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Biomass combustion emissions

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Abstract

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The paper deals with gaseous emissions generated in biomass combustion in water boilers. It provides results of analyses of gaseous emissions and boiler efficiency in combustion of branches of apple trees from spring pruning, spruce cuttings and corn cobs obtained from kernel harvest. Measurements were done in laboratory conditions. Average CO emission values observed in combustion were from 334.7 to 650.18 mg/m^3 and average NO_x emission values were low, between 50.1 and 157.2 mg/m^3. Boiler efficiency in applewood combustion was lower – this was caused by its higher moisture.

Keywords: CO; NO_x; heat production; boiler efficiency

At present, household biomass boilers, which burn mainly logs and wood chips, are again becoming widely used. Small boilers for central heating for individual households are more widespread in temperate regions and usually have a nominal output between 10 to 50 kW. They use different types of solid biomass usually depending on their regional availability. It is important to observe emissions from smaller combustion installations due to number of such installations, their various types of combustion techniques, and range of efficiencies and emissions. „Generally large combustion units, with carefully monitored combustion control form low levels of pollutants whereas small units with poor mixing, poor instrumentation and no control tend to result in high levels of pollutants." (Williams et al. 2012)

Fuel combustion is the process of oxidation of the fuel by means of atmospheric oxygen resulting in intense releasing of heat, which is, in turn, efficiently utilised. The combustion produces combustion products – flue gases, solid combustion products and heat (Mikolaj, Kažimírová 2009).

The complete combustion of wood produces emissions of carbon dioxide (CO_2), nitrogen oxides (NO_x) and fine particulates, whereas the incomplete combustion of wood results in the release of volatile organic gases, much higher levels of particulates, carbon monoxide (CO) and other undesirable substances, some of which are carcinogenic. The emission of black smoke from a chimney is a visible sign of incomplete combustion. Dzurenda et al. (2005) and Jandačka et al. (2008) dealt whit quantitative representation of the components in dry and wet flue gas from the combustion of wood.

Emission from biomass largely depends not only on the composition of the biomass, but also on the technology used in combustion. The water contained in the fuel constitutes the primary factor that significantly influences the work of the combustion equipment (Malaťák, Passian 2011). The moisture content of wood depends on the type of wood and the amount of drying prior to combustion. Typical values for moisture content include 60% for green wood, 55% for wet hog fuels, 30% for hogged scrap wood from sawmills, 10% for planer shavings and sawdust from dried wood, and 4.5% for pellets (Beauchemin, Tampier 2008).

The goal of the observations was to establish the concentration of gaseous emissions generated in the process of heat production by direct combustion of various types of biofuels in a low output boiler.

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MATERIAL AND METHODS

Apple branches, spruce chips and corn cobs were used for combustion. A muffle furnace Nabetherm L9/11/SW (Nabertherm GmbH, Lilienthal, Germany) with heating device power of 3.0 kW was used in the measuring of moisture, combustible matter, and ash contents. The muffle furnace was equipped with a Controller P 320 (Nabertherm GmbH, Lilienthal, Germany) control unit and digital scales Kern EW 420-3NM (Kern & Sohn GmBb, Balingen, Germany) with the accuracy of ± 0.001 g.

Observations were done in laboratory conditions. Standard hot water boiler Rojek 25m (Rojek dřevoobráběcí stroje a.s., Častolovice, Czech Republic) was used. According to the information provided by the manufacturer, this model is intended for solid fuel combustion, including biomass in the form of briquettes, chips and lump wood. Its rated output is 20 kW.

Gaseous emissions were measured using flue gas analyser Testo 330-2 LL (Testo AG, Lenzkirch, Germany). The device can also measure other combustion parameters, such as air ratio, flue gas temperature, combustion air temperature, flue gas loss and boiler efficiency.

Before the beginning of the observations, the heating system was brought to stable operating state, in which the heating water temperature on the outlet was 55°C. Flue gas analyser probe was placed into the beginning of the duct system, at 750 mm from the boiler's flue gas outlet. Concentrations of CO, CO_2, NO and NO_x were measured. Values of emissions (mg/m^3) are adjusted to O_2 reference point, which is set to 11% for biomass.

RESULTS AND DISCUSSION

Values of used fuel moisture are listed in Table 1, together with other results of gravimetric analysis.

Applewood combustion measurements

The results of measurements done during the combustion of branches from spring pruning of an apple orchard are listed in Table 2. Due to the higher moisture of the wood during combustion, increased amount of gaseous emissions of CO, harmful for the environment, was observed. The increased moisture also affected the boiler efficiency, which only reached the value of 66.33%.

Spruce chips combustion measurements

Results of measurements of emissions and boiler's operating parameters, done during the combustion of spruce wood chips, obtained as a waste from carpentry production, are listed in Table 2. Values of CO_2, NO and NO_x emissions observed were slightly higher than in applewood combustion, while the value of CO was slightly lower. Boiler efficiency in spruce chip combustion was higher, reaching an average value of 72.33%.

Corn cob combustion measurements

Results of measurements of emissions and boiler's operating parameters done during the combustion of corn cobs, obtained after kernel harvest, are listed in Table 3. Value of CO emissions observed was higher than in applewood, but the values of CO_2, NO and NO_x emissions were lower. Boiler efficiency was the highest observed, amounting to the average of 73.87%.

Measured values of gaseous combustion emissions are presented in Fig. 1.

The average values of observed parameters were as follows: amount of CO emissions was the highest in corn cobs (650.1 mg/m^3) and lowest in spruce chips (334.7 mg/m^3). CO_2 values were the highest in spruce chips (6.02%) and lowest in corn cobs

Table 1. Results of gravimetric analysis of observed biomass

Parameter	Apple branches	Spruce chips	Corn cobs
Moisture of original sample (g/g)	0.2747	0.1431	0.1208
Ash content (g/g)	0.0419	0.0453	0.0601
Combustible content (g/g)	0.6834	0.8116	0.8191
Ash content in dry mass (g/g)	0.0578	0.0529	0.0684
Combustible content in dry mass (g/g)	0.9422	0.9471	0.9317

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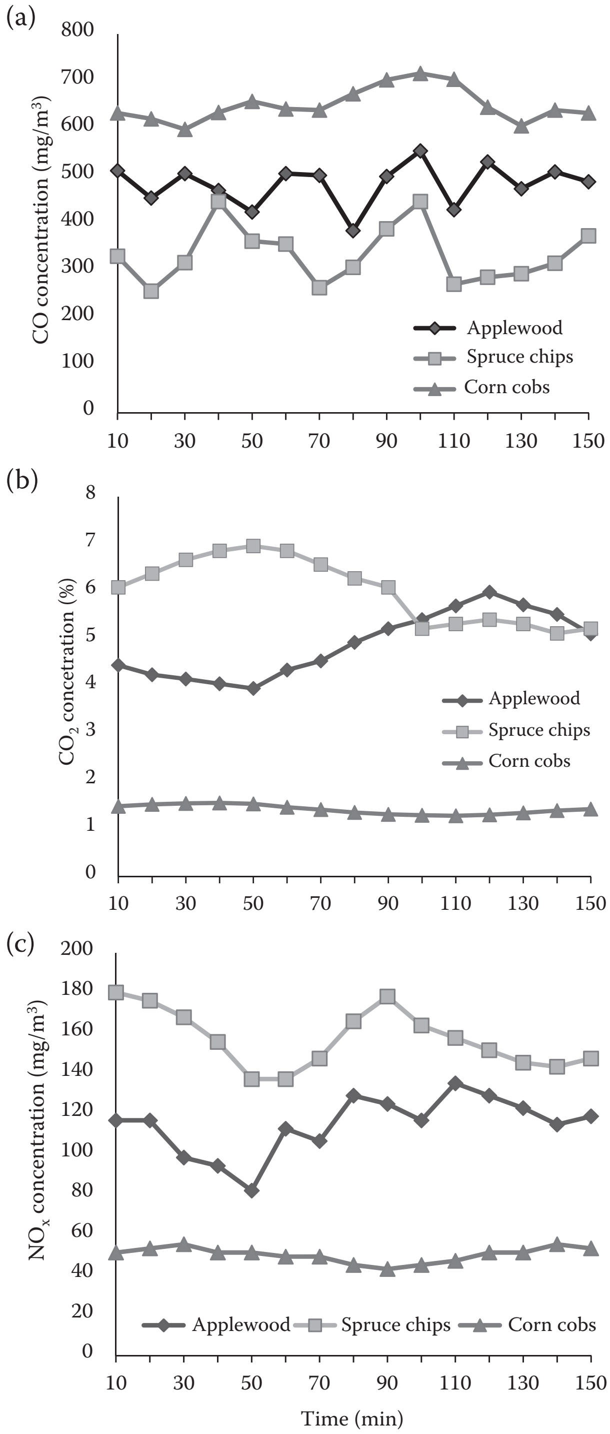

Fig. 1. CO (a), CO_2 (b) and NO_x (c) concentration in flue gases

(1.41%). NO and NO_x values were highest in spruce chips (96.4 mg/m^3 and 157.2 mg/m^3, respectively) and lowest in corn cobs (31.0 mg/m^3 and 50.1 mg/m^3, respectively).

Emissions limits for fuel combustion devices are set by Resolution of Ministry of Agriculture and Rural Development of the Slovak Republic No. 356/2010 Coll., executing selected provisions of Act on air.

For devices containing boilers that were granted permission to operate since January 1, 2011 that perform biomass combustion, Resolution sets the limits for devices with rated thermal input of 0.3 MW to 50 MW as follows: 350 mg/m^3 for NO_x and 250 or 150 mg/m^3 for CO, depending on input interval.

In case observed, taking the low boiler output, Resolution does not set specific emission limits, though it states that in boilers with rated thermal input under 0.3 MW, only pure, uncontaminated natural wood, mechanically treated according to manufacturer's instructions, can be used for combustion. This includes lump wood, briquettes, chips, pellets, or other natural biomass treated for fuel use according to manufacturer's instructions, such as straw or reed.

This means that there was no need to uphold any specific limits of gaseous emissions in observations done. In comparing observed values of emissions with limits set for boilers with rated input of 0.3 to 50 MW, it can be seen that NO_x emissions from combustion of none of the observed materials exceeded the limits. Limit for CO emissions, however, was exceeded in all three observed materials, with lowest concentration in spruce chips and highset in corn cobs.

According to Resolution of Ministry of Economy of the Slovak Republic No. 548/2008 Coll., which establishes the procedure for regular revisions of boilers, efficiency of boilers with rated input under 100 kW in biomass combustion shall be at least 71%. Such value was observed in corn cobs, where the boiler efficiency was 73.87% and in spruce wood chips, where the boiler efficiency was 72.33%

Vitázek et al. (2014) provides results of gaseous emissions concentration measurements gathered in detached house heating done by means of wooden biomass combustion. According to this study, the most suitable fuel for the boiler observed is firewood, CO emissions of which were several times higher than values observed in our research, but NO_x emissions were comparable with the values observed. The issue of biomass combustion emissions, whether form wood or pellet combustion, have previously been discussed by several authors (Johansson 2004; Liu et al. 2013; Ozgen et al. 2014). Comparisons of results confirms that emission values of these materials differ in dependency on the type of wood only to a minimal extent, with quality of pellets having a more significant impact on emission values.

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Table 2. Emissions and boiler's operating parameters measurements done during applewood and spruce chips combustion

Measurement No.	Emissions concentration				Air ratio (–)	Boiler efficiency (%)	Air temperature (°C)	Flue gas temperature (°C)
	CO (mg/m^3)	CO_2 (%)	NO (mg/m^3)	NO_x (mg/m^3)				
Applewood combustion								
1	511.68	4.45	71.28	116.85	4.57	68	20.1	289.7
2	453.87	4.25	71.28	116.85	4.77	69	20.1	215.8
3	505.53	4.16	60.72	98.40	4.88	71	20.2	202.6
4	469.86	4.06	58.08	94.30	5.00	64	20.4	234.0
5	424.35	3.96	50.16	82.00	5.12	70	20.1	245.5
6	505.53	4.35	68.64	112.75	4.67	65	19.8	300.4
7	501.84	4.54	66.00	106.60	4.47	63	20.1	286.2
8	384.99	4.93	79.2	129.15	4.12	64	20.1	278.1
9	499.38	5.22	76.56	125.05	3.89	67	20.3	308.2
10	553.50	5.41	71.28	116.85	3.75	65	19.8	312.8
11	429.27	5.70	83.16	135.30	3.56	64	20.1	318.3
12	530.13	5.99	79.20	129.15	3.39	67	20.3	315.1
13	473.55	5.72	75.24	123.00	3.42	63	20.2	313.5
14	509.22	5.52	69.96	114.80	3.48	68	20.1	297.6
15	488.31	5.11	72.60	118.90	3.87	67	20.1	287.7
Average	482.73	4.89	70.22	114.66	4.19	66.33	20.12	280.36
Spruce chips combustion								
1	330.87	6.09	110.88	180.40	3.33	67	23.7	272.6
2	257.07	6.38	108.24	176.30	3.18	71	24	285.3
3	317.34	6.67	102.96	168.10	3.04	68	23.9	252.0
4	446.49	6.86	95.04	155.80	2.96	77	24	271.5
5	362.85	6.96	84.48	137.35	2.92	80	23.9	258.5
6	356.70	6.86	84.48	137.35	2.96	73	25.4	289.0
7	264.45	6.57	91.08	147.60	3.09	69	25.4	298.2
8	307.50	6.28	101.64	166.05	3.23	67	25.4	354.3
9	388.68	6.09	109.56	178.35	3.33	69	25.3	247.2
10	446.49	5.22	100.32	164.00	3.89	72	25.5	286.2
11	271.83	5.32	96.36	157.85	3.82	68	25.4	277.2
12	286.59	5.41	92.40	151.70	3.75	70	25.5	270.2
13	293.97	5.32	89.76	145.55	3.82	75	25.4	229.9
14	316.11	5.12	88.44	143.50	3.96	78	25.4	192.7
15	373.92	5.22	91.08	147.60	4.04	81	25.5	165.8
Average	334.72	6.02	96.45	157.17	3.42	72.33	24.9	263.37

CONCLUSION

Biomass is currently considered to be a renewable energy source with great potential. Biomass combustion can be used for heat production, electricity production, combined heat and electricity production, as well as a gaseous or liquid fuel in transportation.

This paper states the observed amounts of gaseous emissions production in combustion of three types of waste biomass. Average CO emission values observed in combustion were from 334.7 to 650.18 mg/m^3 and average NO_x emission values were low, between 50.1 and 157.2 mg/m^3. Boiler efficiency in applewood combustion was lower – this was caused by its higher moisture. From the results it can be gathered that waste wood mass resulting from orchard pruning and chemically untreated spruce wood waste from carpentry production are, in terms of gaseous emissions production, suitable

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Table 3. Results of emissions and boiler's operating parameters measurements done during corn cob combustion

Measurement No.	Emissions concentration				Air ratio (–)	Boiler efficiency (%)	Air temperature (°C)	Flue gas temperature (°C)
	CO (mg/m^3)	CO_2 (%)	NO (mg/m^3)	NO_x (mg/m^3)				
1	633.45	1.48	31.68	51.25	2.32	79	25.6	153.5
2	621.15	1.52	33.00	53.30	2.31	78	25.6	155.2
3	599.01	1.54	34.32	55.35	2.13	78	25.5	155.4
4	634.68	1.55	31.68	51.25	3.30	78	25.6	154.6
5	658.05	1.53	31.68	51.25	2.14	75	25.7	152.8
6	642.06	1.46	30.36	49.20	2.40	76	25.7	150.8
7	639.60	1.41	30.36	49.20	2.61	74	25.8	147.2
8	674.04	1.35	27.72	45.10	3.16	71	25.9	143.3
9	703.56	1.31	26.40	43.05	2.76	72	25.9	141.7
10	717.09	1.29	27.72	45.10	2.15	77	25.9	142.2
11	704.79	1.28	29.04	47.15	2.14	70	26.0	144.2
12	645.75	1.30	31.68	51.25	2.10	69	25.9	146.4
13	606.39	1.34	31.68	51.25	2.63	71	26.0	148.5
14	639.60	1.39	34.32	55.35	2.53	70	25.9	151.2
15	633.45	1.42	33.00	53.30	2.10	70	25.9	152.3
Average	650.18	1.41	30.98	50.16	2.45	73.87	25.79	149.29

and affordable fuel for small heat producers, especially households.

Biomass is an inexhaustible energy source, its main advantages being sufficient heat value and low ash content, environmental friendliness, and affordability. The amount of CO_2 released in biomass combustion does not exceed the amount consumed by plant growth. Therefore, biomass is, in terms of greenhouse gases production, neutral energy source and can be economically and – if proper combustion conditions are provided – also ecologically suitable local energy source for heat production in rural areas.

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