Nanoparticle emissions from an ethanol fueled HCCI engine

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Outline

- Introduction
- Experimental apparatus
- Dilution sensitivity
- Results
  - Engine performance
  - Variable intake temperature
  - Role of solid particles
  - Preliminary hydrogen results
- Conclusions

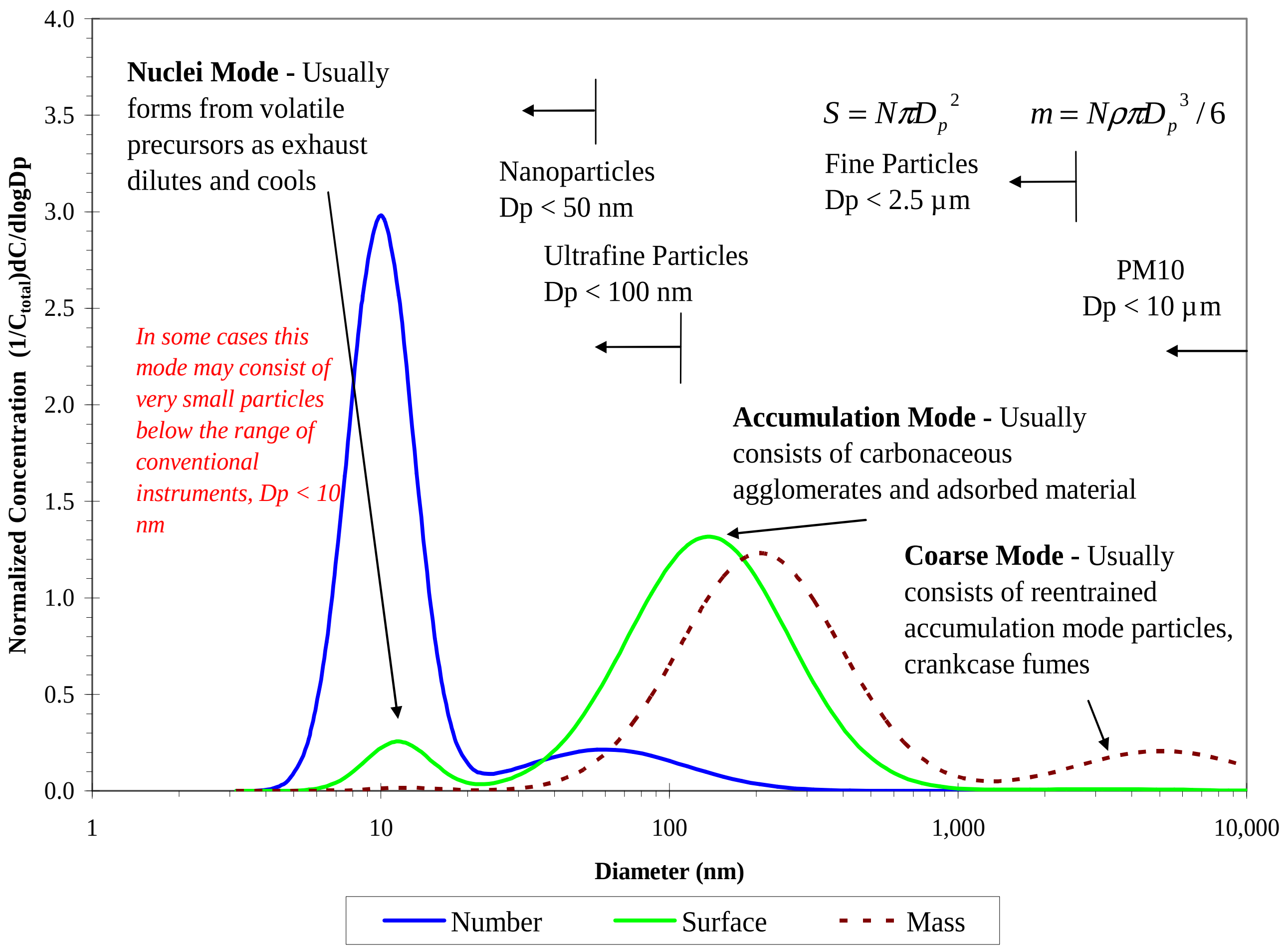
Renewable fuel research

- **Ethanol / H_2 HCCI**
- Ethanol / H_2 Diesel
- Synthesis gas HCCI / PCCI / fumigation
- DME Diesel
- FAME, ULSD, and hydro-treated vegetable oil in Caterpillar ACERT Diesel
- Cold flow filter plugging with FAME
- Butanol Diesel / SI

HCCI

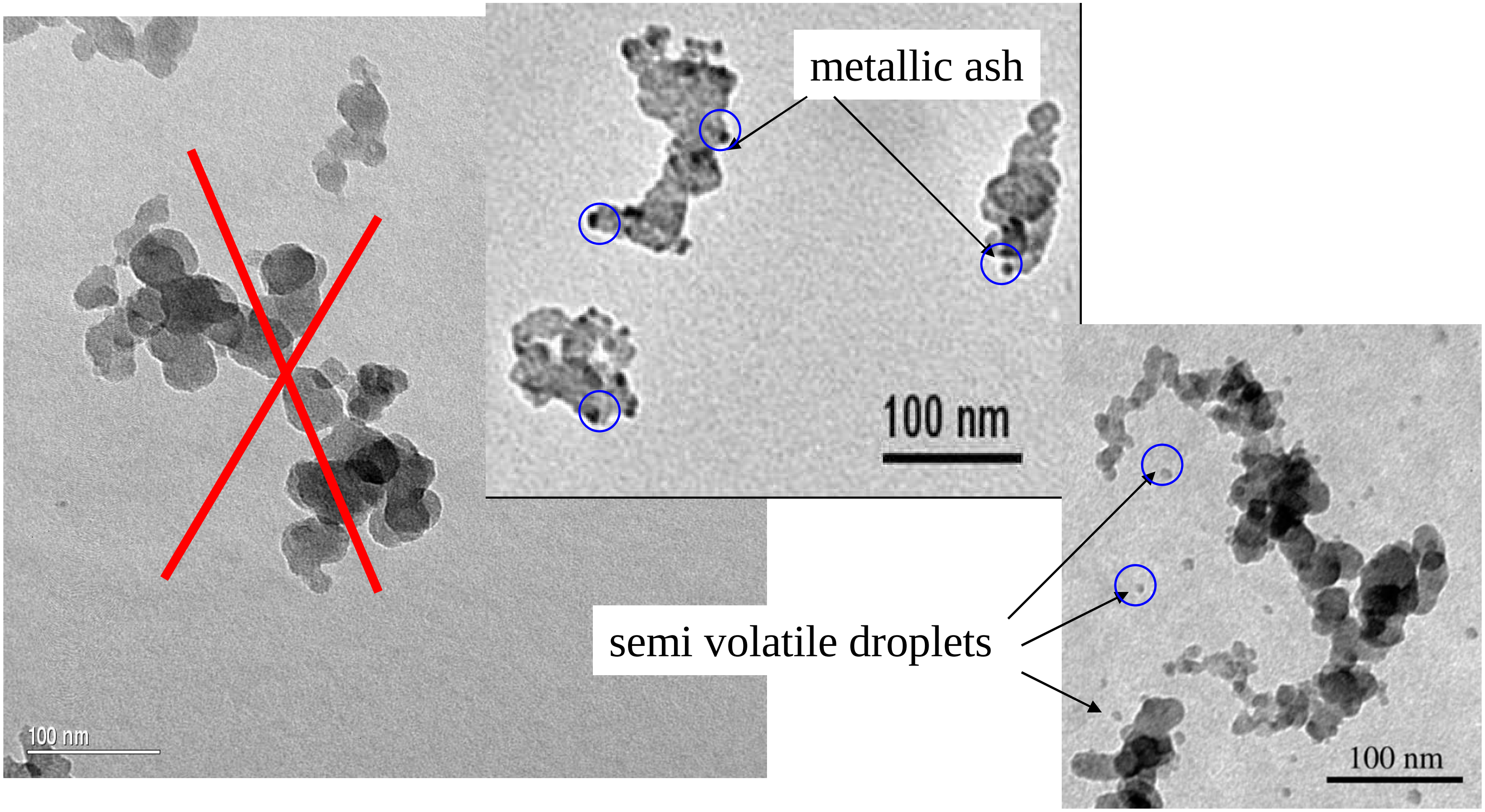
- Homogeneous charge compression ignition (HCCI) engines utilize a combination of high compression ratio and premixed highly dilute charge to achieve low temperature premixed combustion that avoids both soot formation and significant NO_x formation but CO and hydrocarbon emissions are high
- It is difficult to utilize this type of combustion at high engine loads and it is difficult to control the timing of the combustion process.
- We explored three means of controlling the combustion timing and measured the resulting gaseous and particle emissions
  - Intake air heating
  - Exhaust gas recirculation
  - Hydrogen injection - ethanol used was the primary fuel because it can easily be reformed to make hydrogen
- Number and mass emissions of nanoparticles were of the same order as those from contemporary Diesel engines without aftertreatment but the particles were nearly all volatile

Typical engine exhaust particle size distribution by mass, number and surface area



Kittelson, D.B. 1998. "Engines and Nanoparticles: A Review," J. Aerosol Sci., Vol. 29, No. 5/6, pp. 575-588, 1998

Carbonaceous agglomerates comprise most of the mass from Diesel engines but are largely eliminated by HCCI



Without Exhaust Aftertreatment

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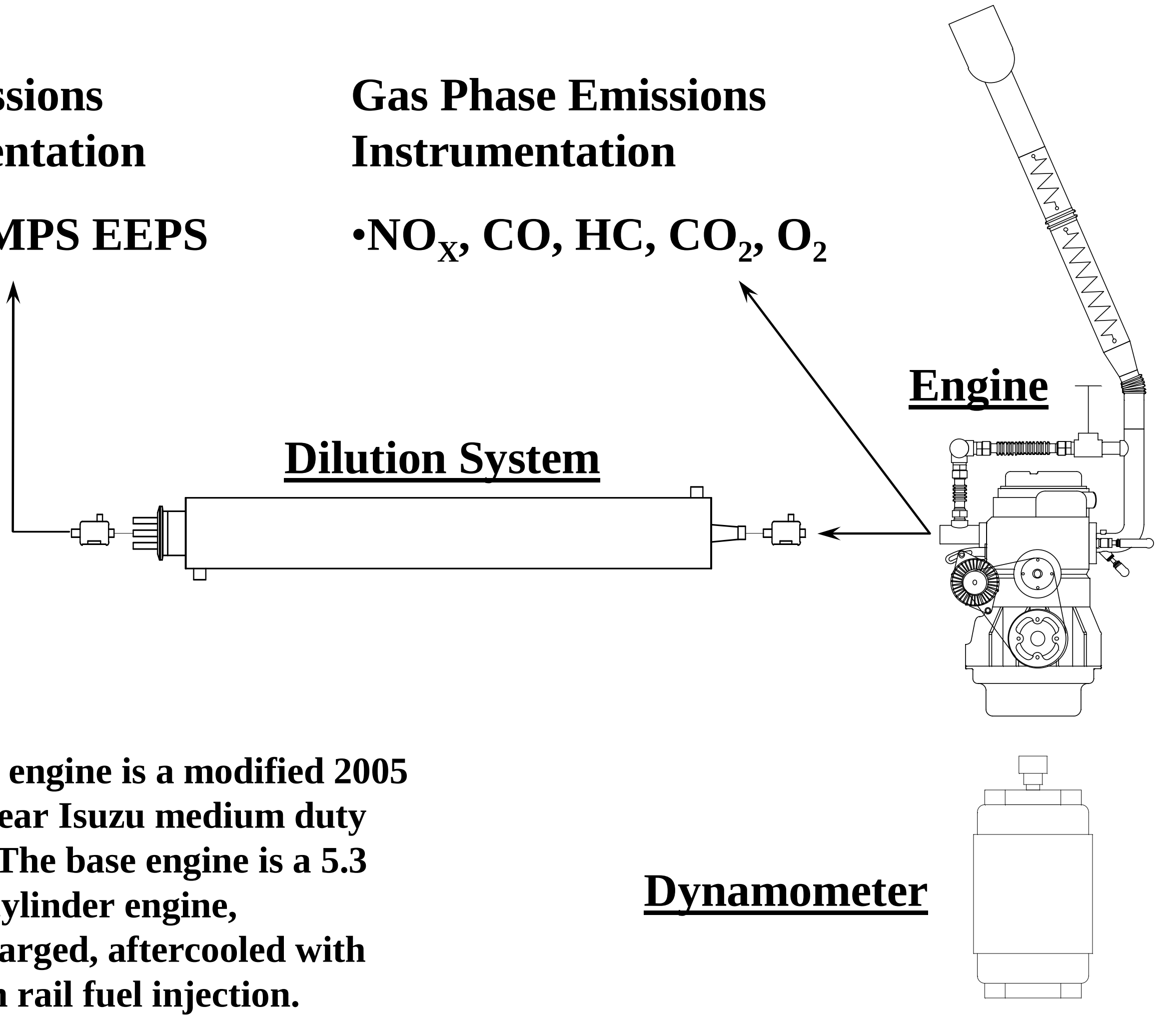
Experiment apparatus



PM Emissions Instrumentation

- CPC, SMPS EEPS

Gas Phase Emissions Instrumentation

- NO_X, CO, HC, CO_2, O_2

Engine

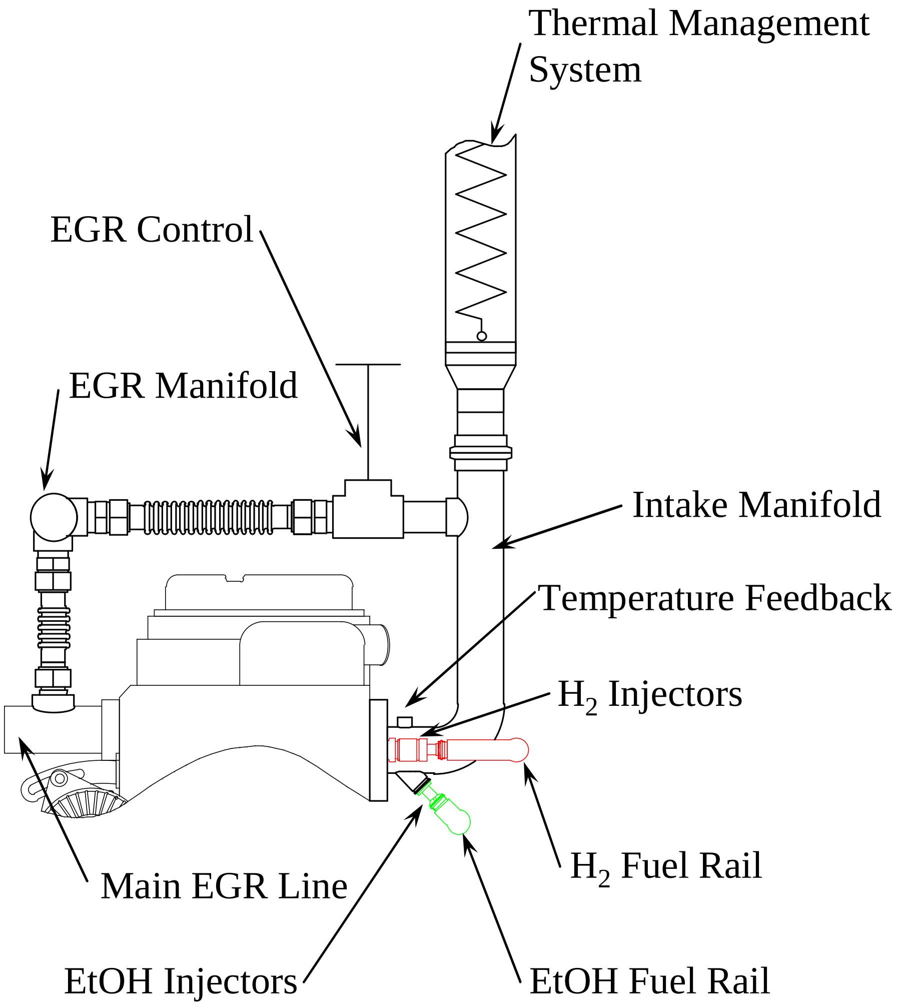
Dilution System

Dynamometer

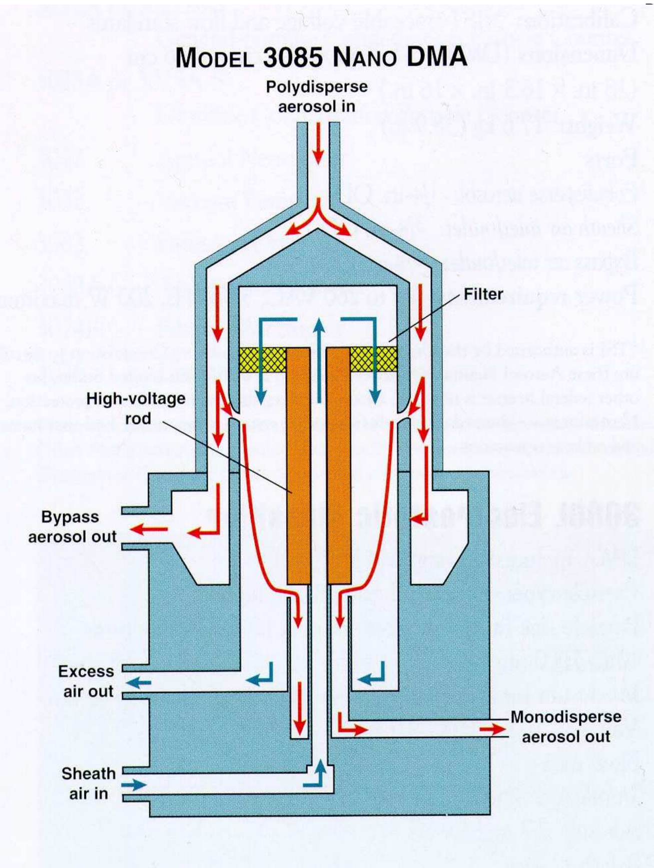
The test engine is a modified 2005 model year Isuzu medium duty engine. The base engine is a 5.3 liter, 4 cylinder engine, turbocharged, aftercooled with common rail fuel injection.

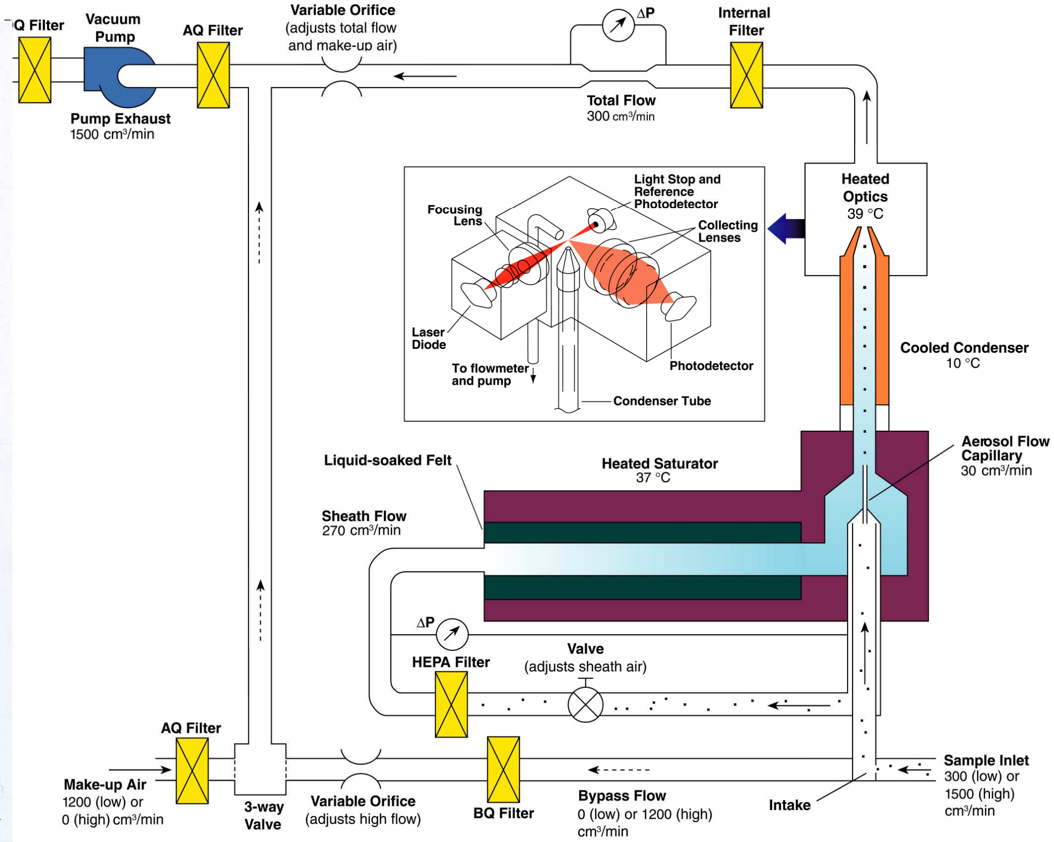
Engine modifications for HCCI

- Turocharger and aftercooler removed
- Common rail Diesel fuel injection not used
- Primary fuel ethanol preheated to improve atomization
- Independent control of EGR, air temperature, hydrogen, ethanol
- Closed loop controlled thermal system capable of maintaining temperatures of 150 °C
- MoTeC engine management system used for fuel injector control

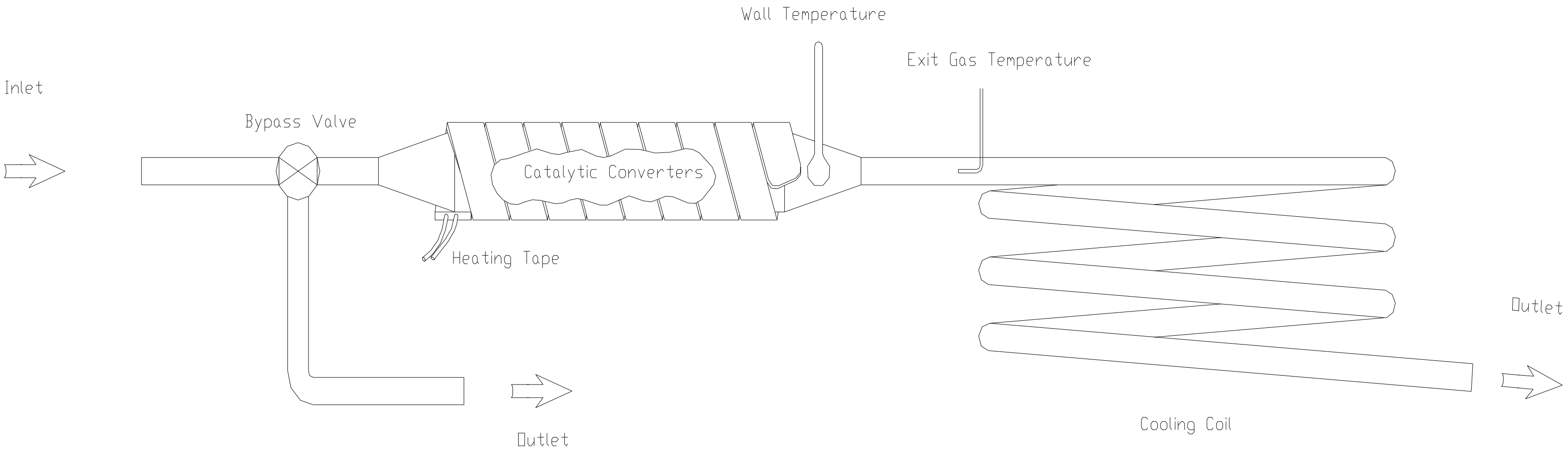


Particles were measured with a nano DMA and a 3025 ultrafine CPC configured to scan from 2 to 64 nm





A catalytic stripper was used to differentiate volatile and solid particles



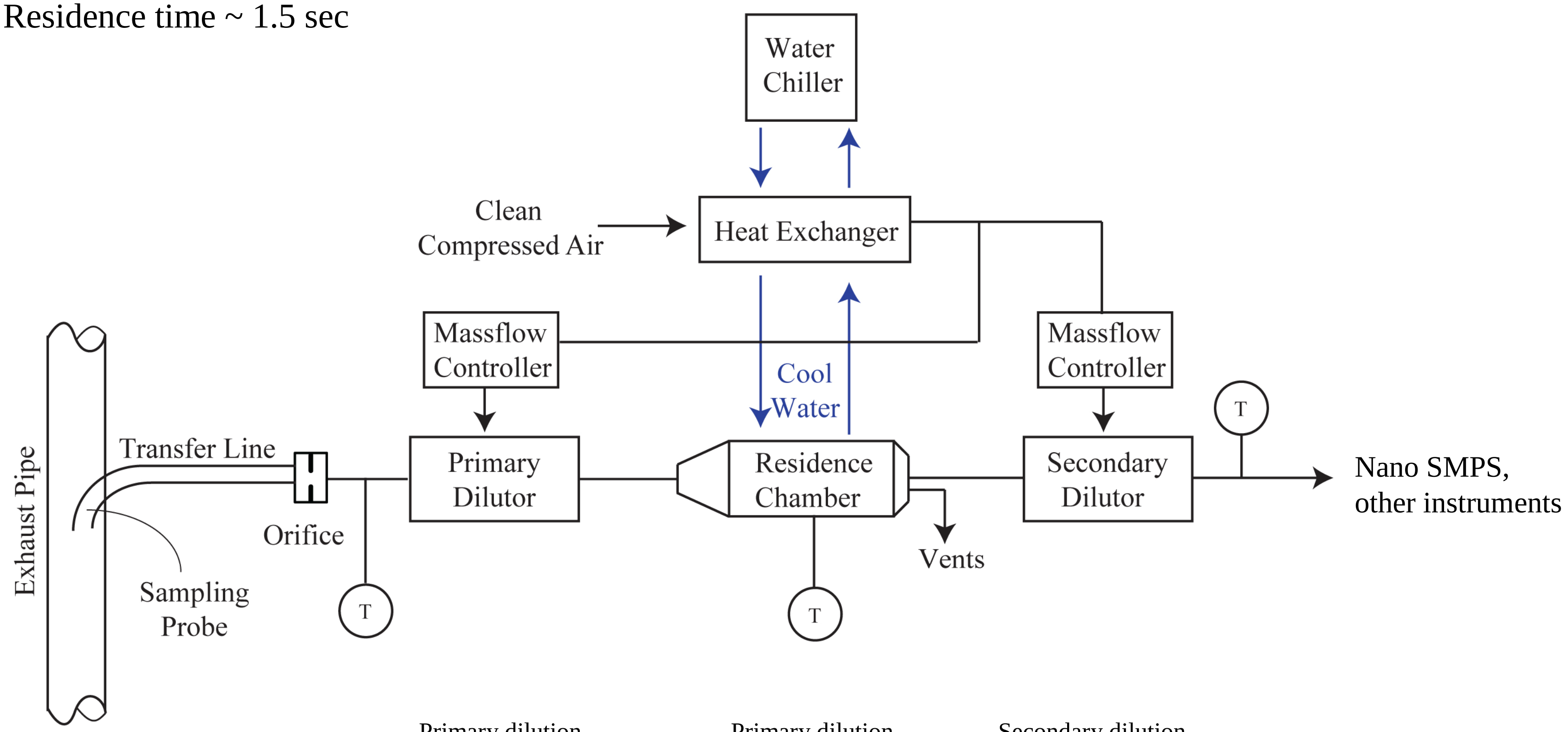
- Recent stripper design
  - Stripper consists of a 2 substrate catalyst* followed by a cooling coil
  - The first substrate removes sulfur compounds
  - The second substrate is an oxidizing catalyst
  - Diffusion and thermophoretic losses present but well defined

*Catalysts were provided by Johnson-Matthey

Kittelson, D. B.; Watts, W. F.; Savstrom, J. C.; Johnson, J. P. Influence of catalytic stripper on response of PAS and DC. *J. Aerosol Sci.* ***2005***, *36*, 1089–1107.

Sampling and dilution system

Dilution ratios, primary = 18, secondary = 15
Residence time ~ 1.5 sec



Water Chiller

Clean Compressed Air

Heat Exchanger

Massflow Controller

Cool Water

Massflow Controller

T

Exhaust Pipe

Transfer Line

Orifice

Sampling Probe

T

Primary Dilutor

Residence Chamber

Vents

T

Secondary Dilutor

Nano SMPS,
other instruments

Primary dilution
air temperature,
25 – 45 C

Primary dilution
tunnel temperature
25 – 45 C

Secondary dilution
air temperature, 25 C

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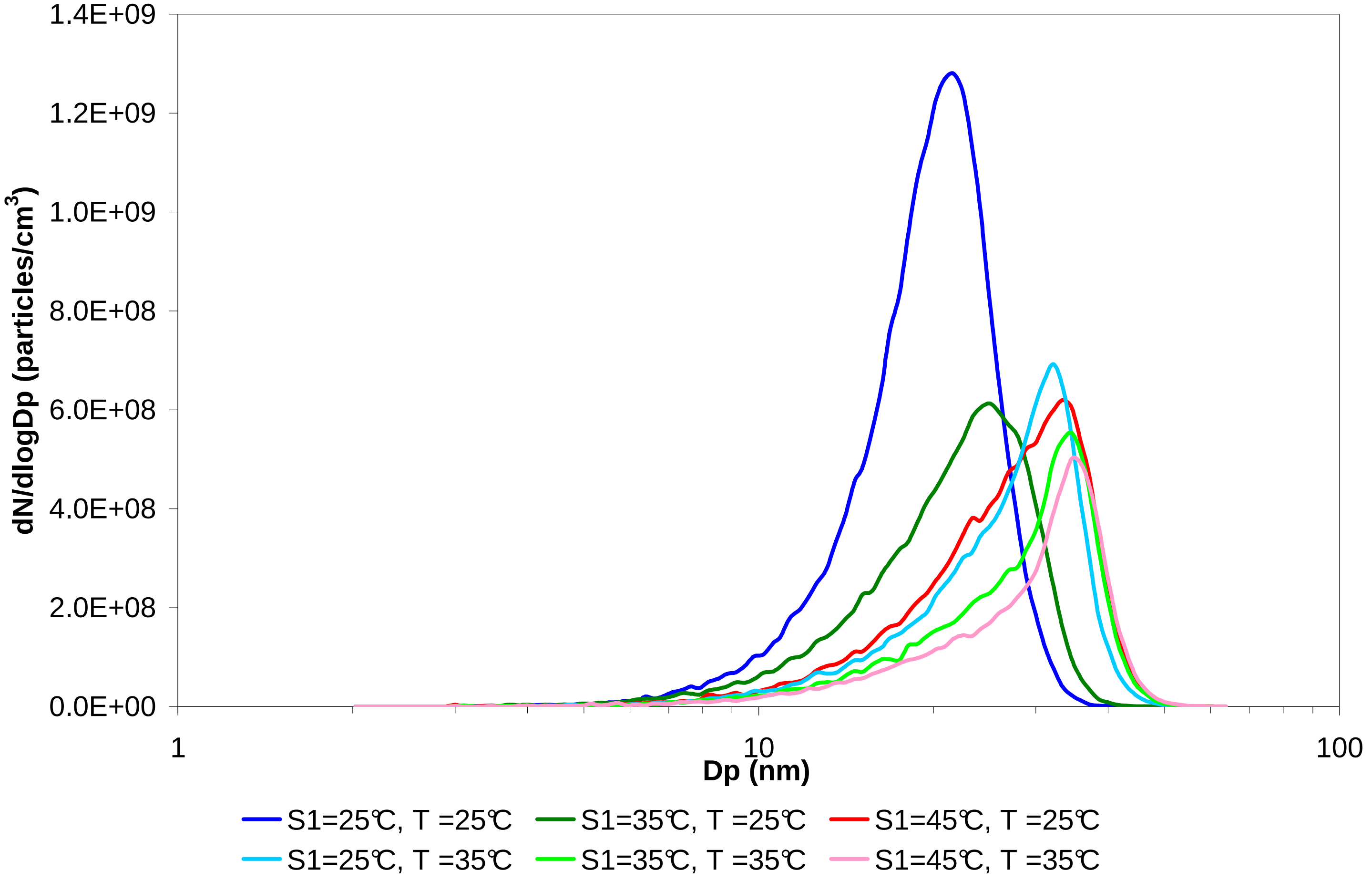
The first thing we wanted to do was to establish dilution conditions – dilution sensitivity



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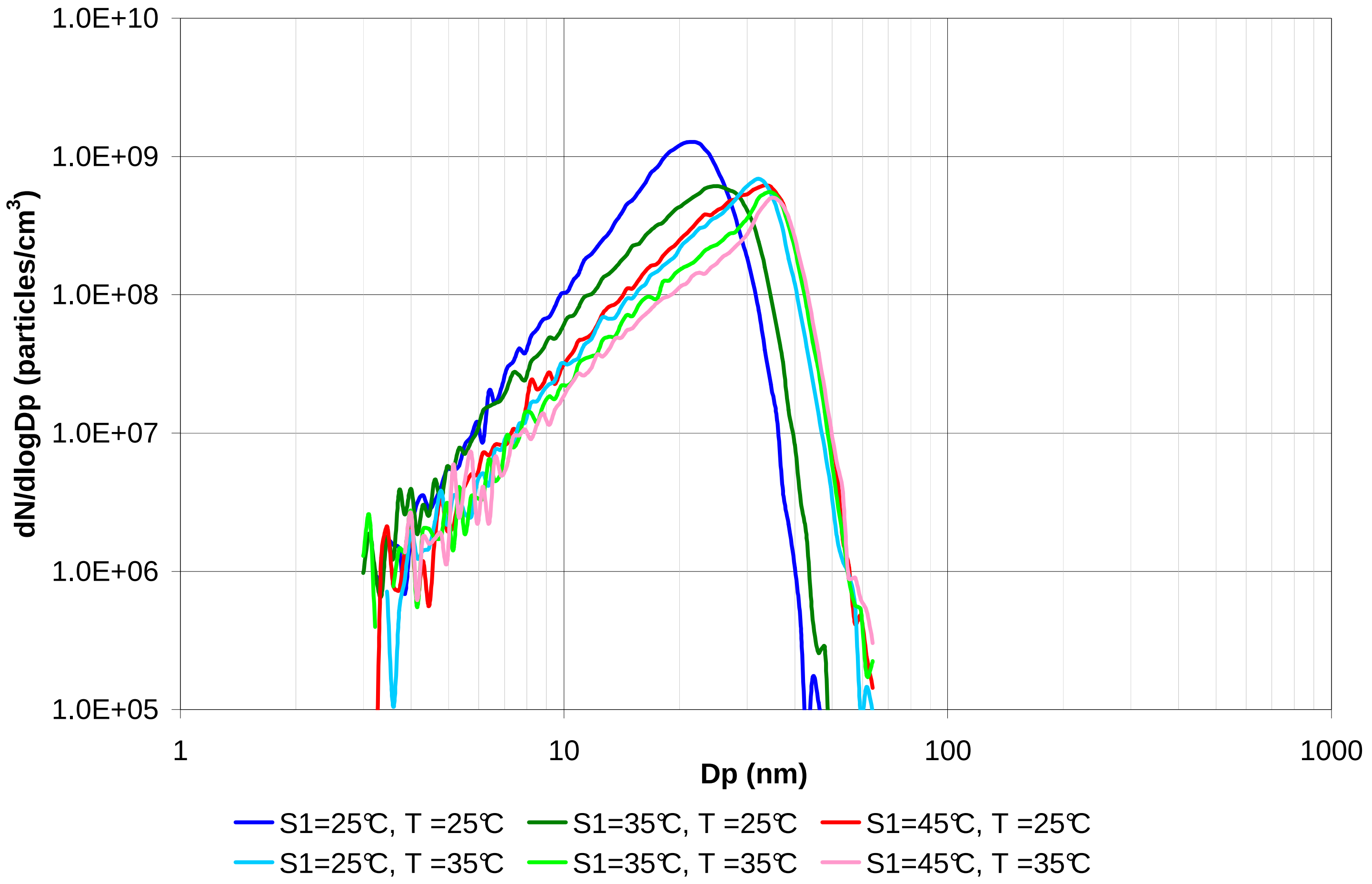
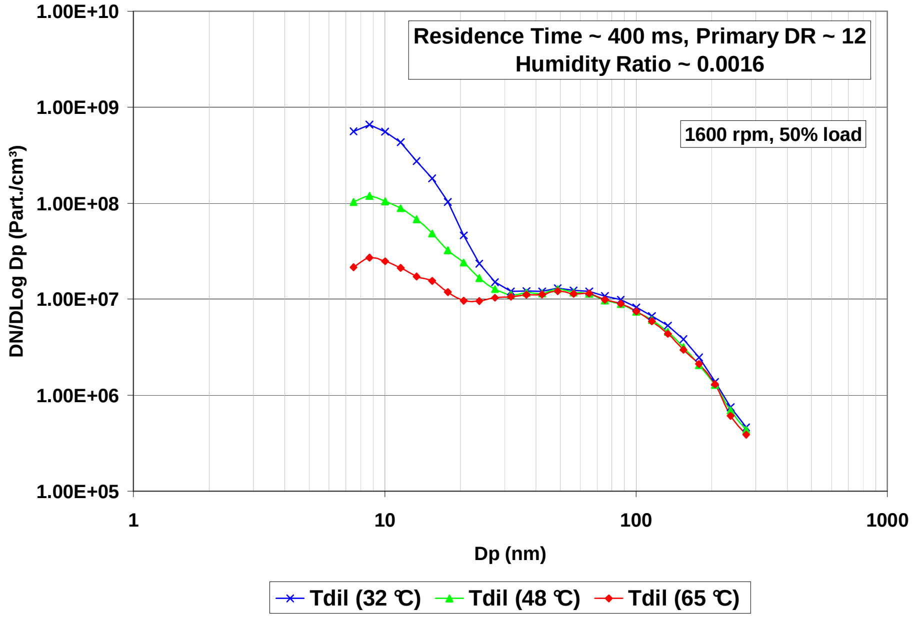
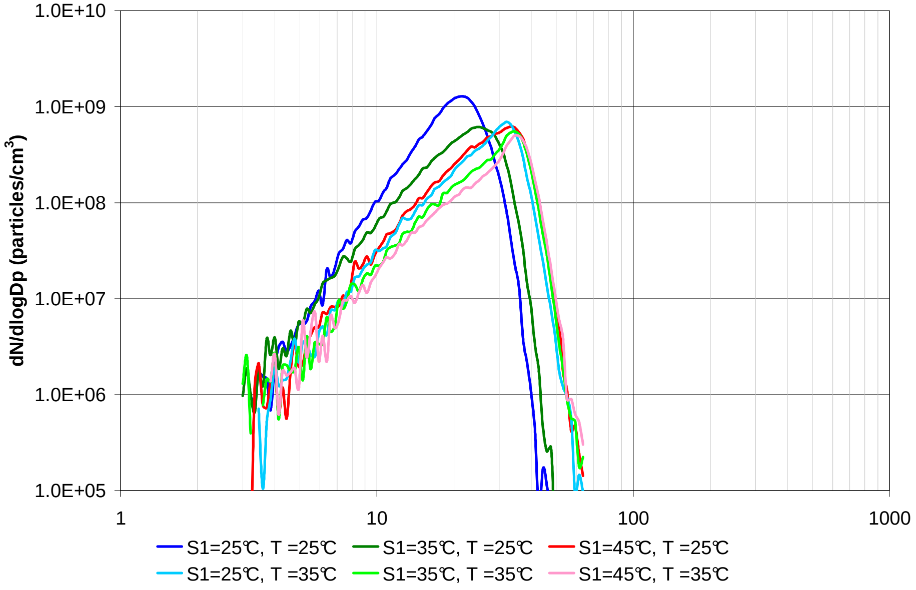


Comparison with earlier Diesel dilution sensitivity experiments





Abdul-Khalek, I., D.B. Kittelson, and F. Brear. 1999. “The Influence of Dilution Conditions on Diesel Exhaust Particle Size Distribution Measurements,” SAE Paper No. 1999-01-1142, 1999.

The sensitivity to dilution conditions is somewhat less than we have observed with Diesel nanoparticles. We decided to go with intermediate tunnel and dilution air temperatures, 35 and 35 C, respectively

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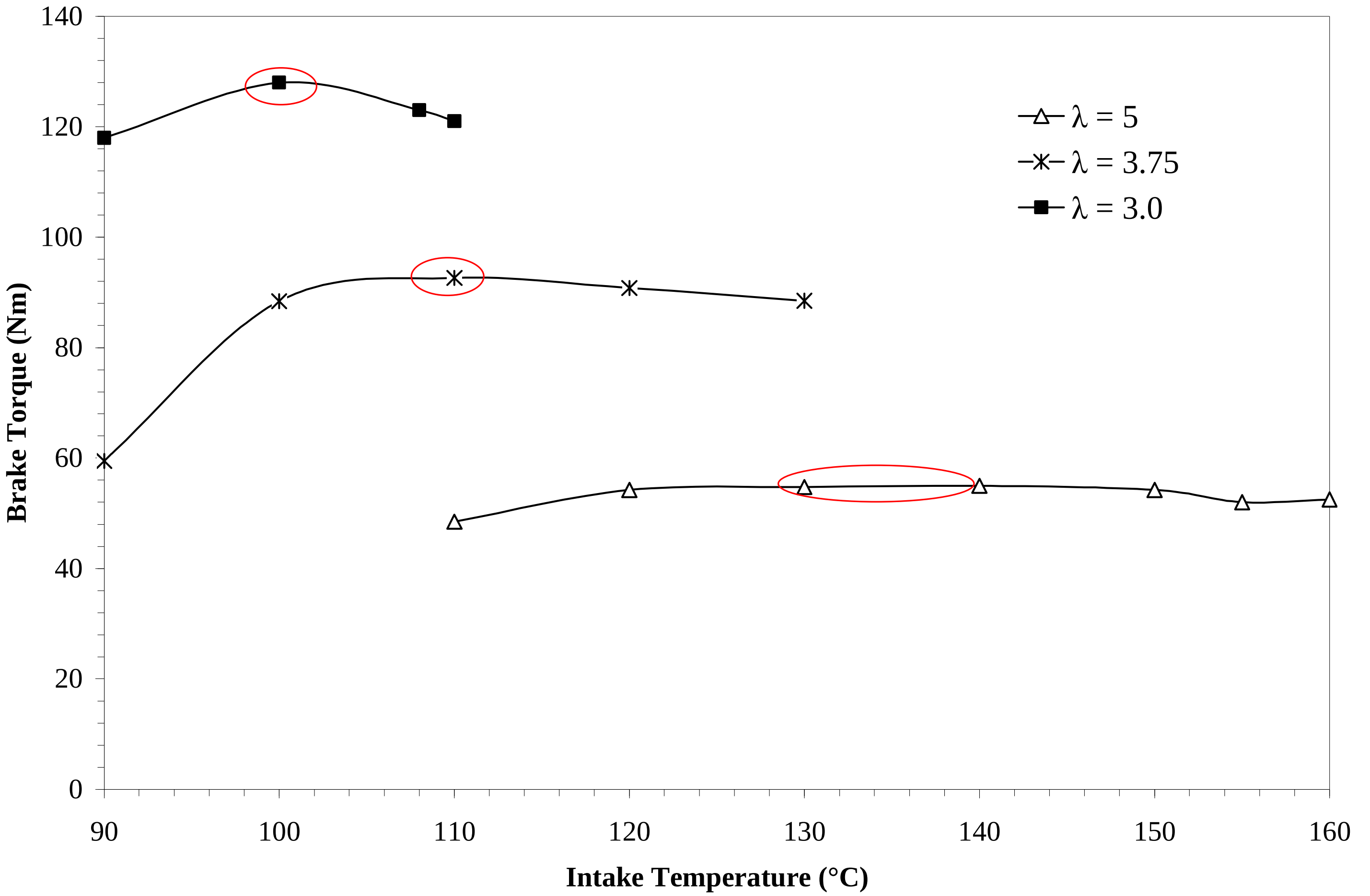
Variation of output with intake temperature for 3 fixed fueling rates, 1500 rpm



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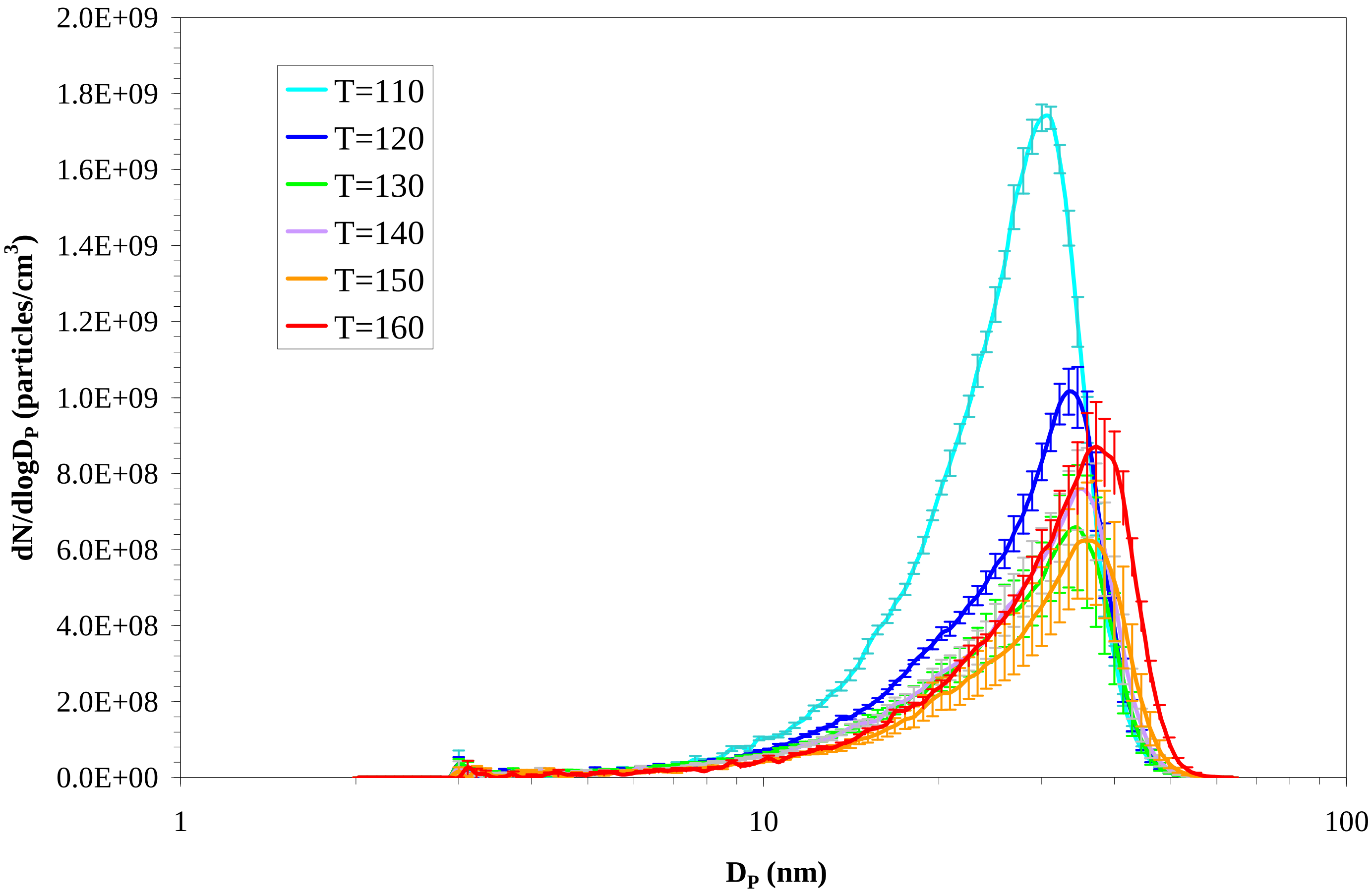
Ethanol HCCI with varying Intake Temperature, λ~4.5, 1500 RPM, No EGR



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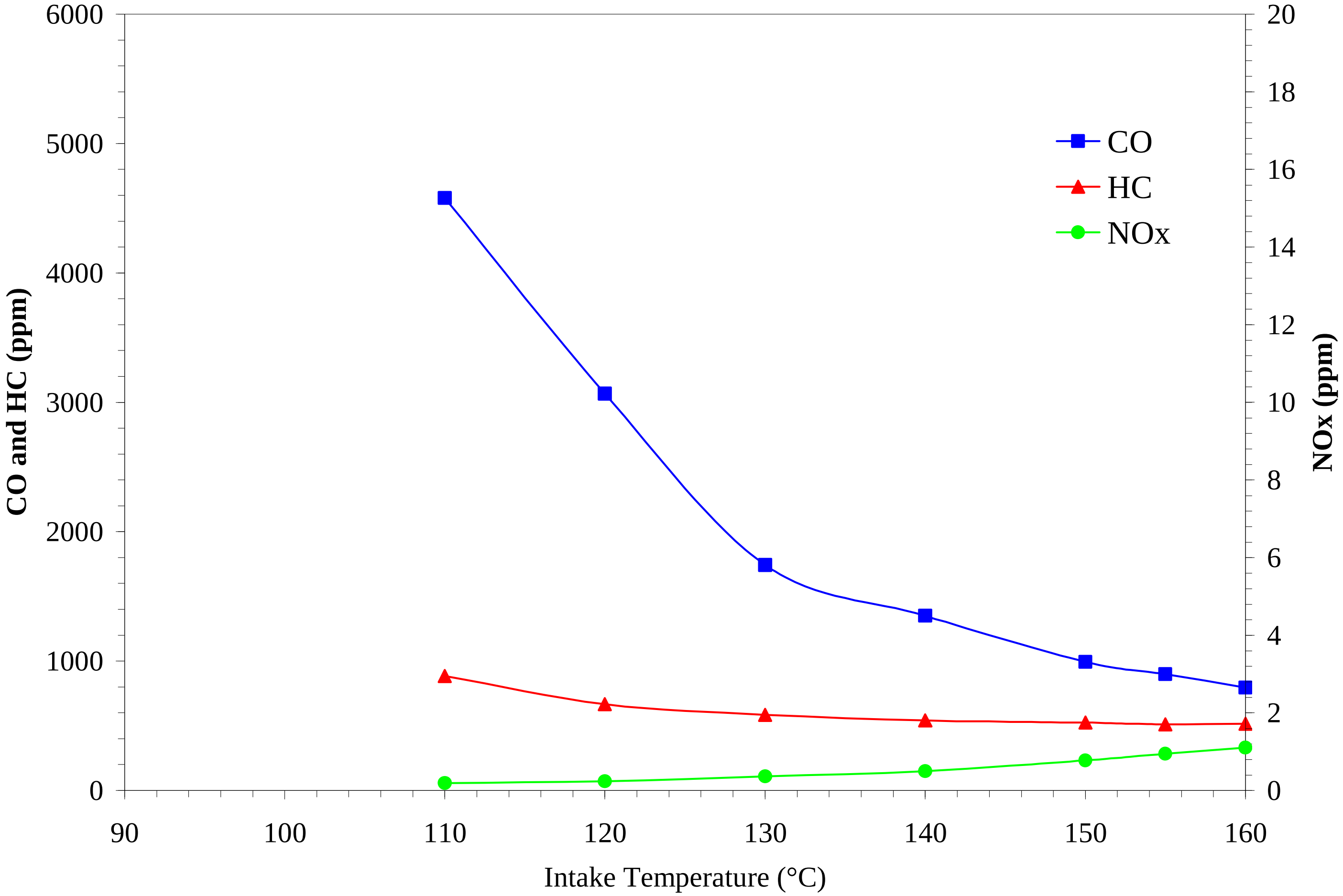
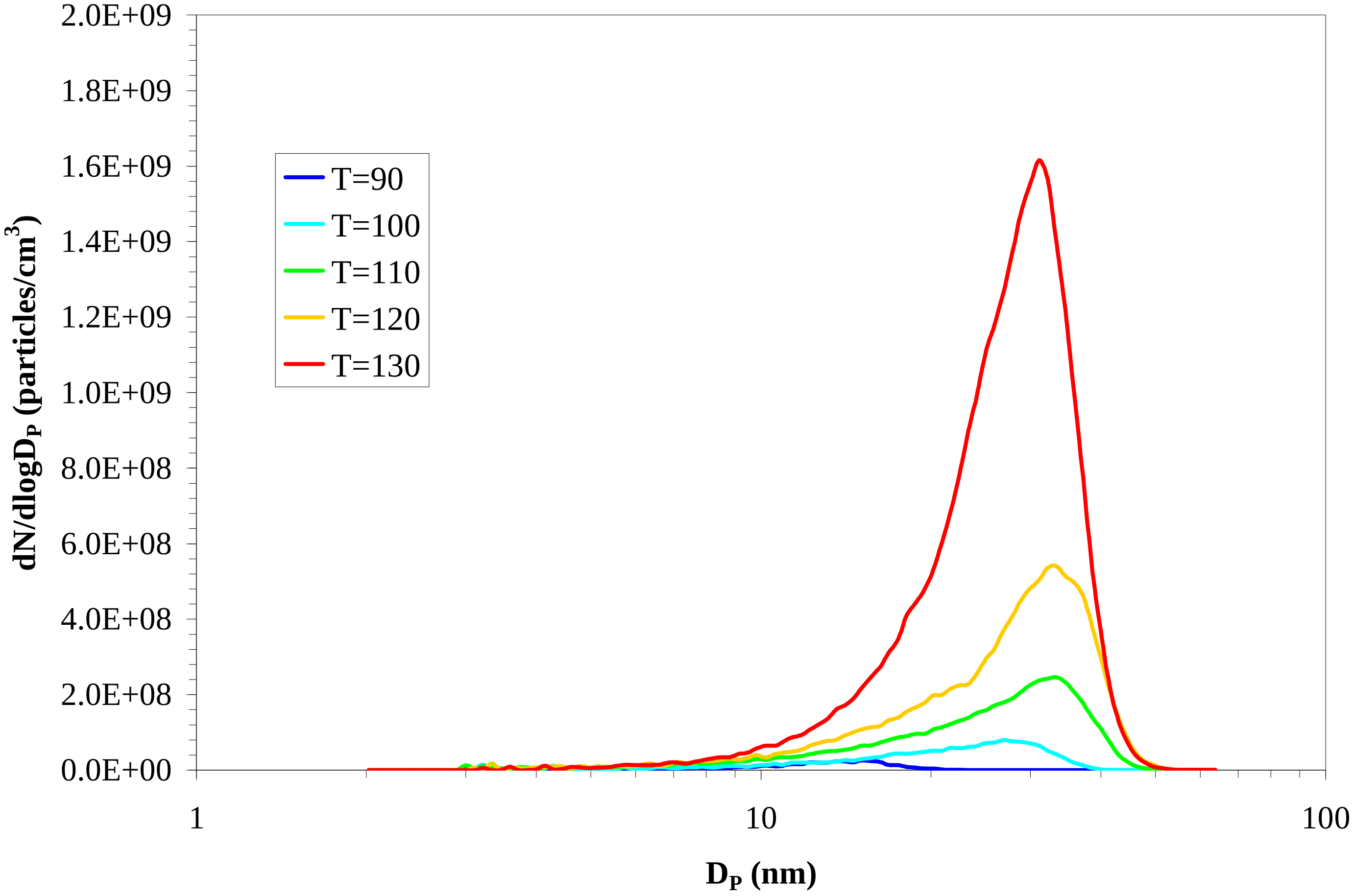
Ethanol HCCI with varying Intake Temperature, λ~4.5, 1500 RPM, No EGR



Ethanol HCCI with varying Intake Temperature, λ~3.75, 1500 RPM, No EGR



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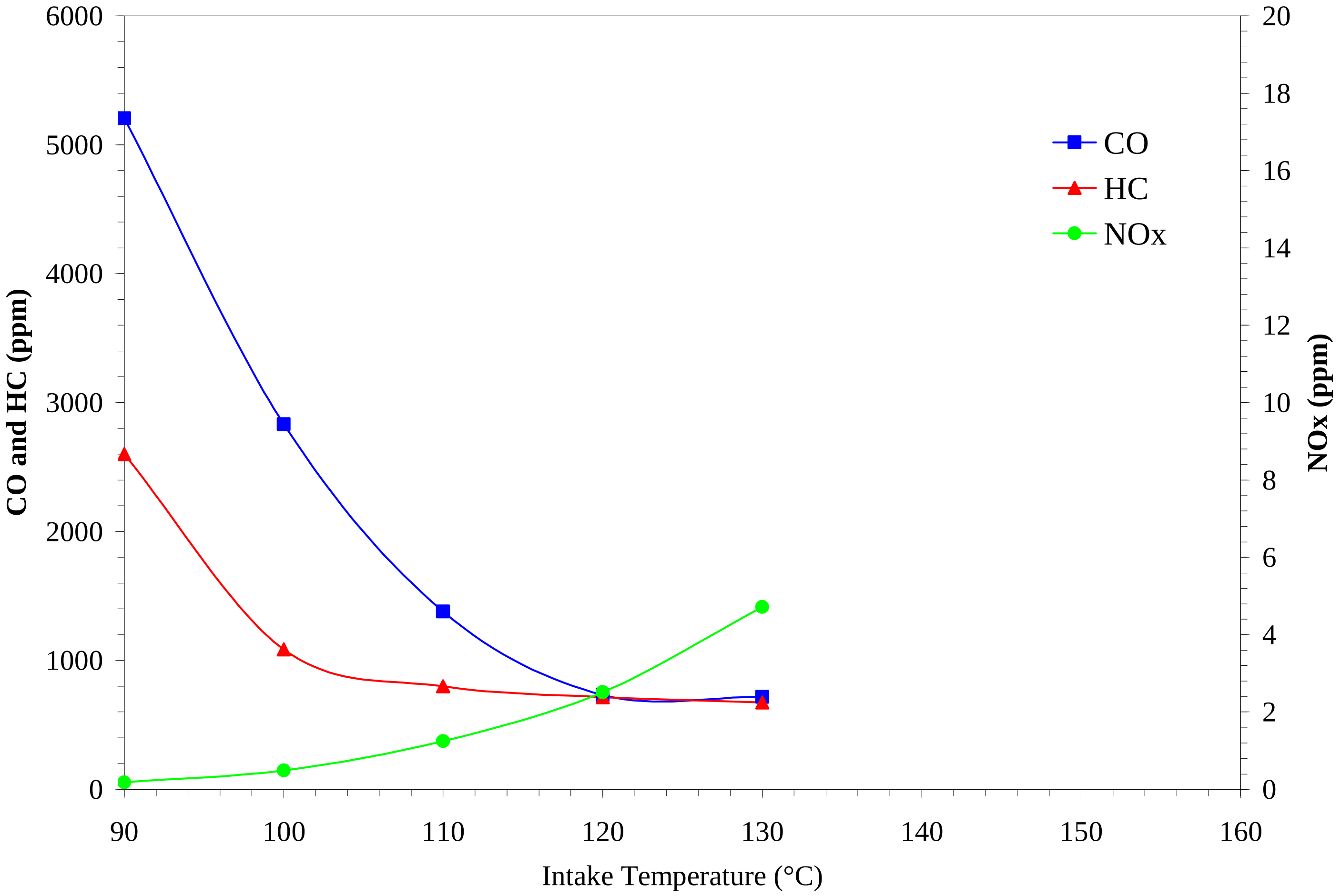
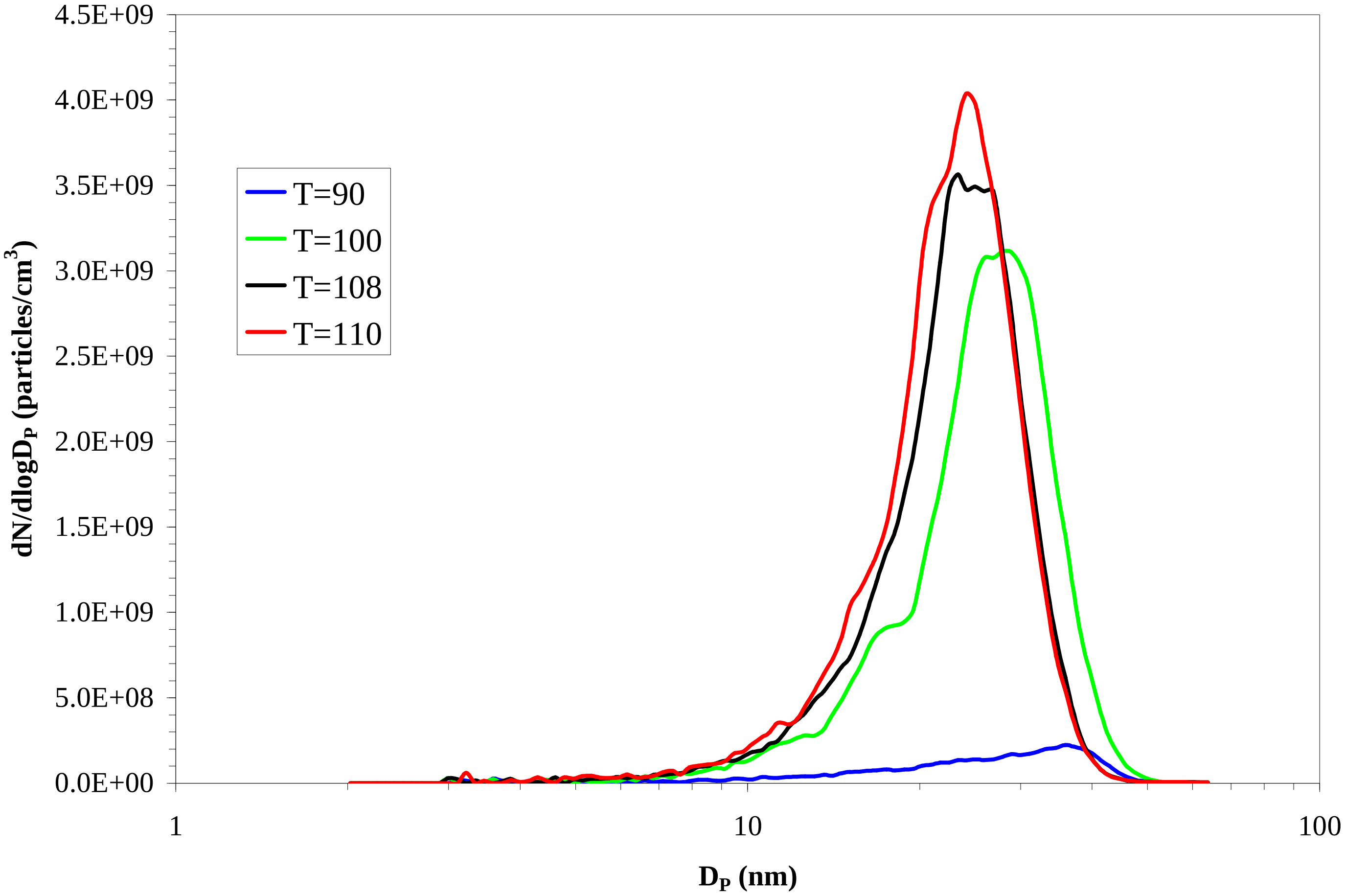
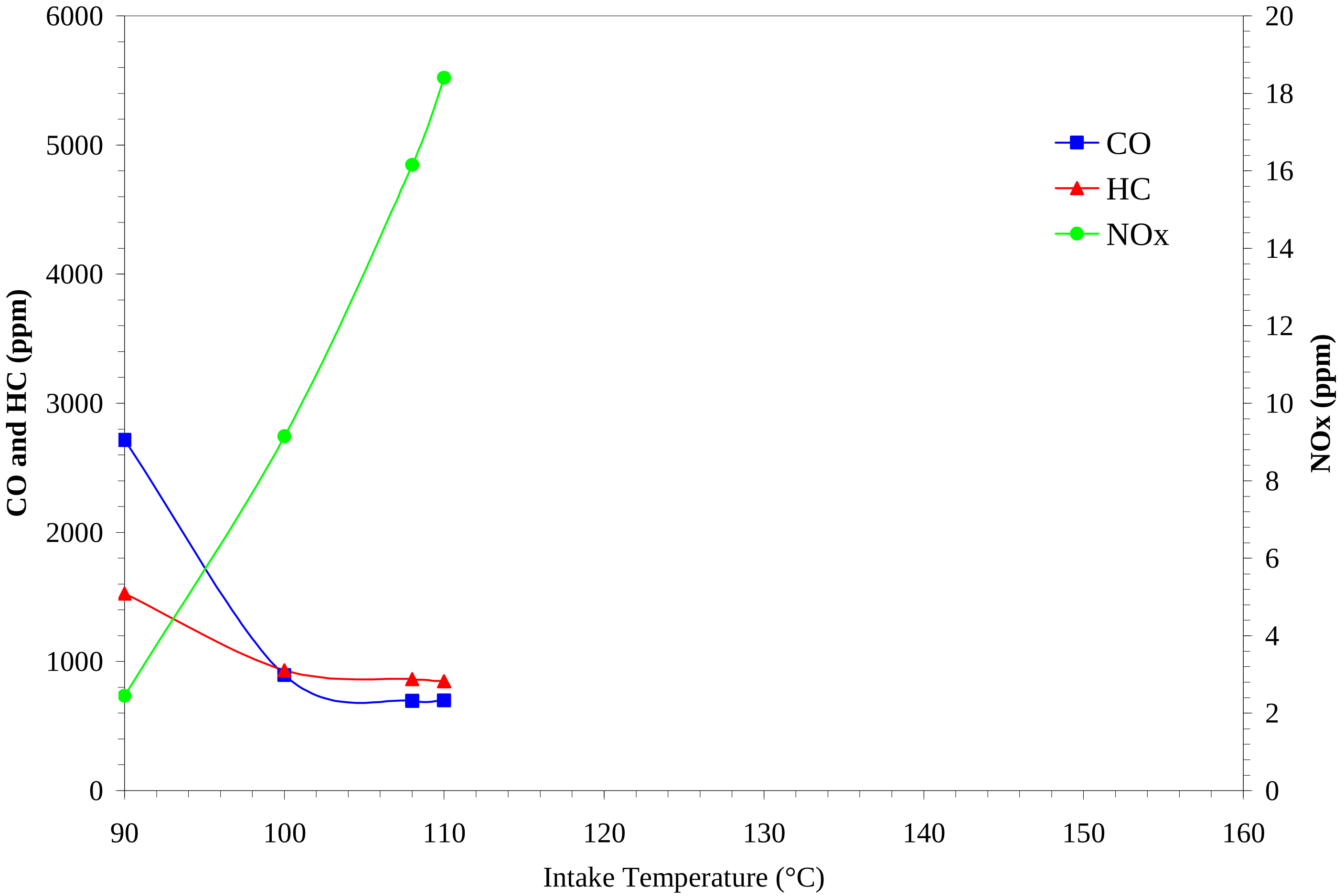
Ethanol HCCI with varying Intake Temperature, λ~3.75, 1500 RPM, No EGR



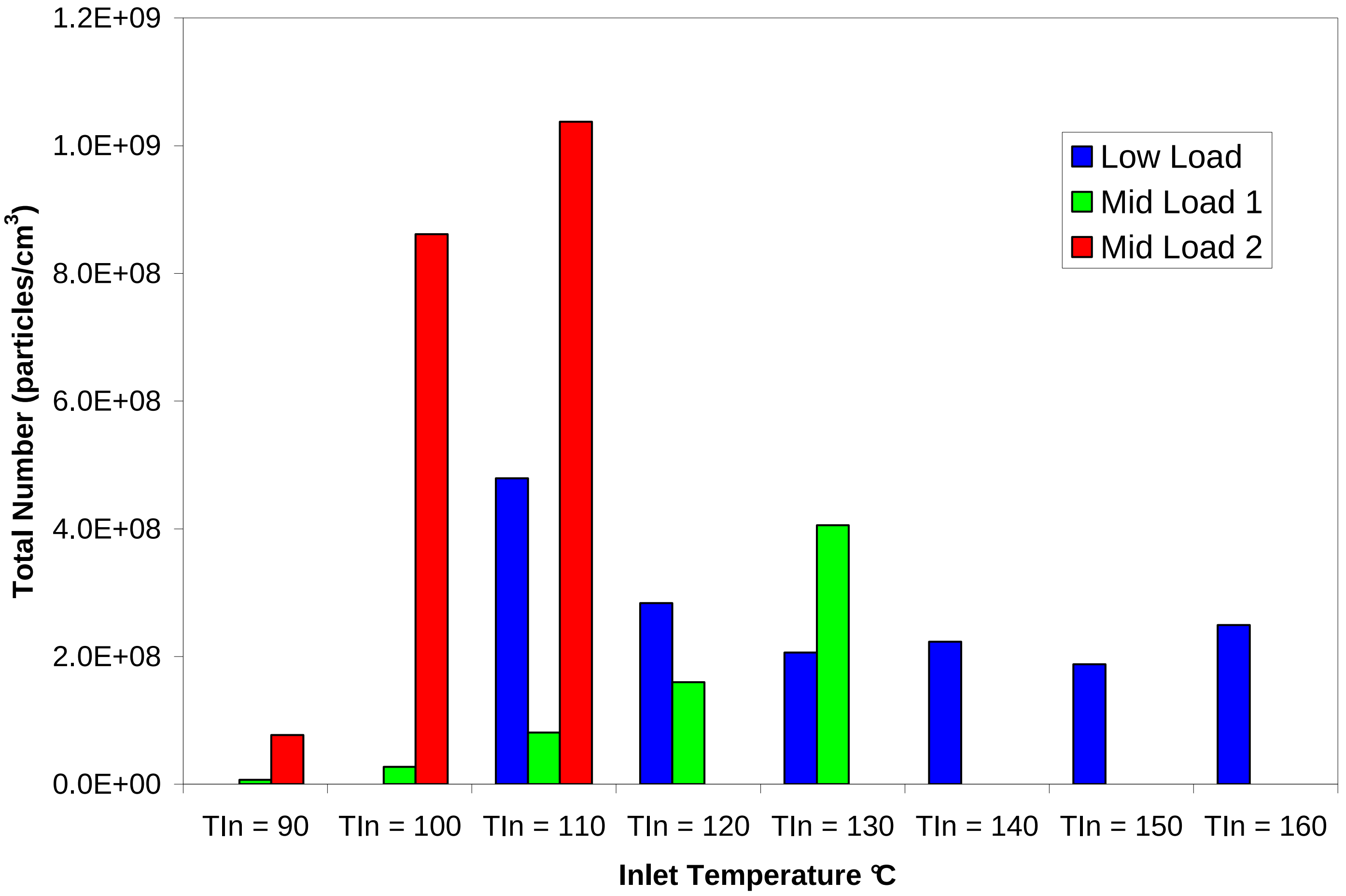
Ethanol HCCI with varying Intake Temperature, λ~3.0, 1500 RPM, No EGR



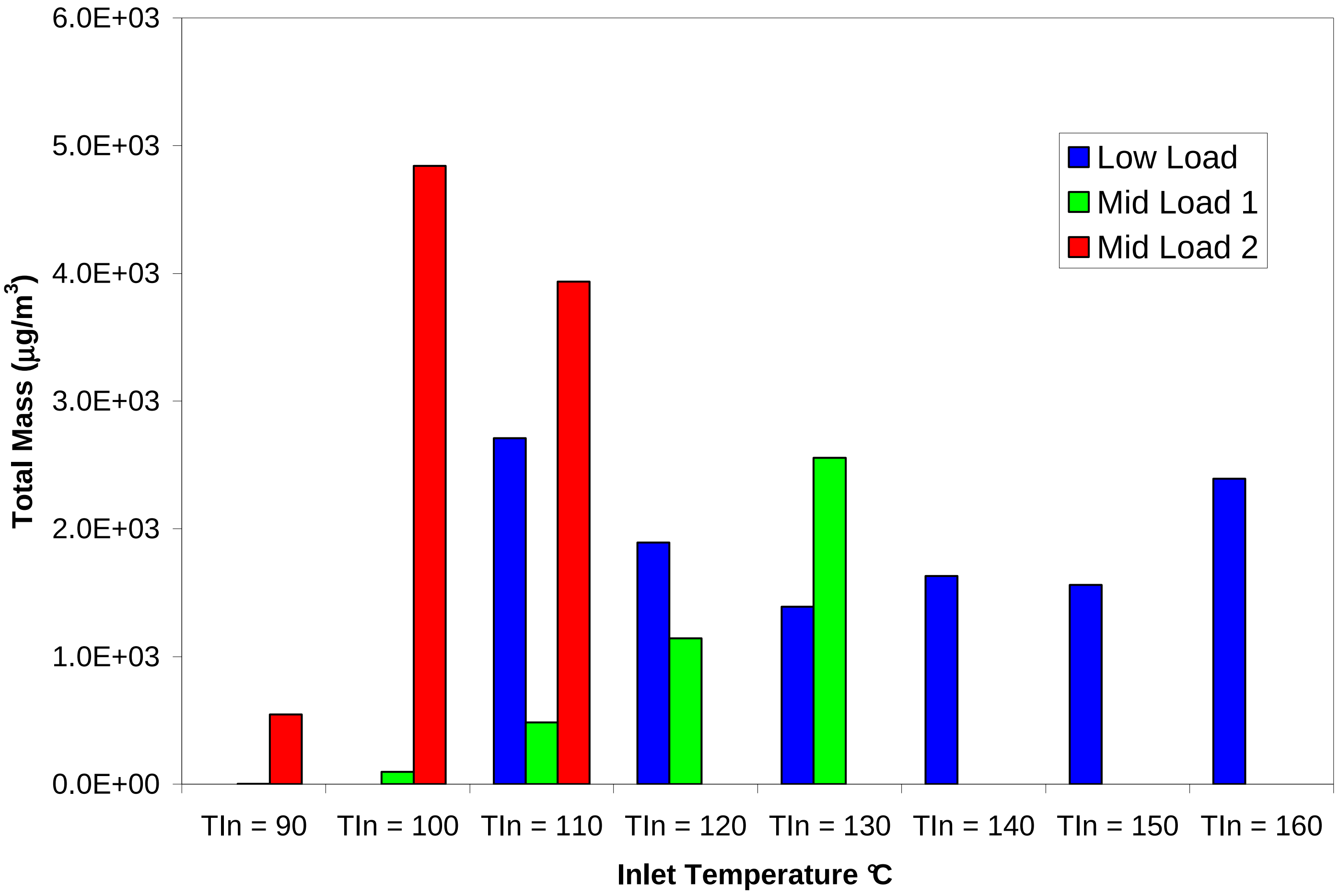
Ethanol HCCI with varying Intake Temperature, λ~3.0, 1500 RPM, No EGR



Summary total number emissions



Summary total estimated mass emissions – these are at Diesel engine levels



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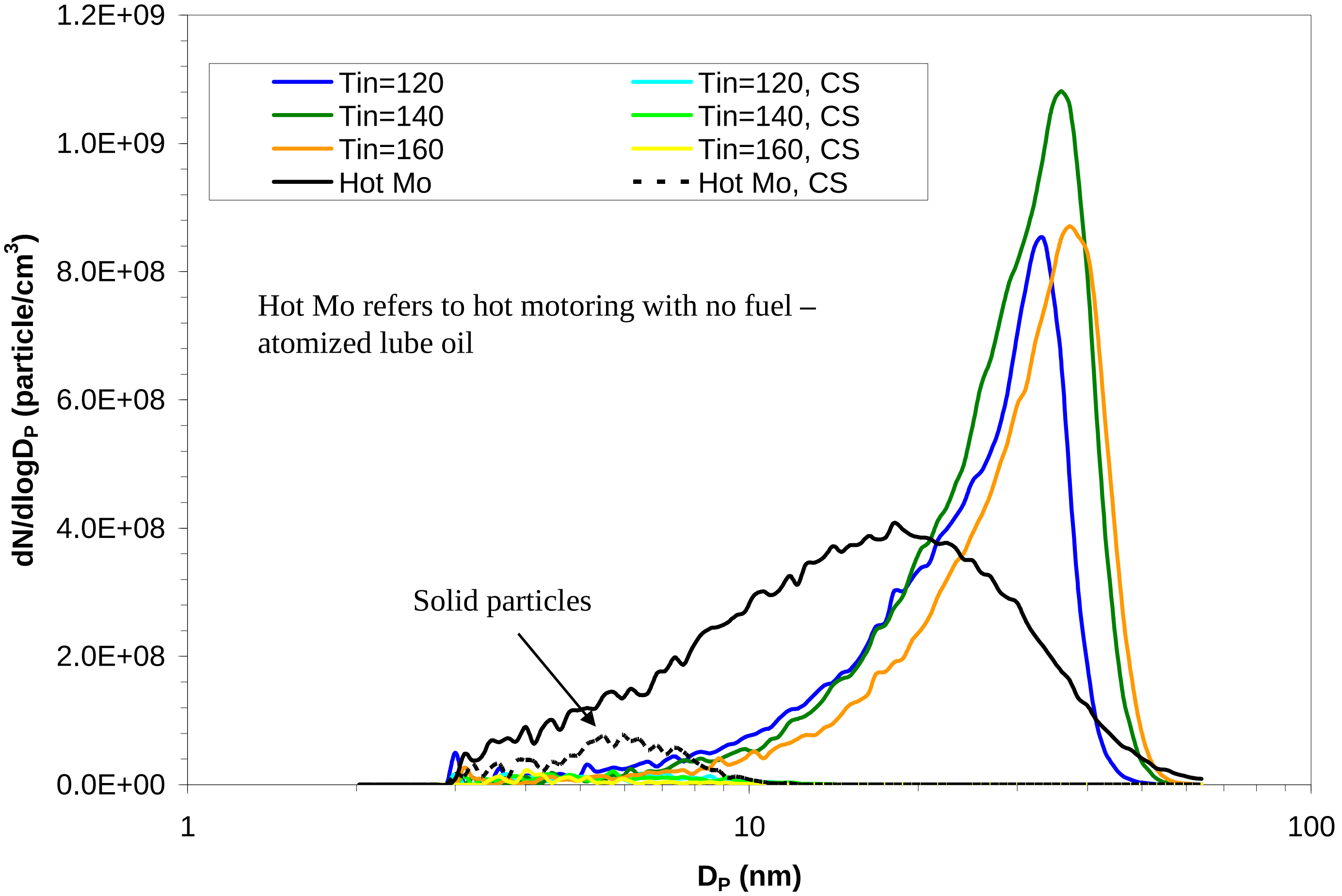
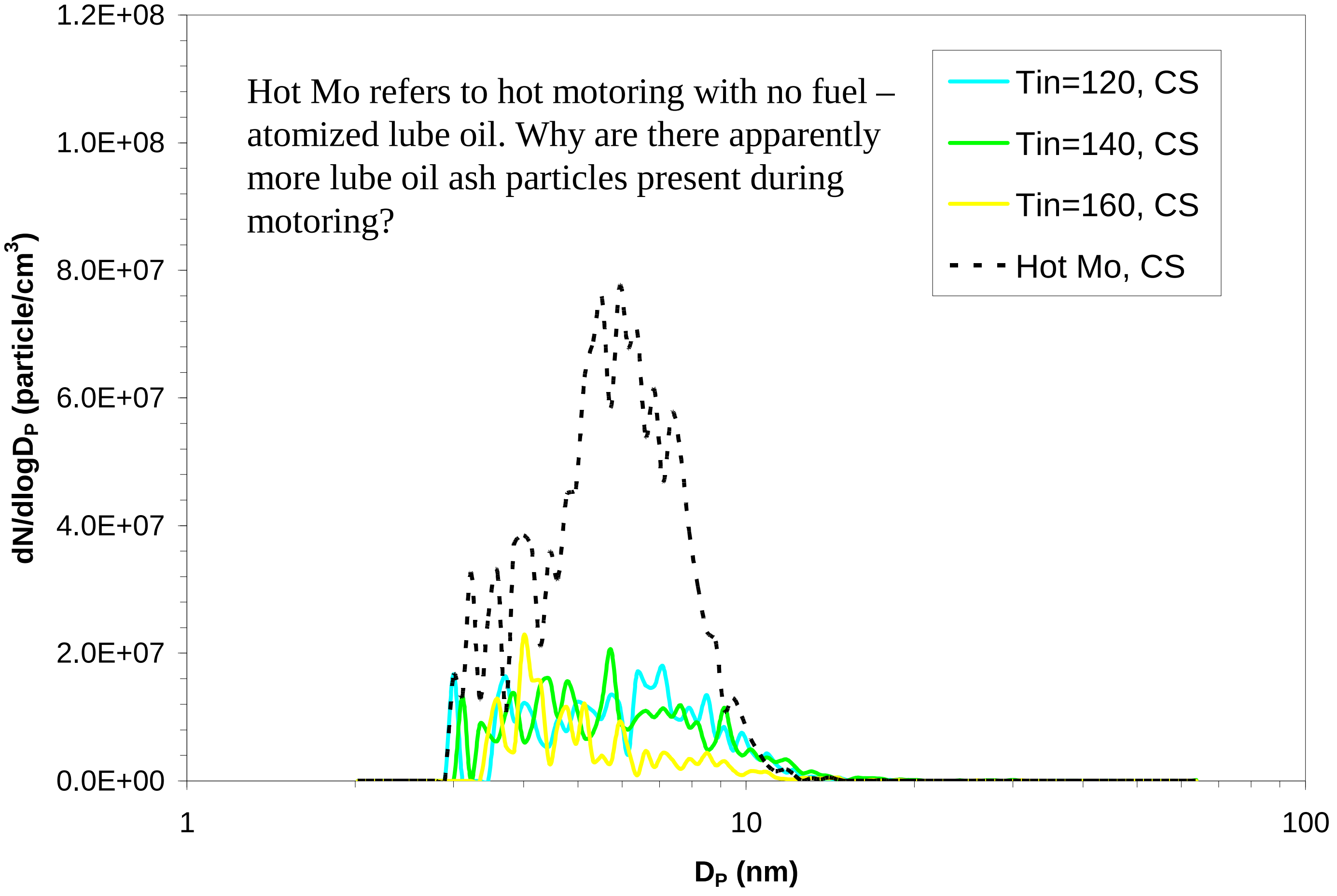
What about solid particles – here are some results with and without the catalytic stripper at light load



Hot Mo refers to hot motoring with no fuel – atomized lube oil

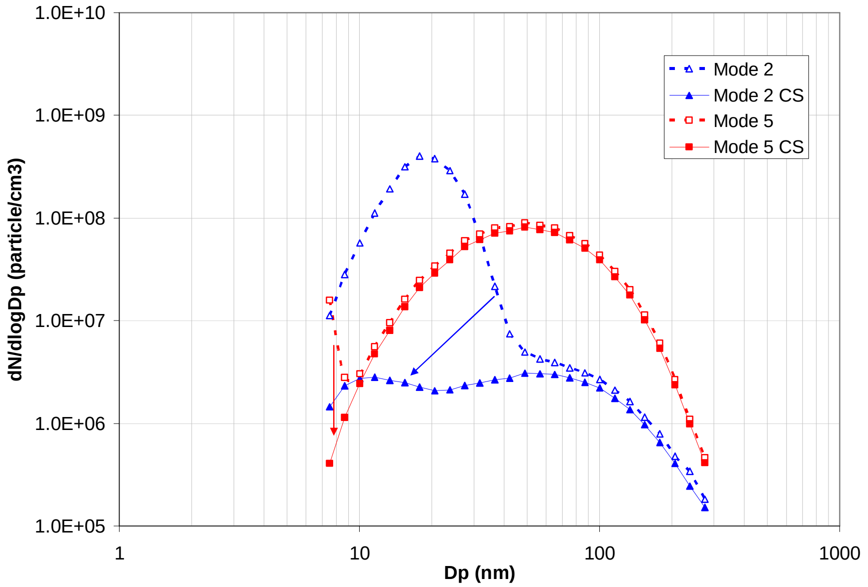
Solid particles

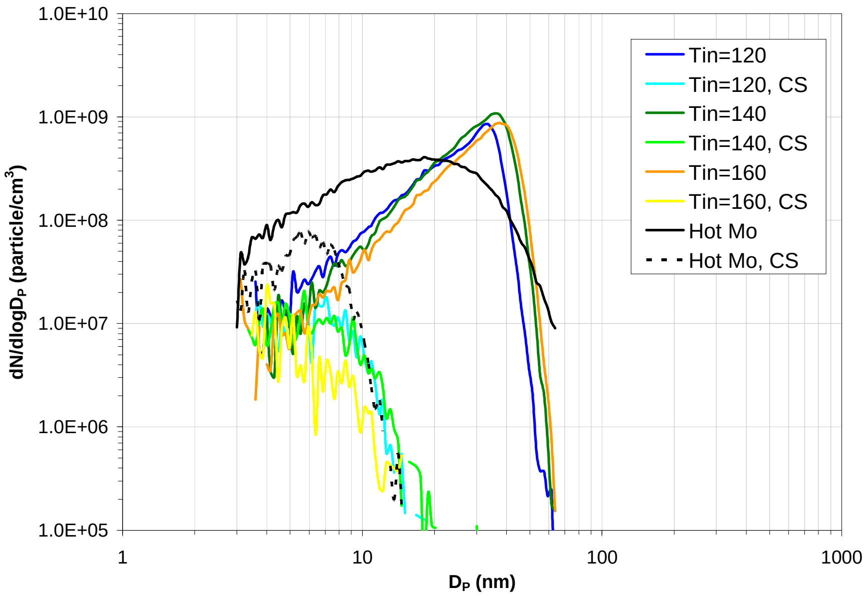
Solid particles from previous slide 10x scale



Hot Mo refers to hot motoring with no fuel – atomized lube oil. Why are there apparently more lube oil ash particles present during motoring?

Comparison with solid particles from a modern Diesel. HCCI nucleation mode particles much smaller but in higher concentration.





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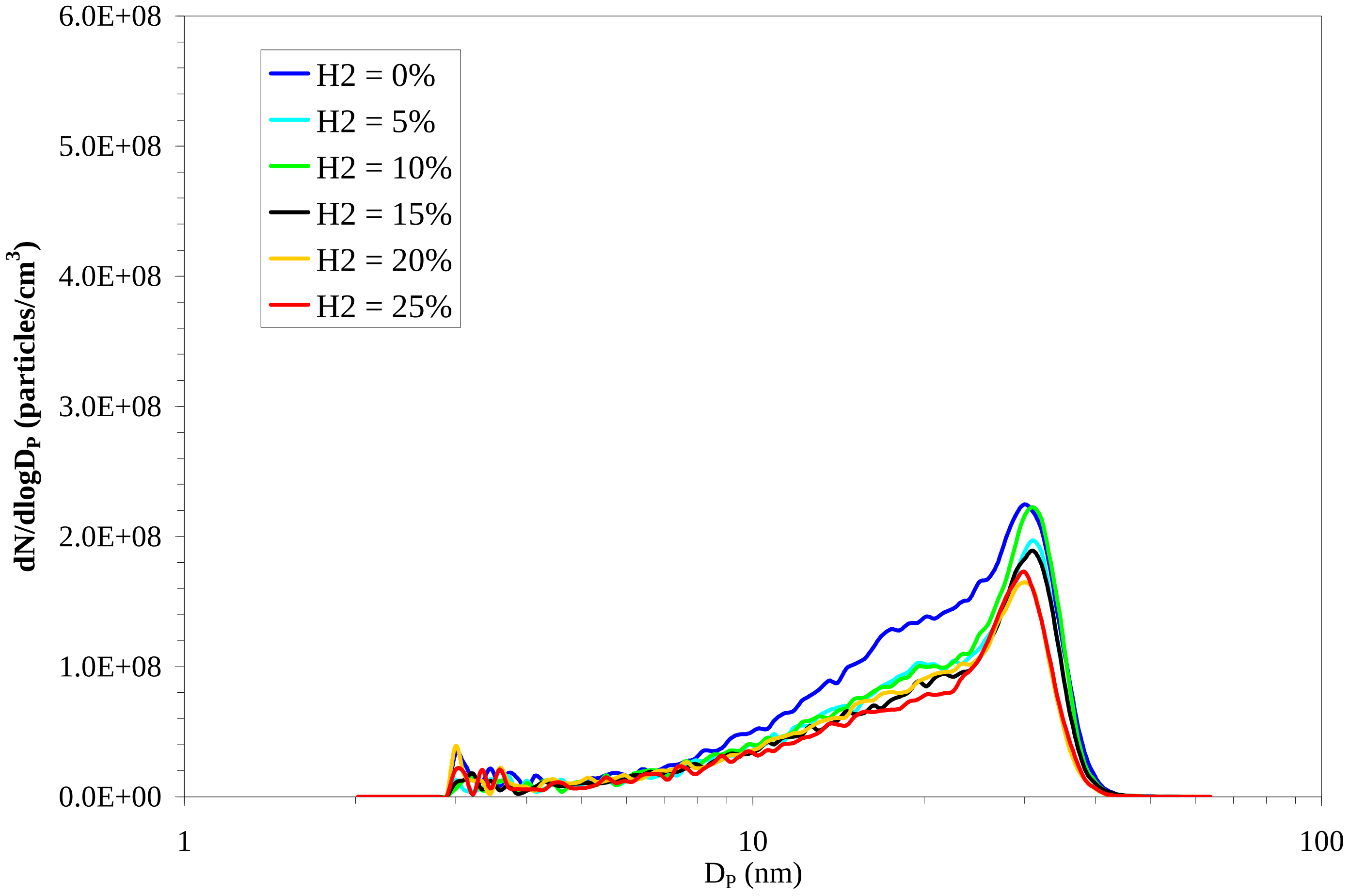
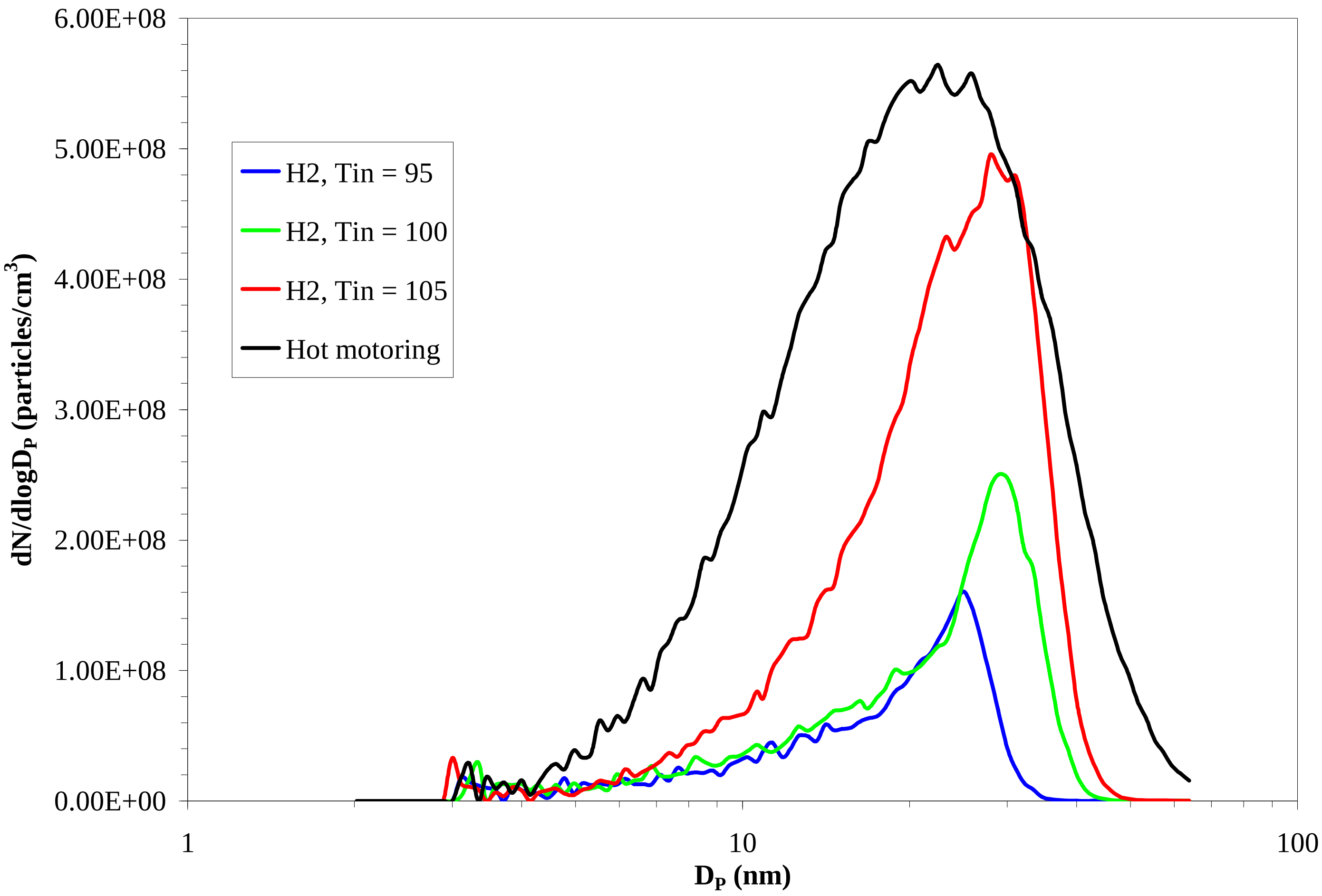
Ethanol HCCI with varying fraction H_2 energy input, λ~4.5, 1500 rpm, T intake = 130° C



Hydrogen HCCI with varying intake temperature, λ~5, 1500 rpm, 50 N-m



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Conclusions

- Significant mass and number emissions observed
  - Most of material between 10 and 50 nm
  - Nearly all volatile
  - Some solid particles between 3 and 10 nm
  - Particle emissions do not correlate with HC and CO emissions
  - Significant particle formation even with pure H_2 fuel
    - Lube oil must play an important role
    - Need to consider detailed in cylinder temperature history and impact on lube related particles
    - Should explore other lube oil formulations and oil atomization mechanisms
- This is a work in progress – data collection and analysis continues
  - In-cylinder pressure measurements for heat release rates and IMEP
  - Variable EGR results
  - Additional hydrogen tests
  - This system could be test bed for lube oil generated particles with non sooting systems, HCCI, DME, CNG, H_2

Related work on HCCI particle emissions

	Kaiser *et al* (2002)	Price *et al* (2007)	Misztal *et al* (2009)	Zinola & Lavy (2009)
Engine	DI, Intake heating, CR=15.2:1,	DI, 19 valve timings, λ=1 only,	Mixed hot/cold intake streams, variable valve timing	2.2 liter, DI, CR=14:1, boost, cool/hot EGR mixing
Fuel	Gasoline	Gasoline	Gasoline	low sulfur(<10ppm) diesel, CN =56.1
Instrumentation	SMPS, 2 stage dilution	DMS500	DMS500	SMPS 3071A ,with 3022 CPC
Findings	-Mid load HCCI yielded more and larger accum. mode PM than DISI operation	-HCCI showed more accum. mode PM and less nucl. mode PM than DISI	-Increased EGR-decreased total PM -Lack of dilution monitoring/control reported	-NO_2:NO_X ≈12-17% -VOF 75-90% for low load HCCI -no nucleation mode PM present -no dilution conditions reported