LES Analysis of SI Combustion Process in a Hydrogen Unsteady Jet

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Background

Hydrogen fueled Spark-ignition Engine

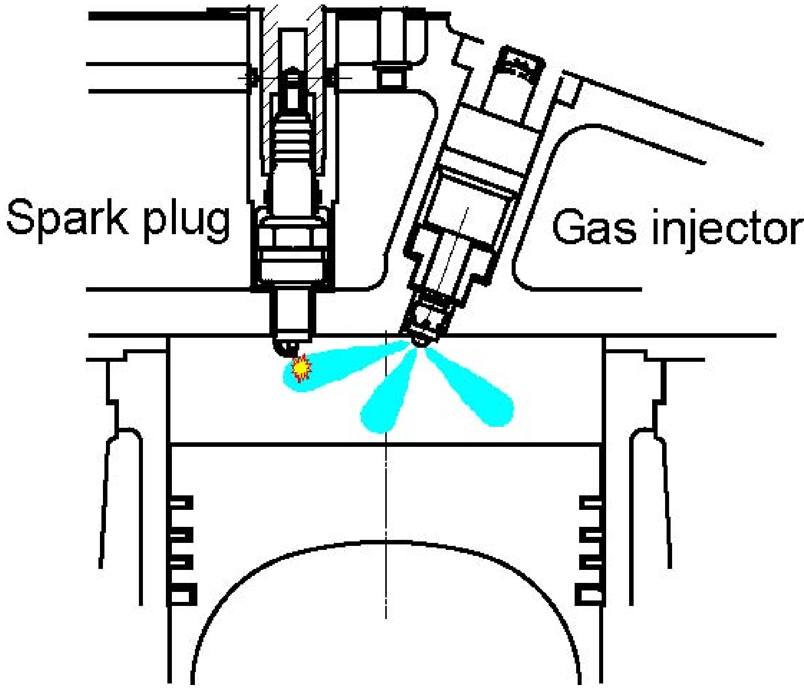
Combustion Characteristics of H_2

-High Burning Velocity

Rapid Combustion (Knocking like Combustion)

-High Ignitability

Abnormal Burning (Backfire)



-to Achieve

Higher Output Power

and

Higher Thermal Efficiency

-Control the SI-Combustion

Direct-injection Spark-ignition System is Feasible for a Hydrogen Engine

Visualization Image of DI-SI Combustion Process

Analysis of Spark-ignited Combustion Process of a High-speed Unsteady Hydrogen jet in CVV

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80 mm

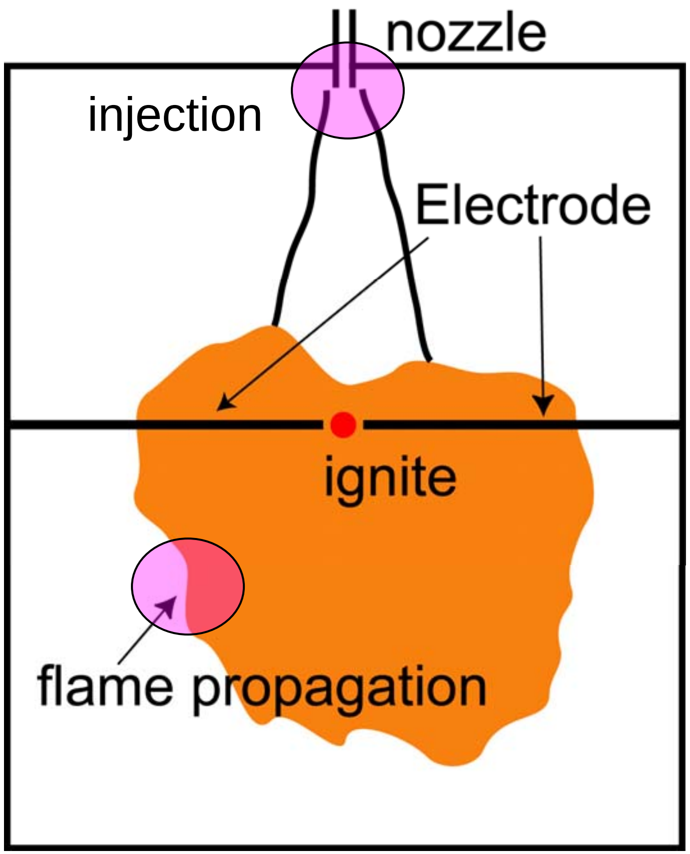
H_2 Direct Injection Spark Ignition Combustion (Constant Volume V□essel)

Injection Press. p_j=8MPa
Nozzle Diam. d_0=0.8mm
Ambient Press. p_a=0.5MPa
Ambient Temp. T_a=291K

Objective

□Large Eddy Simulation
→Mixing Process by Unsteady Fluid Motion

□Flame Propagation Model
→G-equation Model to reduce calculation load



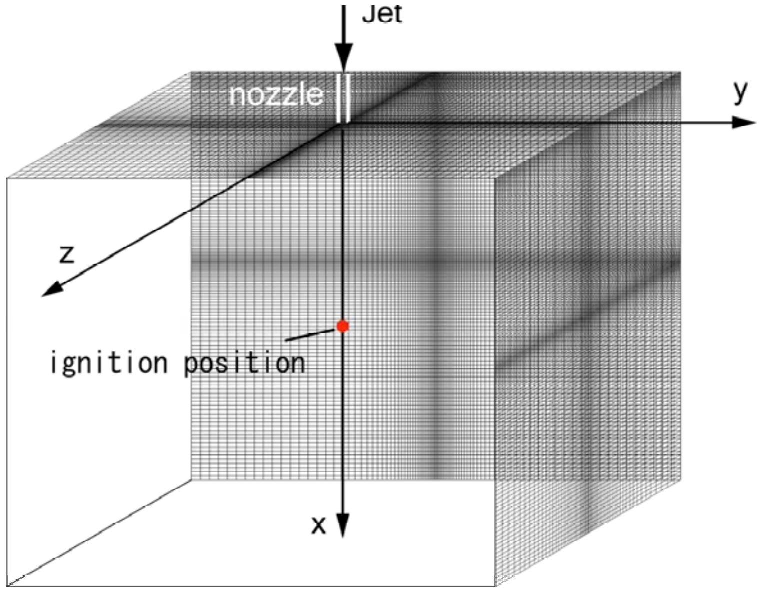
Contents

1. Comparison Calc. and Exp.
2. Mixture Formation Process
3. Flame Structure
4. Local Heat Release Rate

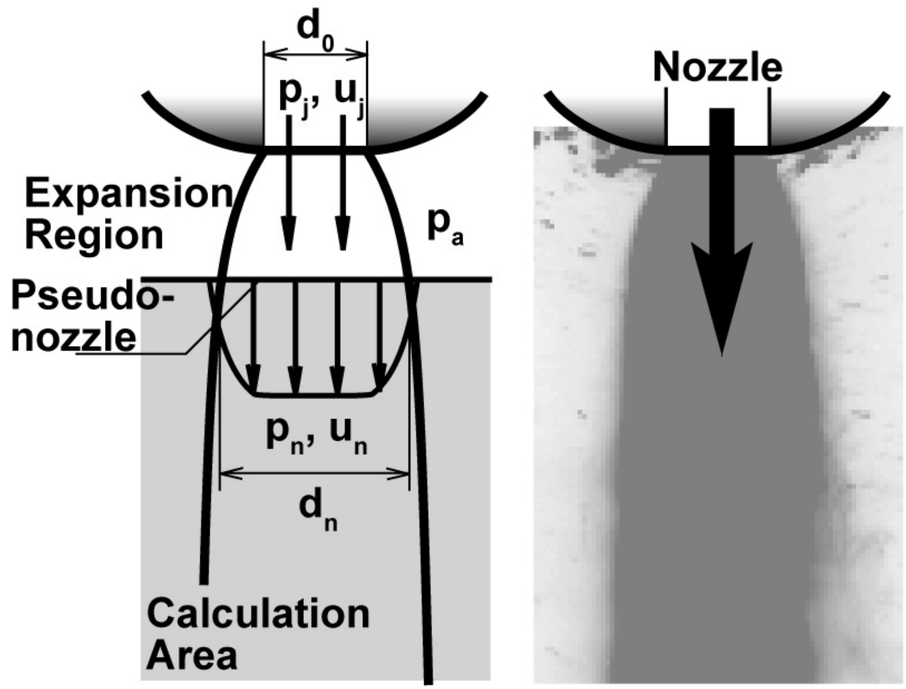
Calculation Condition

Fuel	Hydrogen
Injection Pressure p_j (MPa)	8
Ambient Pressure p_a (MPa)	0.5
Ambient Temperature T_a (K)	300
Nozzle Diameter d_0 (mm)	0.8
Ambient Gas	Air (O2: 21% N2: 79%)
Ignition Position (x,y,z) (mm)	(35,0,0)

SGS: Smagorinsky Model
(C_s=0.11, Sc_t=1.0)



Pseudo-nozzle Concept



Pseudo-nozzle Concept (A.D.BIRCH□1983)

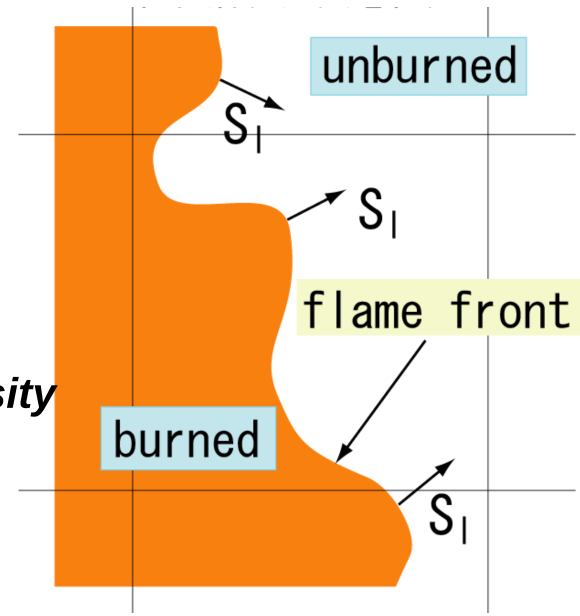
$$d_n = d_0 \sqrt{C_D \frac{p_j}{p_a} \left(\frac{2}{\gamma + 1} \right)^{\frac{\gamma+1}{2(\gamma-1)}}}$$

Ideal Gas□Adiabatic Expansion
d_n: Pseudo-nozzle diam.
u_j, u_n:Sonic Speed
C_D:Flow Rate Coef.
γ:Specific Heat Ratio

Flame Propagation Model

$$\frac{\partial \bar{\rho}\tilde{G}}{\partial t}+\frac{\partial \bar{\rho}\tilde{G}\tilde{u}_j}{\partial x_j}=-\frac{\partial R^{SGS}}{\partial x_j}+\bar{\rho}_u S_T\left|\nabla \tilde{G}\right|$$

ρ_u **: Density of Unburned Gas**
S_T **: Turbulent Burning Velocity**
R^{SGS}**: SGS-Scalar Flux of G**



$$\frac{S_T}{S_L}=1+1.25\left(\frac{u'}{S_L}\right)^{0.7}$$

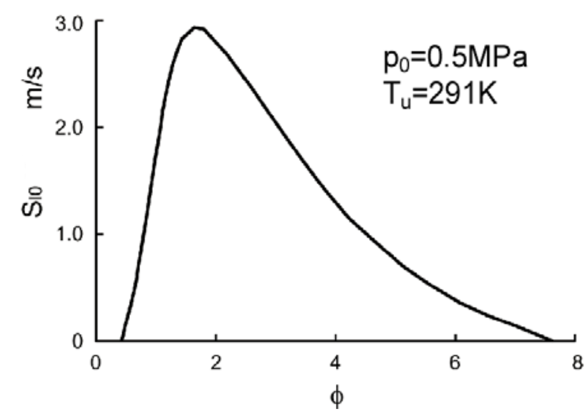
u' **: SGS Fluctuation Intensity**
S_{ij}**: Strain Rate**
Δ **: Filter Size**

$$u'=0.28\Delta\sqrt{2S_{ij}S_{ij}}$$

$$S_L=S_{L0}\left\{1+\beta\log\left(\frac{p}{p_0}\right)\right\}\left(\frac{T_u}{T_{u0}}\right)^{\alpha}$$

$$\alpha=1.54+0.025(\phi-1)$$

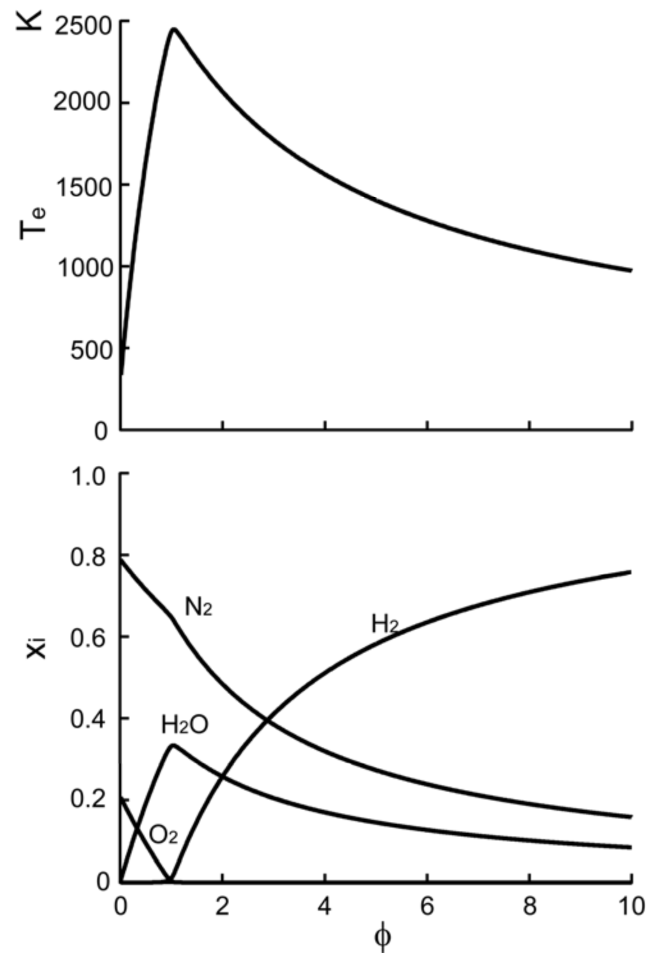
$$\beta=0.43+0.003(\phi-1)$$



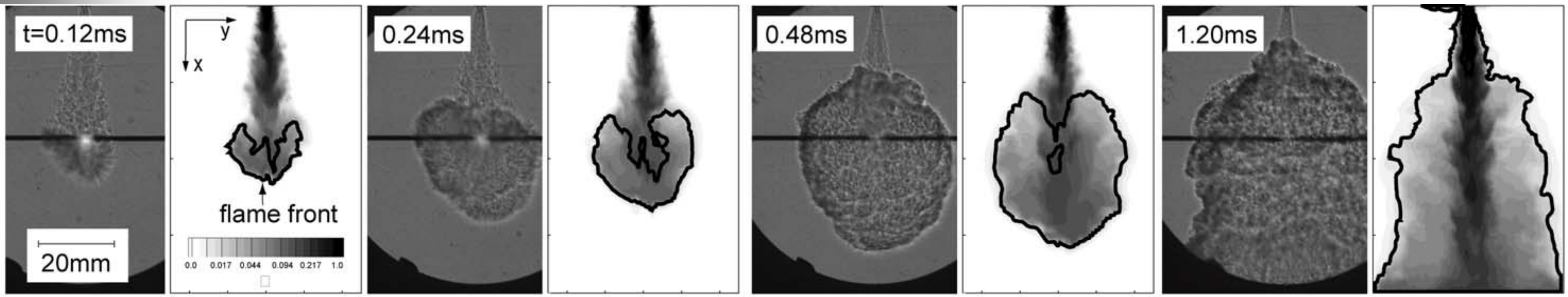
Burnt Gas Temperature (Diffusion Flame)

Chemical Equibrium
(Burned Gas)
→ ***Temperature***
Species Concentration
Calculated based on the Local Mixture Fraction

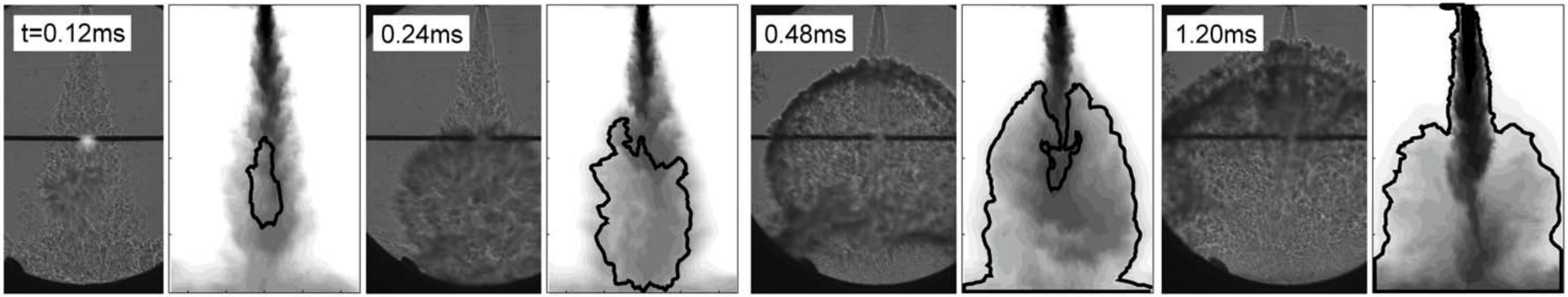
Products(7 Species)
H_2,O_2,N_2,H_2O,OH,O,H



Combustion Process (compared with Exp.)

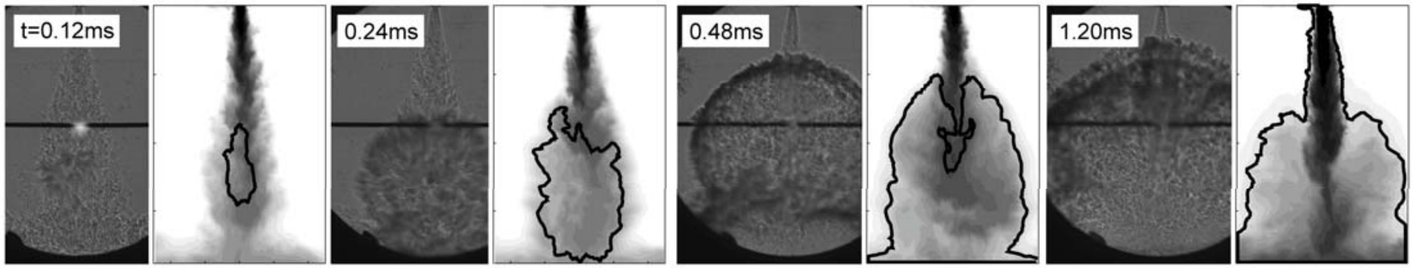


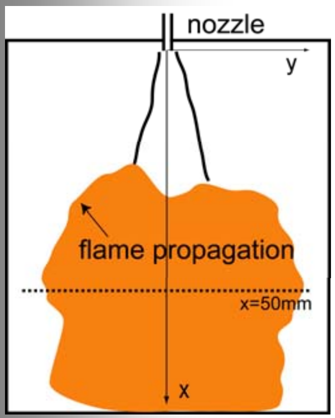
t_i = 0.3ms(Ignited at Jet Tip Condition)

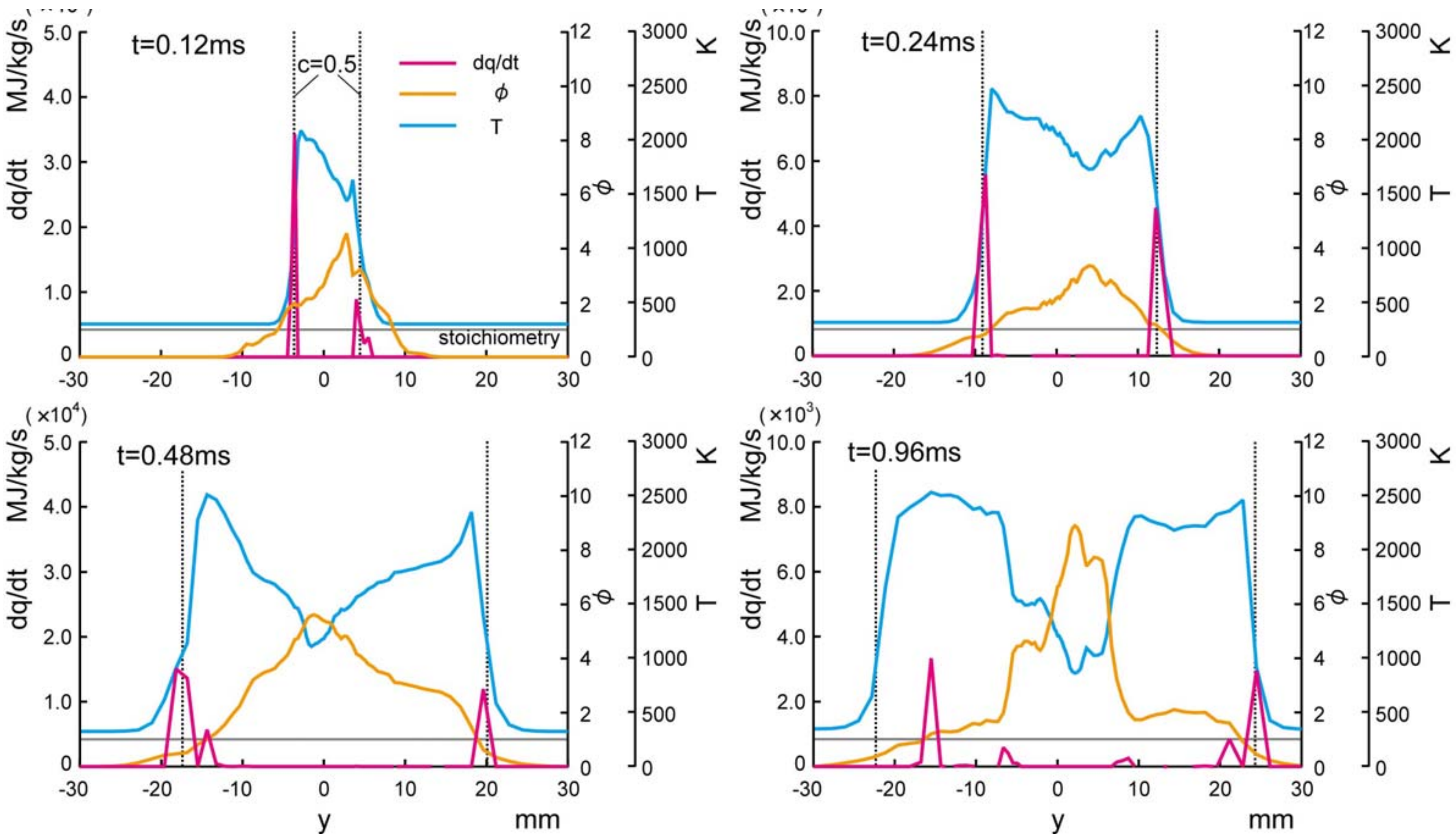


t_i = 1.8ms(Ignited inside Jet Condition)

Flame Structure (t_i = 1.8 ms)

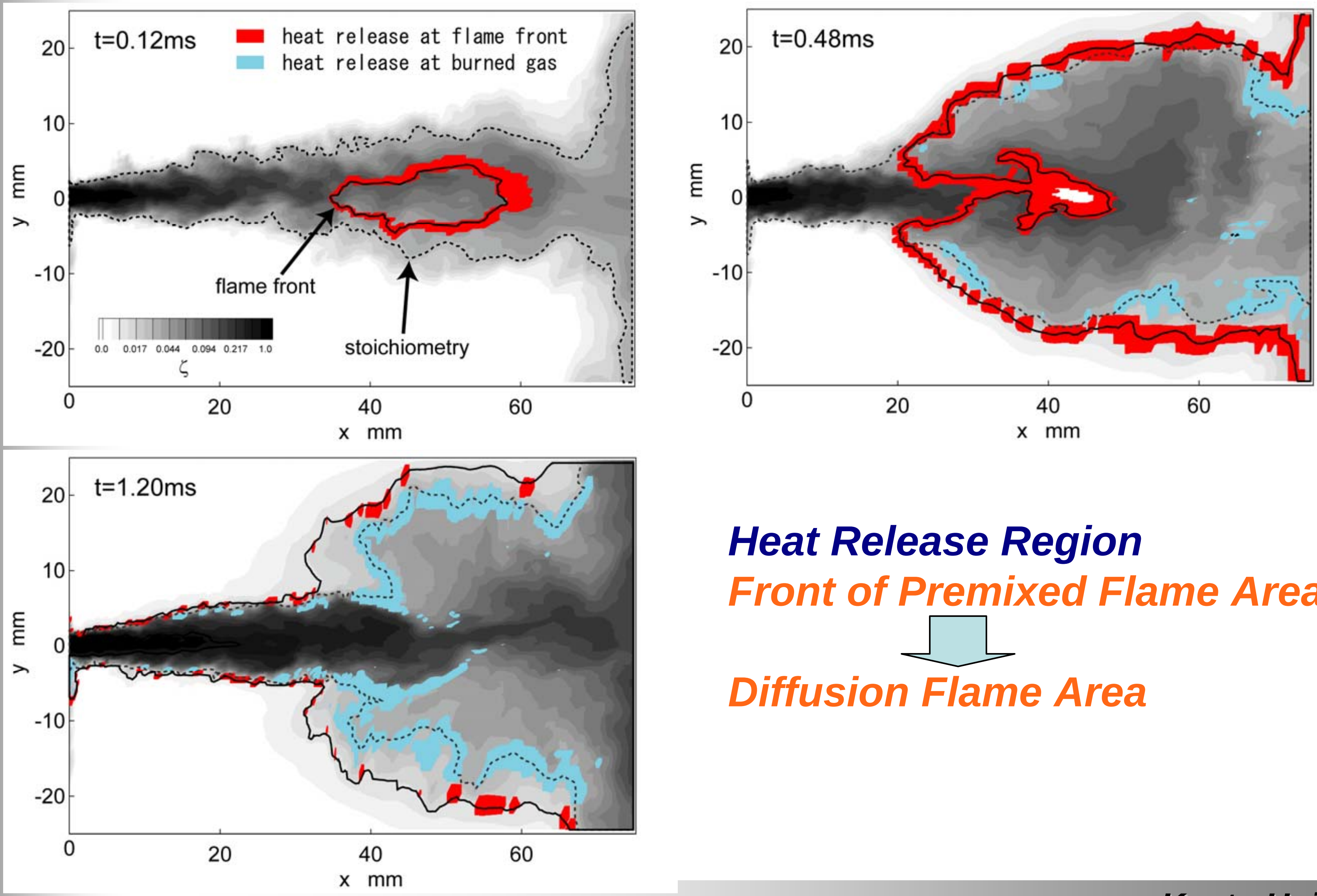






Local Heat Release Ratio

Ignition Timing: t_i = 1.8ms(Ignited inside Jet condition)



Heat Release Region

Front of Premixed Flame Area

Diffusion Flame Area

Summary

Flame propagation process of a high-speed unsteady jet was successfully calculated by means of large eddy simulation with the G-equation flamelet and diffusion flame models

Change of combustion process is well predicted with different ignition timing.

Combustion progresses gradually with supplying fuel in the condition of a jet tip ignition. On the other hand, flame propagates quickly outward in the condition of ignition inside jet.

After the flame propagation, combustion progresses gradually at the stoichiometric region as a diffusion flame.