Application of color measurements for evaluation of fly ash properties

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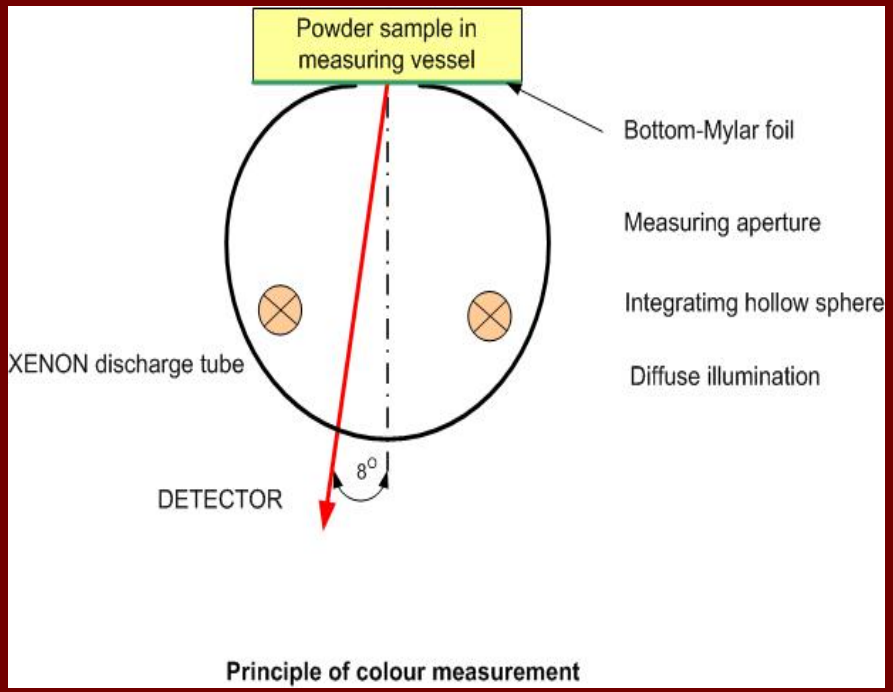
Measurement of color

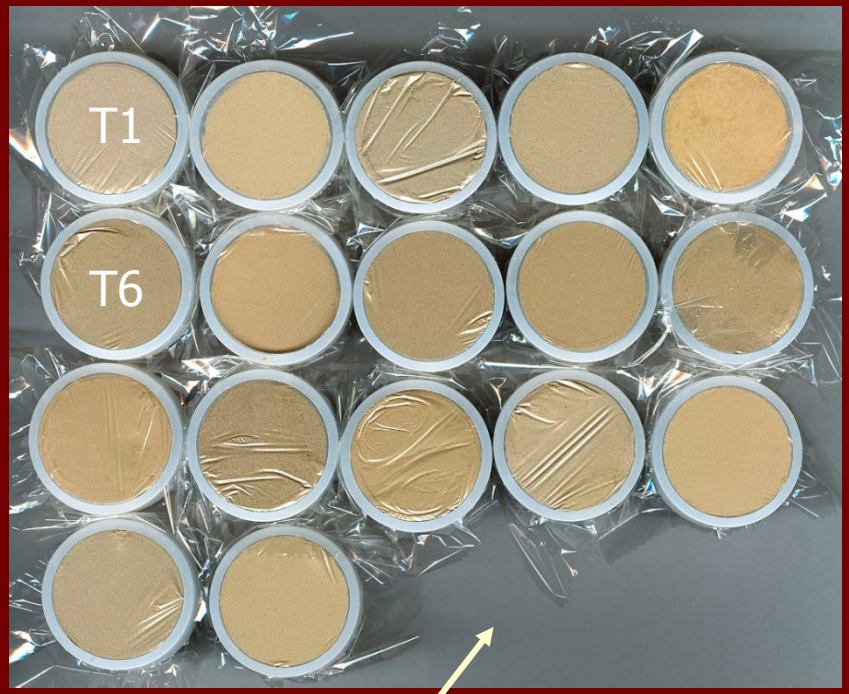
Spectrophotometer ColorEye XTH (GretagMacbeth Regensdorf, Switzerland)

Conditions of measurements

- Spherical geometry, diffuse illumination, configuration D/8, illumination type D65.
- Source: Xenon discharge lamp.
- Spectral range: 360 – 750 nm.
- Integrating sphere, diameter 38 mm.
- Angle of measured beam 8°.
- Illumination aperture – circular, diameter 10 mm, measuring aperture – circular, diameter 5 mm.
- Sample: powder in measuring vessel with bottom formed by mylar foil (thickness 3.5 μm).

Principle of color measurement





Samples from Power Plant Třebovice (Ostrava)

Measurement of colors – expression of results

- Color space L*, a*, b*. CIELab (CIE 1976) – Commission International de l'Eclairage

- Munsell Color System

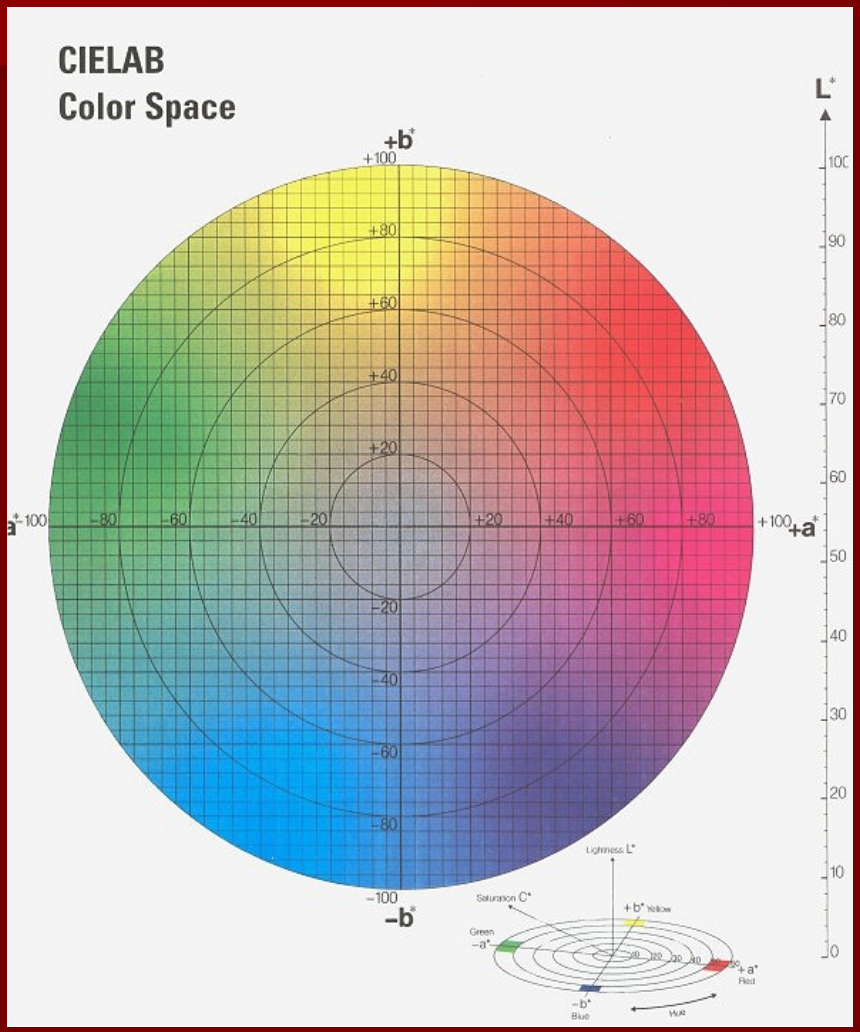
  Hue – spectral position of color (Y – yellow, YR – yellow-red etc.), range from 0 to 10 for each color.

  Value – whiteness/blackness (10 - white, 0 – black).

  Chroma – intensity of color (content of pigment),

  0 – no pigment, 10 – maximum of pigment.

CIELab color space



- Color space L*, a*, b*. CIELab (CIE 1976) – Commission International de l'Eclairage

L* whiteness/blackness (100 – white, 0 – black)

a* red (+100), green (-100)

b* yellow (+100), blue (-100)

Why color identification?

- Simple method for determination. Portable instrument, fast measurement.
- Relationship of color with mineralogical phase composition and chemical composition of fly ashes.
- Indication of nature of processes during combustion and stability of environment in combustion unit (presence of magnetite or hematite x color).
- Contribution to the technological evaluation of processes – relationship between color and noncombustible organic matter.

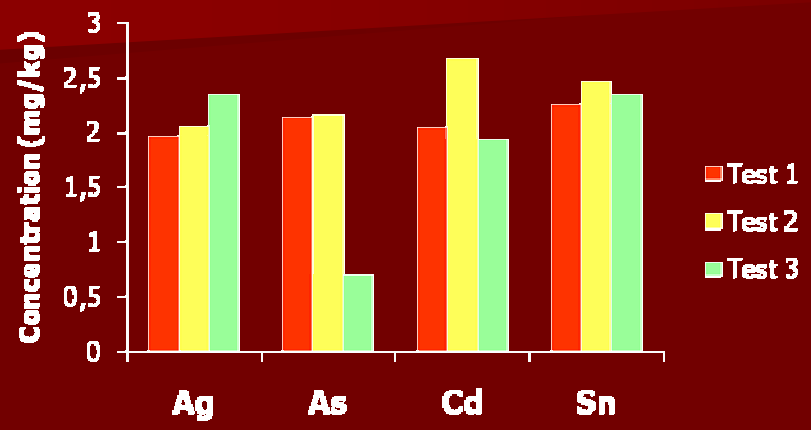
Combustion test – Energetika Třinec

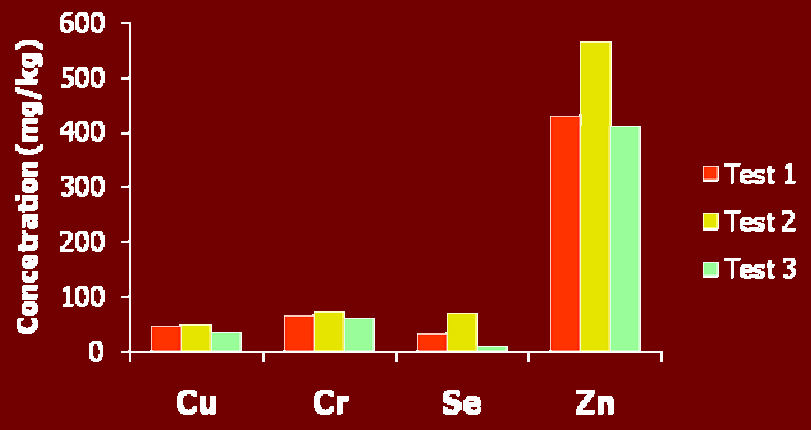
Three combustion tests – Power Plant Energetika Třinec (fluidized-bed boiler)

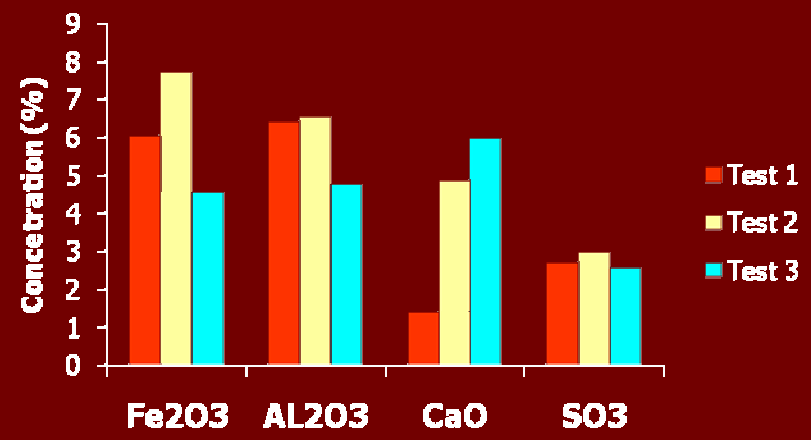
- **Test 1** - Bituminous coal from Poland
- **Test 2** – Mixture of coal (90 %) with oil rafinery sludge (old ecological load Ostramo). ***Minimum output (102 t/h).***
- **Test 3** - Mixture of coal (90 %) with oil rafinery sludge (old ecological load Ostramo). ***Maximum output (141 t/h).***

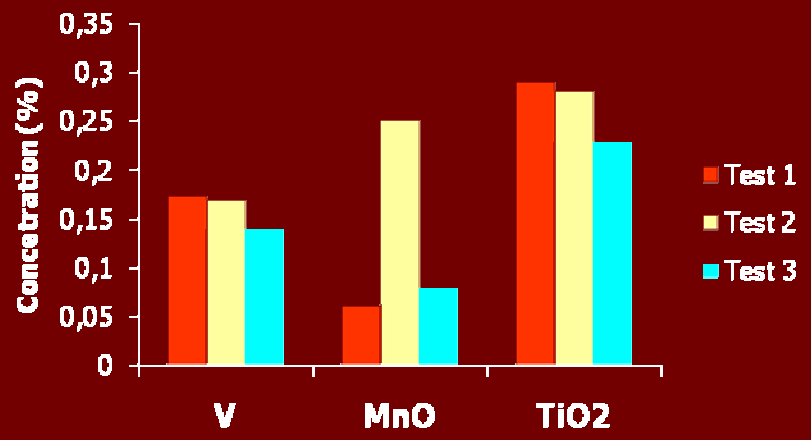
- Combustion temperature in fluidized-bed layer was comparable for first and third test: lower part 850 ^{o}C, middle part 834 ^{o}C, upper part 878 ^{o}C. For minimum output was temperature 826 ^{o}C, upper part 846 ^{o}C.

Differences in chemical composition of fuel

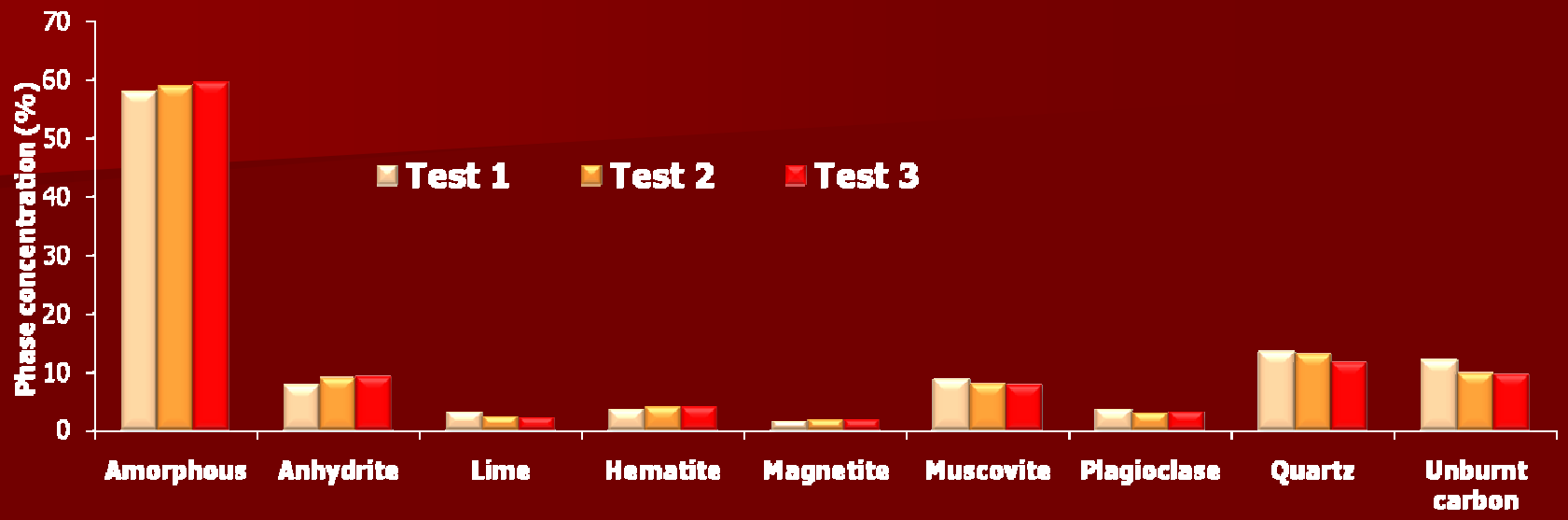


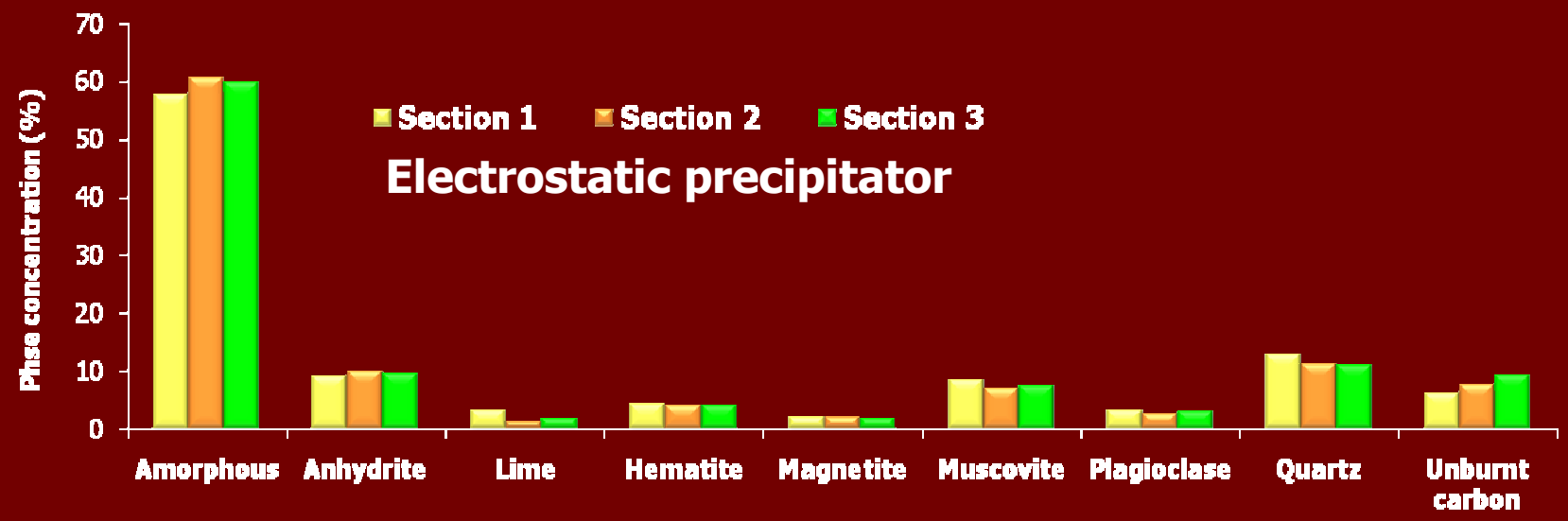




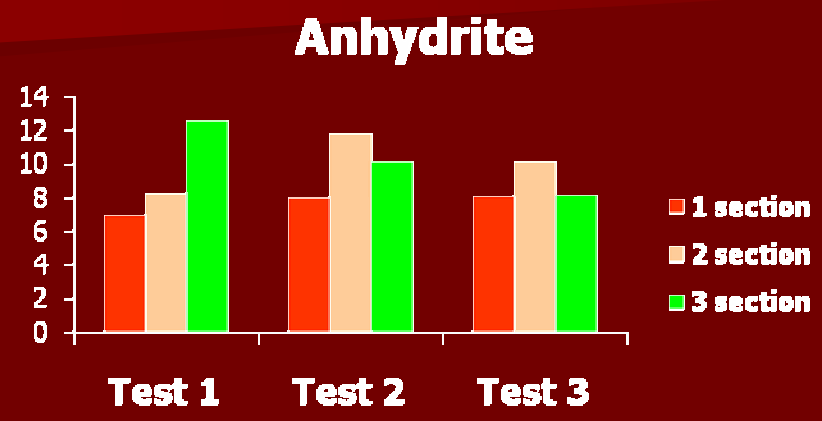


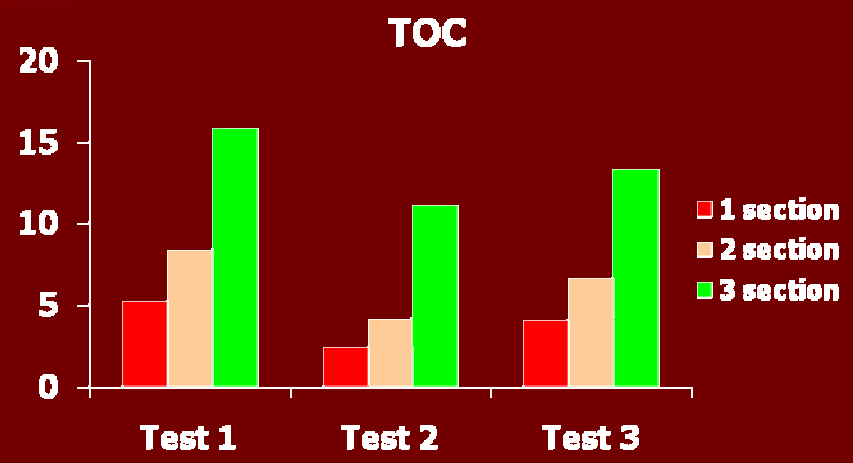
Average mineral phase composition of fly ash

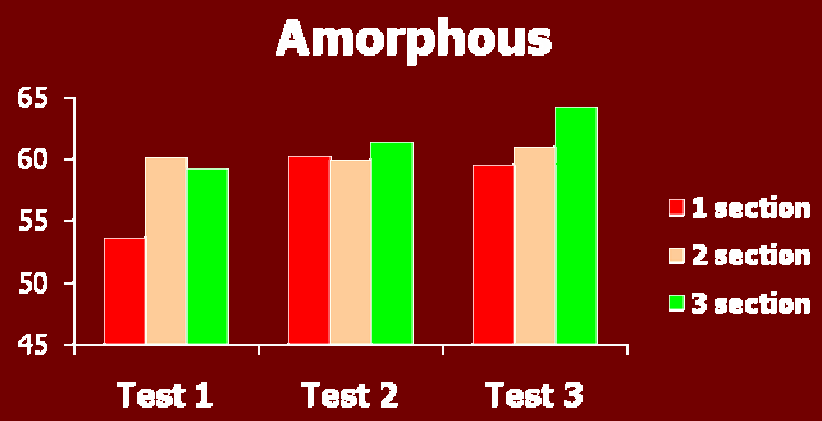


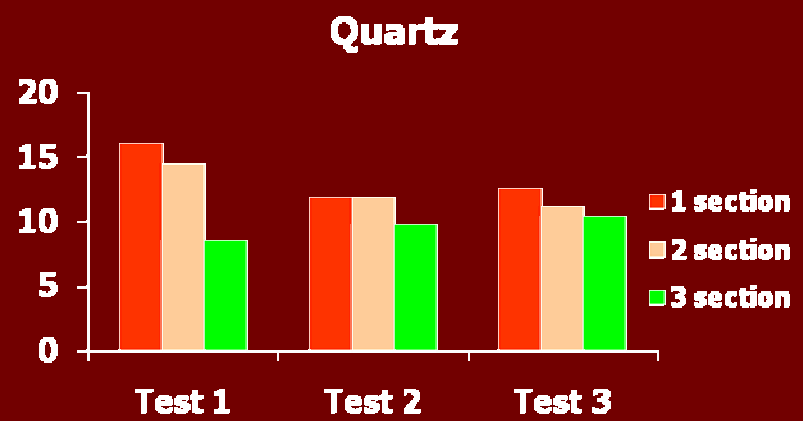


Phase composition of fly ash from individual sections (%)

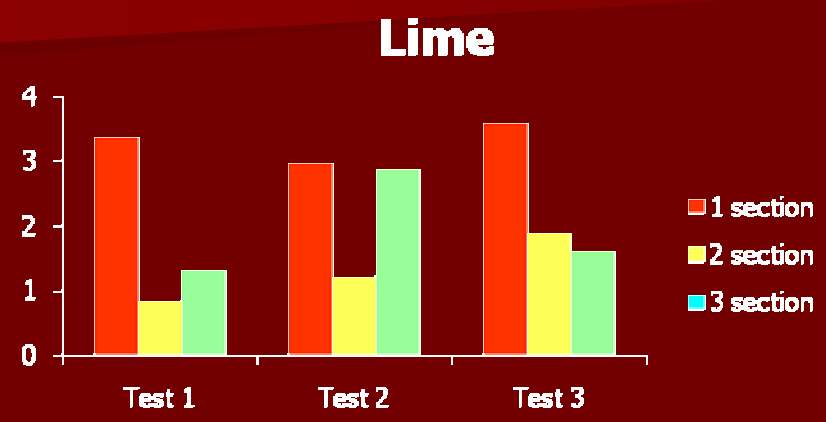


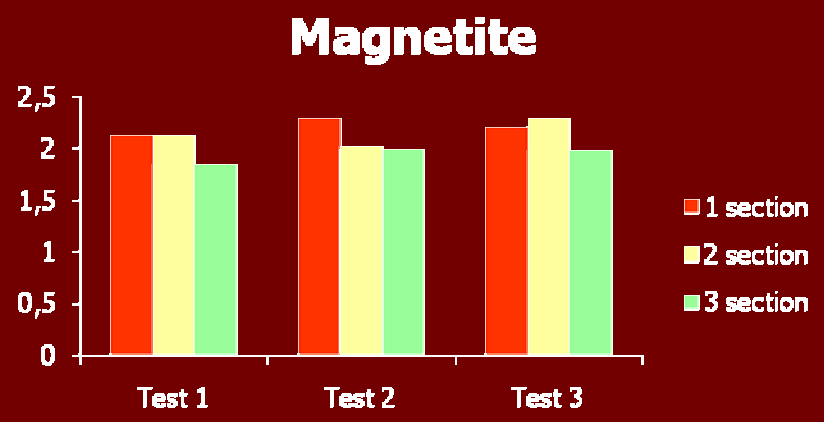


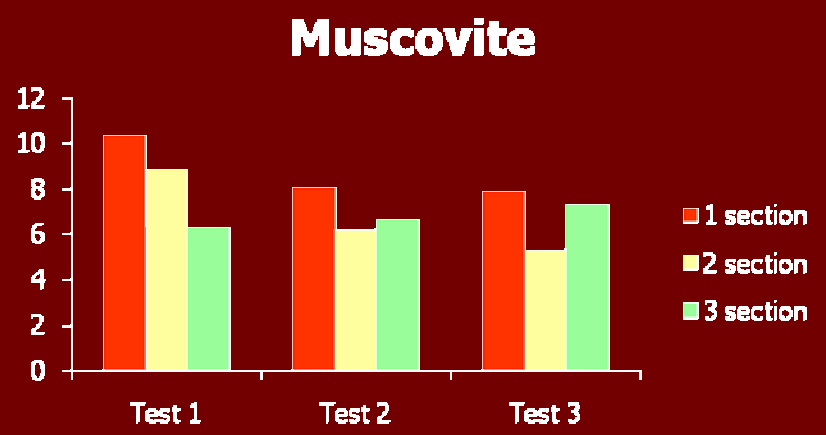


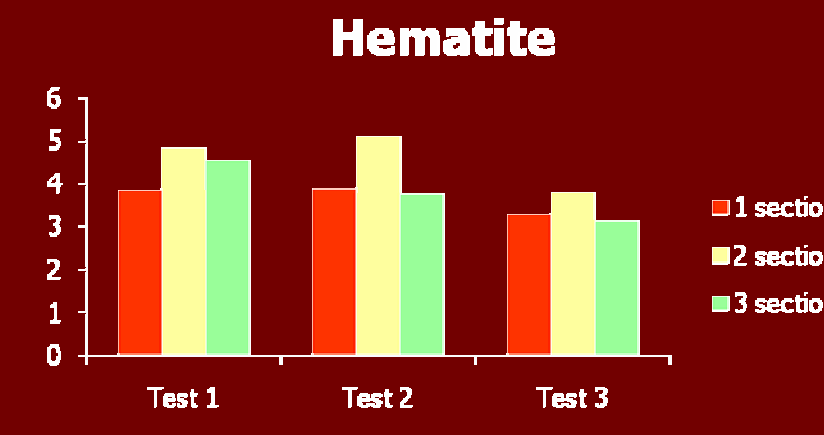


Phase composition of fly ash from individual sections (%)

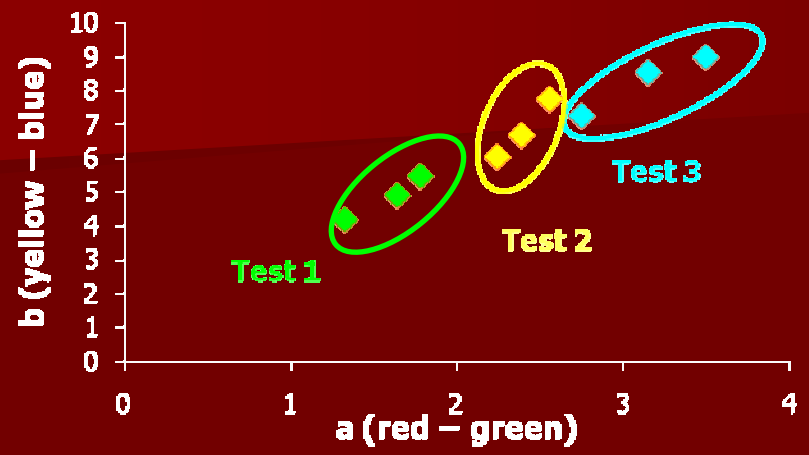


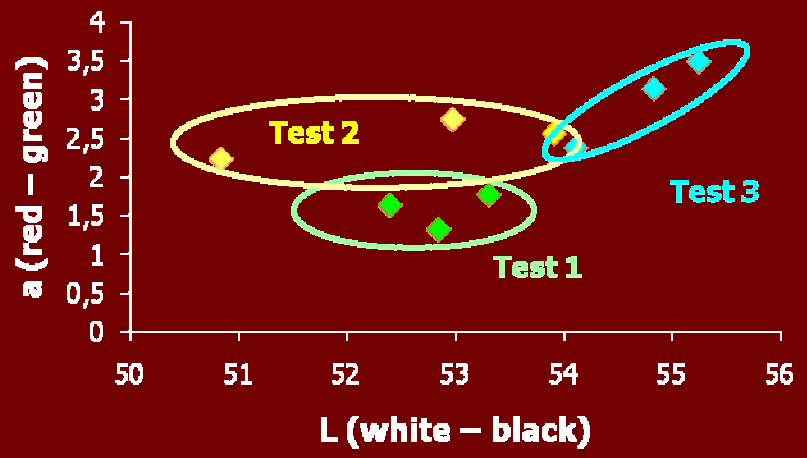




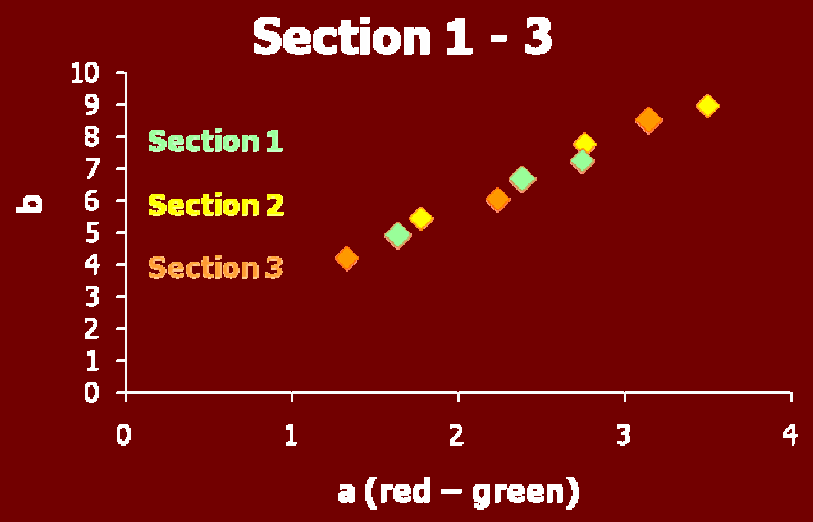


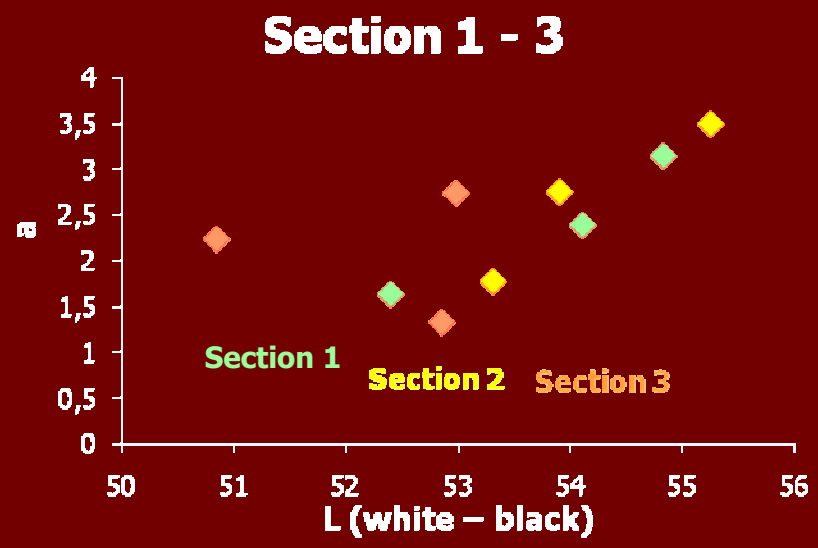
Color of fly ash in individual combustion tests



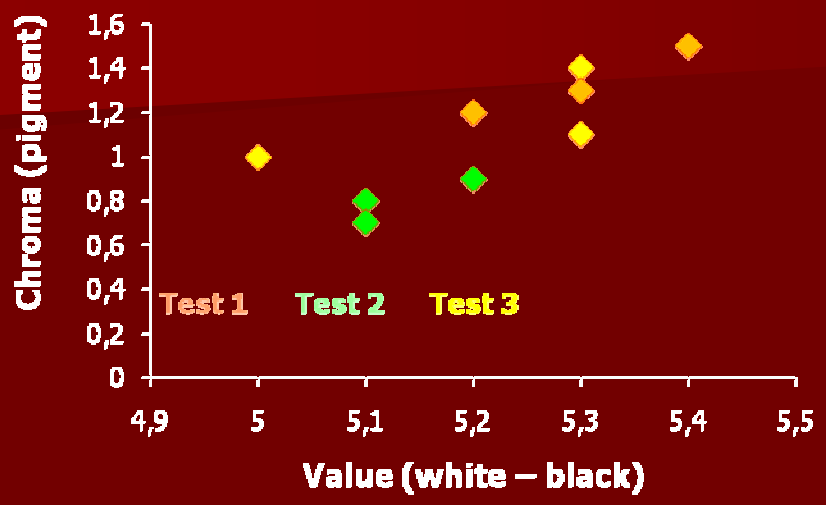


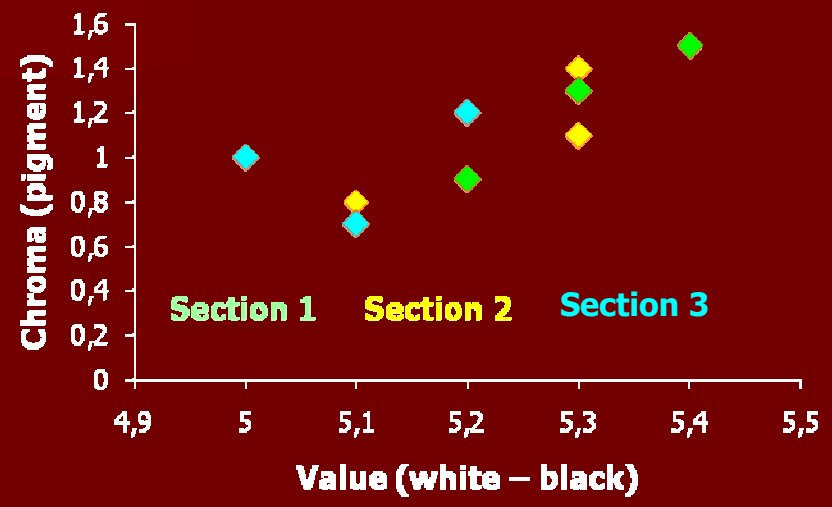
Color of fly ash from individual sections of precipitator

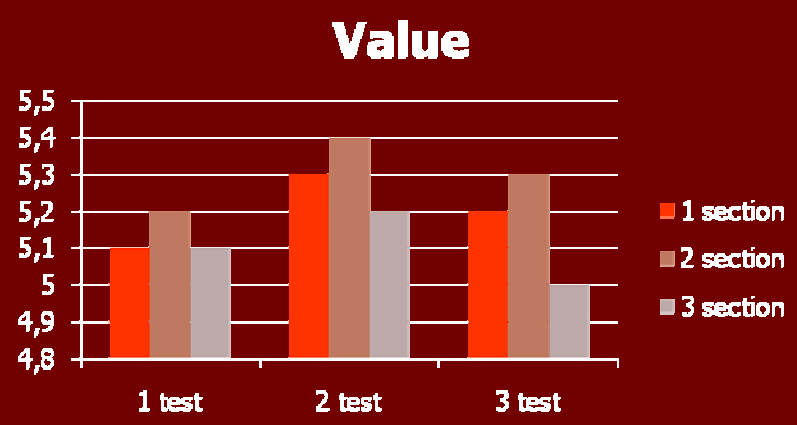


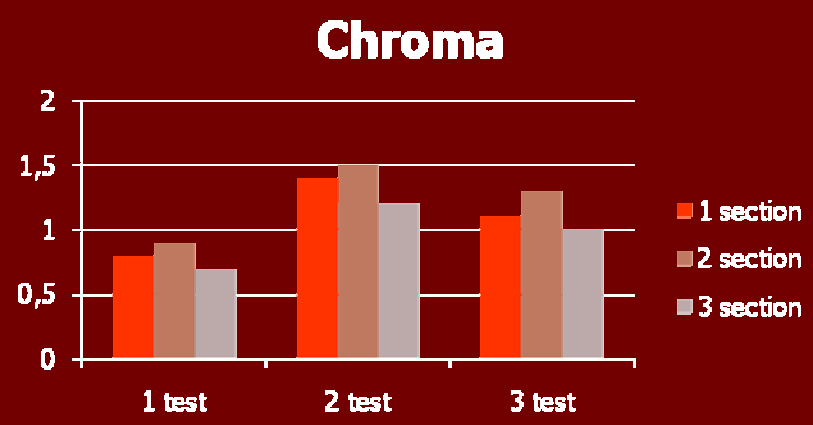


Color changes of fly ash for individual tests





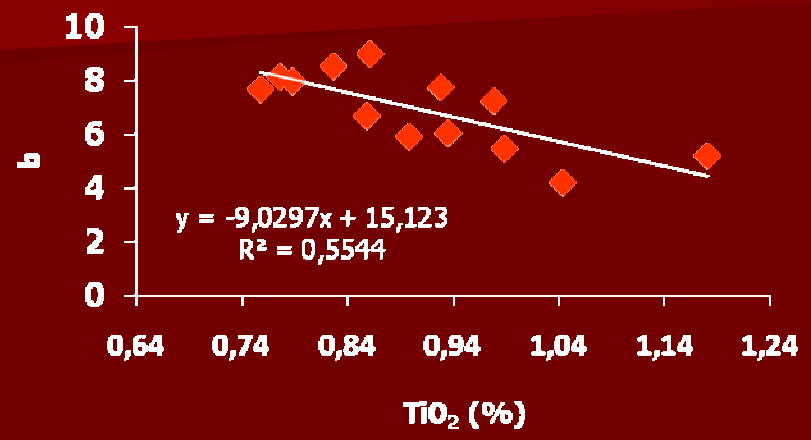


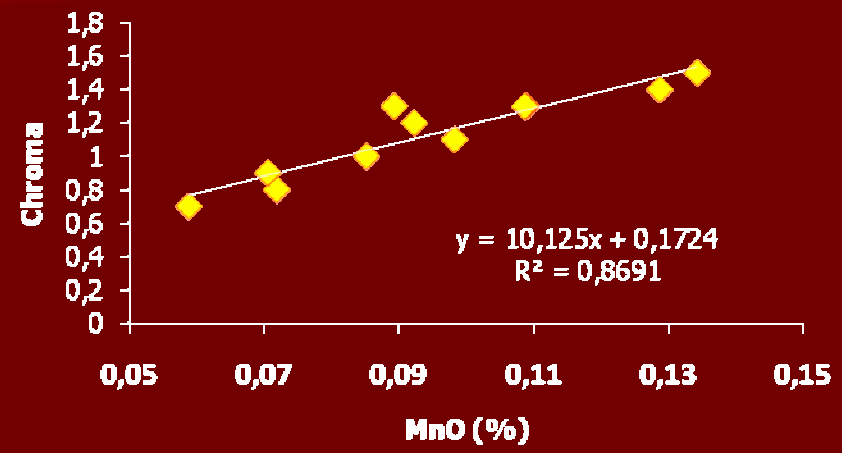


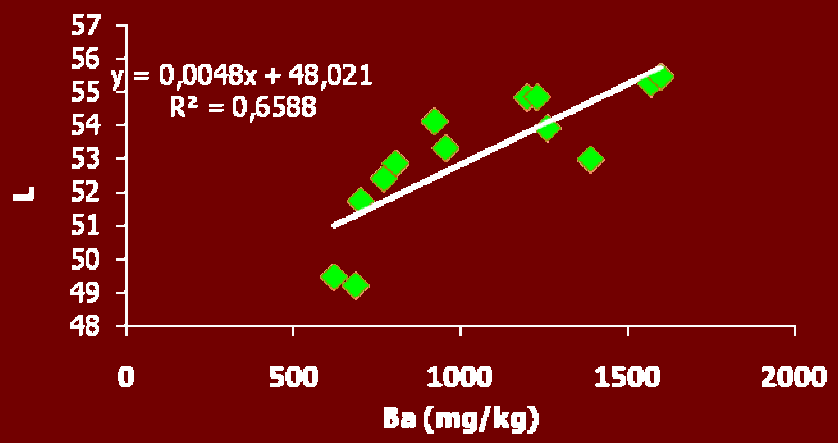
Relationship between phase composition and minor elements

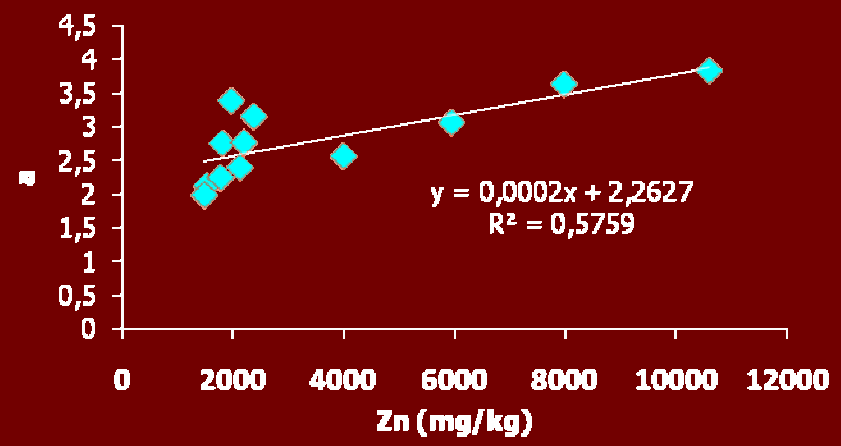
Phase composition	Correlation coefficient (r)		
	0.60 ≤ r ≤ 0.70	**0.71 ≤ r ≤ 0.80**	**r ≥ 0.81**
Hematite	Ba, **-Cr, -Zn**		
Magnetite	Cr, **-As, -Ni**	Sn, **– Sr, - V**	Zn, **-Se**
Lime	**-Cd, -Cu, -Zn**		**-Sn**
Amorphous	Ba, Co, Sr, V, **-Sn**	Cl, **-Cr**	**-Zn**
Anhydrite	Cl, Ni, **-Cd, -Cr**	As, **-Zn**	Ba, Sr, V, **-Sn**
Muscovite	**-As, -V**	**-Ba,-Ni, -Pb,-Sr**	
Quartz	Zn	**-As, -Ba, -Ni, -Se**	**-Sr, -V**
Unburnt carbon		As, Co, Ni, Sr, V, P	**-Cl,** Cr, Se,Zn

Chemical composition and color





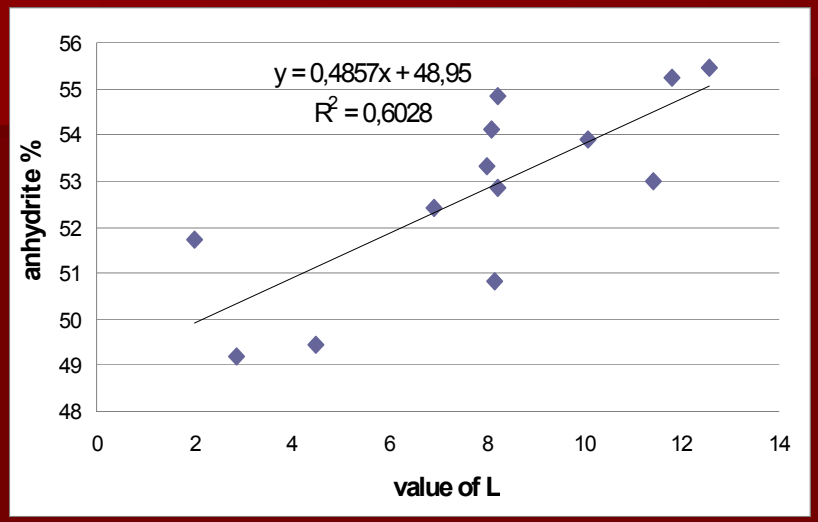


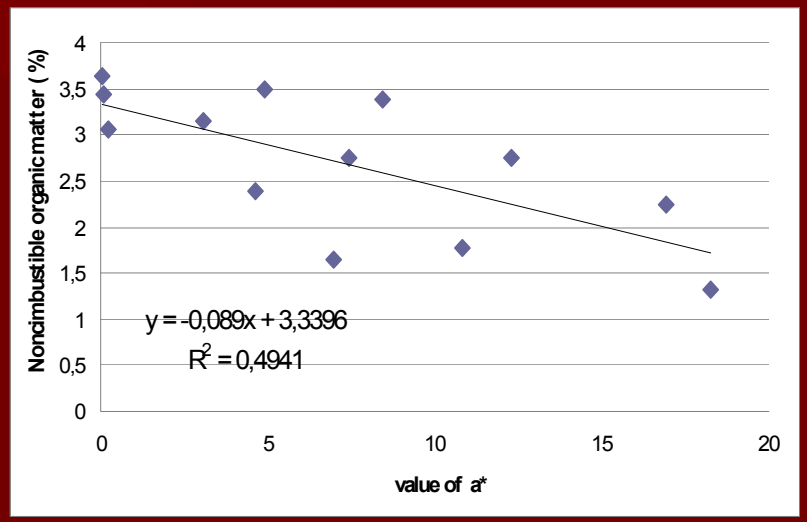


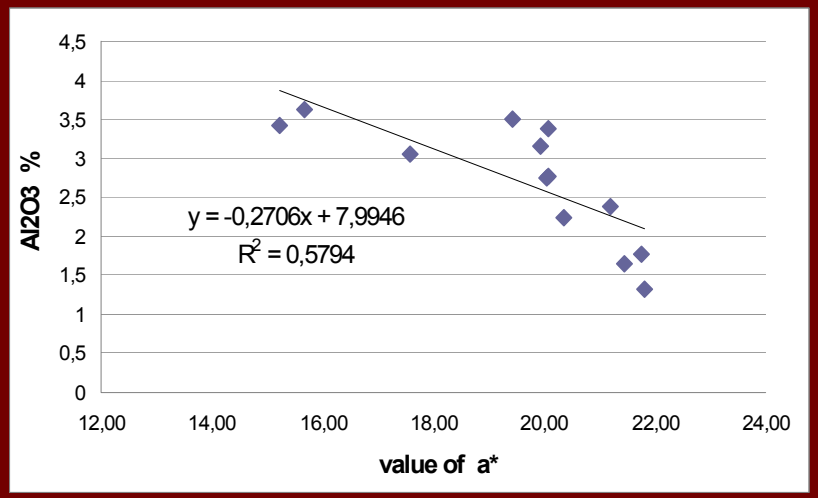
Relationship between chemical composition and color

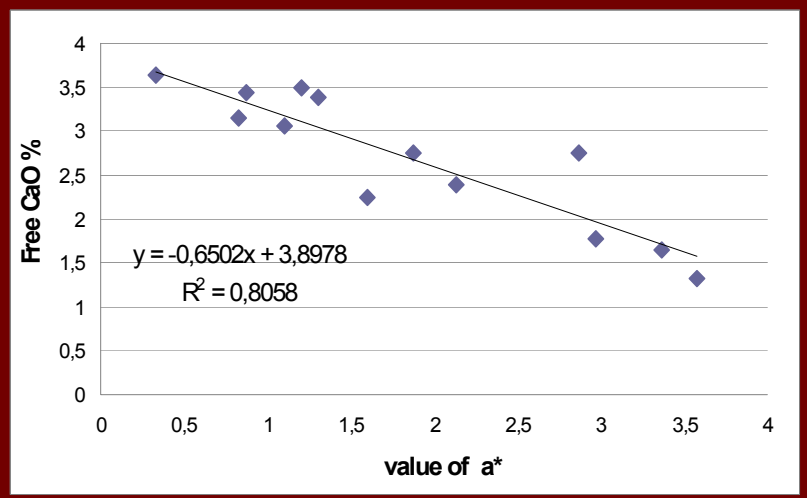
	Correlation coefficient (r)	
Color	**0.60 ≤ r ≤ 0.70**	**0.71 ≤ r ≤ 0.80**
L* (white – black)	Ba, **- Zn**	CaO, SO_3, **-SiO_2,** TOC
a* (red – green)	Ag, Cd, Cu, Cr, Sn, Zn	Fe_2O_3, Mn, **- Al_2O_3**
b* (yellow – blue)	Cd, Sn, **-Se**	**-TiO_2**
Value (white – black)	As, Ba, **-Zn**	CaO, SO_3
Chroma (pigment)	Ag, Cd, Cu, Sn, **-Se**	Al_2O_3, MnO

Relationships between phase composition and color - FBC Třinec









Color and main components of silicate analysis for other power plant

FBC Třinec

coefficient of correlation between a*,b*,L* and main compounds: TiO_2, Fe_2O_3, MnO and CaO

(r > 0.7 for 18 samples) and TOC.

Melting boiler Dětmarovice

SiO_2, TiO_2 and Al_2O_3.

Dry bottom boiler Třebovice

Al_2O_3, TiO_2 and Fe_2O_3 (only b* and L*).

Relationship between color and mineralogical phase analysis of fly ash

FBC Třinec

magnetite, hematite, anhydrite and TOC (r > 0.7) for 18 samples. Noncombustible organic matter has higher content (> 5%) than in other fly ashes.

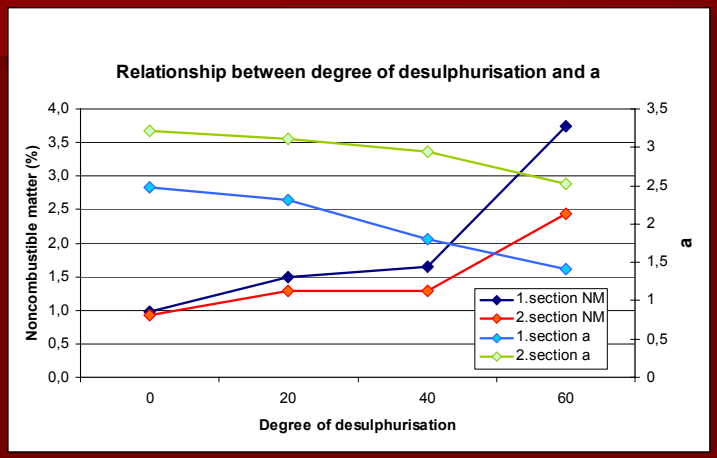
Melting boiler Dětmarovice

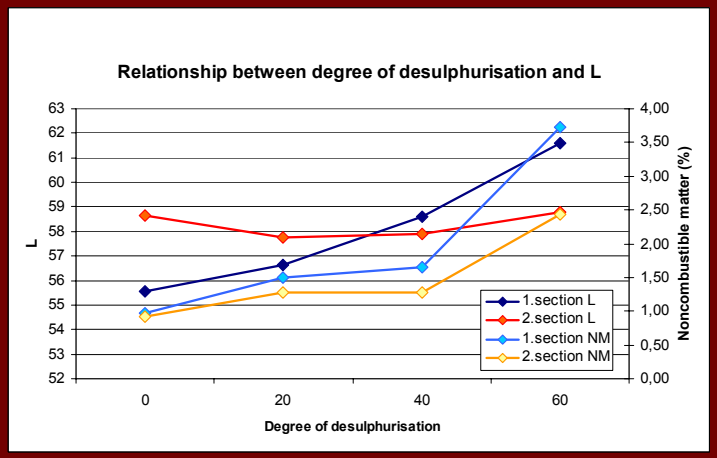
quartz, amorphous matter.

Dry bottom boiler Třebovice

TOC, magnetite, hematite, anhydrite, rutile

Degree of desulphurisation – changes of color in fly ash dry bottom boiler Třebovice





	Noncombustible organic matter	TOC
L*	0.45	0.41
a*	**0.78**	**0.83**
b*	0.64	**0.72**
Hue	0.68	0.67
Value	0.21	0.31
Chroma	0.67	**0.77**
Samples	16	

Relationship between color and trace elements

- **FBC Třinec**

  Fly ash from FBC Třinec has lower correlation coefficients ($r \leq 0.7$) for all trace elements.

- **Melting boiler Dětmarovice**

  The highest number of important correlation coefficients ($r > 0.85$) was found for fly ash from Power Plant Dětmarovice (As, Ba, Cu, Mo, Ni, Pb, Se, Sn, Sb, Zn).

- **Dry bottom boiler Třebovice**

  Fly ash from Power Plant Třebovice has high corelations ($r > 0.85$) for Sr, Ba and V.

Important relationships were determined for Cu (r with lime) and Zn in fly ash from all three power plants. Zn (r = hematite, magnetite, unburnt carbon and amorphous) .

Conclusions

- It was found that color parameters have strong relationships with mineralogical phases and chemical components of fly ash.
- This simple measurement can be used for estimation of oxidation/reduction conditions and their stability in combustion processes.
- The relationships allow quantitative calibration.
- Relationships are better expressed using L, a, b than Munsell value and chroma.
- Color of ash is influenced more by the composition of input fuel, rather than by technological conditions.