Particle Size and Number Emissions from Dual-Fuel Reactivity Controlled Compression Ignition

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Outline

- Introduction
- Effects of Gasoline SOI
- Effects of Gasoline/Diesel Proportion
- Conclusions

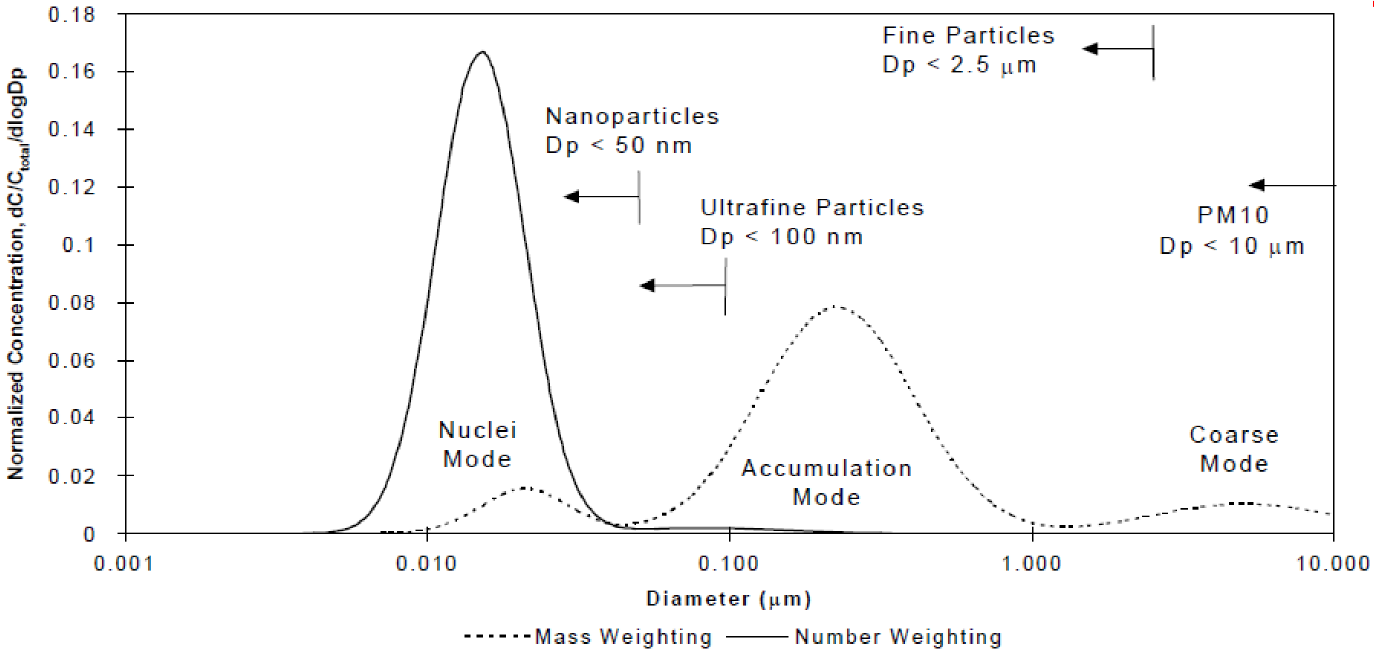
What is Dual-Fuel RCCI?

- Premixed Combustion
  - Very Low PM and NO_x emissions through low local equivalence ratios during combustion
- In-Cylinder Blending of Higher and Lower Reactivity Fuels
  - Increased control of ignition (longer premixing possible)
  - Stratification of fuel reactivity and local equivalence ratio for lower rate of combustion
  - Greatly reduced EGR dependence compared to premixed diesel LTC concepts
- Increased Brake Thermal Efficiency
  - Through reduced heat transfer losses and optimized combustion phasing
  - Decreased specific fuel consumption
  - Decreased specific CO_2 emissions

Objectives

- Measure particle size and number emissions from heavy-duty dual-fuel RCCI with both fuels injected in-cylinder
- Study effects of in-cylinder gasoline injection timing on exhaust particle emissions (while fixing in-cylinder diesel injection timings)
- Investigate effects of gasoline/diesel proportioning on exhaust particle emissions

Conv. Diesel Particle Size Distribution



Kittelson Model

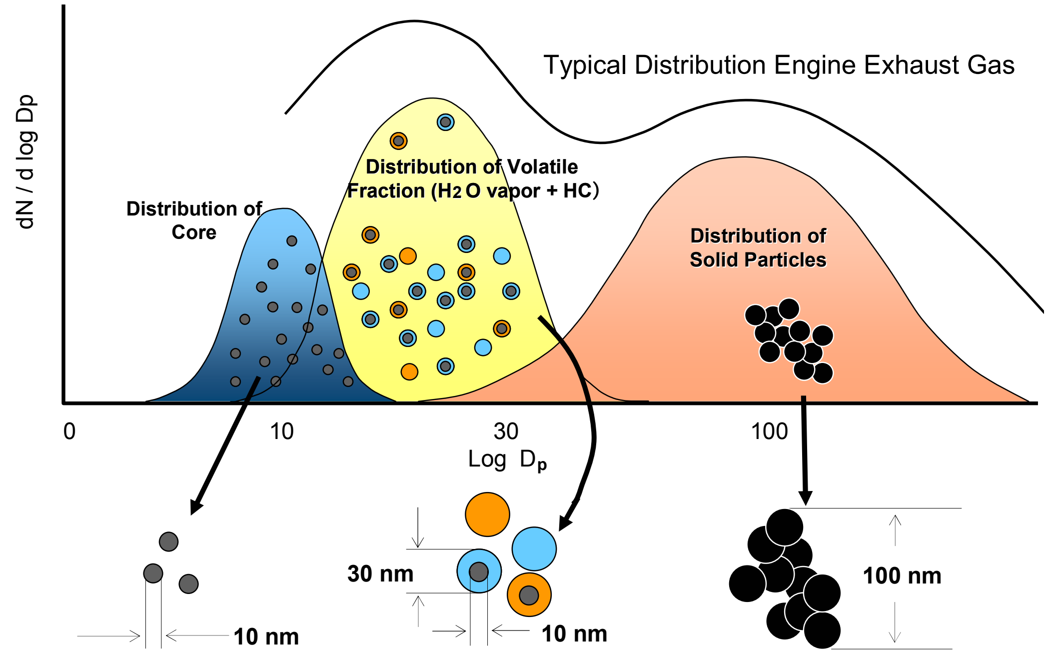
"The nuclei mode typically contains 1-20% of the particle mass and more than 90% of the particle number."

Kittelson, J. Aerosol Sci., 1998

Kawai Model

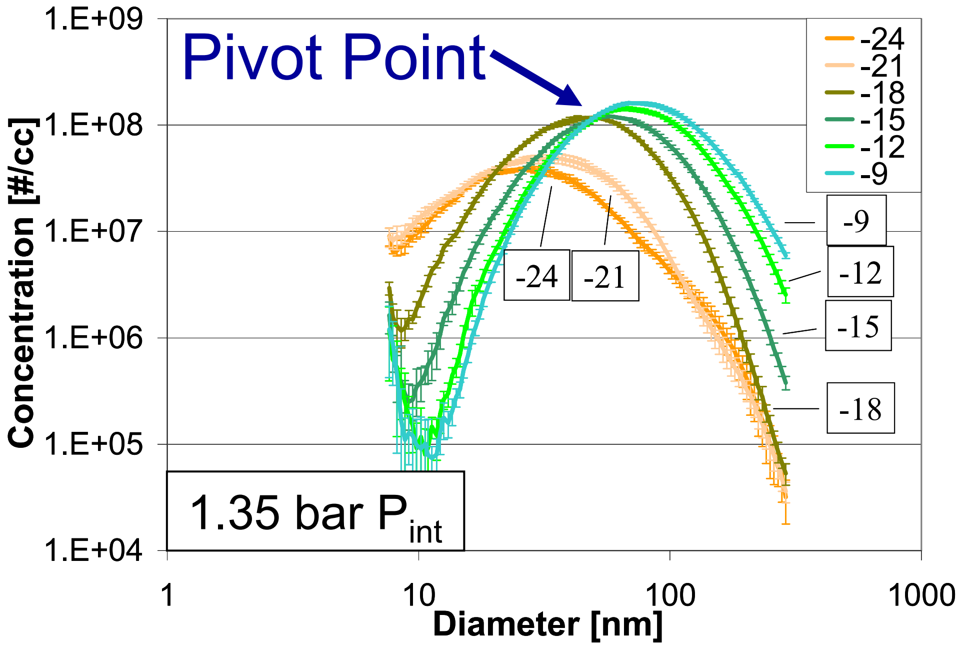
"Hypothetical model for Diesel nano-particle distribution."

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



Premixed Diesel LTC PM - SOI

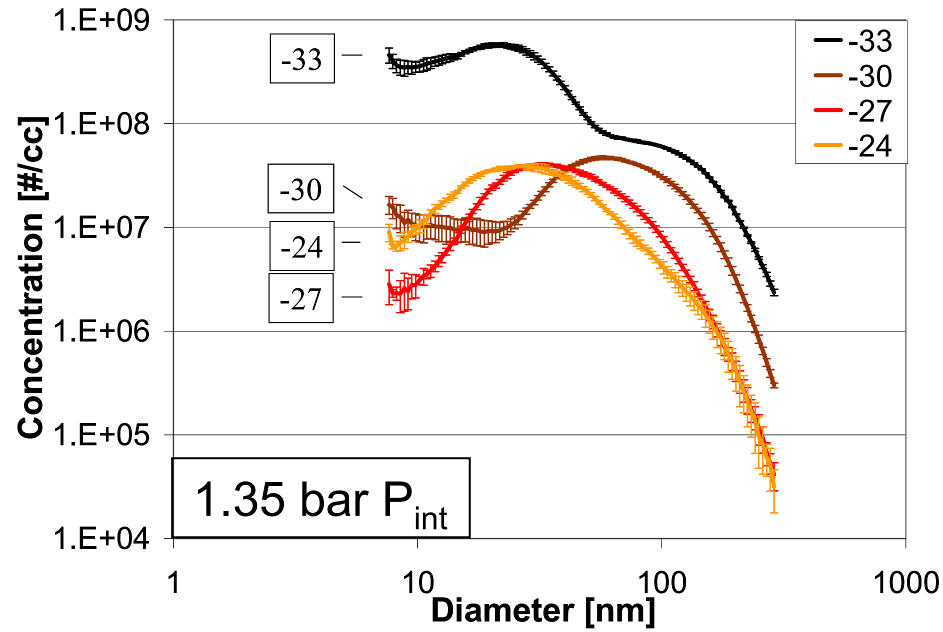
- Mono-modal shaped size distribution
- Decreased number of larger particles was accompanied by increased number of smaller particles

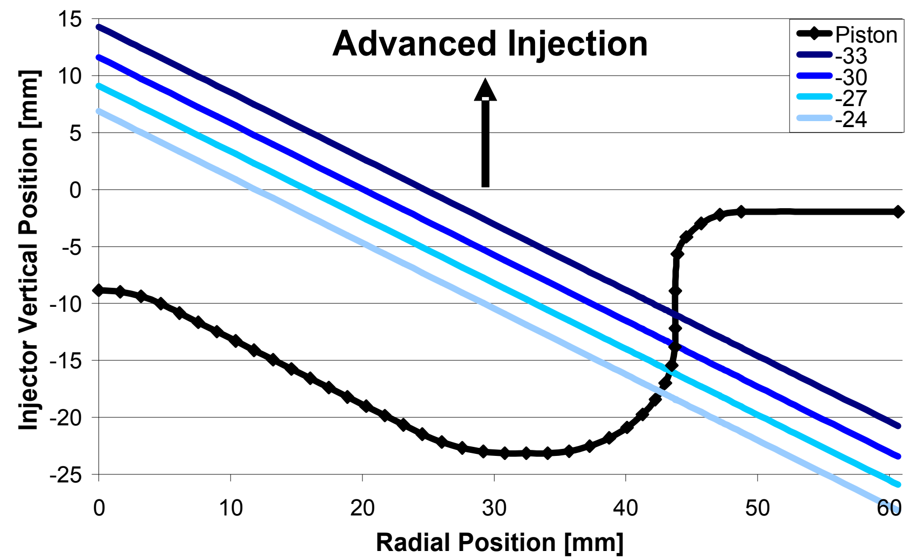


SAE 2010-01-1121
(Benajes, Novella, Arthozoul, Kolodziej)

Premixed Diesel LTC PM - Impingement

- Liquid fuel impingement during earlier injections
- Initially only increased number of larger particles
- Bi-modal size distribution when number of smaller particles increased as well (by 2 orders of magnitude)

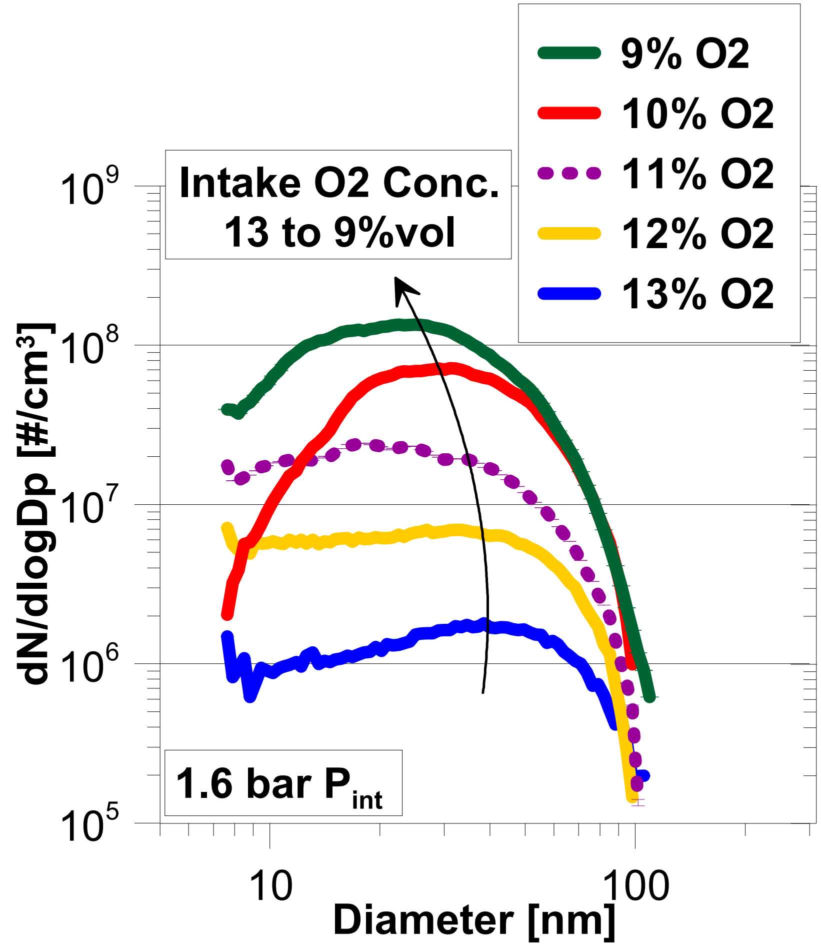




Benajes, Garcia-Oliver, Novella, Kolodziej, Fuel, 2011

Premixed Diesel LTC PM – Intake O_2

- Decreased intake O_2 caused a general increase in mono-modal size distributions, though PM mass was similar
- Much fewer particles larger than 100 nm compared to conventional diesel combustion (higher P_{int} than previous slide)
- Diameter of peak number concentration smaller than 60 nm



SAE 2011-01-1355
(Payri, Benajes, Novella, Kolodziej)

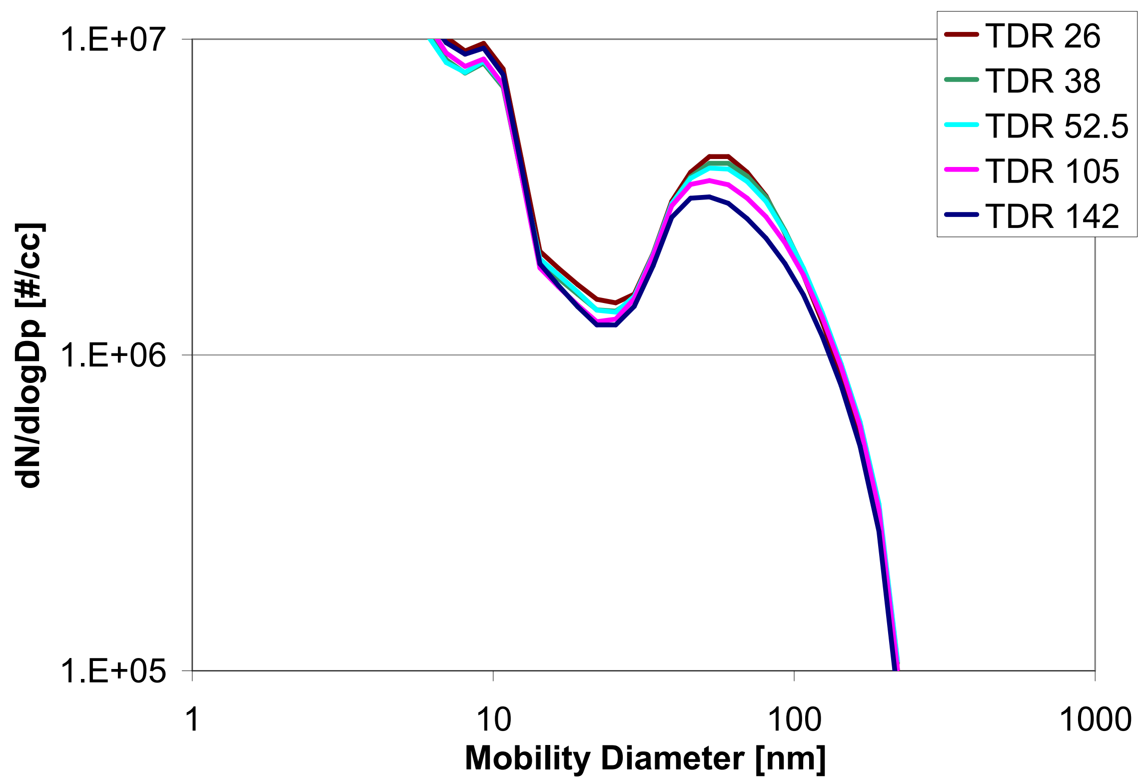
Test Methodology

- Sweep gasoline injection timing from -300 to -360 °aTDC at each fuel reactivity test condition
- Vary intake temperature to maintain constant CA50
- Vary intake pressure to maintain overall equivalence ratio

Gasoline In-Cylinder Injection Timing [°aTDC]	**-360, -340, -320, -300**			
First Diesel In-Cylinder Injection Timing [°aTDC]	-58			
Second Diesel In-Cylinder Injection Timing [°aTDC]	-38			
Gasoline Proportion [%]	**65**	**74**	**80**	**84**
Diesel Proportion [%]	**35**	**26**	**20**	**16**
Intake Temperature [°aTDC]	27	37	47	57
Intake Pressure [bar]	1.09	1.1	1.13	1.15
EGR Rate [%]	0	0	0	0

RCCI Exhaust Dilution Conditions

- Varied heated primary dilution air ratio
- Fixed ambient-temperature secondary dilution ratio at maximum of Dekati FPS-4000 diluter
- Total dilution ratio (TDR) of 130-135:1 was used for testing



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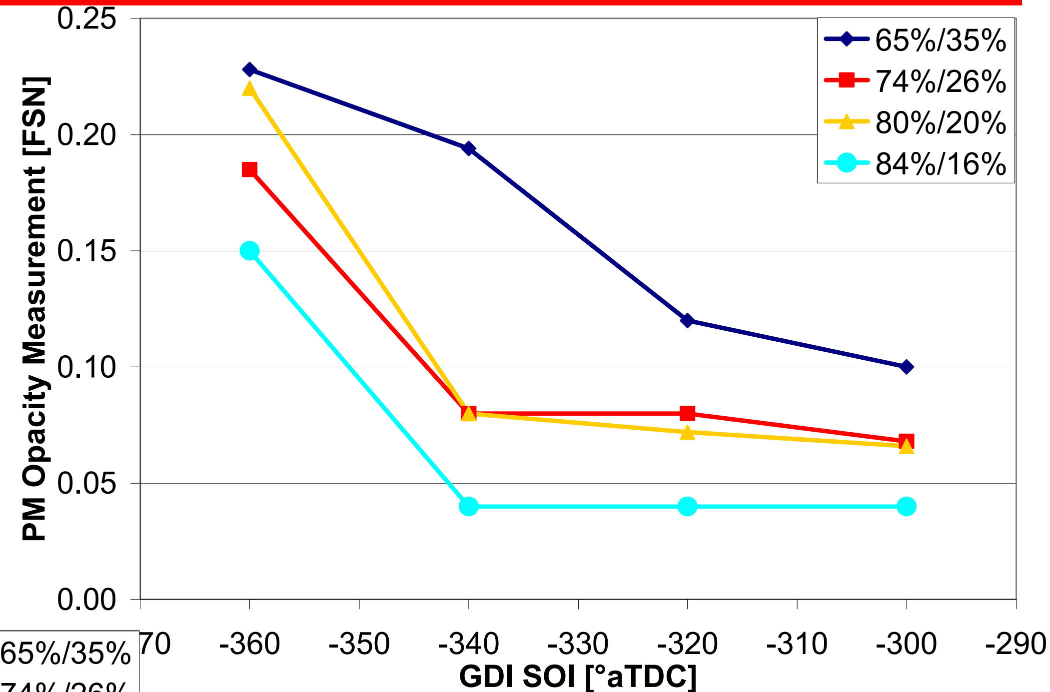
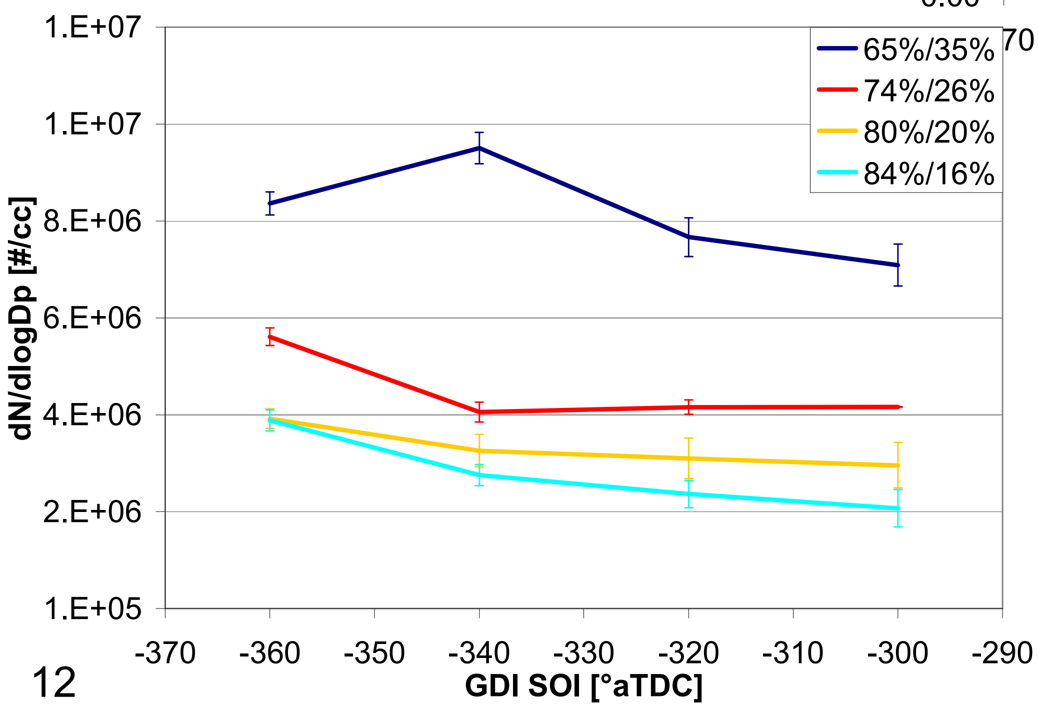
Effects of Gasoline SOI

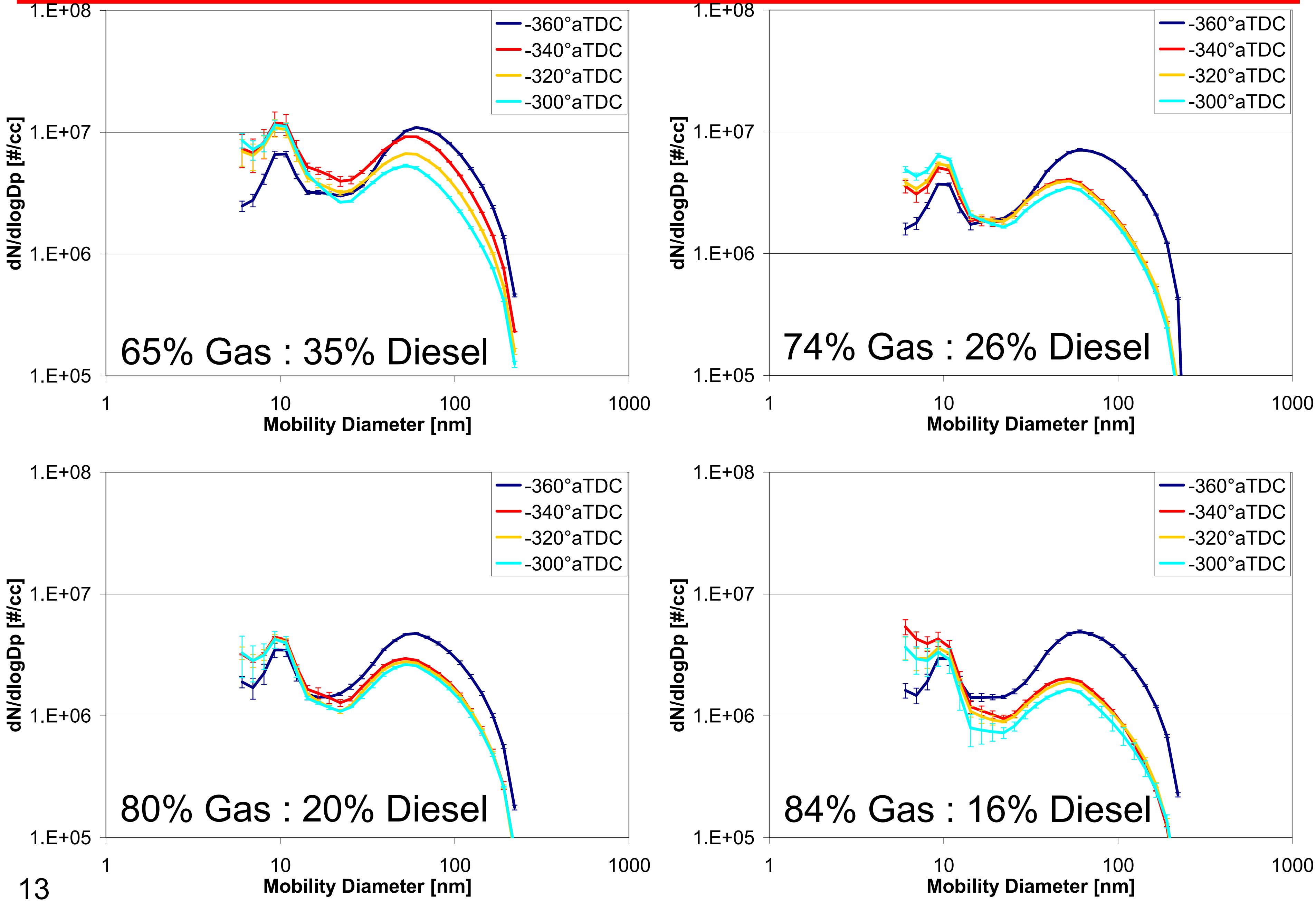
- Advanced gasoline injection timing caused slight PM mass increase from -300 to -340°aTDC
- More noticeable increase from -340 to -360°aTDC





- Slight decrease in total particle numbers from -360 to -300°aTDC
- Two-fold higher particle number emissions from lowest gasoline proportion

Effects of Gasoline SOI



Conclusions (Gasoline SOI)

- Advancing gasoline SOI increased PM mass and number emissions for all gasoline cases, especially from -340 to -360°aTDC
- Change from -340 to -360°aTDC was characterized by a sharp increase in accumulation mode and simultaneous decrease in nucleation mode (similar to diesel LTC SOI study)
- Decreased number of larger particles with increased number of smaller particles produced less change in total particle numbers than in PM mass
- Further work is needed to determine if decreased number of larger particles (and PM mass) was due to decreased formation or increased oxidation effects

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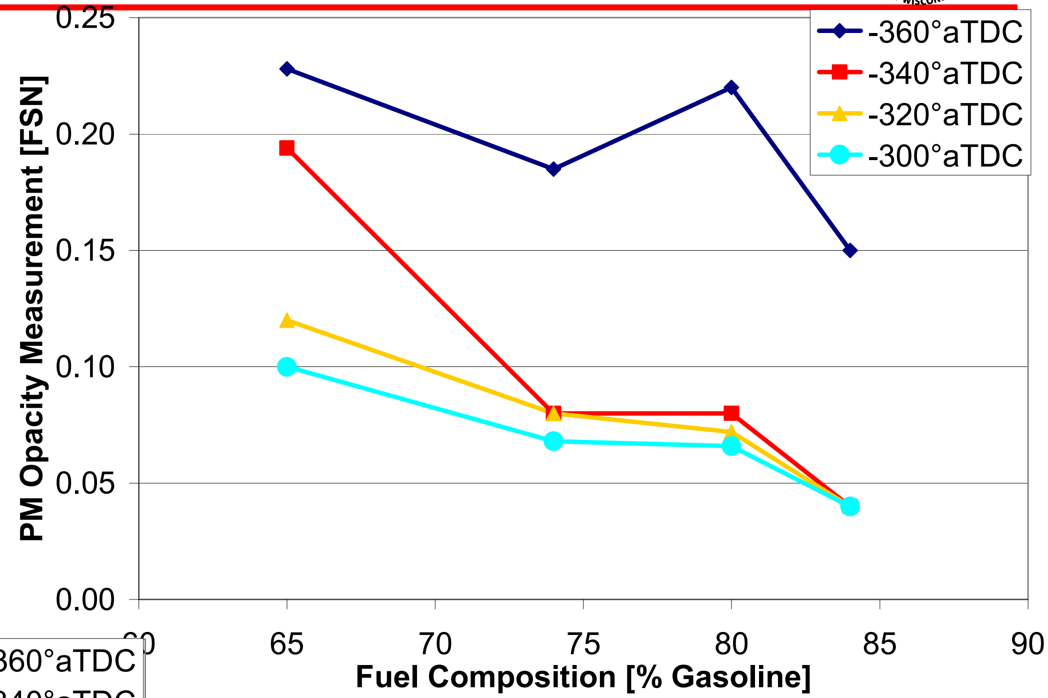
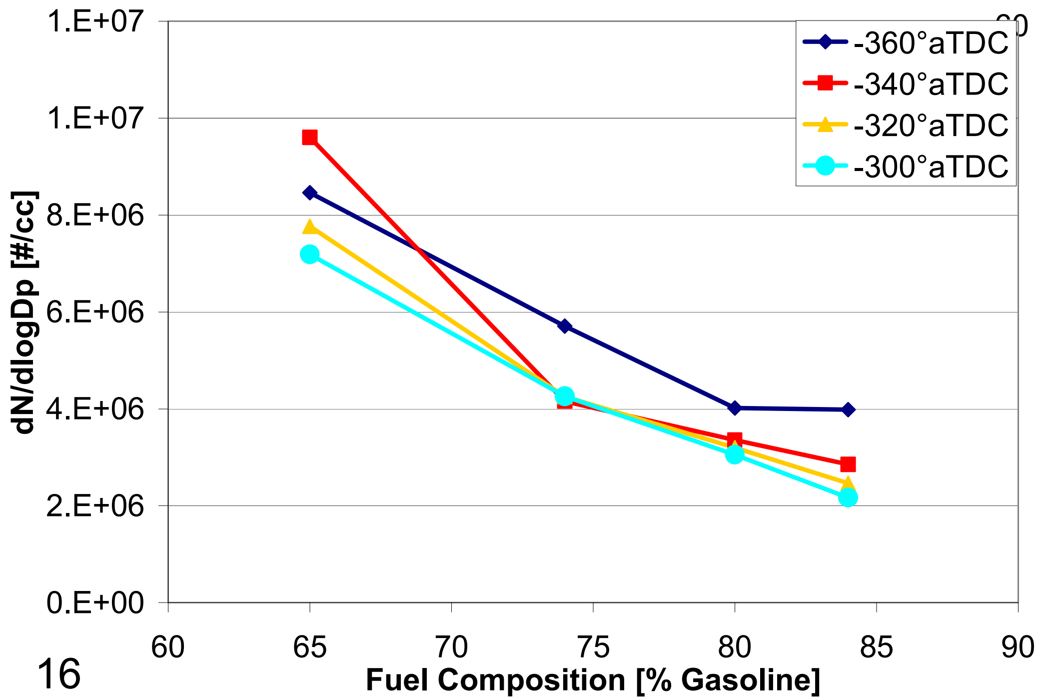
Effects of Gasoline Proportion

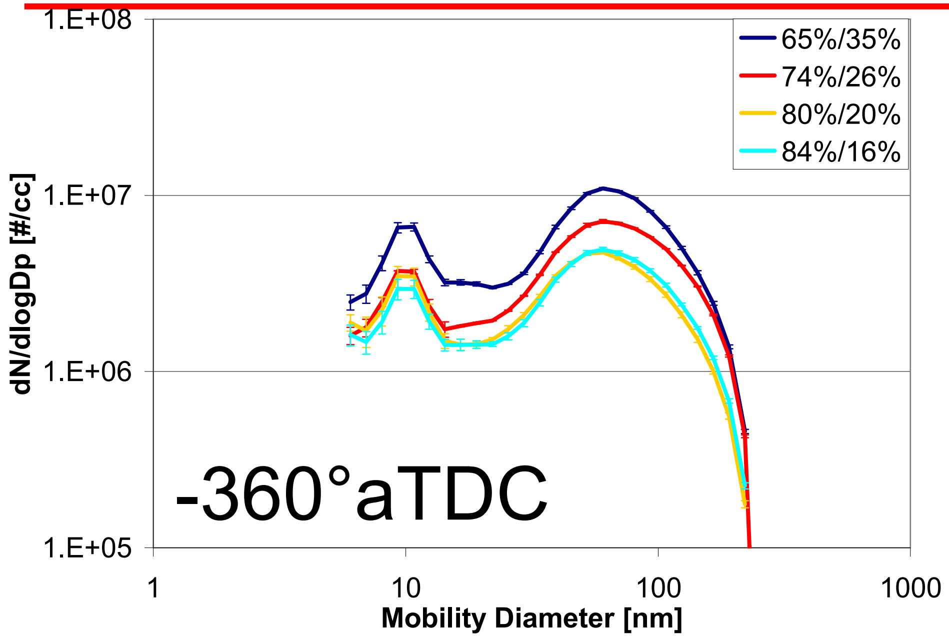
- Increased gasoline proportion, decreased PM mass
- Gasoline -360°aTDC SOI had higher PM for all fuel blends

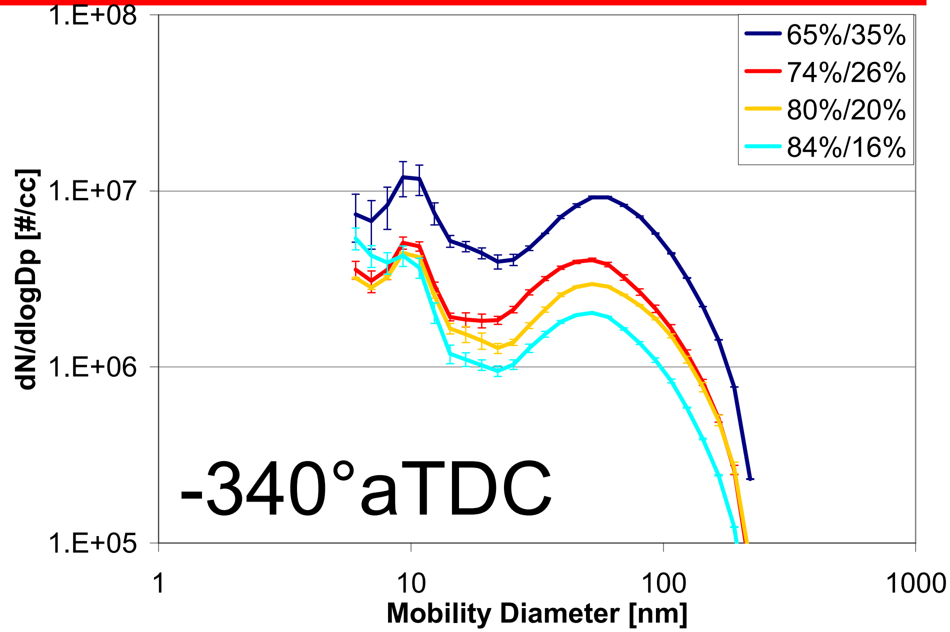


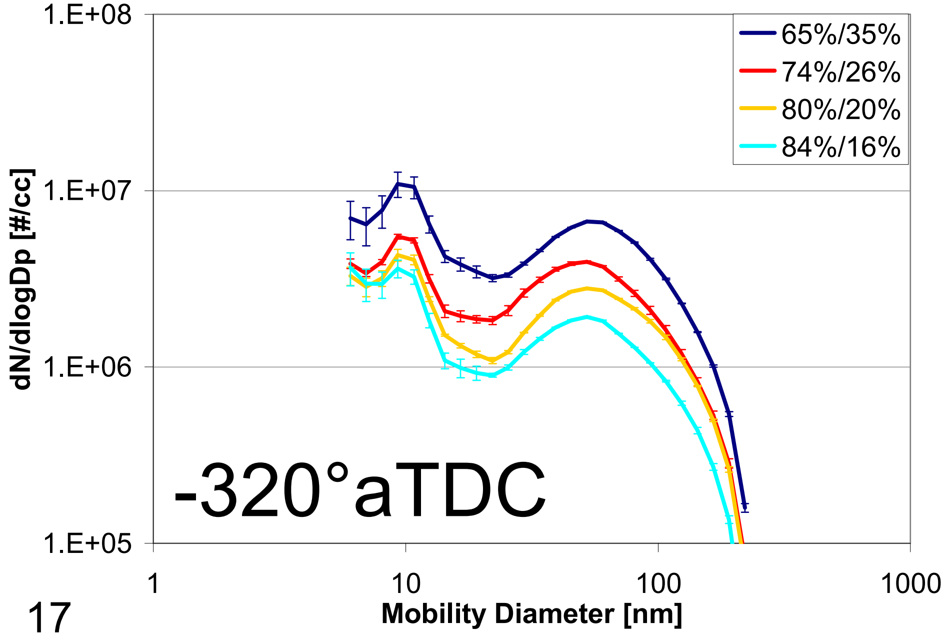


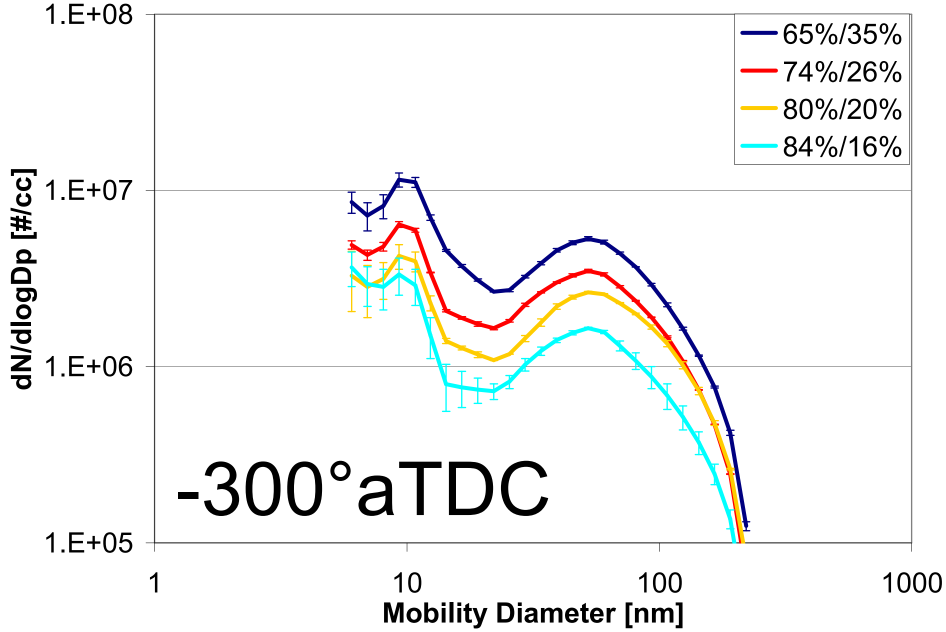
- Increased gasoline proportion also decreased total particle numbers

Effects of Gasoline SOI









motores térmicos

Conclusions (Fuels)

- Increasing gasoline proportion caused a simultaneous decrease in numbers of larger and smaller sized particles (similar to diesel LTC intake O_2 study)
- Further work needed to understand driver of the simultaneous decrease in both the smaller and larger sized particles with increased gasoline proportion

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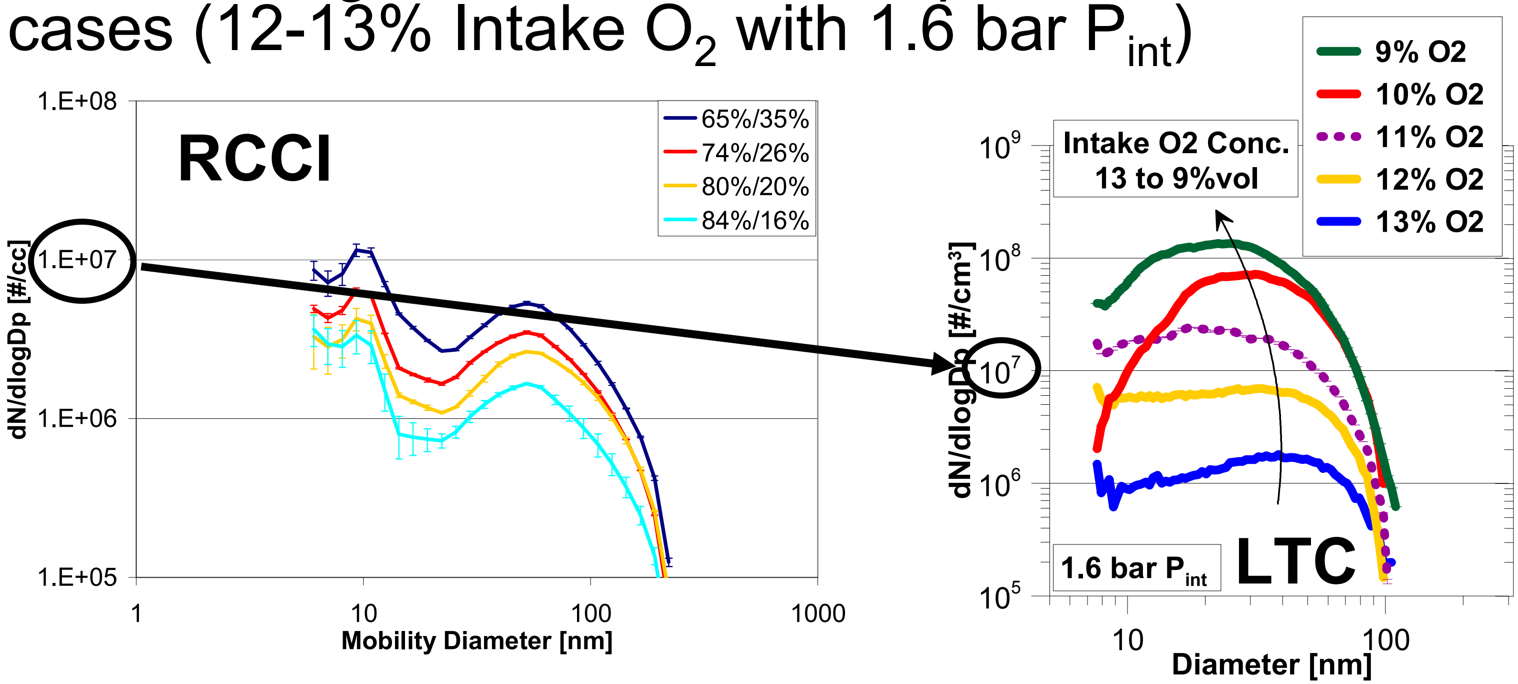
Conclusions (General)

- PM mass emissions were reduced below the Smokemeter minimum detection limit (<0.05FSN) in lowest engine operating conditions
- Particle number emissions were reduced to a similar order of magnitude as the "best" premixed diesel LTC cases (12-13% Intake O_2 with 1.6 bar P_{int})



- Although RCCI is a form of premixed combustion, its particle size distributions were bi-modal (unlike the mono-modal size distributions typical of premixed diesel LTC)

Thank you for your attention.

Questions?

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