Center of Excellence for Aerospace Particulate Emissions Reduction Research

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Tandem DMA Approach for Real Time Measurements of Deliquescence and Volatility of Plume Processed Jet Engine PM Exhaust.

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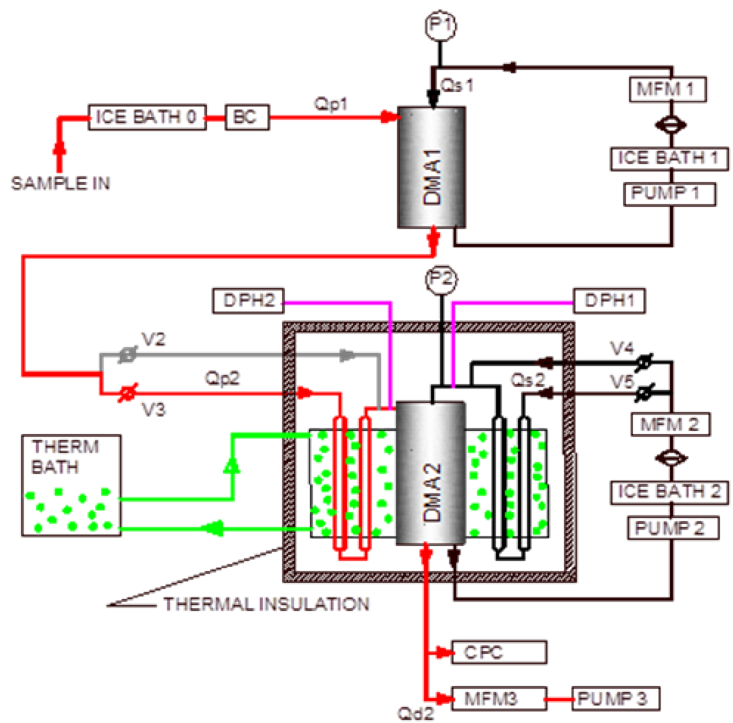
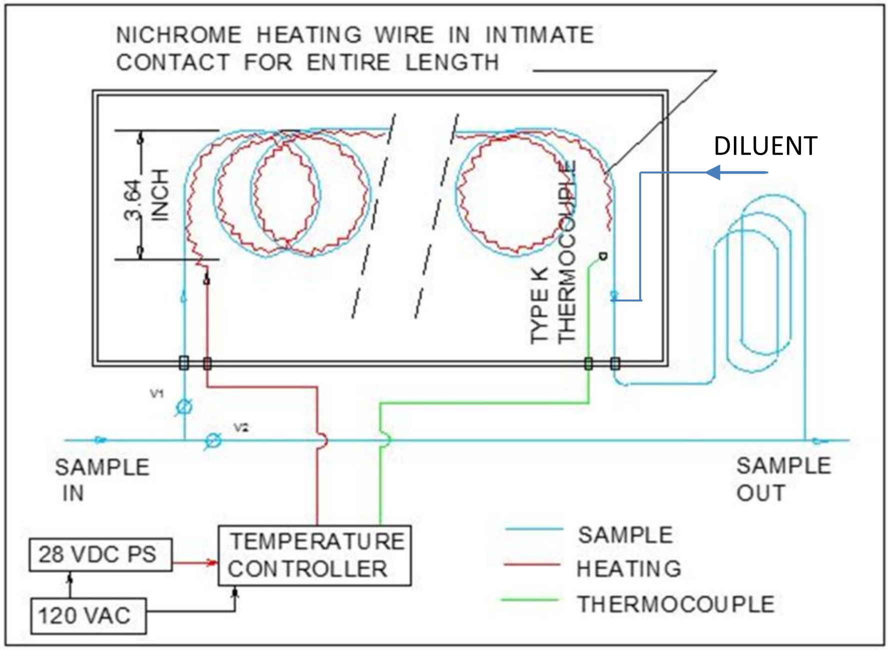
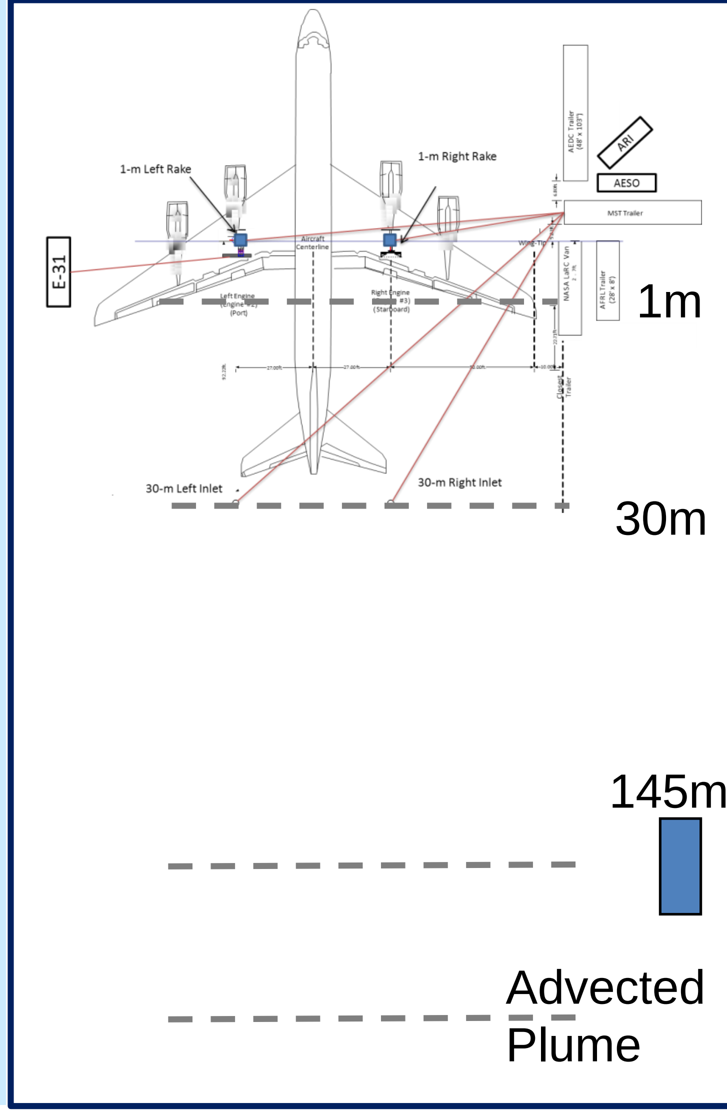
Introduction

- Volatile materials in exhaust condense onto soot particles and nucleate new particles.
- Useful metrics: SMF (Soluble Mass Fraction) and VMF (Volatile Mass Fraction)
- Use deliquescence measurements to quantify SMF.
- Use volatility measurements to quantify VMF.
- Explore SMF & VMF variation with distance in plume.





Project AFFEX-2



OBJECTIVE

Perform static aircraft engine testing using Hydro-treated Renewable Jet (HRJ) and other fuels to determine effects on engine performance and emissions.

APPROACH

Utilize the NASA DC-8 aircraft with CFM 56 engines at the Dryden Operational Facility in Palmdale, CA to perform emissions testing using various alternative fuels and a JP-8 reference fuel, and obtain gaseous, solid, and aerosol samples for analysis at 1, 30, and 145 meters downstream of the aircraft engine exhaust.

Fuels Studied	JP8	HRJ (Beef Tallow)	HRJ – JP8 Blend	FT (CTL)	FT+THT

Differences in fuel properties, especially fuel aromatic content and fuel sulfur content can influence PM Emissions


1m probe assembly


1 and 30m diagnostic trailers


NASA
N817NA
30m probe assembly


145m probe assembly

Methodologies for VMF and SMF

VMF Methodology

- Measure the total and non-volatile size distributions.
- Take the non-volatile size distribution and calculate what it's size distribution would become, when it gets coated with volatile material, assuming that that the non-volatile particles collect a volume of volatile material proportional to their surface area, with proportionality constant b. b is the object of the measurement.
- Adjust b to minimize the difference between the GMD for the modeled total size distribution and that for the measured total size distribution.
- Use b to calculate a Volatile Mass Fraction, VMF.

$vmf_i = \rho_v b x_i^2 / [(\pi/6)\rho_s x_i^3 + \rho_v b x_i^2]$

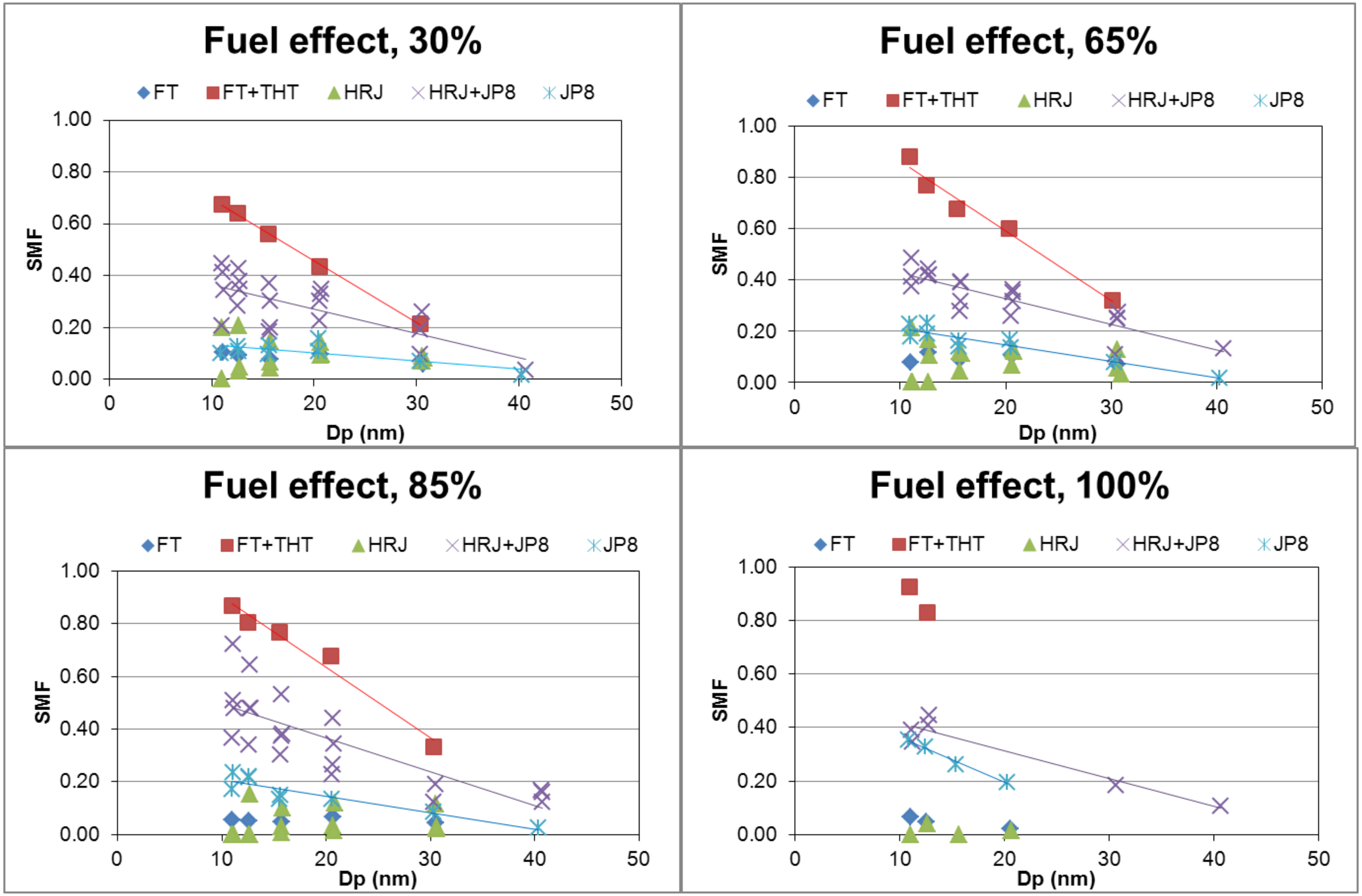
ρ_s = Soot density

ρ_v = Density of volatile material

SMF Methodology

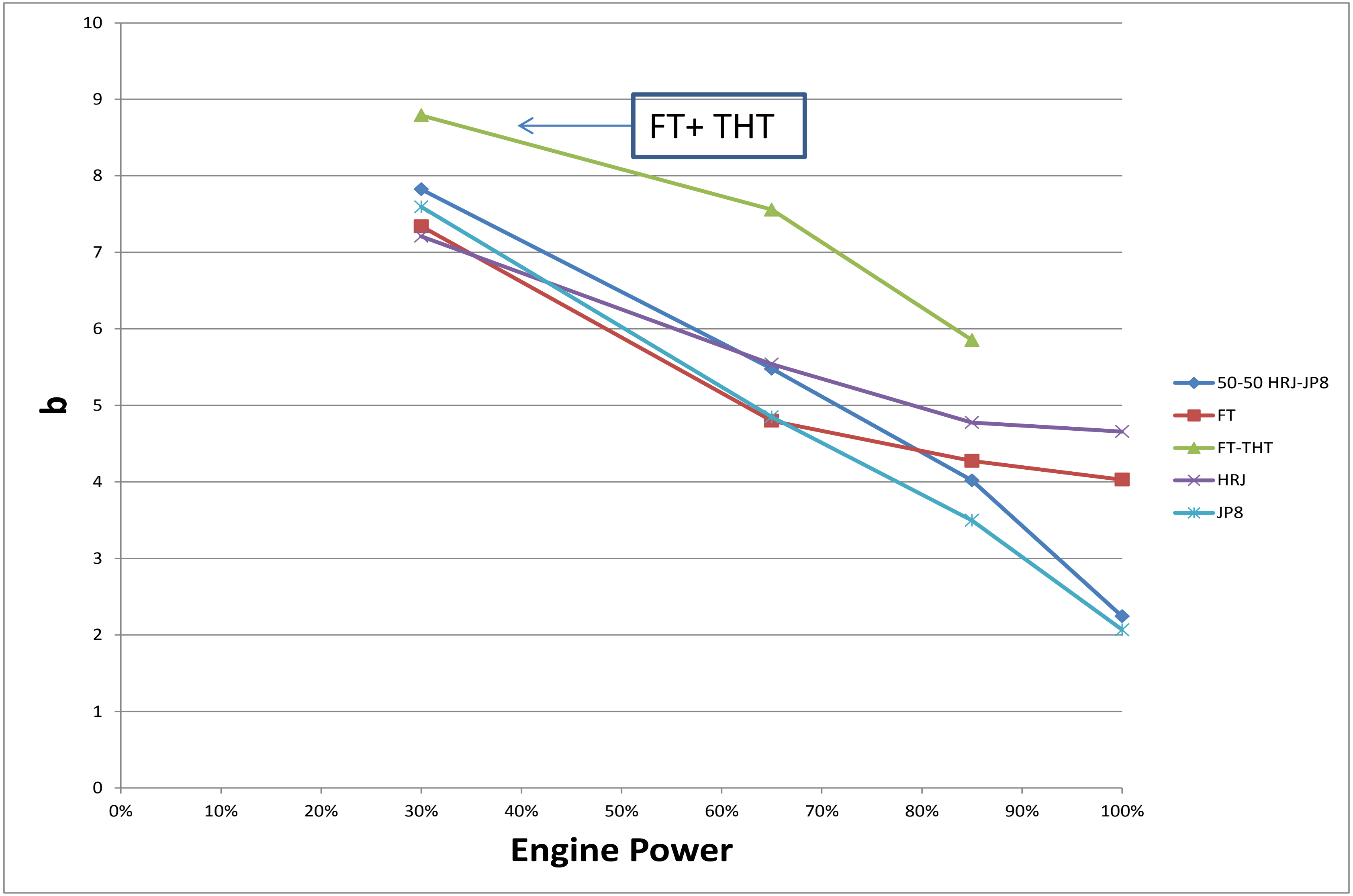
- Measure dry diameter.
- Measure wet diameter, (86% RH)
- SMF = (sol mass)/(tot mass)
- Calculate critical supersaturation (assuming soluble material sulfuric acid)

Soluble Mass Fraction (SMF) 145m



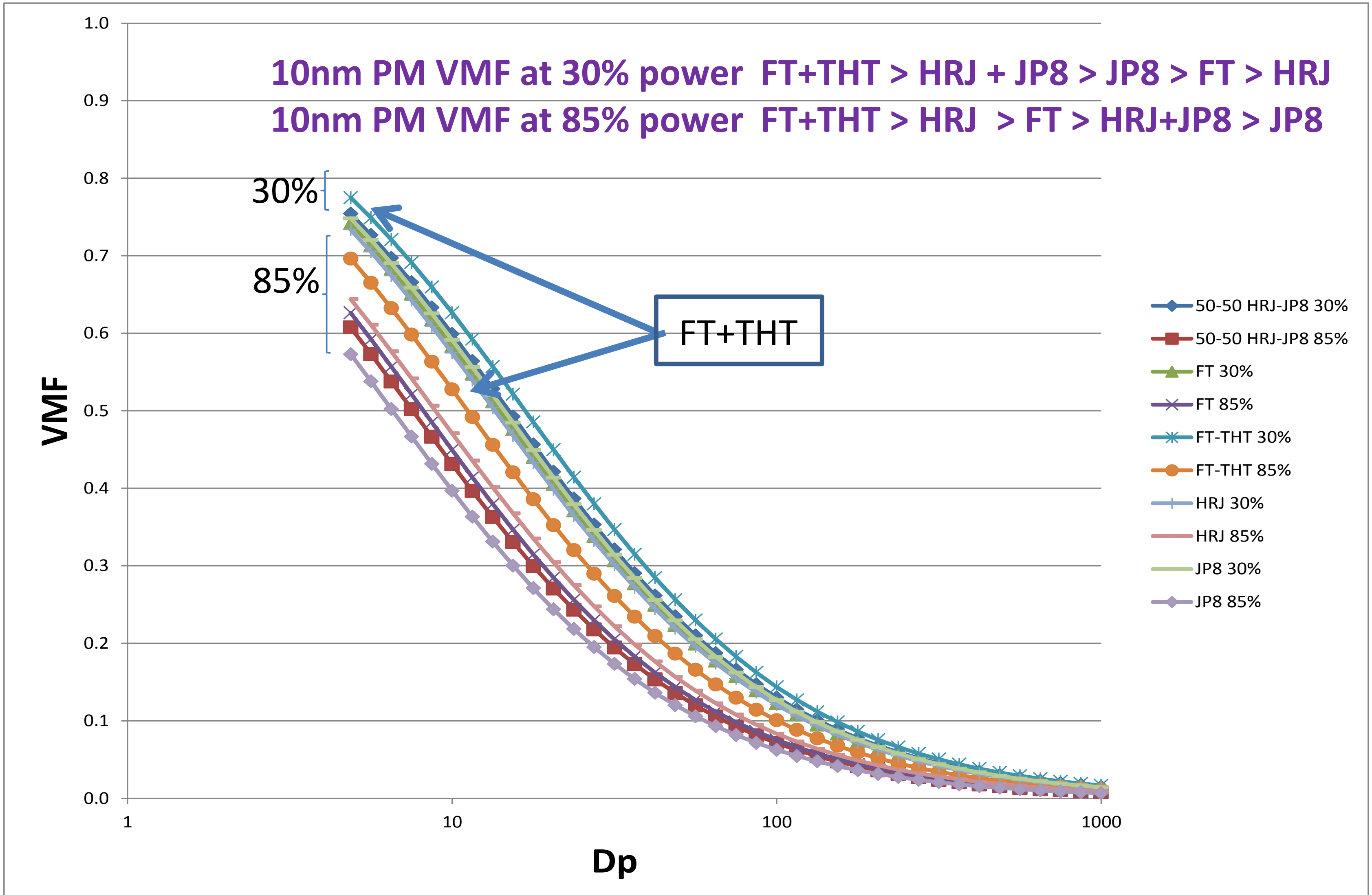
SMF increases with fuel sulfur content and engine power condition, and decreases with particle diameter

VMF Studies Proportionality Constant (b) vs Engine Power

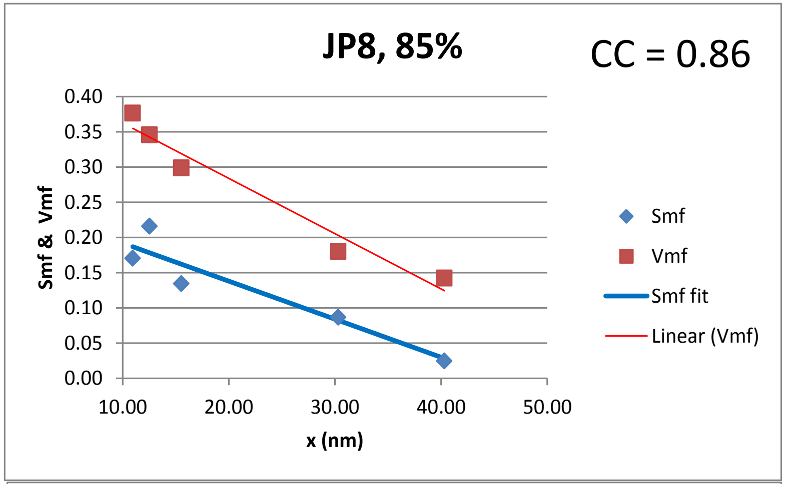


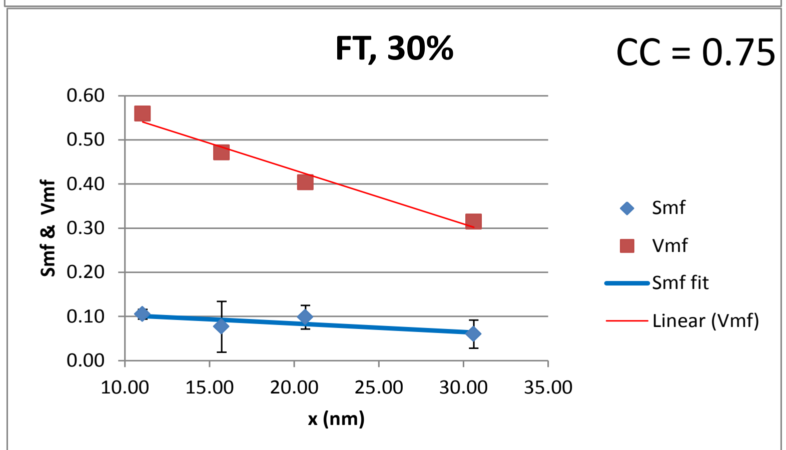
FT+THT has highest propensity for collecting volatile material, as evidenced by largest b value for the fuels studied.

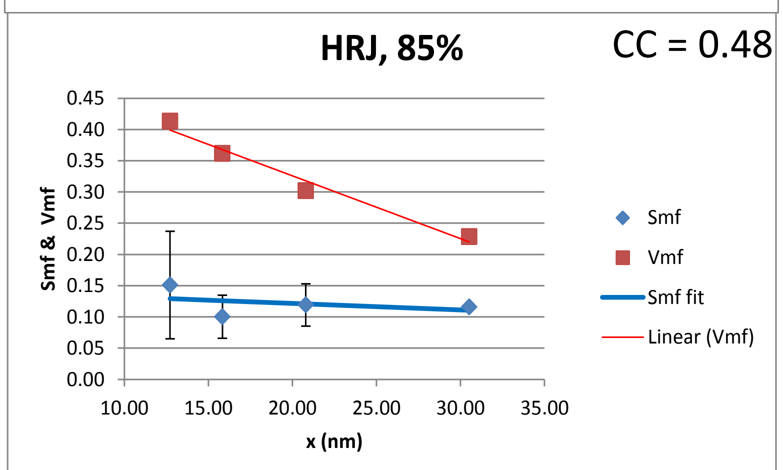
VMF vs Particle Diameter



VMF increases as engine power decreases and has its highest value for the FT+THT mixture.

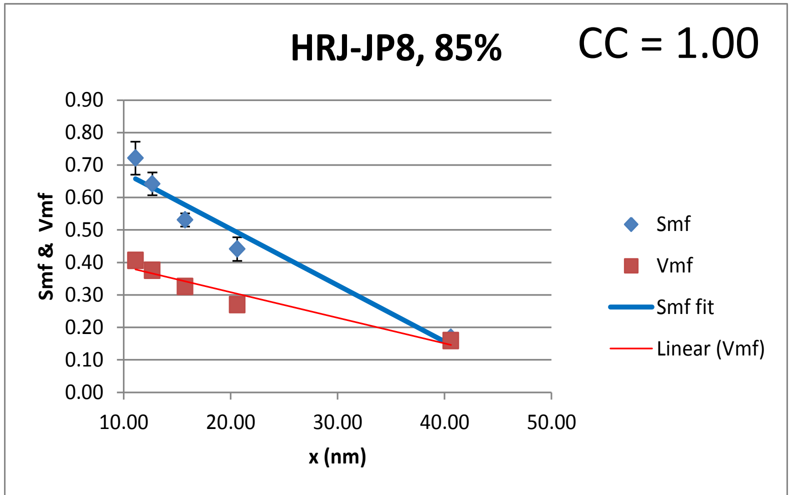


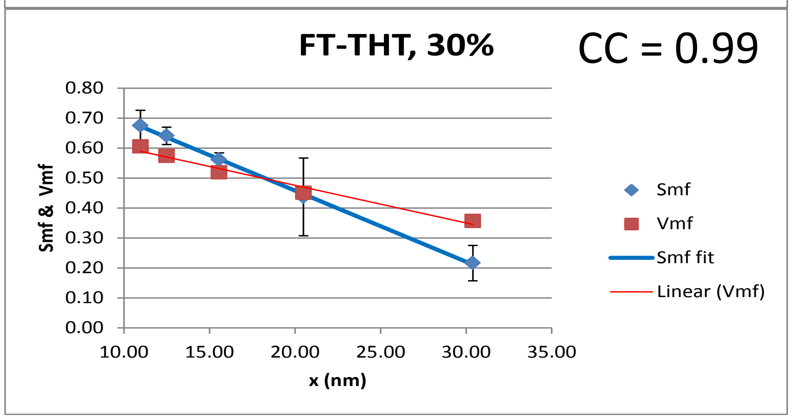


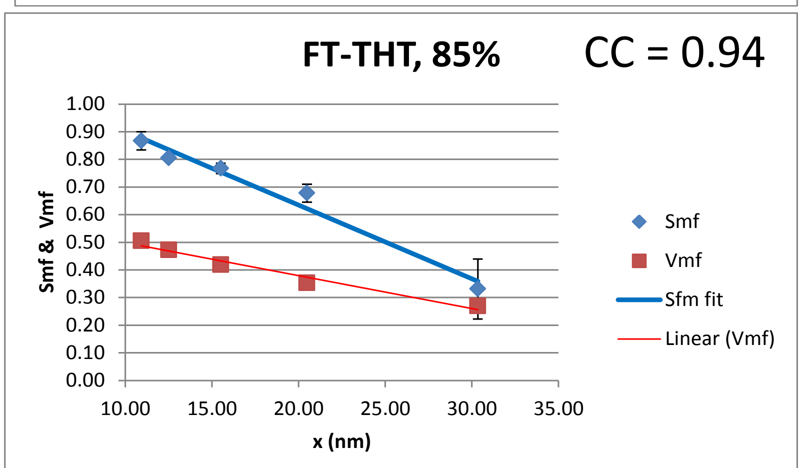


Comparing SMF and VMF as a function of particle diameter for lower sulfur fuels

For fuels with lower sulfur content their VMF values are found to be greater than SMF. This indicates that not all volatile material is water soluble, for the fuels with lower sulfur content. The CC values are correlation coefficients and reflect confidence in the linear fits to the data.







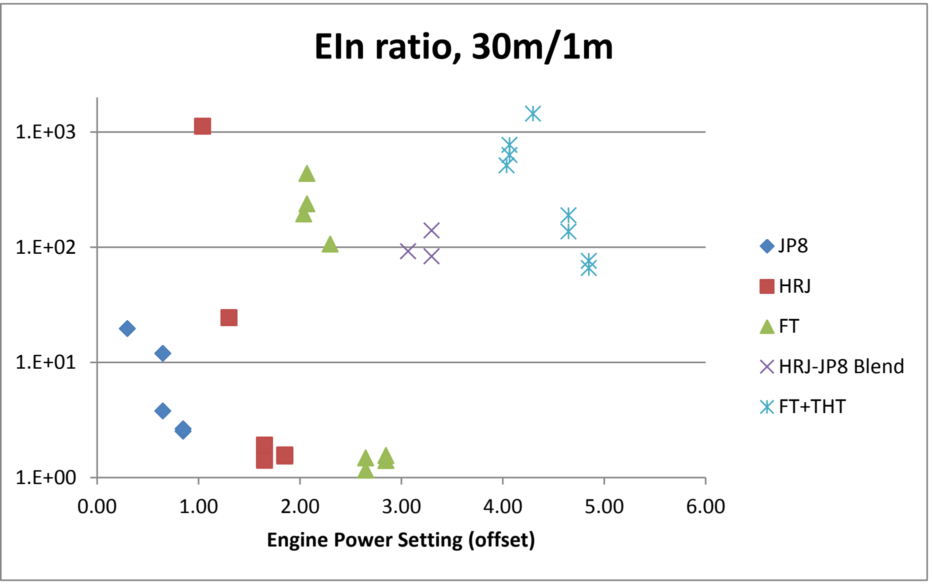
Comparing SMF and VMF as a function of particle diameter for higher sulfur fuels

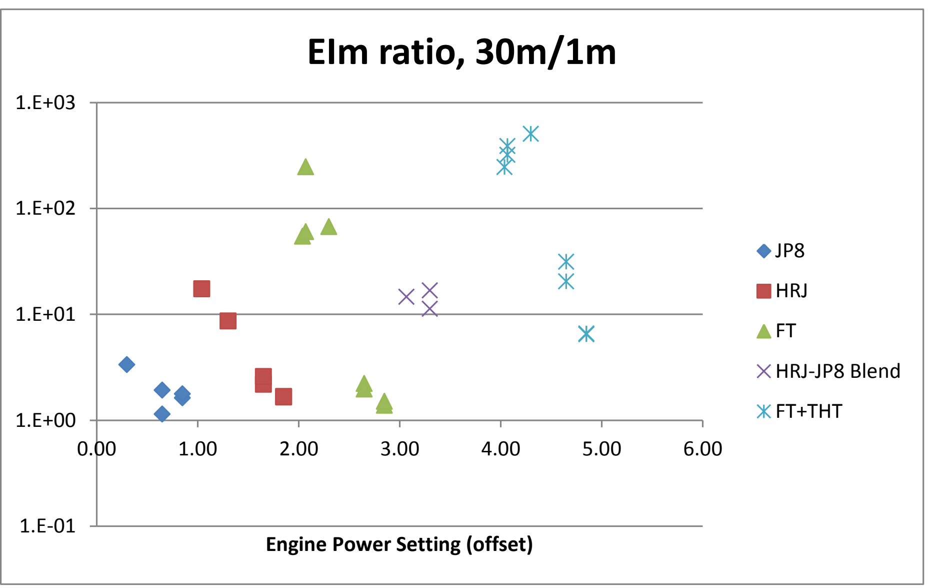
For fuels with higher sulfur content their SMF values are found to be greater than VMF. The CC values are correlation coefficients and reflect confidence in the linear fits to the data.

SMF and VMF Conclusions

- SMF can be measured via deliquescence.
- VMF can be measured via thermal desorption.
- SMF is found to:
  - Increase with fuel sulfur content and engine power
  - Decrease with particle diameter
- VMF increases with decreasing engine power and hence longer residence time in plume.
- The PM from the FT + THT fuel had highest propensity for collecting volatile material.
- For low sulfur fuels:
  - VMF > SMF
  - not all the volatile material is water soluable
- For high sulfur fuels:
  - SMF > VMF
  - SMF and VMF are highly correlated

EIn and EIm Ratios



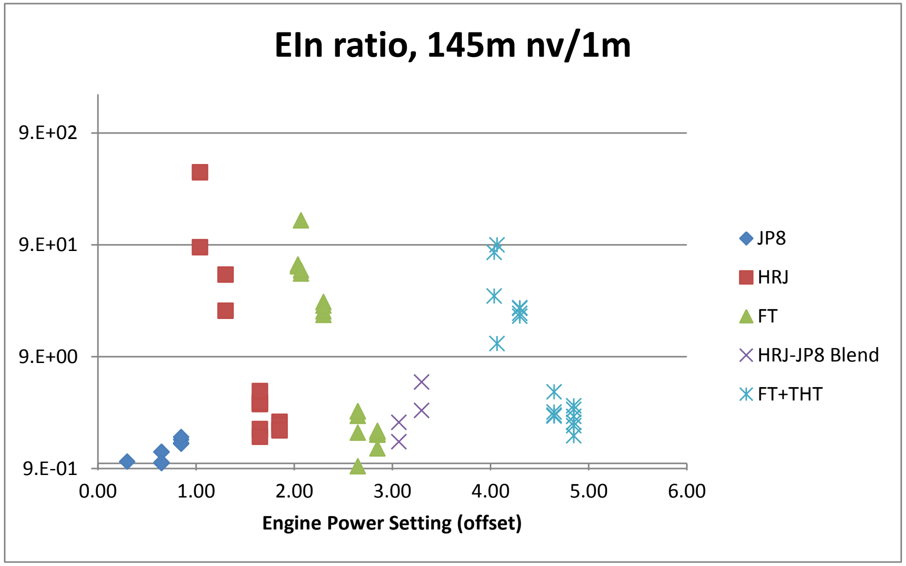


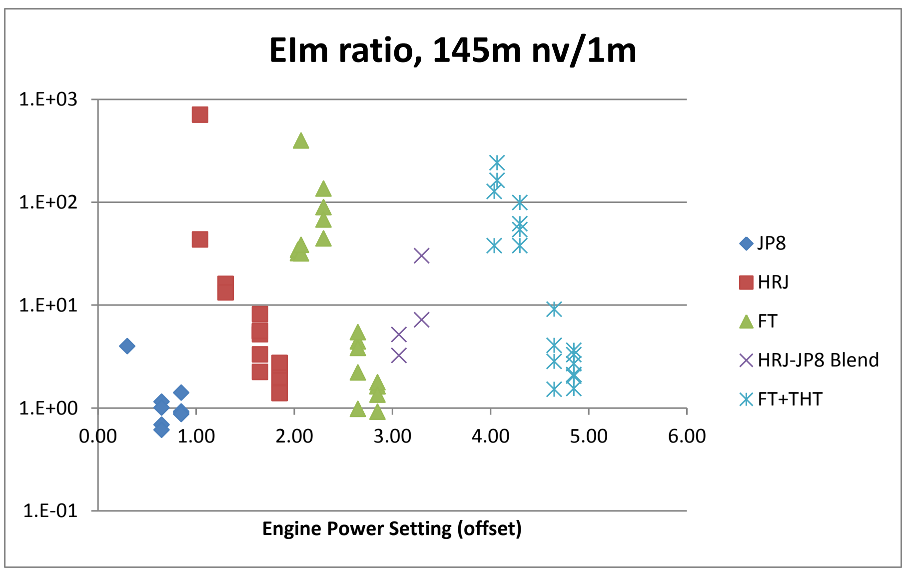
Particles (total) are generated in the near field between 1 and 30m.
PM mass is generated between 1 and 30m

Particle generation decreases as power increases.
PM mass generation decreases as power increases.

Particle generation is small at high power, except for FT+THT.
PM mass generation is small at high power, except for FT+THT.

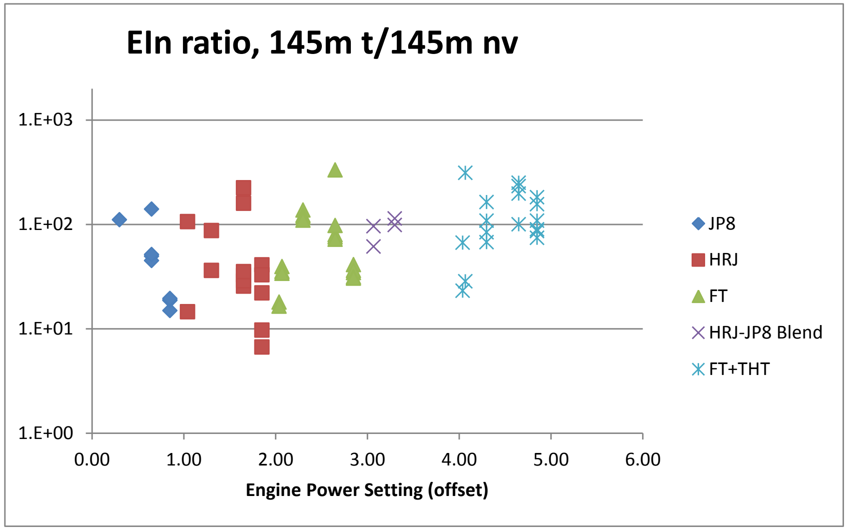
EIn and EIm Ratios

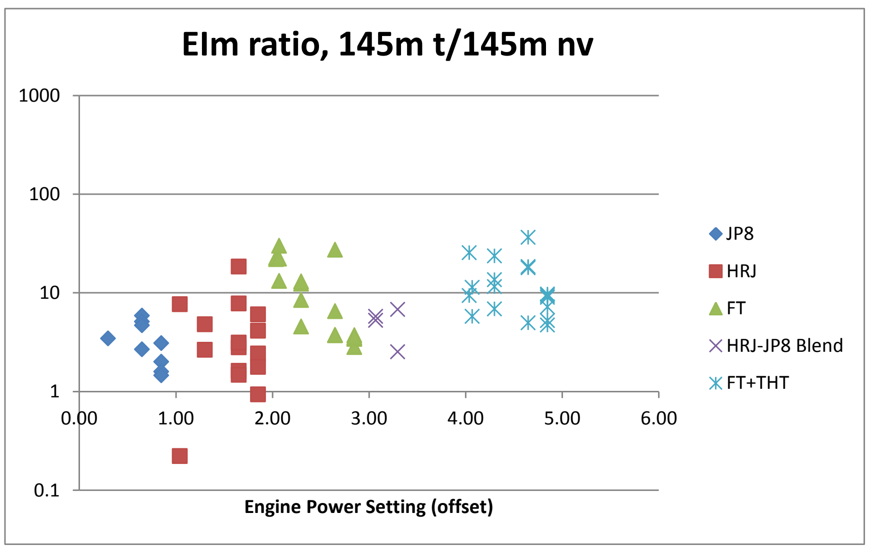




- Non-volatile particles are generated between 1 and 145m.
- PM non-volatile mass is generated between 1 and 145m.
- Non-volatile particle generation decreases with increasing engine power.
- PM non-volatile mass generation decreases with increasing engine power.
- JP8 and HRJ-JP8 blend show lowest proclivity for particle generation.
- PM non-volatile mass generation is small at high power, including the case of FT+THT.

EIn and EIm Ratios





- PM Number -
- No dependence on fuel type or engine power.
- The volatile population is greater than non-volatile population by a factor ranging from 10 to 300, with an average ~ 50.
- No dependence on engine power.
- PM Mass -
- A modest fuel dependency is observed, the total/non-volatile mass ratio increases in the order: JP8, HRJ-JP8 mix, HRJ, FT, FT+THT.
- The volatile population is greater than non-volatile population by a factor ranging from 1 to 25, with an average ~ 7.
- The ratio EI number average >> EI mass average ➔ the volatile particles are small.

Acknowledgements

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- Several particle measurement instrument companies.

Back up Slide – Legend for tandem DMA system