Engine Crankcase Particulate Matter: Measurement Issues

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Introduction

- We were asked to find the reasons for unexpected temperature dependent performance of crankcase particle control devices

- This work describes examination of this issue with two types of crankcase particle control devices
    - Coalescing filter
    - Rotating Inertial Separator

- Other particle sources that may have similar issues include, vents on transmissions, hydraulic machines, etc.

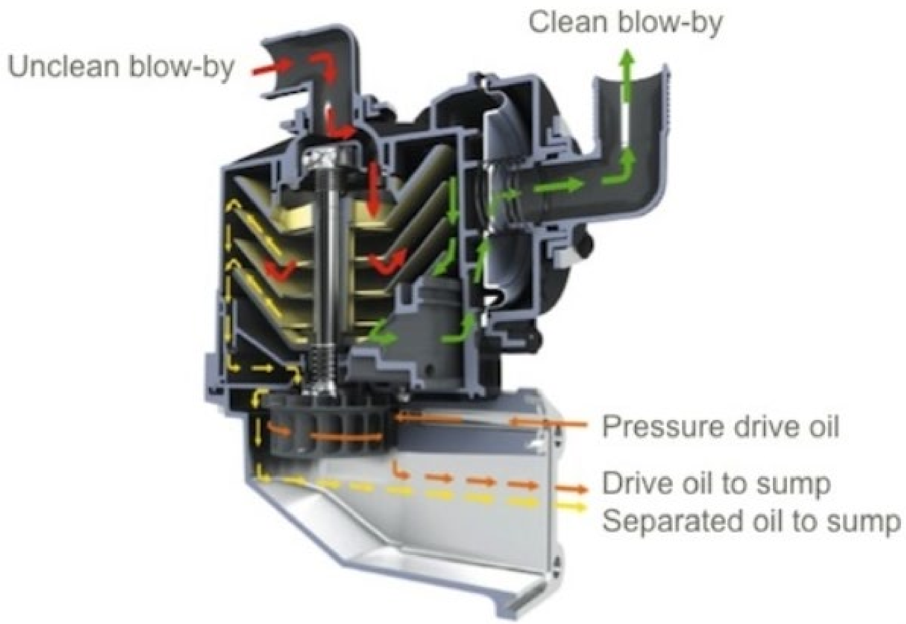
Background

- There is a small amount of leakage of combustion products, particles and gases, past the piston rings of reciprocating engines, approximately 1% of exhaust flow
- Traditionally either recycled to intake or vented to atmosphere
- If untreated, may foul intake components, or if vented to the atmosphere can constitute a significant emission source
    - Recent road tunnel study suggests unburned lube oil from combination of crankcase fumes and leakage are major sources of primary organic aerosol[1]
    - Four heavy-duty engines with DPFs and crankcase separators showed an average increase in PM emissions of 70% when crankcase fumes were included[2]
    - New EPA proposed standard requires heavy-duty highway CI engines from 2027 MY to be equipped with closed CV systems[3]
    - Not a new issue, first passenger car emission control system, positive crankcase ventilation, required by CA starting in 1961

[1]Worton, et al., 2016, Lubricating Oil Dominates Primary Organic Aerosol Emissions from Motor Vehicles
[2]Khalek, et al., 2009. Phase 1 of the Advanced Collaborative Emissions Study, Final Report, Coordinating Research Council, Inc.
[3]EPA, "Proposed Rules: Control of Air Pollution From New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards ," Vol. 87, No. 59 , Mar. 2022.

Devices tested

Coalescing filter element on left, saturated with oil, continuously draining, housing on right

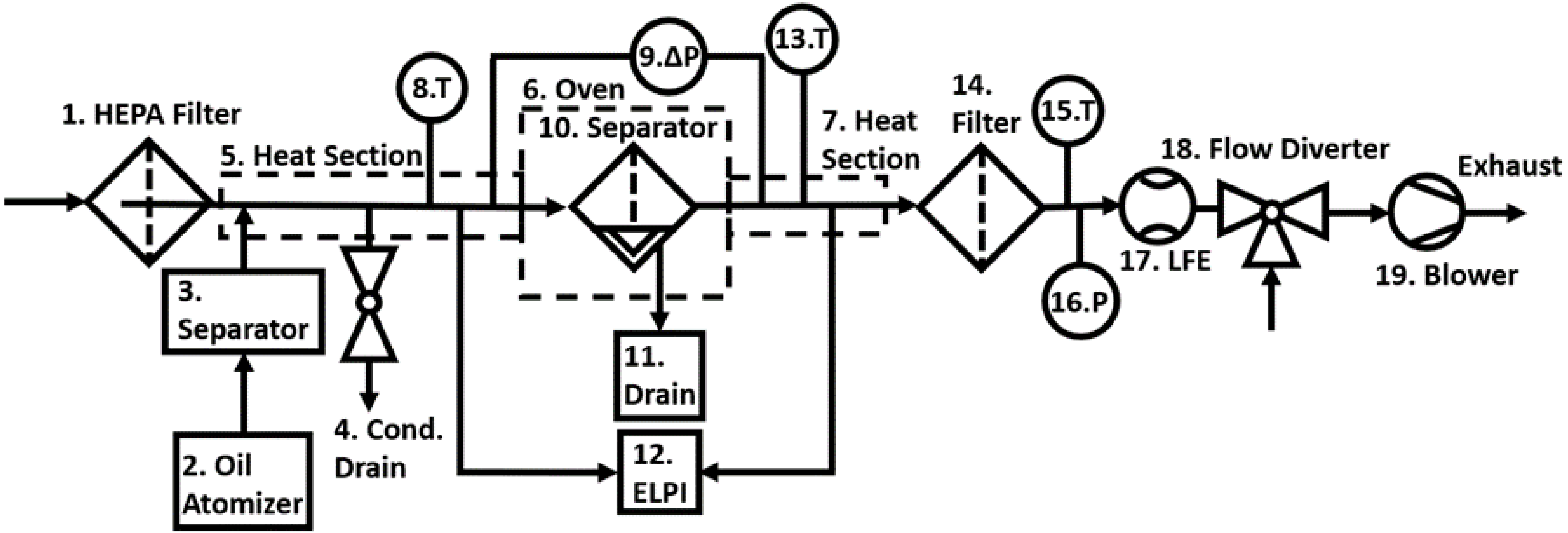


Inertial separation
Alfex g centrifugal separator shown here, *but not the one used in our tests*

Apparatus

- The crankcase aerosol removal device testing apparatus designed to meet ISO 17356-4 requirements for CV laboratory based fractional efficiency testing
- The system was designed to maintain isothermal conditions throughout
    - Inlet isokinetic sampling section
    - Oven housing removal device
    - Outlet isokinetic sampling section
- Palas PLG 2100 aerosol generator
    - Heated oil-bath reservoir generates polydisperse submicron oil aerosols with Laskin nozzle.
    - Particle size range like that of crankcase fume particles
- Dekati Electrical Low-Pressure Impactor used to measure particle size and concentration
    - Sizes by aerodynamic diameter
    - 12 size bins from 0.044 to 8.46 μm
- Range test with temperatures from 30 to 115 °C
- Range of standard and unconventional test oils

Apparatus



1. HEPA Filter
2. Oil Atomizer
3. Separator
4. Cond. Drain
5. Heat Section
6. Oven
7. Heat Section
8.T
9.ΔP
10. Separator
11. Drain
12. ELPI
13.T
14. Filter
15.T
16.P
17. LFE
18. Flow Diverter
19. Blower
Exhaust

Oil Properties

Density (g/cm^3)				
Temp.	Standard 15W-40	High Vol. 15W-40	Low Vol. 15W-40	Vacuum Pump Oil
40°C	0.85	0.84	0.81	0.82
80°C	0.83	0.81	0.78	0.79
100°C	0.81	0.80	0.77	0.78

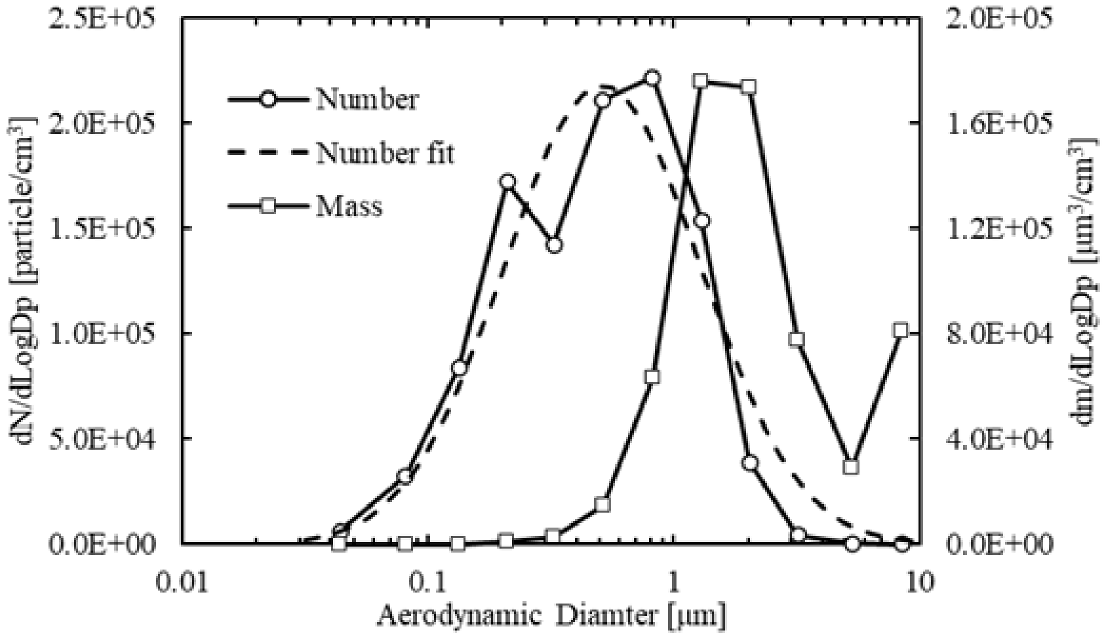
Surface Tension (mN/m)				
Temp.	Standard 15W-40	High Vol. 15W-40	Low Vol. 15W-40	Vacuum Pump Oil
40°C	25.31	29.35	28.03	28.45
80°C	23.21	25.98	25.19	25.89
100°C	22.04	24.74	23.66	24.17

Dynamic Viscosity (Pa s)				
Temp.	Typical 15W-40*	High Vol. 15W-40	Low Vol. 15W-40	Vacuum Pump Oil
40°C	0.037	0.035	0.027	0.043
80°C	0.009	0.009	0.008	0.012
100°C	0.006	0.006	0.005	0.008

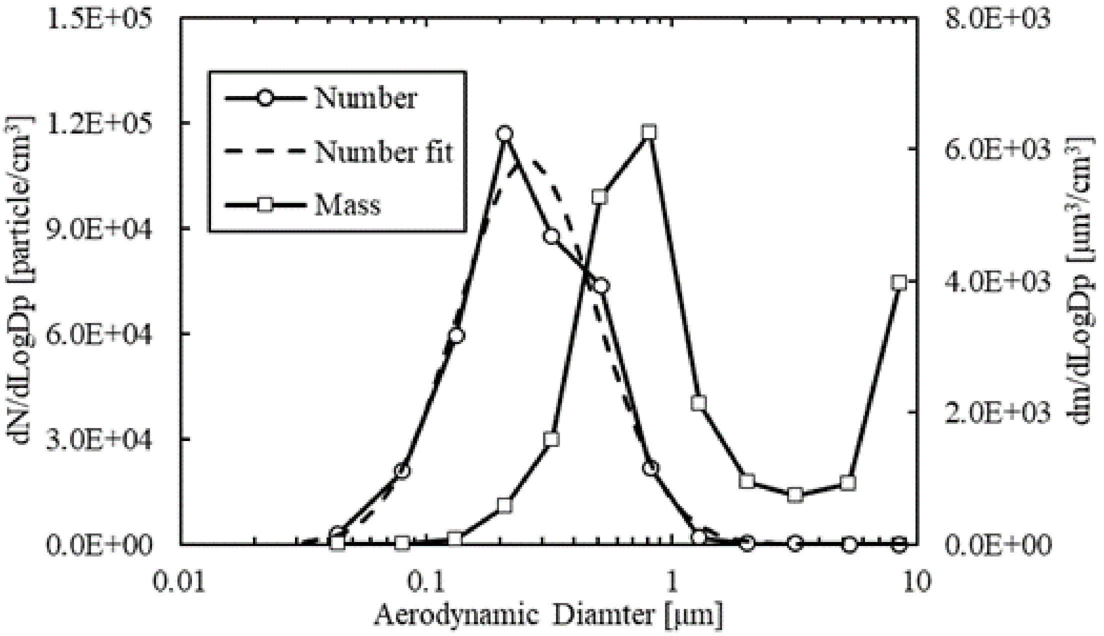
Noack TGA Evaporation Percent [%] at 250°C			
Standard 15W-40	High Vol. 15W-40	Low Vol. 15W-40	Vacuum Pump Oil
8.4-11	16.6	6.4	1.3

Coalescing Filter Performance – typical upstream and downstream size distributions, overall penetration

Upstream Base oil standard 10W-40, 25 °C

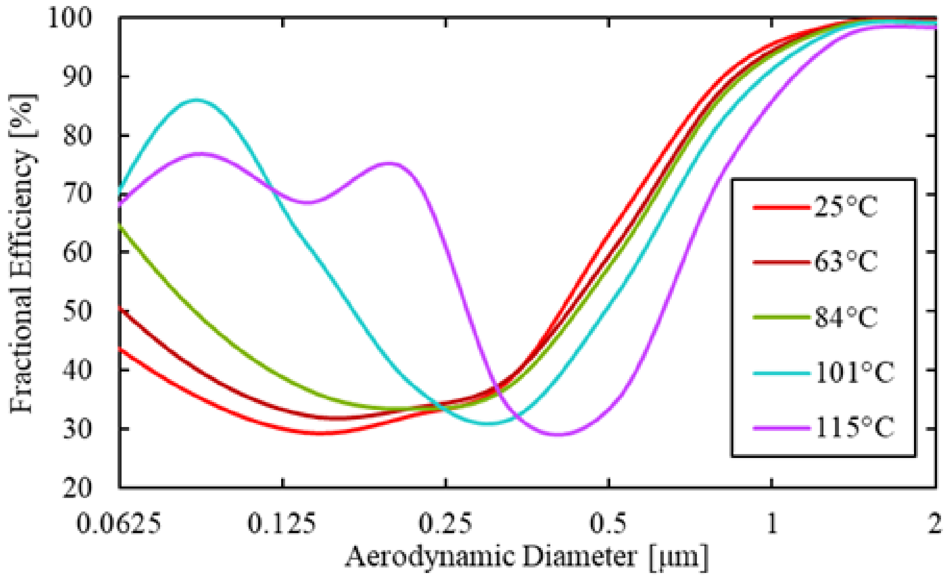


Downstream Base oil standard 10W-40, 25 °C

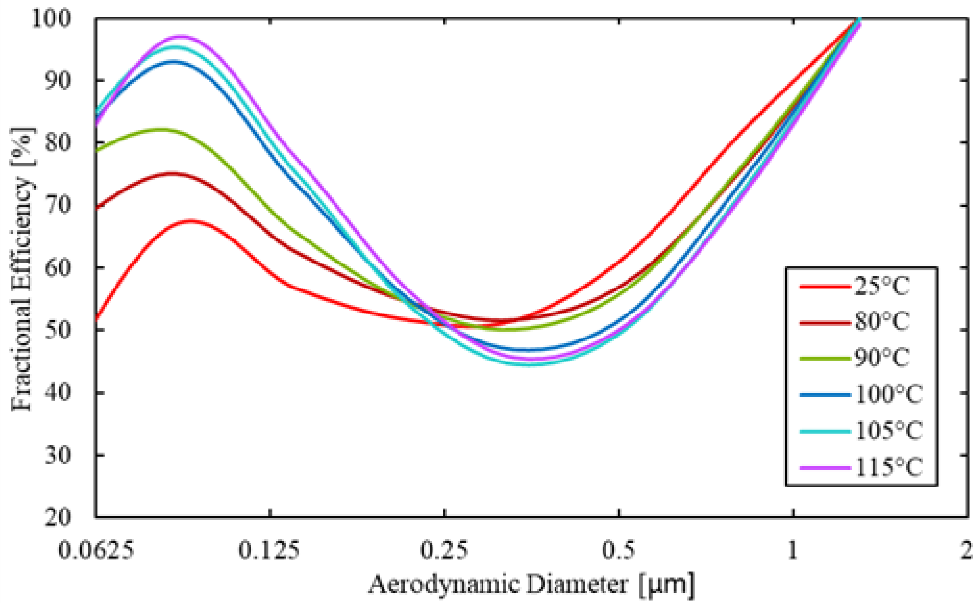


Coalescing Filter Performance – significant shifts in efficiency with temperature and oil volatility

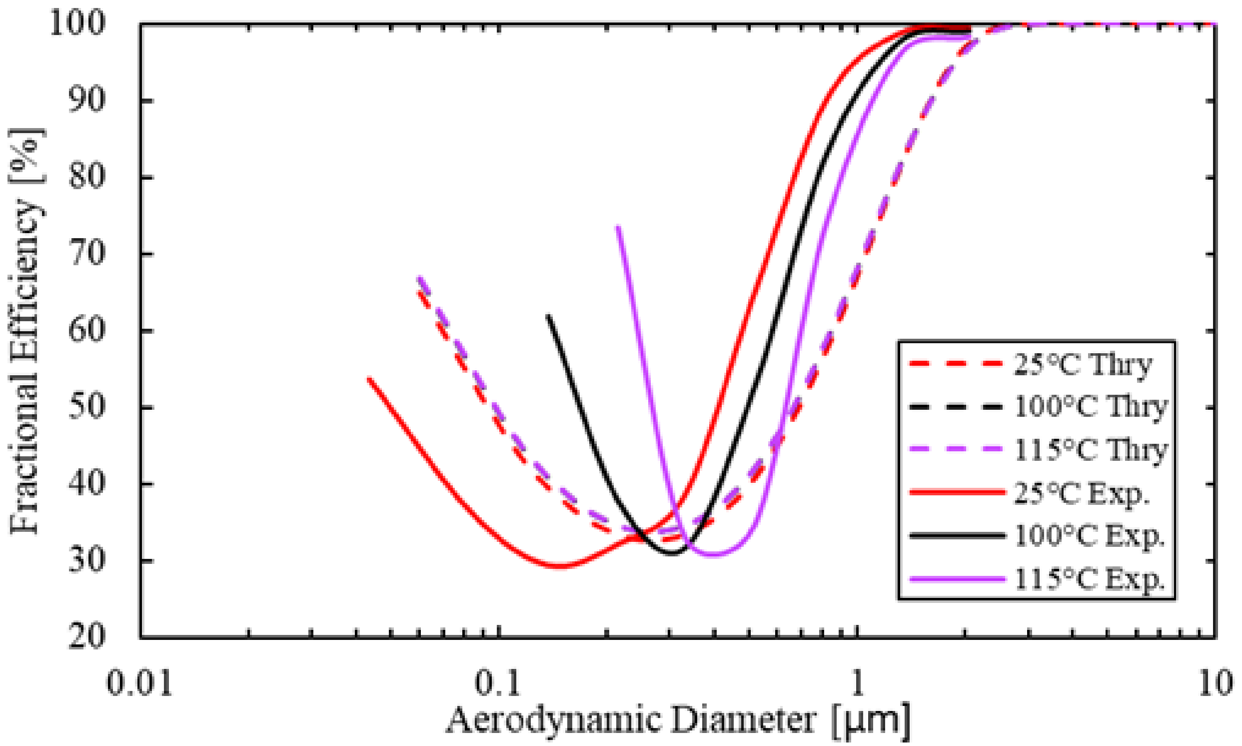
Typical 15W-40 Oil



Low volatility 15W-40 Oil

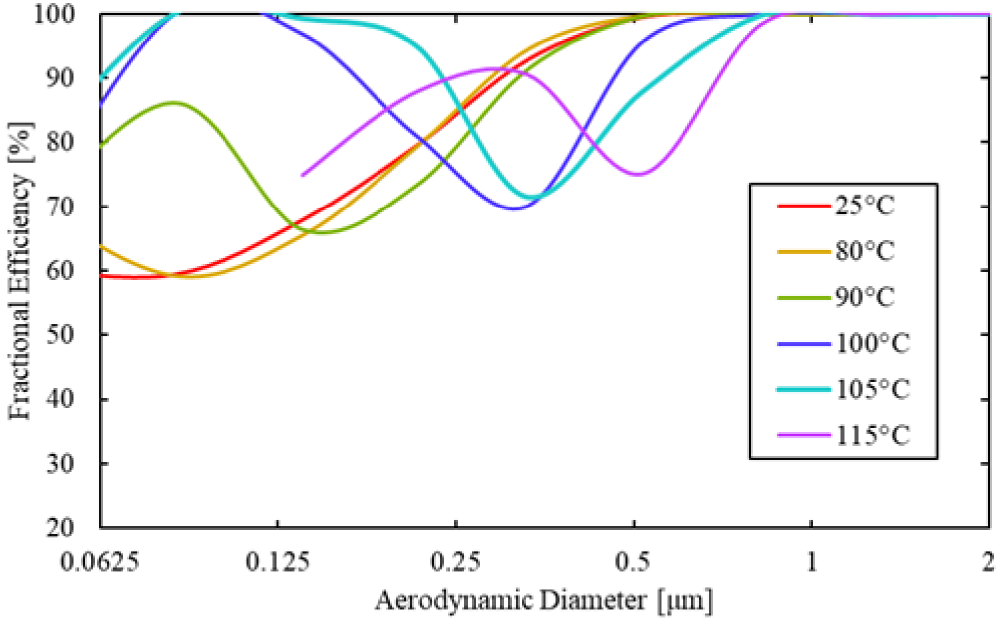


Coalescing Filter Performance – simple filtration theory does not predict temperature dependence



Performance of Rotating Inertial Separator – similar volatility dependent performance

Typical 15W-40 Oil



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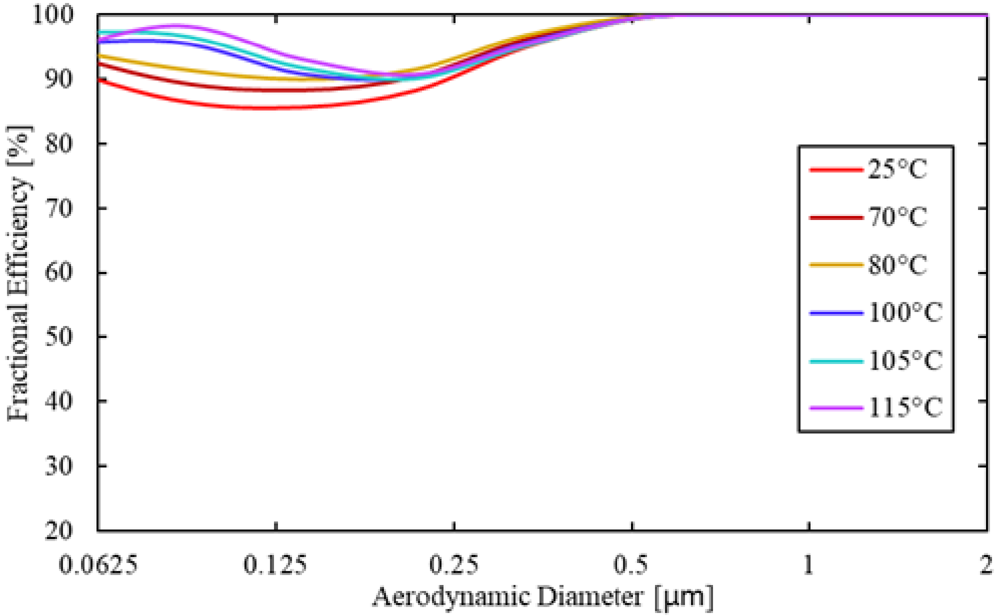
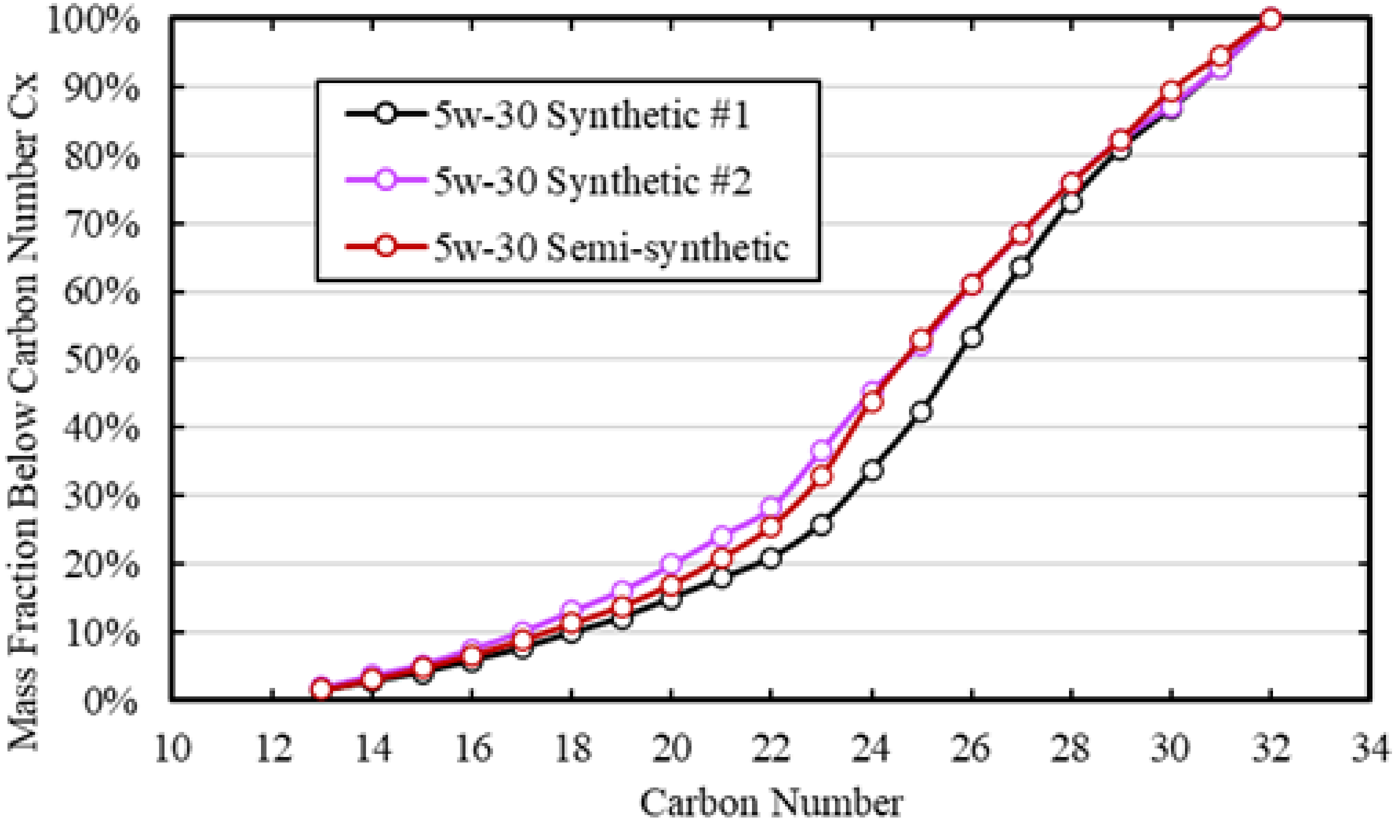


Typical Lube Oil Composition



Droplet Evaporation and Growth Times

Evaporation Time For Normal Alkane Droplets C20, C24, C28 versus Temperature, Initial Diameter, Dp=0.5µm

	Evaporation Time [s]		
T [°C]	C20	C24	C28
25	53.28	1536.03	67785.72
70	0.25	5.35	120.33
80	0.09	1.85	36.58
90	0.03	0.68	11.86
100	0.014	0.26	4.08
110	0.006	0.11	1.48

Residence time in heated section ~ 3 s

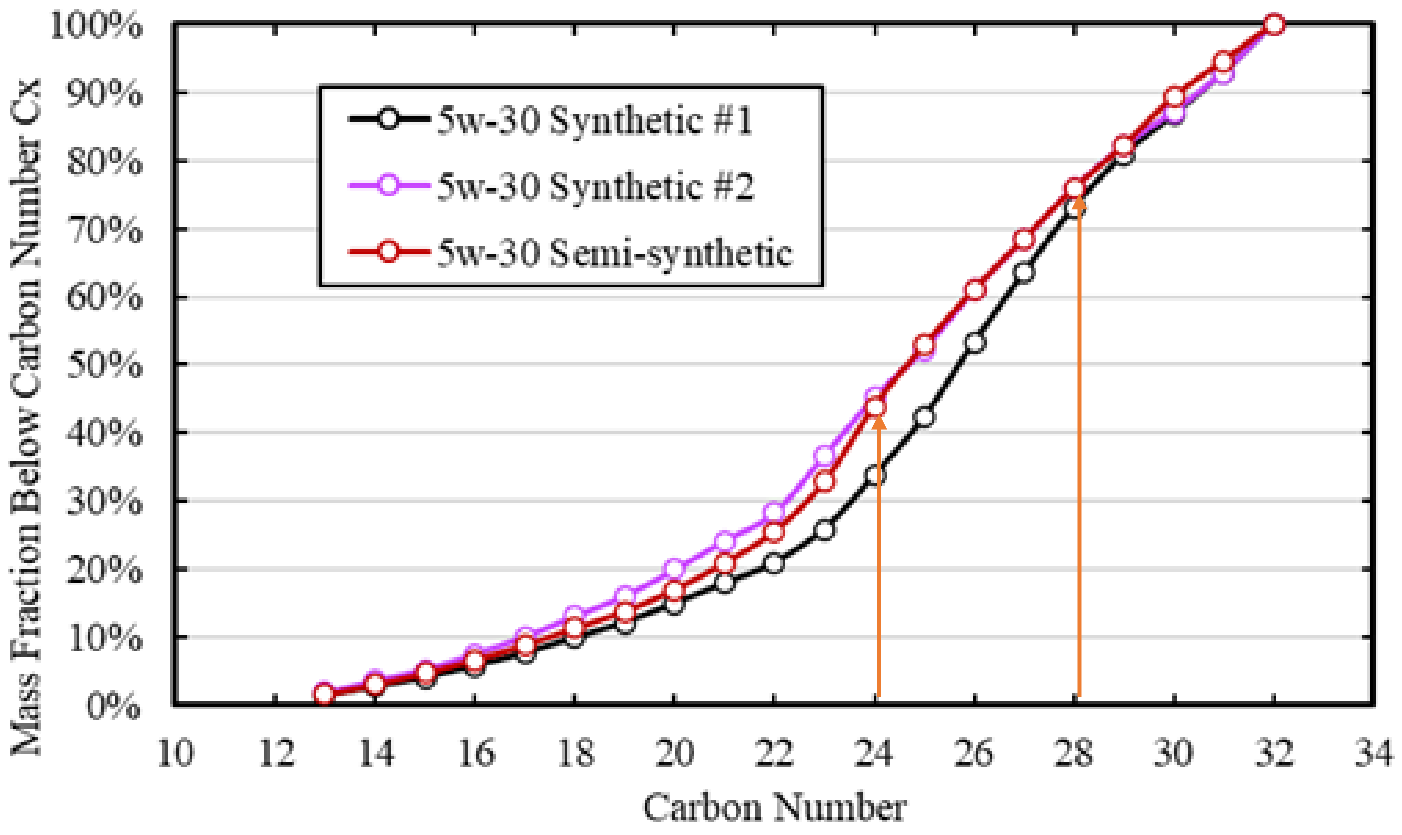
Growth Rate For Normal Alkane Droplets, C20, C24, C28 versus Temperature, Initial Diameter, Dp=0.5µm

	Growth Rate [µm/s]		
T [°C]	C20	C24	C28
90	8.43	0.44	0.03
100	21.40	1.16	0.07
110	51.82	2.95	0.21
115	79.30	4.62	0.35

Residence in sampling lines ~ 10 s

Plenty of time for evaporation and growth

Typical Lube Oil Composition



Evaporation could lead to 45 – 75% mass loss, 18 to 37% diameter reduction

Causes of apparent temperature dependent changes in removal efficiency

- During sampling and measurement particles are in dynamic equilibrium with their vapors, there is no dilution, so vapors are not lost
- Particles shrink in inlet system but grow again when they pass from upstream measurement port to instrument
- Particles remain small in isothermal removal device and a filtered or processed at this reduced size
- Particles grow again when they pass from downstream measurement port to instrument
- Particles being treated are not the particles being measured

How should these particles be measured?

- To determine device performance at temperature
  - Measurement systems operating at same temperature as the device
  - Dilution probes

- But… in actual application particles will regrow as they cool through outlet duct

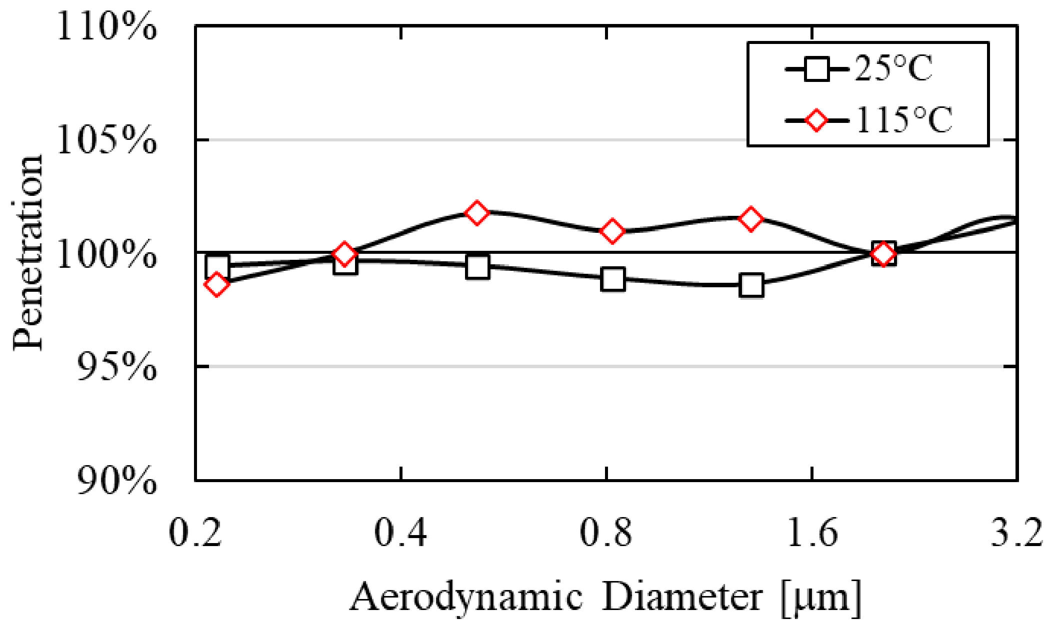
- Take care!

Thank You, questions?

Extra slides

Shrinkage and regrowth

- Penetration through system without an oil separation device
- There appears to be no change in particle size or concentration
- Shrinkage and regrowth are fast enough that heating and coolant produces no apparent changes in the particles



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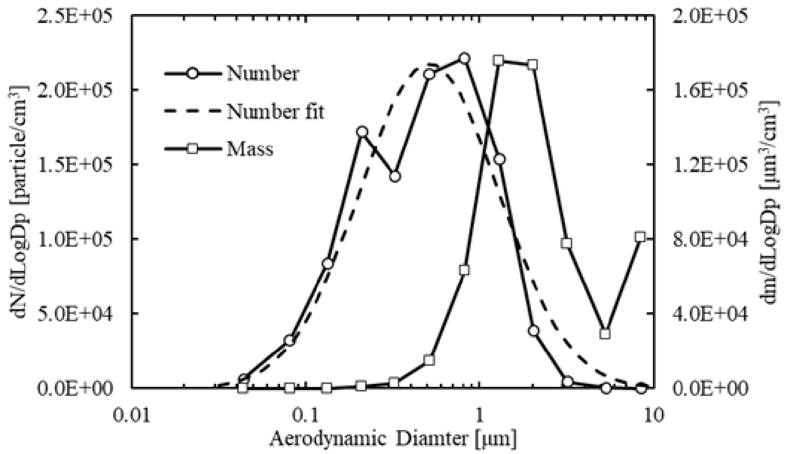
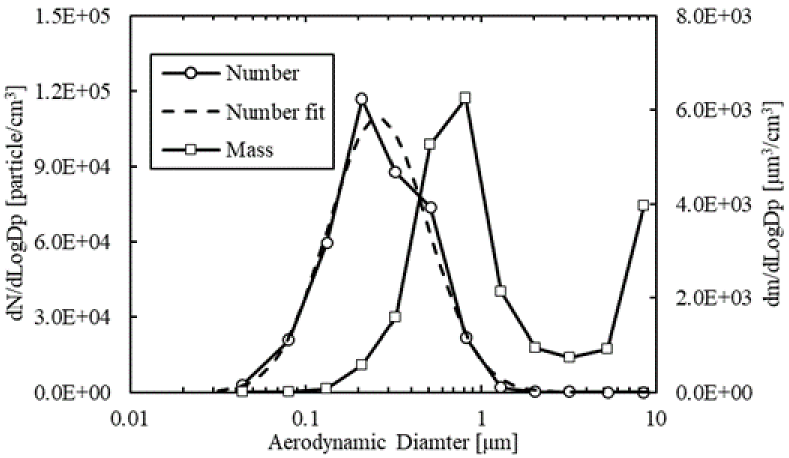
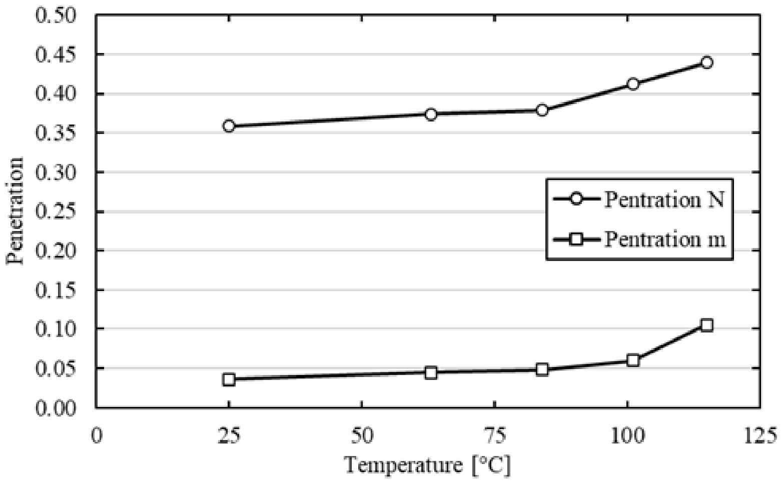


Downstream Base oil standard 10W-40, 25 °C





Current crankcase emission management

- In summary for Diesel –
  - High Horsepower (engines greater than 15-20L) – tend to be Open Crankcase – although there are some closed. This includes mining, rail, marine, power generation, oil & gas, etc.
  - Heavy Duty in North America – tend to be Open Crankcase
  - Heavy Duty in Europe – tend to have moved to Closed Crankcase
  - Light Duty in North America - can be open or closed.
- For Natural Gas or the upcoming Hydrogen combustion engines that are being proposed, will be closed crankcase.