CRITERIA POLLUTANT EMISSION FACTORS OF DOMESTIC THERMAL UNITS

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Domestic thermal units (DTU) combusting various solid and/or fluid fuels are significant source of air pollution. Their contributions to the air quality should be taken into account. Criteria pollutants emission factors are quite high and exceed those of huge fireplaces. Emission factors of CO, SO_2, NO_2, TOC, SPM and POP's for different fuels and appliances were calculated on the recently measured values. Those factors would be used for evaluation of a real impact of small appliances on the ambient air.

Keywords: criteria pollutants; DTU; emission factors

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1. Introduction

Residential combustion in domestic thermal units (DTU) is a major source of the ambient air pollution with potential health hazard [1-3]. Its impact to the local air quality was confirmed in numerous studies by different methods such as emission inventories, air quality data monitoring and modeling, and source-receptor transmission modeling [4-7]. However, the real operation mode of domestic solid fuel appliances was generally not considered in those evaluations. Recently used test methods for quality labels focus onto emissions during optimum operation on full load conditions. Furthermore, the national emission factors (*EF*) for DTU were generated from measurement trials primarily during stationary operation mode of DTU in optimal combustion conditions.

Pollutant emissions from DTU are mainly caused by incomplete combustion of fuel in the combustion chamber due to an inadequate mixing of air and fuel, an overall lack of available oxygen, too low over all combustion temperatures, non-homogeneous temperature distribution in the combustion chamber (cold zones), as well as too short residence times. The emission rates thus depend on operational practices that could differ significantly between appliances and firing staff.

The present work aimed to determine average *EF*s for DTU, solid fuels and firing behavior typical for Czech Republic. Some of those EFs were already published [8,9]. The work assessed the *EF*s of manual operated DTU investigating the influence of the fuel type and burning cycle mode on the emissions in order to support the new policy frameworks needed to lower the DTU emissions. Differently from the standard emission testing methods, user habits were simulated in a schematic way in the laboratory employing different combustion cycles representing a realistic user behavior. The experimental results were compared with the reference values determined using equal methods in huge power plant firing brown coal in Czech Republic and typical domestic natural gas firing boiler used in Czech Republic.

2. Experimental

Technical characteristics of four tested appliances are summarized in Table 1. A power plant data were added for comparison.

Tab. 1 Description of the tested appliances

Appliance (nominal heat output, [kW])	Fuel	Air regulation	Heat transfer
Stove (6.3)	Wood briquettes Coal I	Natural draft	Natural convection
Boiler DOR 24 (24)	Wood briquettes Coal II Brown coal briquettes	Manual	Water
Automatized boiler A25 (25)	Wood pellets Pellets (agriculture wastes) Wheat corn Oat corn	Automatic	Water
Gas boiler G27 (27)	Natural gas	Automatic	Water
Power plant* (135×10^3)	Brown coal	Automatic	Steam

* Fluid bed furnace equipped by a „dry” desulfurization unit.

Eight types of solid fuel (spruce wood pellets, pellets made from agriculture wastes and spruce sawdust and shavings, wheat and oat corn, brown coal briquettes, brown coal I from Czech Republic, brown coal II from Poland) were used for the feeding of manual and automatized appliances.

The main characteristics of tested fuels were determined using methods based on the international standard methods EN 15407:2011 for elemental analysis (C, H, N), ISO 587:1997 for chlorine content, EN 14918:2012 for net calorific value, EN 15414:2011 for moisture and ash content and EN 15980:2004 for sulfur content.

Aiming to be representative of the average user behavior, the „*real life*“ cycle has been defined as follows and was subsequently reproduced in laboratory for manual operated appliances:

- the ignition phase - load of a small amount of solid fuel (0.5 kg) keeping the air regulation valve completely open throughout the phase;
- after 20 min from the ignition, an amount of fuel equal to the nominal fuel load (defined by the manufacturer) was added and the air valve was partially closed;
- after 1 hour a second load was added;
- after another hour a final full load was added.

The duration of each load was limited to a maximum of 60 min; the fire has been stoked if necessary, not more than once in the time between one load and the following.

The *real life* combustion cycle of automatic appliances was monitored after 1 hour of appliance operation and lasts for 1 hour at nominal heat output.

In order to obtain a realistic evaluation of ambient air pollution due to tested appliances emissions and to measure the condensable particles produced by tested heating systems, the emissions sampling was performed in a stack fulfilling requirements of EN 15259. The appliances for solid fuels were placed on a scale to measure the weight variation and fuel consumption during the test period. The uncertainty of the weight measurement for the total fuel consumed during the test was less than 1% due to the scale resolution of 10 g.

A set of thermocouples was located in the combustion chamber and in flue gas duct to measure the flue gas temperature. The thermal outputs of tested appliances were measured using heat transfer circuit.

The flue gas extracted from the testing stack by means of heated probe at 180 °C was distributed in manifold to a selected set of flue gas analyzers: a flame ionization detector (Microfid, ABB); multicomponent flue gas analyzer for monitoring of NO/NO_x, SO_2, CO, CO_2 and O_2 (Horiba PG250, Horiba), and psychrometric Ultrakust (Bartec) for water vapor monitoring.

Total suspended particle matter emissions were measured for each test of solid fuel combustion according to EN 13284-1:2004 using *in-stack* filtration technique. Prebaked (3h at 800 °C) and pre-weighed 47 mm quartz fiber filters were used for all those tests.

Polycyclic aromatic hydrocarbons (PAH), polychlorinated dibenzodioxins (PCDD), and polychlorinated dibenzofurans (PCDD/PCDF) were measured according to the EN 1948-1:2006. Those pollutants were collected using the common sampling system (cooled probe technique). The system included a titanium sampling probe heated to 150 °C, a combined quartz fiber filter and polyurethane foam (PUF) filter to collect the particulate matter, a cooling system collecting at 4 °C condensable gaseous species and PUF to fix the released gaseous components. The filters and the PUF were extracted, treated and analyzed together with the condensate and rinsing solution by HRGC/MS using method based on EN 1948-2:2006, EN 1948-3:5006, and EN 1948-4:2010. A sampling standard addition of ^{13}C isotope marked standards was used for the extraction efficiency assessment.

A calibrated Prandtl tube type S in combination with the pressure transducers were used to measure the flue gas flow rate in the stack during all phases of combustion test. The actual density of the flue gas was calculated using known composition temperature, and static pressure characteristics of the flue gas in a measuring plane according to EN ISO 16911-1:2015.

The EF values may be estimated from average pollutant concentration and average flue gas volume flowrate in relation to the amount of fuel consumed (e.g. $g/kg_{dry\ fuel}$) or in relation to the energy input to the combustion process (e.g. g/MJ). While the method may work quite well with stable combustion process, assuming constant flue gas flow rate, deviations from the average emission factor calculated in this way may occur in batch combustion installations with variations among different combustion phases.

3. Results and discussion

The summary of the average EFs values of tested appliances is shown in Tab. 2 for gaseous pollutants and in Tab. 3 for condensed phase pollutants.

Average CO emissions relative to the solid fuel types and manually operated appliances are in the same order with a maximum difference of four times between spruce wood briquettes presenting the lowest and coal I the highest EF value. EF values for automatically operated DTU and huge power plant are of different orders of magnitude.

Tab. 2 Emission factors (kg/MWh) of gaseous pollutants related to effective energy output

Appliance	Fuel	CO	SO_2	NO_2	TOC	CH_4
Stove	Wood briquette	40.9	0.1	0.9	23.1	8.2
	Coal I	16.4	2.2	0.7	7.8	2.7
Boiler DOR 24	Wood briquette	10.7	0.1	0.4	0.8	0.6
	Coal II	10.0	0.6	0.5	5.8	1.1
	Brown coal briquette	26.5	0.8	1.0	8.7	5.6
Automatized boiler A25	Wood pellets	0.48	0.05	0.42	0.05	0.02
	Pellets (agric. waste)	3.1	0.38	2.7	0.2	
	Wheat corn	2.0	0.50	3.1	0.3	
	Oat corn	2.9	0.22	1.8	0.1	
Gas boiler G27	Natural gas	0.03	0.01	0.16	-	
Power plant	Brown coal	0.49	1.32	0.89	0.01	0.01

Tab. 3 Emission factors (µg/MWh) of condensed phase pollutants related to effective energy output

Appliance	Fuel	PM (g/MWh)	PAH	PCCD/F (µg/MWh)	PCB
Stove	Wood briquettes	1000	97	0.66	66
	Coal I	2200	444	1.48	123
Boiler DOR 24	Wood briquettes	200	57	0.11	24.7
	Coal II	2300	535	5.32	175
	Brown coal briquettes	1400	505	0.08	30.4
Automatized boiler A25	Wood pellets	380	57	0.11	24.7
	Pellets (agric. waste)	410	105	1.89	47
	Wheat corn	810	43	0.23	20.8
	Oat corn	230	37	0.18	18.4
Power plant	Brown coal	72	0.001	0.012	74.9

Emissions result for SO_2, NO_2, TOC, CH_4, PM and POPs are similar for DTU firing solid fuels. All pollutant EFs for gas burner and huge power plant are significantly lower.

Regarding the automatic appliances, better pellet quality (i.e. lower ash content) corresponds to lower incomplete combustion product emissions (i.e. CO and TOC) and higher NO_2 emissions due to higher combustion temperatures.

4. Conclusions

The impact of the parameters outlined in this study (e.g. fuel type, appliance type, combustion mode) on actual emission rates suggests the emissions of the batch working process are strictly related to the combustion mode and the treatment of solid fuel rather than the fuel type. General emission performance of the manually operated observed appliances do not to differ notably between different types of commercially available fuel.

It is known that the design of a heating appliance (i.e. primary and secondary air supply, stack dimensions etc.) directly influences the emission characteristics, however the reported results indicate that SO_2 and NO_2 emissions from the advanced appliance are similar or higher than the traditional appliances, and are only slightly lower for PM and PAH. Those finding highlight importance of the real-world emission factors in the evaluation of the environmental performance of the heating appliances.

Given results confirm the fact that a set of small appliances affects the surface layer of atmosphere more than huge plants.

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