ФІЗИКА І ХІМІЯ ТВЕРДОГО ТІЛА
Т. 4, № 2 (2003) С. 358-364

PHYSICS AND CHEMISTRY OF SOLID STATE
V. 4, № 2 (2003) P. 358-364

УДК 539.23: 537.311

Katarzyna Styszko-Grochowiak[1], Janusz Gołaś[1], Henryk Jankowski[2]

Performance of Optoelectronic Monitoring System for Determination of Unburned Carbon in Fly Ash from Pulverised Coal Fired Power Station Boiler

[1] *Faculty of Mining Surveying and Environmental EngineeringDepartment of Environmental Sciences, jgolas@uci.agh.edu.pl*
[2] *Faculty of Electrical Engineering, Automatics, Computer Science and Electronics, University of Mining and Metallurgy, Al. Mickiewicza 30, 30-059 Cracow, Poland*

Selected qualities of coal fly ash produced during the work of a congeneration power plant with a chamber to combust hard coal were defined. The samples were taken using an inspection method in two power plants of Poland. Samples of coal fly ash were examined for their chemical and physical properties. Correlation between laboratory and industrial measurements of the unburned carbon content of ash was discussed. This allowed the assessment of the measurement method of %C through the optic analyzer and the quality of the system of automatic measurement of %C in the power plant.

Keywords: optoelectronic monitoring, process of combustion, optical dispersion-reflection technique.

Article was received on 19.05.2003; proposed to print on 11.06.2003.

I. Introduction

The development of civilization caused the increase of the amount of wastes. Their quantity and character have been making greater problem in global scale. Fly ash is the principal by-product of coal combustion. The control of the residue of unburned carbon in fly ash has constantly been an up-to-date problem in the exploitation of coal power plants, because of need for the optimisation of the process of combustion, protection of environment and the use of ash in industry [1-9]. The loss-on-ignition (LOI) [10] test is now the standard method for determination of the carbon content of fly ash from coal fired boilers. On-line monitoring systems for determination of unburned carbon in coal fly ash use several techniques [11-18]:

microwaves absorption
capacity measurement
fotoacoustic effect
infrared emission
optical dispersion-reflection technique.

The last method is mostly used in Polish power plants. The optoelectronic system for on-line determination and monitoring of the unburned carbon content of ash samples operates on the principle that the reflectance of infrared light is proportional to carbon content (Kubelka-Munk law) [19]. Ash samples are collected isokinetically from the flue gas duct and placed in sample tube with a flat glass bottom (Fig. 1). The sample is exposed to the monochromatic light of λ=1μm. The reflectance intensity is used by the system computer to determine residual carbon content from correlation curves [17, 18]. The sample is then air purged

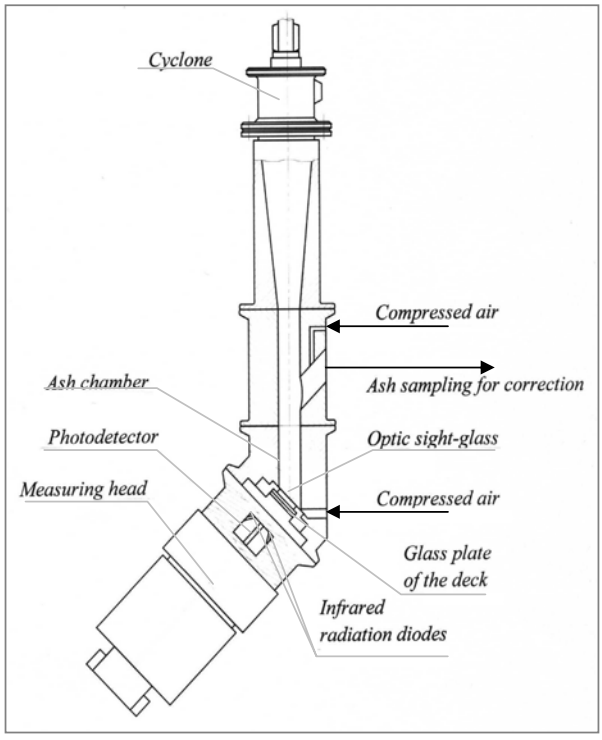

Fig. 1 Stand for carbon content measurement.

back to the duct or to the attached sample container to enable laboratory check analysis. The total cycle takes between 5 to 10 minutes. Real time results of carbon content with accuracy 0.3 ÷ 0.7 % are reported and can be used for boiler controlling. At the present Polish power plants use discriminated coal from different sources. This variation in the kind of coal used must be taken into account during the control of fired coal boiler. Proper control of combustion process maybe effectively improved if current information on the amount of unburned carbon is provided in real time. The goal of this research study carried out during the production process was to systematically follow up the results of measurements by an industrial analyzer and link them to physical and chemical properties of ashes. The study should facilitate the improvement and verification of data obtained from industrial analyzer as well as its practical utility.

II. Experimental

The fly ash used in the experiment originated from Polish power plants - "Kraków" Combined Heat and Power Plant S.A. (EDF Group) and "Będzin" Combined Heat and Power Plant S.A. - that use the technique of pulverized fired boiler. On the output duct, before the electro filter an on-line industrial optic analyzer (AWP model, Kwant Instruments, Poland [20]) was installed to determine the content of non-combusted carbon in ash by using the technique of optical dispersion reflection. The efficiency of the boiler in "Kraków" Power Plant (KPP) is 380 MW and in "Będzin" Power Plant (BPP) is 140 MW. The samples were taken using an inspection method. Fly ash samples have been collected from the site where the industrial analyzer was installed. Gravimetry samples were taken in BPP. The set included the ash samples from industrial analyzer. In particular, the process of measurement involved a regular sampling of 2 g of ash for the purpose analysis. It was accepted that the ash sample from the analyzer consisted of five or six single portions (2 g) of ash, where the content of unburned carbon was determined by the instrument and also an overall sample was taken from the ash collected in the container of the analyzer. This was done to make particle size distribution analysis of the fly ash. The study was performed in KPP for three subsequent months and in BPP for two months. Systematic observation of the properties of the ash allowed to monitor the work of the industrial analyzer during a relatively long period of the power plant work. To measure the content of unburned carbon in fly ash - loss on ignition method was used. Fly ash overall samples from the analyzer were sieved (63 μm sieve) and two fly ash fractions obtained: fraction of lower granularity F1 (<63 μm) and fraction of higher granularity F2 (>63 μm.). The content of combustible parts obtained in the fractions was analyzed by the LOI method. To characterize physical properties of the fly ashes the particle size distribution was measured by Laser-Particle Sizer (FRITSH analysette 22). Morphology was analyzed by Scanning Electron Microscopy (JOEL 5400 (EDS) Link ISIS 300, Oxford Instruments). It allowed the observations of the structure of particles, their size and qualitative chemical composition. The samples were examined by XRD using a Philips X'Pert Pro spectrometer and copper Kα radiation.

III. Results and discussion

Morphology and mineralogy

Examination of fly ashes with Scanning Electron Microscopy SEM showed that samples were composed mostly of small, spherical aluminosilicate particles interspersed with larger irregular carbon particles. Microscopic analysis allows the qualitative assessment of the sample surface and the determination of its chemical composition (Fig. 2). Although the samples are principally composed of quartz, mullite and glass, were observed periclase and hercynite (Table 1).

FeO and Fe_3O_4 are black and Fe_2O_3 varies from red to black. Iron oxides present in fly ash can reduce the intensity of the light reflectance [21, 22]. One should mention that iron oxides can significantly change the albedo of an ash sample, which can change the measurements of an instrument. Fig. 3 illustrates the particles of oxide iron on surface of glass grain.

The basic problem with the application of a standard method (LOI) of determining the amount of unburned coal is the influence of other components of the ash on the obtained results. The participation of hydrated sulfates, calcium hydroxide and carbonates is particularly important. Undetectable level of these compounds in the

Table 1.

Mineralogical composition of repesentative fly ash samples from„Kraków" Power Plant and „Będzin" Power Plant determined by XRD.

Phase	**„Będzin"**	**„Kraków"**
	Weight %	
Glass	13,5	14,3
Mullite ($Al_6Si_2O_{13}$)	39,5	35,6
Quartz (SiO_2)	39	47,1
Periclase (MgO)	2	3
Hercynite $(Fe_{0,882}O_{0,118})(Al_{1,882}Fe_{0,118})O_4$	6	----

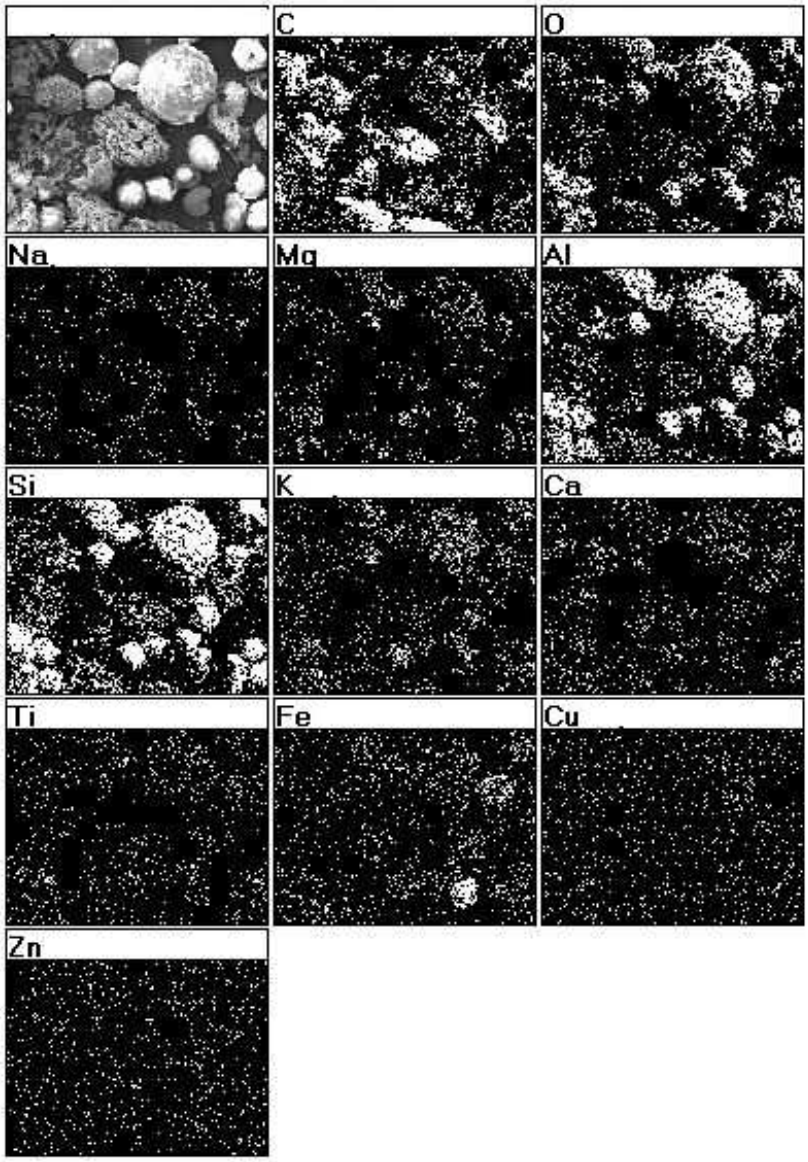

Fig. 2 Scanning electron micrographs fly ash from optic analyzer illustrating distribution of elements (C-carbon, O-oxygen, Na-sodium, Mg-magnesium, Al.-aluminium, Si-silikon, K-potasium, Ca-calcium, Ti-titanium, Fe-iron, Cu-copper, Zn-zinc) on ash sample surface.

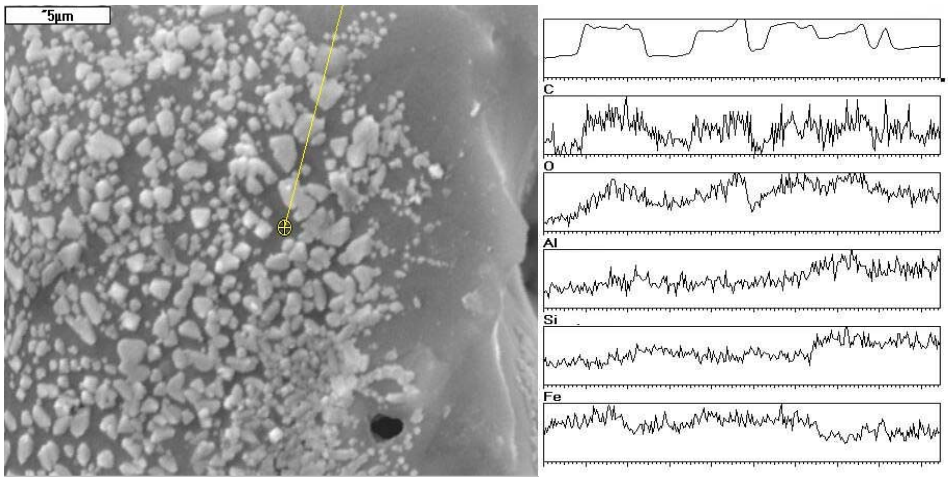

Fig. 3 Scanning electron micrographes of particles of iron oxide on the surface of glass grain.

Table 2.

The amount of unburned carbon (weight %) for samples collected in "Kraków" Power Plant.

	method		1. A	2. B	3. C	4. D	5. E	6. F	7. G	8. H	9. I	10. J	11. K	12. L
Sample collections from optic analyser	Analyser results	1.	7.56	3.21	3,15	5,98	4,01	7,44	4,89	3,42	5,99	3,23	4,03	4,33
		2.	6.25	2.96	3,19	5,61	3,31	6,43	5,97	3,65	5,09	3,24	4,91	5,13
		3.	6.43	2.82	2,92	5,77	3,42	6,64	6,21	2,74	6,14	3,62	5,17	4,34
		4.	5.59	2.86	2,27	5,39	4,09	6,74	4,15	3,46	5,45	3,25	4,76	4,60
		5.	5.77	2.98	3,92	5,19	4,01	6,31	10,89	3,35	5,55	3,48	4,71	5,52
	LOI	1.	8,15	5,88	5,73	6,96	7,31	6,57	5,44	2,93	6,02	4,06	3,52	4,00
		2.	5,93	5,92	5,33	6,34	6,75	6,07	6,26	2,40	4,70	3,77	3,14	3,78
		3.	6,81	5,87	6,41	5,79	6,76	6,24	6,13	2,45	6,31	4,99	3,38	3,15
		4.	5,93	6,11	6,55	6,04	6,79	6,06	5,20	3,12	5,91	4,05	3,18	2,84
		5.	5,52	5,61	6,54	6,74	7,08	6,25	5,60	2,67	5,23	4,46	3,44	3,36
		overall sample	A1 6,22	B2 5,58	C3 4,90	D4 4,69	E5 5,70	F6 6,14	G7 4,79	H8 4,98	I9 6,16	J10 3,79	K11 3,33	L12 4,10
Quality of grinding	R_{224} R_{125} R_{90}		1,4 25,4 53,3				1,2 21 12,9				0,8 19,5 48			
Average efficiency	MW		95				101				77			
Month			February				March				April			

analyzed ashes allow the application of this method. Thus a standard (LOI) method could successfully be applied as a comparative method for industrial analysis.

Particle size and unburned carbon.

The contents of unburned carbon in ash, defined by the optic analyzer and LOI method are presented in Table 2 and Table 3.

The highest content of combustible parts was observed for fraction F2 (>70 μm) (Table 4, Table 5). The amount of unburned carbon in fraction F1 (<70 μm) is about four times smaller. The amount of unburned carbon in fraction F1 (<70 μm) doesn't have significant importance for total lost weight in LOI method. The amount of unburned carbon decreases as fineness increases. The fluctuations in the particle size distributions are significant for the content of unburned carbon in the ash. Comparing the results for fraction F2 (>70 μm) obtained by LOI method one should notice that

Table 3.

The amount of unburned carbon (weight %) for samples collected in "Będzin" Power Plant.

	Method		1. A	2. B	3. C	4. D	5. E	6. F
Sample collections from optic analyser	Analyser results	1.	1. 4,05	1. 5,05	1. 2,04	1. 4,18	1. 4,78	1. 5,30
		2.	2. 4,34	2. 4,68	2. 1,83	2. 3,72	2. 5,28	2. 5,61
		3.	3. 3,56	3. 4,77	3. 1,80	3. 2,81	3. 4,18	3. 4,99
		4.	4. 5,16	4. 5,66	4. 1,94	4. 4,46	4. 4,07	4. 7,64
		5.	5. 5,58	5. 4,16	5. 2,43	5. 4,48	5. 4,20	5. 5,74
		6.	6. 6,04	6. 5,31	6. 1,52	6. 4,02	6. 4,70	6. 6,49
	LOI	1.	1. 4,71	1. 6,08	1. 2,66	1. 5,09	1. 7,79	1. 6,55
		2.	2. 5,49	2. 6,54	2. 2,42	2. 4,32	2. 6,11	2. 5,99
		3.	3. 5,32	3. 6,29	3. 2,47	3. 4,63	3. 5,47	3. 5,04
		4.	4. 5,87	4. 5,82	4. 2,29	4. 4,92	4. 6,09	4. 6,05
		5.	5. 6,62	5. 5,58	5. 2,14	5. 4,62	5. 5,39	5. 8,29
		6.	6. 6,99	6. 6,12	6. 2,08	6. 4,25	6. 6,34	6. 6,65
		overall sample	P1 8,84	P2. 4,65	P3 5,27	P4 4,02	P5 5,09	P6 4,94
Gravimetry sample	LOI		G1 8,18	G2 4,54	G3 5,07	G4 4,12	G5 4,75	G6 4,64
Quality of grinding	R_{200} R_{90}		2,8% 15%					
Steaming capacity of a boiler	t/h		148	144	140	141	140	144
month			February				March	

Table 4.

Size fractions of the ash components and the carbon content in each.

Samples "Kraków" Power Plant	Total LOI	Size fractions (%)		F1	F2
	Weight % C	F1 (<70 μm)	F2 (>70 μm)	Weight % C	Weight % C
A1	**6,22**	45,60	**54,40**	2,19	**16,55**
B2	5,58	46,22	53,78	2,63	12,67
C3	4,90	38,79	61,21	2,01	9,56
D4	4,69	32,56	67,44	2,03	7,72
E5	5,70	38,81	61,19	2,37	9,63
F6	**6,14**	31,83	**68,17**	2,94	**9,57**
G7	**4,79**	38,65	**61,35**	1,82	**8,00**
H8	4,98	50,77	49,23	2,23	7,93
I9	**6,16**	38,46	**61,54**	2,80	**9,36**
J10	**3,79**	40,95	**59,05**	1,69	**4,99**
K11	**3,33**	52,74	**47,26**	1,11	**8,15**
L12	4,10	43,02	56,98	1,80	6,57

Table 5.

Size fractions of the ash components and the carbon content in each.

Samples "Będzin" Power Plant	Total LOI	Size fraction (%)		F1	F2
	%wag. C	F1 (<70 μm)	F2 (>70 μm)	%wag. C	%wag. C
P1	**8,84**	28,44	**71,56**	3,37	**15,56**
P2	**4,65**	34,85	**65,15**	1,96	**8,85**
P3	5,27	28,5	71,5	1,88	9,04
P4	**4,02**	35,93	**64,07**	1,56	**6,57**
P5	5,09	30,7	69,3	1,47	8,56
P6	4,94	31,11	68,89	1,61	7,99

the content of fractions over 70 μm is very important. Although carbon contents in fractions F2 are high, total lost weight for samples are small, because the content of fractions F2 is on small level in all mass. Because of this it can be stated that the size of ash particles has its influence on standard and industrial methods of analysis and the content of unburned carbon is closely linked to the particle size distribution in fly ashes. Analyzing the distribution of grain size for sample from analyzer and gravimetry sample it can be found that the content of grains are different (Fig. 4). Although difference of particle size distributions between sample from analyzer and gravimetry sample, LOI measurements of these samples are very similar (Table 6). The relative error of LOI represents specific disadvantage of cyclone that applied in analyzer for filter off fly ash. With respect to differences in fineness with operating boiler load, the fines was slightly better at the load of 77 MW than at load 95 or 101 MW. Based on the analyses it should be stated that the results of content of unburned carbon can depend on the degree of grinding the coal dust. In particular, the content of coarsest fractions over 200 μm. The highest amount of grains over 200 μm in coal dust was in BPP, thus the higher content size fraction over 70 μm was in fly ash from BPP than in fly ash from KPP. The low operating boiler load and content of grains over 200 μm in pulverized coal is linked to the low content of combustible parts.

IV. Conclusions

The properties of the ash first of all depend on types of the coal used, grinding, the kind of technology applied and parameters of combustion. From the morphological point of view the analyzed ash consists mainly of quartz, mullite and glass, occurring in the form of spherical grains. The unburned carbon particles are larger and formed in irregular grains. This was not only confirmed by microscopic observations, but also by the results for

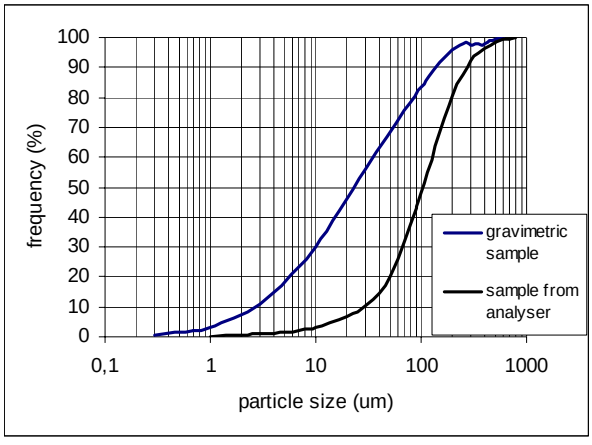

Fig. 4 Comparison of average size distribution of fly ash collected from optical analyser with average size distribution gravimetric samples.

Table 6.

The amount of carbon in sample from analyser and gravimetry.

Gravimetry sample		Sample from analyser		ε
Symbol	Weight % C	Symbol	Weight % C	(%)
G1	8,18	**P1**	8,84	8,07
G2	4,54	**P2**	4,65	2,42
G3	5,07	**P3**	5,27	3,94
G4	4,12	**P4**	4,02	-2,43
G5	4,75	**P5**	5,09	7,16
G6	4,64	**P6**	4,94	6,47

the measurements of the content of combustible parts for fractions F1 (<63 μm) and F2 (>63 μm) on the level of 9 %. With the smaller size of particles the content of unburned carbon diminishes. Although difference of particle size distributions between sample from analyser and gravimetry sample, LOI measurements of these samples are very similar. When the boiler is operated at full operating load (101 MW) in comparison with operating at lower load (77 MW), the unburned carbon content was greater. Evaluating the work of an optic industrial analyzer in the whole measurement period it should be emphasized that the mean content of unburned carbon for the industrial and LOI method is the same for samples from „Kraków" Power Plant – 4,73% and 4,77% respectively. The average LOI measurement (5,25%) for samples from „Będzin" Power Plant is clearly higher than the mean carbon content for the industrial method (4,35%). Thus an optic analyzer enables to control the boiler and keep it on a stable level, allowing the obtaining of a valuable by-product.

Acknowledgments

This work was supported by the Polish State Committee for Scientific Research (KBN) under university grant no 10.10.150.549 and by the Kościuszko Foundation, American Center for the Polish Culture with the funds provided by Alfred Jurzykowski Foundation. We appreciate the help of Barbara Trybalska and Jacek Kordek in performing analyses on the fly ash samples.

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К. Стижко-Грохов'як[1], Я. Голец[1], Г. Янковський[2]

Характеристика оптоелектронного моніторингу системи для визначення очищення вуглецю у вивітреному попелі з розпиленого вогнем вугілля розміщеного у машинному котлі

[1] *Факультет гірничої справи і екологічної інженерії, кафедра екологічних наук,*
jgolas@uci.agh.edu.pl
[2] *Факультет електричної інженерії, автоматики, комп'ютерних наук і електроніки,*
Університет гірничої справи і металургії,
вул. А. Міцкевича,30, 30-059 Краків, Польща

Дано характеристику відбору якості вугільного попелу, отриманого в процесі роботи однорідно розміщеного обладнання з камерою для горіння твердого вугілля. Зразки взяли для перевірки на два провідні підприємства Польщі.. Здійснено перевірку хімічних та фізичних властивостей зразків вугільного попелу. Проведено обговорення співвідношення між лабораторними та промисловими дослідженнями розпиленого вугільного попелу. Це дозволило оцінити метод вимірювання %C оптичним аналізатором, а також якість системи автоматичного вимірюваня %C на установках підприємств.