Determination of emission factors for combusting solid fuels in residential combustion appliances

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Introduction

Combusting of solid fuels in small sources to air pollution utilized at residential heating represents a significant source of pollution in the Czech Republic (PM_{10} – 66%, PAU – 35%[5]). Emission balances utilize emission factors, but their published values differ more than by three digit positions[1]. Selecting this value affects results of emission balance in an essential way; according to our opinion, used emission factors are rather undervalued. Determination of emission factor for small combustion devices (up to 50kW) is a problem, being methodically very complicated and affected by many parameters. The representative isokinetic flue gas sampling on back of the boiler is hardly feasible; the method of dilution tunnel is thus used. Different values of defined emission factors back of the boiler refer to the influence of sampling point.

Emission balance in the Czech Republic

Emission sources in the Czech Republic are registered in "Emissions and air pollution sources registry" (REZZO). Data for the balance of large and medium pollution sources are predominately obtained from the continual measurement or periodically repeated measurements at these sources. The target category of air pollution sources, which are described in this contribution, represent small sources of air pollution, used at heating households and combusting solid fuels. The balance is based on calculations, using statistical data, climatologic information and emission factors[3].

Emission factor

Emission factor - is the value, expressing a medium amount of the monitored pollutant, formed during combusting the unitary amount of the given fuel in the given combustion device under defined conditions. The emission factor of monitored pollutants characterizes the particular combustion device under specific operation conditions with a specific fuel. The real value of emission factor is very variable, predominately depending on following factors:

- combusting device construction (combustion chamber, combusting air distribution, combustion /gasification type, fire-through and fire-off),
- the way of fuel stocking (continual, discontinuous),
- operation conditions of the combusting device (temperature in its combustion chamber, regulation of the combustion air, staff qualification),
- fuel properties (humidity, granulometry).

From facts mentioned above it implies, that defining one value of emission factor for one fuel is very problematic and balance results are influenced by a significant uncertainty. Values of actual emission factors were historically defined, but nowadays they have to be actualized and checked via the critical analysis.

Emissions from heating households and their share within the whole Czech production

The new legislative, regulating the area of air quality[4] accepted in 1991, caused decreasing the amount of produced emissions from large and medium air pollution sources in the essential way; this exhibits in the improved air quality. On the other hand, the problem of emission from small sources (household heating) was little resolved. The Czech grant policy (1993 – 1996) successfully supported exchanging the fossil fuels for nature gas. Its continually increasing price caused the recurrence of using cheaper solid fuels. This "return" can be seen within the heating season due to smoking chimneys and odor. Outputs regarding the yearly emission balance also demonstrate, that the small pollution sources share (in the whole pollution by some toxicants) is expressive, if not dominant. Compiled studies[5] speak on almost 66% share in the pollution by polycyclic aromatic hydrocarbons (PAH) and 35% share of primary particles PM_{10}, produced at heating households by solid fuels. Consistently increased concentrations of air pollutants (PM_{10} and $PM_{2,5}$) represent one of the most serious current problems in the area of air quality in the Czech Republic. This problem is naturally connected with POP emissions. The trend of increased share of small non-industrial sources in whole emissions is all-European. From the PCDD/F emission balance in 17 European states it implies, that only about 23% of PCDD/F emissions arose from non-industrial sources in 1985; small non-industrial sources produced 50-60% of all PCDD/F emissions in 2005[6].

Determination of small sources emission factors
Determination of the emission factor of SP, PCDD/F, PCB and PAH for combusting solid fuels in small sources of pollution represents a specific methodical area, due to the necessity to overcome some nonstandard conditions:
- the periodic – discontinuous fuel transport is used; the whole combustion process is periodic, dynamic - unstable combustion process,
- unstable pressure conditions in chimneys (depending on changes of the flue gas temperature),
- variable fuel consumption and varied amount of flue gases within the combustion period,
- variable concentration of pollutants within the combustion period,
- low flue gas velocities in the chimney (about 0,5 - 2m/s); problems with its specification and adjusting the isokinetic sampling,
- limited repeatability at combustion tests (system sensitivity due to external interferences, changing conditions),
- common operation conditions are very different from the situation at laboratory tests,
- POP can arise back of the sampling point in chimney (flue gas temperatures 200–500℃)
- various combustion devices,
- various fuels.

Due to specific conditions cited above it is obvious that adjusting the isokinetic sampling in chimneys is difficult and sampling not representative. One of possibilities how to resolve the problem is using the dilution tunnel - see Figure 1. The digester is situated over the chimney, exhausting all flue gases into the line. Gases are cooled and diluted by the surrounding air (the tunnel was constructed considering principles under EPA 5G and AS/NZS 4013:1999, CEN 27.9.2006). Conditions for isokinetic dilution in the tunnel (sampling point no.2) are more favorable than in the measuring section back of the boiler (sampling point no.1). Sampling pollutants back of the dilution point has following main advantages:
- flue gas velocities can be affected via adjusting the dilution ratio; velocities fall in better measurable values 4 - 6m/s. A good possibility to adjust the flue gas isokinetic exhausting,
- "cool" sampling is executed, so POP formation is neglected,
- sampled emissions are closer to real values, comprehending the possible chimney influence,

- water vapor concentrations in the dilution tunnel are by one digit position less than back of the combustion device; this simplifies the problem of dew-point and condensed water in the sampling equipment.

Combustion appliances and sampling methods
As the combustion device, the automatic hot-water boiler was used, utilizing the principle of lower fuel stoking (specific output 25 kW). The automatic boiler was chosen in order to minimize the combustion process instability. The six hour´s sampling was executed 2 hours after launching the appliance. As the fuel, the mixture of brown coal and grinded PVC (8 kg BC / 0,1 kg PVC) was used. PVC was added in order to increase forming POP matter. Sampling and quantifying amounts of PCDD/F, PCB and PAH was executed considering standardized methods in accordance with EN 1948 (filtration-condensation method). The request of these standards regarding the minimum velocity of flue gases was not observed in the measuring point no.1 (chimney).

Results and Discussion
Sampling was executed in 2 points (chimney and dilution tunnel, see Fig. 1) by two devices, working simultaneously. The distribution of tested agents between the solid and gaseous phase of combustion products (on filter) was ascertained in both sampling points. The low flue gas velocity in the chimney did not enable to adjust isokinetic sampling; the sampling representativeness is thus affected. We therefore suppose that values measured in the chimney are affected by a significant error and are not of a real relevance. Moreover, temperatures of flue gas in the chimney sampling point were about $260\pm50^{o}C$. From this fact it implies another possibility of POP formation back of the sampling point. From comparing emission factors, found in both point (Table 1), it implies:
- emission factors for particular pollutants are different,
- the value of PCDD/F emission factor (in dilution tunnel) is by 44% less than back of the boiler,
- the value of PCB emission factor (in dilution tunnel) is by 12% higher than back of the boiler,
- the value of PAH emission factor (in dilution tunnel) is by 31% higher than back of the boiler,
- the influence of sampling points regarding detected values of emission factors is considerable,
- the essential part of PCDD/F, PCB and PAH is bound with solid particles; the influence of non-isokinetic sampling back of the boiler can be considerable.

The exact explanation regarding the trend of changed emission factors for PCDD/F, PCB and PAH in the dilution tunnel / chimney is still obscure; the internal logic of such a behavior was not found. According to our opinion, one reason can be non-representativeness of the sampling point, i.e. the detected emission factor has no real sense. The latter reason can be the formation of further POP matter back of the sampling point. Considering the fact that the majority of monitored compounds are deposited on solid particles, the phenomenon can be explained by particles deposited on chimney walls. In order to identify reasons better, further experiments shall be executed. The balance of total outputs (observed agents from the combustion process, i.e. flue gases and fly-ash, deposited in chimneys) shall form their part.

Conclusion
Using the dilution tunnel in order to define emission factors for combusting solid fuels in residential combustion appliances seems to be a right way, however, having its specific effects. Defining the emission factors in a credible way is the problem, which is methodically complicated and needing further attention. Due to the fact, that values of EF in the Czech Republic can significantly affect balances of emissions, produced by using solid fuels in small combustion devices, it is necessary to follow this problem in future. Further research phases shall follow still unconsidered factors (effects of combustion devices, operation conditions, etc.).

References
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Figure 1: Dilution tunnel scheme with marked measuring points
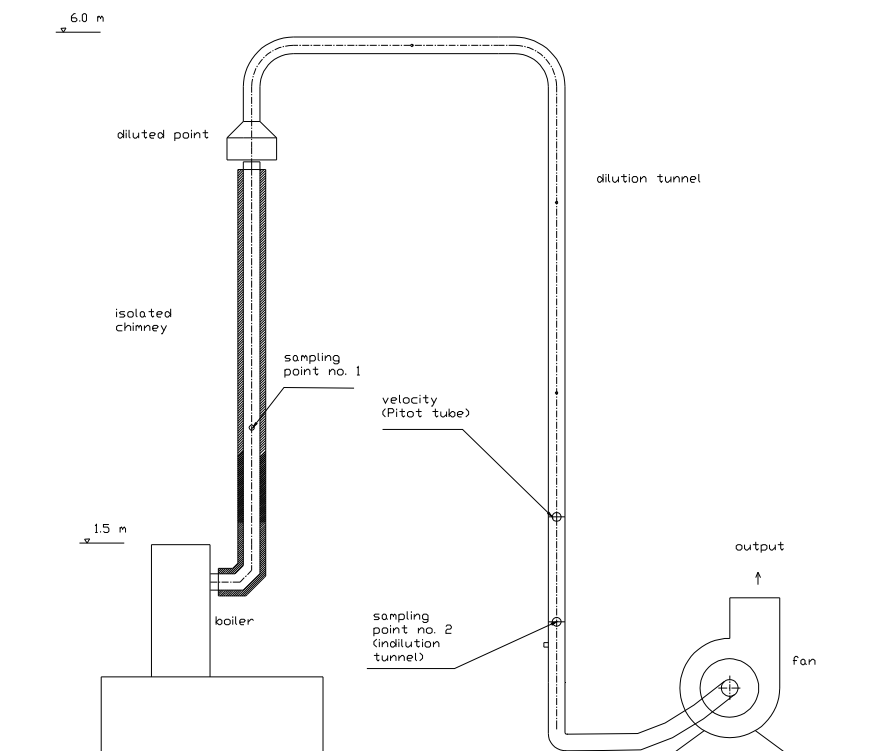
Table 1:   Resulting EF back of the boiler and in the dilution tunnel

emission factor		back of boiler (sampling point no.1)			in dilution tunnel (sampling point no.2)		
		on filter	on sorbent	total	on filter	on sorbent	total
PCDD/F	ng/kg	57,7	23,4	81,1	25,9	19,3	45,2
TEQ (PCDD/F)	ng/kg	7,15	3,94	11,09	2,96	2,85	5,80
PCB	ng/kg	20,5	20,3	40,8	14,7	30,9	45,6
PAU	µg/kg	141	136	278	199	164	363