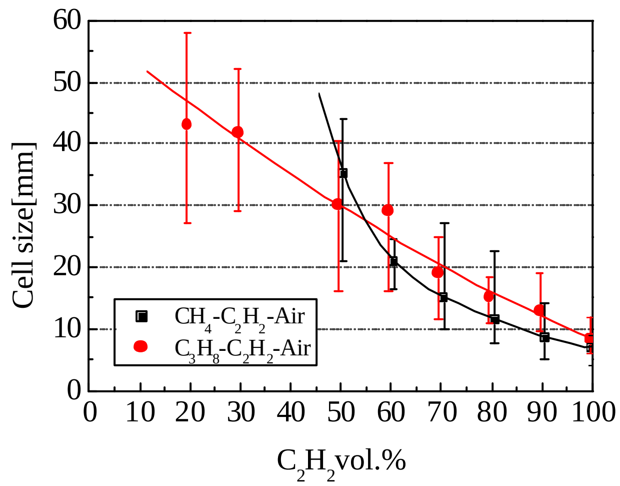

Fig. 5 Effects of addition of acetylene on cell size of binary fuel mixture.

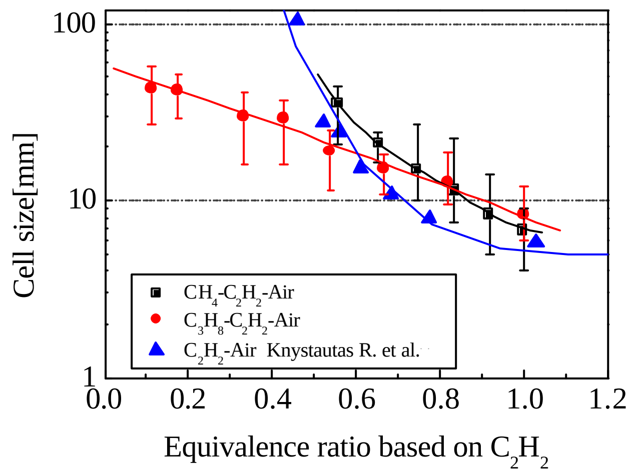

Fig. 6 Cell size of binary fuel mixtures with various equivalence ratio based on C_2H_2.

Figure 6 shows relationship between cell size and equivalence ratio of binary fuel mixture, where the equivalence ratio is calculated under the condition that only acetylene is treated as a fuel. For comparison, cell sizes of acetylene-air-mixtures[2] are also plotted in Fig. 6. Using this equivalence ratio it is found how portion of CH_4 or C_3H_8 contributes to decrease in cell size of binary fuel mixtures. In the cases of equivalence ratio less than 0.5, cell size of acetylene-air-mixtures increases drastically up to 100 mm with decrease in equivalence ratio, while cell size of propane-acetylene-air-mixtures shows less than 40 mm. This means that heat release from oxidization of propane governs the cell size in this region. As for the cases of equivalence greater than 0.5, propane-acetylene-air-mixtures and acetylene-air-mixtures shows almost the same cell size, which means that acetylene dominates determination of cell size.

4. Conclusions

DDT properties of binary fuel mixtures containing acetylene were experimentally investigated under the condition that total equivalence ratio was kept 1.0.

(1) DDT can be achieved within 2 m from the ignition point with a Shchelkin spiral 1.5 m in length for methane-acetylene-air mixtures containing acetylene 50 % or more in volume and for propane-acetylene-air mixtures containing acetylene 20 % or more.

(2) Increase in volumetric percentage of acetylene of binary fuel mixture causes faster acceleration of flame front and a consequent shorter DDT time.

(3) For steady detonations, cell size monotonically increases with decrease in volumetric percentage of acetylene.

(4) For the cases of equivalence ratio less than 0.5, acetylene dominates cell size of binary fuel mixture.

References

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