7th ETH Conference on Combustion Generated Particles
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Particle Size and Composition Measurements at Modern Engines and Aftertreatment Systems

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CUTEC

structure

1. equipment @ CUTEC to
   - generate particles
   - measure
     - particle size
     - composition
   - minimize particles
2. test conditions & results
     - engine out
     - filter out
3. summary/conclusion

structure

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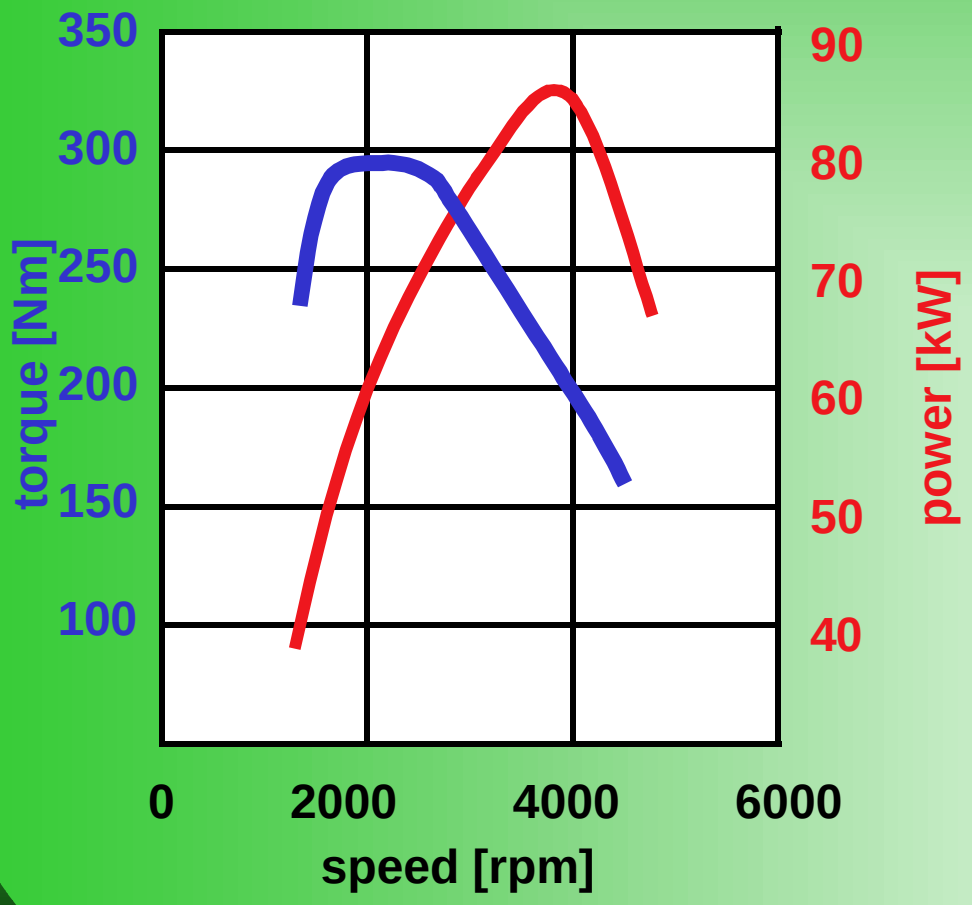
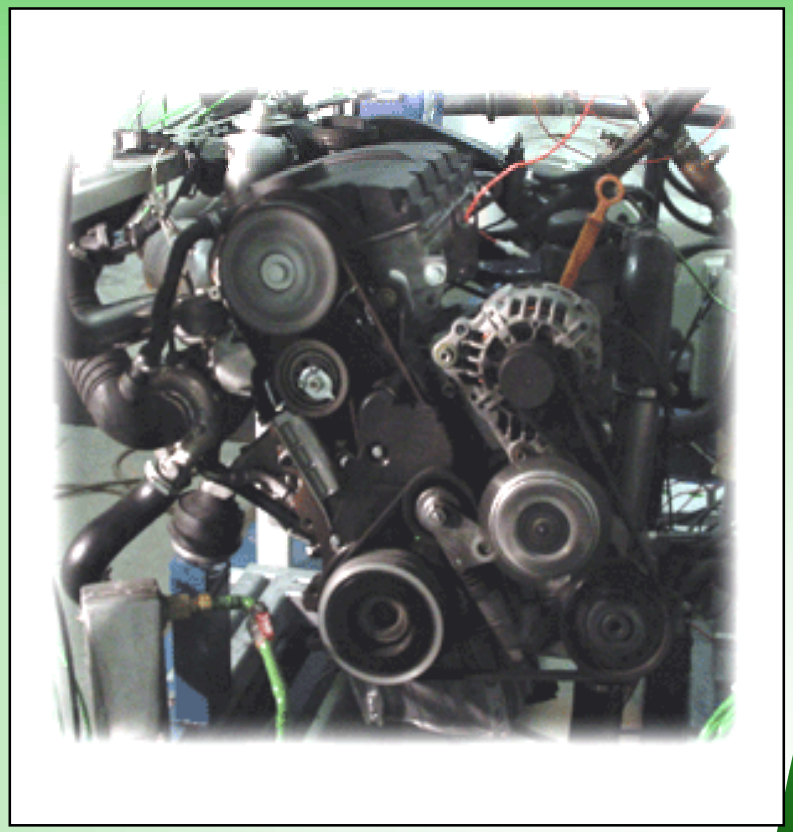
engine

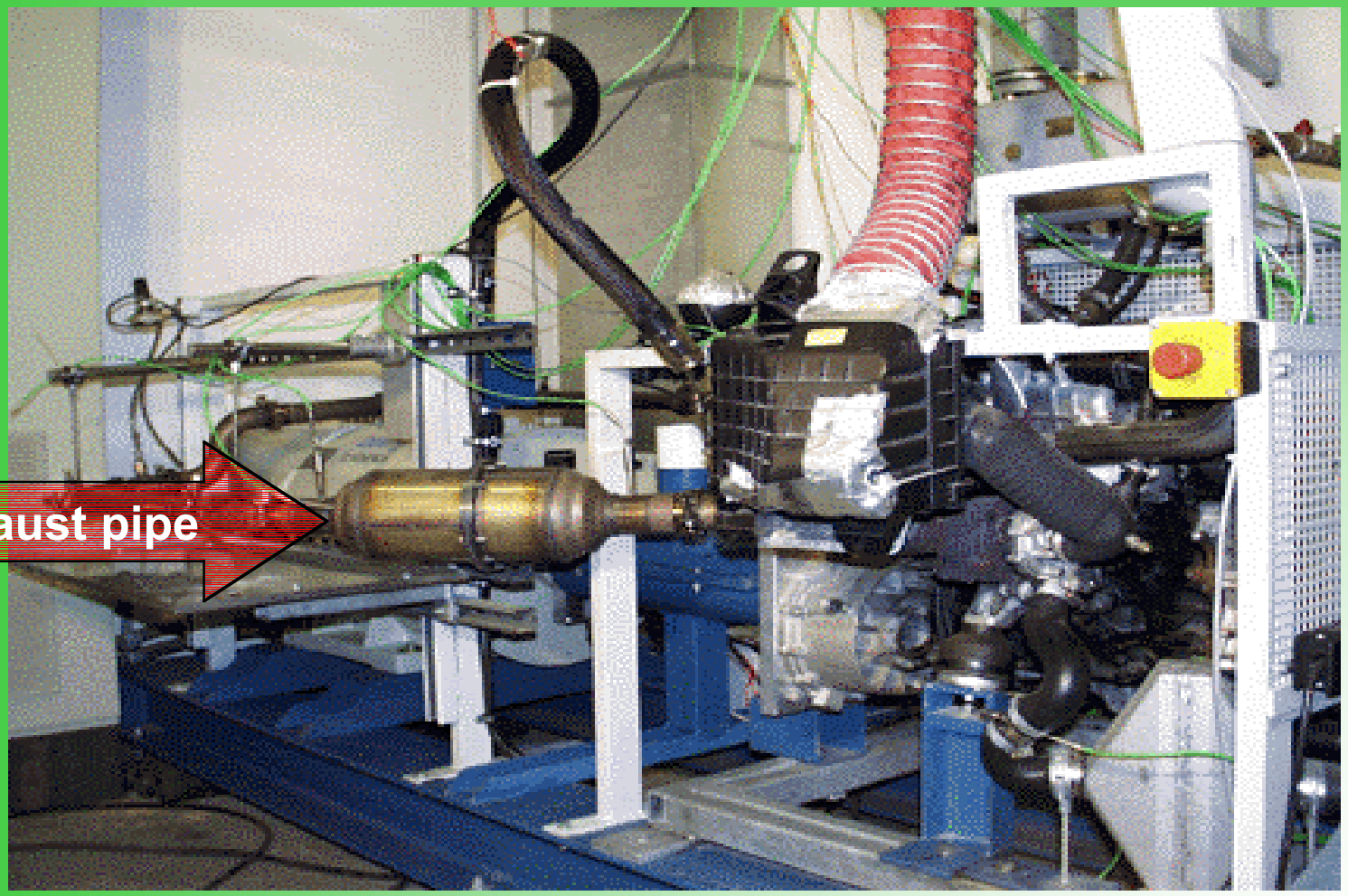
VW TDI-PUI 4 cylinder 1.9 L, 85 kW, 285 Nm, EURO 3





equipment @ CUTEC to generate particles

Engine/Filter test bench



220 kW Schenk DYNAS engine-dynometer

VW TDI-PUI 4 cylinder 1.9 L, 85 kW, 285 Nm, EURO 3

structure

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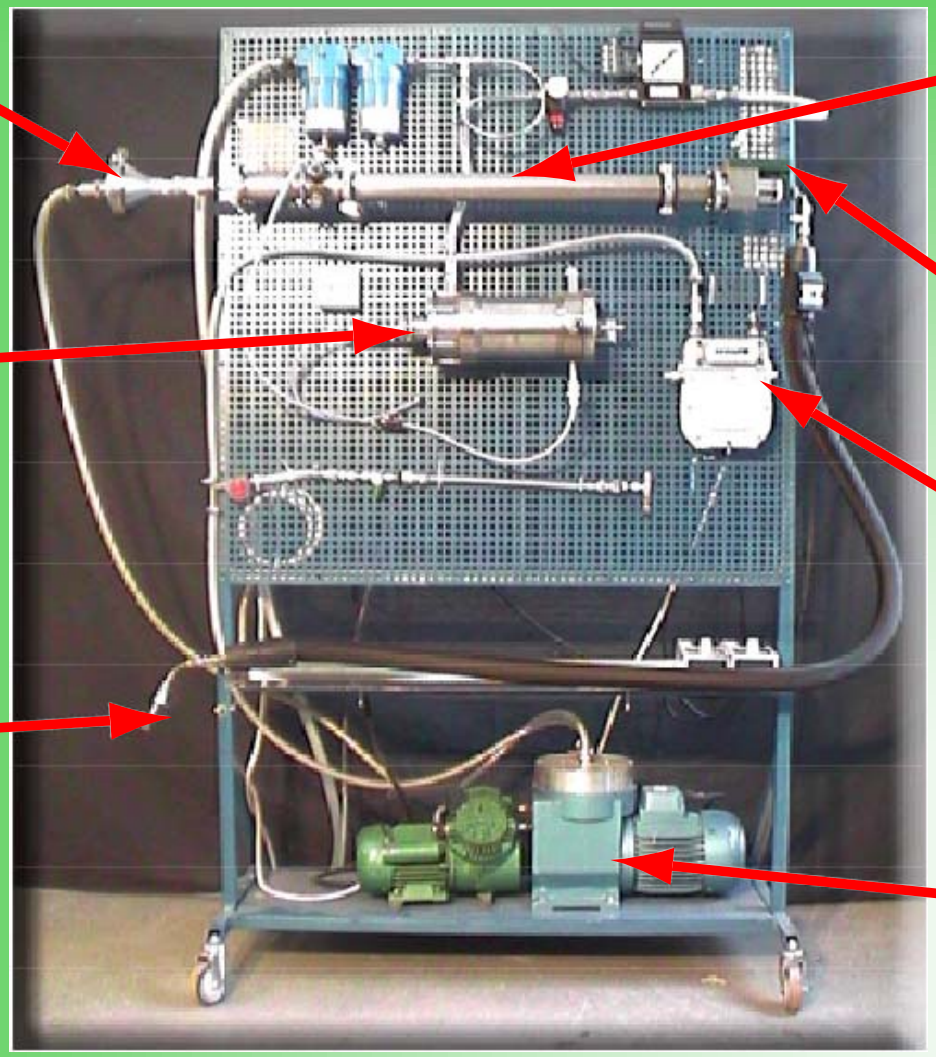
equipment @ CUTEC to measure particle size & composition

Dilution Tunnel



filter holder or impactor

Second injector dilution ratio: 1:5 - 1:30

heated hose

micro dilution tunnel

injector dilution ratio: 1:7 - 1:10

flow meter

pump

particle size measurement

Exhaust tube

↓

Constant Volume Sampling

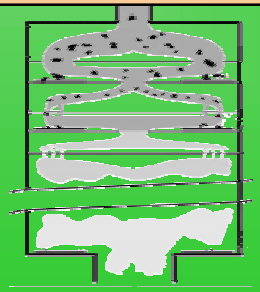
↓

dilution system T ≤ 52 °C

dilution ratio 1 : 300 | dilution ratio 1 : 10

↓ TSI - SMPS

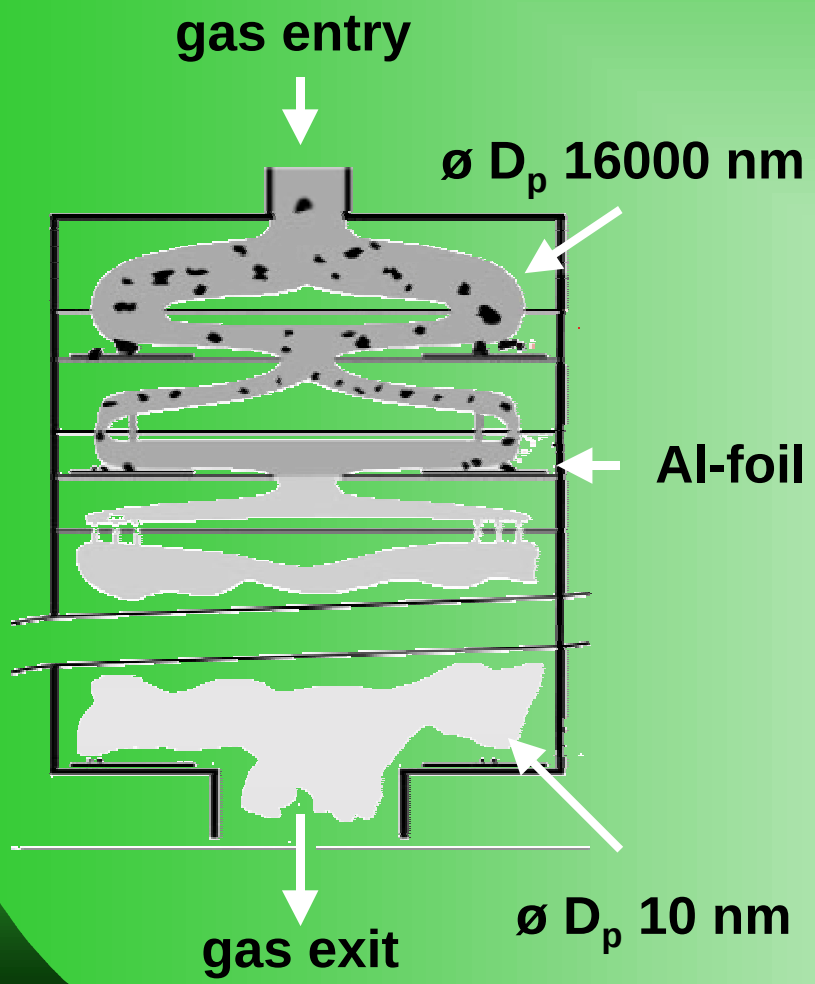
↓ 12 stages Berner - impactor



CU TEC

particle size

12-cascade impactor



determination of
particle mass distribution

↓

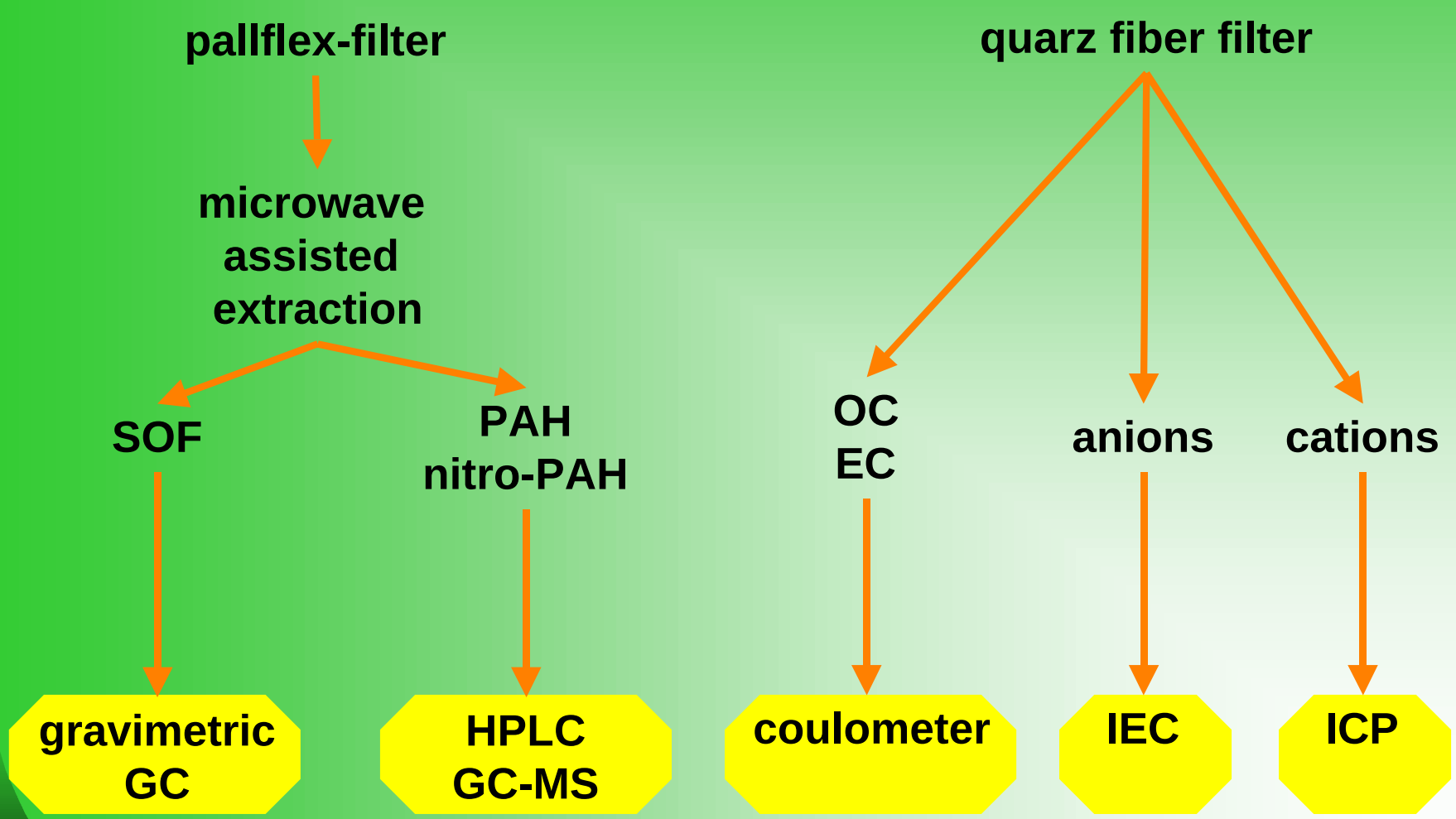
particles are collected on
Al-foil seperated by aerodynamic
diameter

↓

chemical analysis of collected classified particles

equipment @ CUTEC to measure particle size & composition

chemical analysis of soot samples



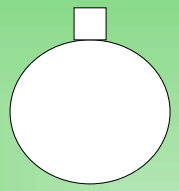
equipment @ CUTEC to measure particle size & composition

state of the art SOF determination

filter

3 - 5 mg soot

soxhlet extraction



solvent: 200 mL

weighing

0.5 -1 mg SOF

duration: 8 hours

equipment @ CUTEC to measure particle size & composition

SOF determination @ CUTEC

filter

microwave assisted extraction

GC

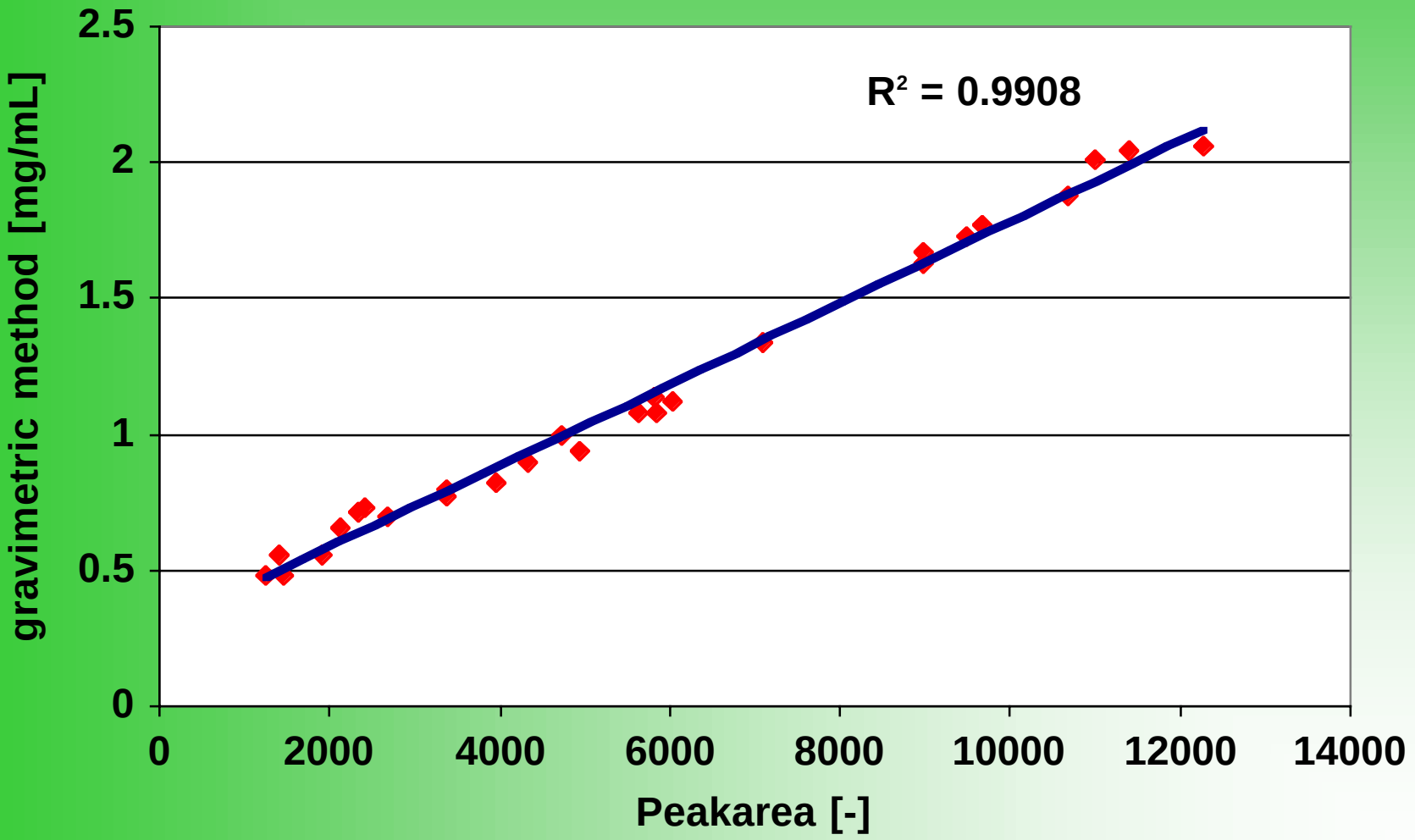
1 - 3 mg soot

solvent: 30 mL

peak area

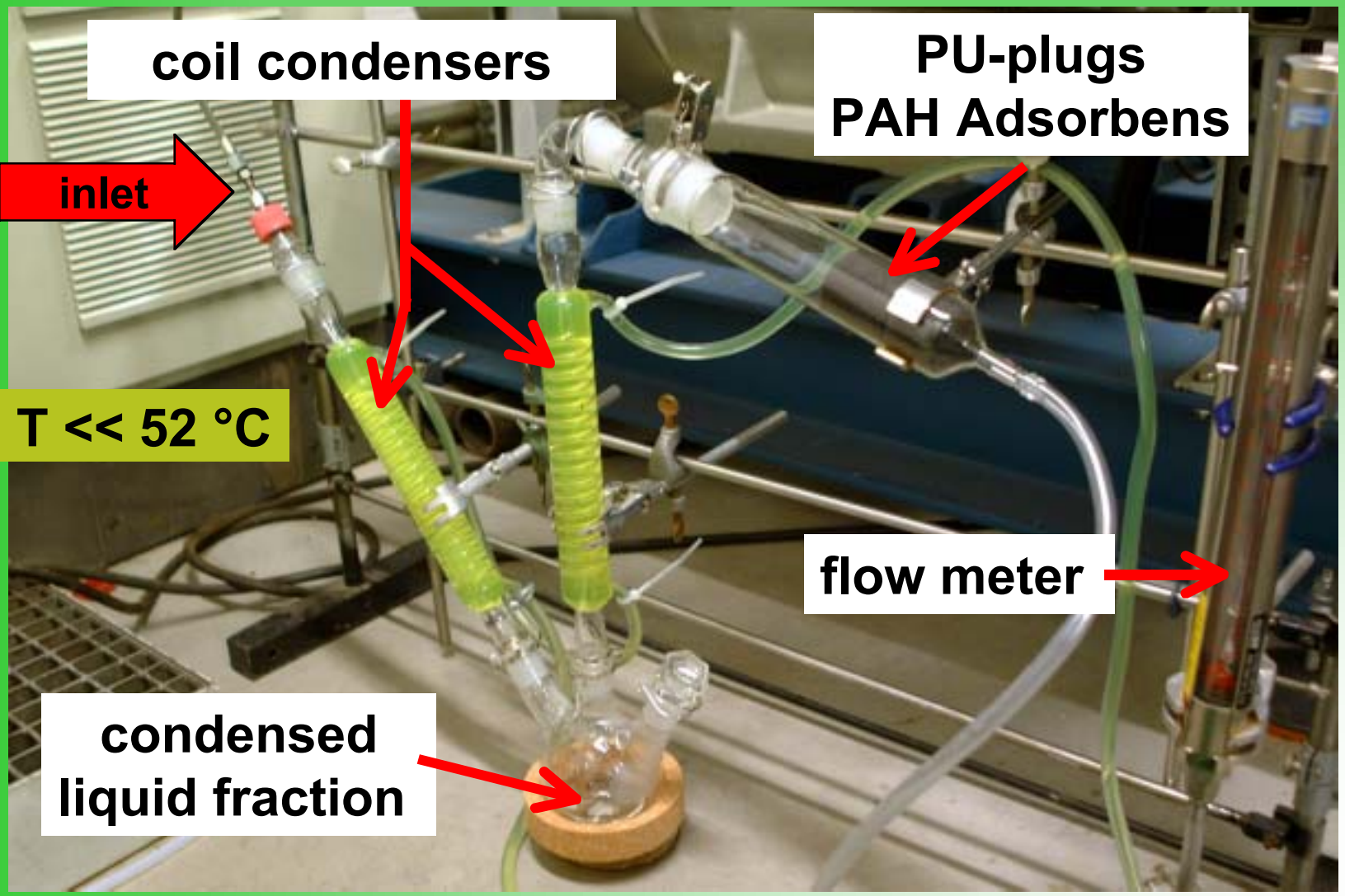
duration: 2 hours

Comparison of SOF determination by GC or gravimetry



equipment @ CUTEC to measure particle size & composition

Determination of gaseous PAH



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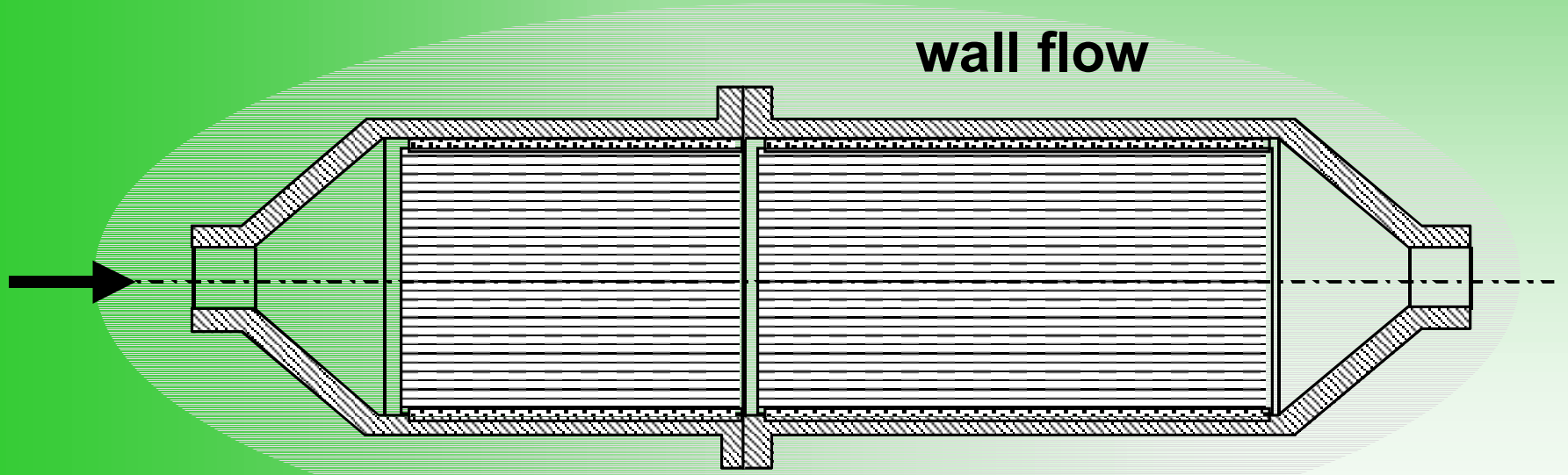
Particle emission reduction

- primary
  - fuel quality (sulfur 50 ppm - 10 ppm)
- secondary
  - aftertreatment systems
    - DOC
    - DPF, CCF

aftertreatment systems

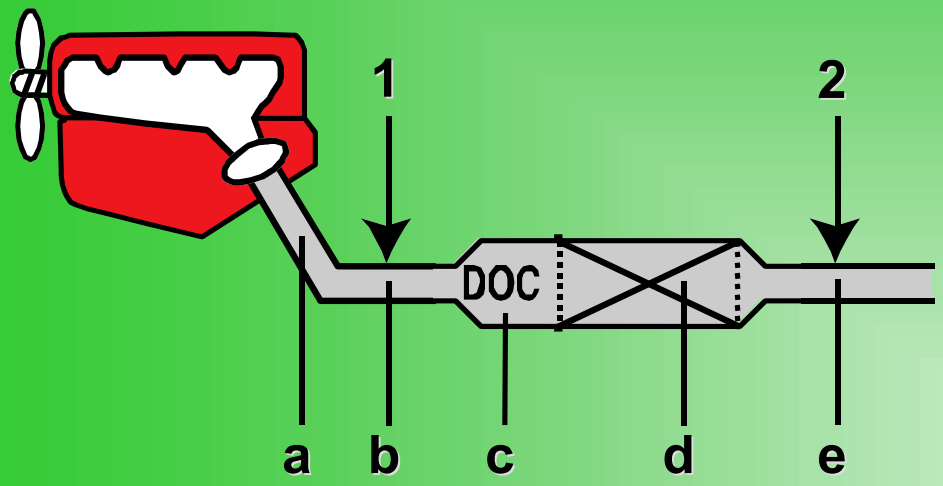
- DOC/CCF



DOC 5.66” x 3.54”
cordierite

CCF 5.66” x 6”
silicon carbide

Experimental setup DOC/CCF



Sampling points:

1 engine out

2 DOC/CCF out

Temperature:

a engine out

b upstream DOC/CCF

c DOC

d inside CCF

e downstream DOC/CCF

strucure

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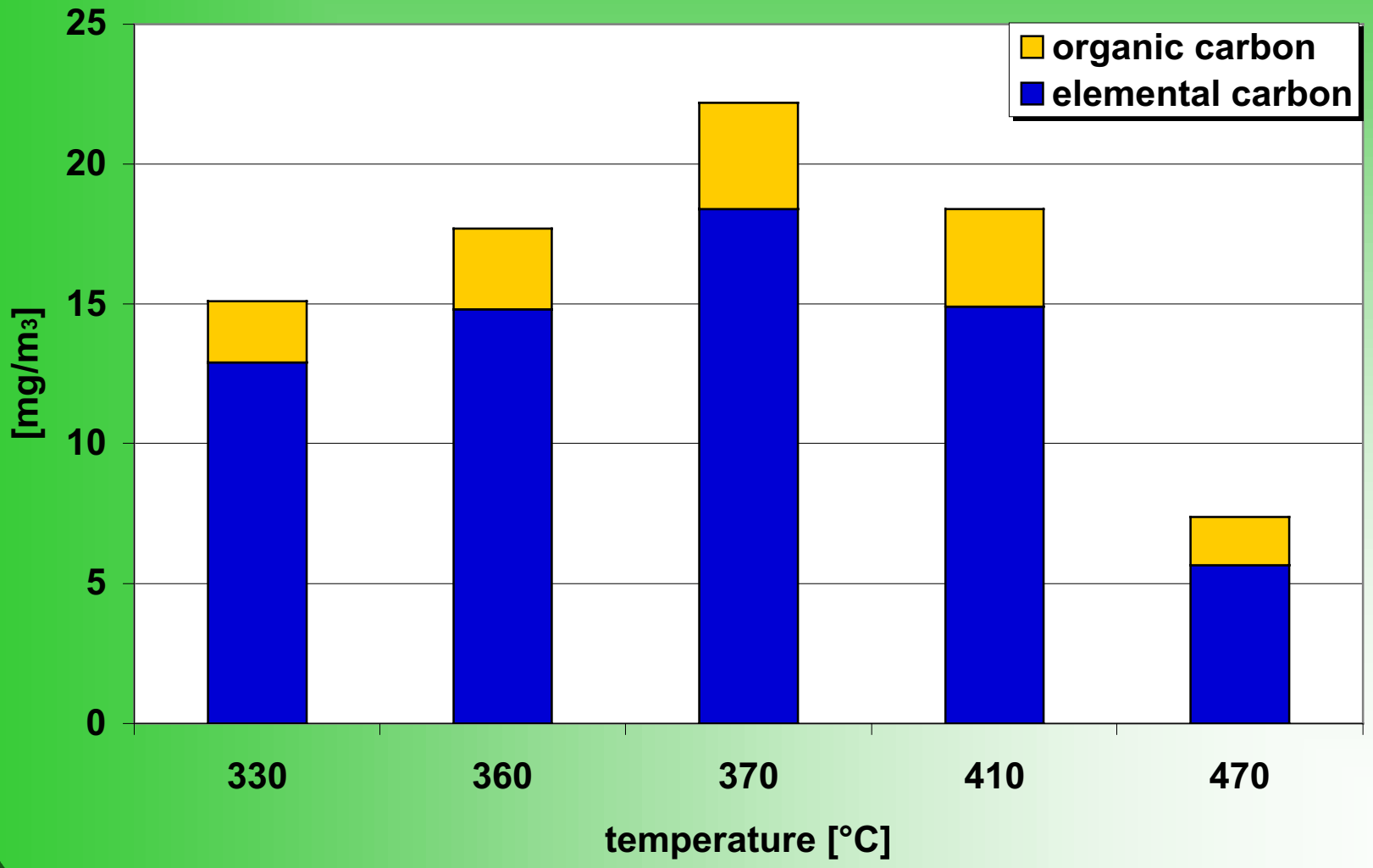
   - minimize particles
2. test conditions & results
   - engine out
     - OC/EC = f (T, particle size)
     - PAH = f (T)
     - fuel quality (50 ppm - 10 ppm S)
   - filter out
3. summary/conclusion

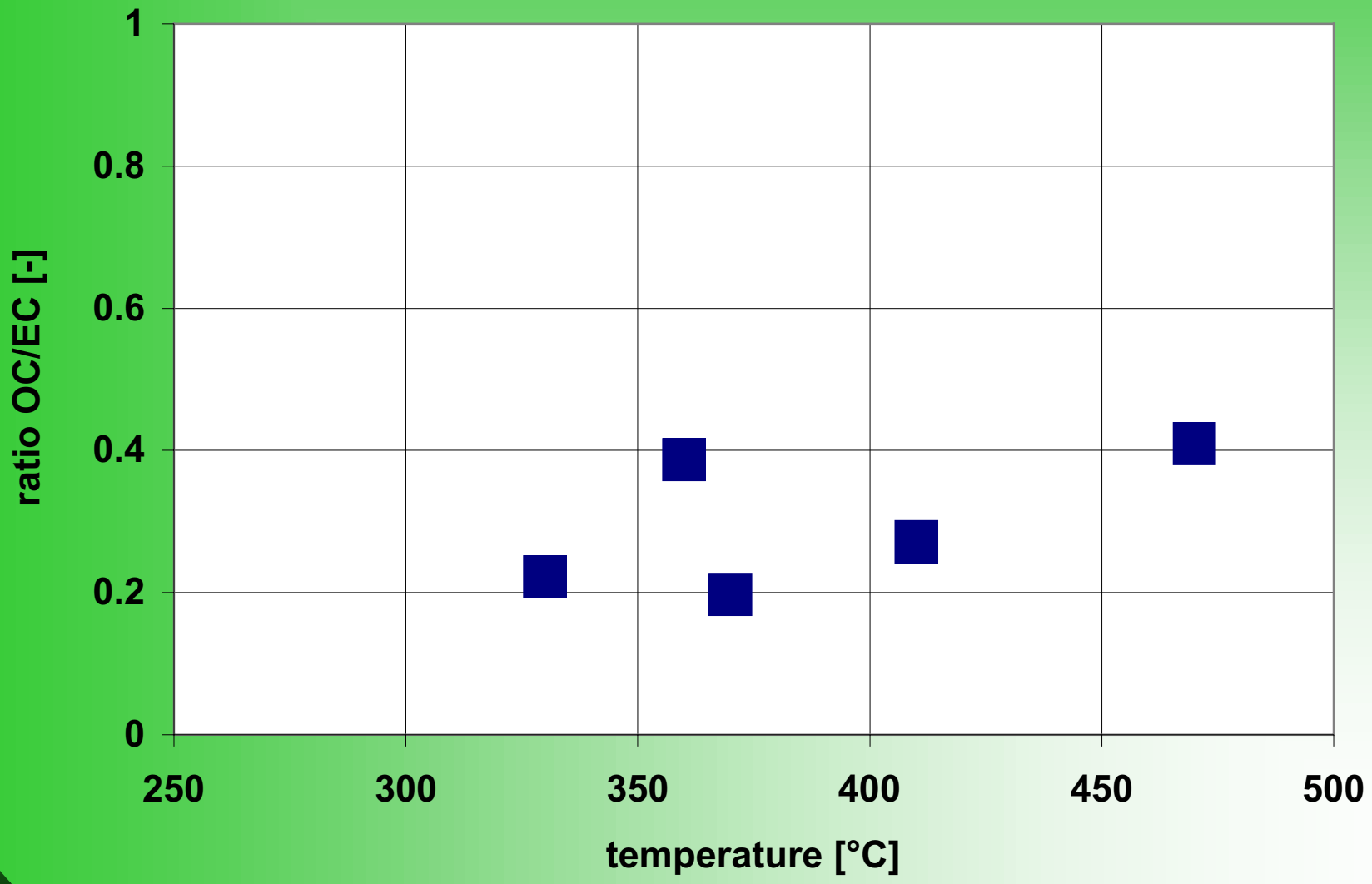
results engine out (50 ppm S)

OC + EC emissions = f (temperature)



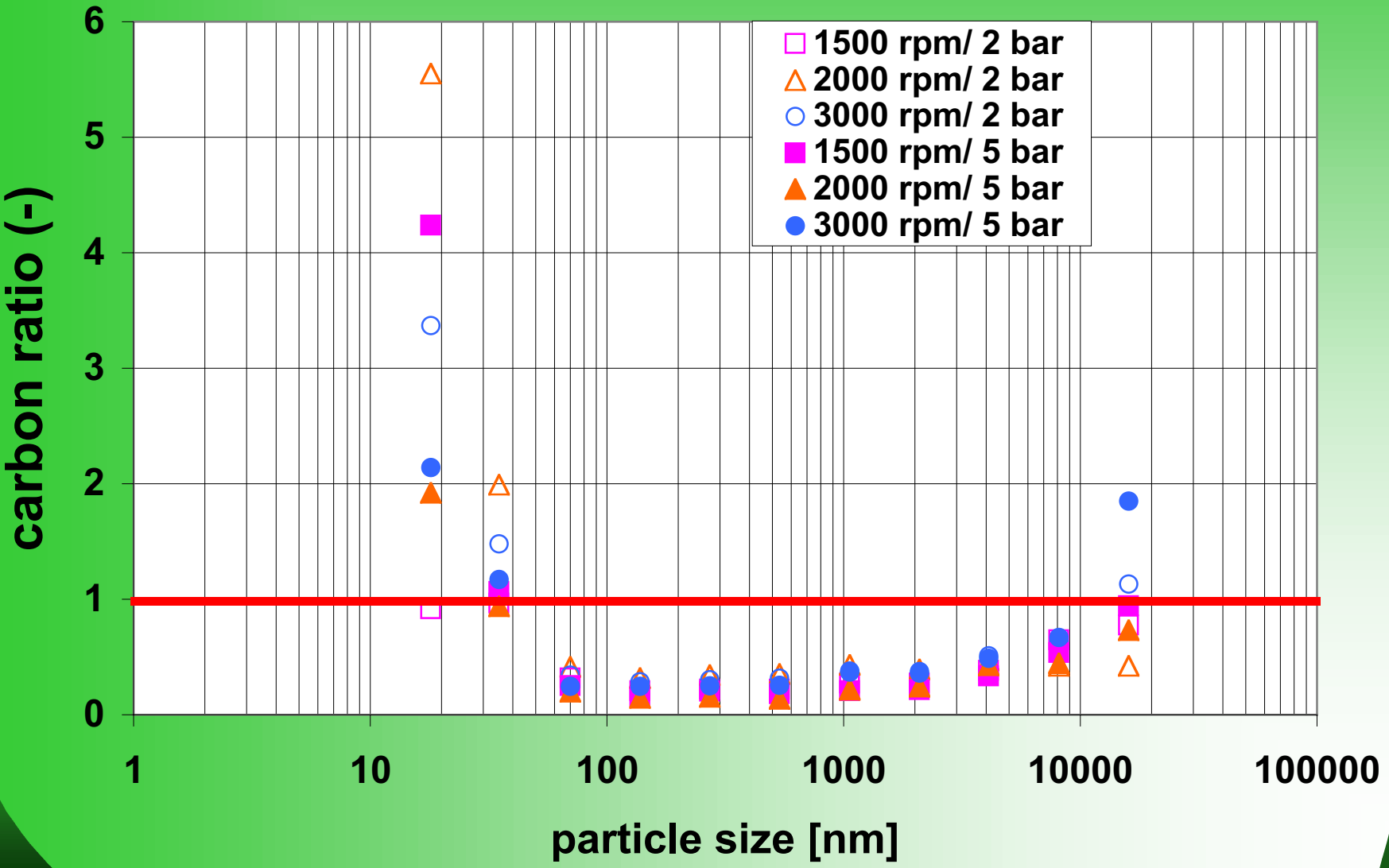
results engine out (50 ppm S)

OC/EC - ratio = f (temperature)



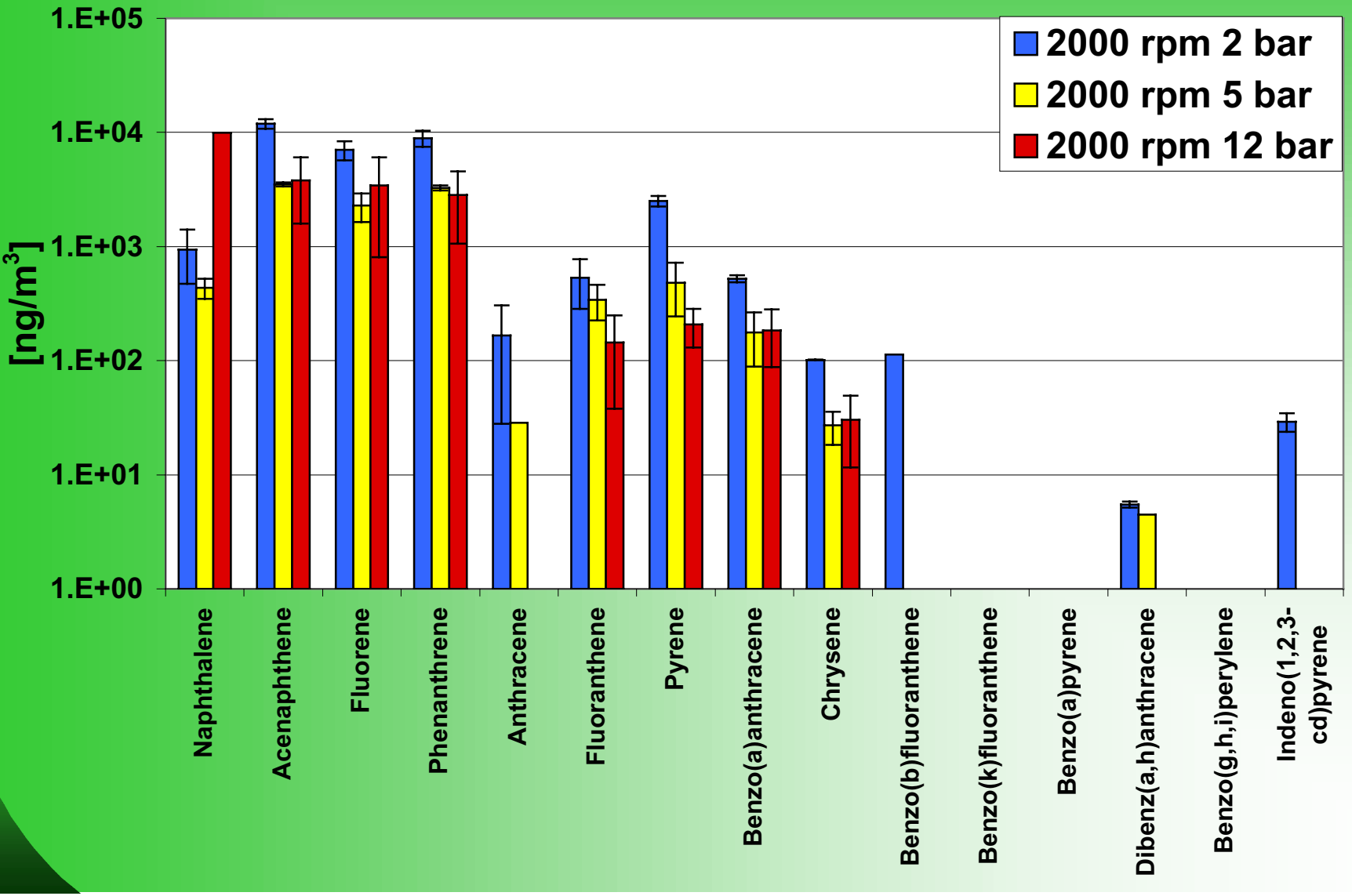
results engine out (50 ppm S)

OC/EC - ratio = f (particle size, temperature)



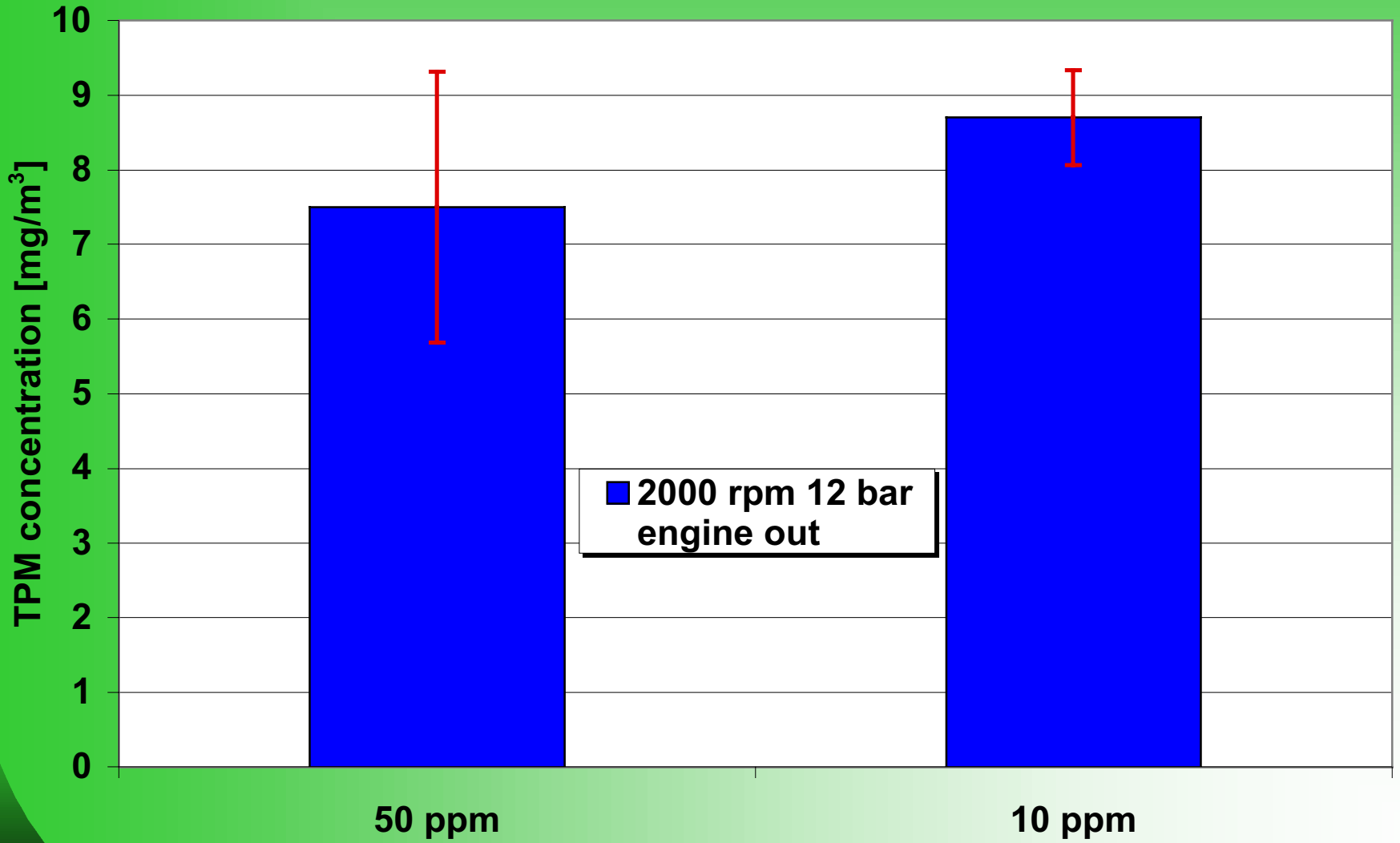
results engine out (50 ppm S)

PAH = f (temperature)



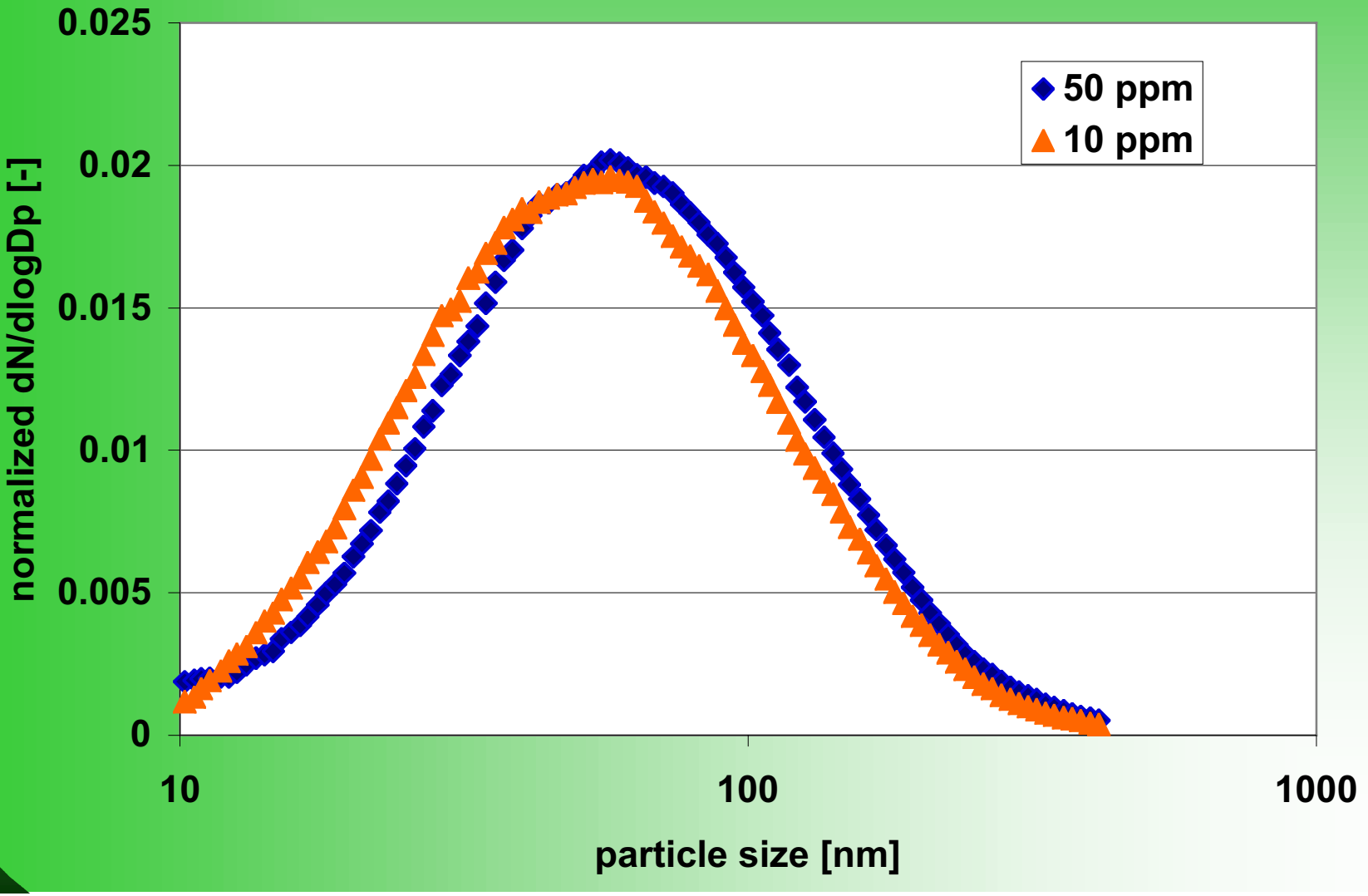
TPM = f (fuel quality)

2000 rpm 12 bar ; T = 430 °C



Particle size distribution = f (fuel quality)

2000 rpm 12 bar 430 °C cold dilution



strucure

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     - filter out
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1. equipment @ CUTEC to
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2. test conditions & results
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       - TPM filtration efficiency
       - OC/EC = f (T, particle size, filter)
       - PAH = f (T, soot loading)
       - TPM = f (fuel quality)
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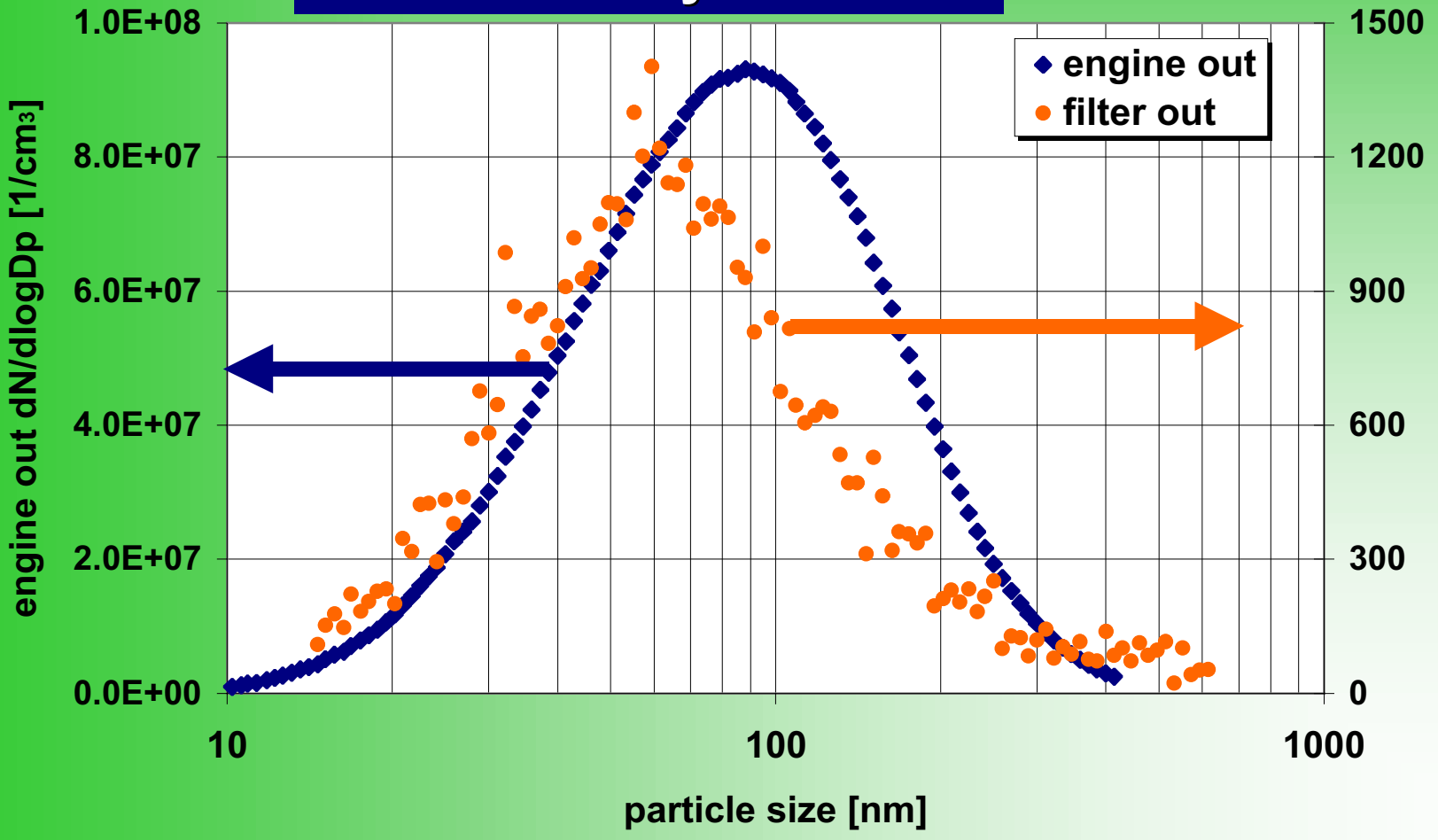
results filter out (50 ppm S)

TPM filtration efficiency

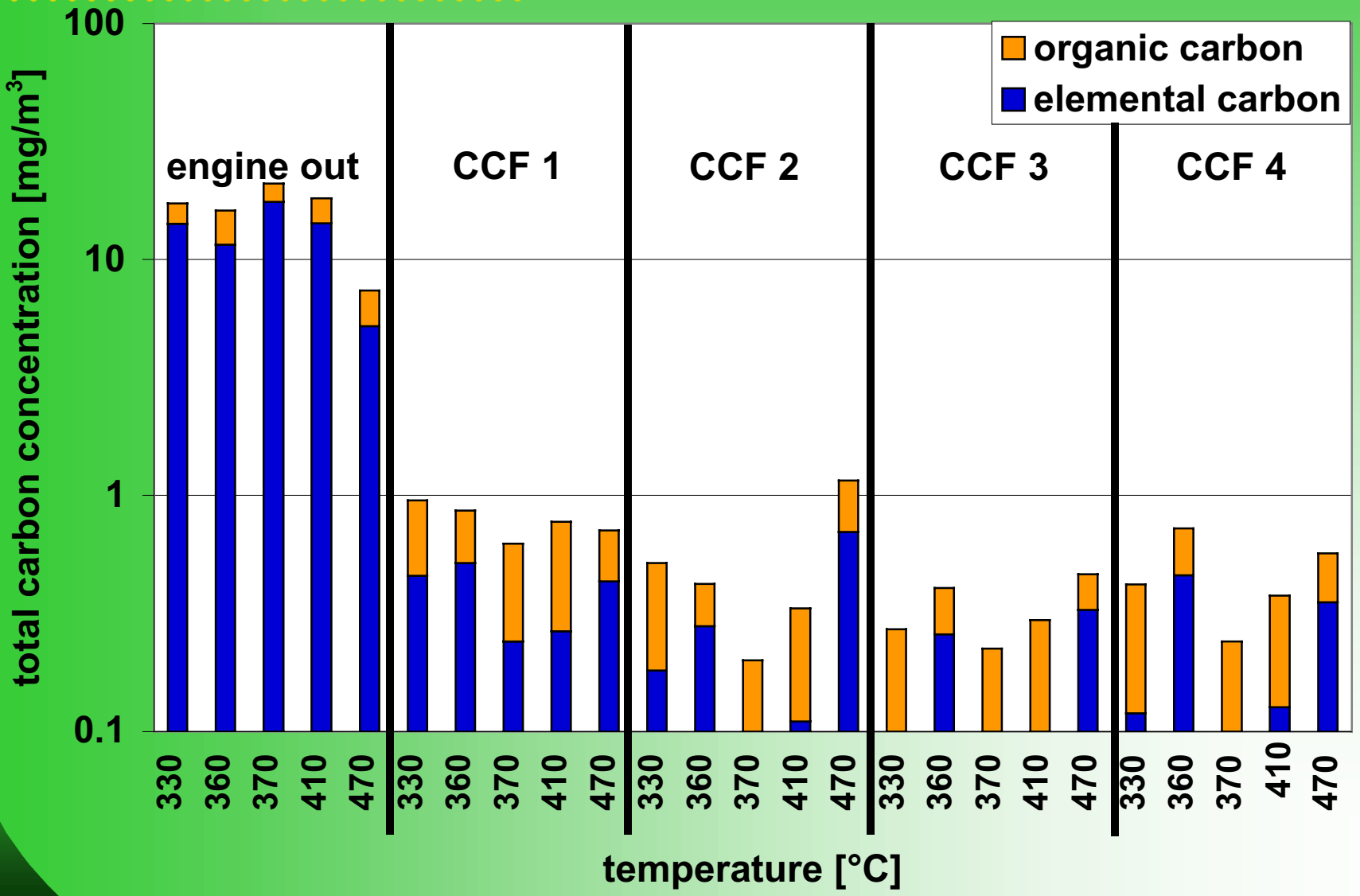
2000 rpm 5 bar ; T = 360 °C; CCF 1

filter efficiency : 99.98 %



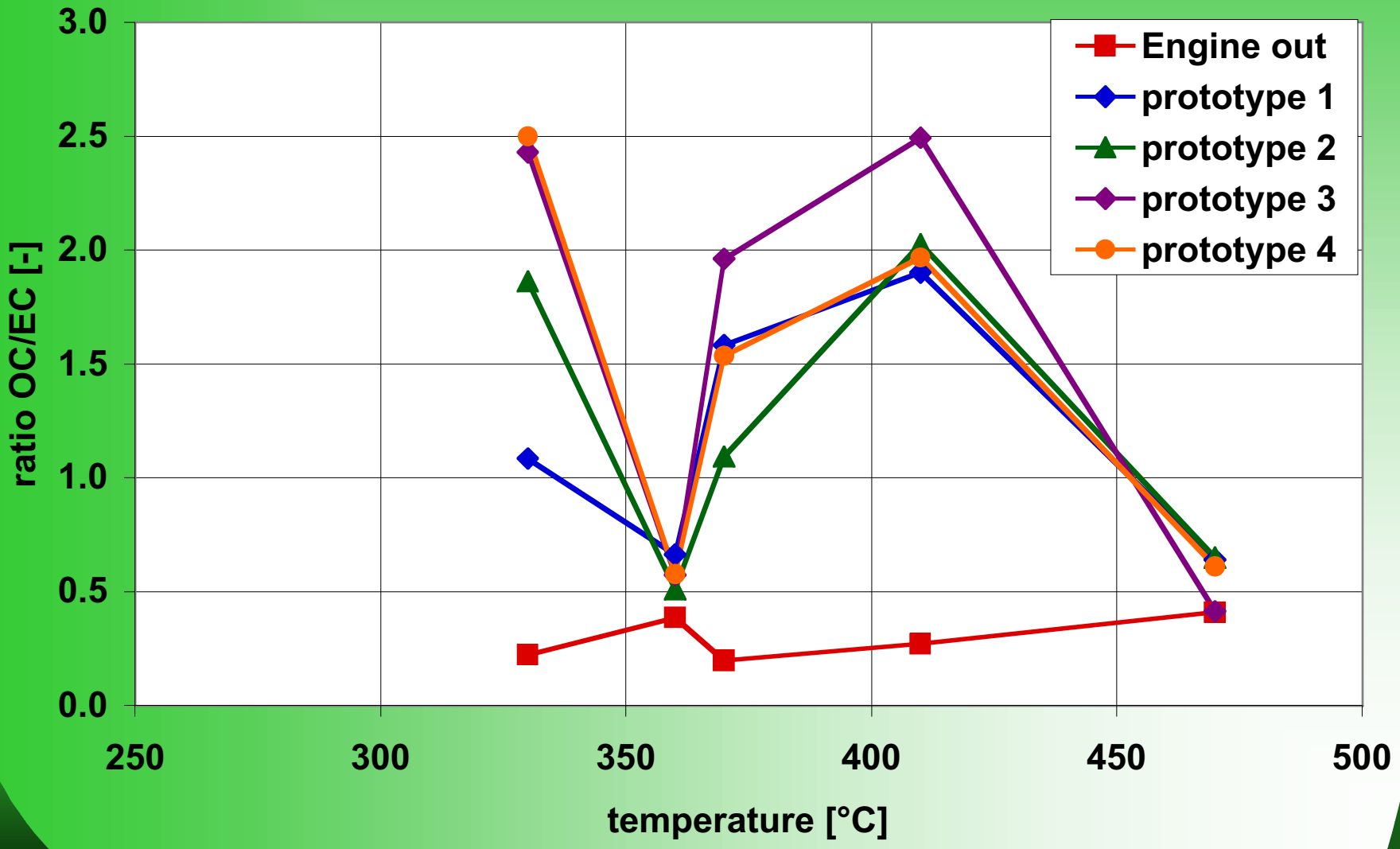
results filter out (50 ppm S)

OC & EC = f (temperature, CCF)



results filter out (50 ppm S)

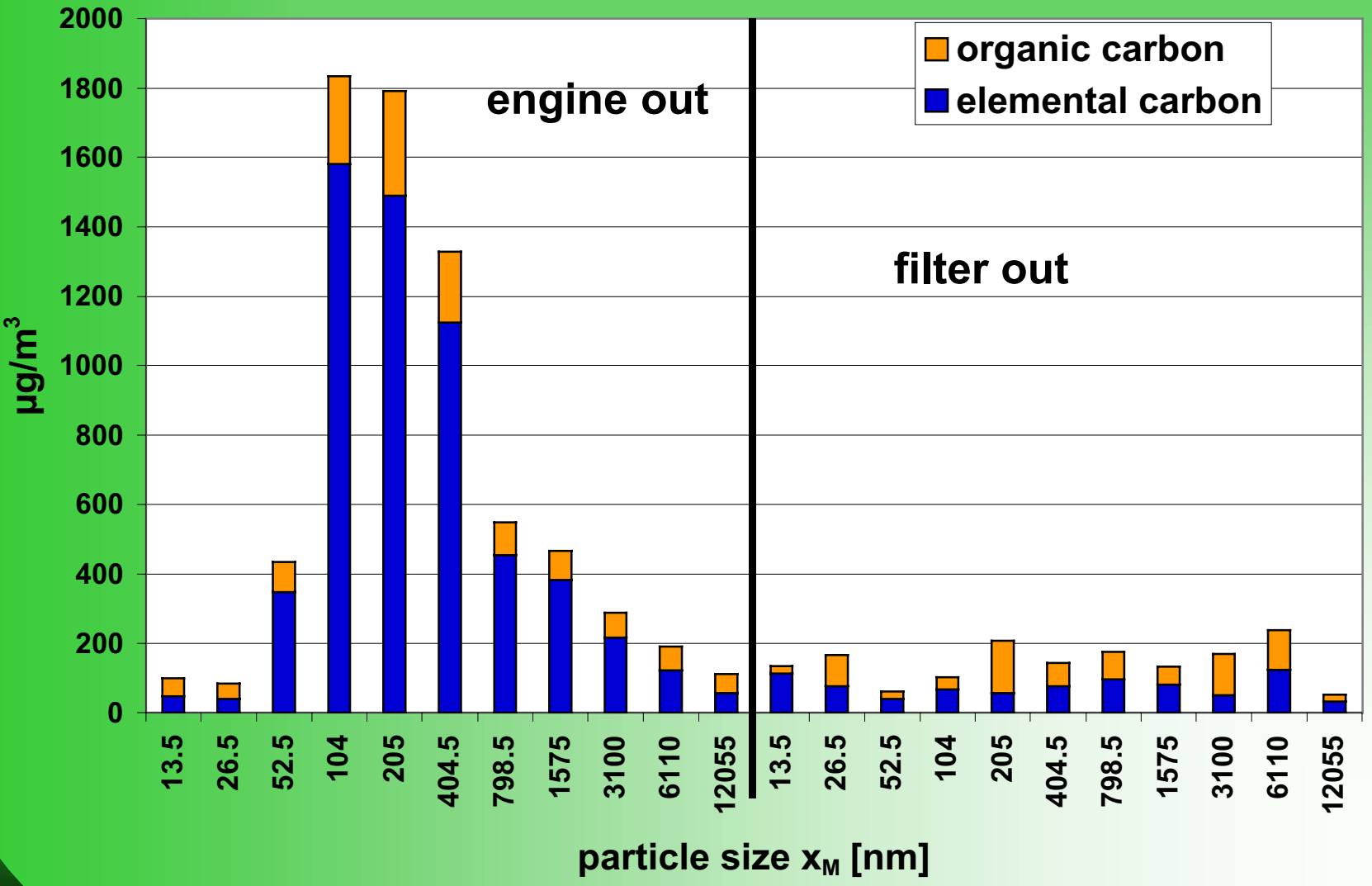
OC / EC - ratio = f (temperature, CCF)



results filter out (50 ppm S)

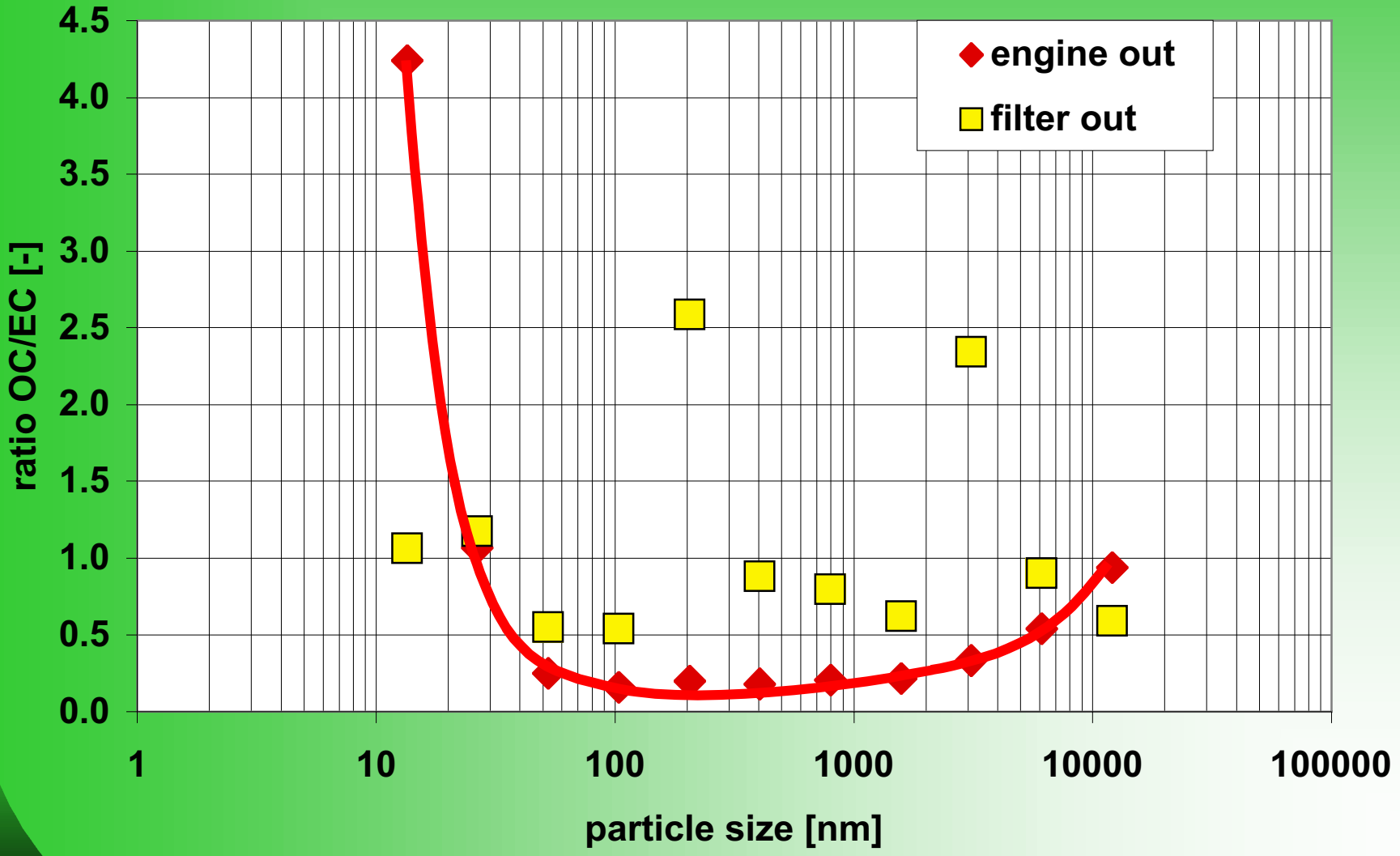
OC & EC = f (particle size)

2000 rpm 5 bar (360 °C)



OC / EC - ratio = f (particle size)

2000 rpm 5 bar (360 °C)



Comparison OC/TC @ engine out & CCF out

2000 rpm 5 bar 340 °C

	Engine out [µg/m³]	CCF 1 out [µg/m³]	Reduction [%]
Organic carbon	1307	768	41
Elemental carbon	5873	822	86
OC/TC [-]	0.18	0.49	

TC = OC + EC

strucure

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2. **test conditions & results**
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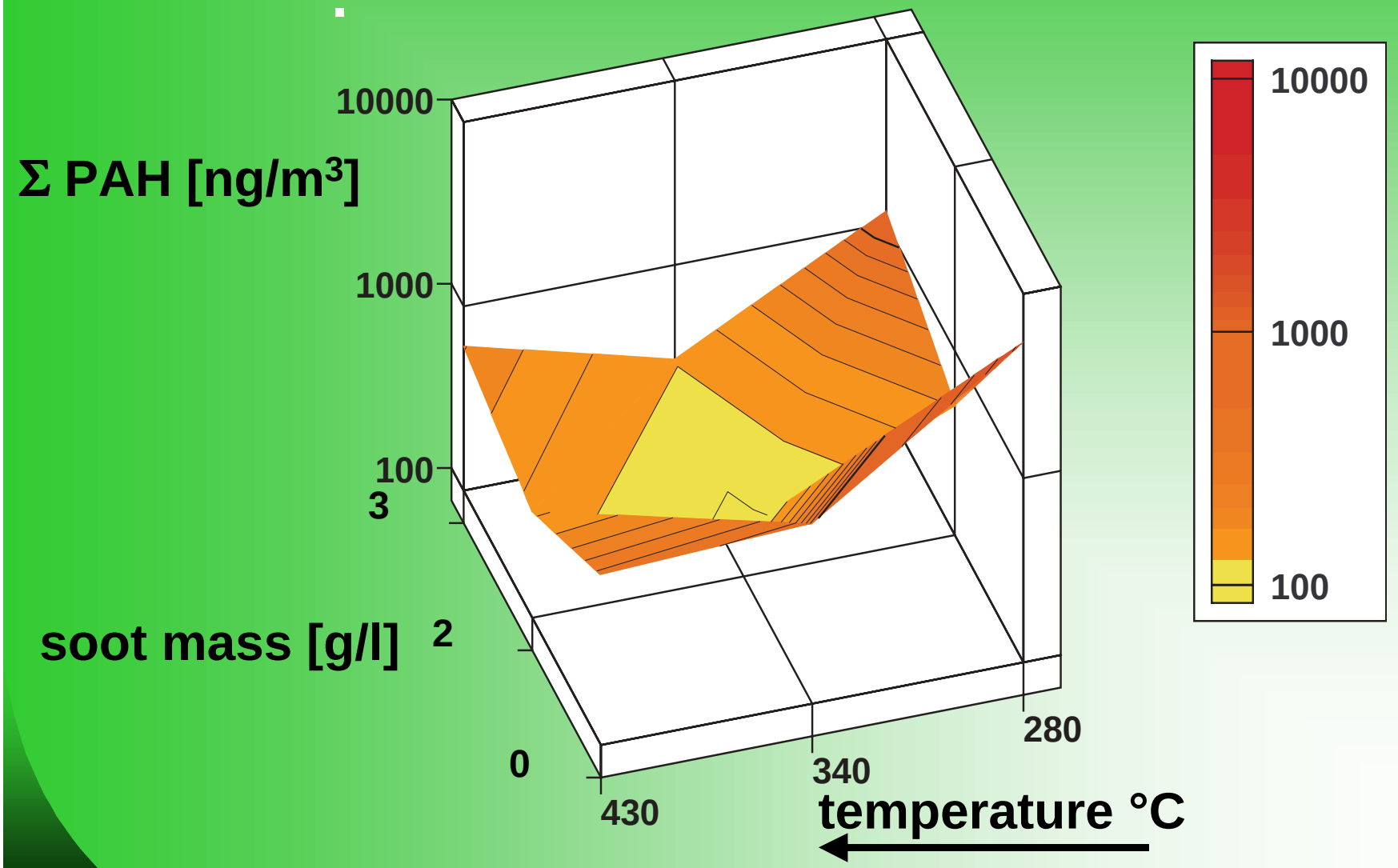
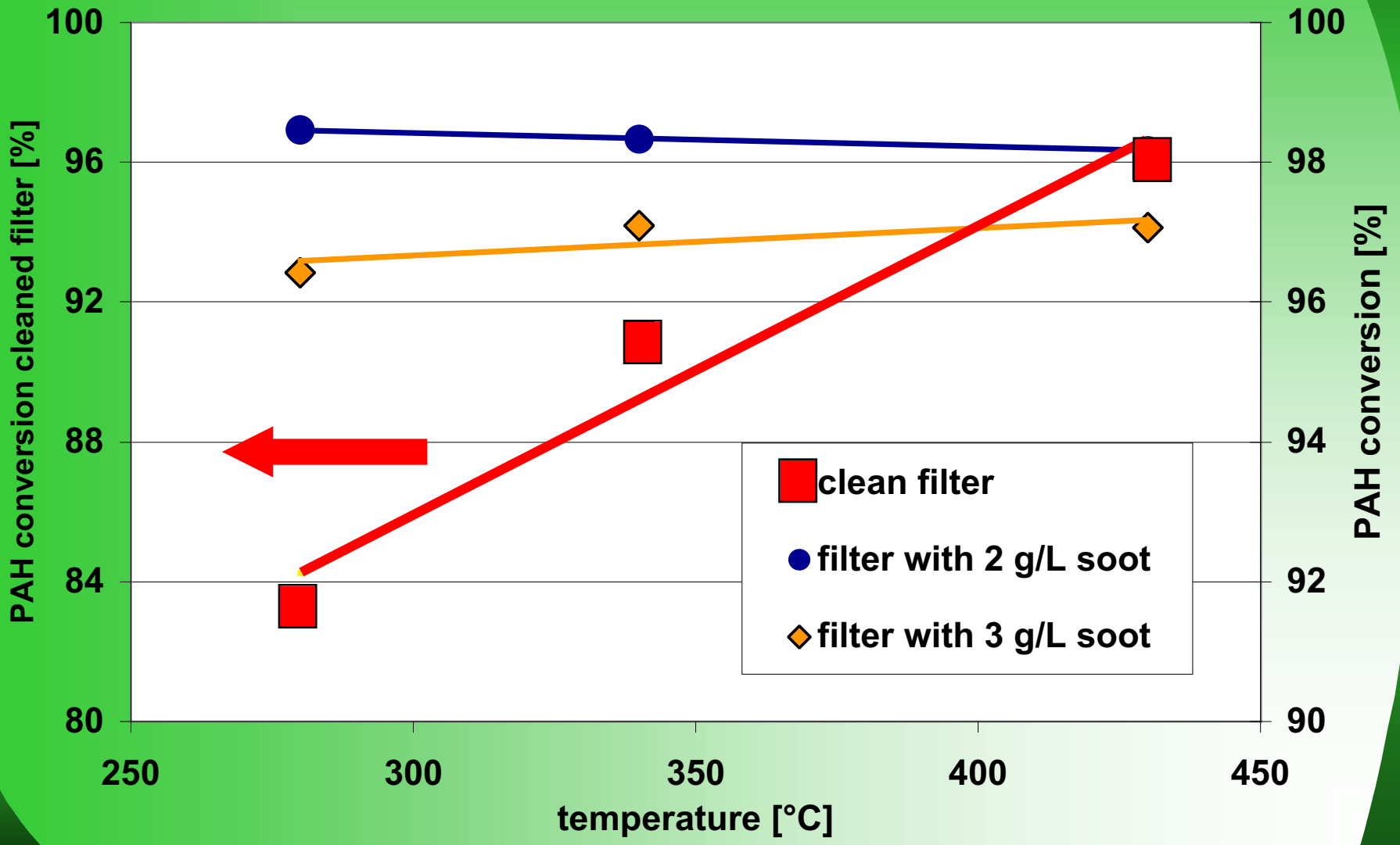
     - **filter out**
       - TPM filtration efficiency
       - OC/EC = f (T, particle size, filter)
       - **PAH = f (T, soot loading)**
       - TPM = f (fuel quality)
3. summary/conclusion

Σ PAH = f (temperature, soot loading)



PAH conversion = f (temperature, soot loading)



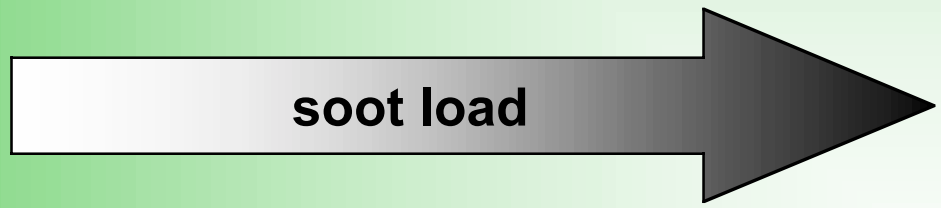
PAH reduction = f (temperature)

PAH	2000 rpm 2 bar	2000 rpm 5 bar	2000 rpm 12 bar
Phenanthrene	98 %	98 %	97 %
Pyrene	95 %	92 %	85 %
Benzo(a)anthracene	82 %	77 %	85 %

engine operations point
2g/L soot load CCF 1

PAH reduction = f (soot loading)

PAH	clean	2 g/L soot	3 g/L soot
Phenanthrene	97 %	98 %	97 %
Pyrene	96 %	95 %	99 %
Benzo(a)anthracene	81 %	82 %	72 %



engine operations point
2000 rpm 2 bar 280°C CCF 1

strucure

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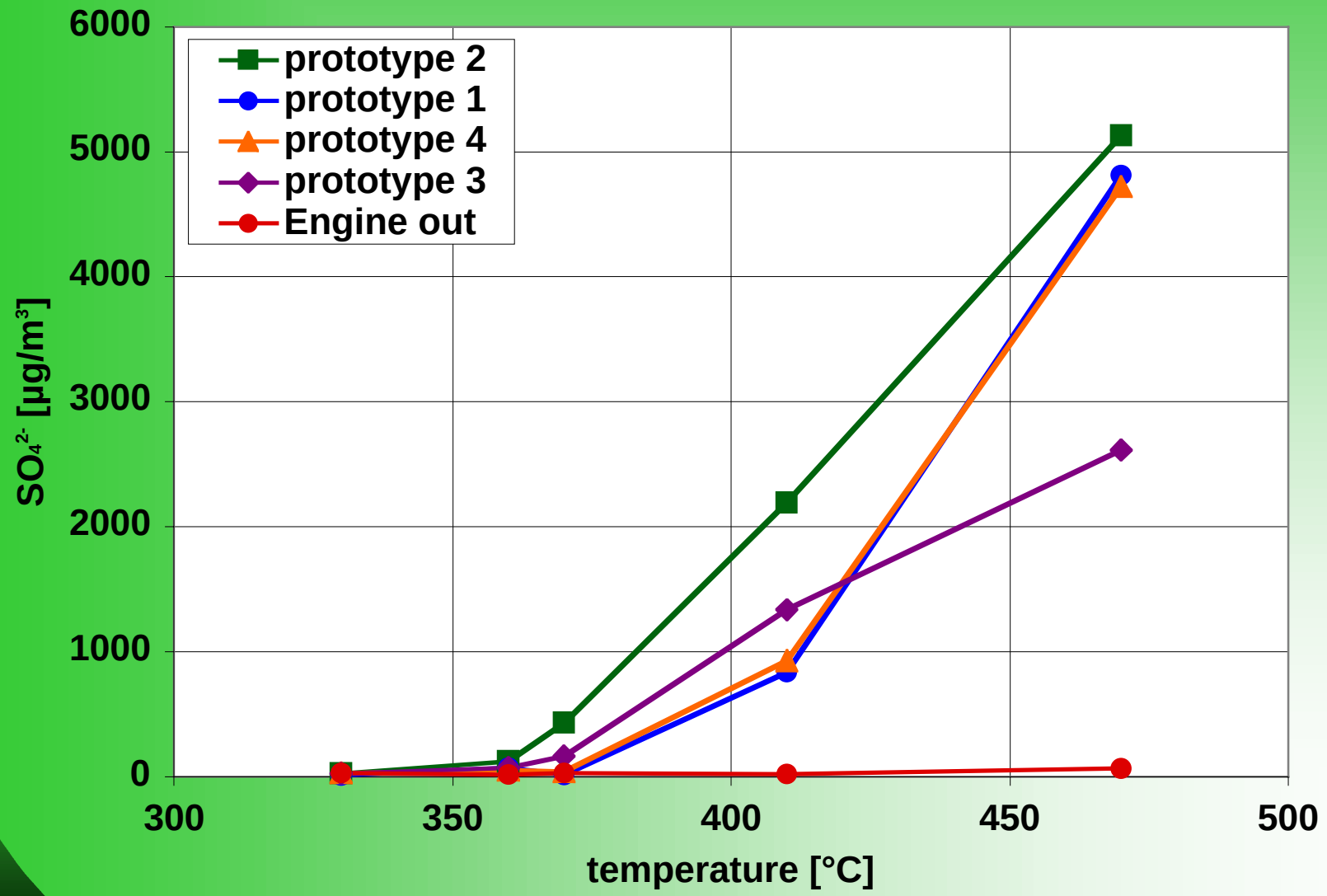
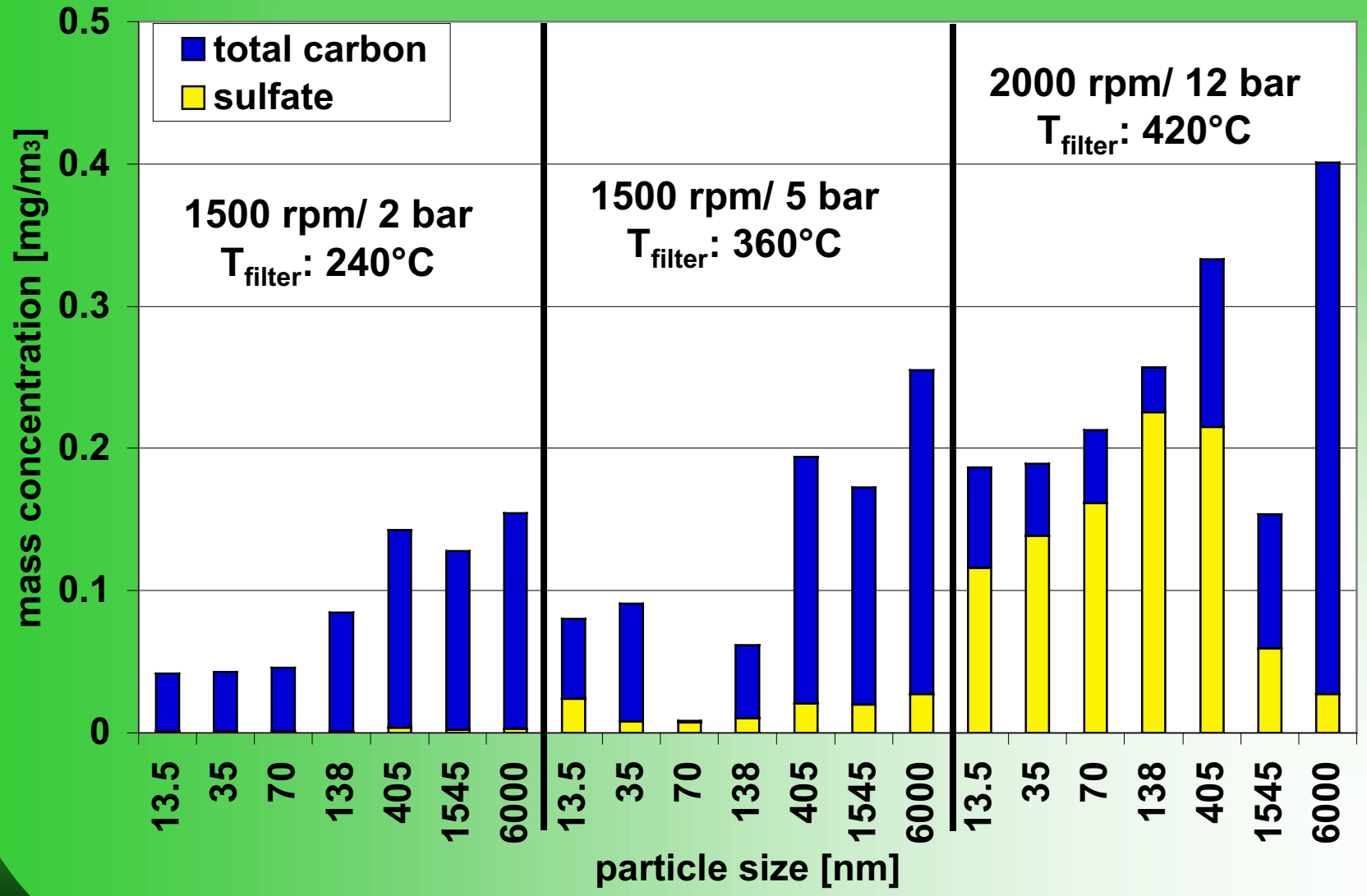
SO_4^{2-} = f (temperature, CCF)

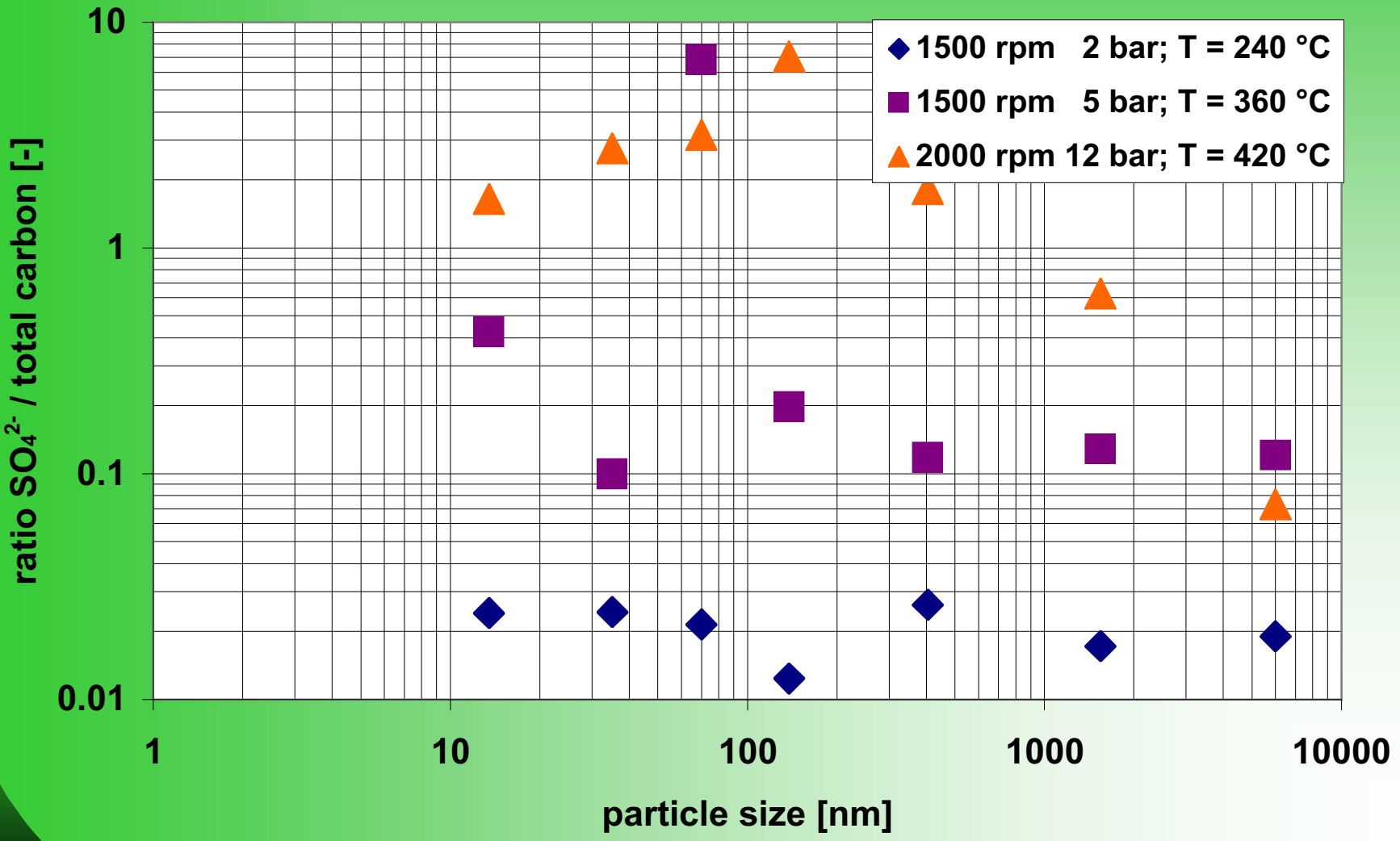


CU TEC

SO_4^{2-} & TC = f (temperature, particle size



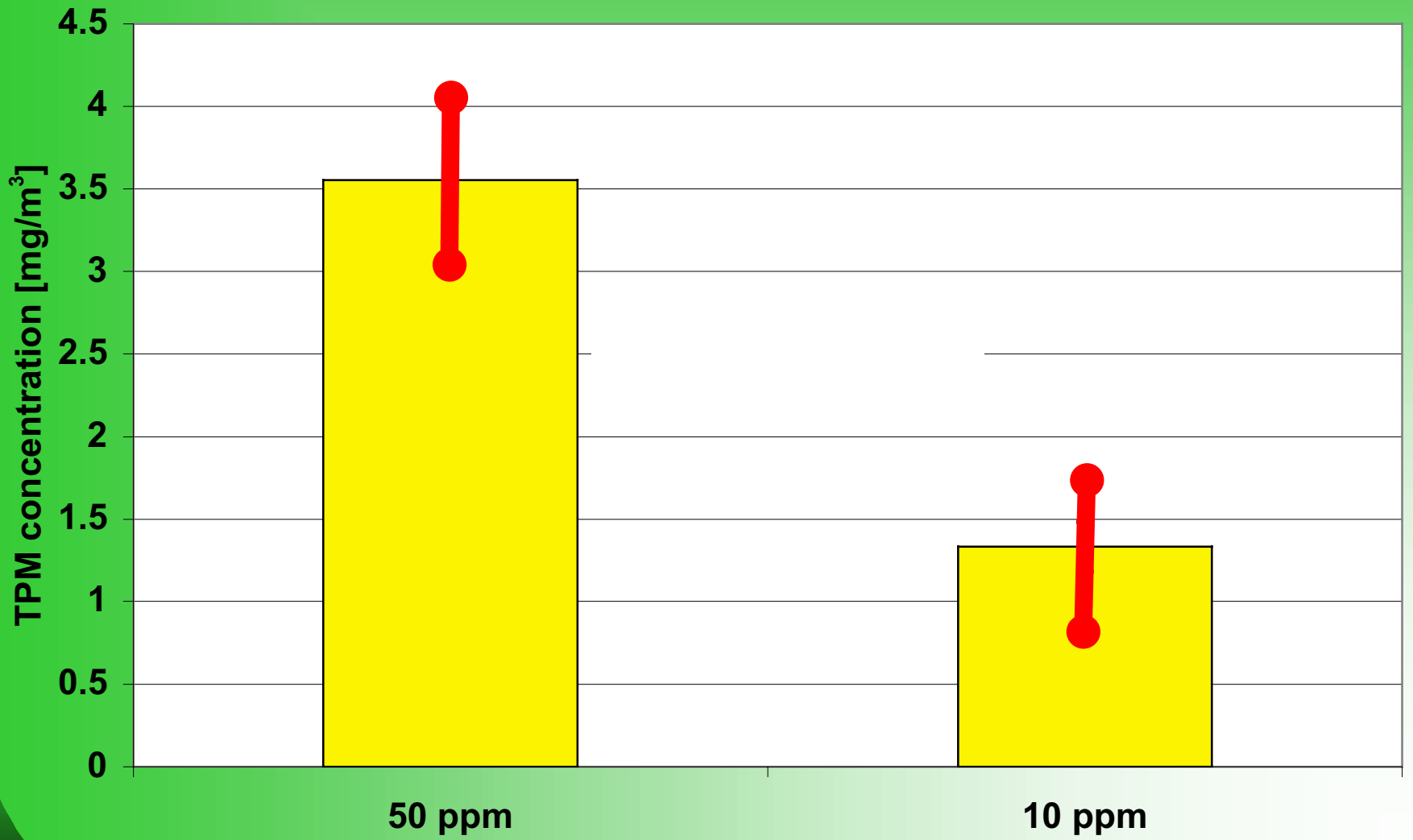
SO_4^{2-} / TC -ratio = f (temperature, particle size



results filter out CCF 1

TPM = f (fuel quality)

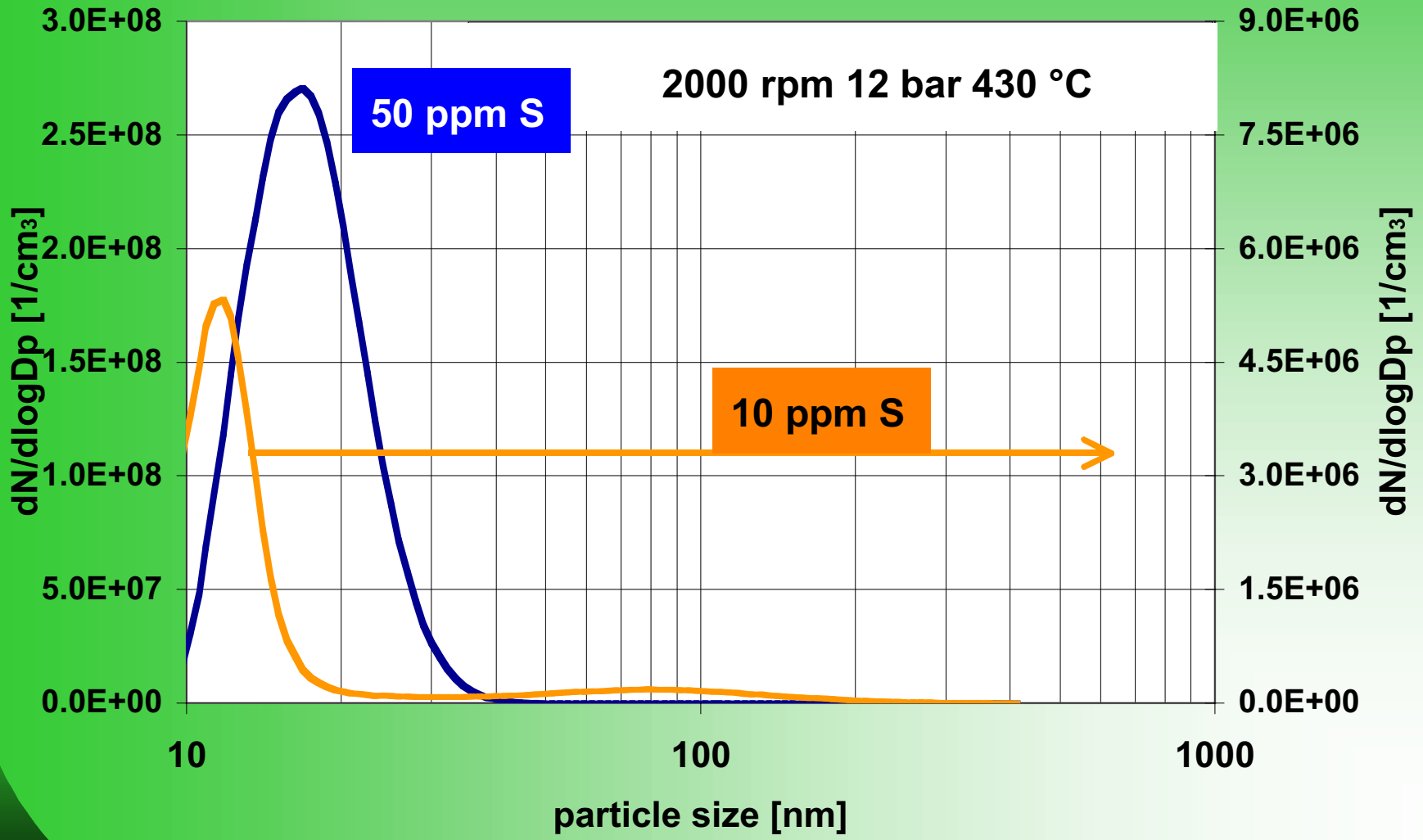
2000 rpm 12 bar ; T = 430 °C



results filter out

Particle number distribution = f (fuel quality)

cold dilution



Sulphur effect on the emissions engine out

	engine out		filter out	
S [ppm]	TPM [mg/m³]	SOF [mg/m³]	TPM [mg/m³]	max. particle number (nuclei range) [1/cm³]
50	7.5 ± 1.8	3.3 ± 0.6	3.5 ± 0.49	$3*10^8$
10	8.7 ± 0.6	3.4 ± 0.8	1.3 ± 0.35	$5*10^6$
80 %	0	0	63 %	98 %

strucure

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summary/conclusion

Particle Size and Composition Measurements at Modern Engines and Aftertreatment Systems

	engine out	DOC+CCF out
OC + EC = f (T)	maximum	effected by CCF
OC/EC-ratio = f(T)	no tendency OC/EC = SOF/TPM	CCF minimum (360 °C)
OC + EC = f(particle size)	maximum	no tendency
OC/EC-ratio= f(particle size)	OC/EC < 1 30 nm < TPM < 10000 nm	no tendency
PAH = f(T)	strong	minimum (clean, soot load)
TPM = f (sulfur)	no effect	strong
SO_4^{2-} = f(T)	low effect	strong (360 °C)
particle size / number = f(sulfur)	weak	98 %
filtration efficiency		99.98 %

CU TEC

- R & D
  - filter material
  - catalytic coating
  - filtration characterisation / -kinetics
  - regeneration strategies / - kinetics

CU TEC

Thank you for your attention !

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