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Emission factors of gaseous pollutants from small scale combustion of biofuels

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HIGHLIGHTS

- Emission factors from small scale biomass combustion were measured.
- Different load regimes and wooden and agricultural biofuels were tested.
- Definition of testing conditions must be present.
- Results are consistent in NO_x and SO_2 emission factors with literature.
- CO emission factors significantly differ.

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ABSTRACT

The paper presents results of determination of emission factors for CO, NO_x and SO_2 from combustion of wooden and various sorts of agricultural biofuels in a commercially available small scale pellet boiler. The emission factors (EF) were determined at three different power loads of the boiler and are presented in mass, LHV and utilizable energy form. The results show significant influence of operating conditions as well as conditions of the boiler itself. Comparison of the results with various literature data shown significant impact of the experimental procedure on CO EFs and turned out that definition of the experimental conditions is essential for relevance of the presented data. EFs for NO_x and SO_2 were found to be particularly affected by nitrogen and sulphur content in the biomass respectively.

1. Introduction

Small scale residential biomass combustion has been proved to significantly contribute to local quality of air. Therefore, it is important to be able to evaluate amounts of pollutants released into the atmosphere from these individual sources [1]. This is also important in relation to the proposed development of micro cogeneration units based on biomass combustion [2]. The emission limits for appliances above 500 kW of the power capacity are established and measurement of concentration of pollutants must be done either periodically or continuously. The Directive 2010/75/EU is the general document of the EU concerning the emission limits from stationary combustion sources and it sets the emissions limits for nominal power load capacities above 50 MW [3]. The power capacity range from 0.5 to 50 MW is currently covered by national legislations. The governing document for small scale combustion below 500 kW is the standard EN 303-5. This standard was introduced in 1999 and it was updated in 2012 [4]. The standard classifies the small scale boilers into the emission classes. The version EN 303-5:1999 defines emission classes 1–3, while in the updated EN 303-5:2012 are added the classes 4 and 5 and the classes 1 and 2 are removed. The emission limits for NO_x are not included in the EN 303-5 standard. They are currently included only in national legislation of Austria [5] for small scale boilers. The emission limits are set to 150 mg/MJ for wooden pellets and logwood (100 mg/MJ from 2015) and 300 mg/MJ for non-wooden standardized biofuels in automated feeding boilers. The standard EN 303-5 describes testing procedure that must be carried out for each type of the boiler before introducing on the market. Testing of the boiler is performed at nominal capacity load and lowered load at 30% of the nominal value while the limits given by the EN 303-5 must be met for the nominal capacity load. According to the 2012 update, the limits for PM must be met for both testing loads.

When the boiler comes to the market after the testing procedure, no further measurement of emissions is required during its

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List of symbols

C	carbon mass fraction in the fuel (kg/kg)	O	oxygen mass fraction in the fuel (kg/kg)
C_m^X	mass concentration of the component "X" (mg/m$_N^3$)	O_{2ref}	oxygen reference concentration (% vol.)
C_V^X	volumetric concentration of the component "X" (ppm)	O_{2meas}	measured oxygen concentration (% vol.)
EF_{mass}^X	mass emission factor for the component "X" (mg/kg)	p_{ref}	reference (normal) pressure (kPa)
EF_{LHV}^X	energy in fuel related emission factor for the component "X" (g/GJ)	R	universal gas constant (J/(mol K))
EF_{PE}^X	produced energy related emission factor for the component "X" (g/GJ)	S	sulphur mass fraction in the fuel (kg/kg)
H	hydrogen mass fraction in the fuel (kg/kg)	T_{ref}	reference (normal) temperature (K)
LHV	lower calorific value (MJ/kg)	V_{CA}	specific volume of combustion air (m$_N^3$/kg)
M_X	molecular weight of the component "X" (g/mol)	V_{FG}	specific volume of flue gas (m$_N^3$/kg)
N	nitrogen mass fraction in the fuel (kg/kg)	η_B	boiler thermal efficiency (–)
		λ	excess air ratio (–)

operation. An exception is Germany where a check of the CO and PM limits must be made every second year [6]. It is obvious that real levels of the emitted pollutants can be totally different from laboratory testing. The real emissions mostly depend on quality of fuel, way of operating the boiler and maintenance of the boiler. Therefore, it is difficult to make a reliable calculation of amount of the emitted pollutants in a certain urban area without knowing the real emission levels.

Using the emission factor is a way how to evaluate these levels of pollutants emitted from a combustion source if a direct measurement cannot be carried out, typically for domestic small scale boilers. Such a measurement is technically and legally complicated and also expensive. The emission factor is typically defined as the amount of a concerned pollutant emitted per the unit of burned fuel mass or per a defined task performed. This is often referred to the mass-based emission factor and has units such as g of a pollutant per kg of burned fuel. An alternative representation is done by the amount of a pollutant per MJ of calorific value of the fuel. Emission factors can be alternatively defined as the amount of emitted pollutant per some defined task performed. They can be called task-based emission factors [7,8] and can be expressed in different ways, e.g. amount of a pollutant related to a kWh of produced energy or to mass unit of a final product. When an emission factor is presented, it should be always accompanied by description of the testing procedure and by the conditions how was it obtained. If such an information is missing, the value of the emission factor cannot be considered as reliable.

In the literature, there can be found several studies that were aimed on measurement of the emissions factors from small scale biomass combustion, but results are quite different and there are only few references that involve features of operation of an automated domestic biomass boiler. If such a work is published, then it typically uses wooden pellets as the tested fuel. However, current trends in domestic heating show increase in using non-wooden biomass, typically agricultural residues and energy crops. A short overview of the published work is presented here and some of the interesting results are used for comparison in the Section 3. Authors [8] studied emission factors from wood and charcoal fired cookstoves that were manually fed by the fuel and obtained emission factors in mg/kg of fuel and g/MJ of useful heat energy. The publication by Ndiema et al. [9] was also focused on biomass stoves. In both references, biomass stoves, that are recently used only rarely for domestic heating, were used [10] and therefore do not have significant relevance for European conditions. Authors [11] studied emission factors from combustion of cereal residues, but the experimental work was carried out in a testing chamber in order to simulate an open fire, which does not correspond to the conditions in residential heating systems. The work by Wiinikka and Gebart [12] concerned a small scale pellet combustor and was focused particularly on emission of particulate matter. In addition, the authors evaluated emission factors for CO and NO_x given in mg per MJ of calorific value of the fuel. Wooden pellets were used in this case. The work published by Chinese authors [13] is very interesting by studying emission factors from combustion of various crop residues. However, the work was aimed at simulation of combustion in stoves for cooking in rural areas. In the work by Yuntenwi et al. [14] there were studied emission factors of CO and PM from biomass cook stoves. An extensive work was done with standardized pellets in both manual and automatically fed appliances with both wooden and non-wooden materials by Schmidl et al. [15], however, this work was focused particularly on PM emissions and measurement of gaseous pollutants was not converted to emission factors by the authors. A study focused on emissions from various kinds of pellet boilers in real operation regime was done by Win et al. [16]. All boilers used in this study were market available and soft-wood pellets were used for testing. The test comprised of start-up and stop phase with six days of operation between. However, no more information is provided concerning the condition of the boilers. The work by Johansson et al. [17] was also focused on pellet-fired boilers, where the authors compared modern and old-type boilers, again with wooden pellets. Probably the most recent and the most comprehensive work concerning several appliances and combustion cycles was done by Ozgen et al. [18], however using only wooden biomass. To the recent investigations also belongs work done by Amaral et al. [19], but this work was focused particularly on Amazon hard- and soft-wood batch combustion characteristic. Emission factors from small scale combustion are also published in the EEA emission inventory guidebook [20]. It is a comprehensive and for public available overview, but it lacks details about conditions at which the emission factors were obtained.

The work presented in this paper used a commercially available automatically fed 25 kW pellet boiler. Combustion tests were carried out for four different materials, including wood and non-wooden pellets, at three different power loads of the boiler. This approach aims at reflecting real operation conditions of a small scale boiler during the heating period. The emission factors were obtained for CO, NO_x and SO_2 related to mass unit of fuel, MJ of calorific value of the fuel and MJ of useful heat energy.

2. Materials and methods

2.1. Fuels and experimental set-up

Five different sorts of biomass fuels were chosen for evaluation of the emission factors – wood, rape straw and grain straw in the form of pellets, jatropha residues in the form of pressings and palm nut shells. Selection of the biomass sorts covers traditional wooden