Particle Size Distribution Measurements from Early to Late Injection Timing Low Temperature Combustion

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- **Background**
- Experimental Setup
- Combustion Results
- Particle Emissions Results
- Conclusions

Introduction

- Premixed, Diesel Low Temperature Combustion (LTC) can greatly reduce NOx and particulate matter (PM) emissions
- HC and CO emissions optimization required
- PM emissions possible at minimum opacity-based detection limits through early or late injection timing

What are the differences between particle size distributions below opacity-based minimum detection limit?

How does PM mass (opacity-based) and number correlate?

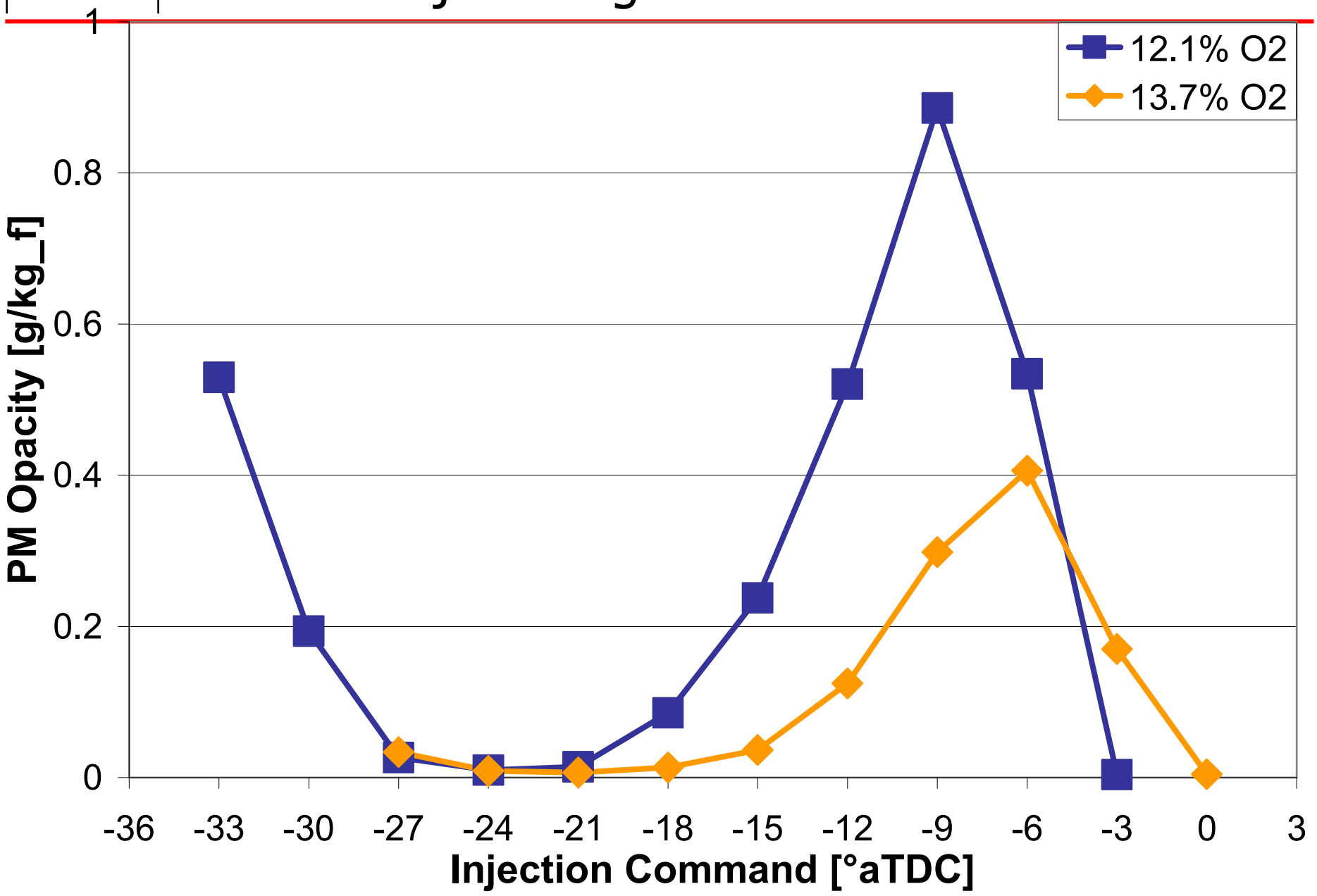
Objectives

- Find a low PM, NOx, CO, and HC HD-Diesel engine operating regime with minimal intake pressure, EGR cooling, and EGR rate requirements

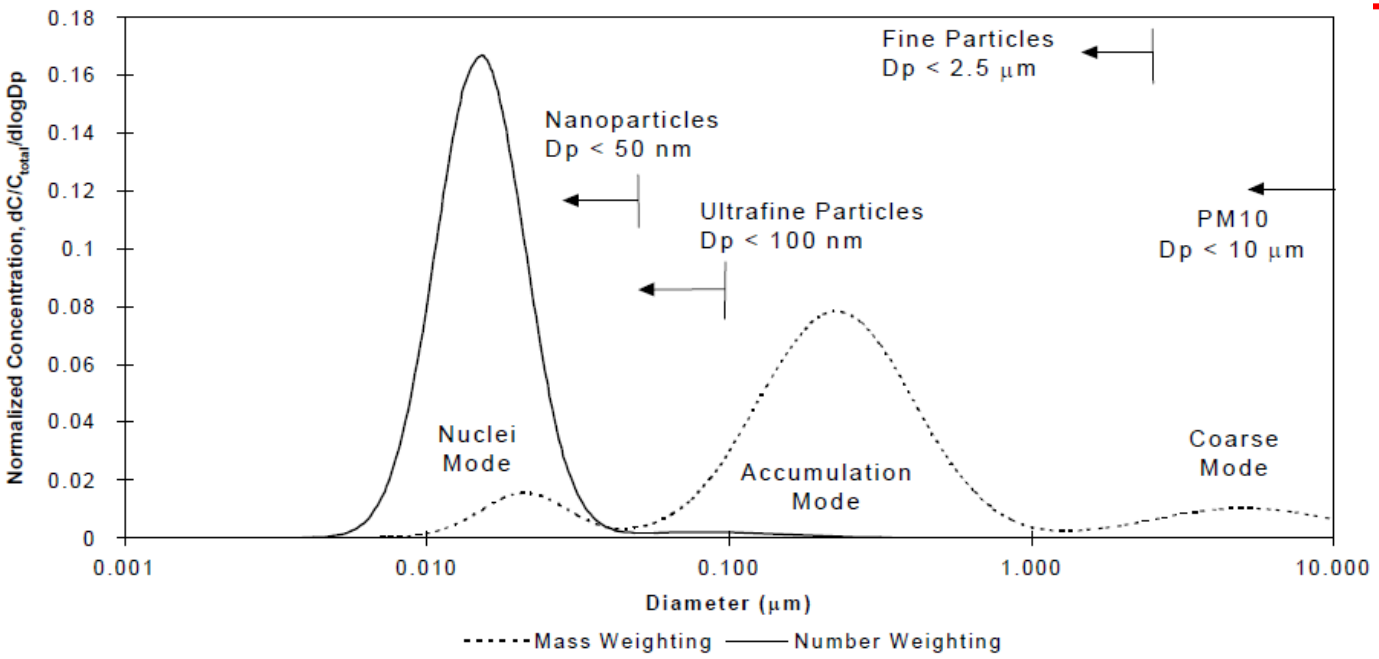
- Correlate emissions of particle sizes and numbers to calculated in-cylinder combustion values

- Provide LTC particle size and number emissions information to combustion as well as after-treatment researchers

Effect of Inj. Timing on Particulate Matter



Conv. Diesel Particulate Matter (PM)



Kittelson Model

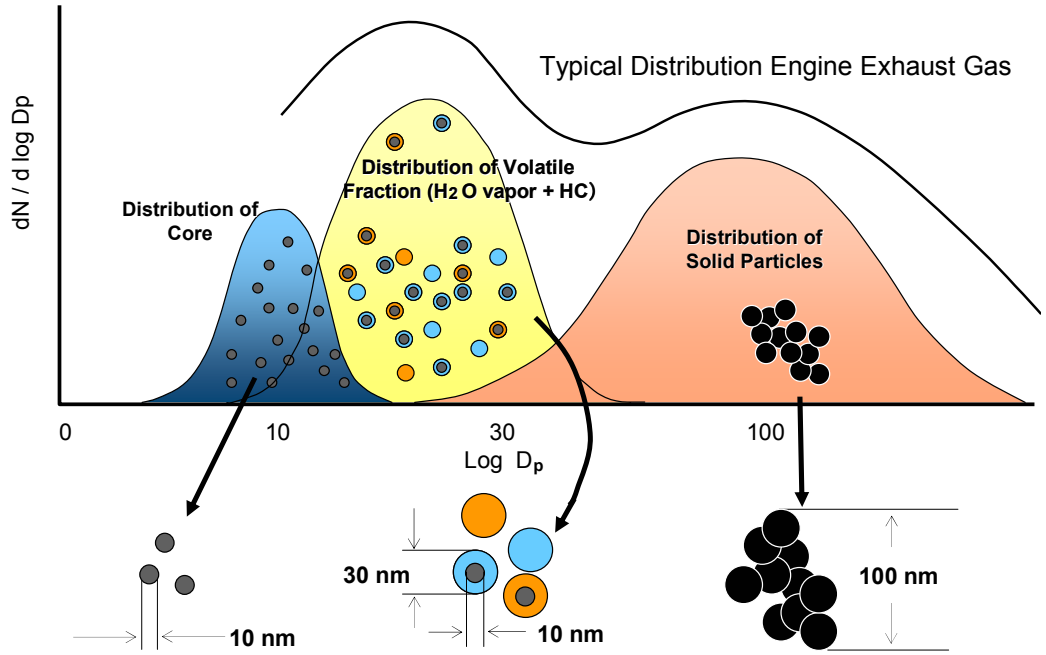
"The nuclei mode typically contains 1-20% of the particle mass and more than 90% of the particle number."

Kittelson, J. Aerosol Sci., 1998

Kawai Model

"Hypothetical model for Diesel nano-particle distribution."

Montajir, Kawai, Goto, Odaka, SAE 2005-01-0187



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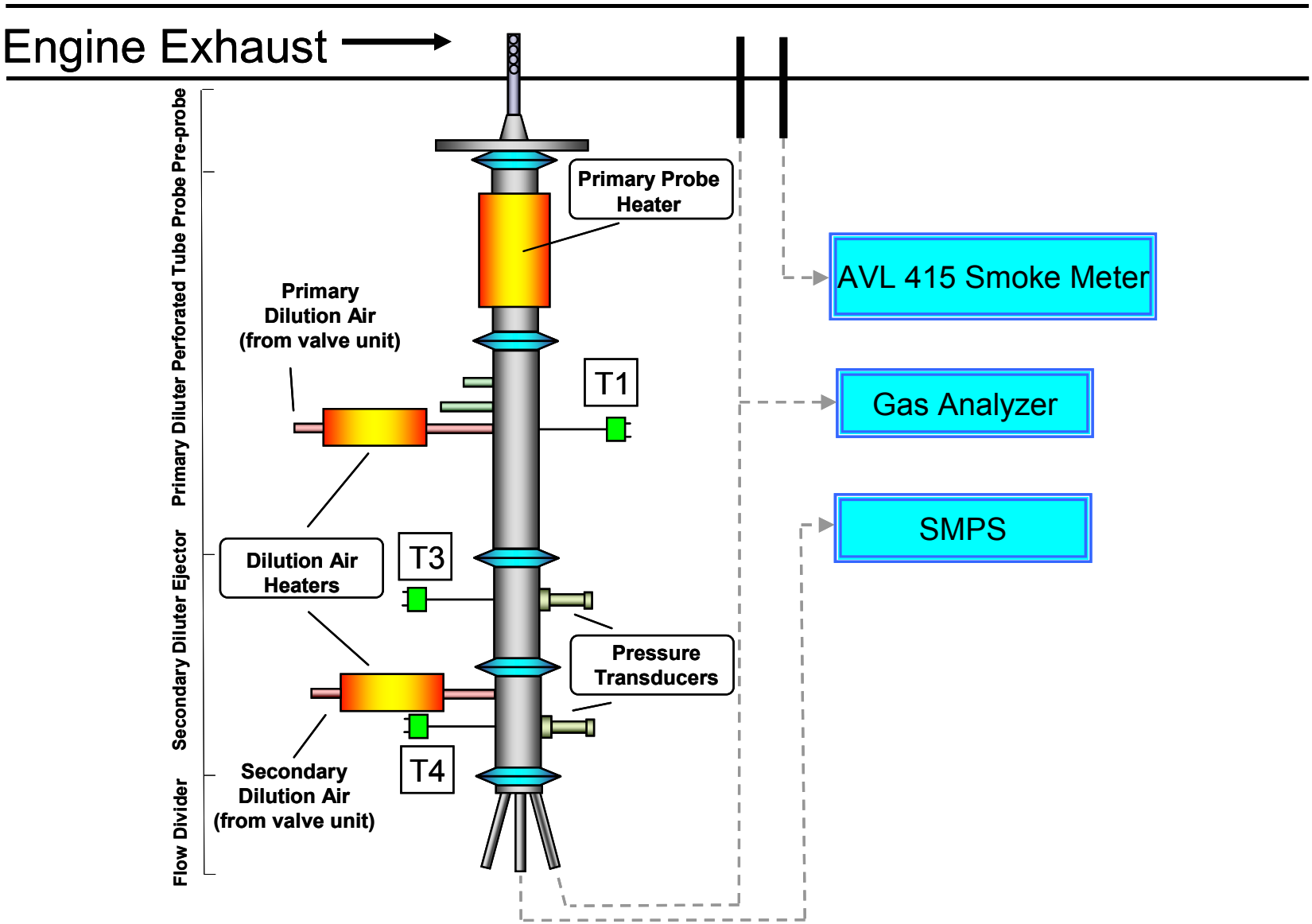
Experimental Equipment

Research Engine	**1.8L Single-Cylinder, 14.4:1 CR**
Exhaust Dilution	**Dekati FPS-4000, Heated Prim. and Ambient Sec. Dilution**
Opacity-Based PM	**AVL 415 Smokemeter**
Particle Size Dist.	**TSI SMPS 3936 (3080L Long DMA, CPC 3010)**

Schematic of Dilution System



Dilution Conditions

Case		1	2
Intake O2	[%]	13.7	12.1
Exhaust T	[C]	305-340	295-325
Probe T	[C]	300	290
PDT Setpt.	[C]	300	
PDT	[C]	195-230	180-200
SDT	[C]	28	
TDR	[-]	40	40, 65

Intake O2 = Engine Intake Oxygen Concentration (Volumetric)
Exhaust T = Exhaust Sample Point Temperature
Probe T = Heated Diluter Sample Probe Temperature
PDT Setpt. = Primary Dilution Temperature Heater Setpoint
PDT = Actual Primary Dilution Temperature
SDT = Secondary Dilution Temperature
TDR = Total Dilution Ratio

Engine Operating Conditions

Case	1	2
Speed [RPM]	1200	
IMEP [bar]	~7	
m_{fuel} [mg/cycle]	70	
Inj. Command [°aTDC]	-27→0	-33→-3
Mech. Inj. Delay [CAD]	1.53	
$P_{injection}$ [bar]	1450	
Intake O2 [%_vol]	13.7	12.1
Equivalence Ratio [-]	0.75	0.83
T_{intake} [°C]	45	
P_{intake} [bar]	1.35	
$T_{exhaust}$ [°C]	365-418	365-410
$P_{exhaust}$ [bar]	1.45	

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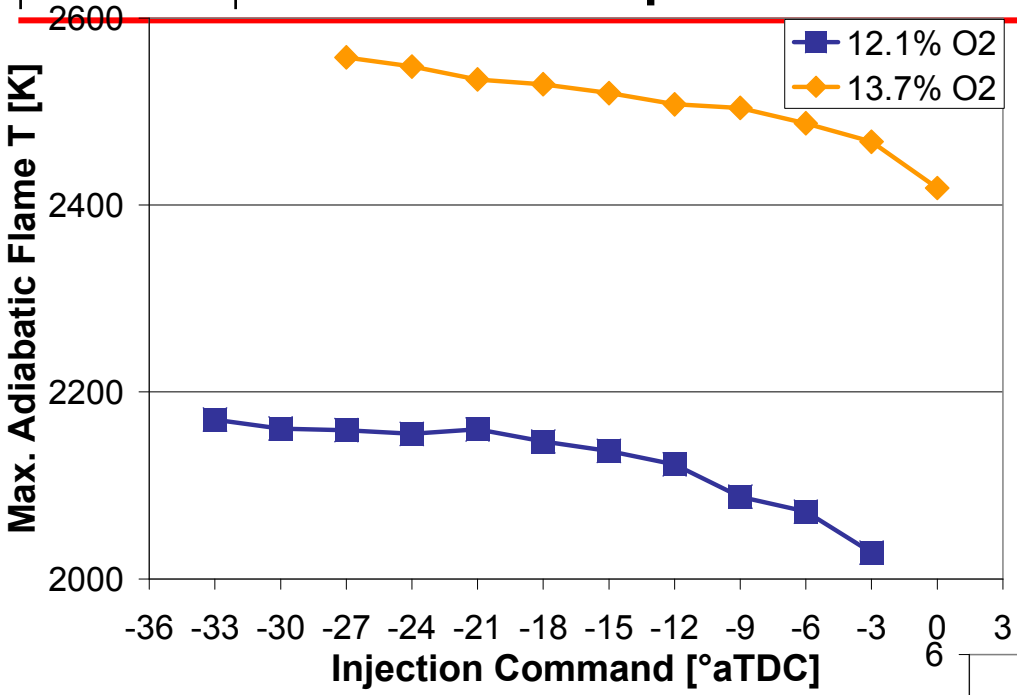
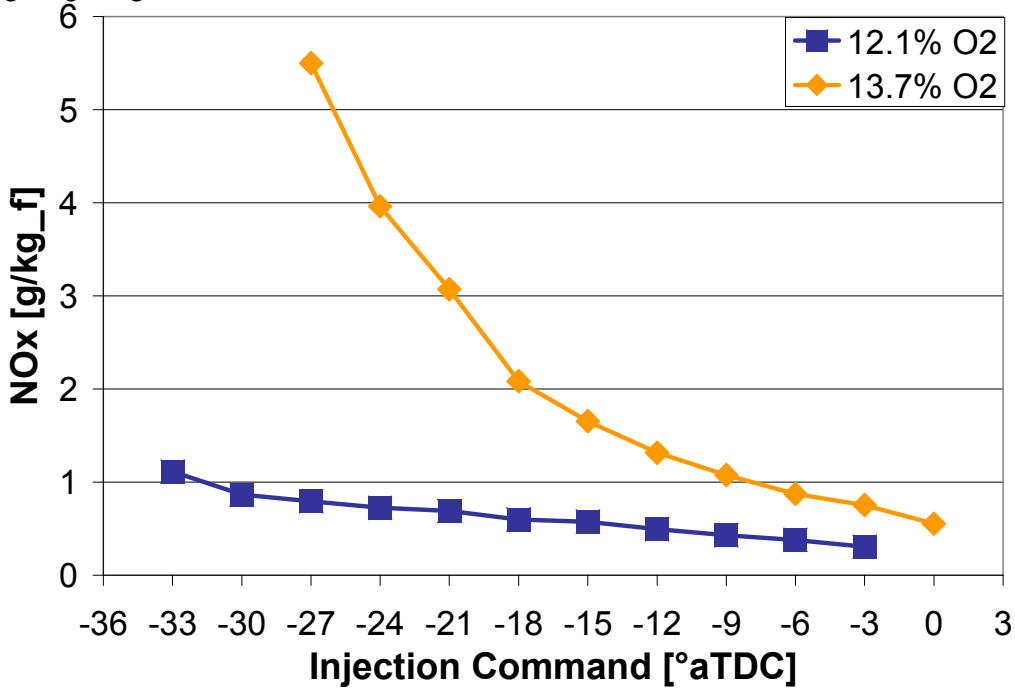
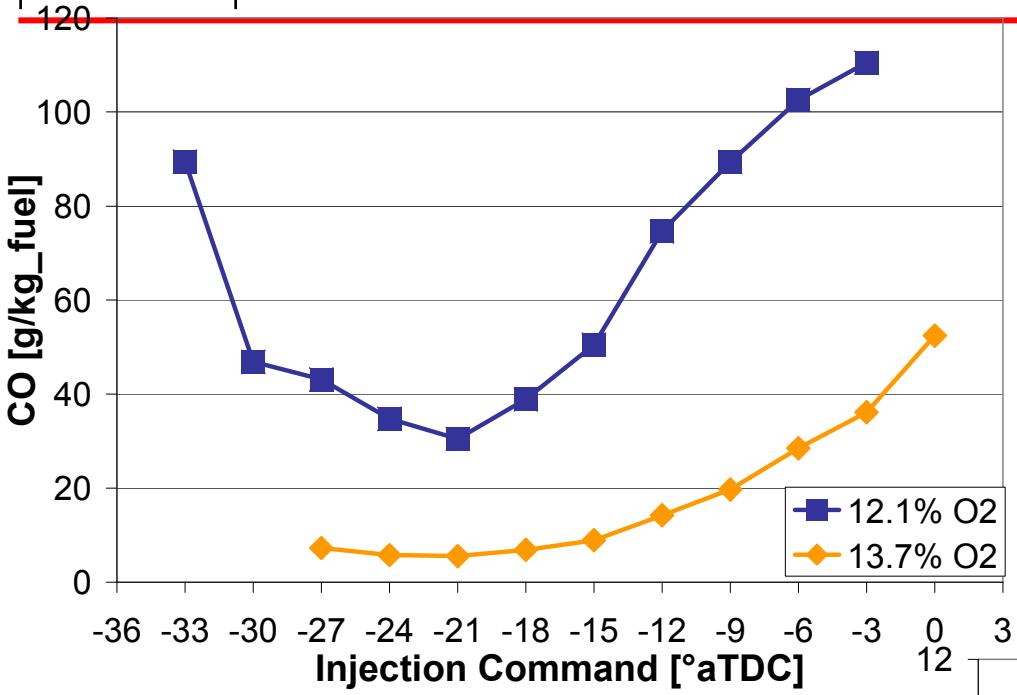
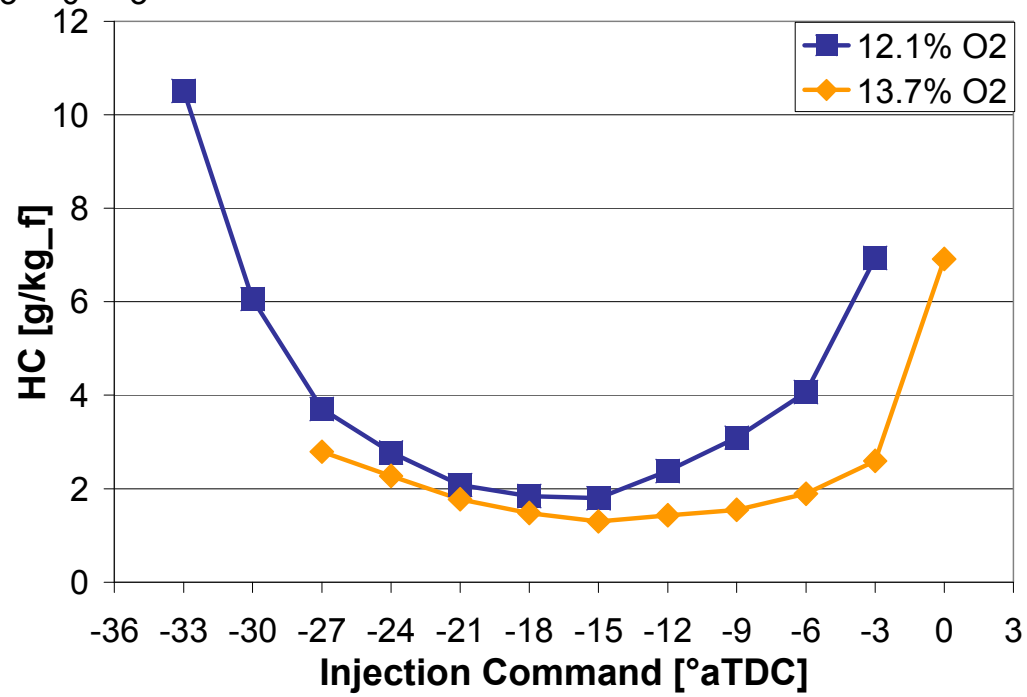
Flame Temperature and NOx Emissions





CO and HC Emissions





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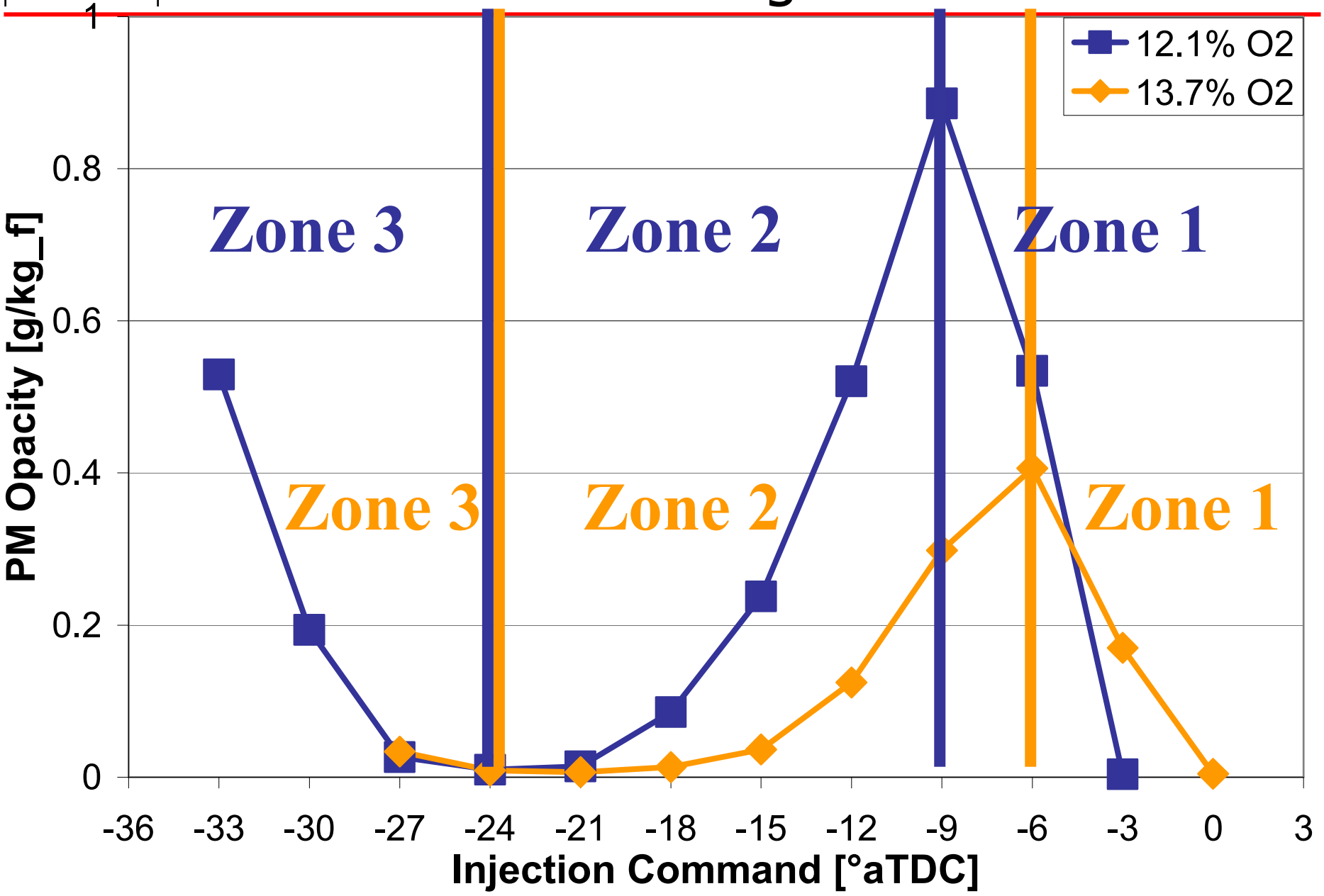
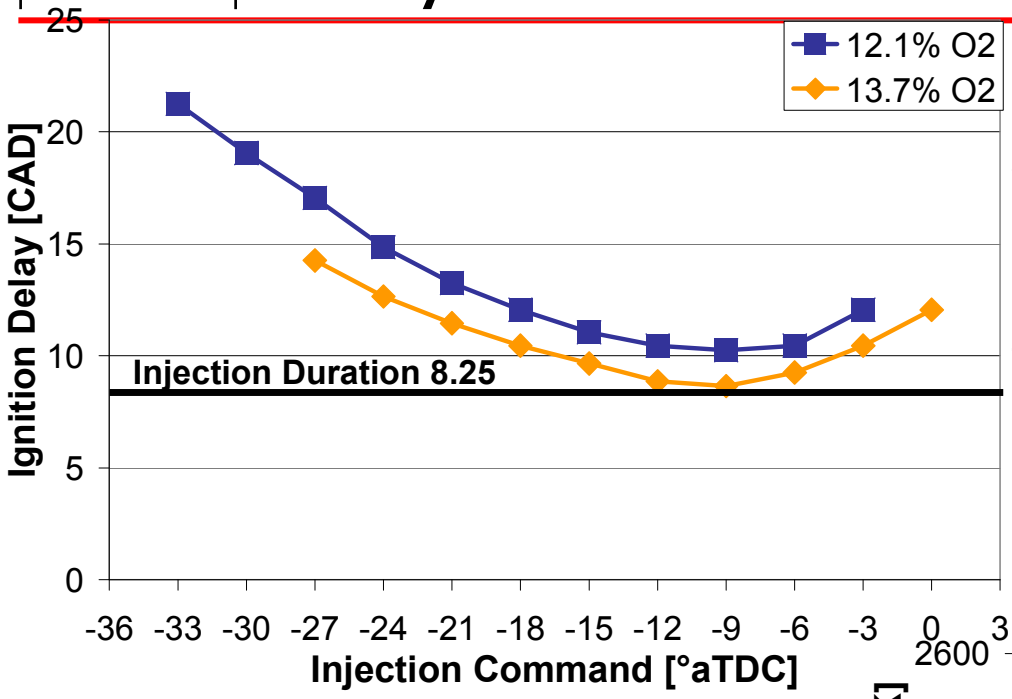
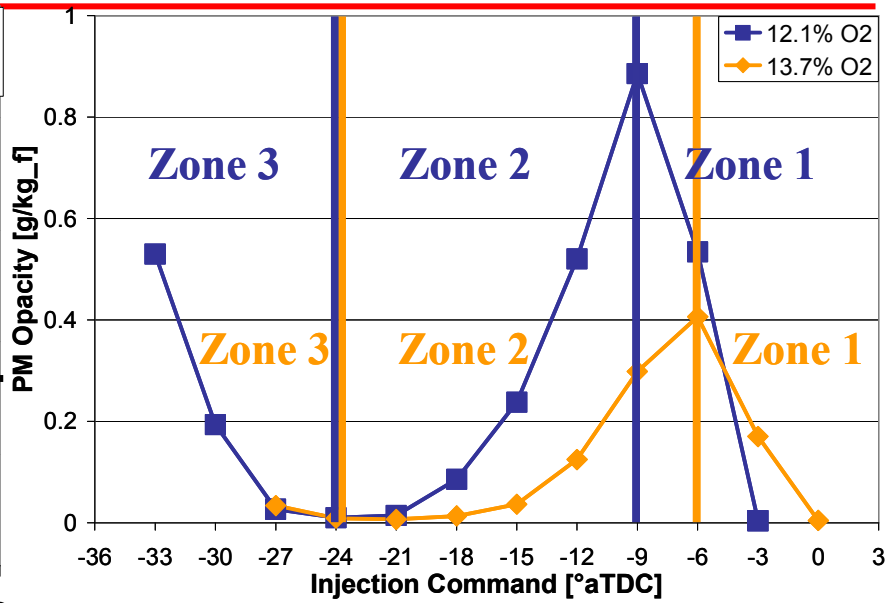
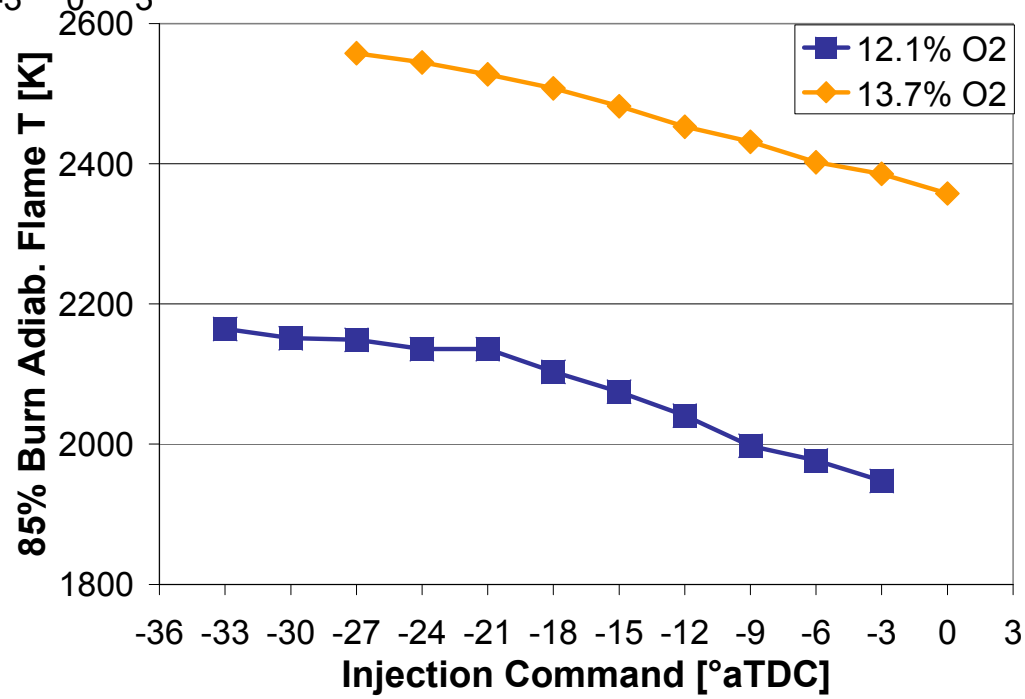
PM Zones Legend



In-Cylinder Pre-Mixing and Oxidation

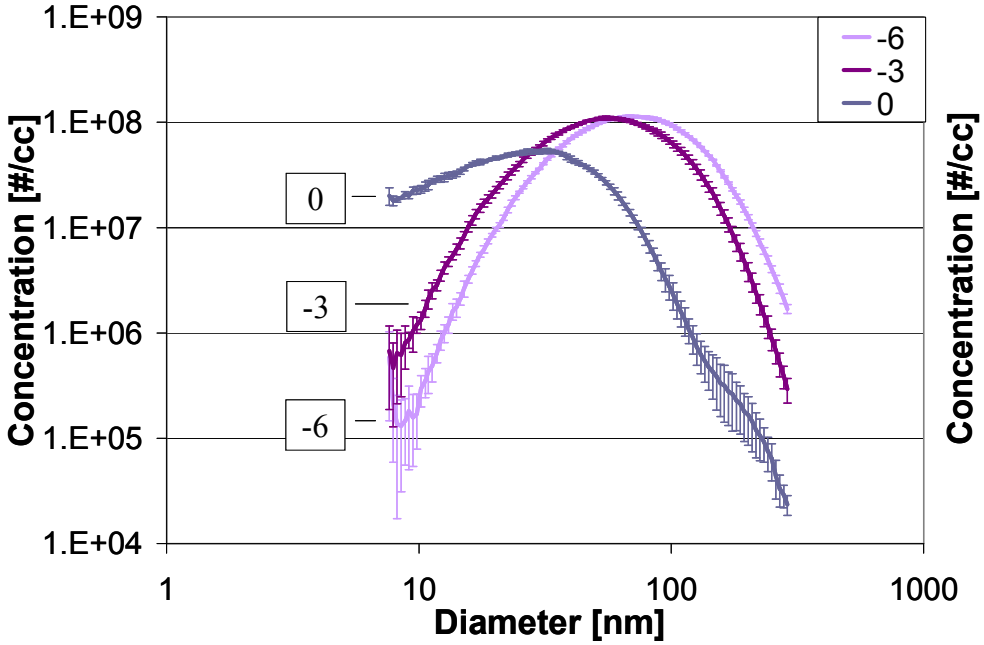




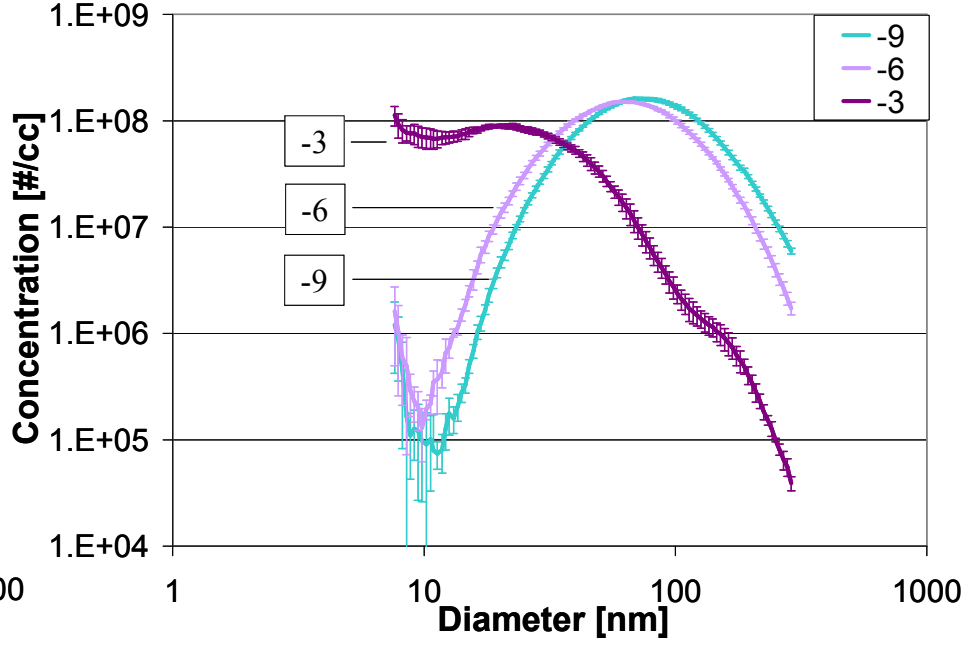


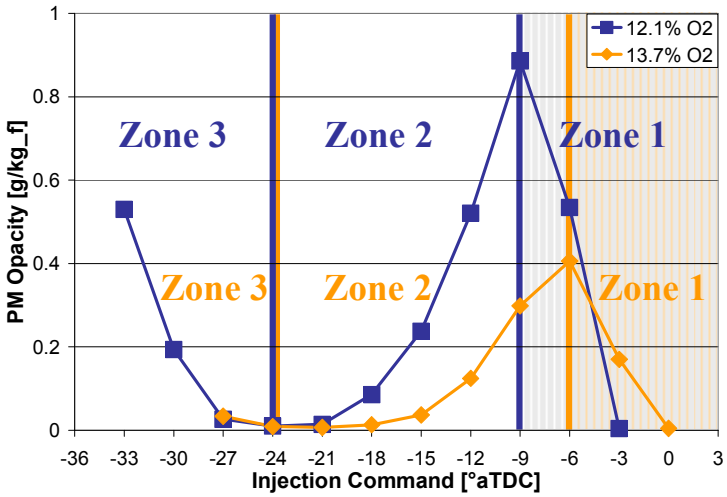
Zone 1 Particle Size Distributions

Case 1 – 13.7% O2



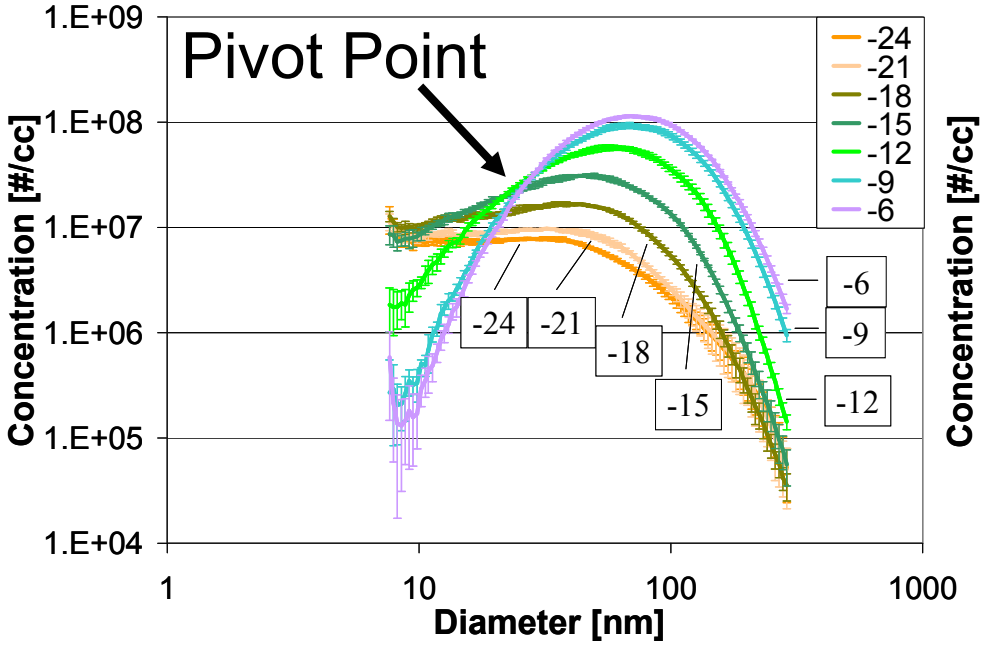
Case 2 – 12.1% O2



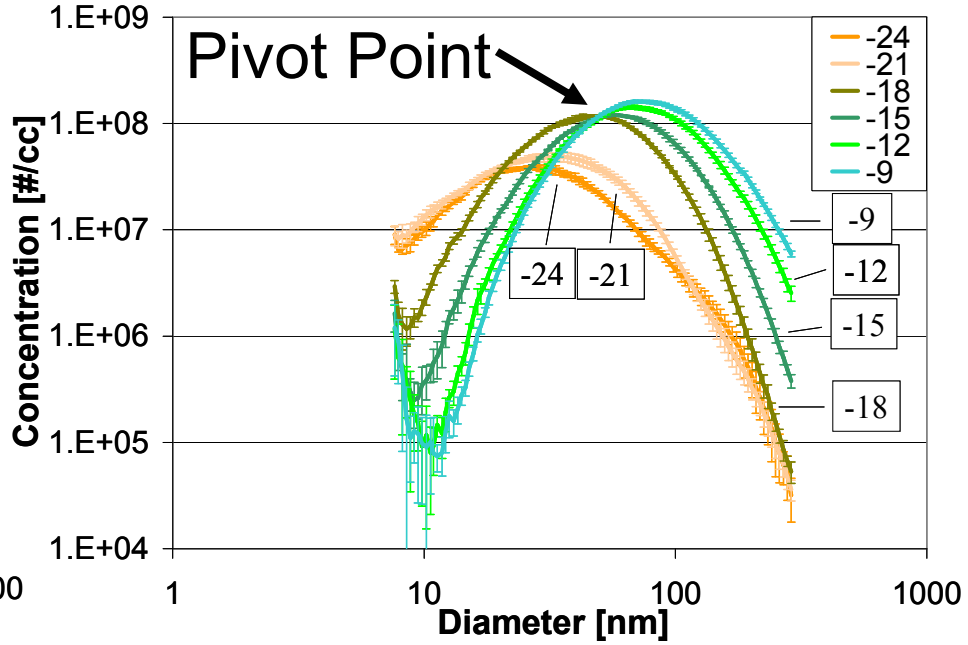


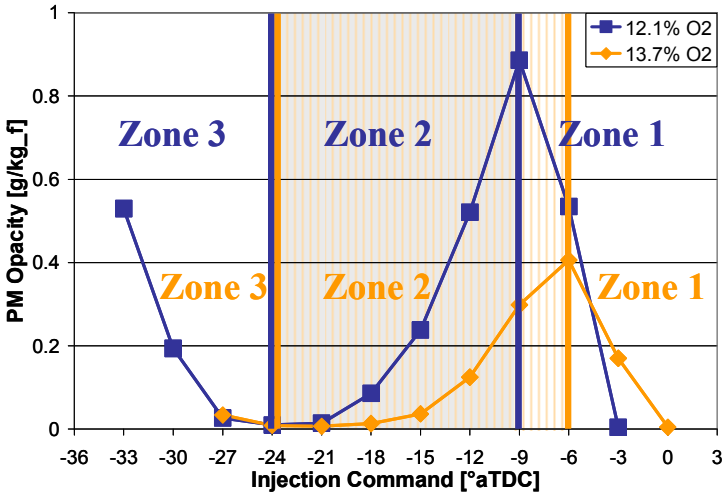
Zone 2 Particle Size Distributions

Case 1 – 13.7% O2



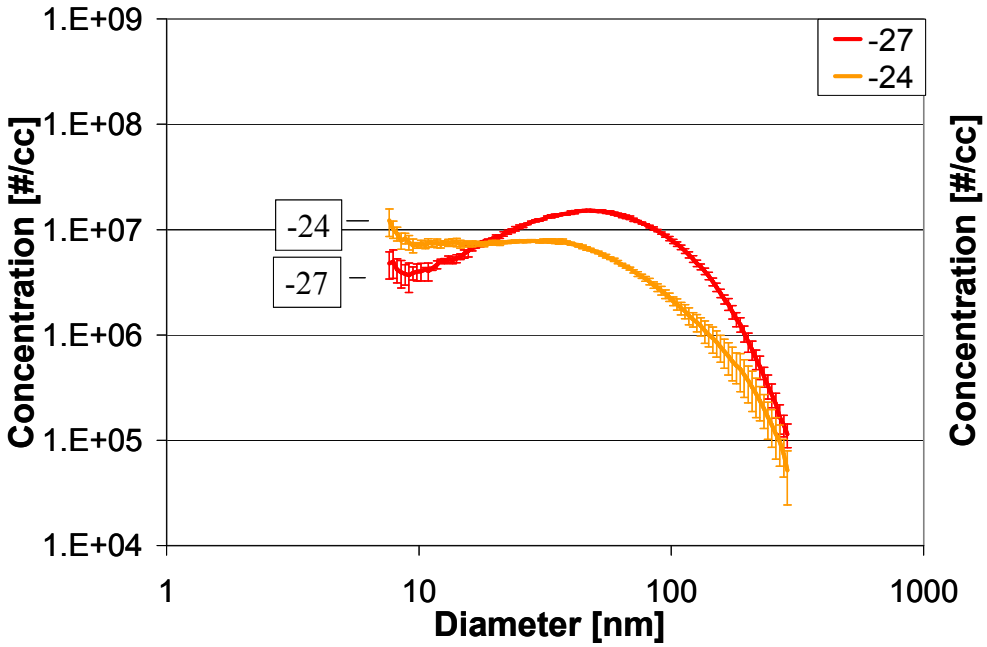
Case 2 – 12.1% O2



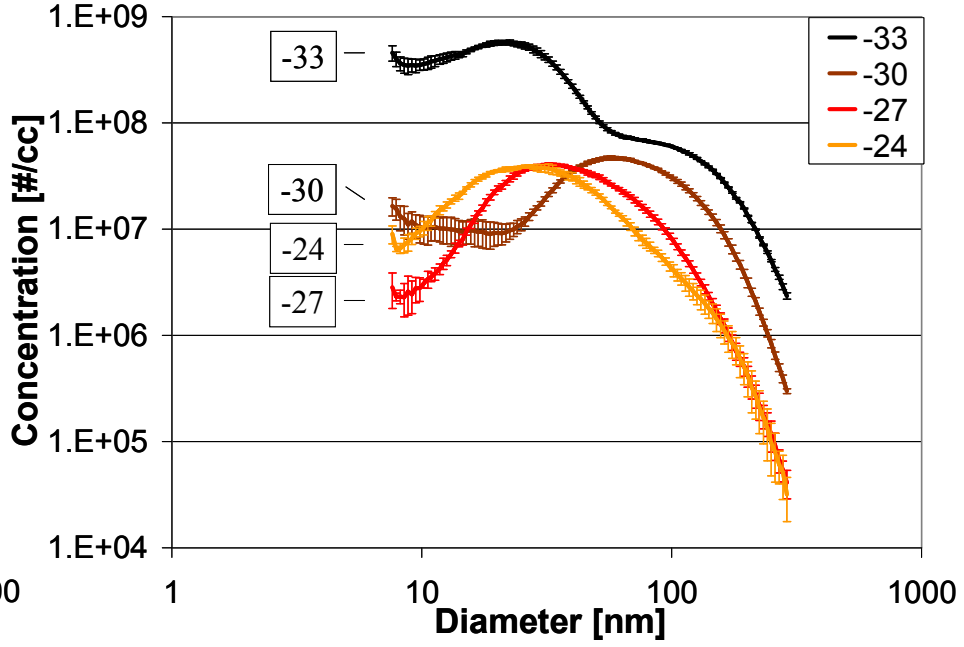


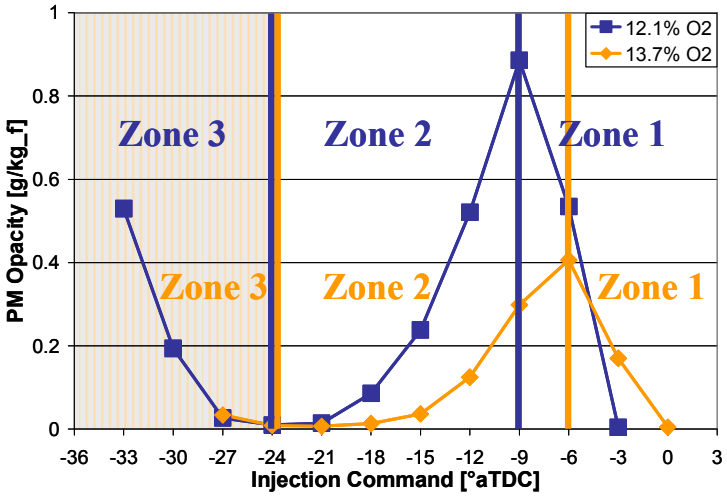
Zone 3 Particle Size Distributions

Case 1 – 13.7% O2



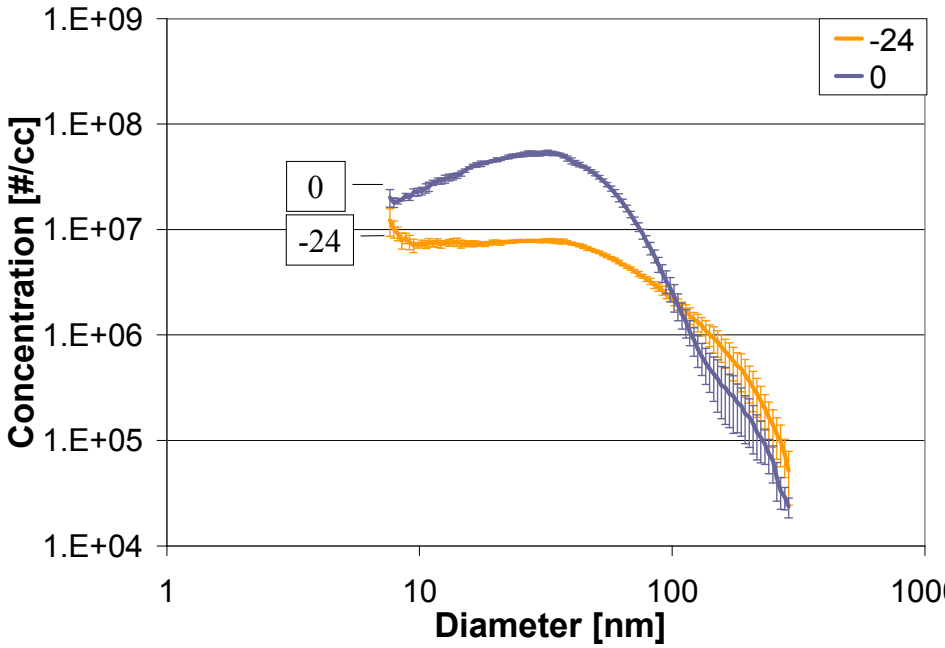
Case 2 – 12.1% O2



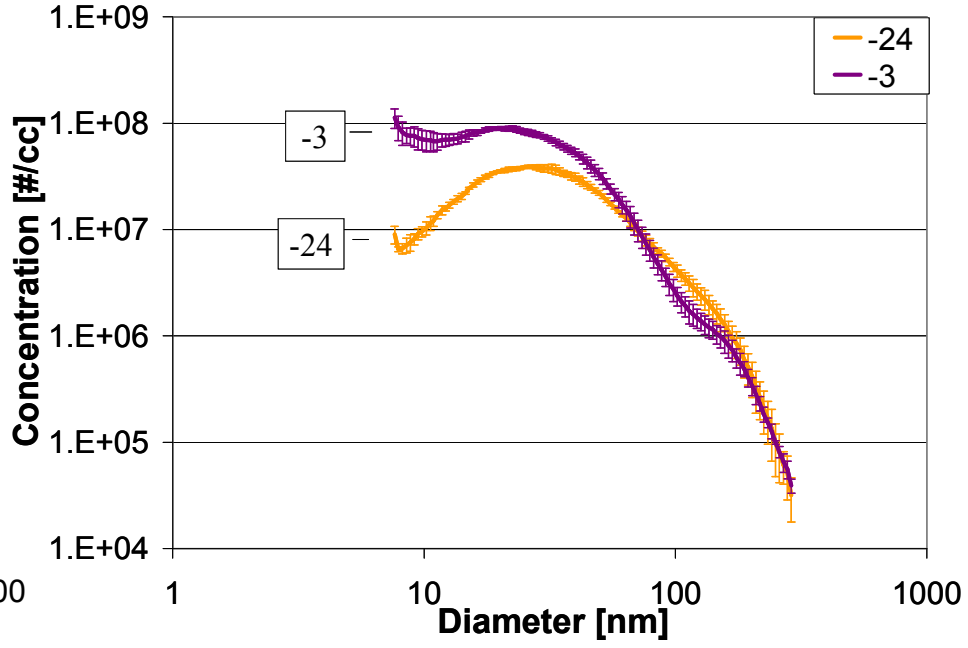


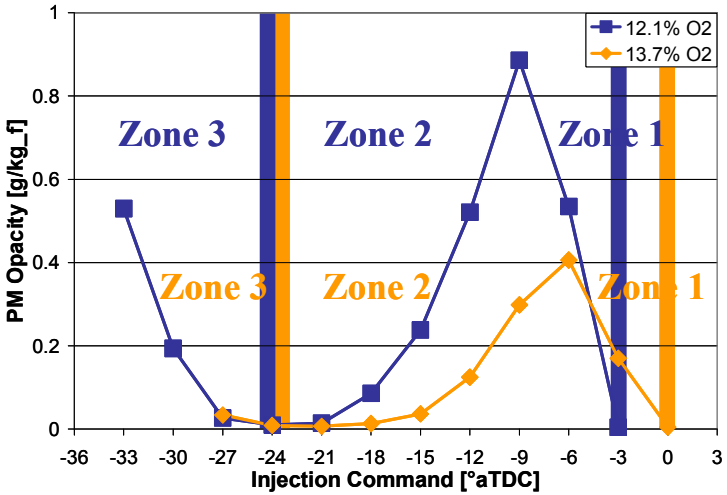
Early vs. Late Minimum PM Injection

Case 1 – 13.7% O2

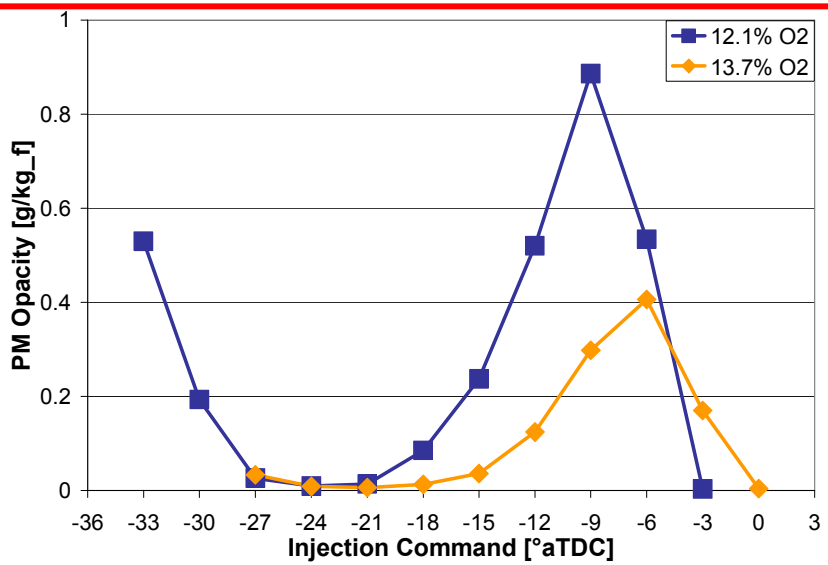


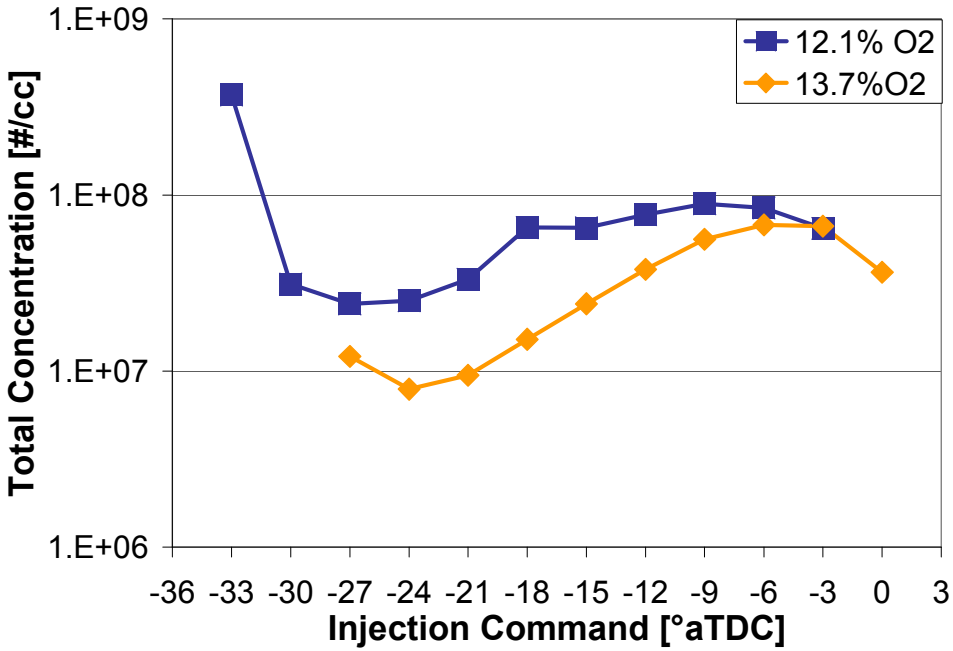
Case 2 – 12.1% O2

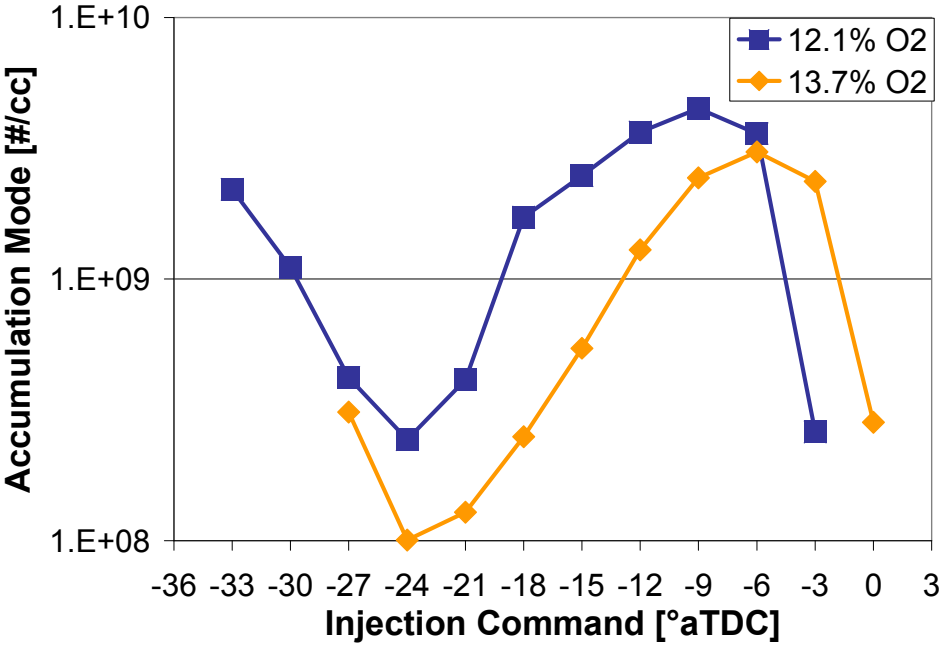




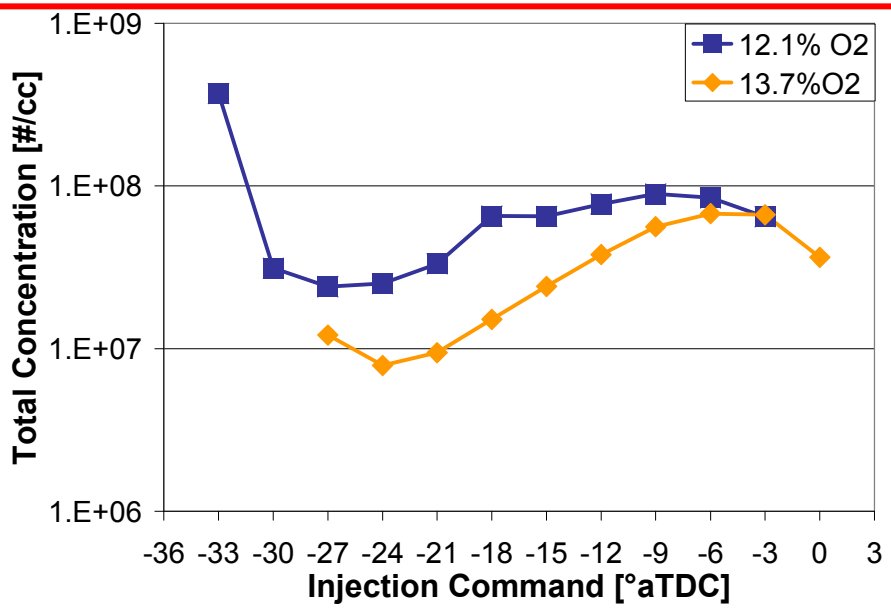
Accumulation Mode (>50nm)

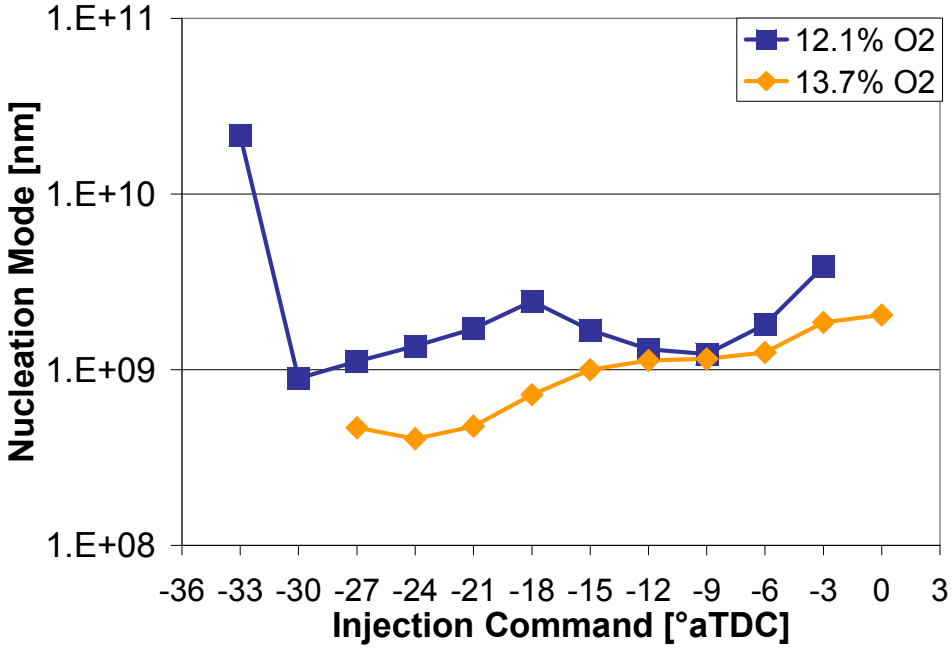


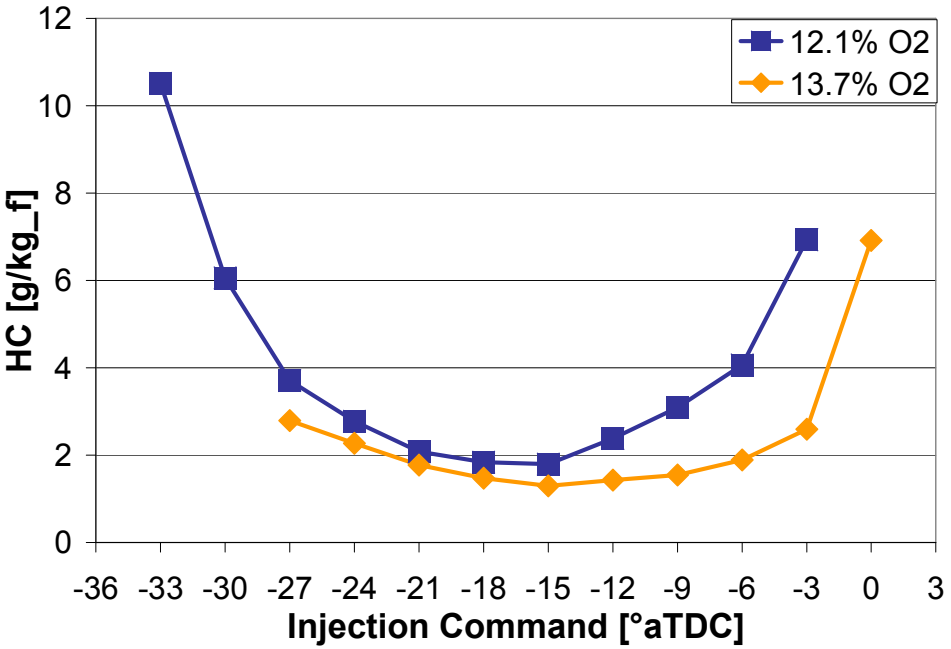




Nucleation Mode (<50nm)







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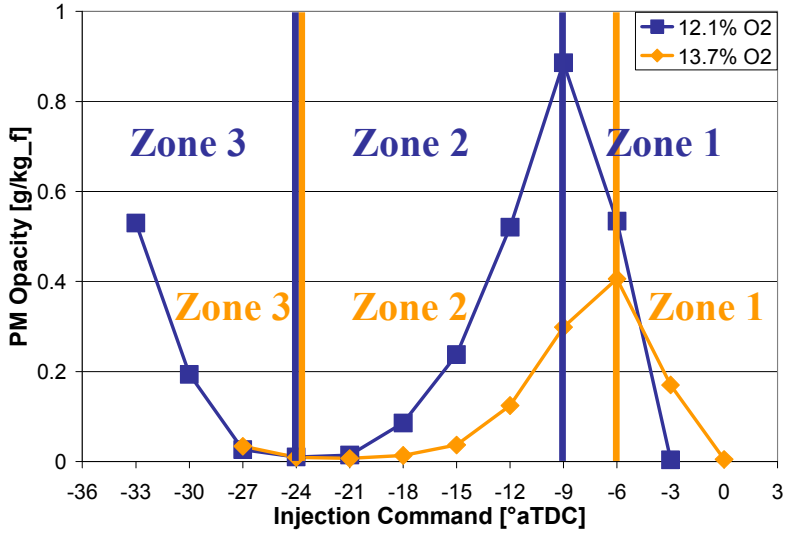
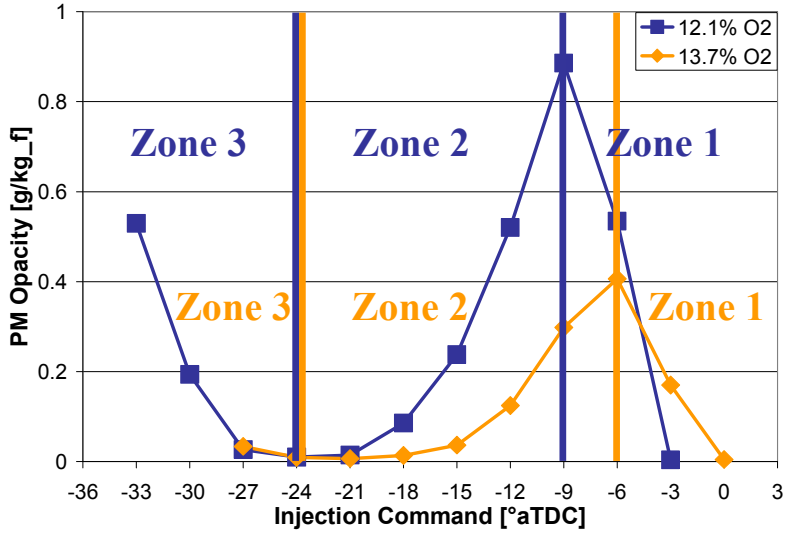
Conclusions

- Within Zone 1, PM mass and number emissions increased rapidly with advancing injection timing (due mostly to decreasing ignition delay)
- In Zone 2, PM mass and number emissions decreased with injection timing advance (due to increased ignition delay and 85% burned adiabatic flame temperature)
- Strong trade-off between accumulation and nucleation modes existed in Zone 2 (pivot point)



Conclusions (Cont.)

- Zone 3 showed increased PM mass and number in both accum. and nucl. modes with injection timing advance, but much greater nucleation mode increase than accumulation mode
- Since HC emissions also dramatically increased from -30°aTDC to -33°aTDC, spray-combustion chamber impingement is suspected as primary cause of increased PM
- Though minimum-PM injection timings had similar accumulation modes, later injection timings had higher nucleation modes, accompanied by higher HC emissions



Acknowledgements

- Spanish Ministry of Education
- Universidad Politécnica de Valencia
- Gabriel Alcantarilla
- Rogério Jorge Amorim
- Sara Goska

Thank You for Your Kind Attention

Questions?

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