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MEASUREMENTS AND INVESTIGATIONS OF EMISSION OF DUST AND GASEOUS POLLUTANTS FROM CIRCULATING FLUIDIZED BED BOILERS

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POMIARY I BADANIA EMISJI ZANIECZYSZCZEŃ PYŁOWYCH I GAZOWYCH Z KOTŁÓW Z CYRKULACYJNYM ZŁOŻEM FLUIDALNYM

Streszczenie

W porównaniu z tradycyjnymi technologiami energetycznego spalania paliw, stanowiącymi główne źródło emisji zanieczyszczeń w Polsce, mało zbadana jest emisja zanieczyszczeń z palenisk fluidalnych. Pracujące w kraju kotły z cyrkulacyjnym złożem fluidalnym wykazały zalety techniczne, technologiczne, ekonomiczne i ekologiczne, co sprawia, że otwiera się przed nimi perspektywa szerokiego zastosowania w energetyce komunalnej, zakładowej i zawodowej do spalania węgla, mułów i przerostów oraz paliw z odpadów i biopaliw. Aby wypełnić istniejącą lukę, jeśli idzie o znajomość właściwości emitowanego pyłu i zanieczyszczeń gazowych, przeprowadzono pomiary, analizy i badania czterech wybranych kotłów z cyrkulacyjnym złożem fluidalnym w elektrociepłowniach EC Tychy, EC Chorzów ELCHO, EC Katowice i El. Jaworzno III (Zakład II). Zmierzono emisję pyłu, jego skład ziarnowy i zanalizowano nagromadzone na cząstkach pyłu niebezpieczne substancje: wielopierścieniowe węglowodory aromatyczne i związki pierwiastków śladowych, w tym metali ciężkich oraz polichlorowane dibenzodioksyny i polichlorowane dibenzofurany (PCDD/PCDF). Zmierzono emisję ditlenku siarki, ditlenku azotu, tlenku węgla, chlorowodoru, fluorowodoru i lotnych związków organicznych. Do badania składu ziarnowego emitowanego pyłu stosowano impaktor kaskadowy, co pozwala uniknąć błędów spowodowanych koagulacją pyłu występującą podczas pomiaru za pomocą filtra mierniczego. Przeprowadzone badania są, pod względem sposobu podejścia i metodyki, kontynuacją wcześniejszych prac autorów nad emisją zanieczyszczeń towarzyszącą spalaniu węgla i stanowią zbiór aktualnych informacji o zanieczyszczeniach gazowych i pyłowych emitowanych przez kotły z cyrkulacyjnymi paleniskami fluidalnymi, pozwalający na pełną ocenę emisji w aspekcie zagrożenia środowiska. Syntetycznym rezultatem pracy są wskaźniki emisji z palenisk fluidalnych pyłu ogółem oraz frakcji PM2,5 i PM10, ditlenku siarki i azotu, tlenku węgla, chlorowodoru i fluorowodoru, wielopierścieniowych węglowodorów aromatycznych i lotnych związków organicznych oraz dioksyn i furanów wyrażone w g/Mg spalonego paliwa. Wyniki badań, pomiarów i analiz potwierdziły ekologiczne zalety spalania węgla i mułów węglowych w paleniskach z cyrkulacyjnym złożem fluidalnym, a w szczególności niską emisje tlenków siarki i azotu oraz znikomą emisję chloro- i fluorowodoru, dioksyn i metali ciężkich. Wskutek stosowania wysokosprawnych elektrofiltrów bardzo niska jest też emisja pyłu. Uwidocznił się wpływ warunków spalania na emisję niektórych zanieczyszczeń, a zwłaszcza w odniesieniu do WWA i tlenku węgla.

Summary

Emission of air pollutants from fluidized bed furnaces is not as well known as emission from the traditional technologies of energetic combustion of fuels, the main source of air pollution in Poland. Boilers with circulating fluidized beds (CFB), working in Poland, proved their technical, technological economical and ecological advantages, gaining good perspective for their applications in municipal, industrial and national energetic – the more so, as they may be fueled with coal, coal slime, recycled wastes and bio-fuels. To fulfil the gap in knowledge concerning properties of dust and gases emitted to the atmospheric air from such boilers, measurements, analyses and investigations of emissions from four selected CFB boilers were performed. The examined CFB boilers belonged to the Polish heat generating plants Tychy, Chorzów EL-CHO, Katowice and Jaworzno III (Department II). Emission of dust from each of these four CFB boilers was measured, the dust granulometric composition was determined and hazardous substances, such as polycyclic aromatic hydrocarbons (PAHs), compounds of trace elements (including heavy metals), polychlorinated dibenzodioxins (PCDD) and polychlorinated dibenzofurans (PCDF), accumulated on the dust particles, were analysed. Emissions of sulphur dioxide, nitrogen dioxide, carbon monoxide, hydrogen chloride, hydrogen fluoride and volatile organic compounds (VOCs) were measured. The granulometric composition of dust was determined by using a cascade impactor – this allowed avoiding errors due to dust coagulation occurring when measuring filters are used. The investigations, with their approach and methodology, are continuation of the authors' earlier investigations of emissions from combustion of coal. They present actual information on gas and dust emissions from the CBF boilers, allowing for complete evaluation of these emissions from the perspective of the environmental hazard. A synthetic result of the work is the factors for emission of total dust, PM2.5, PM10, sulphur dioxide, nitrogen dioxide, carbon monoxide, hydrogen chloride, hydrogen fluoride, PAHs, VOCs, dioxins and furans from the CFB boilers, expressed in grams of emitted substance per 1 Mg of combusted fuel. All received results confirmed ecological advantages of combusting coal and coal slime in the CFB boilers – particularly, the low emissions of sulphur dioxide and nitrogen dioxide as well as minimal emissions of hydrogen fluoride, dioxins and heavy metals. Also, due to application of highly efficient electro-filters, the dust emission is low. The results revealed the effect of conditions of fuel combustion on emissions of some pollutants, especially PAHs and carbon monoxide.

INTRODUCTION

To improve air quality in urban agglomerations, especially in the Silesian Region, the sector of energy and heat production is continually modernized and financially supported. Installations basing on low-emission techniques of fuel combustion and combined heat and power (co-generating) systems, some using renewable energy, are being introduced. The thermal power plants, equipped with the CFB boilers, posses all advantages of such installations.

Combusting coal grains suspended in a flowing stream of air, the CFB operating principle, provides preferable conditions for oxygen – fuel contact and allows for intensive burning in low, not exceeding 1200°K, temperature. The high intensity of burning is reflected by the very high coefficient of combustion heat release characteristic of these boilers. Due to several times greater factor of heat penetration from the fluidized layer to a steamer surface, the CFB boiler is smaller than a convectional draught pulverized-fuel boiler of comparable capacity. Lowered combustion temperature yields lower amount of nitrogen oxides; intensive mass exchange between solid and gaseous phases enables fixation of sulphur dioxide, hydrogen chloride and hydrogen fluoride by supplying alkaline additive to the fluidized bed. The several times lower emissions of these compounds may be achieved in this way. Applying electrofilters allows for compliance with high standards concerning dust emission. Another advantage of the fluidized bed furnaces is their ability to utilize coals containing considerable amounts of mineral substances and coals mixed with recycled wastes and biomass. Also, fuel for CFB boilers, not having to be so finely ground as fuel for PC boilers, is prepared in a less energy-consuming way. All this proves appreciable ecological advantages of combusting fuels in the fluidized beds [5, 8–12].

In modern power stations, the heating processes are accomplished in combined systems. The main product is heat; the produced electric power is a by-product. The electric power, sold to customers, substitutes energy that would cost additional fuel and emission of pollutants if produced in power stations working in other than co-generating systems. Efficiency of the combined heat and power production is greater than the sum of efficiencies of separate power and heat production [13]. So, in the combined systems, the chemical energy of fuels is saved and releasing great amounts of air pollutants, coming from combustion, prevented.

The CFB boilers reached level of constructional and technological development that allows their application in various branches of energetic having presently to meet higher and higher ecological standards [4].

Compared with the main source of air pollution in Poland, i.e. the traditional technologies of energetic combustion of fuels, the emission of air pollutants from fluidized bed furnaces is less known. To fulfil a gap in the knowledge concerning particle size distribution, respirable fraction content and properties of the emitted dust, and to determine kinds and amounts of gaseous air pollutants, measurements, analyses and investigations of emissions from four CFB boilers were performed.

GOAL AND SCOPE OF THE WORK

The cognitive goal of the work was the complete, realized for the first time in Poland, investigation of the emission of air pollutants from combustion of coal and other fuels in the CFB boilers. The practical goal of the work was determination of the emission factors for fluidized bed furnaces.

The investigations, carried out at four Polish heat generating plants (HGP) Tychy, Chorzów ELCHO, Katowice and Jaworzno III (Department II), all equipped with the CFB boilers and fuelled with hard coal and coal slime, covered measurement of emission and analysis of dusts and gases.

The particle size distribution in the emitted dust, the dust morphology, density, chemical composition and phase composition were investigated. Also hazardous substances, such as PAHs, compounds of heavy metals, dioxins: polychlorinated dibenzodioxins (PCDD) and polychlorinated dibenzofurans (PCDF) were determined. Gaseous pollutants, emissions of which were measured, included sulphur dioxide, nitrogen dioxide, carbon monoxide, hydrogen chloride, hydrogen fluoride and VOCs.

The scope of the work covered determination of emission factors for total dust, PM2.5, PM10, sulphur dioxide, nitrogen dioxide, carbon monoxide, hydrogen chloride, hydrogen fluoride, PAHs, VOCs and dioxins, in grams of emitted substance per 1 Mg of burned fuel. The granulometric composition and morphology of the dust, occurrence of PAHs and trace elements shall be the subject of separate publications.

METHODOLOGY OF MEASUREMENTS AND INVESTIGATIONS

Measurements of the volumetric flow rate, temperature, humidity and concentration of flue gas were performed with the use of an automatic P-10 ZA gravimetric dust meter, psychrometer with resistance probes and with a digital thermometer.

Density, inflammable matter and chemical composition of the sampled dust were determined. The dust in the flue gas from the CFB boiler was composed of fly ash, sulphates, chlorides and fluorides of calcium (products of the additive reaction with sulphur dioxide, hydrogen chloride and hydrogen fluoride), and of calcium oxide coming from excessive amount of the additive.

The determinations were performed as follow:

- absolute density of dust – with the use of a liquid psychrometer,
- inflammable matter in dust – as a loss of mass during calcinations,
- basic chemical composition of the dust: SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, SO_3, TiO_2, P_2O_5, and BaO, Mn_3O_4, SrO and ZnO – with the use of the X-ray fluorescence spectrometry.

The granulometric composition of the dust was determined by using a cascade impactor Andersen Mark III connected to the dust sampling train. The dust was sampled from a dedusted flue gas pass of an electrofilter. The impactor comprised six stages, each trapping proper granulometric fraction from the dust stream, and the seventh stage, being a filter substrate arresting dust grains of the aerodynamic diameter less than 0.5 μm.

The dust was sampled by using the impactor. The time of aspiration, determined experimentally in a pretest preparation before the actual sampling, was usually from 180 to 220 min, depending on the flow rate and dust content in the flue gas. During the aspiration, the proper parameters of the gas flow in the measuring train were maintained by adjusting efficiency of the suction nozzle to receive iso-kinetic stream of the gases. After the aspiration, the impactor was taken out of the flue gas pass and the substrates from particular stages of the impactor, as well as the end filter, were weighed to determine masses of particular granulometric dust fractions. On the basis of measured volume of the sampled flue gas and its temperature, with the use of characteristics from the sampler manual [1], the cutting diameters, thus the limits of fractional intervals corresponding with proper shelves of the impactor, expressed as equivalent diameters of dust grains, were determined. With the masses of the dust from the impactor stages and the end filter known, the averaged fractional dust proportions, expressing mass contributions of dust from particular fractional intervals to mass of total collected dust, and cumulated values for fraction diameters, each being a sum of all fractional proportions for fractions with diameters not greater than a chosen one, were calculated for each plant.

The chemical composition of the gases was determined (O_2, CO_2, SO_2, NO_2, NO and CO) by using a Sick's photometric gas analyser MCS 100 E equipped with a system for flue gas conditioning. Concentrations of water soluble chlorides and fluorides, volatile at the temperature of filtration, were determined with the potentiometric method using ionoselective electrodes. Determinations of VOCs, containing C_1 to C_{10}, including alkanes, alkenes, ketones and aromatic hydrocarbons, were performed by collecting samples to Tedlar bags. VOCs were analysed by using a Varian Star 3400 CX gas chromatograph, equipped with a photo-ionization detector.

Concentrations of dioxins, i.e. polychlorinated dibenzodioxins (PCDD) and polychlorinated dibenzofurans (PCDF), as normalized values expressed in toxic equivalent quantity per cubic meter of gases – TEQ/m^3_u – were determined by the Trace Analyses Laboratory of Inorganic Chemistry and Technology Institute at the Technical University of Krakow, following guidelines of the European Union Council Directive 2000/76/EC of December 2000 [2]. The dioxins were collected on filters made of quartz fibres seated on sintered glass (dust fraction) and, after separating solid fraction, in condensate and on solid sorbent – polyurethane foam (gas fraction). Preparation of samples for the gas chromatography combined with mass spectrometry (GC-MS) was performed by using methods basing on the fluid – solid extraction techniques and techniques of the multistage liquid chromatography. Analyses were performed by using GC-MS with dual fragmentation of examined molecule on a Finnigan MAT GCQ apparatus and GC-MS/MS. The analyte recovery was computed by using standards, isotopically marked ^{13}C-PCDDs and ^{13}C-PCDFs, introduced into samples before the extraction. The toxic equivalent concentration, in nanograms of TEQ per m^3_u of flue gas, was computed on the basis of determinations of 17 congeners of PCDDs and PCDFs with the use of the 2,3,7,8-TCDD toxicity equivalency factor (TEF). The determination limit for the dioxins in the applied method was 0.001 ng TEQ/m^3.

To determine selected trace elements in the dust, the dust samples were solved in a mixture of nitric, hydrochloric and hydrofluoric acids in a microwave chamber under pressure of 24–27 bar, at the temperature of 473°K, and analysed with the use of a sequential Jobin Yvone ICP-AES spectrometer, type JY-36.

PAHs were determined in samples of the dust. After extraction of organic substances with methylene chloride in an ultrasonic bath, PAHs were separated in a column packed with stationary phase. The extract comprising the PAH fraction, condensed in the helium atmosphere, was analysed by using the gas chromatography (GC) on a Hewlett-Packard 5890 gas chromatograph with a flame ionization detector (FID). Concentrations of the 16 PAHs and concentration of computed as toxic equivalent concentrations of benzo(a)pyrene (TEC B(a)P).

The emission factors for air pollutants were calculated from measured concentrations of these substances in the flue gas, flue gas volumetric flow and mass of fuel burned. The emission factors are expressed in mass unit of emitted substance per (metric) ton of fuel.

CHARACTERISTICS OF THE EXAMINED OBJECTS

At the four heat generating plants, the CBF boilers combusting only hard coal or hard coal as main fuel was examined. The limestone is added to their fuel and electrofilters are used to de-dust their flue gases. Parameters of coal combusted in the boilers, averaged over the period of investigations, are presented in Table 1.

Table 1. Parameters of fuel combusted in examined boilers

Coal parameters	Unit	Heat Generating Plant					
		Tychy	ELCHO	Jaworzno		Katowice	
				coal	coal slime	coal	coal slime
Calorific value	KJ/kg	19915	19775	18942	9000	19454	9053
Moisture content	%	10.51	14.90	20.90	42.00	13.80	40.70
Sulphur content	%	0.92	1.22	1.26	0.80	1.17	0.73
Ash content	%	24.78	14.90	15.67	28.00	19.70	26.10
Volatile matter	%	28.91	25.08	23.26	n.a.	27.00	n.a.

At the HGP Tychy, S.A., the Norwegian Aker Kvaerner ASA boiler, type Cymic, working since 2000, was examined. Its thermal power is 70 MW_t. Its nominal steam production is 135 Mg/h, and it is fuelled with hard coal.

At the HGP Chorzów ELCHO Ltd., the Compact type boiler, provided by Foster – Wheeler, of the thermal power 274 MW_t, set working in 2003, was examined. The nominal steam production of this boiler is 404 Mg/h, it is fueled with hard coal.

At the HGP Jaworzno II, also the Foster-Wheeler's Compact boiler, started in 1999, was examined. Thermal capacity of the boiler is 180 MW_t, it produces steam in the amount of 260 Mg/h. It is fuelled with a mixture of coal and coal slime in mass proportion 1 : 1.

The last examined boiler was at the HGP Katowice, and also it was the Foster-Wheeler's Compact boiler, started in 1999. Its thermal capacity is 200 MW_t, its nominal steam productivity is 483 Mg/h. Te boiler combusts coal and coal slime mixed in the chemical energy proportion 7 : 3.

RESULTS OF MEASUREMENTS AND INVESTIGATIONS

Results of measurements and investigations, averaged over three sessions, are presented in Table 2. The received results were evaluated in two ways: one, by comparing measured concentrations of dust and gases in flue gases from the CFB boilers with concentrations in other boiler flue gases, second, by comparing emission factors for the CFB boilers with the factors for other ones. In the latter, the authors referred to earlier experiences acquired during many year investigations of emissions from PC boilers, mechanical stocker boilers with and hand-fired grate furnaces (domestic furnaces) [6, 7]. Concentrations of dust and gases in flue gas from the CFB boilers differ considerably from concentrations measured lately by the authors in flue gases from the PC boilers. Namely, concentration of dust in flue gas from the CFB boilers is from 12 to 28 mg/m^3_u while from the PC boilers it is from 78 to 254 mg/m^3_u. The difference is due to modern electrofilters installed on the CFB boilers. Comparison of other pollutants is following: sulphur dioxide from 504 to 657 mg/m^3_u for CFB boilers and from 1063 to 2241 mg/m^3_u for PC boilers, nitrogen dioxide from 124 to 328 mg/m^3_u for CFB boilers and from 273 to 490 mg/m^3_u for PC boilers, carbon monoxide from 25 to 76 mg/m^3_u for CFB boilers and from 16 to 50 mg/m^3_u for PC boilers, water soluble fluorides from 0.001 to 0.0016 mg/m^3_u for CFB boilers and from 1.3 to 2.8 mg/m^3_u for PC boilers, water soluble chlorides from 0.09 to 0.15 mg/m^3_u for CFB boilers and from 3.7 to 9.6 mg/m^3_u for PC boilers.

The results of measurements and analyses were compared with results of earlier works concerning furnaces combusting Upper Silesian hard coal. It was done by computing the emission factors expressed in mass units of polluting substance per 1 Mg of combusted coal (Tab. 3). The emission factors for the CFB boilers are confronted in Table 4 with the factors for the PC boilers, mechanical stoker (MS) boilers and hand-fired grate furnaces (domestic furnaces). Presented in Table 4 coal quality and efficiency of de-dusting may be considered typical of each furnace. Flue gases from the CFB boilers and PC boilers were de-dusted with electrofilters, from MS boilers – with a cyclone or battery of cyclones.

Table 2. Flue gas volumetric flow rate and concentrations of selected flue gas components

Parameter	Unit	Heat Generating Plant			
		Tychy	ELCHO	Jaworzno II	Katowice
Flue gas volumetric flow rate*	m^3_u/h	157730	420340	261610	556650
Flue gas volumetric flow rate**	m^3_u/h	149318	476385	259866	616026
Dust concentration**	mg/m^3_u	28.0	19.3	12.1	23.9
Flammable matter in dust	%	21.91	5.59	4.82	7.68
PAHs in dust	$\mu g/m^3$	638.11	172.45	157.70	n.a.
TEC B(a)P of dust	$\mu g/g$	165.08	30.25	33.25	n.a.
O_2 concentration*	%	6.8	4.0	6.1	4.4
CO concentration**	mg/m^3_u	76.29	25.18	68.16	47.89
SO_2 concentration**	mg/m^3_u	656.76	527.42	541.29	504.37
NO_2 concentration**	mg/m^3_u	331.68	168.22	280.67	124.40
Water soluble fluorides concentration**	mg/m^3_u	0.0013	0.0010	0.0016	0.0016
Water soluble fluorides concentration**	mg/m^3_u	0.1529	0.1322	0.0858	0.0905
Total VOCs**	% vol. 10^{-3}	0.20	0.86	1.04	0.60
Total VOCs**	mg C/m^3_u	5.4	27.2	24.9	14.0
Dioxin concentration***	ng TEQ/m^3_u	0.012 ± 0.003	0.045 ± 0.010	0.056 ± 0.005	0.060 ± 0.015

* in dry flue gas in standard conditions,
** in dry flue gas having 6% of O_2 in standard conditions,
*** recalculated from content in dust into concentration in dry flue gas having 6% of O_2 in standard conditions

Table 3. Emission factors for air polluting substances coming from hard coal combustion in CFB boilers

Pollutant	Unit	Emission factor
Total dust	kg/Mg	0.160
PM2.5		0.073
PM10		0.151
CO		0.41
SO_2		4.29
NO_2		1.67
HCl	g/Mg	1
HF		$1.2 \cdot 10^{-2}$
VOCs		20.9
Dioxins*	ng TEQ/Mg	452
B(a)P	mg/Mg	0.8
Total PAHs**		16.1
TEC B(a)P**		3.0

* without HGP Tychy,
** in PM10

Table 4. Emission factors for air polluting substances coming from hard coal combustion in various furnaces [kg/Mg]

Furnace	Dust			SO_2	NO_2	CO	HCl	HF	$B(a)P*10^{-3}$
	Total	PM2.5	PM10						
PC	0.82	0.34	0.75	16	6	0.3	0.82	0.11	$0.001*10^{-3}$
Mechanical	9.0	2.97	5.13	17	5	1.5	1	0.15	$0.160*10^{-3}$
Domestic	5.4	1.30*	3.73*	14.4	1.5	100	1	0.15	$5*10^{-3}$
CFB	0.160	0.073	0.151	4.29	1.67	0.41	$1*10^{-3}$	$1.2*10^{-5}$	$0.0008*10^{-3}$ **

* computed following [3],
** on PM10

Dust

Due to very efficient electrofilters, emission factors for dust emission from examined objects are small. The mass contribution of PM10 to total dust is – on average – 94%. The mass contribution of PM2.5 is 46%. The contribution of the fraction of dust grains with aerodynamic diameter greater than 10 μm is small, what proves almost total elimination of this fraction from the emitted dust by an electrofilter. The emission factors are 0.16, 0.151 and 0.073 kg/Mg for total dust, PM10 and PM2.5, respectively. Only small stream of the respirable dust passes into ambient air. The factors for the CFB boilers are several times lower than for typical PC boilers. Similarly low dust emission factors, like for CFB boilers, may be determined for great power stations applying wet flue gas desulphurisation (FGD) methods. The wet FGD installation works like a second stage of flue gas de-dusting.

Detailed results of investigations concerning chemical and granulometric compositions of emitted dust as well as its properties will be the subject of another publication.

Carbon monoxide

The emission factor for carbon monoxide was 0.41 kg/Mg and was somewhat lower than for PC boilers. It was three times lower than for MS boilers and many times lower than for hand-fired furnaces.

Sulphur dioxide

The emission factor for sulphur dioxide was 4.29 kg/Mg. It was four times lower than for PC boilers or MS boilers. However, it was higher than for power stations equipped with the wet limestone FGD. If content of combustible sulphur in coal is 0.9%, then the calculated for sulphur dioxide emission factors prove efficiency of desulphurization of flue gas from the examined CFB boilers, applying the limestone additive, at about 75 to 78%.

Nitrogen dioxide

The emission factor for nitrogen dioxide was 1.67 kg/Mg. It was three times lower than for PC boilers and MS boilers.

Water soluble fluorides

The emission factor for water soluble fluorides was very small what proves almost total bonding of fluorides, or rather hydrogen fluoride, from flue gas by the limestone additive. In contrast, the emission factor for the water soluble fluorides for PC boilers (without wet FGD) was 110 g/Mg.

Water soluble chlorides

The emission factor for water soluble chlorides was 1 g/Mg. It is very small value, proving almost total bonding of chlorides, or rather hydrogen chloride, from flue gas by the limestone additive. The emission factor for the water soluble chlorides for PC boilers (without wet FGD) was 820 g/Mg.

Volatile organic compounds

Concentration of VOCs, recalculated into content of organic carbon, in flue gases emitted from the four CFB boilers into the atmosphere was very low – it was between 5 and 30 mg C/m^3_u. Consequently, the emission factor for VOCs was low, equal to 20.9 g/Mg. It cannot be compared with the factors for other furnaces because of lacking data.

Polychlorinated dibenzodioxins and dibenzofurans

In flue gas from the examined installations, concentration of dioxins was low and computed accordingly to the Directive 2000/76/EC of the European Union Council, it did not exceed 0.060 ng TEQ/m^3_u. The emission factor for dioxins was 452 ng TEQ/Mg. So, being low, the coal combustion in CFB furnaces does not cause hazard by introducing dioxins into the atmosphere.

Polycyclic aromatic hydrocarbons

The factor for PAH content in PM10 was 16.1 mg/Mg. Because the term "total PAHs" is of limited usability in evaluations of hazard caused by these compounds, the toxic equivalent concentration B(a)P (TEC B(a)P) was computed. It was 3.0 mg/Mg. Moreover, the emission factor for B(a)P was determined at the level of 0.8 mg/Mg.

The emission factor for the most interesting polycyclic aromatic hydrocarbon, B(a)P, is almost the same as in the case of PC furnaces, but it is significantly lower than for MS boilers, for which the factors for B(a)P in PM10 emission exceeds 100 mg/Mg, for total PAHs – 2000 mg/Mg, and TEC B(a)P is higher than 800 mg/Mg.

It was noted that elevated content of PAHs in the emitted dust is clearly related to degree of the coal burning out. This was why in the calculation of the emission factors HGP Tychy was not considered – in flue gas emitted by this plant, the content of inflammable matter was several times higher than in other examined plants. The importance of conditions that assure complete combustion of fuel in the CFB boilers should be stressed. Results concerning distribution of PAHs in granulometric fractions of the dust will be published separately.

All the measurements, analyses and investigations yield the conclusion that expectations concerning ecological advantages of the boilers with circulating fluidized beds are fully justified. The expectations are motivated by low emission of nitric oxides and satisfying efficiency of sulphur oxide fixation by limestone additive. The limestone additive eliminates practically whole emissions of hydrogen chloride and fluoride. Depending on efficiency of dedusting devices dust emission is low, what is due to installation of modern electrofilters. Consequently, the emission of toxic substances adsorbed on dust particles – dioxins and PAHs – is low as well. The degree of burning out of fuel depends on technical conditions and exploitation mode of the assessed boilers. In the case of one of the examined boilers, fuel was burnt insufficiently (incompletely).

CONCLUSIONS

The performed measurements and investigations yielded the following conclusions:

- The examined CFB boilers, equipped with highly efficient electrostatic dedusting devices, emit only small amounts of dust; the emission factor for PM2.5 is clearly lower than in the case of PC boilers.
- The emission factors for sulphur dioxide are greater than in the case of energetic boilers equipped with FGD basing on the wet limestone method.
- The emission factors for nitrogen dioxide are two times lower than in the case of PC boilers applying low-emission techniques of combustion.
- The emission factors for carbon monoxide are slightly higher than in the case of PC boilers.
- Emission of water soluble chlorides and fluorides is minimal.
- The examined boilers do not introduce dioxins into the atmosphere in amounts causing hazard.
- Emission of B(a)P is higher than from PC boilers, but it is significantly lower than from MS boilers; good conditions for complete combustion of fuel were proved to be of considerable importance.

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