

## EMISSION FACTORS OF POLLUTANTS FROM THE COMBUSTION OF BROWN COAL IN DOMESTIC APPLIANCES

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### Abstract

Brown coal was combusted in four various types of combustion facilities. They were selected to represent four basic constructions solutions for hot-water boilers from the cost and technical construction point of view.. Concerning the basic qualitative parameters of the combustion process (CO and TOC), the decrease of the values of the emission factors of pollution substances was achieved with the use of modern combustion facilities by about two orders (e.g. for CO from values of approximately 100 g/kg to values of approximately 2 g/kg). The same trend was observed for PAHs (from values of approximately 50 g/kg to approximately 0.3 g/kg).

Values of stated emission factors of I-TEQ PCDD/Fs were lower for modern boilers than for boilers with older constructions, but in general the values of these stated EFs was low (about 0.05-1 ng/kg) compared with EFs used for balance calculations in the Czech Republic (6 ng/kg). Evidently, this is caused by the low content of chlorine in the fuel (40 mg/kg). The resulting emission factors show the possibility of decreasing of emissions by the use of modern types of combustion facilities.

### Introduction

In the Czech Republic, approximately 18 %<sup>1</sup> of households use solid fuels for domestic heating, in particular coal and wood. Solid fuels are mainly combusted in facilities with old constructions and resulting pollutants considerably affect the quality of air. Recently, there were found emission of pollutants originate from domestic appliances (related to total emission, from annual balances), as follows: PAHs about 66%, solid particles (denoted as PM10) 35%<sup>2</sup>, TEQ PCDD/Fs about 10 %<sup>3</sup>. These ratios may be even higher during the period of the heating season.

An emission factor (EF) is used as a quality parameter of particular pollutant. The EF expresses a representative amount of emitted pollutant in the given combustion facility under defined combustion conditions and used fuel. Brown coal was combusted in four various types domestic appliance with hot-water. Flue gases were diluted in a dilution tunnel<sup>4</sup>, where representative sampling were performed with respect to particular pollutants.

### Material and Methods

Experiments were performed on four various hot-water boilers (marked A to D), which represent different methods of combustion:

A – facility with old constructions – *burn through* method of combustion – manual, periodical load of fuel – flue gases pass through the whole layer of fuel,

B – facility with old constructions – *burn up* method of combustion – manual load of fuel – flue gases do not pass through the whole layer; a fuel gradually falls down into the area of the fireplace,

C – facility with modern construction – *burn up* method of combustion – automatic load of fuel by a conveyer – the combustion is performed in a torch area; the fuel is loaded in short time intervals (about tens of seconds),

D – facility with modern construction – gasification– manual load of fuel – flue gases do not pass through the layer of fuel; the fuel is gasified and than combusted in separate independent combustion chamber.

Brown coal was used with the size nut 1 (20 to 40 mm) from Severočeske Doly (see Table 1). It is the best-selling fuel of this type in the Czech Republic.

**Table 1** Analysis of the fuel used for combustion tests

Proximate analysis		Ultimate analysis	
Water <sup>r</sup> (wt. %)	27.5	C <sup>d</sup> (wt. %)	64,6
Ash <sup>r</sup> (wt. %)	4.2	H <sup>d</sup> (wt. %)	5.3
Volatiles <sup>r</sup> (wt. %)	68.3	N <sup>d</sup> (wt. %)	0.9
Ash <sup>d</sup> (wt. %)	5.8	O <sup>d</sup> (wt. %)	22.5
Combustibles <sup>d</sup> (wt. %)	94.2	S <sup>d</sup> (wt. %)	0.9
LHV (MJ/kg)	19.1	Cl <sup>d</sup> (mg/kg)	40

<sup>d</sup> – dry matter

<sup>r</sup> – raw matter

Sampling of gas emission (CO, NO<sub>x</sub>, SO<sub>2</sub> and TOC) was performed in the insulated chimney about 1 metre behind the combustion facility. Determination of CO, NO<sub>x</sub> and SO<sub>2</sub> was realised by IR method according to EN 15058 (CO), ISO 10849 (NO<sub>x</sub>), ISO 7935 (SO<sub>2</sub>), ISO 10396 (standard for sampling). Content of TOC was analysed by FID (EN 12619). Sampling of PCDD/Fs, PCBs and PAHs determination was realised according to the standardized procedure EN 1948. Sampling of PM was performed according to ISO 9096.

For representative sampling of PCDD/Fs, PCBs, PAHs and PM, the isokinetic conditions of sampling are very important. Therefore, target pollutants were sampled in the dilution tunnel where isokinetic conditions for sampling are more favourable. The dilution ratio of flue gases and air was about 1:5<sup>4</sup>.

### Testing conditions

All the above-mentioned facilities were operated according to the the instructions of the producers of the facilities. The average thermal outputs, temperatures of the flue gases with the specifications of experiments are stated in Table 2. Experiment A1 was characterised by products of incomplete combustion (max. CO values were up to 11 vol.%) and the sampling of flue gases for analyses was attended by massive complications. There was choking of filters (by tar). In experiments A2 and A3, the time of adding the fuel was shortened to 30 minutes. It is a non-standard operation of the facility which enables monitoring the influence of the shortened time of adding the fuel.

### Results and Discussion

Altogether, twelve combustion tests (duration of each : 3-6 hours) were performed on four hot-water boilers with one type of coal. In Table 2 there are stated emission factors of the monitored harmful pollutants for all 12 experiments.

Boiler A works with a significant feature of periodicity. In the first phase there is the heating and drying of the fuel, consequently volatile combustible is released and combusted, in the last phase there is the oxidation of de-gassed fixed carbon. These phases are not performed separately but are partially clashed. During the A1 experiment on facility A, the fuel was added for three hours of operation, during experiments A2 and A3 the fuel was added for a half hour operation of the facility in 30-minute intervals. It is possible to observe half-hour periods, e.g. from the curve of O<sub>2</sub>, CO, TOC concentrations in flue gases behind the boiler. By comparing the results from experiments A1, A2 and A3 we can see how important is the frequency of refuelling and generally the way of transportation of the fuel into the combustion chamber. Shortening of the period resulted in a four time decreasing of the production of CO, TOC and PAHs. The volume of produced PCDD/Fs (I-TEQ) was decreased to half and the PCBs volume remained unchanged.

The production of pollution substances on boiler B does not closely relate with the frequency of refuelling because the fuel is not added directly into the fireplace. The dose of fuel is transported to the fuel bin which is located above the combustion chamber but the flue gases do not pass through the fuel layer. The fuel is loaded to the fireplace by gravitation force during the combustion of fuel in the fireplace which is in the lower part of the filler. All the above-mentioned combustion phases run at the same time on a certain part of the fuel.

The fuel in boiler C also passes through the mentioned phases but the principal difference is in the frequency of the fuel supply into the combustion chamber. The fuel is transported from the storage tank by a worm conveyer from the bottom part into the area of the torch. The engine of the worm feeder is controlled by regulator which periodically connect and disconnect the operation of the feeder. The setting 12 s ON and 20 s OFF was used in the experiments. The production of harmful substances copies this frequency, however in relatively short time sections.

Facility D, similarly as facility B, does not depend too much on the frequency of adding fuel. The fuel is added into the storage bin which is located inside the boiler. The fuel is gasified with a restricted supply of air. The originated gas flows through the burner into a thermally insulated combustion chamber where it is mixed with the necessary volume of combustion air.

**Table 2** Basic data about the operation of the facility and emission factors of the main gas and selected organic elements of flue gases

indication of the boiler		A.			B.	C	D
type of boiler		old – burn through			old – burn out	modern – burn out	modern – gasified
indication of experiment		A1	A2	A3	B1, B2, B3	C1, C2, C3	D1, D2, D3
facility output	kW	22	12	15	23	24	34
fuel consumption	kg/h	8.1	4.4	5.1	5.7	5.9	8.0
temperature of flue gases	°C	240	180	210	190	260	310
O <sub>2</sub>	%	11.3	16.6	16.0	10.3	9.8	6.8
CO	mg/kg	200 000	59 000	57 000	86 000 ± 8 000	7 600 ± 530	2 800 ± 1800
NO <sub>x</sub> <sup>a</sup>	mg/kg	1 500	2 600	2 600	1 700 ± 41	3 900 ± 62	2 900 ± 310
SO <sub>2</sub>	mg/kg	7 500	6 400	7 000	7 800 ± 780	9 000 ± 150	8 000 ± 890
TOC	mg/kg	63 000	12 000	11 000	2 000 ± 41	160 ± 48	73 ± 38
TSP	mg/kg	38 000	10 000	10 000	6 100 ± 1200	880 ± 66	350 ± 44
PCBz <sup>b</sup>	ng/kg	- <sup>f</sup>	- <sup>f</sup>	- <sup>f</sup>	110 ± 9	33 ± 9	31 ± 10
PAH <sup>c</sup>	mg/kg	87 000	11 000	20 000	38 000 ± 490	210 ± 120	510 ± 310
PCB <sup>d</sup>	ng/kg	29	28	26	26 ± 3	8.4 ± 1	11 ± 3
I-TEQ PCB	pg/kg	24	23	17	15 ± 0.2	4.4 ± 1	5 ± 1
PCDD/F <sup>e</sup>	ng/kg	220	49	47	58 ± 9	6.5 ± 2	1.9 ± 0
I-TEQ PCDD/F	pg/kg	630	570	350	310 ± 32	73 ± 28	69 ± 13

<sup>a</sup> - NO<sub>x</sub> expressed as NO<sub>2</sub>; <sup>b</sup> - tetra to hexa CBz; <sup>c</sup> - sum of 10 PAH (fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, benzo(g,h,i)perylene, dibenzo(a,h)anthracene, indeno(1,2,3-cd)pyrene); <sup>d</sup> - sum of 14 PCB (PCB81, PCB77, PCB126, PCB169, PCB123, PCB118, PCB114, PCB105, PCB167, PCB156, PCB157, PCB189, PCB180, PCB170); <sup>e</sup> - sum of tetra to octa PCDD/F; <sup>f</sup> - not determined for matrix effects

Combustion facilities stated in Table 2 are classified from the “worst” to the “best” from the viewpoint of the production of pollution substances. EF of CO uniquely state the difference between combustion facilities (A >> B >> C ≈ D). The similar arrangement is also evident from comparing TOC, PM, PAH, PCB, I-TEQ PCB, PCDD/F and I-TEQ PCDD/F.

For EF of NO<sub>x</sub> the trend is opposite, more modern boilers (C and D) report higher EF than older type boilers (A and B). This fact is evidently stated by the origination of NO<sub>x</sub> originated by the oxidation of air nitrogen at higher temperatures in the combustion chamber of boiler.

Results confirm that modern constructions of boilers (C and D) manage to combust fuel more efficiently and with a significantly lower volume of harmful contaminants than boilers with an older constructions. This

comparison for the combustion of brown coal puts the facility D at the best position which works on the principle of the gasification of fuel and the consequent combustion of originated gas.

All here presented EFs of I-TEQ PCDD/F (50-1000 pg/kg) are noticeably lower than EFs used for annual balances (6000 pg/kg is used for brown coal).

It was evidently caused by the low content of chlorine in the fuel (40 mg/kg), but on the other side it is necessary to note that it was the widest used fuel which is combusted in these small combustion facilities.

The resulting emission factors show the possibility of decreasing emissions by the use of modern types of combustion facilities. The acquisition cost of these facilities is five times higher.

The combustion of coal in modern types of combustion facilities (burn out with the automatic transport of fuel and gasification boiler) was accompanied by an important decrease of the production of all monitored pollution substances with the exception of NO<sub>x</sub>. The results show the great potential of the improvement of the quality of air in the case of the replacement of old constructions of boilers (burnt through and burn out with the periodical transport of fuel) with new boilers.

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