Sedimentation field flow fractionation (SdFFF)

of soot particles emitted by a light duty diesel

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- Soot fractionation and size analysis by OMT
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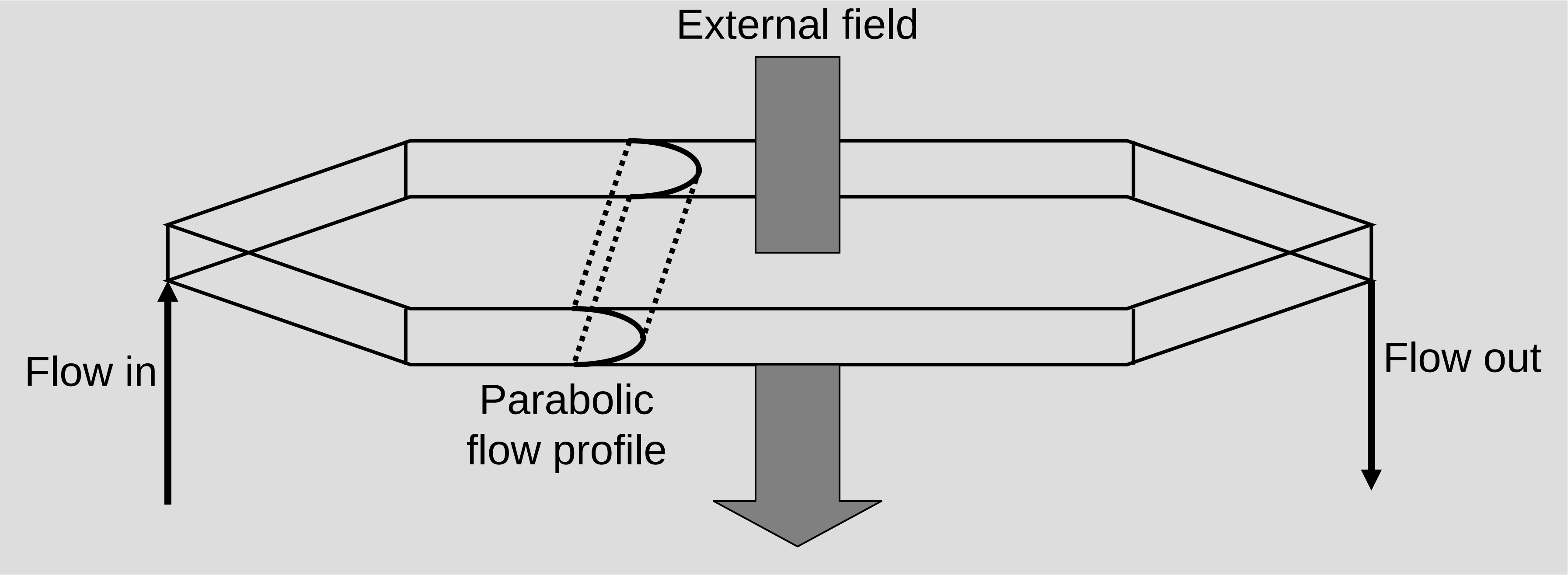
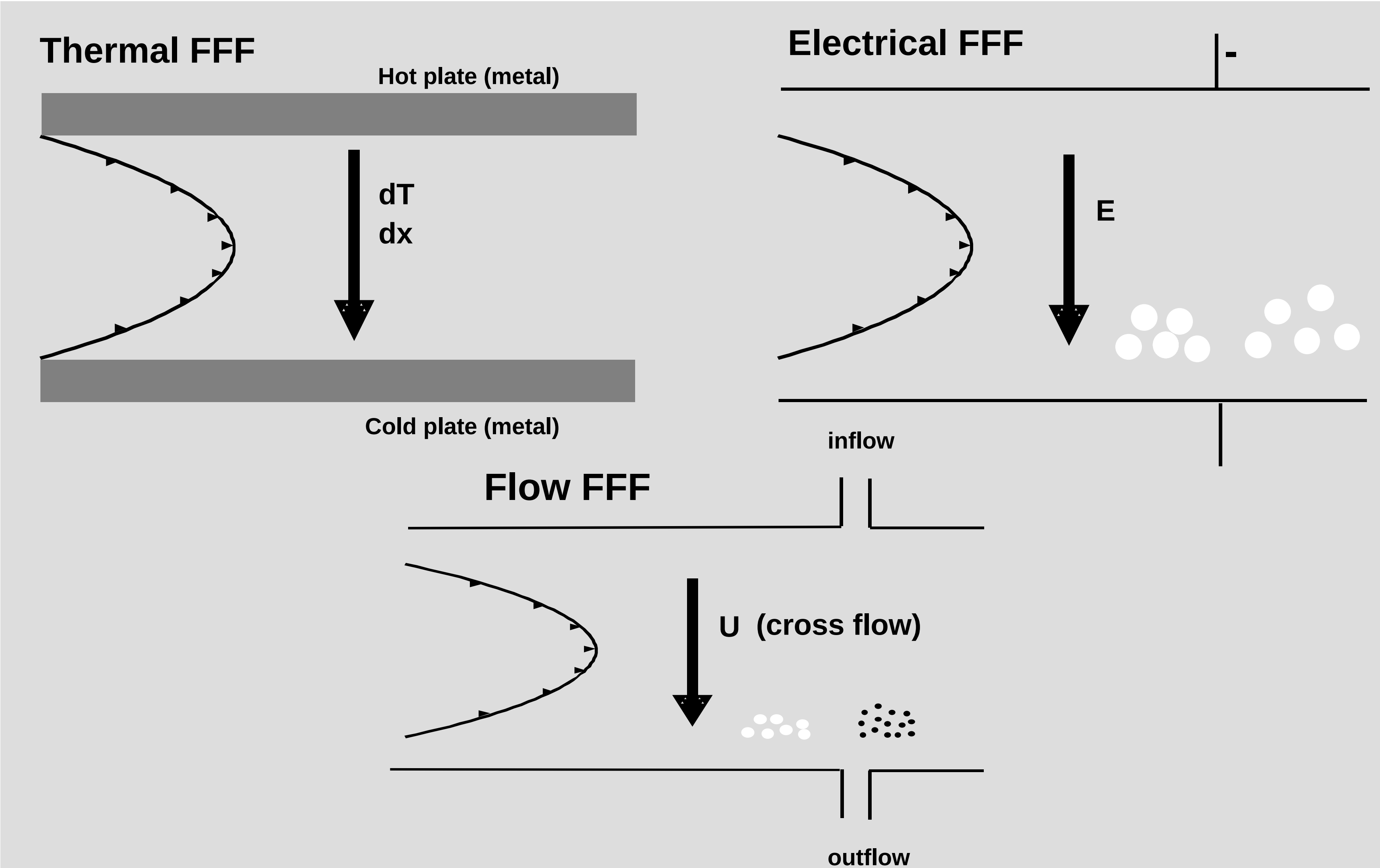
- Conclusion

Field Flow Fractionation (FFF)

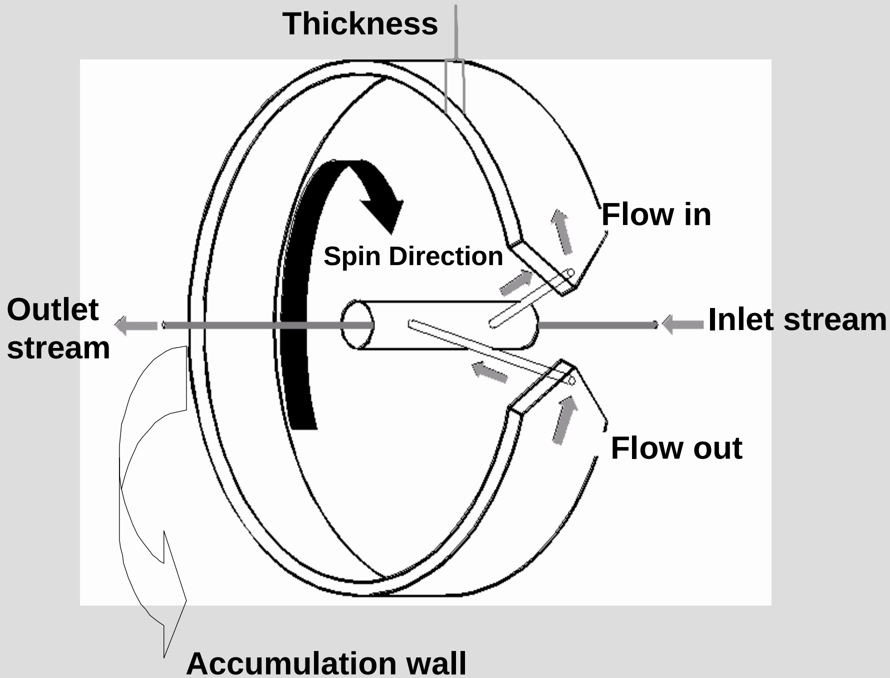
- First conceptualized by Giddings 1960s
- Separation occurs inside a thin ribbonlike channel clamped between two highly polished plane and parallel walls

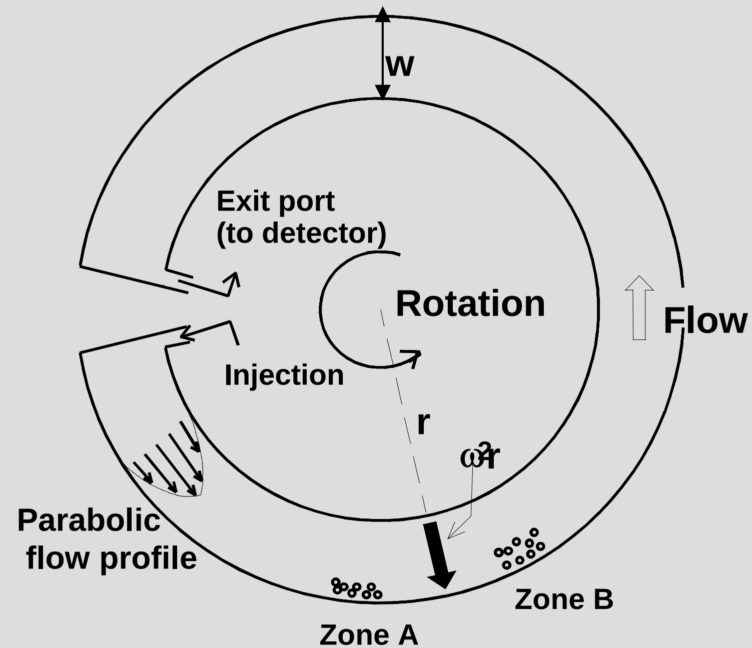


Overview on FFF subtechniques

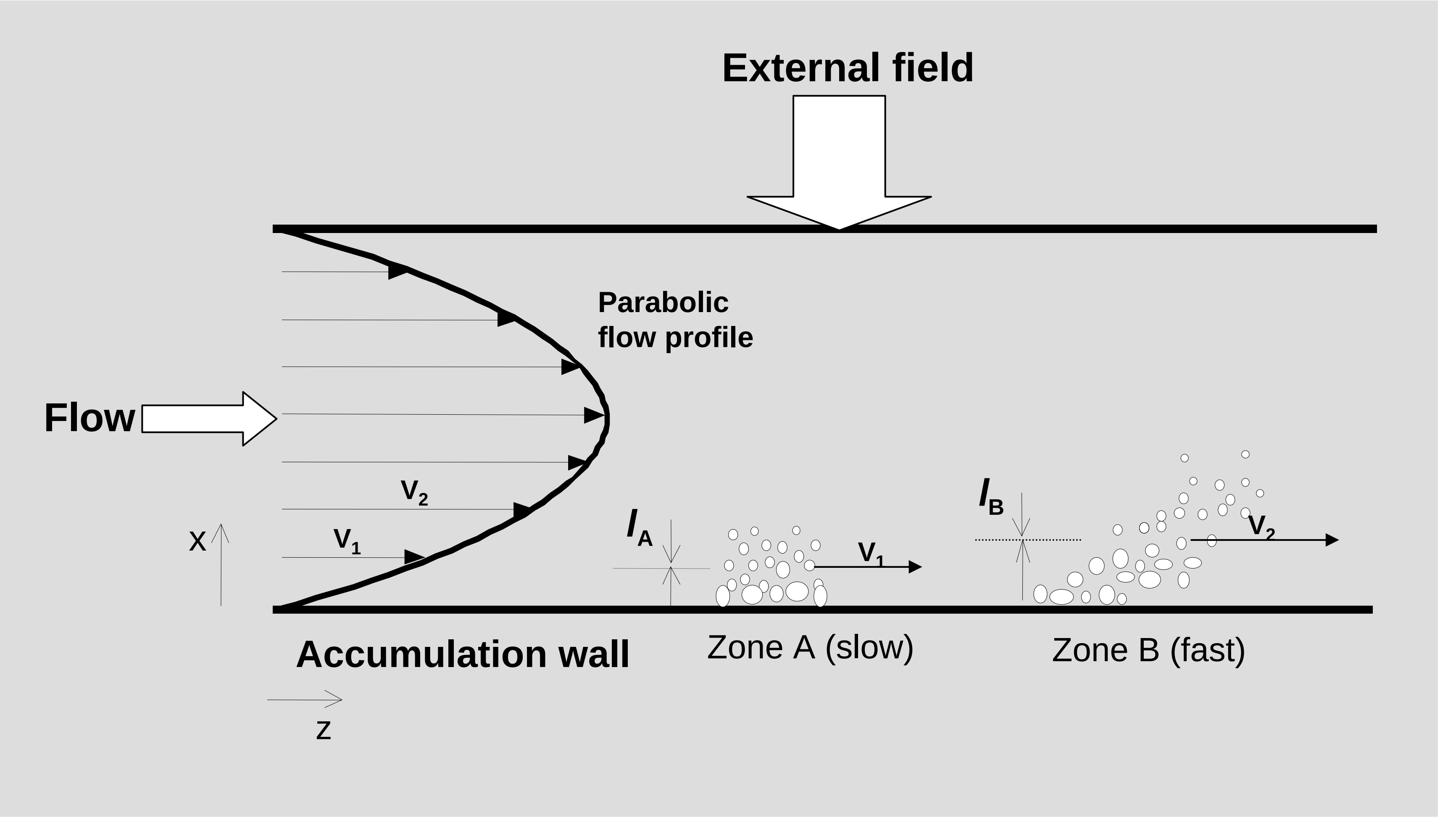


Sedimentation FFF (SdFFF)

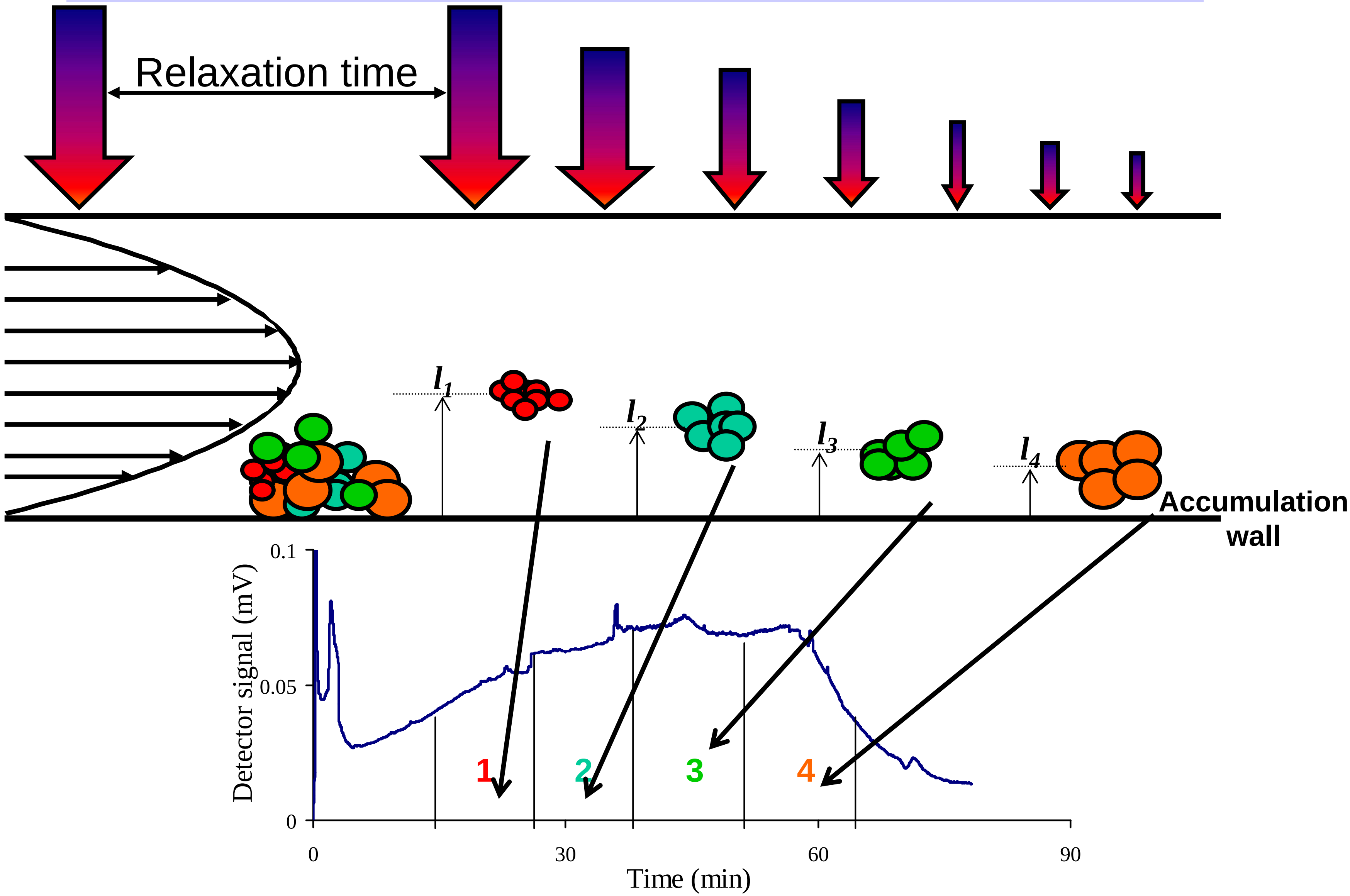




Retention in the normal mode



Sedimentation field programming

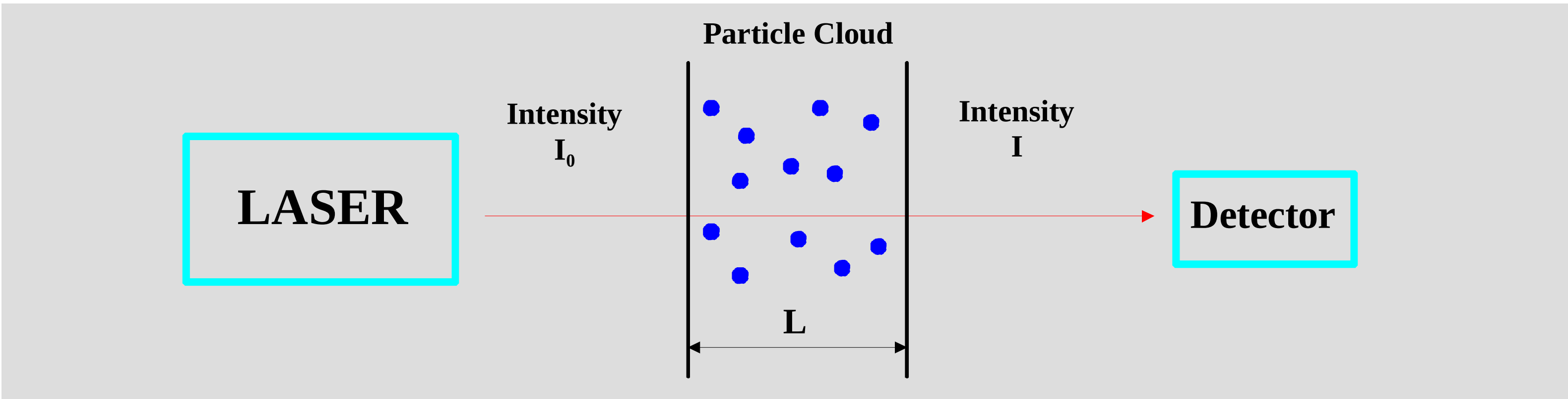


Off-line hyphenation of OMT with SdFFF

Combining the size separation technique SdFFF with the particle sensor OMT (Optical Multiwavelength Technique WIZARD DQ):

- Benefit from the separation potential of SdFFF to measure the mean particle sizes of collected fractions obtained from broadly distributed particulate sample
- Confirmation whether a selective FFF separation occurred according to the concerned elution mode
- Obtained sizes can be compared to those determined by other sizing techniques such as EM and PCS

Dispersion Quotient Technique (1): OMT principle



monodisperse

$$I \;=\; I_0 \cdot \exp\{-N \cdot L \cdot \pi \cdot r^2 \cdot Q_{ext}(r,\lambda,n)\}$$

polydisperse

$$I \;=\; I_0 \cdot \exp\{-L \cdot N \cdot \pi \cdot \int r^2 \cdot Q_{ext}(\lambda,r,n) \cdot p(r)dr$$

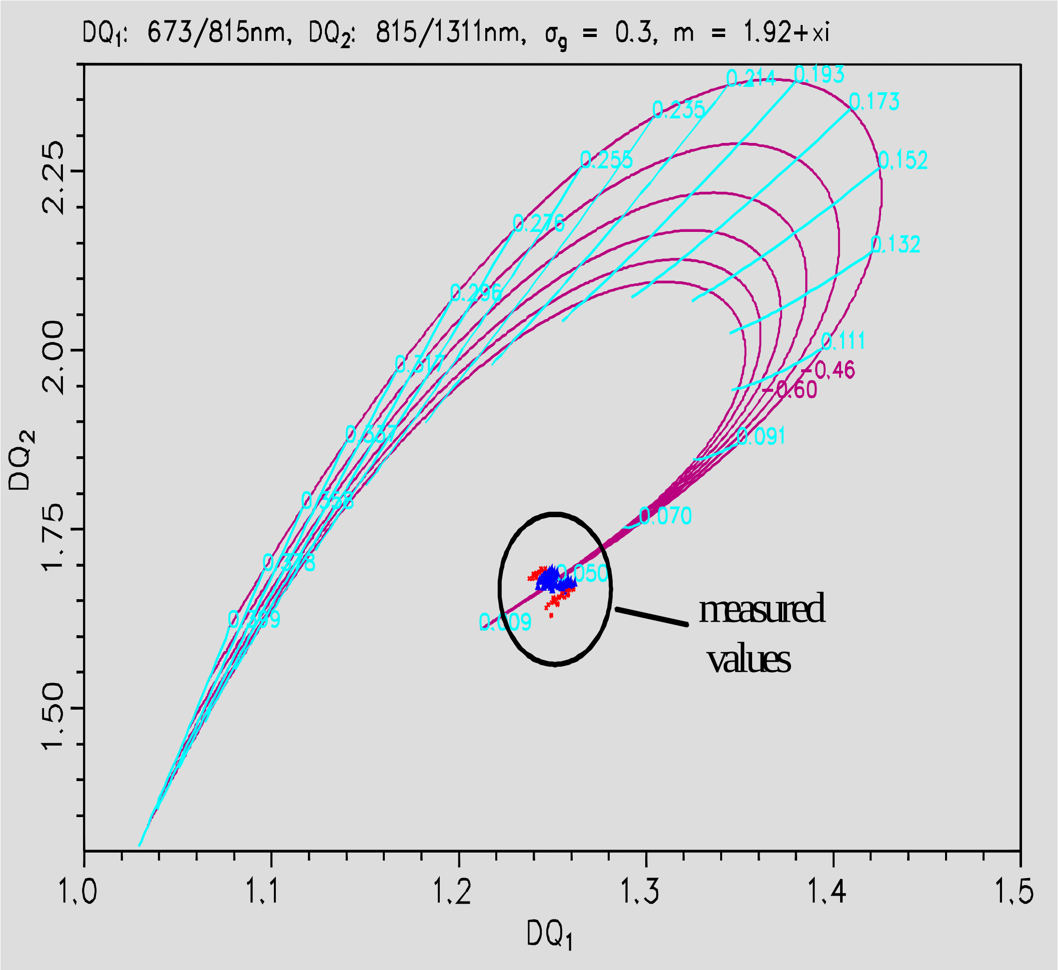
with:

I = intensity
I_0 = initial intensity
N = particle concentration
L = optical path length
r = particle radius
Q_{ext} = extinction coefficient
λ = wavelength
n = refractive index
$p(r)$ = number distribution

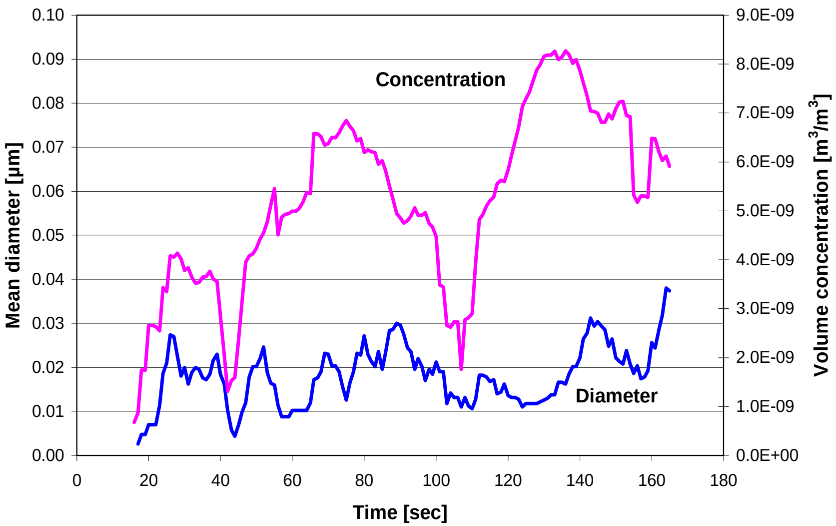
Dispersion Quotient Technique (2)
OMT Principle

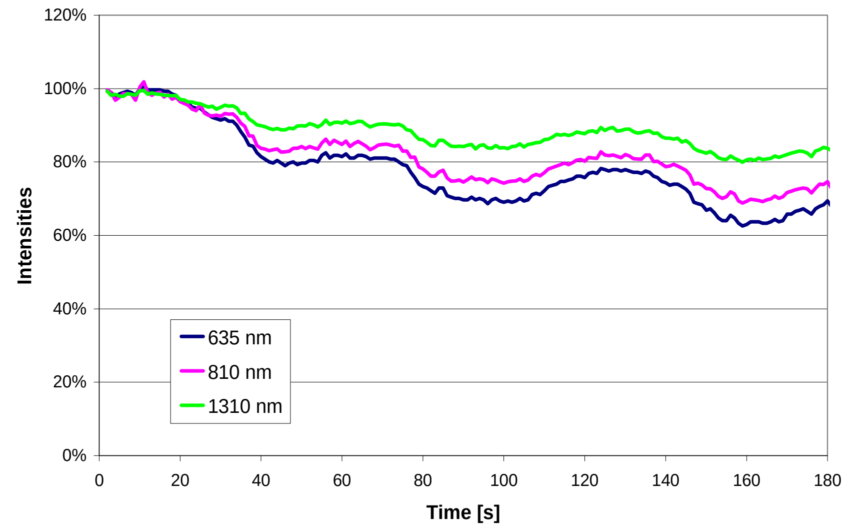
$$DQ_1 = \frac{\ln\left(\frac{I}{I_0}\right)_{\lambda 1}}{\ln\left(\frac{I}{I_0}\right)_{\lambda 2}}$$

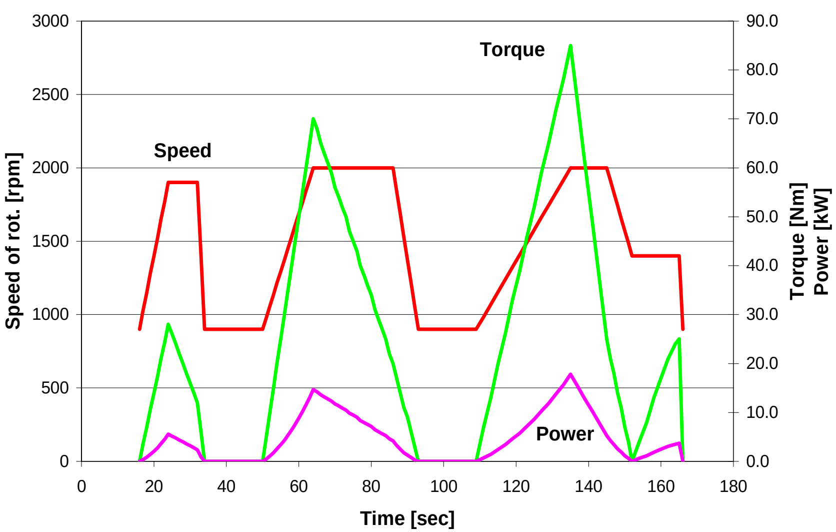
$$= \cancel{\frac{-N \cdot L \cdot \pi \cdot r^2}{-N \cdot L \cdot \pi \cdot r^2}} \cdot \frac{Q_{ext}(r, \lambda_1, n)}{Q_{ext}(r, \lambda_2, n)}$$



Transient Measurements (ECE)





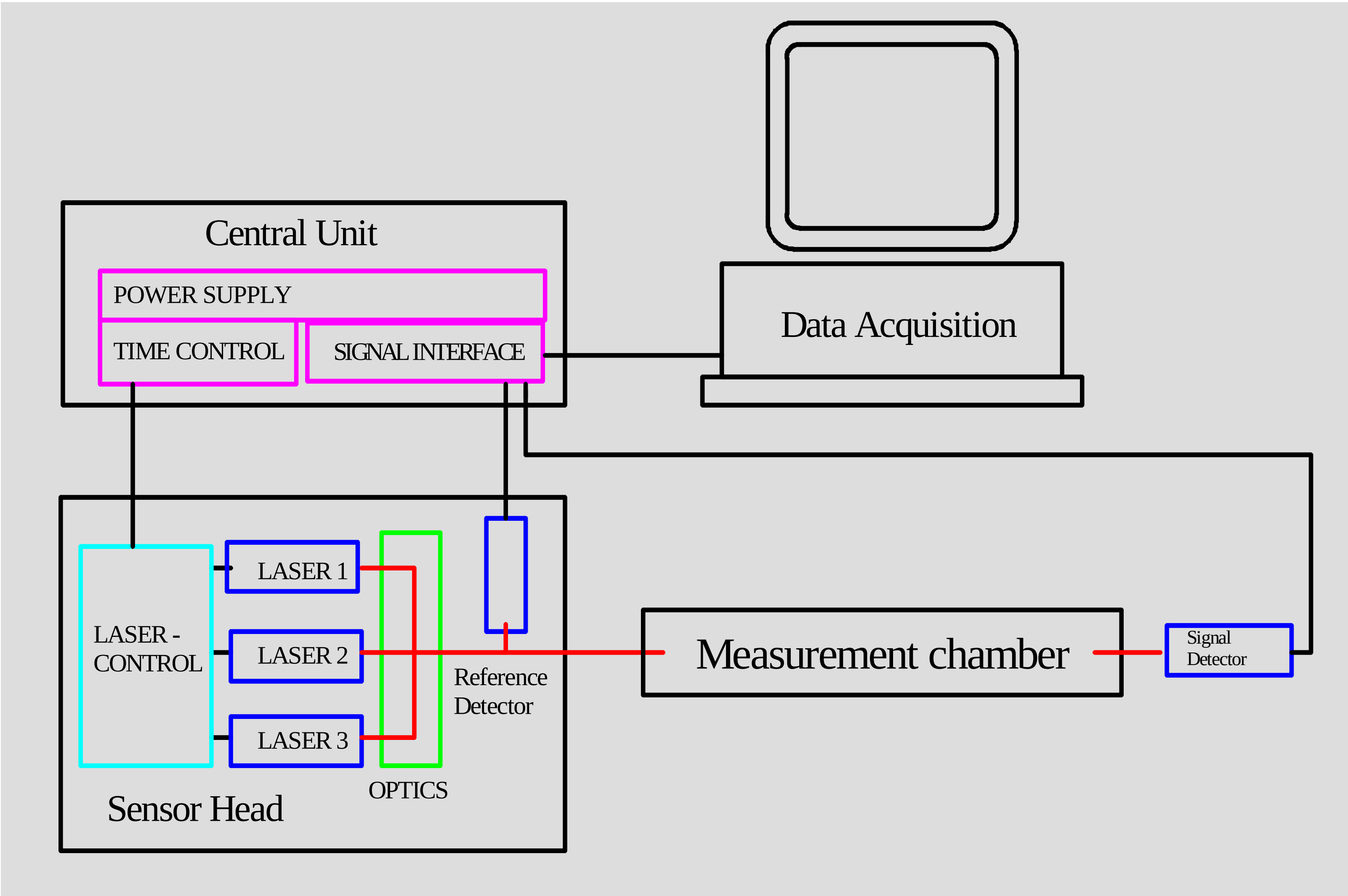


OMT Particle Analyzer (WIZARD-DQL)

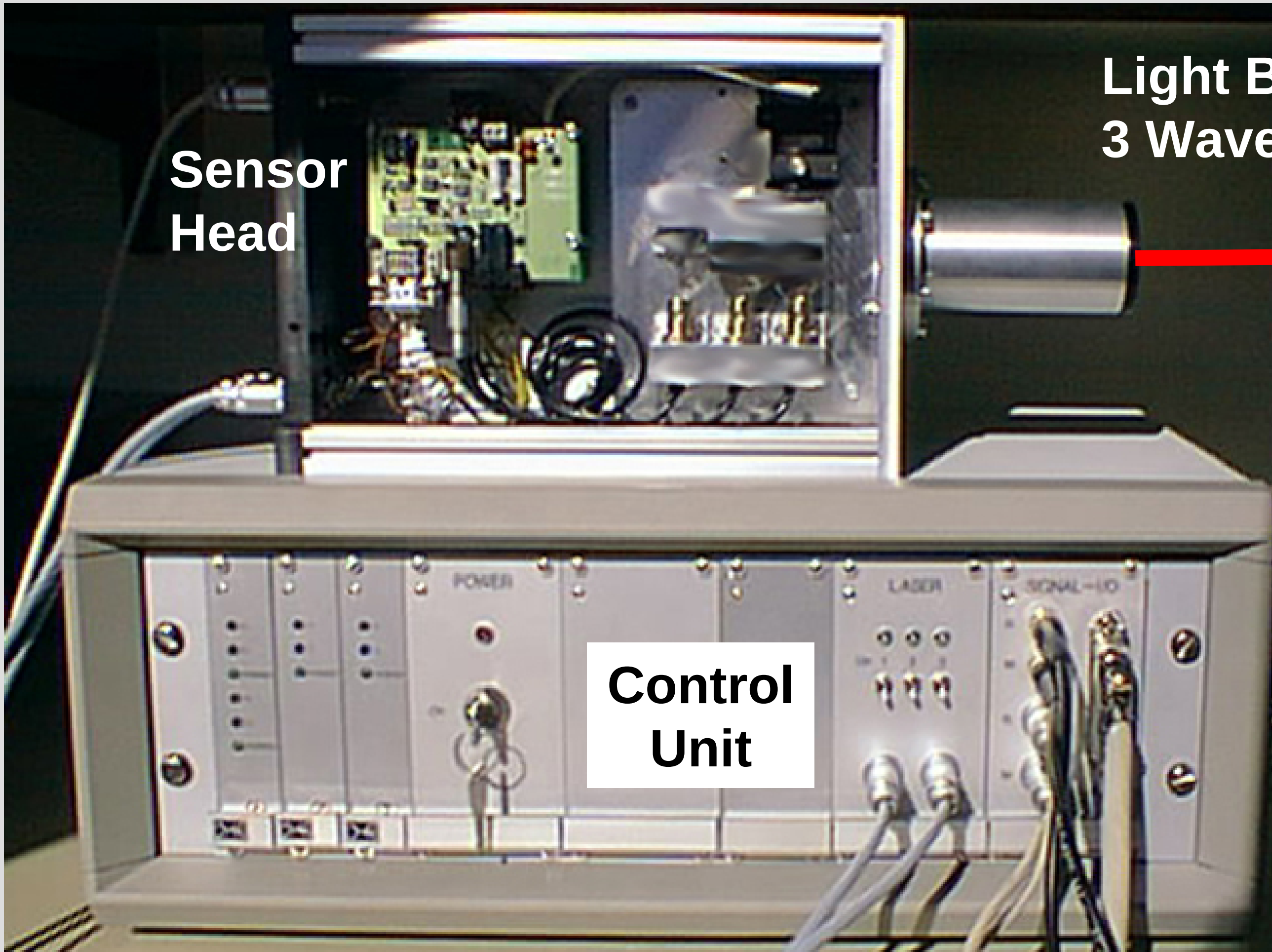
ECE Cycle

LD Engine

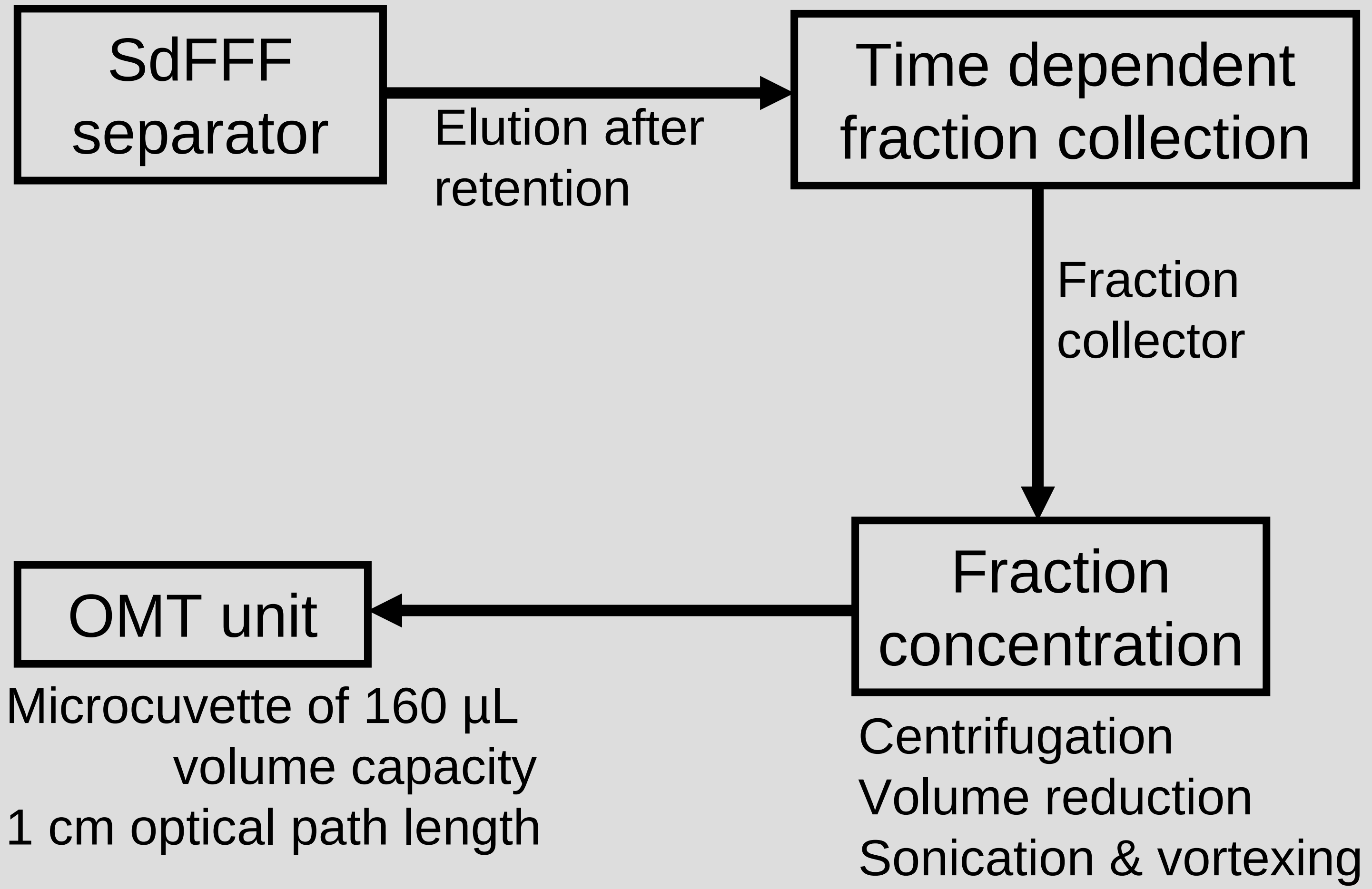
Schematic of the OMT



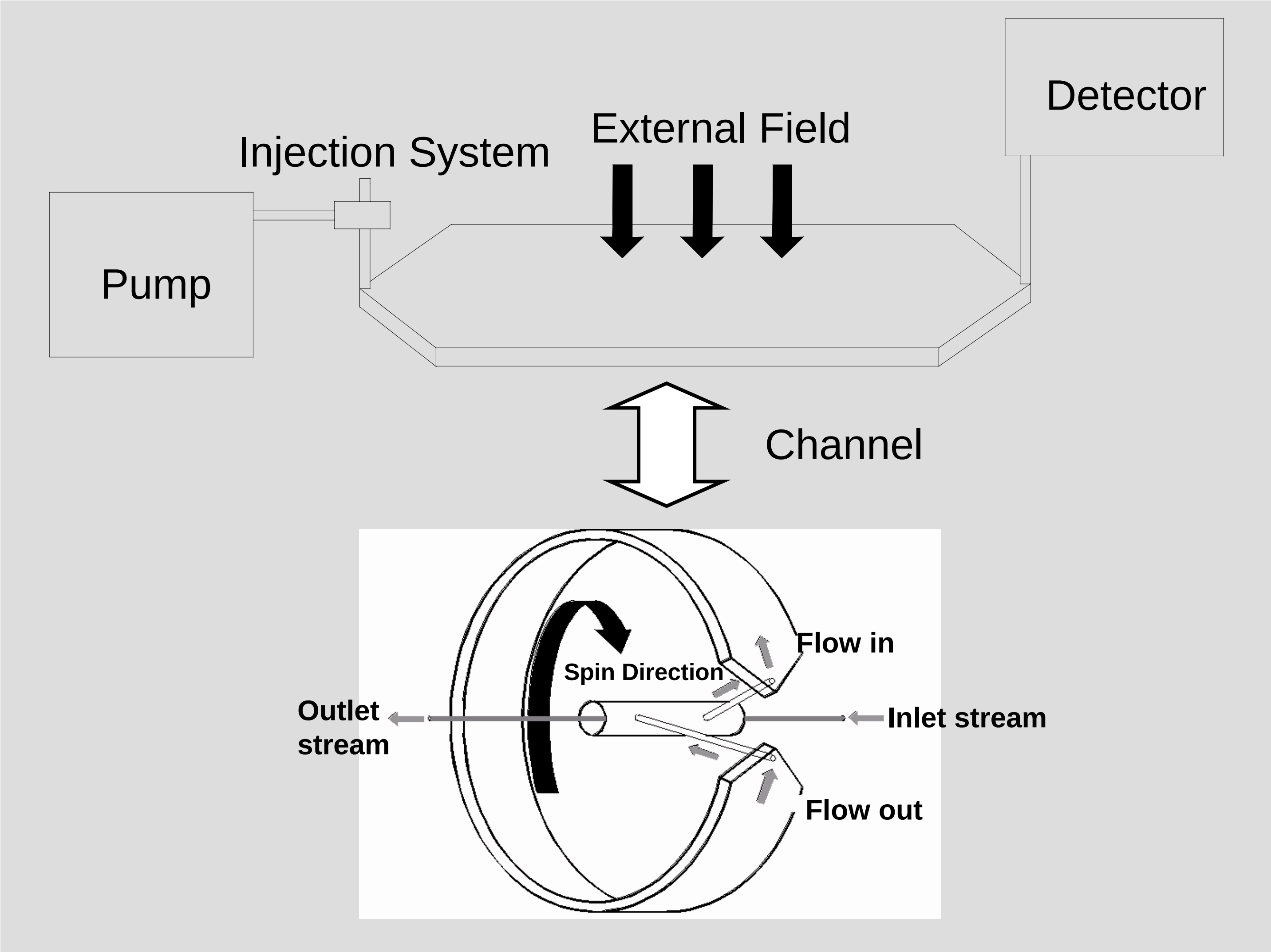
OMT: WIZARD DQL



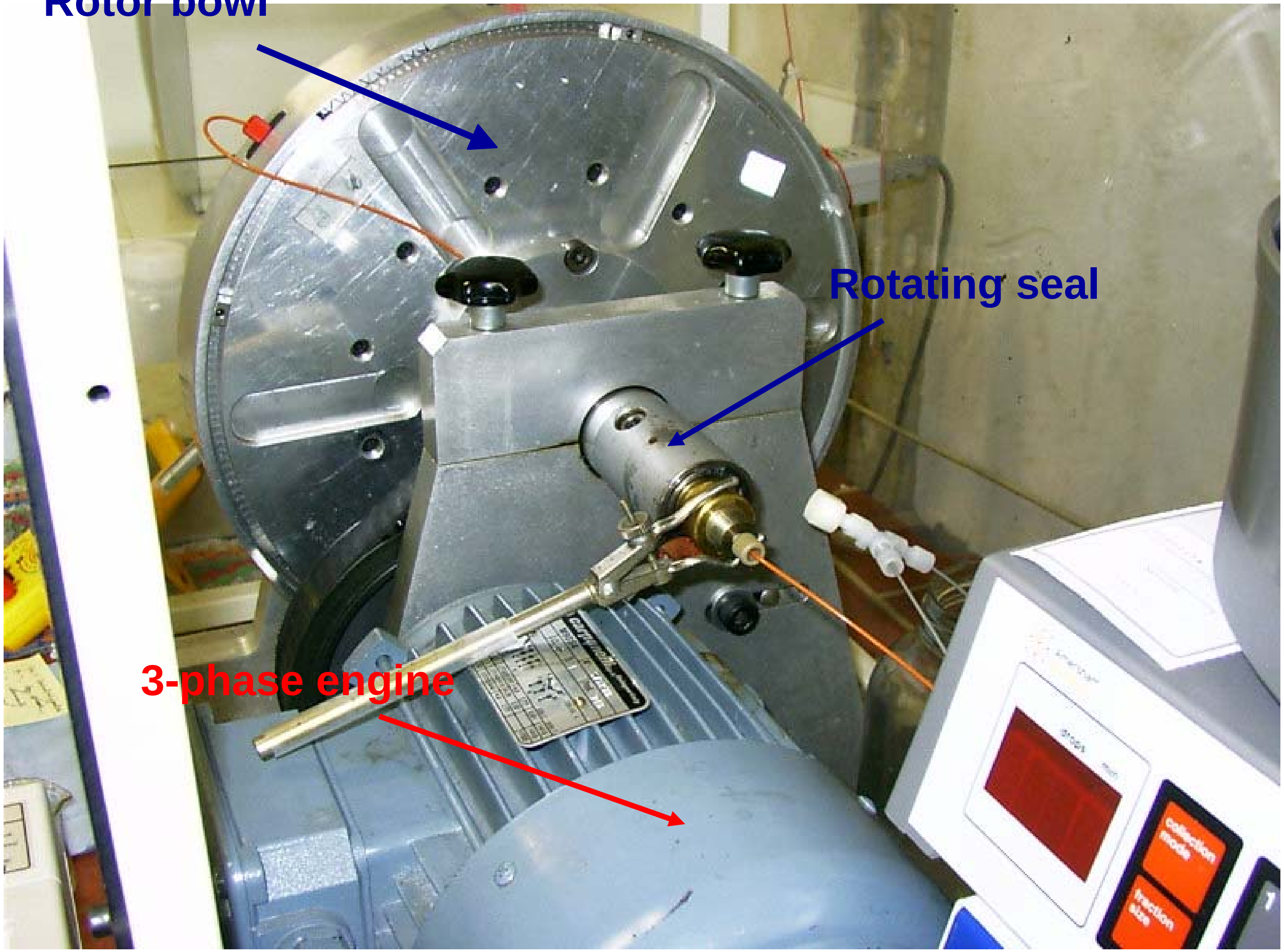
Off-line hyphenation set up



FFF System: SdFFF



SdFFF separator

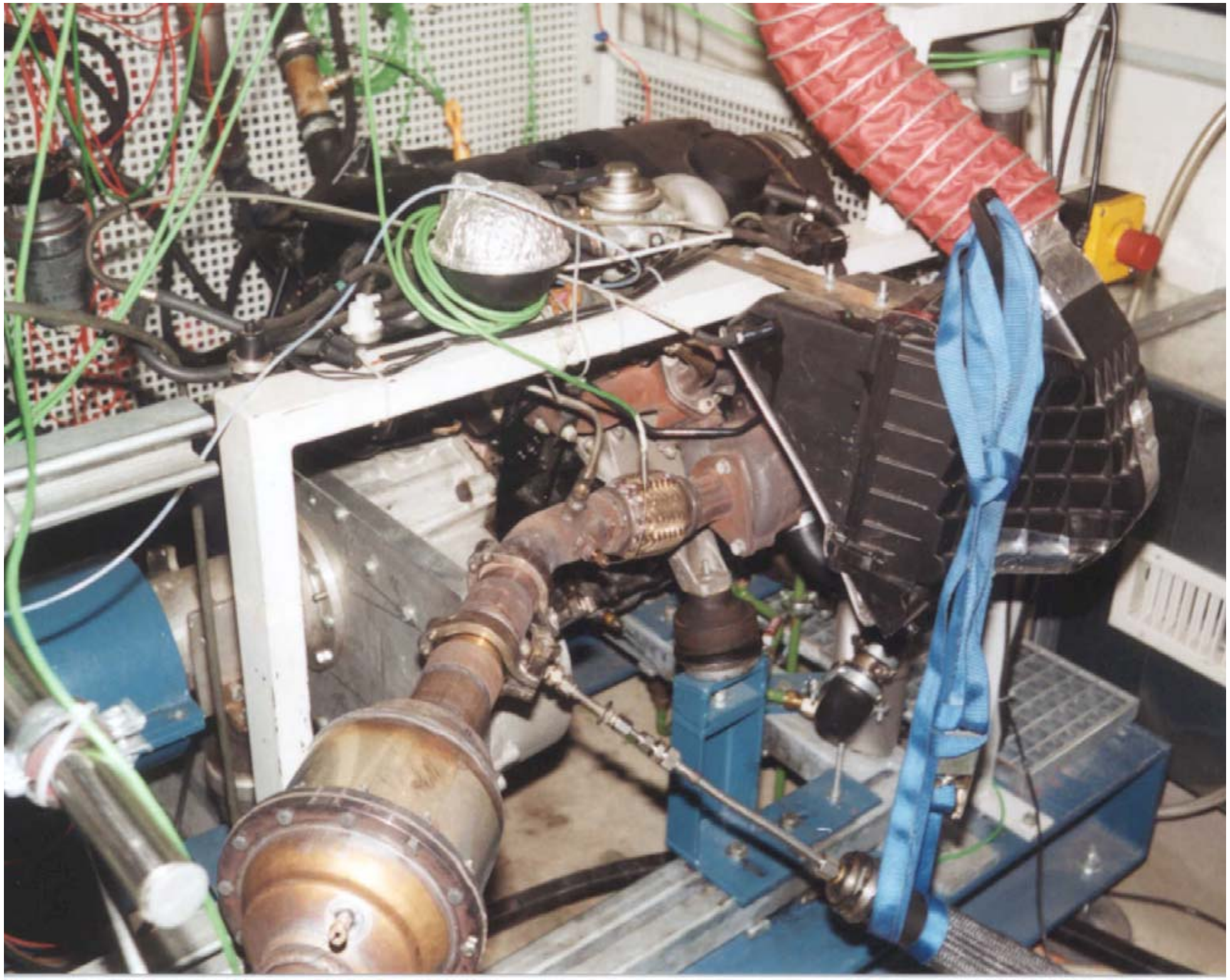


Back View

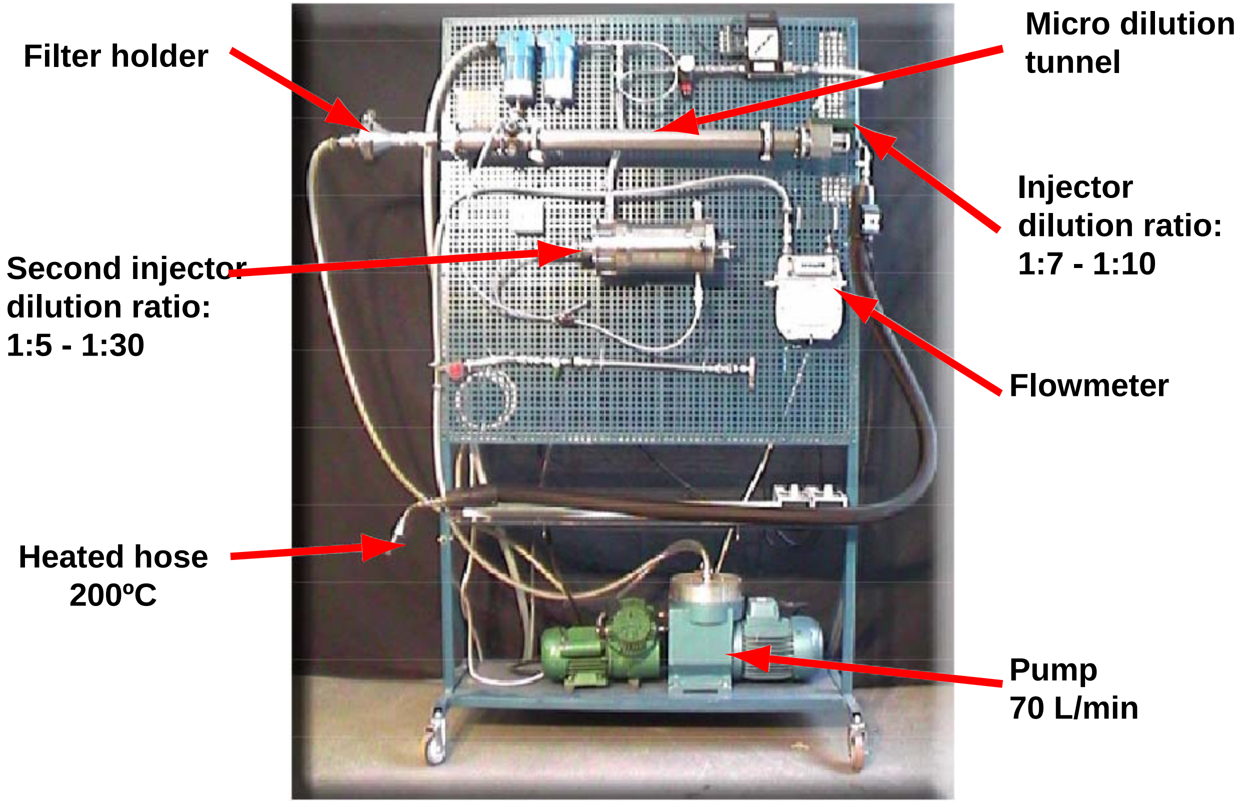
Diesel engine at CUTEC site

- 4 cylinder LD VW EURO III 85 KW engine, displacement volume 1.9 L
- Variable geometry torroidal technology (VGT)
- Exhaust gas recirculation (EGR)
- Pump unit injection (PUI)

Engine Set-up at CUTEC Site



Dilution system

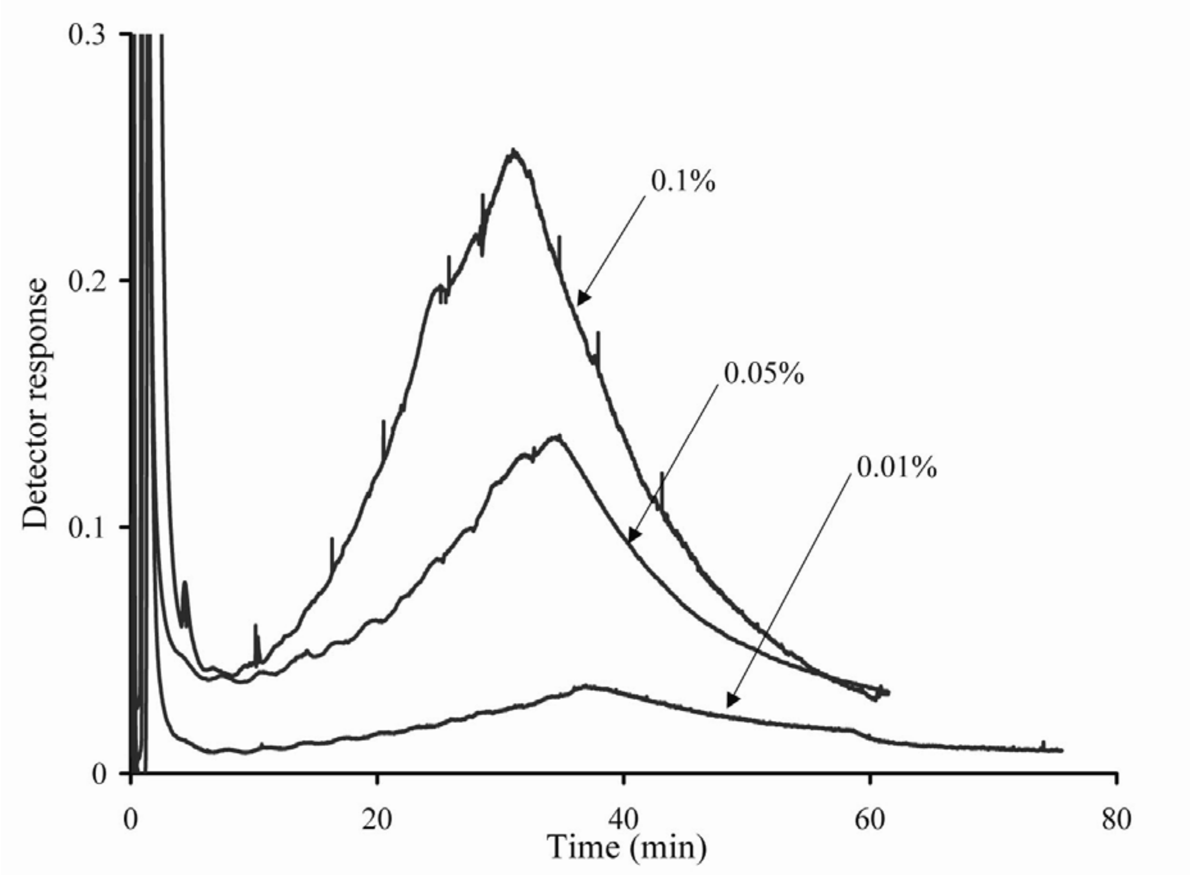


- Micro dilution tunnel
- Rapid mixing with the conditioned ambient air or dilution air
- Constant volume sampling (CVS)
- Teflon coated glass fiber filters Pallflex (70 mm diameter)

Sample preparation

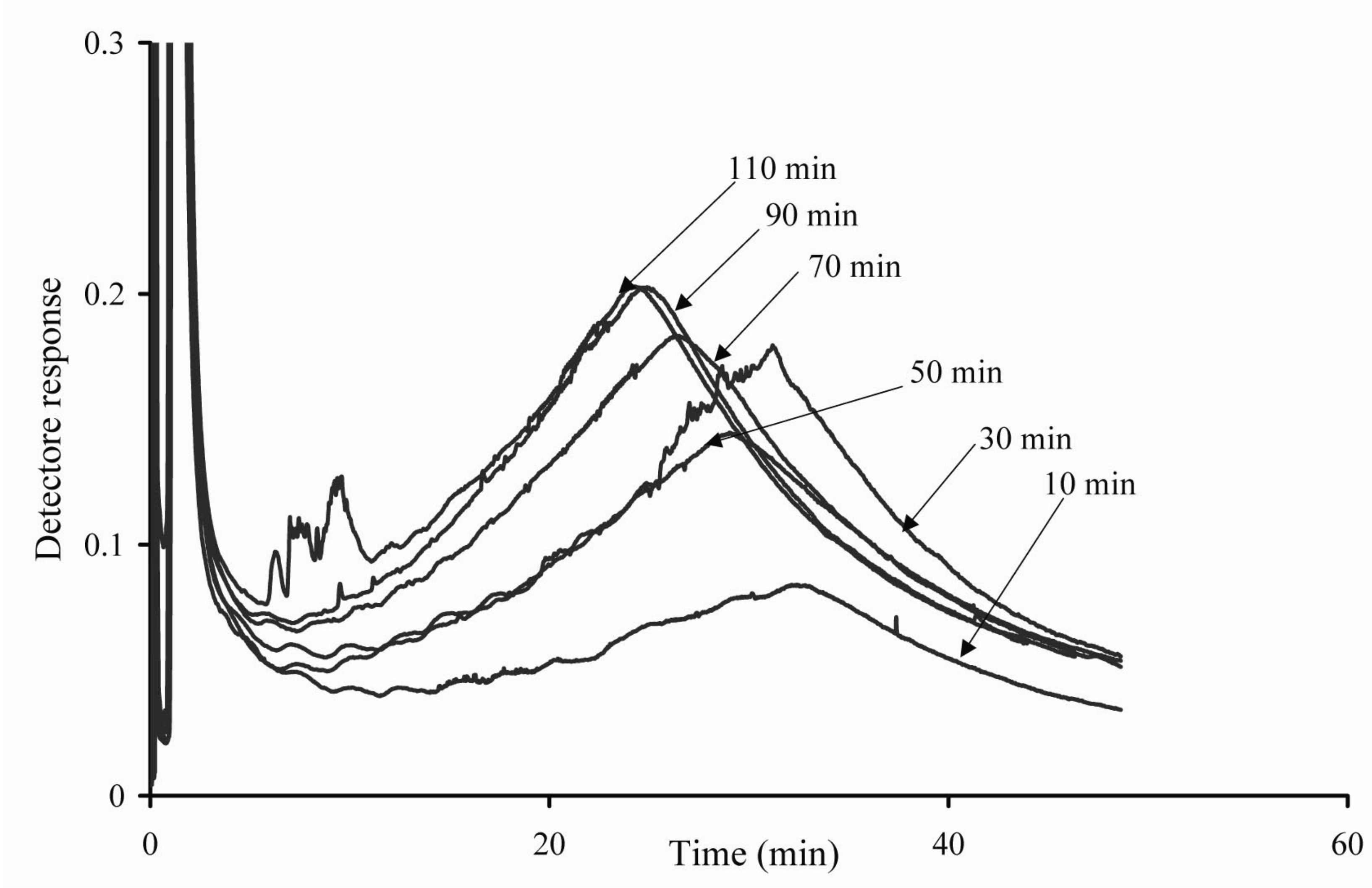
- Soot recovery by bath-sonication in 10 ml ethanol
- Mixture of ethanol+soot with 10 ml n-hexane
- After the removal of n-hexane, 5 ml distilled water containing 0.1% (w/v) and 0.02% NaN_3 are added
- Dispersion by 10 min bath-sonication
- Ethanol evaporation by heating at 70ºC
- Sonication by a sonic dismembrator for 90 min and vortexing
- Carrier liquid and suspension media: doubly distilled water containing 0.1% (w/v) and 0.02% NaN_3
- Injection volume: 100 µL

Surfactant concentration effect

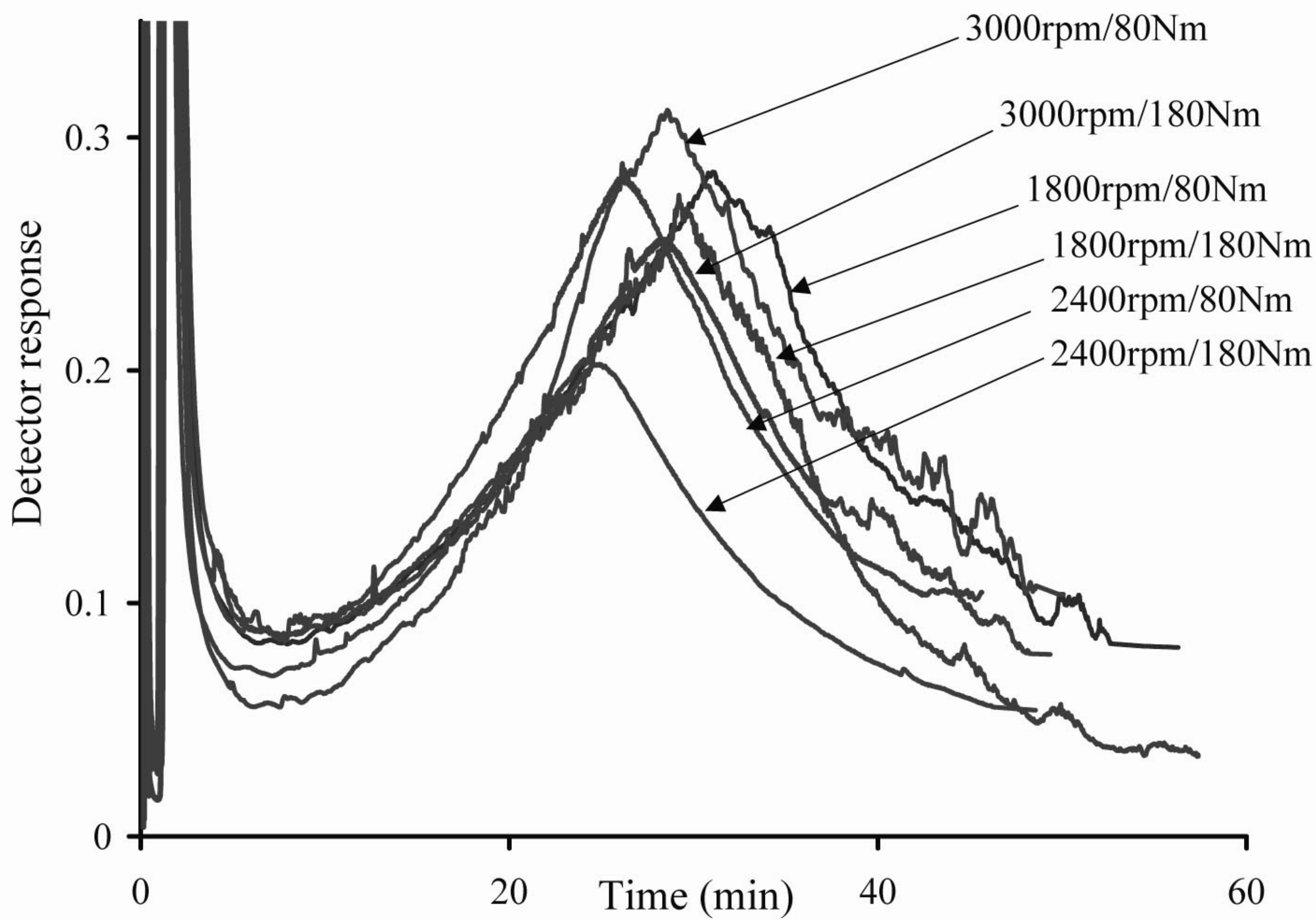


Elution conditions: initial field strength = 600g (1972 rpm);
injection flow rate=0.2 ml/min; Predecay time= 5 min; stop flow time=15 min;
final field strength=29.60g (439 rpm); elution flow rate= 1.2 ml/min

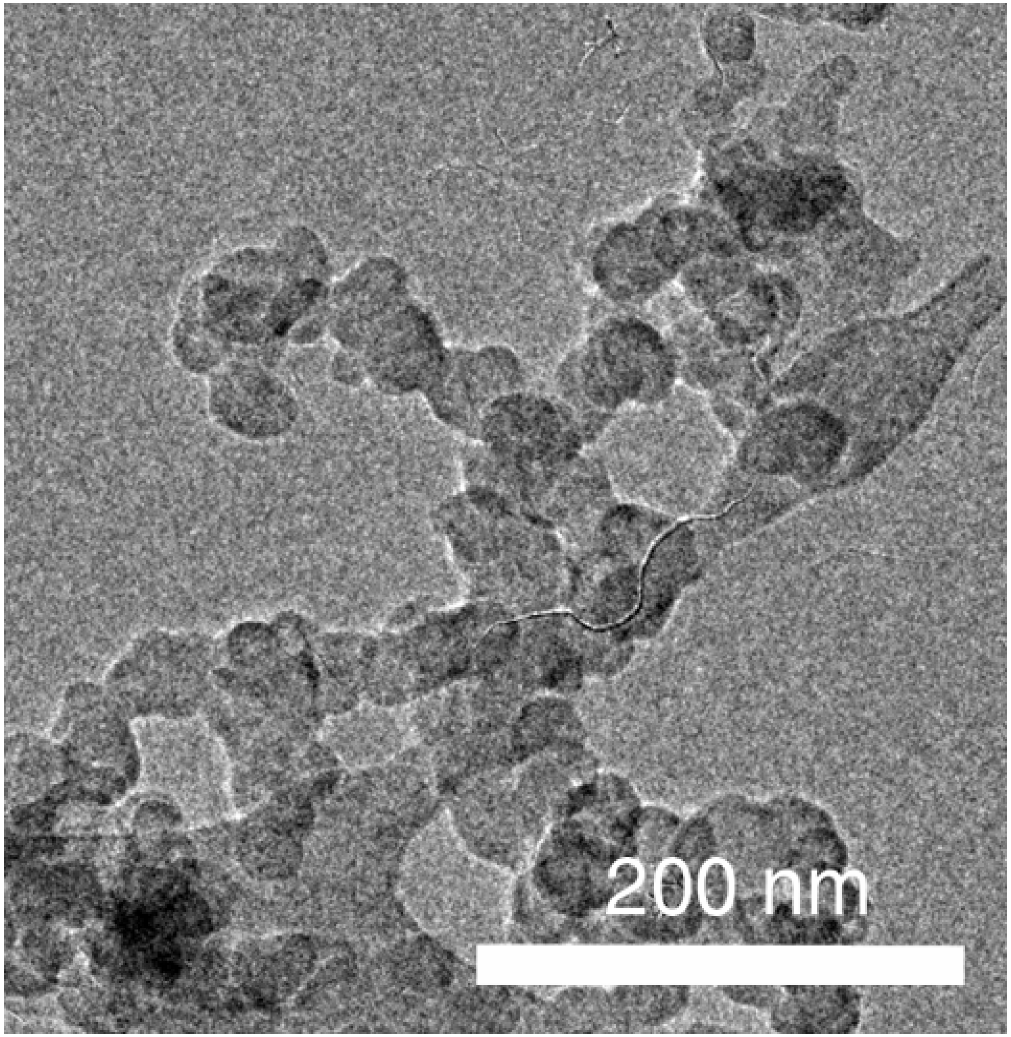
Sonication effect



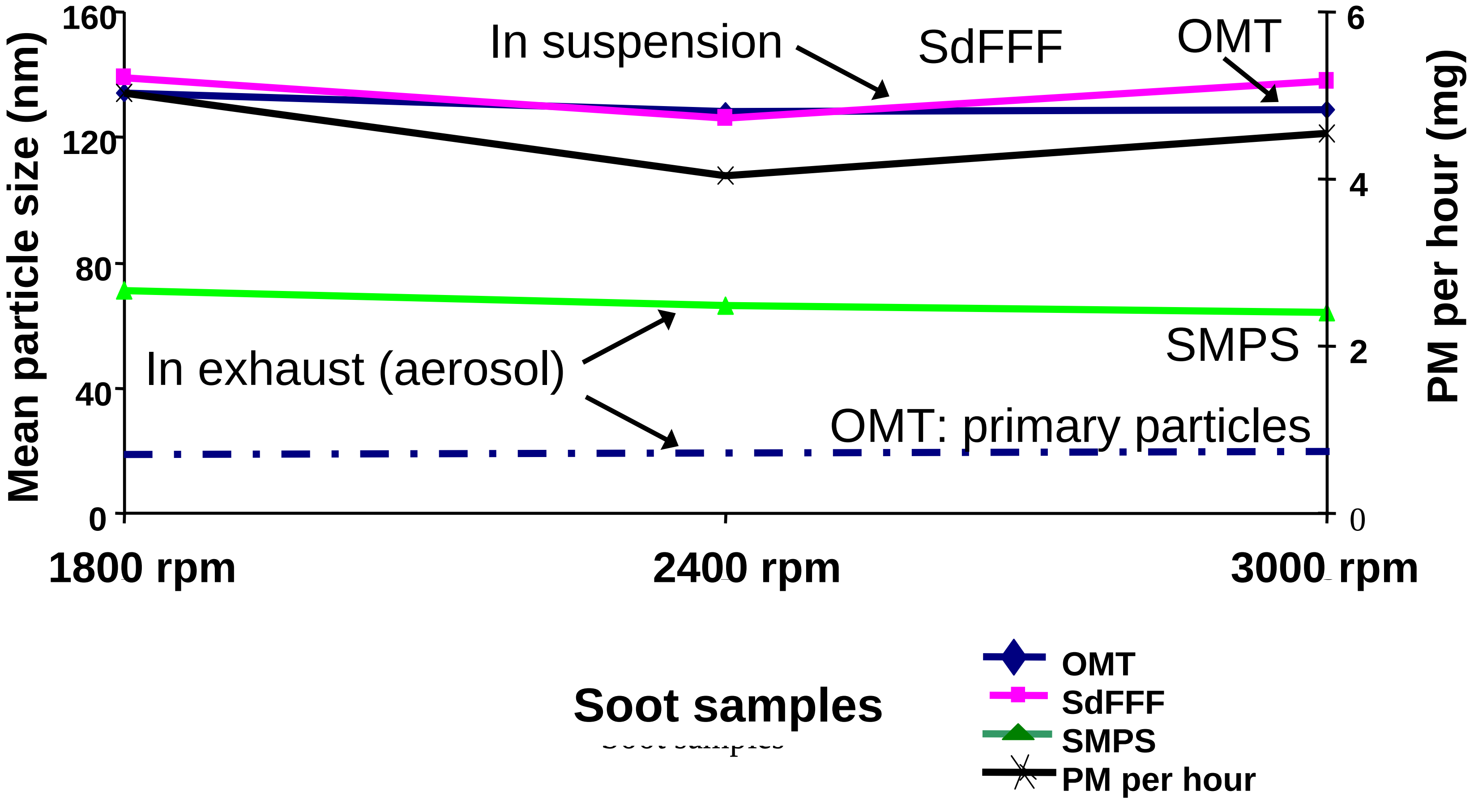
Soot elution by SdFFF



TEM pictures of soot (aerosol)



Engine speed effect on particle size at 180 Nm torque



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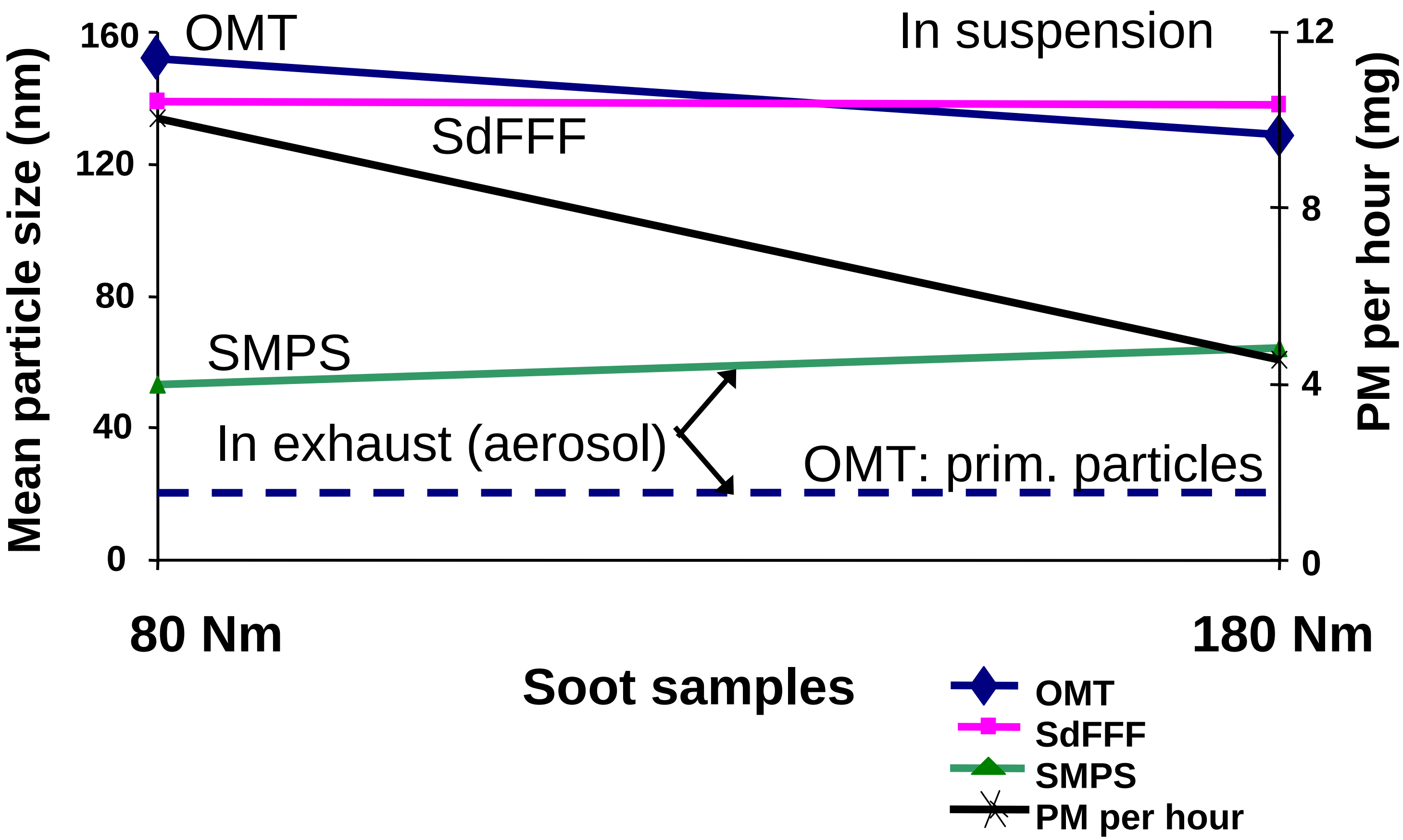
Torque effect on particle size at 3000 rpm



Conclusion

- Soot particle size variation analyzed by OMT and SdFFF in the collected PM amount is related to the different engine load conditions

- The detected mean soot particle sizes in liquid suspen-sions differ appreciably to those in aerosols:

- SdFFF and OMT measurements in liquid: 120 – 160 nm
- OMT measurements in the raw exhaust: approx. 20 nm (primary particles)
- SMPS measurements in the diluted exhaust: 60 – 80 nm

- Different soot agglomerates in liquid and aerosol

- Surprisingly, the suspended soot particles keep specific characteristics related to engine load conditions