COMPARISON OF THE FLUE GAS EMISSION VALUES OF A TRADITIONAL DESIGNED BIOMASS BOILER WITH THE SPECIFIED EMISSION STANDARDS

ERIKA FÁCZÁN – GÁBOR MEGYERI – TIBOR VOJTELA – ANDRÁS BÉRES

Abstract

Reducing emissions of various air pollutants is needed to achieve cleaner and healthier air quality in all EU countries. The National Air Pollution Reduction Programme sets out pollution reduction targets of 55% for particulate matter (PM), 73% for sulphur dioxide, 58% for non-methane volatile organic compounds and 66 % for nitrogen oxides, among other air pollutants, by 2030 compared to the 2005 reference year. The household sector is one of the areas most responsible for the emission of the main air pollutants linked to human activity. Within this, household solid biomass combustion is particularly important as a widely used heating method in Hungary. In this paper, we show how traditional boilers pollute the environment by measuring the results of a given boiler. Furthermore, the study describes how the specific boiler's air pollutant emissions and energy performance occurred. Finally, the research found that traditional boilers cannot meet strict emission standards, so their replacement and further development may be justified.

Keywords: *biomass fuel, combustion technology, air quality, emission limits*

HAGYOMÁNYOS KIALAKÍTÁSÚ BIOMASSZA KAZÁN FÜSTGÁZKIBOCSÁTÁSI JELLEMZŐINEK ÖSSZEHASONLÍTÁSA A MEGLÉVŐ KIBOCSÁTÁSI ELŐÍRÁSOKKAL

Összefoglalás

A tiszta és egészséges levegőminőség eléréséhez a különböző légszennyező anyagok kibocsátásának csökkentésére van szükség az Európai Unió tagországaiban. A Nemzeti Levegőszennyezés-csökkentési Program 2030-ra a 2005-ös referenciaévhez viszonyítva, több szennyező között, a szilárd részecskék (PM) 55%-os, a kén-dioxid 73%-os, az illékony (nem metán) szerves vegyületek 58%-os és a nitrogén-oxidok 66%-os csökkentését tűzi ki célul. A háztartási szektor számít az egyik leginkább felelős területnek az emberi tevékenységhez kapcsolódó főbb légszennyező anyagok kibocsátásáért. Ezen belül, a háztartási szilárd biomassza égetése különös figyelmet igényel, mivel Magyarországon széles körben alkalmazott fűtési módnak számít. A kutatási anyag ismerteti egy adott háztartási kazán mérési eredményein keresztül hogyan alakul a légszennyező anyagok kibocsátása és hogyan változnak a berendezés energetikai jellemzői. Összefoglalóan a vizsgálat eredményeiből megállapítható, a hagyományos kazánok nem tudnak megfelelni a szigorú kibocsátási előírásoknak, ezért cseréjük és további fejlesztésük javasolt.

Kulcsszavak: *biomassza tüzelőanyag, tüzeléstechnika, levegőminőség, kibocsátási határérték*
JEL kód: *Q16, Q53*

Introduction

In the Eastern European region, including Hungary, pollutant emissions from household solid fuel devices play a significant role in the emission of certain air pollutants. Polluted air can damage human health, flora and fauna, and even the built environment, with high costs to society. Air pollution can affect people in various ways, through unpleasant odours, discomfort, irritation of the mucous membranes of the airways, asthma attacks, cardiovascular disease, chronic lung diseases and deaths from malignant cancers. Furthermore, once air pollutants enter the respiratory tract, they can reduce defences against infections and increase the risk of developing allergies (WHO, 2021). In particular, industrial activity, energy production, the residential sector, agriculture, waste management and transport play a significant role in air quality. Whereas in the past industrial activity, today, mainly the residential sector – including household solid fuel combustion – transport and agriculture are responsible for the emissions of the main air pollutants linked to human activities (DOBI et al., 2020). Changes in air quality in extreme cases – like smoke- area immediately perceived by everyone, but the tiny solid and liquid components of the particulate matter are mostly hidden, they become visible only when they settle (SOHRAB et al. 2022). Among the emitted substances in the case of household solid fuel devices, there is also a high level of small particles (aerosol, PM1, PM2.5, PM10, particles smaller than 1 micrometer, 2.5 micrometers and 10 micrometers in diameter). PM originates partly from natural and anthropogenic sources, and the way it is generated strongly influences its composition and particle size (PM10 CSÖKKENTÉSI PROGRAM WEBOLDALA; PM10 CSÖKKENTÉSI PROGRAM, 2017). The issue of the size limit of PM is an important factor because the health impact of larger particles is an order of magnitude smaller, as they get caught in the filters of the respiratory system and do not reach the lungs. However, long-term inhalation of suspended particles can cause serious health damage, and these respiratory diseases are the third most common cause of death in the European Union (EU) (SOHRAB et al. 2022).

To fight air pollution and achieve the EU's 2050 vision of a pollution-free future, the EU's overall clean air policy is based on three pillars: ambient air quality standards, reductions in air pollutant emissions and emission standards for major pollutant sources. Air pollution is a transboundary problem that requires international cooperation, so the European Union has created the National Emissions Ceilings (NEC) directive, which aims to reduce emissions of certain air pollutants. Member states must develop and then implement a programme on a schedule to meet their emission reduction commitments. These requirements are implemented in Hungary within the National Air Pollution Reduction Program (OLP) framework. By 2030, small particle emissions should be reduced by 55%, sulphur dioxide emissions by 73%, ammonia emissions by 32%, nitrogen oxides by 66% and non-methane volatile organic compounds by 58% compared to 2005 (EC, 2016; MINISTRY OF AGRICULTURE, 2020).

The air quality directive of the European Union 2008/50/EC applies the average health limits for PM10 from 2005: Annual: 40 µg/m3; Daily: 50 µg/m3 (can be exceeded a maximum of 35 times in a year). The summary evaluation of the 2020 small aerosol particle sampling program of the National Air Pollution Measuring Network shows that the annual average concentration of PM10 did not exceed the health limit value at any sampling point. However, looking at the 24-hour average values, it can be seen that the measured values were much higher during the heating period than outside it (24-hour health limit value of 50 µg/m3) (OMSZ, 2021). Therefore, PM10 emissions have been on a slightly decreasing trend since 2015. However, household heating was responsible for 55% of PM10 emissions, a significant amount, as other sectors were significantly below this level in 2018 (HOI, 2020). Thus, the exceedances were mainly residential heating and transport, but meteorological conditions can also lead to adverse pollution trends. Overall, compared to the average values for 2019, there was a decrease of 25 measuring points and an increase of 6 (OMSZ, 2021). Unfortunately, there was no decreasing trend in PM2.5 emissions. In 2018, 81% of this pollutant came from residential combustion (HOI, 2020). Also, the National Air Pollution Measuring Network's 2020 sampling programme states that the annual health limit for PM2.5 is 25 μg/m3. None of the seven sampling points exceeded the annual limit (OMSZ, 2021).

Hungary's air quality status shows a slowly improving trend and is increasingly becoming the focus of interest (DOBI et al., 2020). To make the issue of air quality more and more prominent, it is important to examine household combustion equipment in terms of air pollutant emissions since a significant part of the final energy consumption used by the population, 70%, was used for heating households in 2019 (MEKH, 2021; KSH, 2021) and approximately 31,44 % of this was wood (REISZ et al., 2019).

Since the perfect combustion of solid fuels is more difficult to achieve in household devices than in power plants, the specific pollutant emissions are much higher (EC, 2021). This applies, in particular, to manual devices and poorly controlled automatic devices. Emissions resulting from partially imperfect combustion are mainly the result of insufficient mixing of combustion air and fuel in the combustion chamber, general lack of available oxygen, too low temperature and short residence time. When household combustion units are used, the following pollutants are released into the atmosphere, which are partly due to imperfect combustion: sulphur dioxide (SO2), nitrogen oxides (NOx), carbon monoxide (CO), dust (including small particles: PM2,5, PM10), polycyclic aromatic hydrocarbons (PAHs), non-methane volatile organic compounds (NMVOCs), dioxins, furans, benzopyrene (EUROPEAN ENVIRONMENT AGENCY, 2019). For example, in Hungary, 29 % of carbon-dioxide emissions, 85% of carbon-monoxide emissions, 21 % of nitrogen oxides emissions, 63 % of PM10 emissions and 87 % of PM2.5 emissions came from domestic combustion in 2017 (MENTES, 2019).

By burning firewood as efficiently as possible, we can reduce the amount of wood used, thus achieving economical, environmentally friendly operation, and significantly reducing emissions. (TÓVÁRI et al., 2014; BÉRES, 2021). The more environment-friendly operation and perfect combustion can be achieved in one device, the fewer harmful emissions we have to count on. Unfortunately, most household solid fuel units in Hungary are obsolete (EHI, 2022), and the additional problem is that most users are not aware of the rules of proper, environmentally friendly operation, although more and more information is now available. In addition, combustion conditions (e.g., fuel, ignition technique, air supply) have a vital role in emissions (MENTES, 2019). Therefore, the modernization of household combustion equipment is a particularly important task in order to achieve air quality goals, as significant efforts are needed to implement the emission reduction obligation set for 2030. In our study, we would like to show how commercially available conventional boilers are polluting and why there is a need to improve and replace them since they cannot meet the latest emissions requirements.

Material and methods

During the test measurements, the flue gas emissions of a household biomass boiler, including carbon dioxide, nitrogen oxides, carbon monoxide and oxygen concentrations, as well as the emissions of particulate matter and the energy characteristics of the equipment were determined. The measurements were carried out in the Accredited Laboratory Examination for Energetics of the University Laboratory Centre of the Hungarian University of Agriculture and Life Sciences in Gödöllő (Hungary). For the tests, a commercially available boiler (40 kW) with a traditional design was used with regular barkless beech-wood (1. table). The tests were conducted according to the MSZ EN 303-5-2013 with a small modification.

The flue gas test was carried out with an ENVIRO (Advance Optima Uras 14, Advance Optima Magnos 16) flue gas analyser and a KS-404 isokinetic dust sampler. The measuring method of the gas analyser complies with the standard MSZ EN 14789:2017 for oxygen measurement, MSZ EN 15058:2017 for carbon monoxide measurement, MSZ EN 21853-19:1981 for carbon dioxide measurement and MSZ EN 21853-9:1991 for nitrogen oxide measurement. In addition, the measurement method for particulate matter sampling shall comply with ISO EN 13284-1:2018. Oxygen was measured by paramagnetism, carbon monoxide, carbon dioxide and nitrogen oxides by infrared absorption and particulate matter by manual gravimetric method. The energy characteristics of the combustion system were determined with a KRONE UFM610P ultrasonic flow meter and two RHODIUM Pt100 thermometers.

All measuring instruments are regularly calibrated and have a valid calibration certificate. Before the measurements, a "basic ember" was created, and the fuel material, sufficient for one hour, was placed on it. Measurements started immediately after the fuel was loaded and were sampled twice for 30 minutes.

Table 1. ***Characteristics of firewood used for measurement***

Beech-wood sample		
Moisture [%] (at measurement)		9,34
Ash [%]	wet	0,22
	dry	0,25
Higher Heating Value [MJ/kg]	wet	17,561
	dry	19,370
Heating value [MJ/kg]	wet	16,162
	dry	18,078
N [%]	wet	0,068
	dry	0,075
C [%]	wet	45,338
	dry	50,009
S [%]	wet	0,055
	dry	0,061
H [%]	wet	5,369
	dry	5,922
O_2 [%]	wet	39,604
	dry	43,684
Cl [%]	wet	0,002
	dry	0,003

Results and discussion

The results of the flue gas measurements are presented in Table 2. The emission results show that a traditional design boiler cannot perform the latest emission requirements.

The data showed that the limit value for carbon monoxide was exceeded by almost six times, for nitrogen oxides, there was no exceedance and for particulate matter, by less than twice.

The oxygen concentration in the flue gas was almost half of the optimum 10% for the components without limit values. This and other data indicate that the combustion process was inadequate, and that more oxygen was needed. The air supply of the firebox must be improved and developed to make the combustion process more efficient. Improving the mixing of combustion air and fuel in the chamber decreases the amount of air pollutants.

Table 2. Comparison of the measured flue gas emission values and the EU regulation

components with limit values		
components (converted to 10 % oxygen content)	measured value	2015/1189 EU regulation
CO (mg/m^3)	4055,05	700
NO_x (mg/m^3)	59,11	200
Particulate matter (mg/m^3)	108,63	60
components without limit values without conversion		
O_2 (%)	5,81	-
CO_2 (%)	14,29	-

Table 3 shows the specific values per hour, which gives us information about the emission of pollutants in the light of the delivered energy. Data from table 3 show that carbon monoxide and particulate matter specific values (g/GJ) were higher than what can be calculated from the maximum allowed values. This increase in the case of carbon monoxide is 5,8 times, and in the case of particulate matter is 1,8 times. This also showed how environmentally polluting an old-design boiler is.

Table 3. Specific values per hour

Component		Concentration (mg/m^3)	Concentration (kg/m^3)	Volume flow (m^3/h)	Emission (kg/h)	Heat out-put (kW)	Heat output (kWh)	Specific value (g/GJ)
Measured values	CO	4055,05	0,004055	2,05	0,0083128	35,57	17,79	0,0001168
	NO_x	59,11	0,000059		0,0001212			0,0000017
	PM	108,63	0,000109		0,0002235			0,0000031
Regulation values	CO	700	0,0007		0,001435			0,0000202
	NO_x	200	0,0002		0,00041			0,0000058
	PM	60	0,00006		0,000123			0,0000017

The specific values were calculated with the following equation:

$$\frac{\text{CO/NO}_x\text{/ Particulate matter (g)}}{\text{heat output (kWh)x0,004}}$$

Conclusion

It is self-evident that reducing air pollutants is necessary to slow down climate change, decrease global warming and protect people's health. Improving and replacing boilers with traditional designs is necessary to achieve this goal. Our investigation has shown that a boiler with a traditional design did not meet the strict requirements. It is, therefore, necessary to replace old, obsolete boilers and develop new, more efficient ones with better combustion air supply. Besides, the low oxygen levels in the flue gas meant that the combustion air supply had to be improved to allow better mixing of air and fuel. One solution could be to feed combustion air at several points.

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Authors

Erika FÁCZÁN
Corresponding author
University student
Hungarian University of Agricultural and Life Sciences, Institute of Environmental Sciences
H-2100 Gödöllő, Páter Károly utca
faczan.erika@stud.uni-mate.hu

Dr. Gábor MEGYERI
Head of Laboratory
Hungarian University of Agricultural and Life Sciences, University Laboratory Centre
2100 Gödöllő, Tessedik S. u. 4.
megyeri.gabor@uni-mate.hu

Tibor VOJTELA
Test engineer
Hungarian University of Agricultural and Life Sciences, University Laboratory Centre
2100 Gödöllő, Tessedik S. u. 4.
vojtela.tibor@uni-mate.hu

Dr. András BÉRES
Head of Centre
Hungarian University of Agricultural and Life Sciences, University Laboratory Centre
H-2100 Gödöllő, Páter Károly utca
beres.andras@uni-mate.hu