Ignition and Combustion Characteristic of DME-Air Premixture in Micro Flowreactor

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Introduction

Background

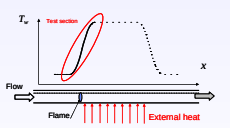
Promising Alternative fuel Dimethly Ether (DME)

- Gaseous fuel under a low pressure (0.5MPa at 298K)
- A clean high-efficiency compression ignition fuel with reduced NOx, Sox, and particulate matter
- Minimum carbon number fuel for engine which exhibits cool flame [1]
- For construction of reduced DME chemistry which can reproduce two stage ignition.

Ignition and combustion characteristics of DME

Our previous research

Micro flowreactor with temperature profile control (Premixed CH_4 - Air mixture)



Maruta et al., *Proc. Combust. Inst.* 30, 2005 [2]

- Experiments
  - Various flame responses[2]
    - ⇨ Ignition and extinction
    - *FREI; flames with repetitive extinction and ignition* (Quasi-stationary process)
    - ⇨ Flame locations ··· Wall temperature
    - Auto-ignition temperature [3], [4]
- 1D numerical simulation with detailed chemistry [2], [3], [4]
- Liner stability analysis[5]

Objectives

Clarify ignition and combustion characteristics of premixed DME – air mixture in a micro flowreactor with temperature profile control experimentally and numerically

Experiments

Experimental setup and Conditions

Micro flowreactor with temperature profile control

⇩

Stationary wall temperature profile by an external heating

- Micro flowreactor: Quartz tube with inner diameter 2 mm
- Equivalence ratio: 1.0
- Pressure: 1.0 [atm]
- Mean flow velocity : U [cm/s]
- Flame location : A single-lens reflex camera with CH filter

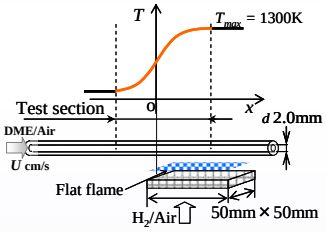
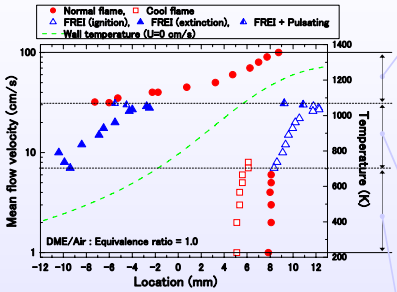
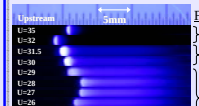


Fig. Experimental setup

Various flame responses

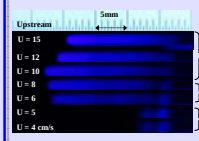


Flame responses and their location with each *U*



From *Normal flame* to *FREI*

- Normal flame
- FREI + Pulsating
- FREI



From *FREI* to *Weak flames*

- FREI
- Weak flame + FREI
- Weak flame + Weak flame

Flame images with CH filter each *U*

(1) High velocity region (U = 32 ~ 100 cm/s)

Normal flame (Stable) U = 50 cm/s

Auto ignition at downstream ⇩ Propagate to the upstream ⇩ Stabilized at the position where $U = V_{propagate}$

- Stabilized points shifted to the downstream as the decrease of U

(2) Moderate velocity region (U = 6 ~ 28 cm/s)

FREI (Unstable) U = 25 cm/s

FREI: flames with repetitive extinction and ignition [2]

Auto ignition at the downstream ⇩ Propagate to the upstream ⇩ Quenched at the downstream due to large heat loss

Repeating Regularly

(3) Low velocity region (U = 1 ~ 5 cm/s)

Double weak flames (Stable) U = 2 cm/s

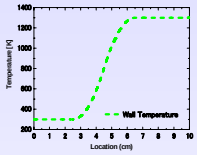
Auto ignition at the downstream ⇩ (Hardly propagate) ⇩ Stabilized at the position where $U = V_{propagate}$

Double flames in a micro flowreactor corresponds to two stage ignition in general RCM experiments.

Numerical simulation

Computational condition

- Flame code : 1D flame code[2][5]
- Thermodynamics, Transport properties : CHEMKIN Ⅱ [6]
- Detailed reaction mechanism : Dimethly Ether 2000[7]
- Computational domain : 10 cm
- Computational conditions; Wall temperature is fixed. Nu number is 4.0. Equivalence ratio = 1, Pressure = 1atm
- Definition of flame location : Peak in mole fraction of CH profile.



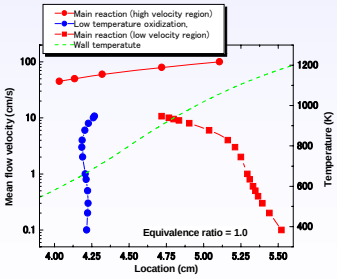
Wall temperature profile

Energy equation

$$\dot{M}\frac{dT}{dx}-\frac{1}{c_p}\frac{d}{dx}\left(\lambda A\frac{dT}{dx}\right)+\frac{A}{c_p}\sum_{k=1}^{K}\rho Y_k V_k c_{pk}\frac{dT}{dx}+\frac{A}{c_p}\sum_{k=1}^{K}\dot{\omega}_k h_k W_k-\frac{A}{c_p}\frac{4\lambda Nu}{d^2}(T_w-T_g)=0$$

Heat convection between gas and solid

Variation of the stabilized flame positions



(1) Upper branch (U = 50 ~ 100 cm/s)

- Only one peak in the CH profile

⇨ Stable flame (Main reaction)

(2) Lower branch (U = 0.1 ~ 11 cm/s)

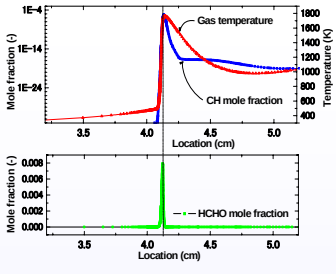
- Two peaks in the CH profile
- Upstream side flames are located at the same positions where wall temperature is low.

⇨ **Stable Double flames (low temperature oxidization + Main reaction)**

Temperature, CH and HCHO profiles

Cool flame is confirmed by luminescence of formaldehyde (HCHO) [8]

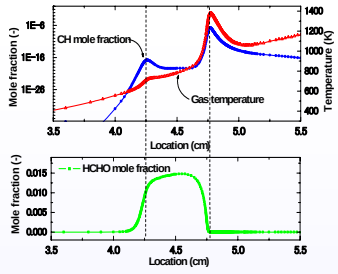
U = 50 cm/s ; Only one stable flame



Temperature, CH and HCHO ··· One peak

- Only one stable flame
- HCHO intermediate specie

U = 10 cm/s; Double stable flames



Temperature and CH ··· Double peaks
HCHO ··· Broadened

- **Double flames stabilized**
- **HCHO is product of upstream side flame**

This result supports experimental result by RCM [1]

Conclusions

Experimental and computational investigations on ignition and combustion characteristics of DME-air mixture using temperature profile controlled micro flowreactor.

- In the experiments, various flame responses were observed by changing the mean flow velocity.
- In lower velocity region, stationary double weak flames were observed. These are corresponding to the two stage ignition by RCM.
- In numerical simulation, two stable solution branches are obtained, which agrees with experimental results. And in the lower velocity solution branch, double CH peaks were also observed.
- HCHO mole fraction profile for the case of double flames supports the RCM results.

References

[1] H. Yamada, K. Suzaki, H. Sakanashi, N. Choi and A. Tezaki, *Combust. and flame*, 140 (2005), 24-33.
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