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FRACTIONAL COMPOSITION OF DUST EMITTED FROM BOILERS WITH CIRCULATING FLUIDIZED BEDS

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Abstract: The paper presents investigations of dust fractional composition concerning combustion of hard coal in circulating fluidized bed boilers (CFBs). Experimentally determined emission factors for such boilers, and also typical pulverized-fuel furnaces, furnaces with mechanical stoker and domestic furnaces are presented. They all have been obtained for Upper Silesian type of coal. Total dust and characteristic fractions: PM2.5 and PM10 are covered.

INTRODUCTION

Combustion of hard and brown coals for energy production is in Poland, aside of making use of liquid fuels in car engines, the greatest source of gases and dusts emission to the atmosphere. Polish statistics of fuels utilization explains this phenomenon quite well: hard and brown coals make up 62.3%, oil and natural gas 32.8% of the power resources. The renewable energy share in the total energy produced is only 0.2% [3]. Production of energy by combusting coal in various furnaces yields annual emission of about 270 thousands Mg of dust, what makes 61% of 443 thousands Mg of total dust emitted per year [3].

Especially harmful are small, local heating systems and also, in great cities districts, domestic furnaces combusting hard coal, built-up with old houses at the beginning of the 20^{th} century. They cause considerable concentrations of PM10, i.e. dust particulates having equivalent diameters up to 10 μm. Due to the PM10 adverse effects, relatively low permissible annual value (40 $\mu g/m^3$) was established for its concentration in atmospheric air. The actual annual concentrations of PM10 in some cities are higher, for instance in the Upper Silesian agglomeration 51.3 $\mu g/m^3$ and in the Krakow agglomeration 67.5 $\mu g/m^3$ [3].

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Ecological effects of atmospheric dust significantly depend on its granular composition – share of grains with various diameters. Most hazardous to humans are fractions (grains of equivalent diameter belonging to a defined range) less than 5 μm with special importance of those not greater than 2 μm, due to its ability to deposit in alveoli and infiltrate into the vascular system (in practical use, as a specimen of all these fractions, PM2.5 is considered). For this reason the granular composition is commonly taken into account while assessing air quality and environmental effects of emission sources. In the USA, for instance, data on concentrations of PM2.5 from a monitoring network are used to determine the Air Quality Index (AQI). The knowledge of dust composition is needed in designing de-dusting and gas emission reducing installations, modernizations of power and heat producing utilities, defining the Best Available Techniques for large combustion plants and assessing emissions of compounds located on dust surface [9]. Also air pollutant propagation models demand data on the granular composition and physical properties of dust to assess its time of floating in the air and range of transport of particular fractions.

Concentrations of PM2.5 are measured in some Polish agglomerations along with overall dust concentration. In circumstances of lacking standard for this fraction, the value of 25 $\mu g/m^3$ is assumed as a desirable limit for PM2.5 concentration in ambient air. This value is not ever fulfilled. In Zabrze (population of 200 000) in the Silesian Agglomeration – the area environmentally degraded by intensive, lasting over 150 years mining, coking, steel and energy production – the annual PM2.5 concentration in 2005 was about 41 $\mu g/m^3$ and PM2.5 mean winter value was about 57 $\mu g/m^3$. Also high daily PM2.5 concentrations, reaching 188 $\mu g/m^3$, were observed. The American AQI computed for Zabrze falls between 151 and 200, meaning conditions harmful to human health (unhealthy) [5].

In practice, while assessing the hazard to the biosphere from dust by investigating emissions, standard PM10 and PM2.5 dust emission factors determined for unclean flue gas, are commonly used. Then the total de-dusting efficiency is considered to calculate final dust emission. Modern de-dusting devices working in big power plants usually maintain concentration of dust in flue gases below relatively low level of 50 mg/m^3. However, due to their greater efficiency in removing coarse fractions, share of fine dust in cleaned gas is much greater than in gas before de-dusting. Consequently, actual concentration of PM10 and PM2.5 dusts in emitted gases remains unknown, what makes applicability of unabated emission factors useless for such calculations [2, 4, 10, 13].

The authors have assessed emissions from the combustion of coal in energy production for years. Among others, their works resulted with experimentally determined emission factors for estimating amount of dust introduced into atmosphere during combustion of Upper Silesian hard coal in typical pulverized-fuel boilers used in power industry without wet desulphurization but equipped with high-efficient electrofilters, furnaces with mechanical stoker and typical cyclones used in municipal heating systems and individual domestic furnaces. Brand and quality parameters of the coal were properly selected for each kind of furnace to go along with local statistics of fuel consumption. They are applicable in determinations of emission of total dust, PM10 and PM2.5 [6, 8, 14].

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Emission from the fluidized furnaces is less known than emission from conventional ones. The fluidized furnaces are promising as they may be applied in energy production on municipal, industrial or commercial scale and fuelled with various kinds of coal, slurry, banded coal and recycled wastes [12]. The fluidized bed combustion technique has been developed from combustion under atmospheric pressure (Atmospheric Fluidized Bed Combustion, AFBC); through pressurized circulating fluidized bed (Pressurized Fluidized Bed Combustion, PFBC) till combustion in binary circulating bed (Multi-Solid Fluidized Bed, MSFB). Also, technologies of coal and wastes combustion in fluidized bed with internal circulation of granular matter (Twin Interchanging Fluidized Bed, TIFB) or with heat exchangers immersed in a fluidized bed (Internally Circulating Fluidized Bed, ICFB) were developed. Combustion in a circulating bed, in presence of alkaline additive, at relatively low temperature and with highly-efficient de-dusting devices allows for meeting very high ecological demands [6].

The paper presents results of fractional composition determination of dust emitted from circulating fluidized bed boilers (CFB). Measurements were performed in 4 power stations; results from only 2, fuelled with Upper Silesian hard coal for energetic purposes, are presented here (the other 2 plants are fuelled with coal and slurry mixed in rather random proportion).

In the paper, the word "dust" stands for solid residuals of fuel combustion, products of reactions between additive and sulphur dioxide, chlorides and fluorides, particles of unutilized additive and components of the bed itself mixed all together in the flue gas leaving de-dusting system.

INVESTIGATED OBJECTS

The fractions of emitted dust were measured in power plants equipped with circulating fluidized bed (CFB) boilers where, to lower SO_2 emission, the lime-stone additive was applied.

TYCHY Power Plant (Elektrociepłownia Tychy S.A., PP. Tychy):

Boiler type – CFB (Aker Kvaerner ASA),
Boiler capacity – 70 MW_t, 40 MW_e,
Steam rated output – 135 Mg/h,
Boiler brand – CFB Cymic,
Started working – 2000,
Average flue gas flow during measurements – 157730 m^3_N/h,
Average concentration of dust in emitted flue gas – 26.5 mg/m^3_N,
Density of dust (captured by the electrofilter) – 2.5551 kg/dm^3.
Coal parameters are presented in Table 1.

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Table 1. Parameters of coal used in PP. Tychy

Coal parameter	Unit	Value
Calorific value	[KJ/kg]	19915
Moisture content	[%]	10.51
Sulphur content	[%]	0.92
Ash content	[%]	24.78
Volatile matter	[%]	28.91

ELCHO Chorzów Power Plant Ltd. (Elektrociepłownia Chorzów ELCHO Sp. z o.o., PP. Elcho):

Boiler type – 2 × CFB (Foster-Wheeler),
Boiler capacity – 274 MW_t,
Steam output – 404 Mg/h,
Live steam pressure – 13.5 MPa,
Live steam temperature – 811 K,
Boiler brand – CFB Compact,
Started working – 2003,
Average flue gas flow during measurements – 420340 m^3_N/h,
Average concentration of dust in emitted flue gas – 21.9 mg/m^3_N.
Density of dust (captured by the electrofilter) – 2.6456 kg/dm^3.
Coal parameters are presented in Table 2.

Table 2. Parameters of coal used in PP. Elcho

Coal parameter	Unit	Value
Calorific value	[KJ/kg]	19775
Moisture content	[%]	14.90
Sulphur content	[%]	1.22
Ash content	[%]	14.90
Volatile matter	[%]	25.08

METHOD OF MEASUREMENT

Dust total concentration in flue gas and its total emission were determined according to the Polish Norm [11]. A gravimetric semiautomatic meter P-10 ZA with a pressure balance-type probe and exchangeable nozzles was used. The apparatus configuration allows for multipoint isokinetic sampling, independent of actual variations of flue gas velocity at a sampling point.

The fractional composition of dust was measured with the P-10 ZA meter with the seven-stage cascade impactor MARK III mounted in a place of the probe, according to the impactor operating manual [1]. Each sampling was preceded by measurements of velocity, temperature and static pressure of the flue gas stream. The velocity and pressure were measured according to [11] by using a Prandtl probe. Humidity of the flue gas was also determined.

During fractional composition measurements, a single, representative of the whole investigated cross-section sampling point was selected and proper gas stream gauge in the meter, ensuring isokinecity of sampling, was computed and maintained. The volume of flue gas drawn through the sampler was calculated from the time of sampling and flow.

The time of sampling, determined experimentally before aspiration for each object, varied from 180 to 220 minutes depending on flow velocity and dust content in flue gas.

DEVELOPMENT OF RESULTS

From the size of the nozzle used, temperature and volume of flue gas passed through the device, the cutoff diameters were determined for the impactor stages. The characteristics provided by the device producer were applied [1]. The cutoff diameter for an impactor stage is defined as the equivalent diameter of particles, of which 50% are arrested at this stage along with all greater ones; all smaller grains pass further to the next impactor stage. Dust particles of equivalent diameter falling in the range between cutoff diameter of current and preceding impactor stage create, for particular measurement, one fraction.

After sampling the fractional dust composition was determined, as the fractional proportion (FP), expressing mass contributions of particular fractions in total collected dust, and also cumulated mass (CM), as a sum of FPs of this fraction and all finer ones.

The cutoff diameters for impactor stages depend on gas flow velocity at a place and in time of sampling. Due to differences in gas velocity assuring isokinetic sampling, these diameters differ for various objects of investigations and often even for consecutive measurements at the same object. Comparison of fractional dust composition between various objects demands defining uniform diameter intervals for particular fractions, to refer results of all measurements to. Four such intervals were defined for the purposes of the presented work: diameters less than 1.0 μm, diameters between 1.0 and 2.5 μm, diameters between 2.5 and 10.0 μm, diameters greater than 10.0 μm. Values of FPs and CMs obtained in particular measurements were interpolated for these intervals. The sequence of computations for the first considered object, PP. Tychy, is presented as an example in Tables 3 and 4.

Table 3. Measured fractional composition of dust, PP. Tychy

Impactor stage	Diameter interval [μm]	Weight of fraction [mg]	FP [a)]	CM [b)]
7	< 0.52	2.18	0.0805	0.0805
6	0.52–1.26	5.40	0.1993	0.2798
5	1.26–2.53	9.90	0.3654	0.6452
4	2.53–4.00	5.90	0.2178	0.8630
3	4.00–8.50	2.57	0.0949	0.9579
2	8.50–13.70	0.66	0.0244	0.9823
1	> 13.70	0.48	0.0177	1.0000

a) – fractional proportion, b) – cumulated mass

Table 4. Uniform fractional composition of dust, PP. Tychy

Fraction	Diameter interval [μm]	FP [a)]	CM [b)]
I	< 1.0	0.2098	0.2098
II	1.0–2.5	0.4269	0.6366
III	2.5–10.0	0.3283	0.9649
IV	> 10.0	0.0352	1.0000

a) – fractional proportion, b) – cumulated mass

Ultimate results of measurements of fractional dust composition for the two investigated plants, related to the uniform fractions, are presented in Table 5.

Table 5. Fractional uniform dust composition for investigated plants

Power station	Diameter interval [μm]							
	< 1.0		1.0–2.5		2.5–10.0		> 10.0	
	FP [a)]	CM [b)]	FP [a)]	CM [b)]	FP [a)]	CM [b)]	FP [a)]	CM [b)]
PP. Tychy	0.2098	0.2098	0.4269	0.6366	0.3283	0.9649	0.0351	1.0000
PP. Elcho	0.1702	0.1702	0.4103	0.5805	0.3693	0.9498	0.0502	1.0000

a) – fractional proportion, b) – cumulated mass

Measured, uniform fractional compositions of dust are presented in the chart shown in Figure 1.

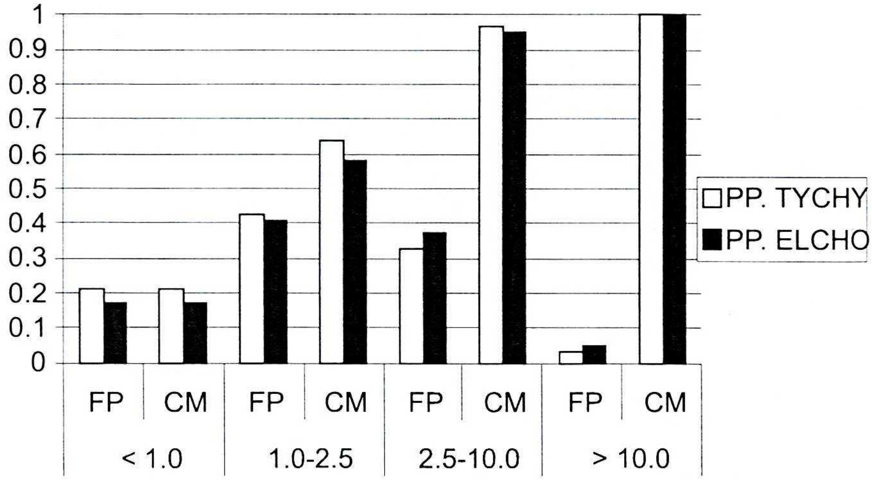

Fig. 1. Fractional uniform composition of dust for investigated plants

Along with measurements of the fractional composition of dust, the total dust emission from both plants was measured in a standard way. The proper CMs were superimposed on dust emissions, and the cumulated fractional emissions received were related to the flux of burned fuel. This yielded the cumulated emission factor for each dust fraction, expressed as a mass of this fraction and all finer ones emitted during combusting of a unitary mass of fuel, kg/Mg. They have been presented in Table 6.

Table 6. Emission factors for investigated CFBs

Power station	Diameter interval [μm]			
	≤ 1,0	≤ 2,5	≤ 10	Total dust
	Cumulated emission factors for dust fraction, kg/Mg			
PP. Tychy	0,035	0,107	0,161	0,167
PP. Elcho	0,028	0,095	0,156	0,164

The cumulated emission of particular dust fractions, related to the unit of burned fuel, is presented in a form of chart – Figure 2.

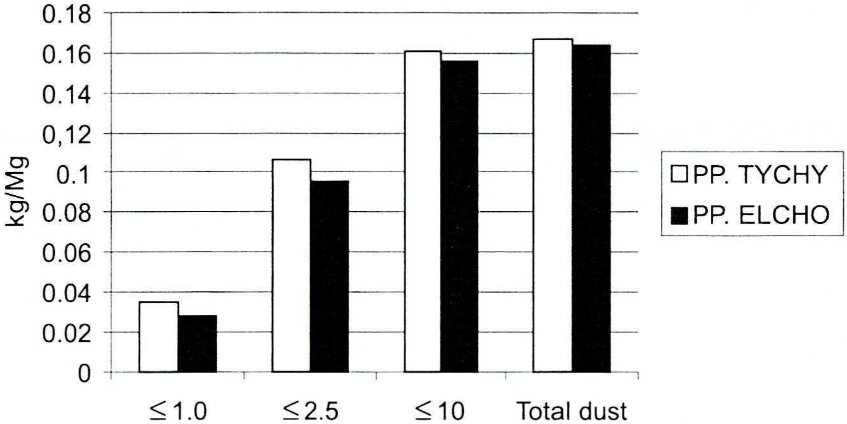

Fig. 2. The cumulated emission of particular dust fractions, related to the unit of burned fuel

CONCLUSION

The results for the two boilers, concerning the fractional composition of the emitted dust and cumulated factors of its emission were similar. The factors for total dust emission are 0.164 kg/Mg for PP. Tychy and 0.167 kg/Mg for PP. Elcho (0.166 kg/Mg in average). The PM2.5 factors are 0.095 and 0.107 kg/Mg, respectively (0.101 kg/Mg in average) and the PM10 factors – 0.156 and 0.161 kg/Mg (0.159 kg/Mg).

The mass share of PM10 in total emission of dust is 95.0% in PP. Tychy and 96.5% in PP. Elcho, the share of PM2.5 is 58.0 and 63.7%, respectively. The PM1 mass shares differ relatively more and are 17.0 and 21.0% for PP. Tychy and PP. Elcho, respectively.

The efficiency of de-dusting systems is high in both plants; concentration of dust in flue gases after electrofilters does not exceed 26.5 mg/m^3_N. Share of coarse fractions, with particle diameters greater than 10 μm, is small due to their almost total elimination by the electrofilters. Relatively small amounts of respirable dust are also emitted: considerably smaller than from boilers with pulverized fuel furnaces applied in typical power plants and tens times smaller than from boilers with mechanic grate furnaces.

The PM2.5 emission factor for the fluidized bed boilers is 0.101 kg/Mg (on average), for pulverized fuel boilers – 0.34 kg/Mg and 2.97 kg/Mg for mechanic grate boilers (Tab. 7). For power plants applying wet methods of de-sulphurization of flue gas this factor is even lower. The factors determined in the presented work contribute to earlier knowledge on dust emission factors [7, 8].

Table 7. Emission factors for various boilers types

Furnace	Emission factors [kg/Mg]		
	Total dust	PM2.5	PM10
Pulverized fuel fed	0.82	0.34	0.75
Mechanical stocker	9.0	2.97	5.13
Domestic stove	5.4	1.30	3.73
CFB	0.166	0.101	0.159

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SKŁAD FRAKCYJNY PYŁU EMITOWANEGO Z KOTŁÓW
Z FLUIDALNYMI ZŁOŻAMI CYRKULACYJNYMI

W artykule przedstawiono wyniki badań nad składem frakcyjnym pyłu pochodzącego ze spalania węgla kamiennego w kotłach z fluidalnymi złożami cyrkulacyjnymi (CFB). Dla kotłów tego typu, a także dla typowych kotłów pyłowych, kotłów z rusztem mechanicznym i palenisk domowych określono w drodze pomiarowej wskaźniki emisji pyłu całkowitego oraz charakterystycznych frakcji PM2,5 i PM10. Wskaźniki dotyczą spalania górnośląskiego węgla kamiennego