International Seminar on Recent Trend of Fuel Research for Next-Generation Clean Engines

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Control of PCCI Combustion using Physical and Chemical Characteristics of Mixed Fuel

Doshisha Univ. – Energy Conversion Research Center
Postdoctoral fellow
Yoshimitsu WADA

Contents

- ✓ Background
- ✓ Combustion Control Methodology using Mixed Fuel
  - simultaneous pursuit of high ignitability and high volatility
  - mixture formation control taking into account two-phase region
- ✓ Spray Characteristics of Mixed Fuel
- ✓ Combustion Characteristics of Mixed Fuel in CI Engine
- ✓ Conclusions

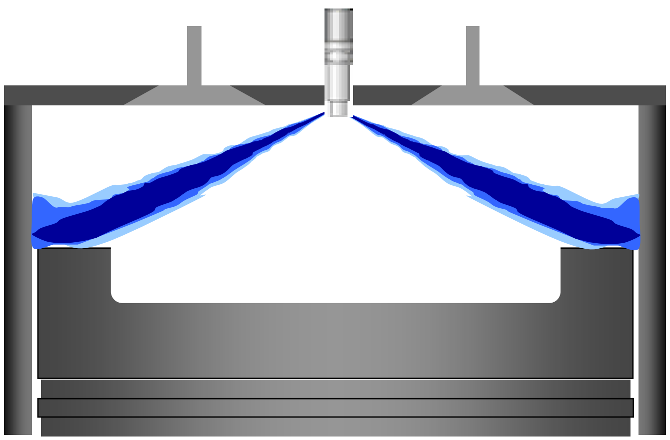
Progress in CI Engine Combustion

PCCI combustion

has the potential to be highly efficient and to produce low PM and NO_x emissions.

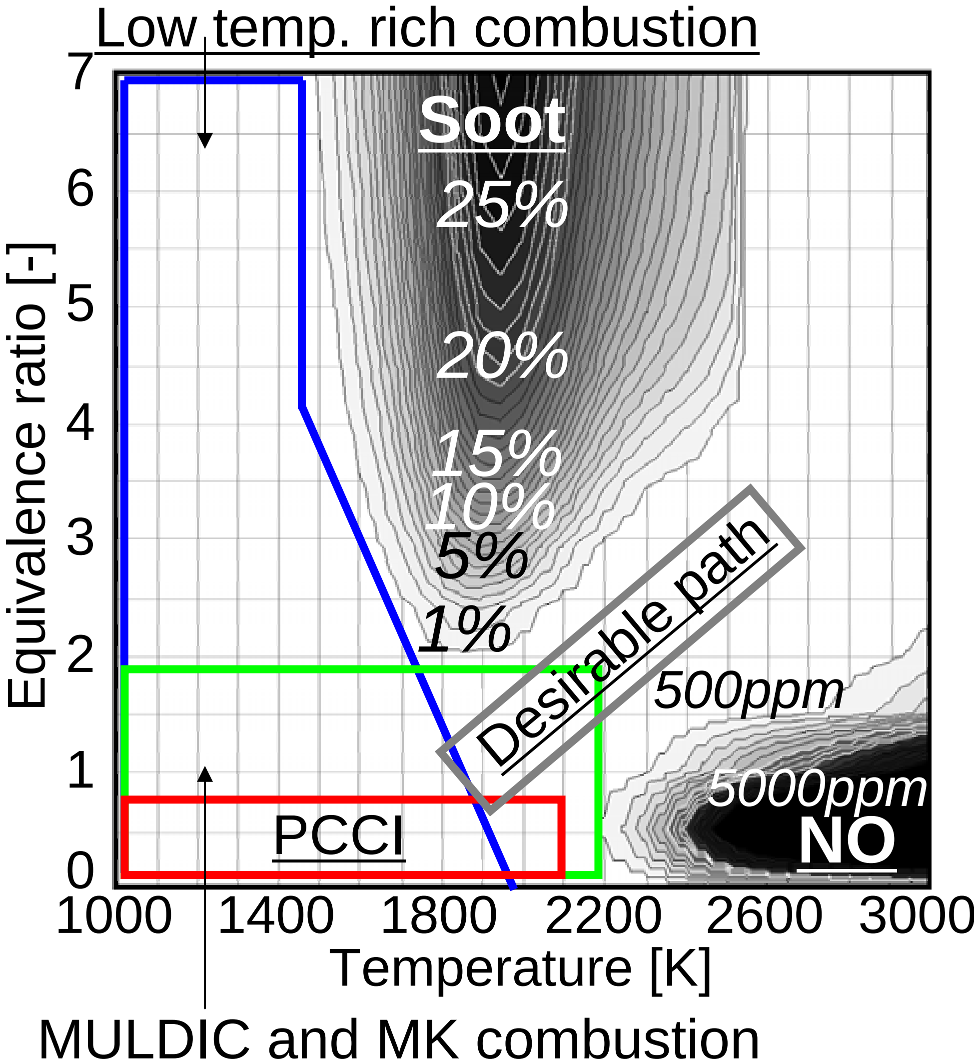
However, diesel fuel…

having low volatility, causes wall-wetting and poor mixture preparation.



In addition,

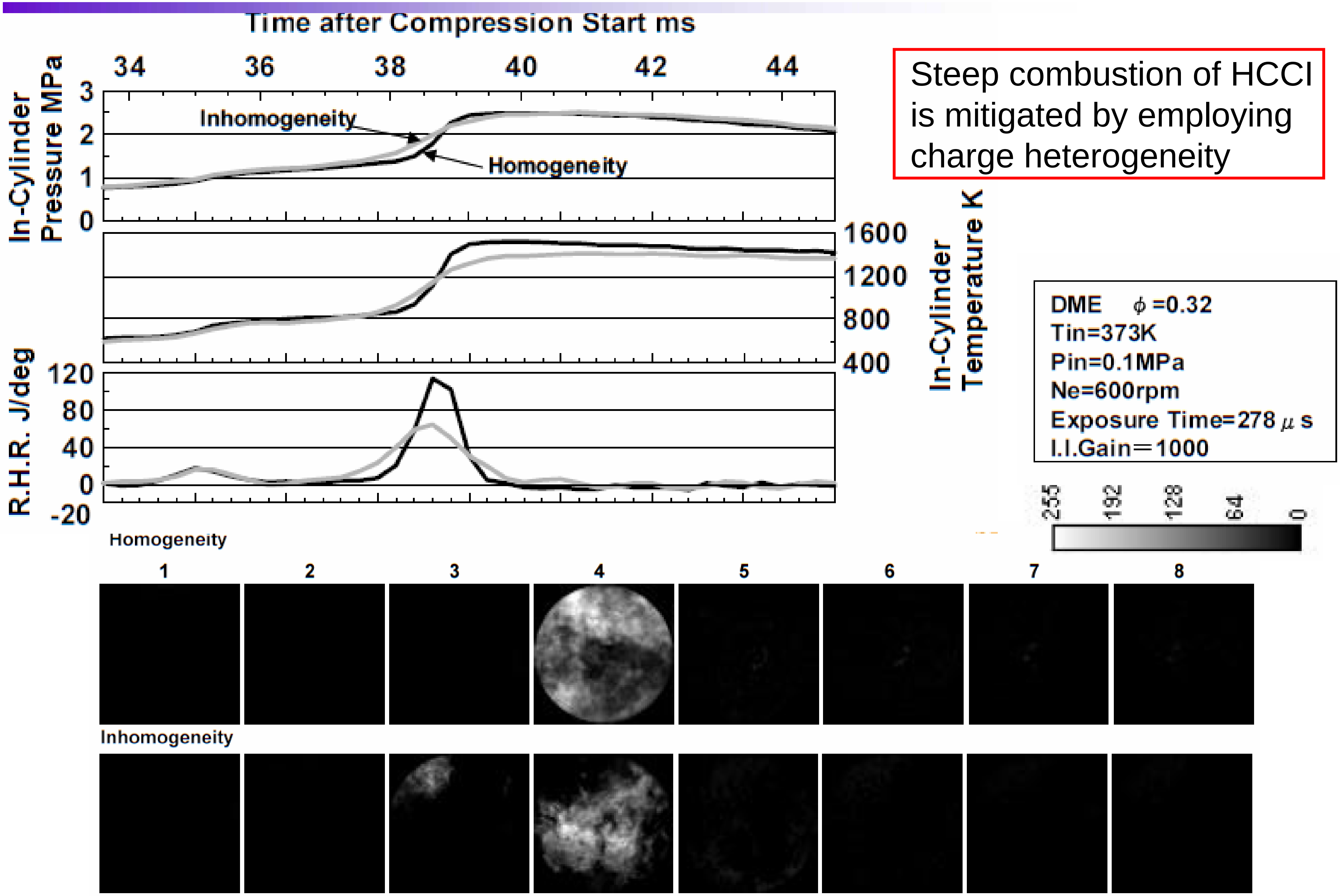
well-mixed mixture ignites simultaneously and the operation is limited by the steep pressure rise.



*n-heptane, reaction time=1ms

Ref) Kitamura, T. et al., *Int. J. Engine Res.*, 2002

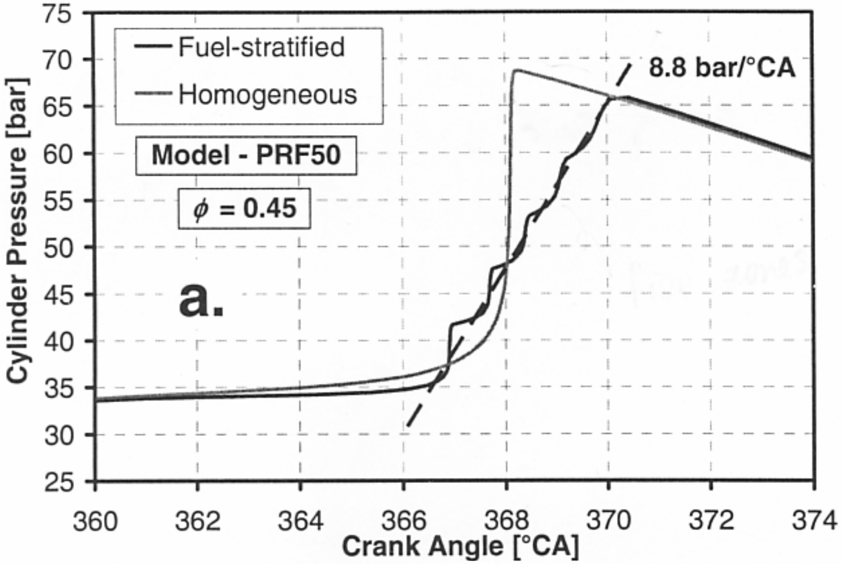
Effect of Charge Heterogeneity on PCCI Combustion

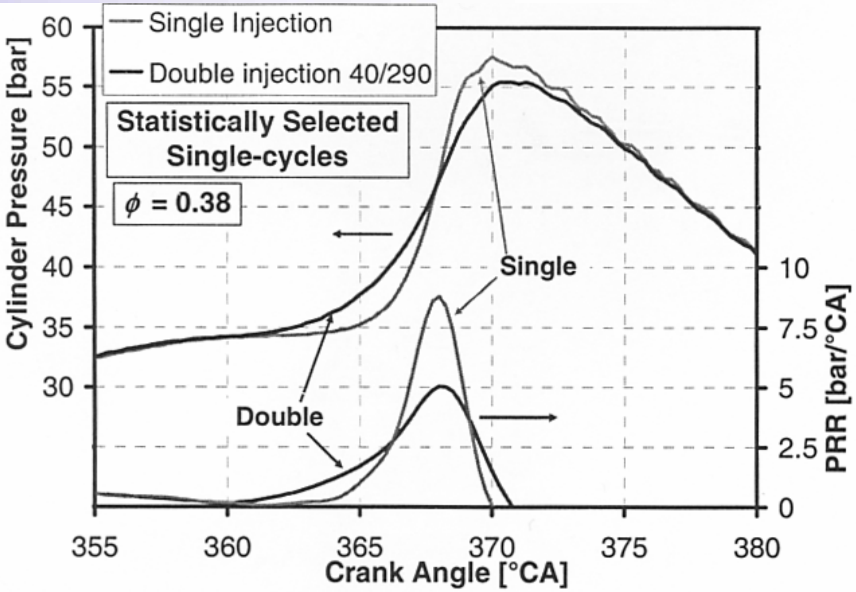


Steep combustion of HCCI is mitigated by employing charge heterogeneity

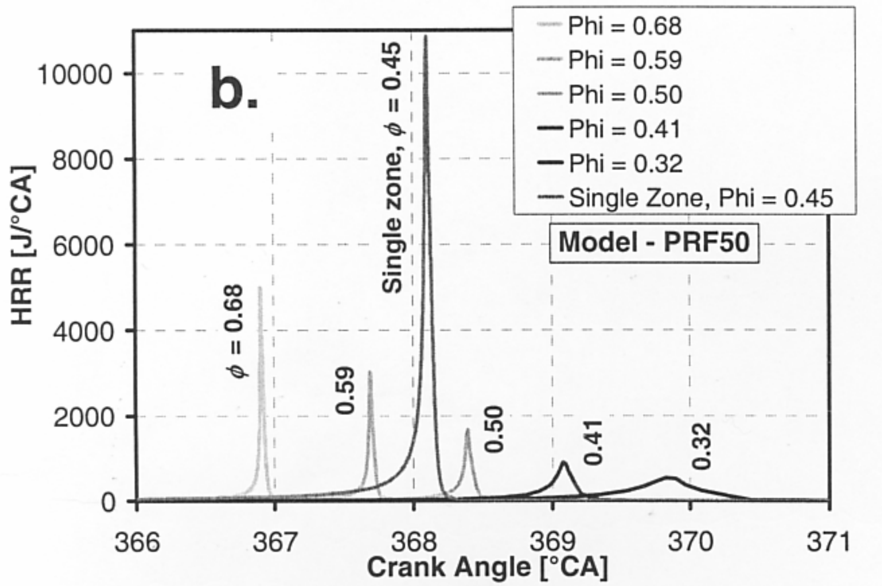
Ref) Kumano, K. and Iida N., SAE Paper 2004-01-1902

Effect of Charge Heterogeneity on PCCI Combustion





<u>Experimental results</u>



<u>Computational results using CHEMKIN-Z</u>

Staged combustion event is achieved by employing partial fuel-stratification because the timing of hot ignition is sensitive to local ϕ.

* Therefore, partial fuel-stratification is effective for fuels exhibiting two-stage ignition (LTR and HTR), such as gas oil.

Ref) Sjöberg, M. and Dec, J. E., SAE Paper 2006-01-0629

☺ Partial fuel-stratification is effective to reduce maximum pressure rise rate due to staged combustion event !

Staged combustion event is achieved by fuels exhibiting two-stage ignition (LTR and HTR) !

However . . .

☹ Fuels exhibiting two-stage ignition such as diesel fuel have low volatility…

How can we get fuels having high ignitability and high volatility ??

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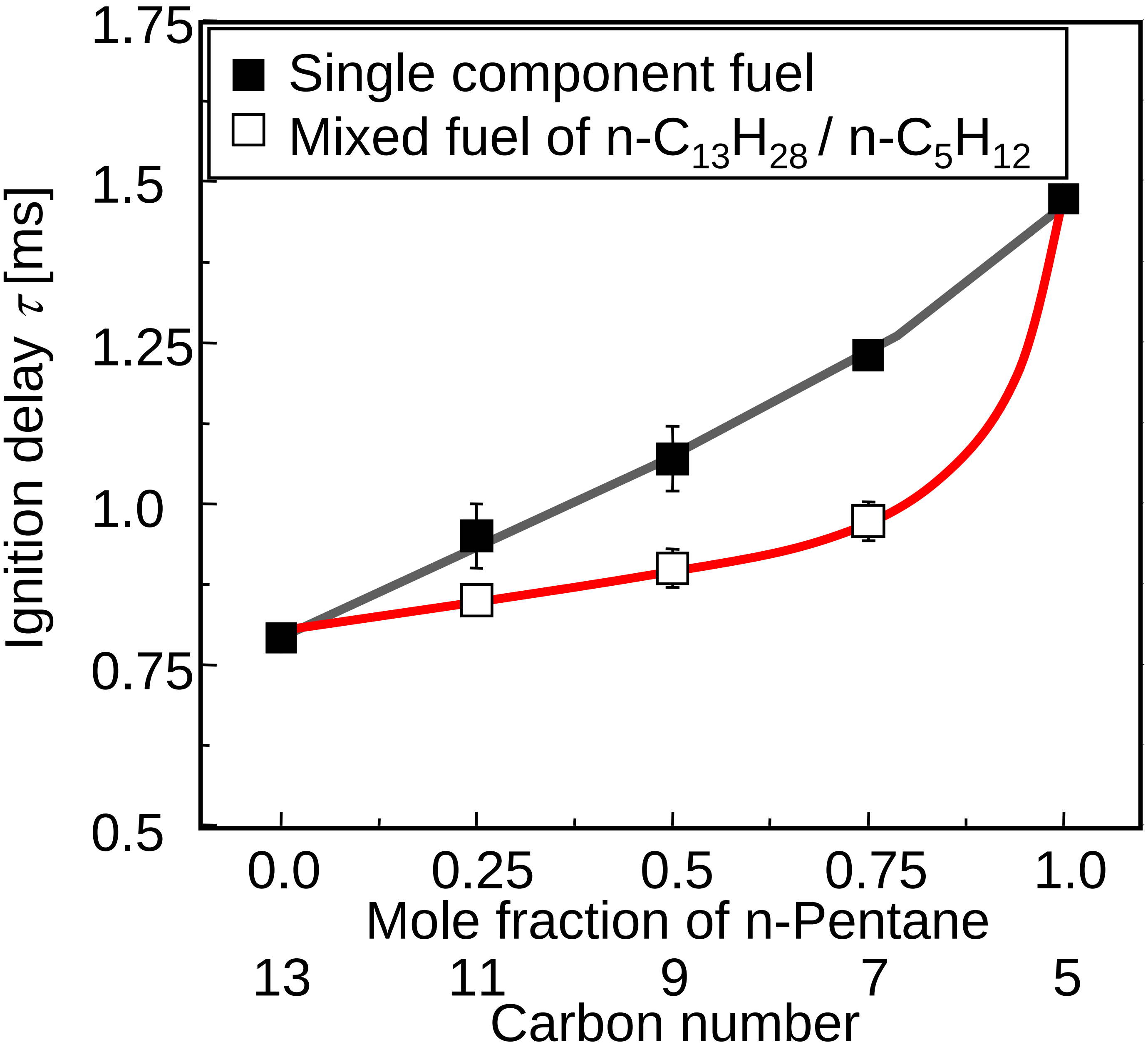
Ignition Characteristics of Mixed Fuel



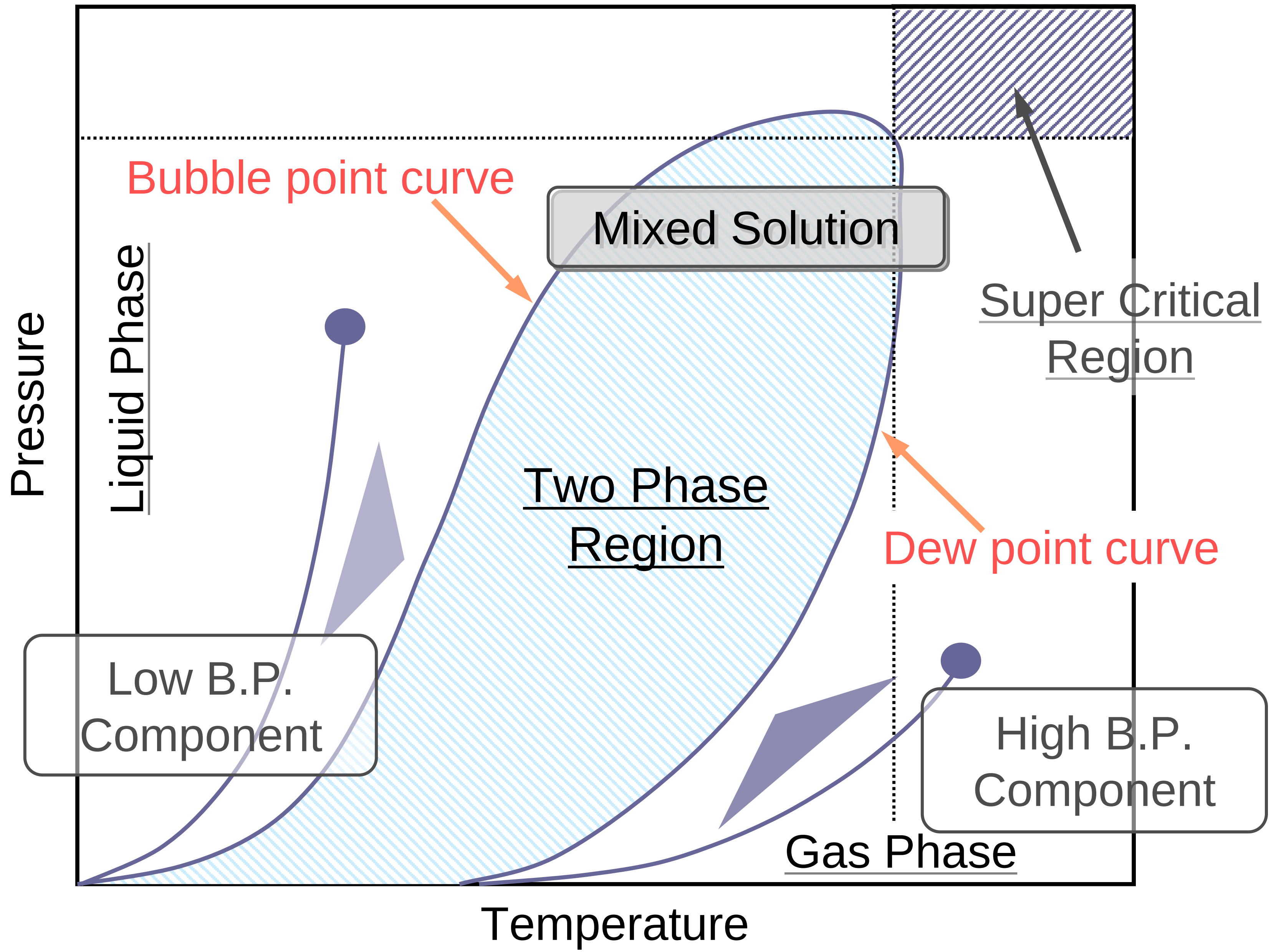
Rapid Compression and Expansion Machine

P_{inj}=15MPa

ρ_a=17.8kg/m^3

T_a=750K

Pressure-Temperature Diagram of Mixed Fuel



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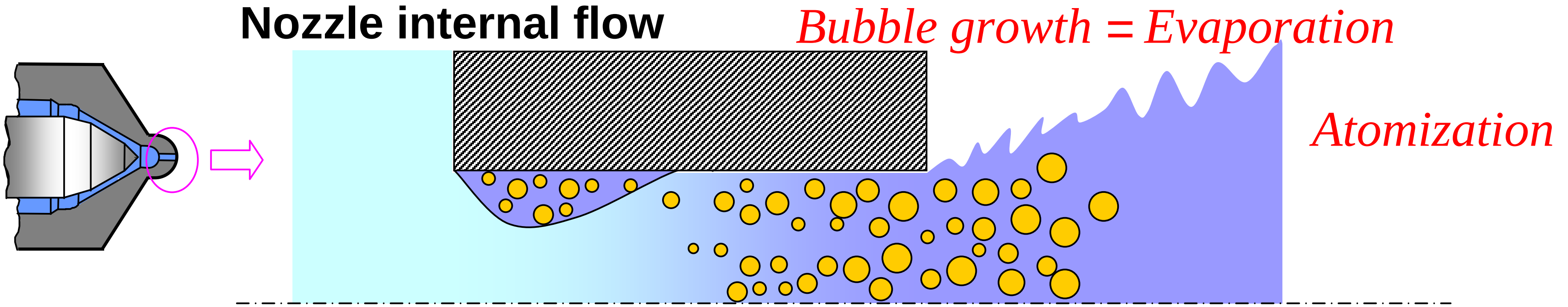
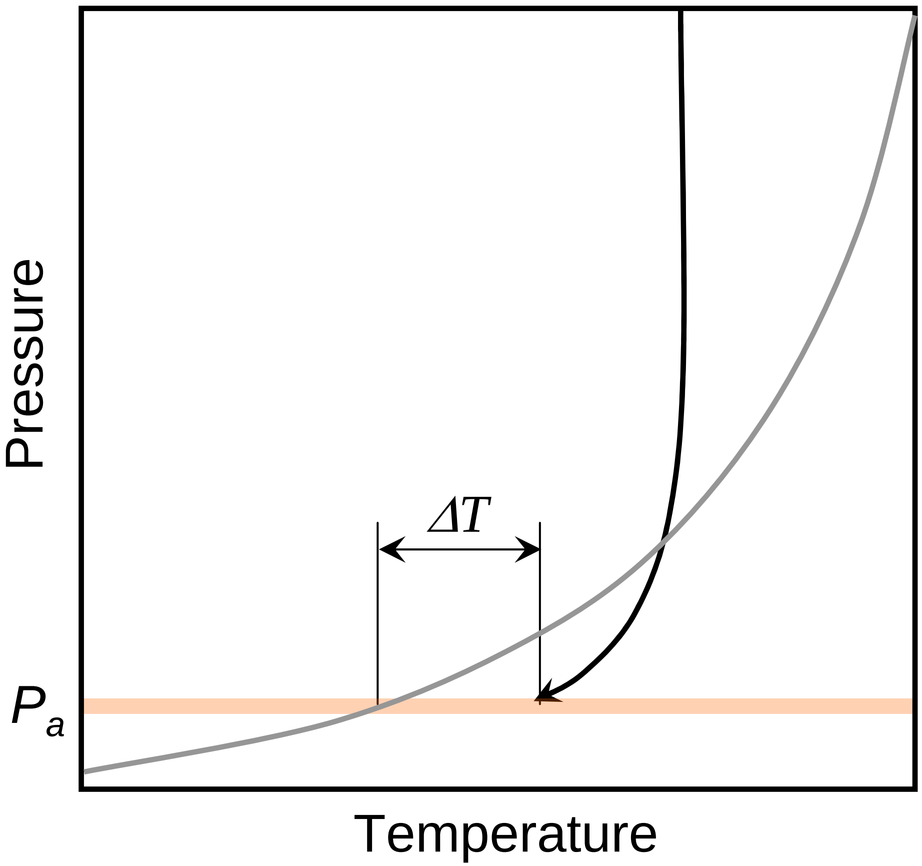
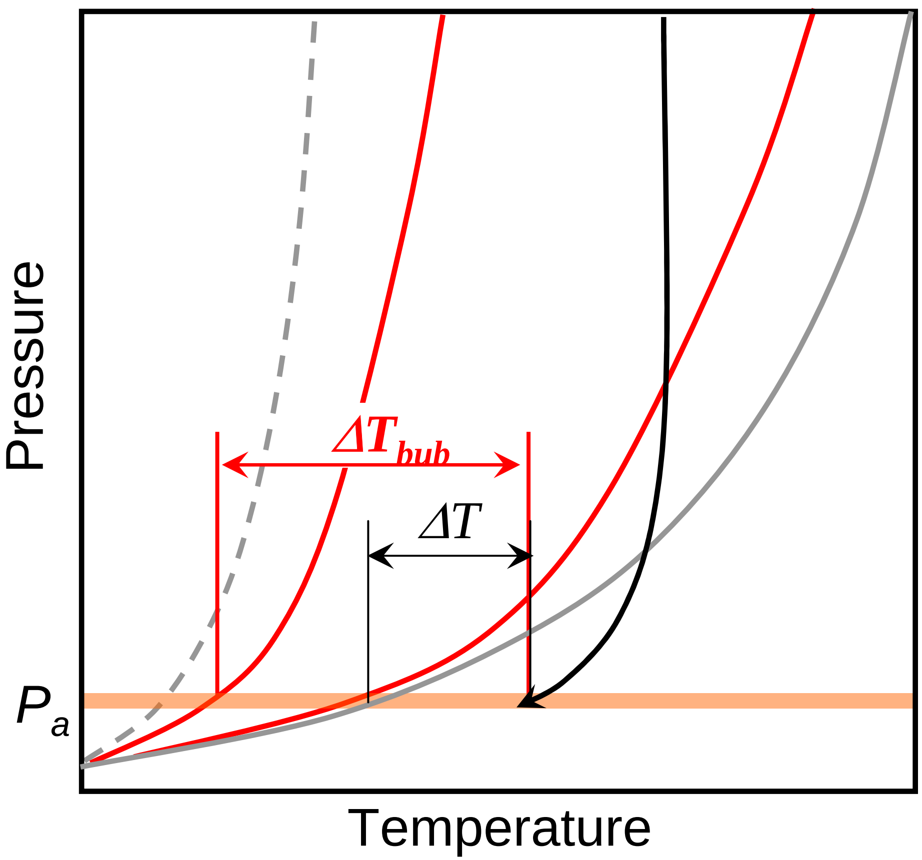
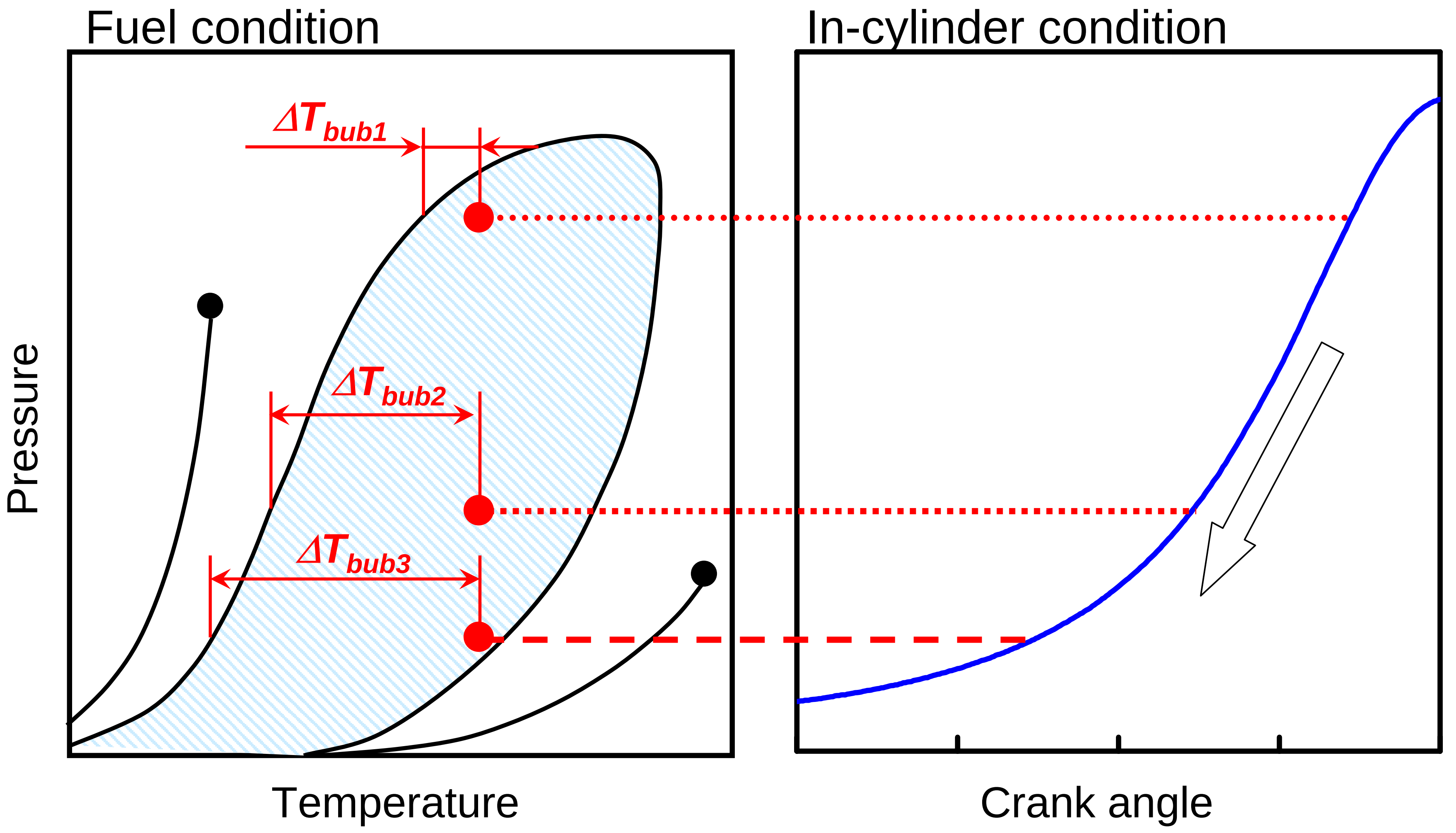
Flash Boiling Phenomena







Advantage of Flash Boiling for Early Timing Injections



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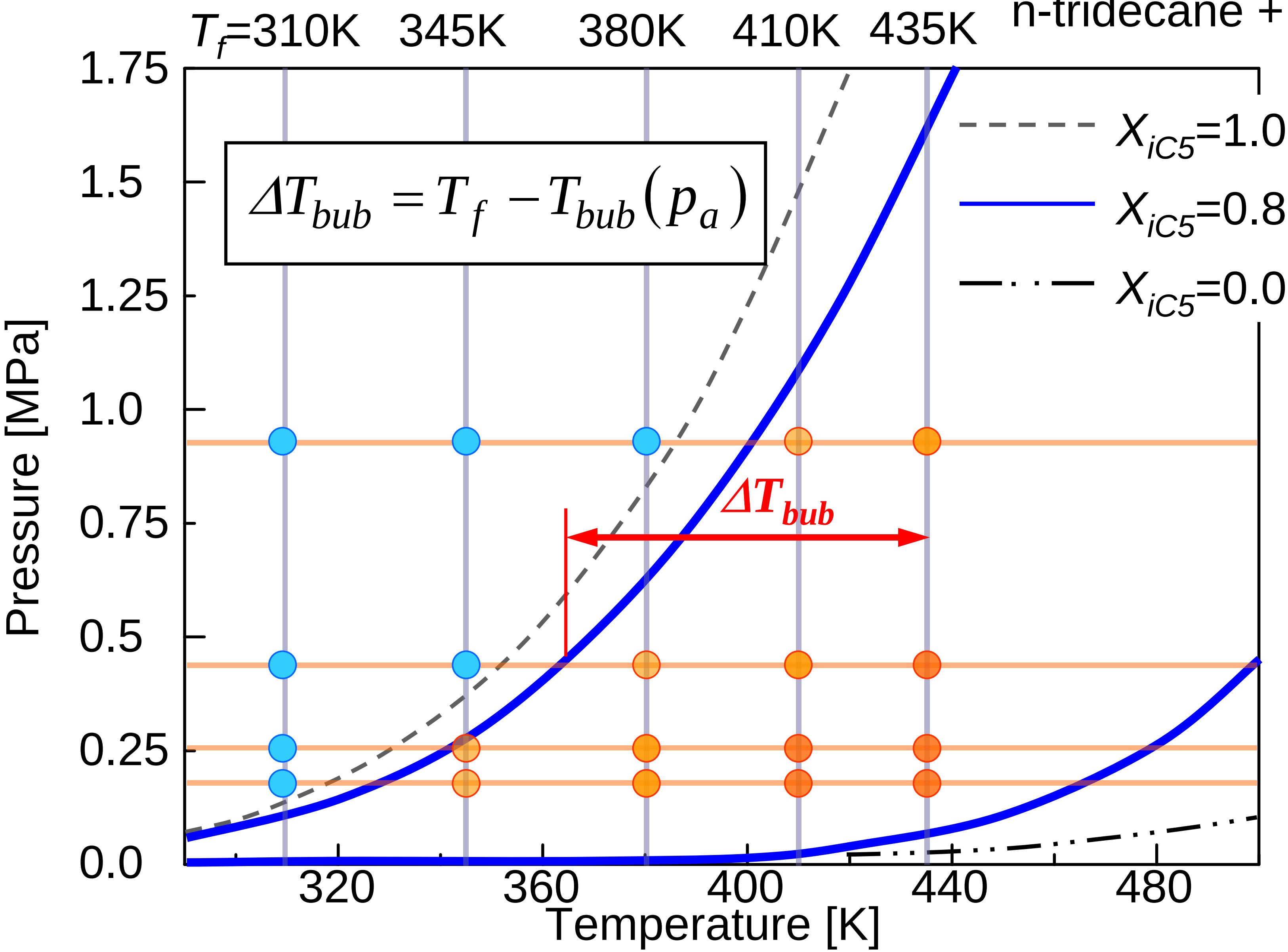
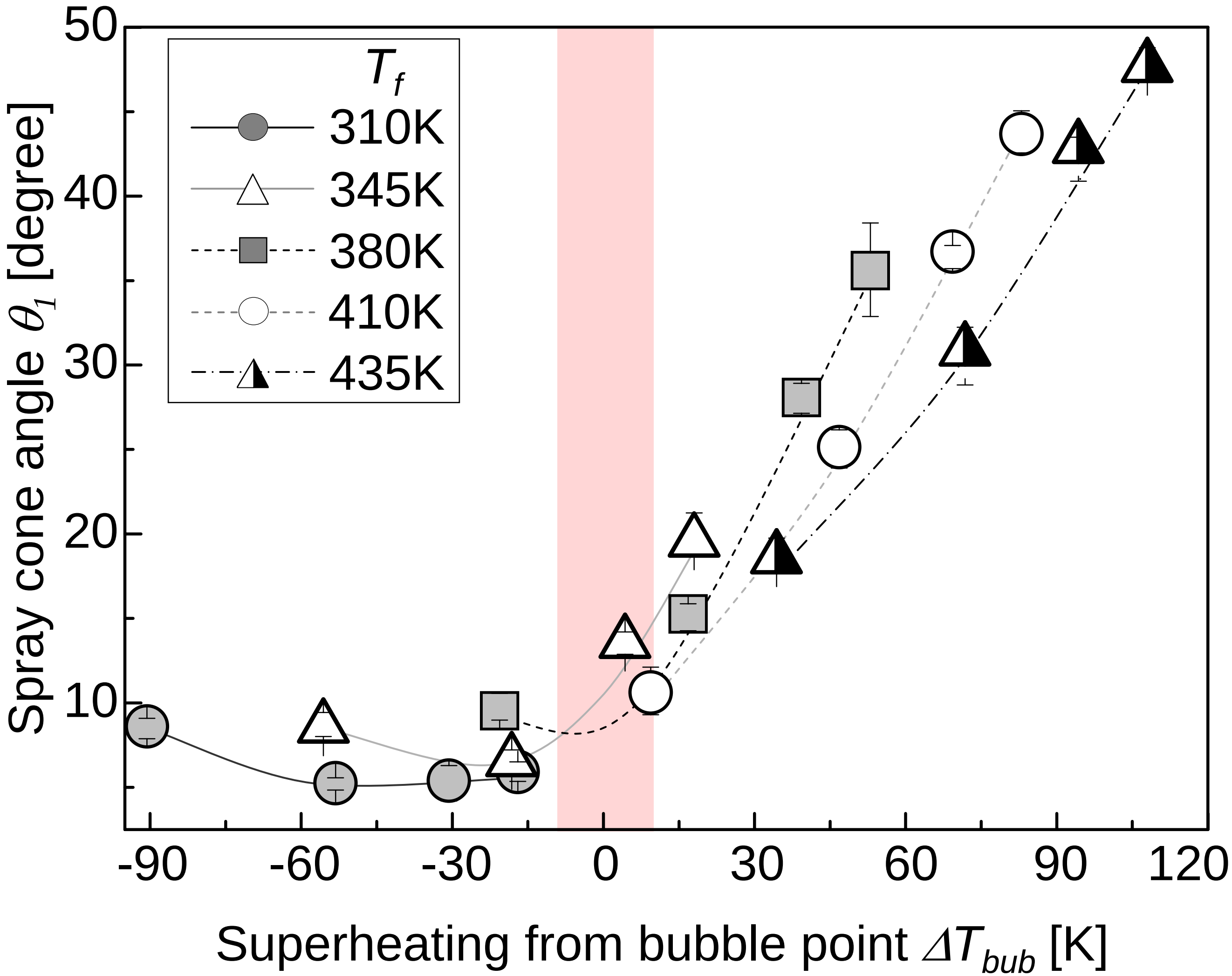
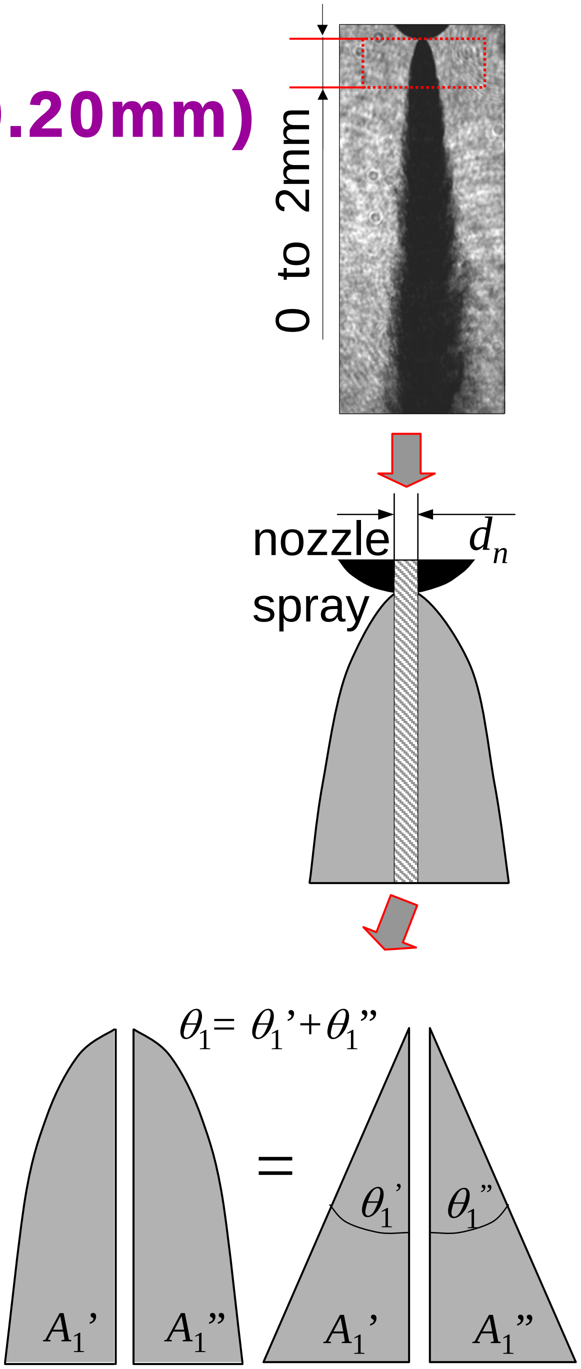
Ambient and Fuel Conditions, plotted on P-T diagram of Mixed Fuel

Test fuel :
n-tridecane + i-pentane

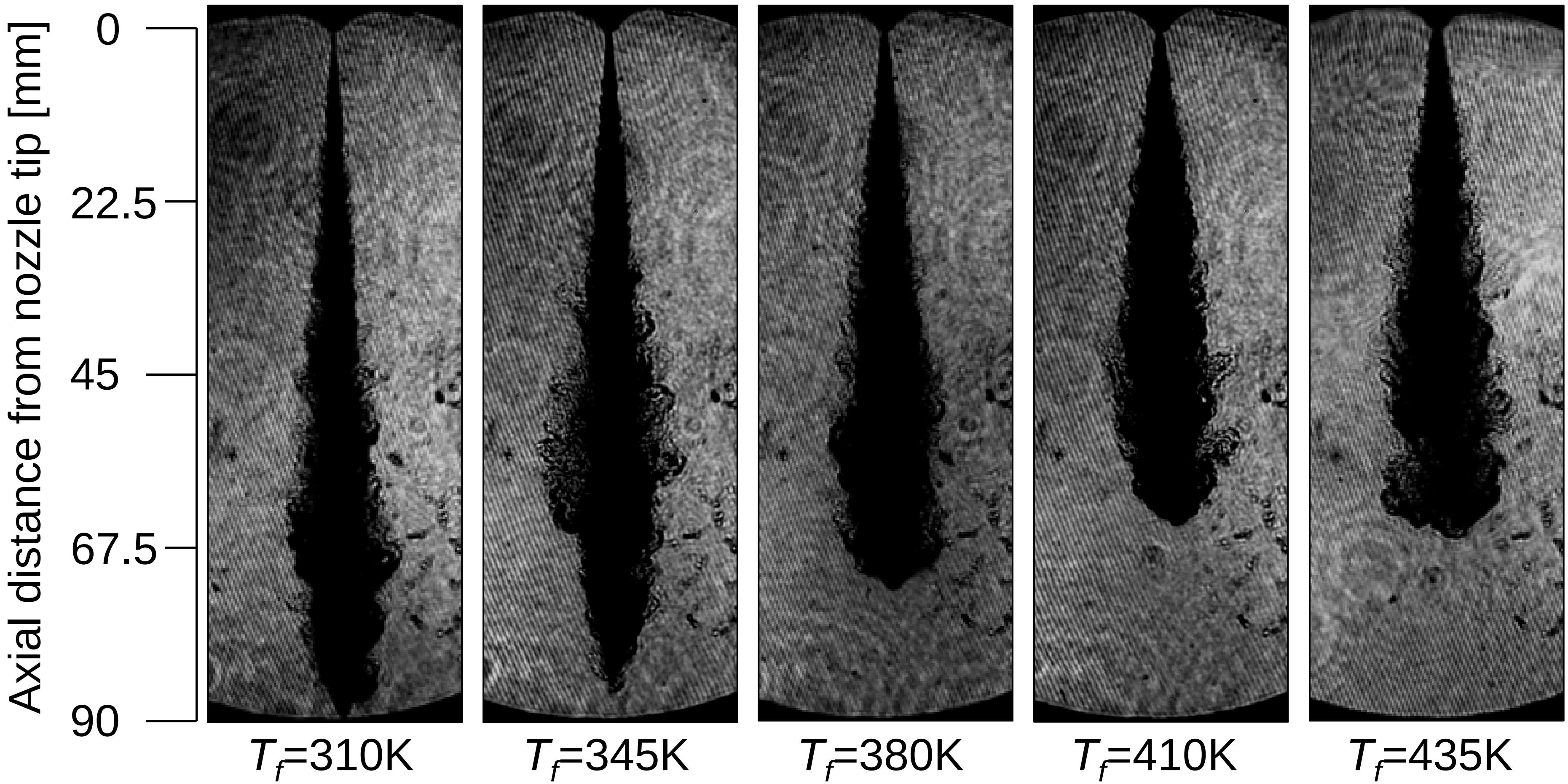


Measured Spray Cone Angle as a Function of ΔT_{bub} (P_{inj}=50MPa, d_n=0.20mm)





Spray Images for each Superheating from Bubble Point (T_a= 445K, ρ_a=2.0kg/m³, P_{inj}=50MPa, d_n=0.20mm)



ΔT_{bub} [deg.] = -30.7 | 4.3 | 39.3 | 69.3 | 94.3

Time after Corrected Start of Injection:0.45ms

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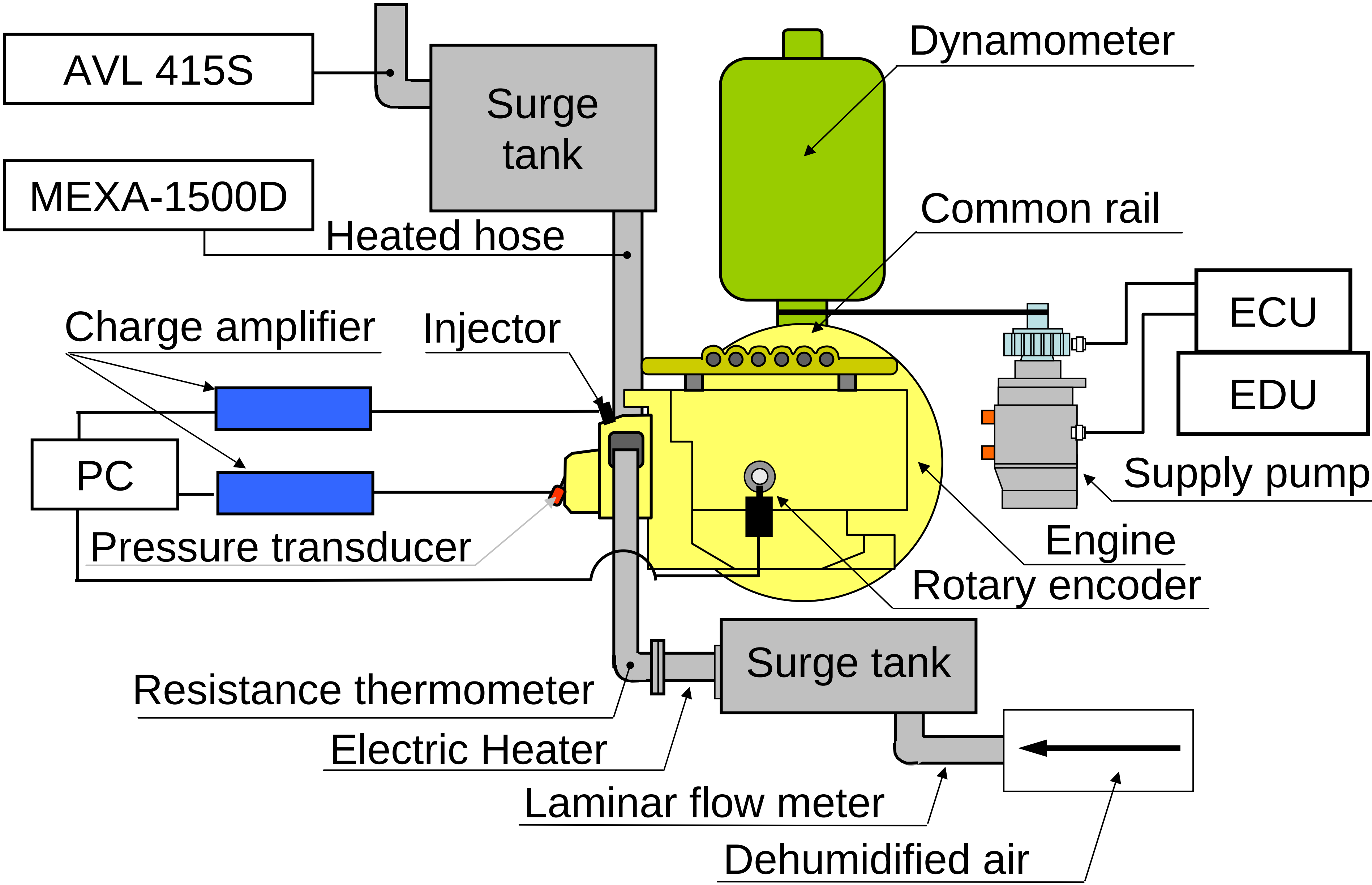
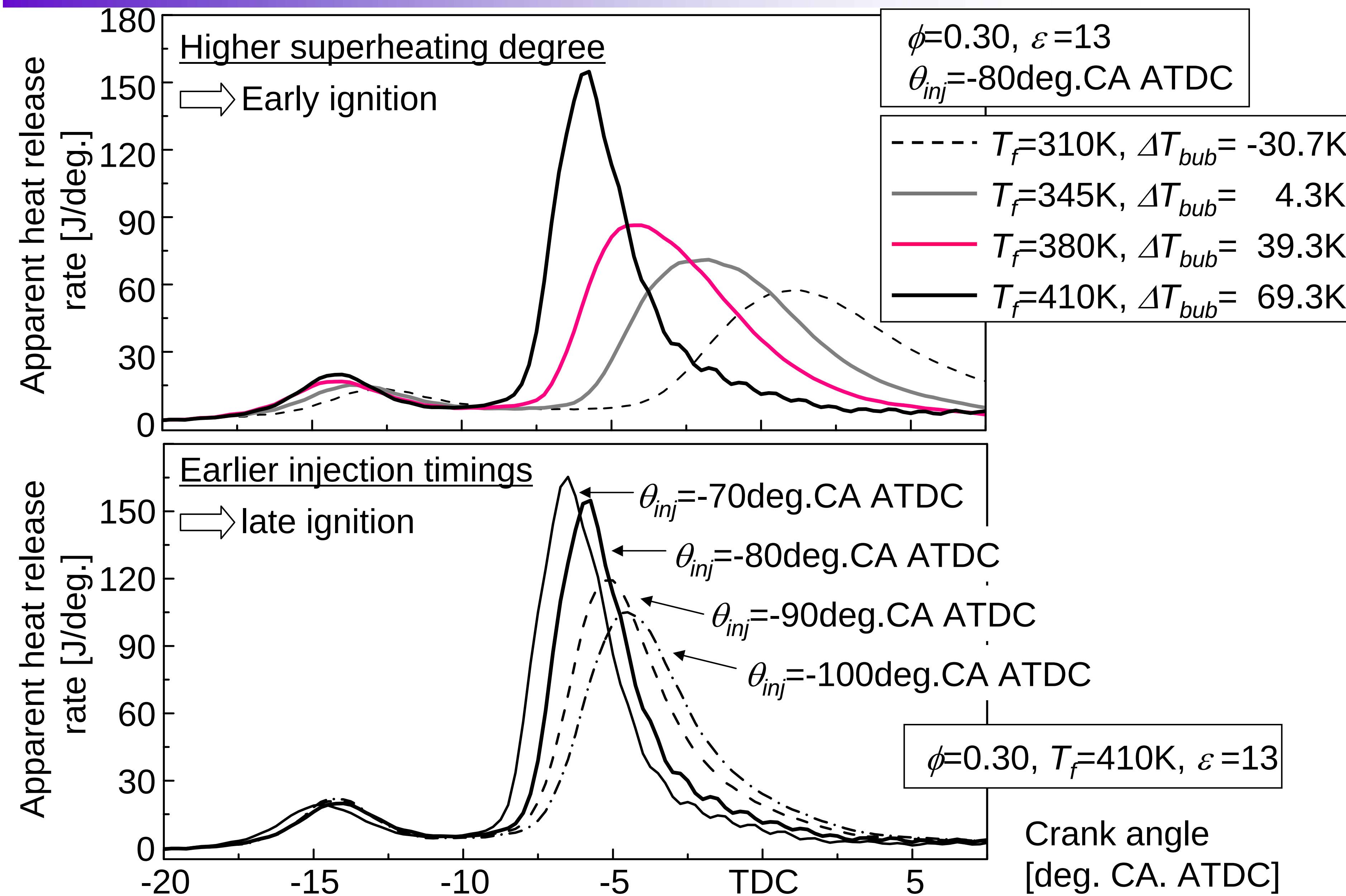
Experimental Setup



Effect of Superheating Degree and Injection Timings on Combustion Phasing (Included Spray Angle = 60deg.)



Experimental Condition for the Case of Single Injection

Fuel injection system		direct injection (common-rail)
Cooling System		water cooled (353K)
Bore × Stroke	[mm]	100 × 106
Compression ratio	[-]	10.0 : 1
Intake temperature	[K]	varied

Fuel		n-$C_{13}H_{28}$ + i-C_5H_{12} (X_{iC5}=0.8)
Fuel temperature T_f	[K]	310, 410
Nozzle hole diameter	[mm]	0.20 (L_n/d_n = 4)
Number of holes		4
Included spray angle	[deg.]	100
Injection pressure	[MPa]	50.0
Effective equivalence ratio ϕ_{eff}	[-]	0.41
50% burned crank angle	[deg. CA ATDC]	5.5 (adjusted by intake air temperature)

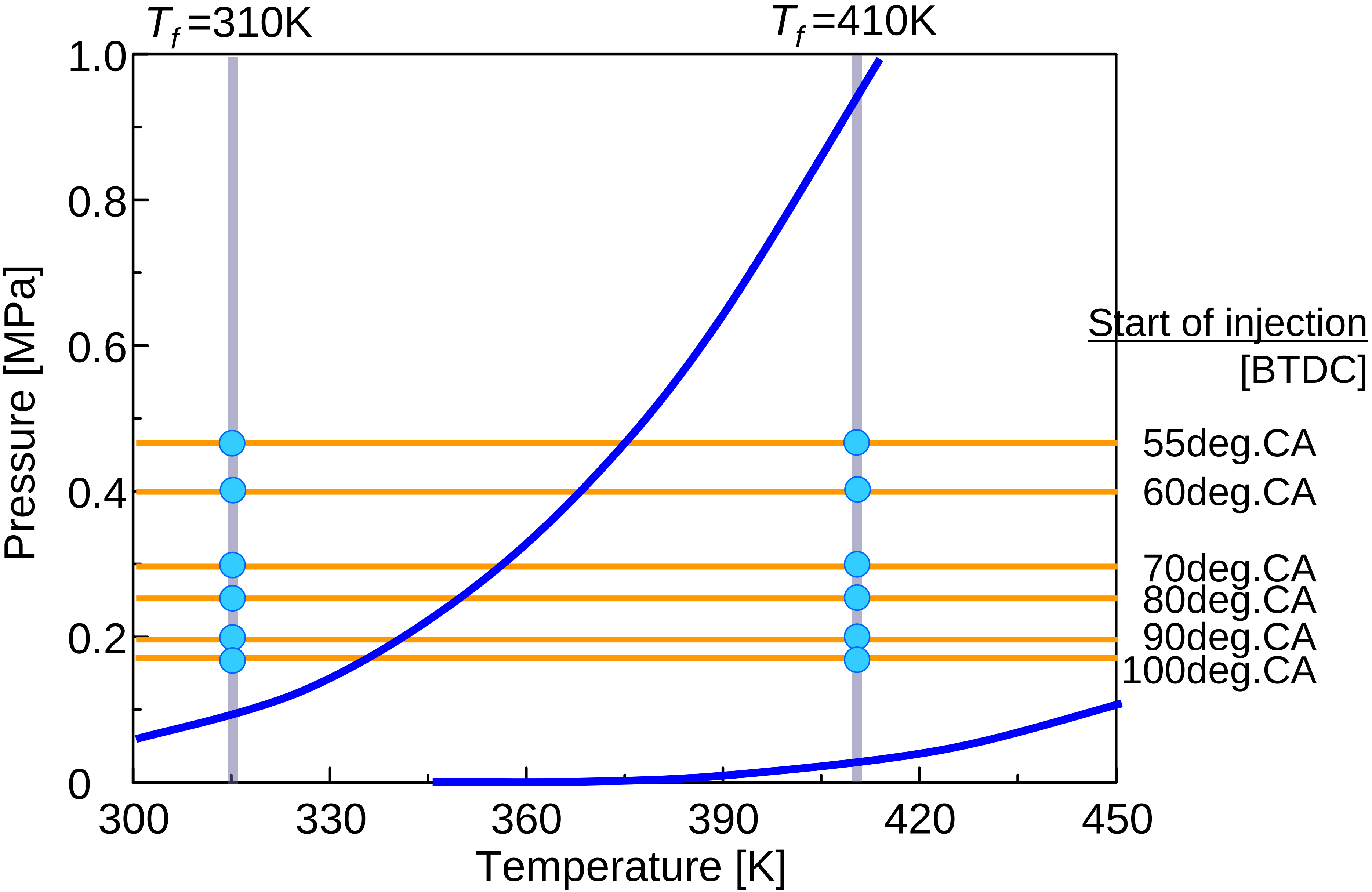
Experimental Condition for the Case of Single Injection

Fuel injection system		direct injection (common-rail)
Cooling System		water cooled (353K)
		100 × 106
		10.0 : 1
		varied
		…$_{13}H_{28}$ + i-C_5H_{12} (X_{iC5}=0.8)
Fuel temperature T_f	[K]	310, 410
Nozzle hole diameter	[mm]	0.20 (L_n/d_n = 4)
Number of holes		4
Included spray angle	[deg.]	100
Injection pressure	[MPa]	50.0
Effective equivalence ratio ϕ_{eff}	[-]	0.41
50% burned crank angle	[deg. CA ATDC]	5.5 (adjusted by intake air temperature)

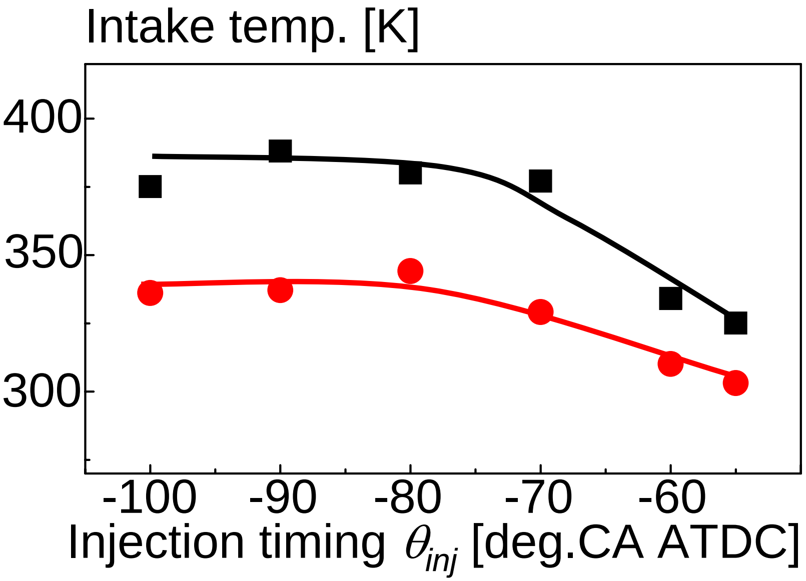
ϕ_{eff}: Effective equivalence ratio calculated from effective injection quantity $Q_{eff,inj}$

$Q_{eff,inj}$: Injection quantity calculated from carbon balance method

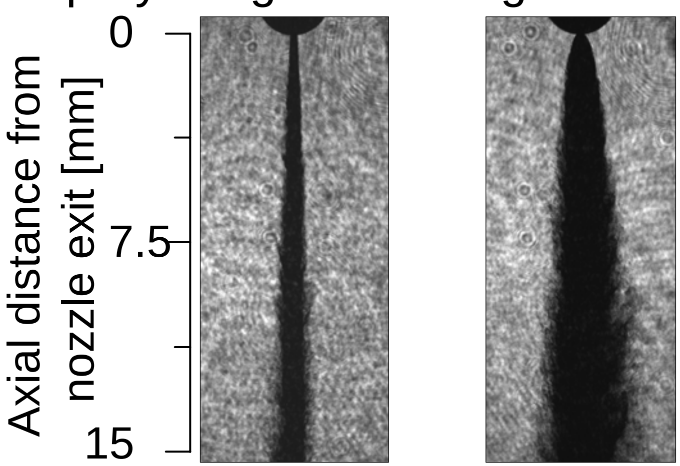
Relation among Two-Phase Region, In-Cylinder Pressure and Fuel Temperature



Combustion and Emissions Characteristics (Single Inj.)

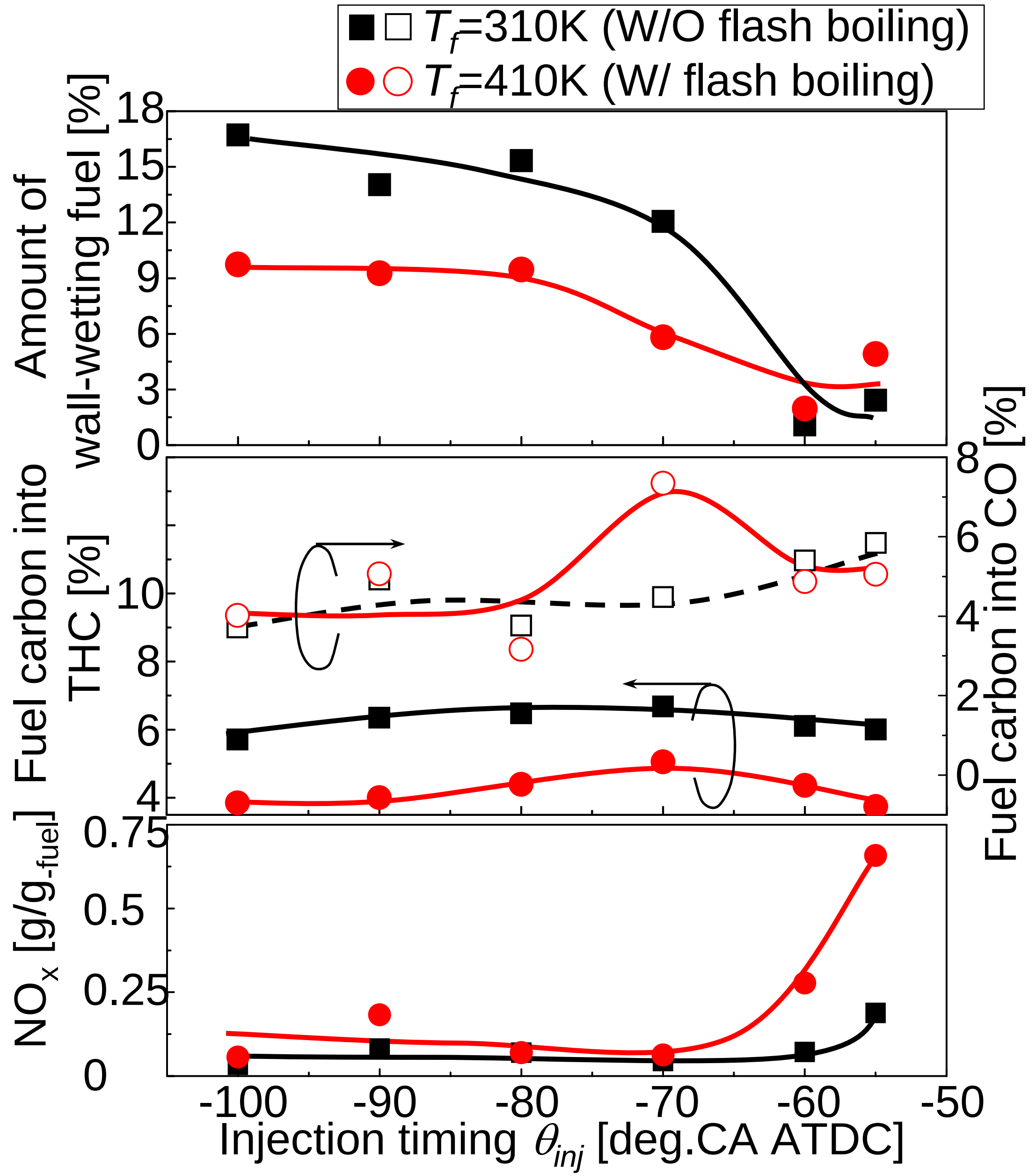


Spray images at 80deg.CA BTDC

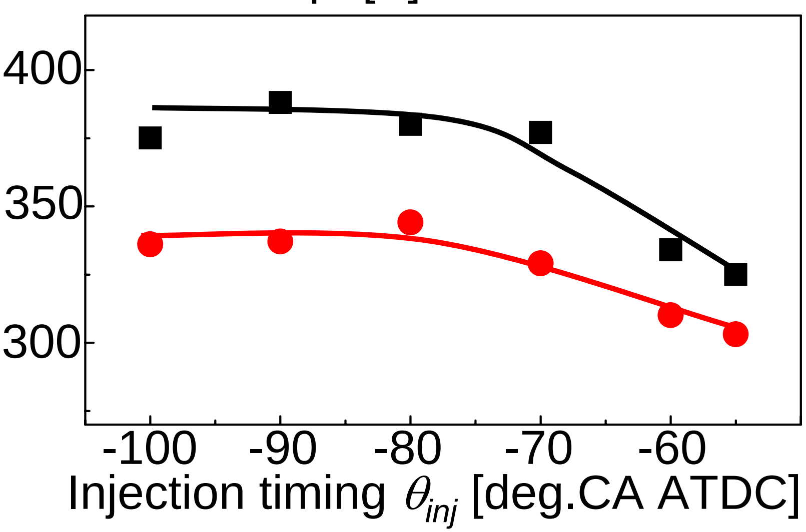


T_f=310K (ΔT_{bub}= -30.7deg.)

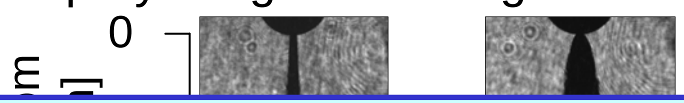
T_f=410K (ΔT_{bub}= 69.3deg.)

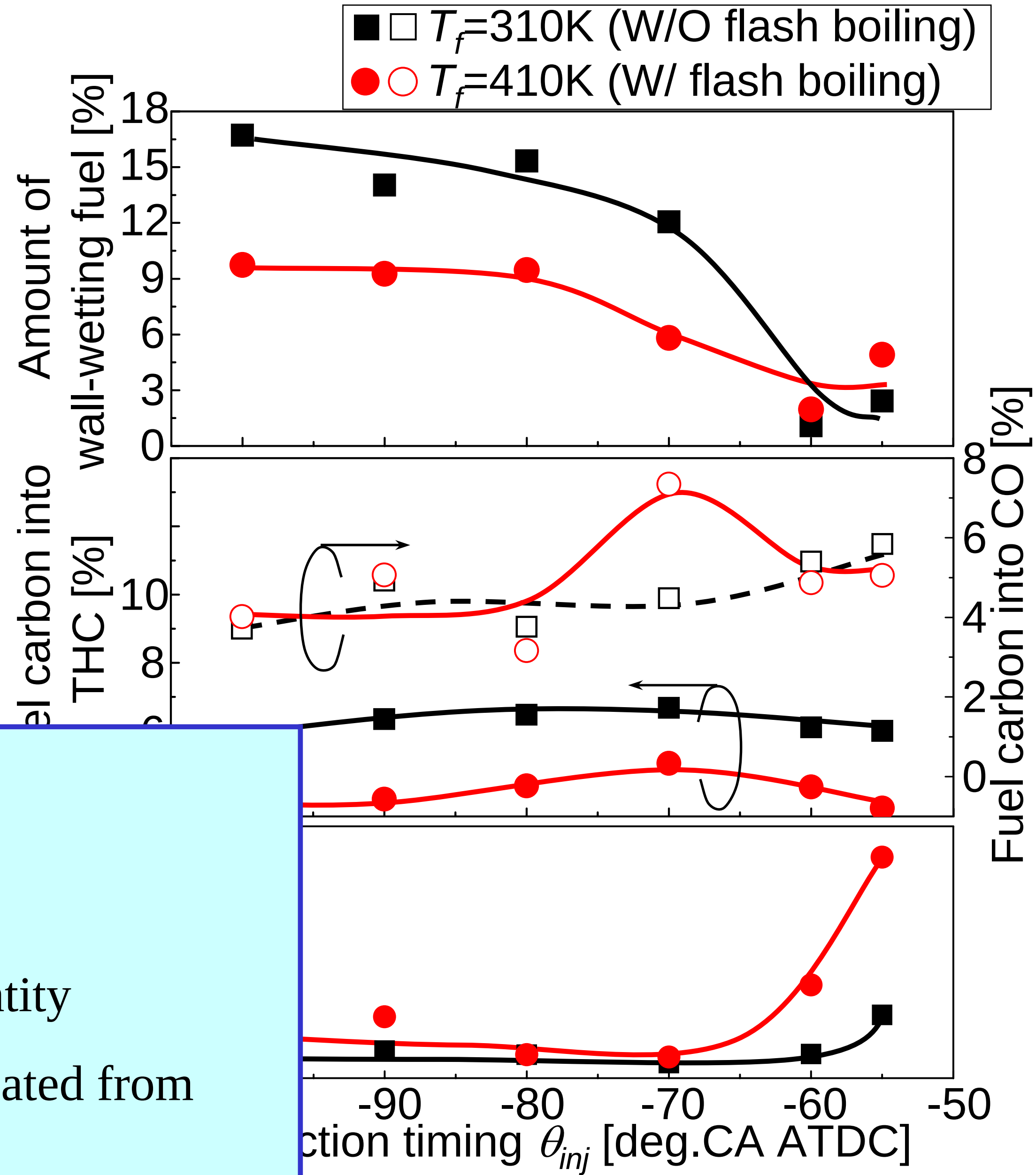


Combustion and Emissions Characteristics (Single Inj.)



Spray images at 80deg.CA BTDC





$$Q_{wall-wet} = \frac{Q_{real,inj} - Q_{eff,inj}}{Q_{real,inj}}$$

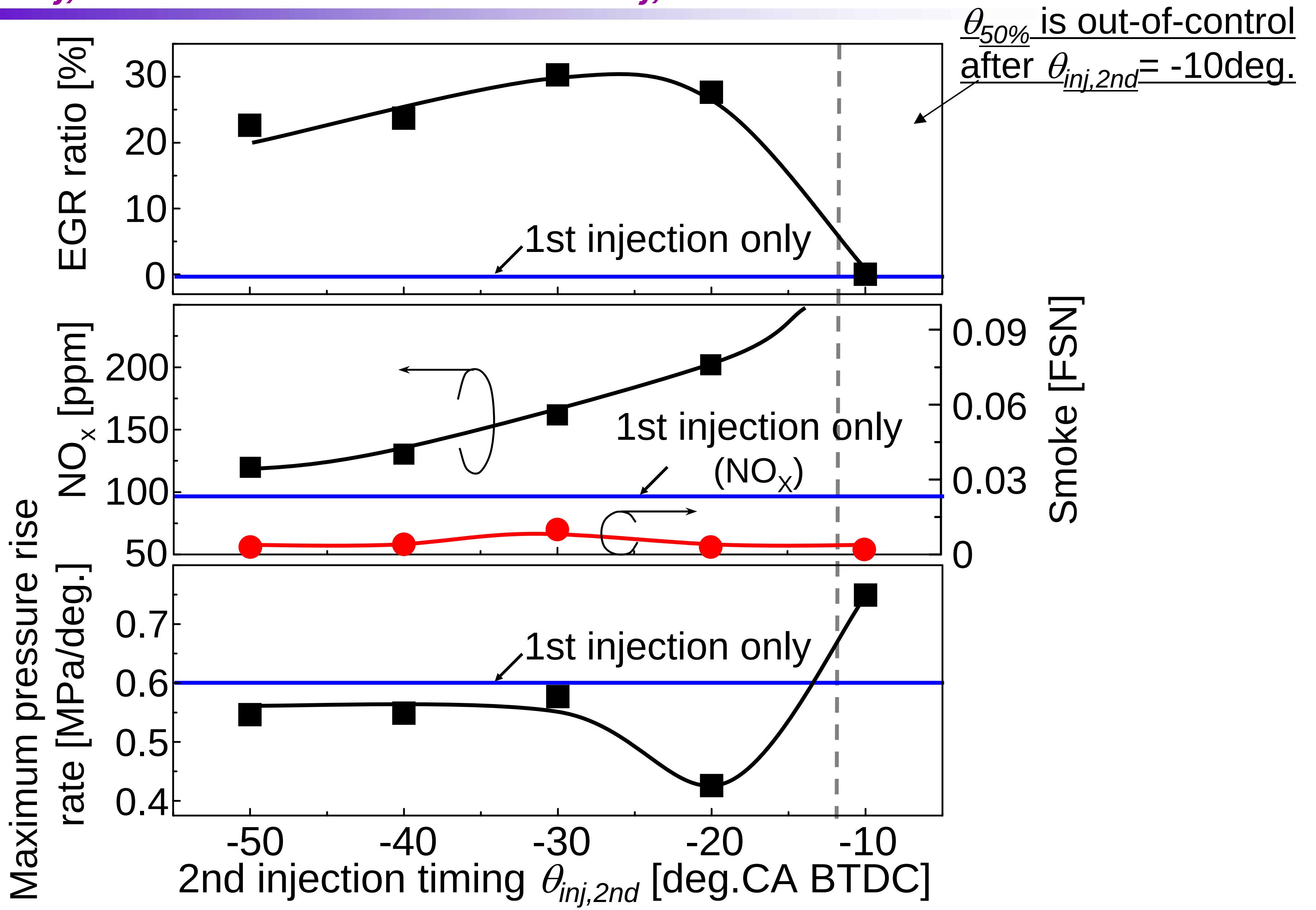
$Q_{real,inj}$: Measured injection quantity

$Q_{eff,inj}$: Injection quantity calculated from carbon balance method

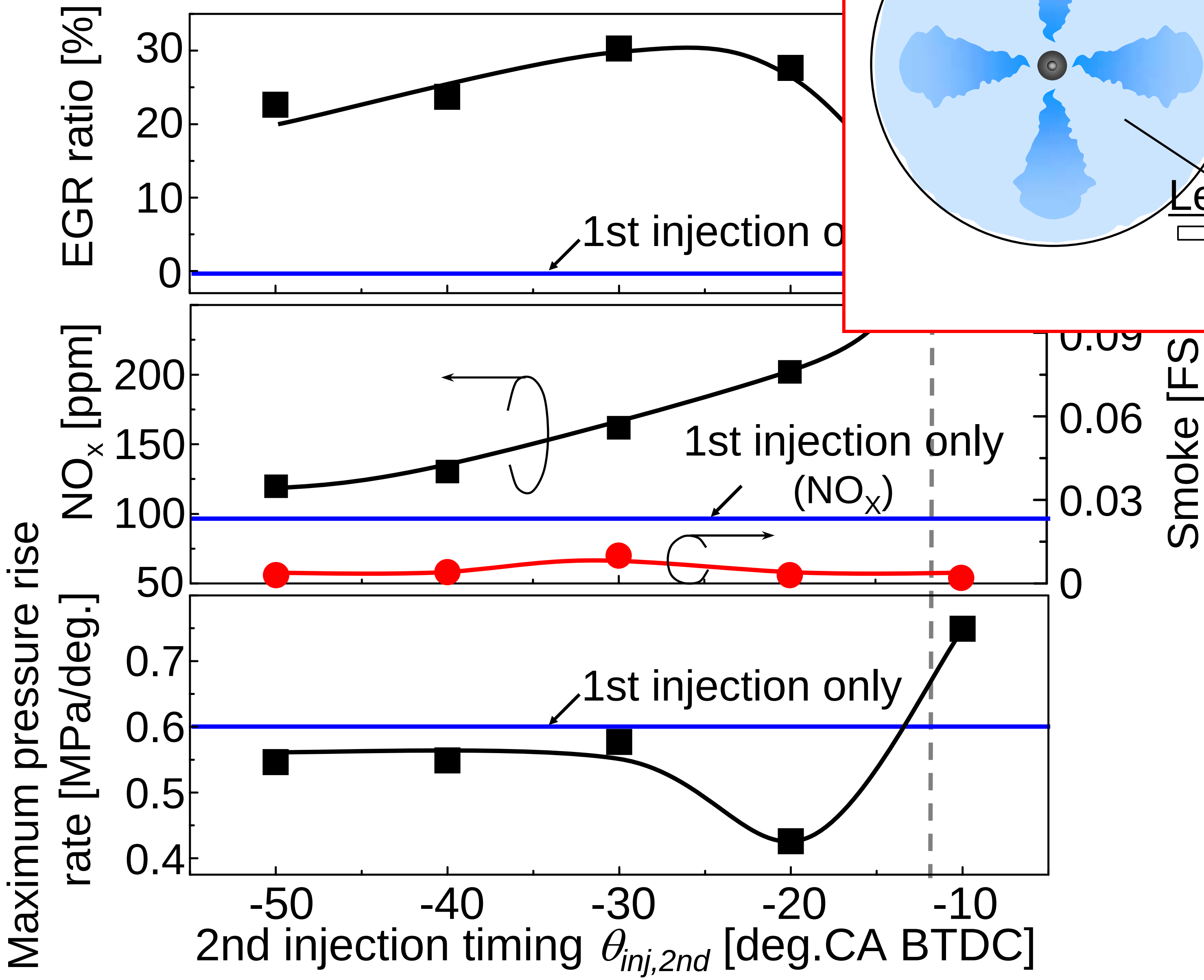
Experimental Condition for the Case of Two-Stage Injection

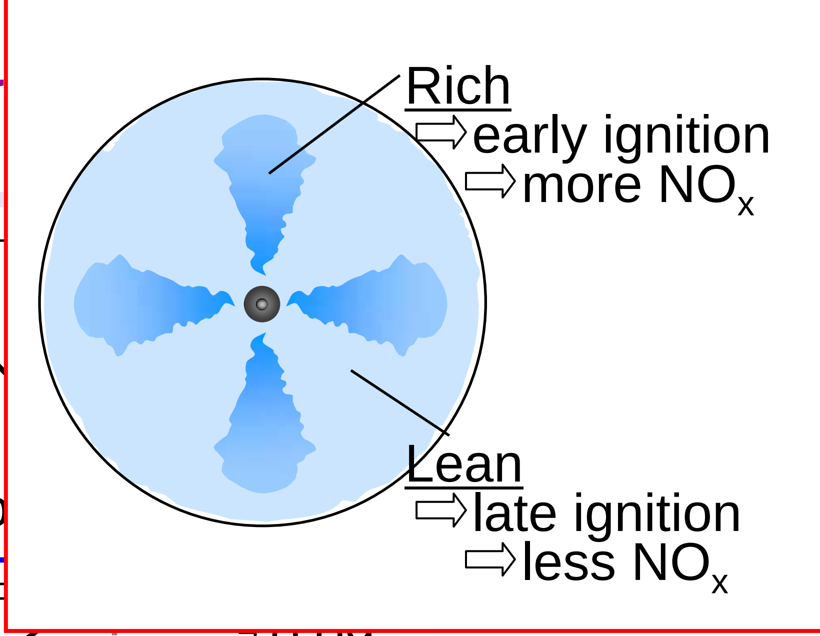
Fuel		n-$C_{13}H_{28}$ + i-C_5H_{12} (X_{iC5}=0.8)
Fuel temperature T_f	[K]	410
Compression ratio	[-]	10.0 : 1
Intake temperature	[K]	307
Nozzle hole diameter	[mm]	0.20 (L_n/d_n = 4)
Number of holes		4
Injection pressure	[MPa]	50.0
1st injection timing	[deg.CA ATDC]	-80
Total supplied energy	[J]	1335 (ϕ=0.43 without EGR)
50% burned crank angle	[deg. CA ATDC]	3.75 (adjusted by EGR ratio)

Combustion and Emissions Characteristics
($\theta_{inj,1st}$=-80deg.CA ATDC, $Q_{inj,2nd}$=30%)

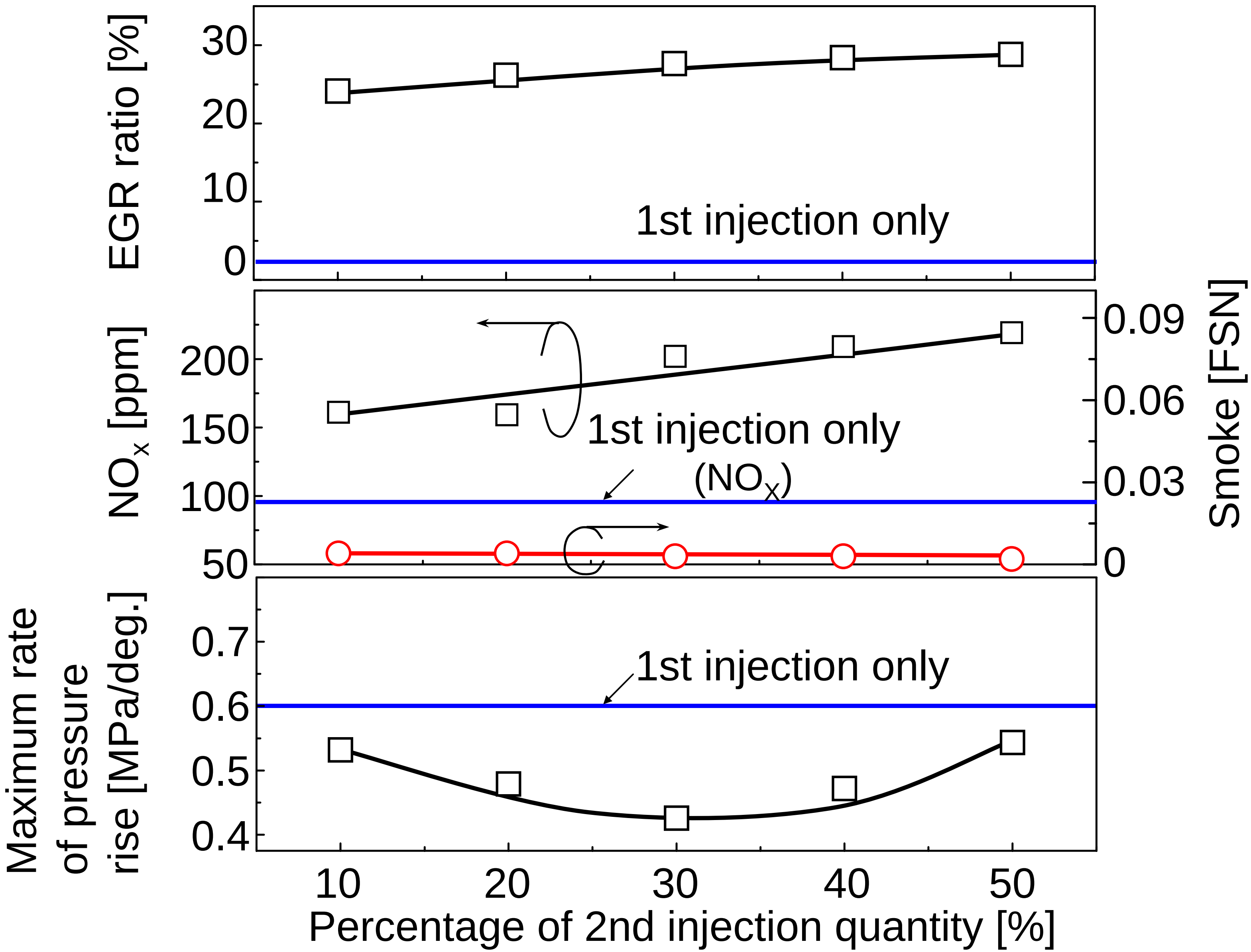


Combustion and Emissions Chara
($\theta_{inj,1st}$=-80deg.CA ATDC, $Q_{inj,2nd}$=

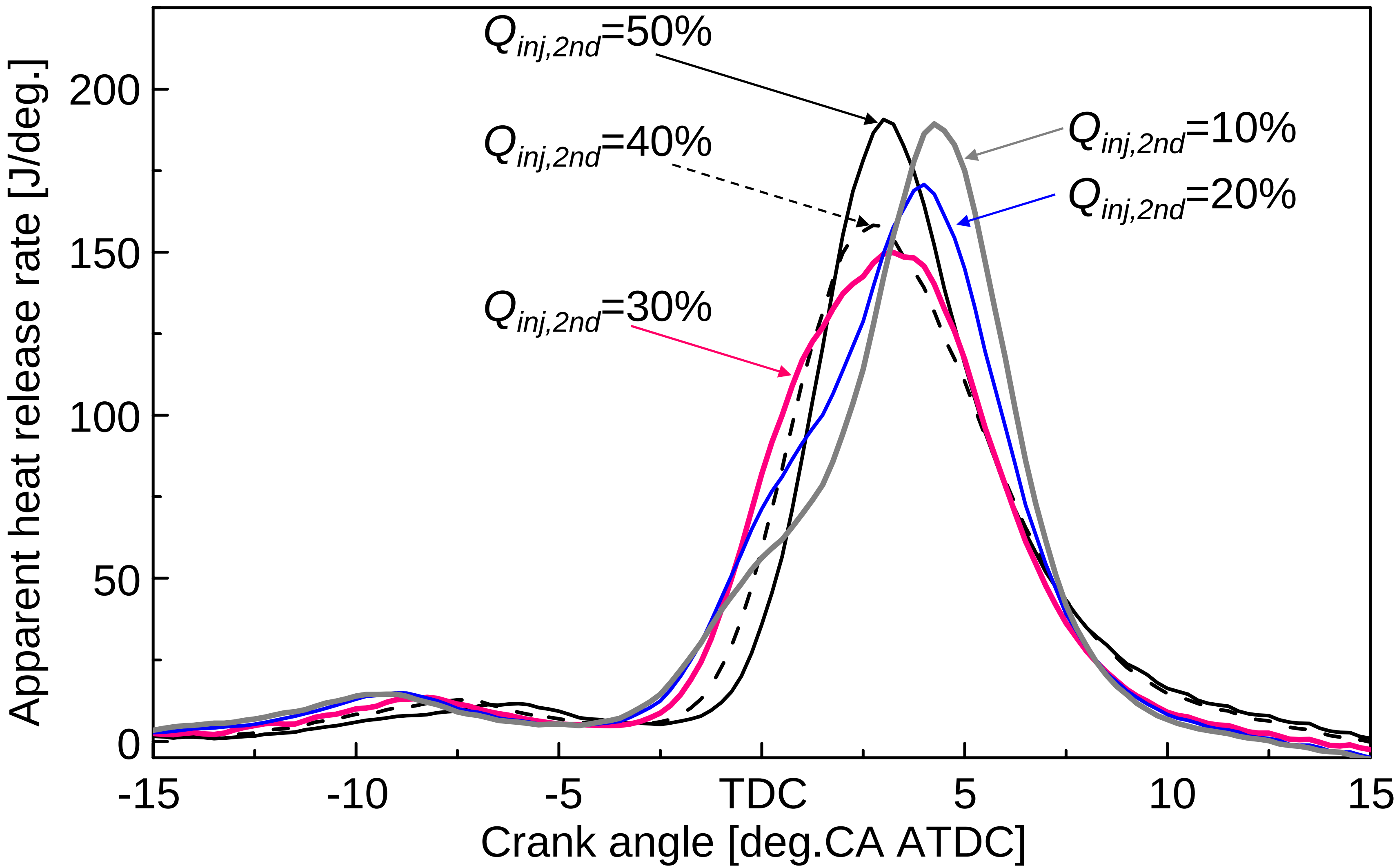




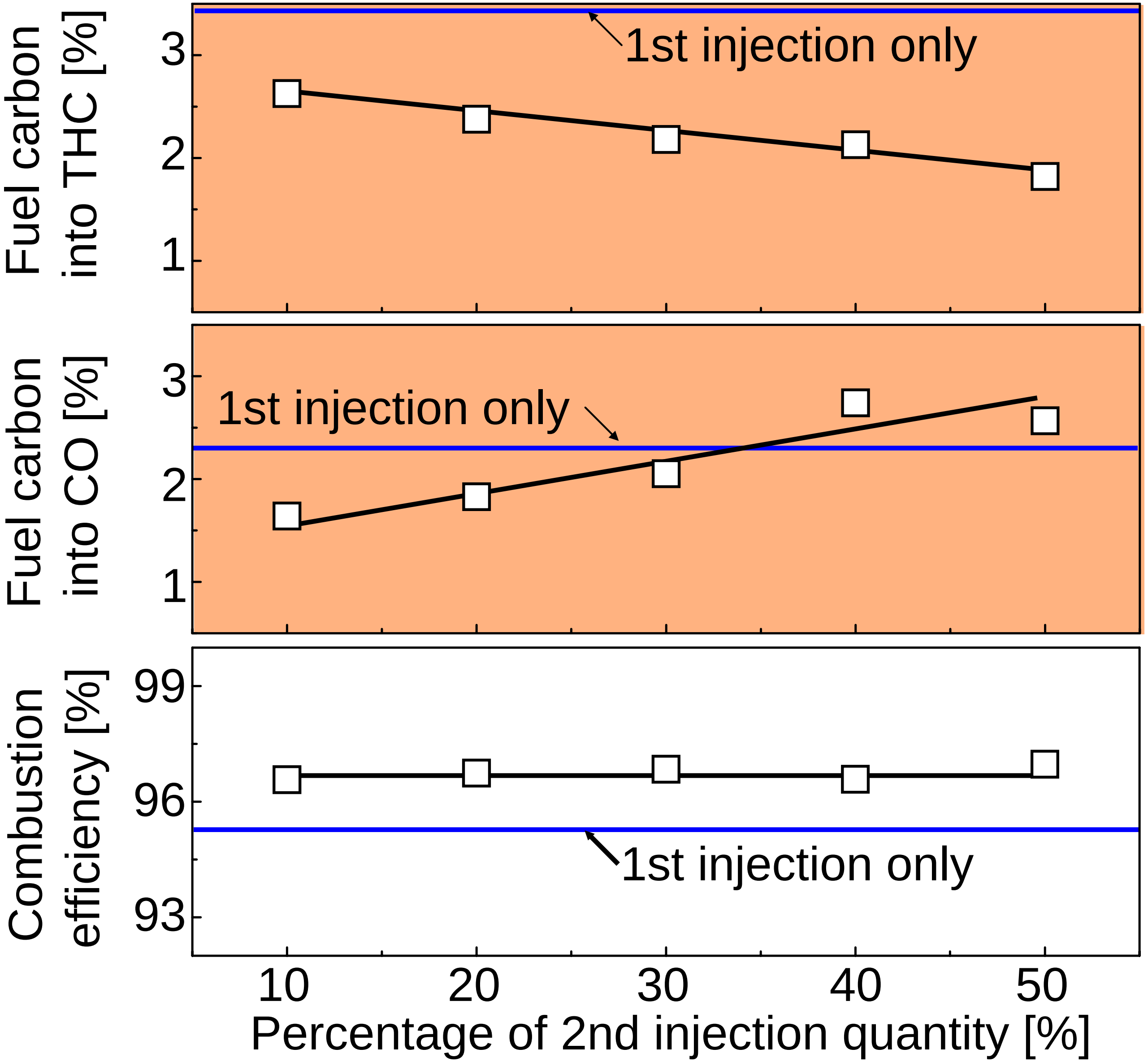
Combustion and Emissions Characteristics ($\theta_{inj,1st}$=-80deg.CA ATDC, $\theta_{inj,2nd}$=-20deg.CA ATDC)



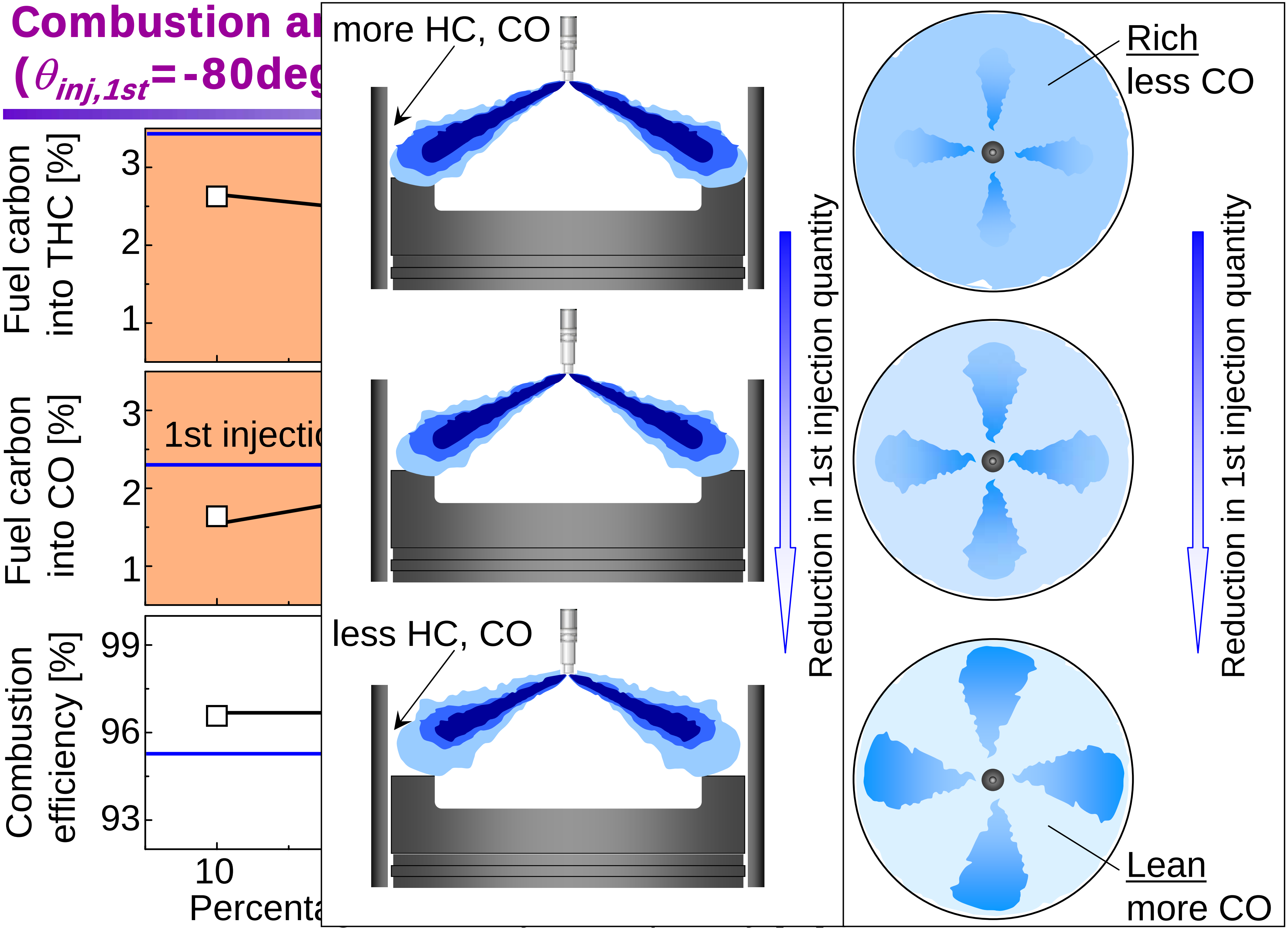
Histories of Apparent Heat Release Rate ($\theta_{inj,1st}$=-80deg.CA ATDC, $\theta_{inj,2nd}$=-20deg.CA ATDC)



Combustion and Emissions Characteristics ($\theta_{inj,1st}$=-80deg.CA ATDC, $\theta_{inj,2nd}$=-20deg.CA ATDC)



Combustion a
($\theta_{inj,1st}$=-80deg



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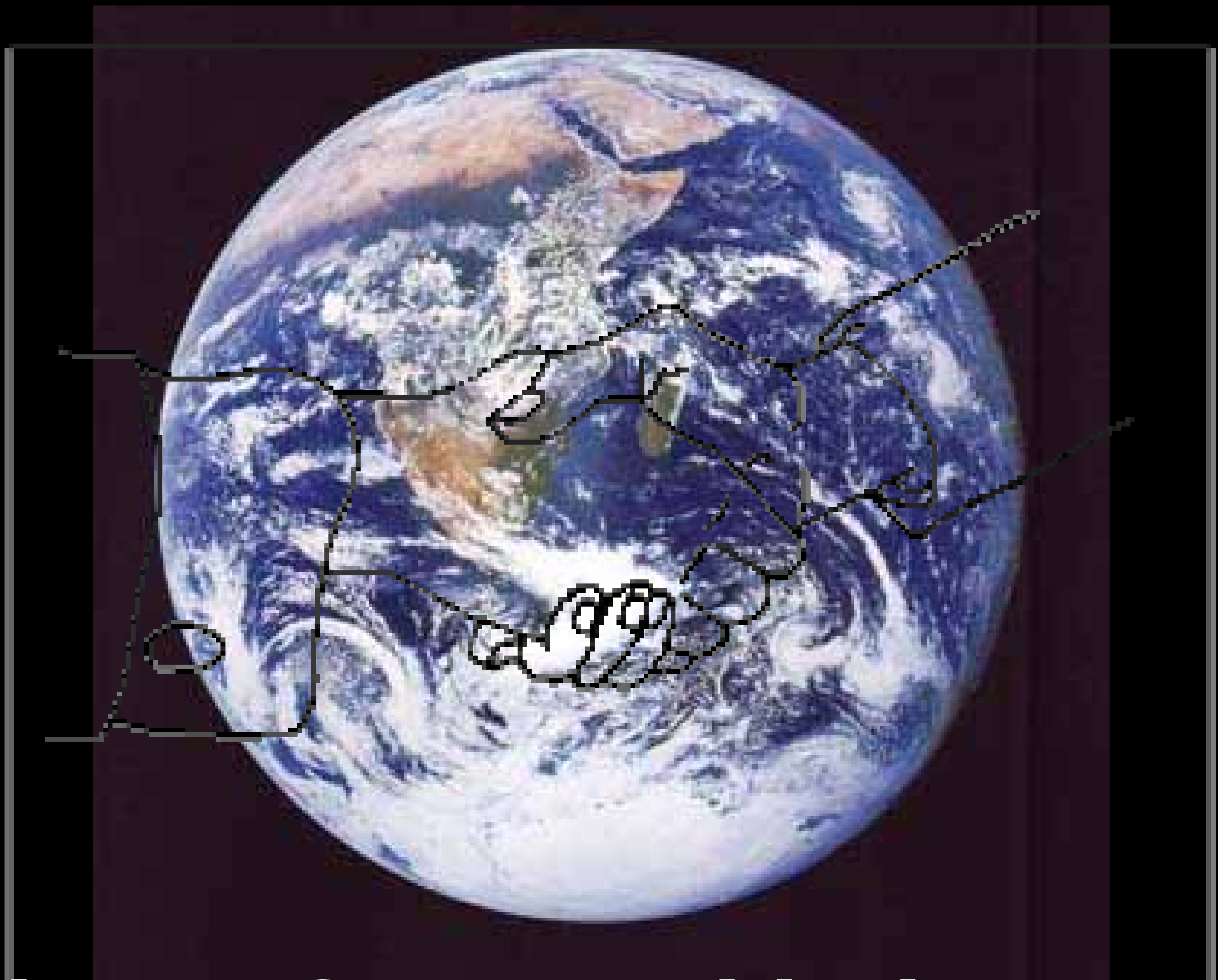
Conclusions

- The flashing spray of mixed fuel is effective to reduce the amount of wall-wetting fuel, THC and CO emissions for early fuel injection.
- Mixed fuel consisting of high and low carbon number fuels exhibits active low temperature oxidation reaction and thus, this character makes it possible to mitigate the steep combustion.
- By choosing optimum ignitability of high carbon number fuel while keeping low temperature oxidation reactivity, further improvement of thermal efficiency would be achieved. (because compression ratio is set at 10 in this study)
- The multiple injection combined with flash boiling spray has a possibility of decreasing in both maximum pressure rise rate and NO_X concentration.



Thank you for your kind attentions