Time Resolved Measurements of Soot Concentrations and Mean Particle Sizes during EUDC and ECE Cycles

R.A. Zahoransky[1], E. Laile[2], M. Claußen[3], A. Konstandopoulos[4]

[1] Fachhochschule Offenburg, Badstr. 24, D-77652 Offenburg; International Quality Network „Nanoparticles & Biological Particles“
[2] WIZARD Zahoransky KG, Schwarzwaldstr. 3, D-79674 Todtnau
[3] CUTEC-Institut GmbH, Leibnisstr. 21+23, D-38678 Clausthal-Zellerfeld
[4] CE.R.T.H/CPERI, P.O. Box 361, 57001 Thermi, Thessaloniki, Greece

Soot particles from combustion engines are under discussion to be one of the most important man-made particles with major biological impact.

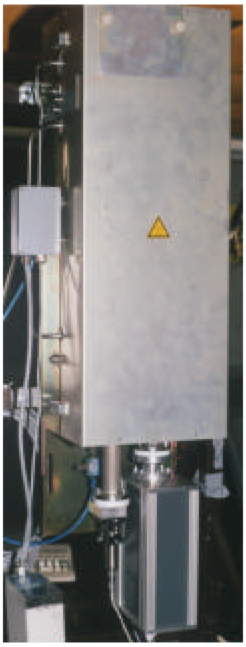


Fig. 1: Sensor head flanged below White cell

Fig. 2: EUDC cycle; Top: Mean particle diameter and particle concentration Bottom: Engine speed and torque

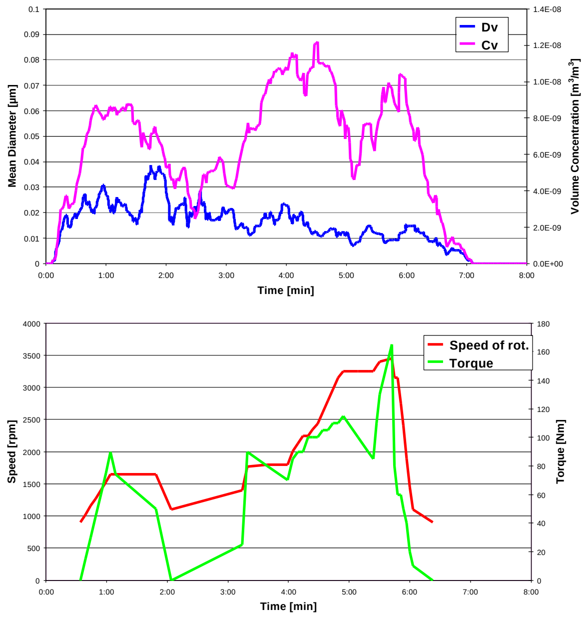
The importance of the soot particle size has grown up with the up-coming discussion of the health effects of soot emissions. Furthermore, sharpened regulations for the particle emissions of diesel engines demand advanced particle measurement systems. The presented system delivers both in on-line mode: Size and concentration of the emitted particulate matter.

The spectral attenuation of three different laser diode wavelengths is used to derive particle diameter and particle concentration.

The relatively low particle concentration and the small primary particles in the exhaust of diesel engines require an optical path length of 10 to 20 m. Fig. 1 shows the sensor, consisting of the signal detector and the transmitting unit adapted to the long-path-cell at the bottom side.

Fig. 2 depicts the behaviour of particle concentration and particle size during the transient EUDC cycle taken by the described on-line measurement system. The transient engine loads are reflected clearly in concentration and size variations.

The particle analyser based on the optical multi-wavelength extinction proved to be a most reliable tool to measure on-line and in-situ directly the undiluted particle emission of diesel engines. The two main aerosol parameters „mean diameter“ and „volume concentration“ are recorded on-line.



Advantages of the on-line measurement system are the accessibilty to the raw, undiluted exhaust gas and the fast adaptation. The on-line capability permits the direct measurement of either stationary or transient motor conditions.

The data delivered by the presented optical multi-wavelength extinction system coincides excellently with gravimetric methods. Furthermore, a fractal analysis correlates perfectly the particle size data with data of DMA measurements.

Further developments in extending the features to record representative gaseous species in the exhaust gas are in progress.

Acknowledgement
The sensor development and the measurements are supported by the EU (DEXA cluster, Project No. GRD1-1999-11154) and the DAAD (International Quality Network “Nanoparticles & Biological Particles”)

Explanation of the oral presentation

Speaker: Prof. Dr. Richard Zahoransky

Figure	Explanation
1	Authors and title of the presentation
2,3	Implemented theory of the system: The attenuations of three laser wavelengths are measured. According to Bouguer´s law and the Mie-Theory, these attenuations are used to calculate the mean diameter and the volume concentration of the aerosol system
4	Schematic of the Long-Path-Multi-Wavelength-Extinction Analyzer
5	Pictures of the heated measurement chamber. Within compact dimensions, the chamber contains an adjustable optical path length in the range of 2.5 to 20 m (folded beam, White principle)
6,7,8,9	Results of transient cycles (EUDC, ECE)
10,11	Preliminary results of the GRPE Particle Measurement Programme (PMP) at EMPA, CH-Dübendorf in June 2002. Seven different time resolved measurements of the European Transient Cycle (ETC) are shown over the complete period of 30 minutes and in detail
12	Conclusion

Contact address for further information:

WIZARD Zahoransky KG
Schwarzwaldstr. 3
79674 Todtnau
Germany
Tel. ++49-7671-9233
Fax ++49-7671-9234
Mail: wizard-todtnau@t-online.de

6th Int. ETH-Conference on Nanoparticle Measurement

R. A. Zahoransky[1], E. Laile[2], M. Claußen[3], A. Konstandopoulos[4]

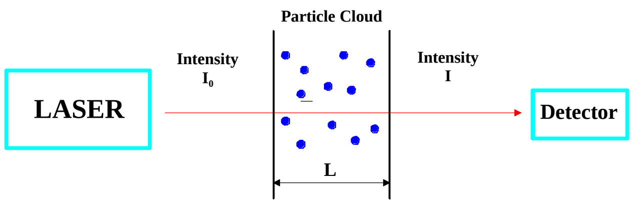
Time Resolved Measurements of Soot Concentrations and Mean Particle Sizes during EUDC and ECE Cycles

[1] Fachhochschule Offenburg, Badstr. 24, D-77652 Offenburg;
International Quality Network „Nanoparticles & Biological Particles“
[2] WIZARD Zahoransky KG, Schwarzwaldstr. 3, D-79674 Todtnau
[3] CUTEC-Institut GmbH, Leibnisstr. 21+23, D-38678 Clausthal-Zellerfeld
[4] CE.R.T.H/CPERI, P.O. Box 361, 57001 Thermi, Thessaloniki, Greece

WIZARD Zahoransky KG

Fig. 1

Principle of the Dispersion Quotient Technique (1)



monodisperse

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

polydisperse

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

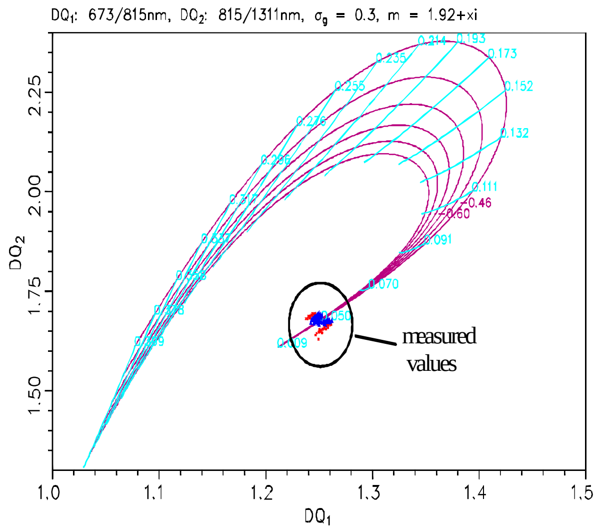
with:
- I = intensity
- I_0 = initial intensity
- N = particle concentration
- L = optical path length
- r = particle radius
- Q_{ext} = extinction coefficient
- λ = wavelength
- n = refractive index
- $p(r)$ = number distribution

WIZARD Zahoransky KG

Fig. 2

Principle of the Dispersion Quotient Technique (2)

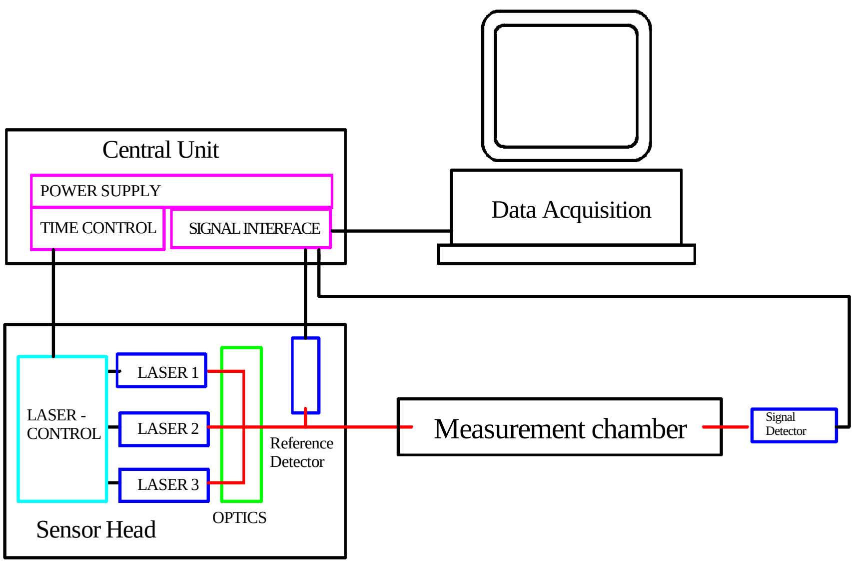
$$DQ_1 = \frac{\ln\left(\frac{I}{I_0}\right)_{l1}}{\ln\left(\frac{I}{I_0}\right)_{l2}} = \frac{-N \cdot L \cdot p \cdot r^2}{-N \cdot L \cdot p \cdot r^2} \cdot \frac{Q_{ext}(r,\ l_1, n)}{Q_{ext}(r,\ l_2, n)}$$



WIZARD Zahoransky KG

Fig. 3

Schematic of the new sensor



WIZARD Zahoransky KG

Fig. 4

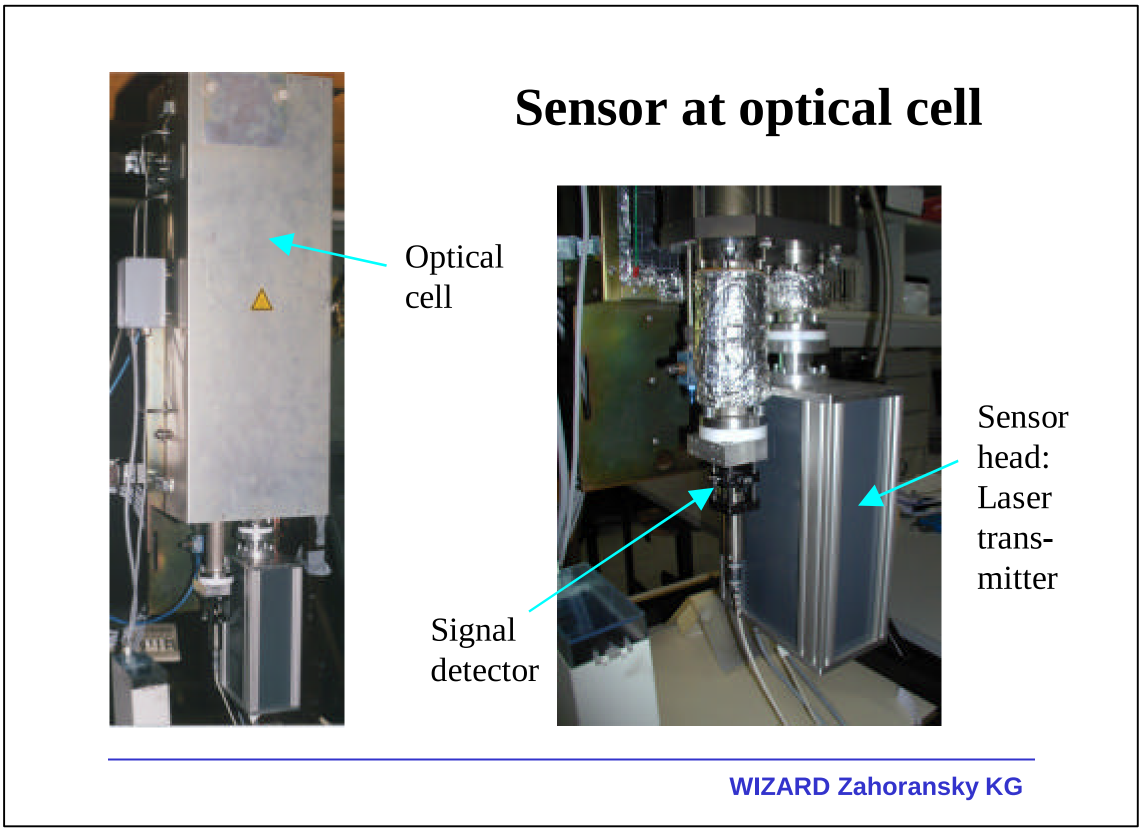

Sensor at optical cell
Optical cell
Sensor head: Laser trans-mitter
Signal detector
WIZARD Zahoransky KG

Fig. 5

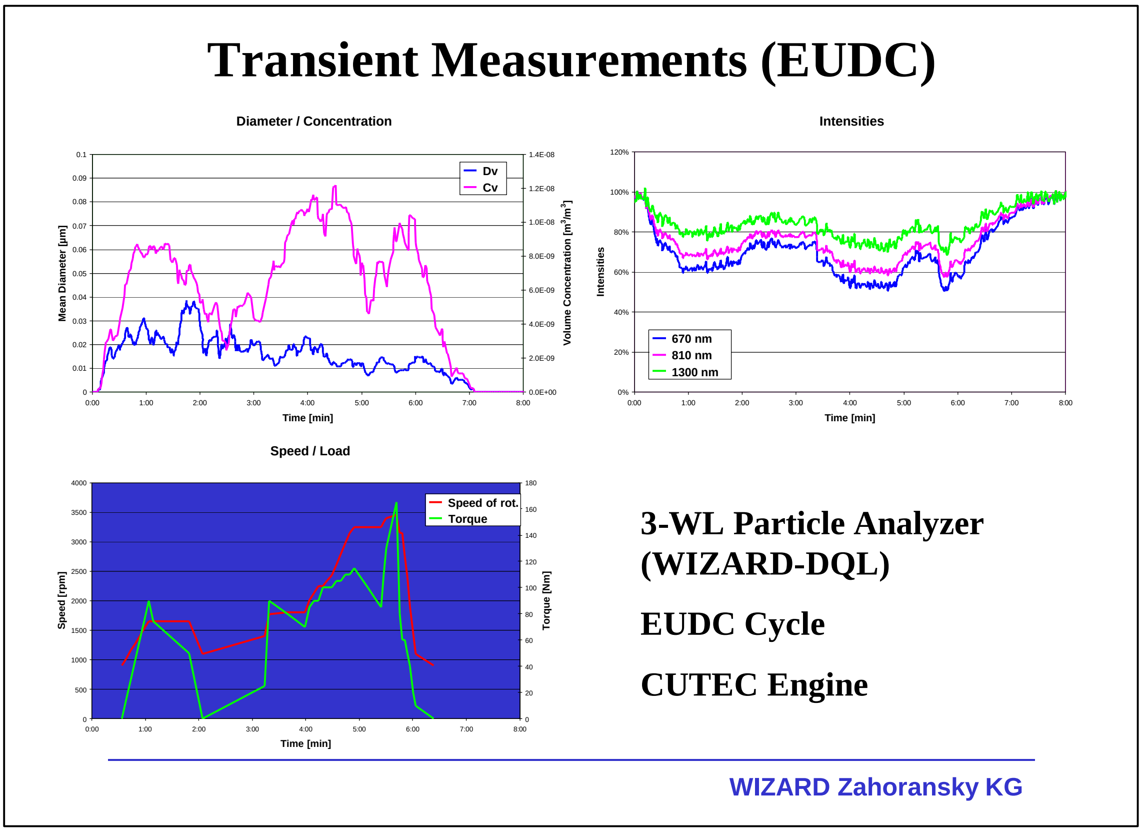

Transient Measurements (EUDC)
Diameter / Concentration
Mean Diameter [µm]
Volume Concentration [m³/m³]
Dv
Cv
Time [min]
Intensities
670 nm
810 nm
1300 nm
Time [min]
Speed / Load
Speed [rpm]
Torque [Nm]
Speed of rot.
Torque
Time [min]
3-WL Particle Analyzer (WIZARD-DQL)
EUDC Cycle
CUTEC Engine
WIZARD Zahoransky KG

Fig. 6

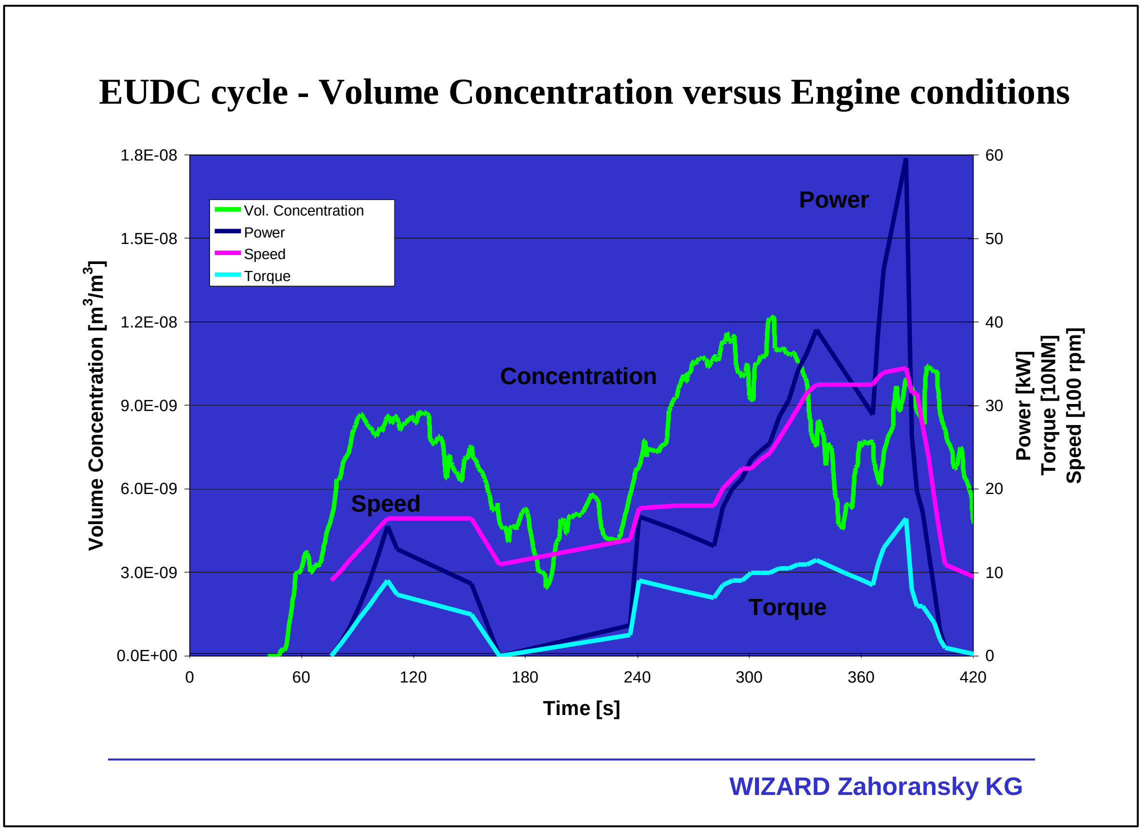

EUDC cycle - Volume Concentration versus Engine conditions
Vol. Concentration
Power
Speed
Torque
Power
Concentration
Speed
Torque
1.8E-08
1.5E-08
1.2E-08
9.0E-09
6.0E-09
3.0E-09
0.0E+00
60
50
40
30
20
10
0
0
60
120
180
240
300
360
420
Time [s]
Volume Concentration [m³/m³]
Power [kW]
Torque [10NM]
Speed [100 rpm]
WIZARD Zahoransky KG

Fig. 7

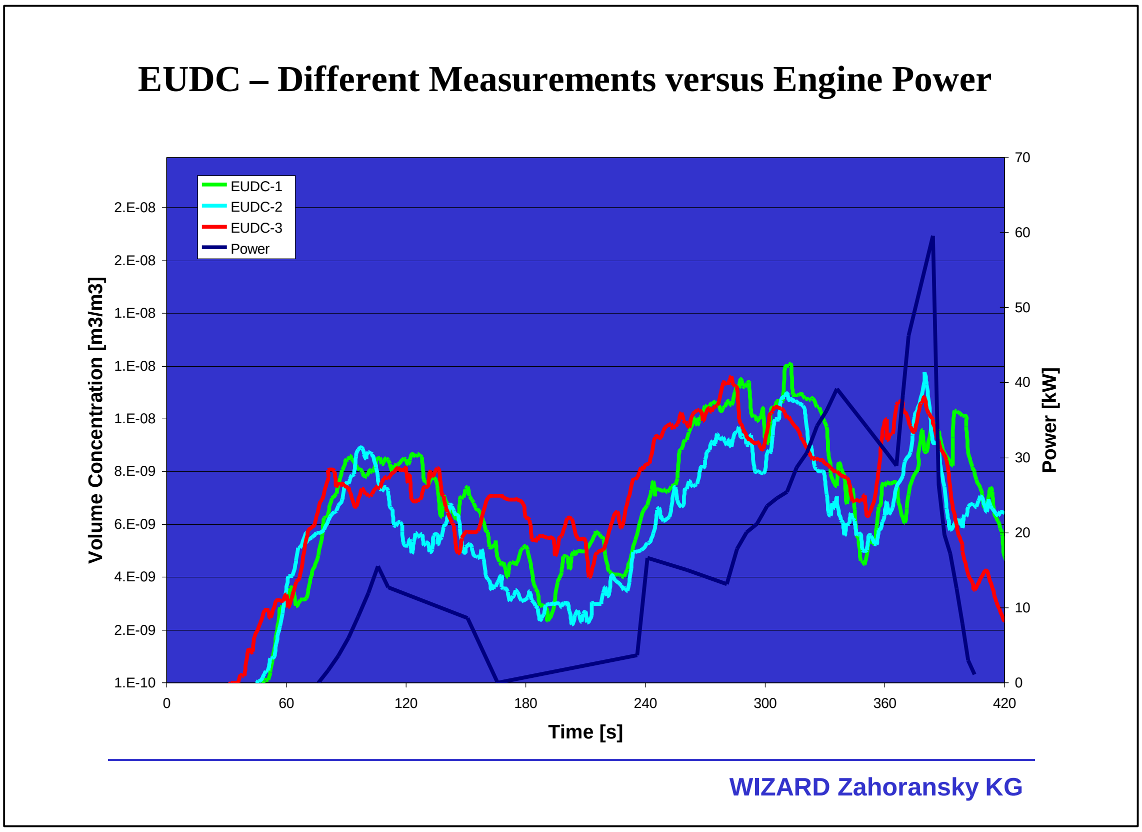

EUDC – Different Measurements versus Engine Power
EUDC-1
EUDC-2
EUDC-3
Power
2.E-08
2.E-08
1.E-08
1.E-08
1.E-08
8.E-09
6.E-09
4.E-09
2.E-09
1.E-10
70
60
50
40
30
20
10
0
0
60
120
180
240
300
360
420
Time [s]
Volume Concentration [m3/m3]
Power [kW]
WIZARD Zahoransky KG

Fig. 8

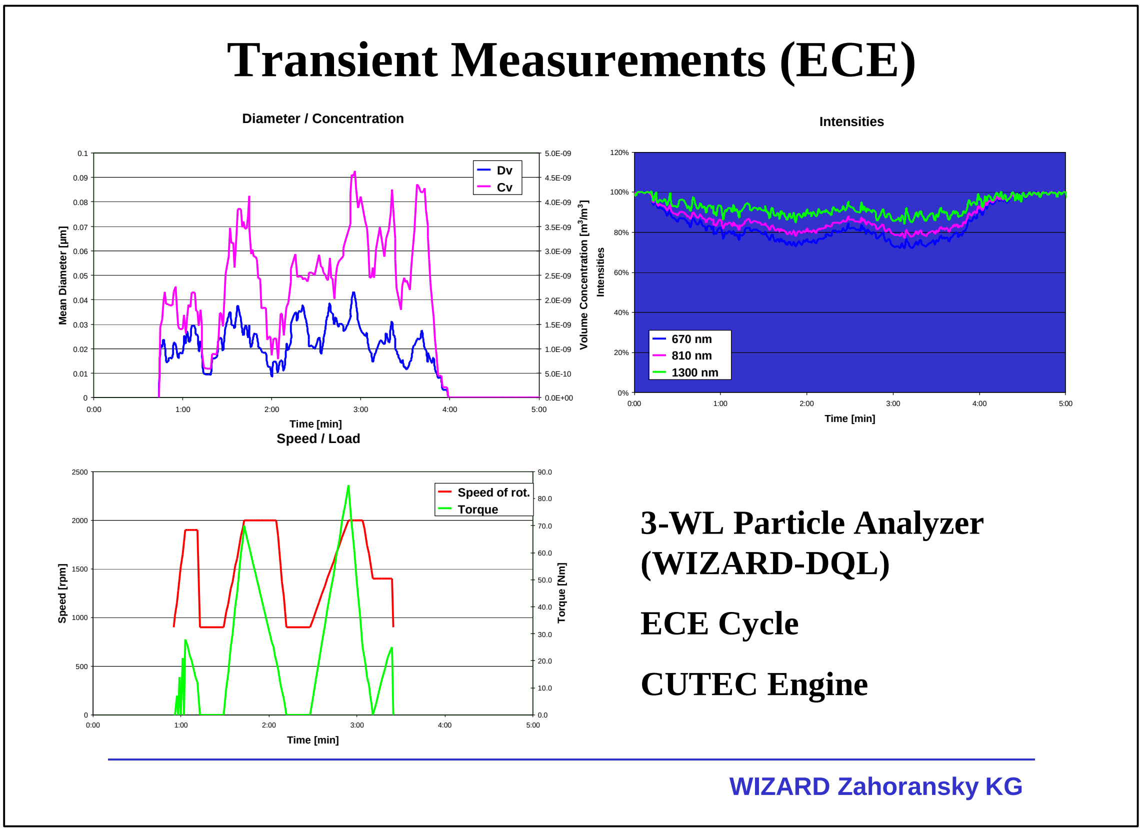

Transient Measurements (ECE)
Diameter / Concentration
Mean Diameter [µm]
Volume Concentration [m³/m³]
Dv
Cv
Time [min]
Intensities
670 nm
810 nm
1300 nm
Speed / Load
Speed [rpm]
Torque [Nm]
Speed of rot.
Torque
3-WL Particle Analyzer (WIZARD-DQL)
ECE Cycle
CUTEC Engine
WIZARD Zahoransky KG

Fig. 9

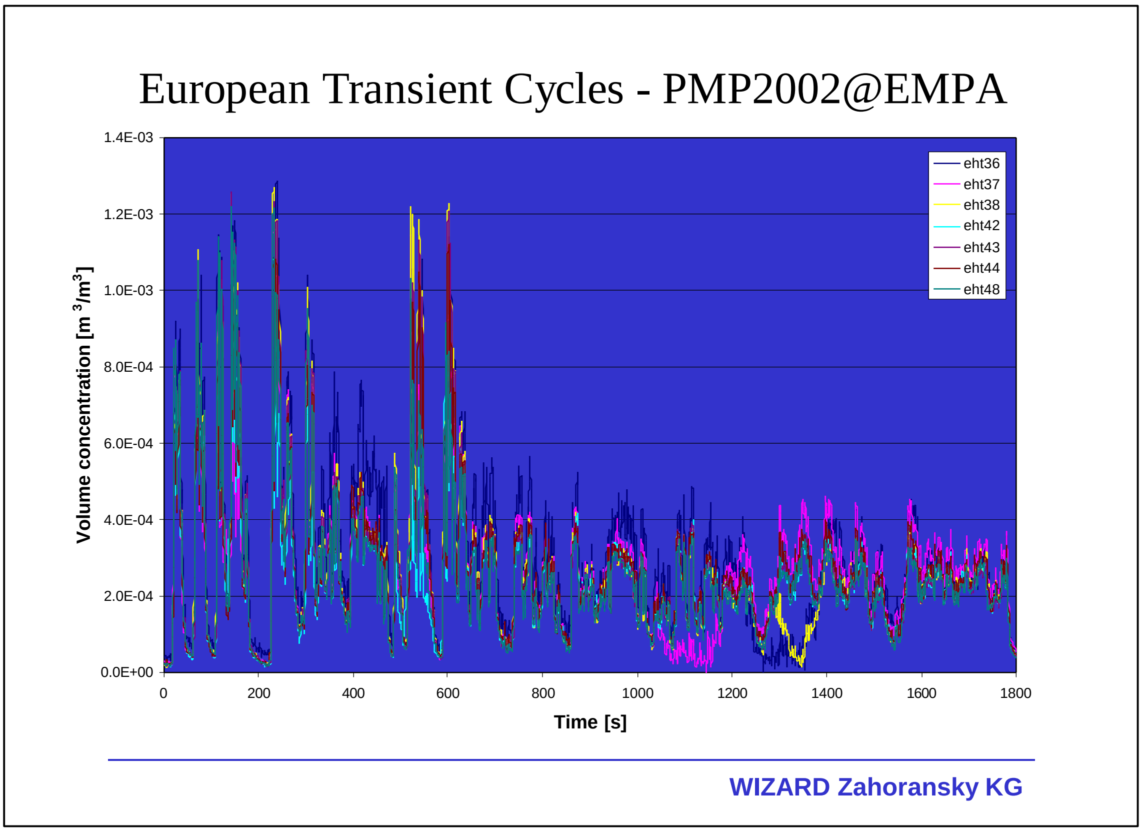
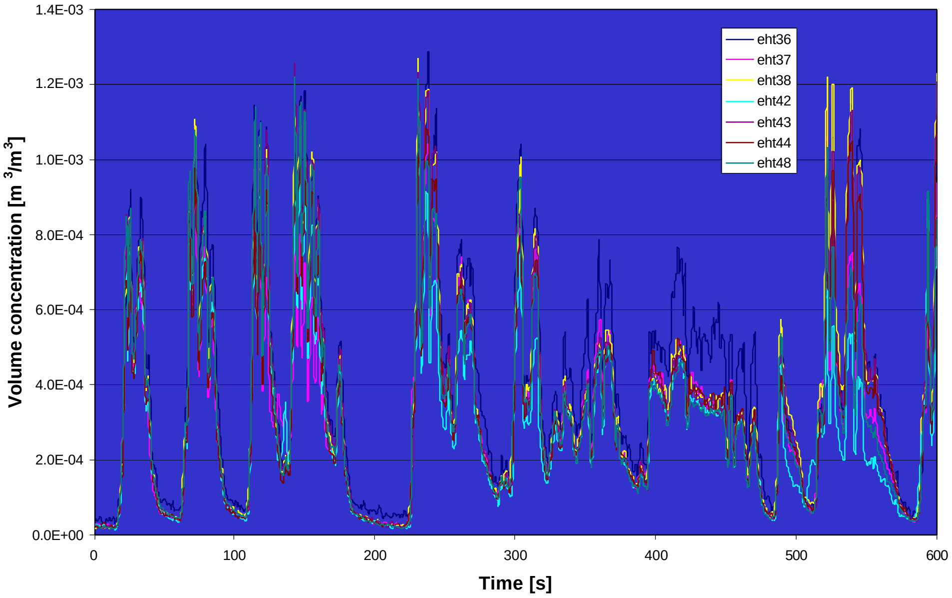

European Transient Cycles - PMP2002@EMPA
Volume concentration [m³/m³]
Time [s]
eht36
eht37
eht38
eht42
eht43
eht44
eht48
WIZARD Zahoransky KG

Fig. 10

European Transient Cycles - PMP2002@EMPA

- urban phase -



WIZARD Zahoransky KG

Fig. 11

Summary LMPE
Long-Path-Multi-Wavelength Extinction Analyzer

Advantages of the new measurement system:

- Direct measurements of the hot, undiluted raw exhaust gas
- Fast adaptation to the engine systems
- Measurement of stationary and transient motor conditions
- On-line/in-line data presentation of mean particle size and concentration, even for fast transient engine conditions, e.g. EUCD, ECE cycles
- Broad concentration range by an adjustable optical path length up to 10 m

Further developments in progress:

- Extending the system to record representative gaseous species in the exhaust gas

WIZARD Zahoransky KG

Fig. 12