



Particulate matter from combustion of different types of dendromass in small fireplace

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Introduction

The combustion of solid fuels causes formation of emissions and particulate pollutants at different concentrations. It is necessary to reduce the amount of pollutants to acceptable levels (Cernecky et al., 2010). Obtaining long-term ambient data in areas that are polluted from large industrial sources, it was found the increase of substances that contribute to changes in the atmosphere. This involves small combustion installations in homes where they are burned different types of solid fuel (Chudikova et al., 2011).

From the combustion chamber of boiler are solid particles entrained with flue gas stream and they are now the most watched emissions. (Labaj et al., 2010)

Today is the greatest attention paid to the size of particles (aerodynamic diameter) less than 10 μm (PM₁₀), which may penetrate into the respiratory tract. Particles of this fraction are divided into two groups based on different sizes, the mechanism, the composition and behavior of the atmosphere. (Jandacka et al., 2011)

The first group is made up of particles of size below 2.5 μm (fine respirable fraction - PM_{2,5}), arising from chemical reactions nucleation, condensation of gaseous emissions generated at the surface of particles or coagulation of the finest particles. Their main sources are coal, fuel, wood, chemical production, transformation NO_x and SO₂ in the atmosphere (nucleation) and the conversion of organic matter. The basic composition of these substances is dominated by sulphates, nitrates, ammonium, elemental carbon, organic compounds and metals. These particles remain in the atmosphere for a long time, which allows them to transport long distances in air flow.

The second group create particles in the range of the size from 2.5 to 10 μm (coarse fraction – PM_{2,5} to 10). These particles formed by mechanical abrasion (crushing, grinding surface) and swirling of dust. Their main sources are the various industrial dusts in mining in quarry industry, construction activities, transport, land management, and so on. This fraction also includes various biotic particles such as bacteria, pollen, plant particles. (Skala & Ochodek, 2007)

Finest particles with a diameter below 2.5 μm (PM_{2,5}) are considered to cause the greatest harm to human health. They deposit deep in the lungs and block the reproduction of cells. This can generate suitable conditions for the development of viral and bacterial respiratory infections, as well as the gradual transition of acute inflammatory changes in the chronic phase creation chronic bronchitis.

The solid particles are entrained with flue gas stream from the combustion chamber of boiler and are now one of the most watched emissions (Urban et al., 2013). Particulate matter (PM) consists of soot, inorganic matter (ash) and organic matter

(non-volatile flammable). (Jachniak & Jagus, 2012) Particles are imported into the flue gas by ash, non-volatile and combustible soot.

Various types of wood have different composition and properties such as calorific value, ash melting temperature, which greatly affects the production of PM (Dzurenda, 2005). In this work, experimental measurements were carried out, focused on the formation of PM during combustion of different types of dendromass in a small heat source.

Methodology for measuring particulate matters

There are many methods for determination of PM during fuel combustion in boilers. Methods for measurement of pollutant emissions can be carried out for particulate matters and gaseous substances. Available methods for measuring solid emissions are based on basic fluid properties. (Soos et al., 2012)

Gravimetric method is the manual single method with sampling of the flow gas by probe. It is based on determination of the median concentrations by sampling from multiple points of measurements cross-section and their subsequent gravimetric assessment. Solid contaminants are usually separated by an external filter.

Representative sampling is performed by sampling probe suitable shape and the correct speed under isokinetic condition (Mihalov & Carnogurska, 1999).

The cumulative collection can provide in the cross section average concentration but not concentration profile. Flow velocity, or flow of the sample gas is measured by ensuring of isokinetic, for example by aperture track and a total collected amount of gas by gas meter. The principal scheme of a gravimetric method is shown in fig. 1.

The advantage of the gravimetric method is its simplicity. In particular, mutual reproducibility and comparability of measurement results regardless of the type of device, the air flow, type of filter material, the suction speed etc.

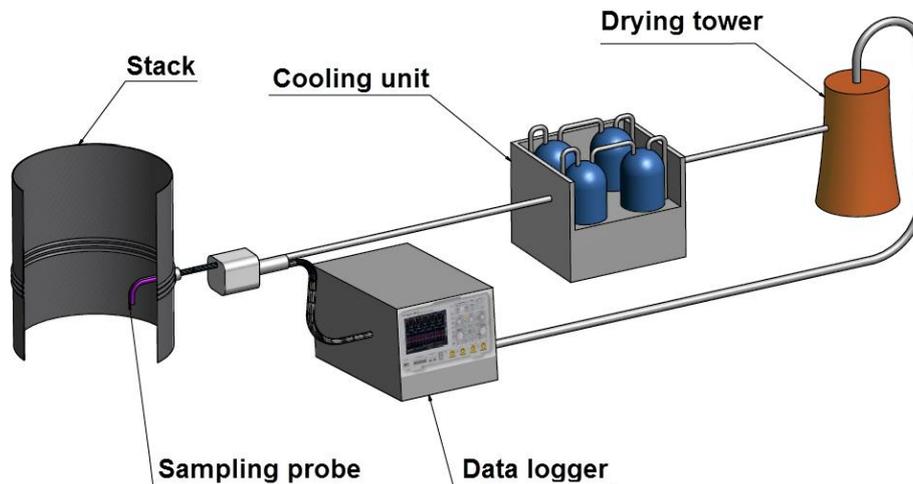


Fig. 1 Scheme of gravimetric method

Representative sampling is performed by sampling probe with suitable shape and the correct speed under isokinetic condition

$$w_{s,j} = w_i \rightarrow c_{s,j} = c_i$$

which sets requirements that the sampling speed was at the mouth of the probe $w_{s,i}$ [$\text{m}\cdot\text{s}^{-1}$] identical with speed w_i [$\text{m}\cdot\text{s}^{-1}$] flow gas. Then the concentration at the mouth of the probe $c_{s,i}$ [$\text{g}\cdot\text{m}^{-3}$], is identical to concentration in a stream c_i [$\text{g}\cdot\text{m}^{-3}$]. Isokinetic sampling conditions are achieved by controlling the exhaust flow (Ochodek et al., 2007).

Concentration of particulate matter in the flue gas is covered to standard conditions and can be determined for wet, respectively for dry flue gas. Measured volume of sample taken on the volume gas meter should be converted to standard conditions, i.e. pressure 101325 Pa and temperature of 273.15 K (0°C). Therefore, the temperature and pressure of measured sample is measured before gas meter.

The conversion of the measured volume by gas meter (V^W) at the time (τ) to standard conditions is calculated on the basis of the relationship (Jandacka et al., 2011)

$$V_{(n)}^W = V^W \cdot \frac{p}{101325} \cdot \frac{273,15}{T} \quad [(\text{n})\text{m}^3]$$

where p is the absolute pressure at the inlet of flow meter [Pa], T is absolute temperature at the inlet of flow meter [K].

If the concentration should be converted to a wet state (wet flue gas), then the total extracted volume is determined by the relationship (Jandacka et al., 2011)

$$V_{c(n)}^W = V_{(n)}^W \cdot \frac{m}{0,804} \quad [(\text{n})\text{m}^3]$$

where m is the mass of the collected condensate from the condenser at time τ [kg]. Concentration of corresponding to the real volume of wet flue gas will then be (Jandacka et al., 2011)

$$c_{(n)} = \frac{\Delta m}{V_{c(n)}^W} \quad [\text{mg}\cdot(\text{n})\text{m}^3]$$

where Δm is the weight gain of the filter in time τ [mg].

Weight of the filter with capture sample will determine in exactly the same procedure as before by measuring its weight (drying and subsequent weighting). If the concentration should be based on a dry basis, then it is necessary to reduce the amount of volume $V_{(n)}^W$ containing saturated water steam corresponding to the state p , T according to the following relation (Jandacka et al., 2011)

$$V_{(n)}^S = V_{(n)}^W \cdot \left(1 - \frac{p_p''}{p}\right) \quad [(\text{n})\text{m}^3]$$

where p_p'' is partial pressure of saturated steam at a temperature (T) found from steam tables.

Concentration corresponding to the real volume of sucked dry flue gas is (Jandacka et al., 2011)

$$c_{(n)}^S = \frac{\Delta m}{V_{(n)}^S} \quad [\text{mg}\cdot(\text{n})\text{m}^3]$$

Experiment methodology

As the heat source was used fireplace with rated power 6kW, which can be seen in fig. 2. At the bottom of combustion chamber is topped with grate and under is the container where the ash falls. Access to the combustion chamber is through the doors that are glazed with high heat resistant glass. During the combustion of the fuel door must always be closed in order to prevent the rapid burning of fuel and overheating of device.

Dust sampling was performed 5 minutes after the start of experimental measurement and sampling duration lasted 30 minutes. Sucked volume passed sampling probe - three-stage separator impactor - with three filters where particles are separated by size to PM_{<10}μm (particles with larger size than 10 μm), PM₁₀ (particles with size between 2,5 μm and 10 μm) and PM_{2,5} (particles with lower size than 2,5 μm). The amount of collected particles was converted into gas sample volume. Mass of the collected PM is found so that after sampling all the captured particles were dried and weighed.

During experimental measurement of all samples were determined also production of carbon monoxide (CO) and nitrogen oxides (NO_x). Production of CO and NO_x was determined by emission analyzer and these values were written by using of logger to personal computer in interval of 20 seconds in accordance with the works of Orzechowski & Orman (2006) and Vitazek et al. (2011, 2013).



Fig. 2 Experimental small fireplace

During the experiment, the different types of wood were tested. Every measurement lasted 1 hour and was burned to about 1,5 kg of fuel. There were used the following types of wood for the experimental measurements that are listed in tab.1.

Tab. 1 Calorific value and humidity of used types of wood

Type of fuel	Calorific value [MJ.kg ⁻¹]	Humidity [%]
Birch with bark	18,1	18,15
Birch without bark	19,2	17,21
Beech	17,5	7,64
Spruce	19,3	7,87

Results of experiment

Formation of emissions is largely influenced by type of fuel that is burned in heat source. Every fuel has different properties and chemical composition, which ultimately affects the combustion process, the amount of actual emissions and ash content. During the experimental measurements were secured the same combustion conditions, i.e. uniform supply of primary, secondary and tertiary air, the same pressure in chimney (12 Pa) and a maximum dose of 1.5 kg of fuel.

Measured concentrations of each type of emissions have been converted to a reference oxygen value ($O_{2ref} = 13\%$). From converted measured values of each emission were calculated average values of emission production.

Time course of production of CO is on fig. 3. The lowest production of CO was measured during combustion of beech where average production of CO was 473,25 mg.(n)m⁻³. The highest production of CO was measured during combustion of spruce where average production of CO was 1820,6 mg.(n)m⁻³. Average production of CO was 905,45 mg.(n)m⁻³, resp. 916,25 mg.(n)m⁻³ during combustion of birch without bark, resp. birch with bark. All these values are under emission limit (2000 mg.(n)m⁻³) in accordance with standard EN 13240. Values of production of CO during combustion of birch (with and without bark) and beech also meet the standard DIN Plus standard for stoves (production of CO must be lower than 1500 mg.(n)m⁻³). (Lazic et al., 2009)

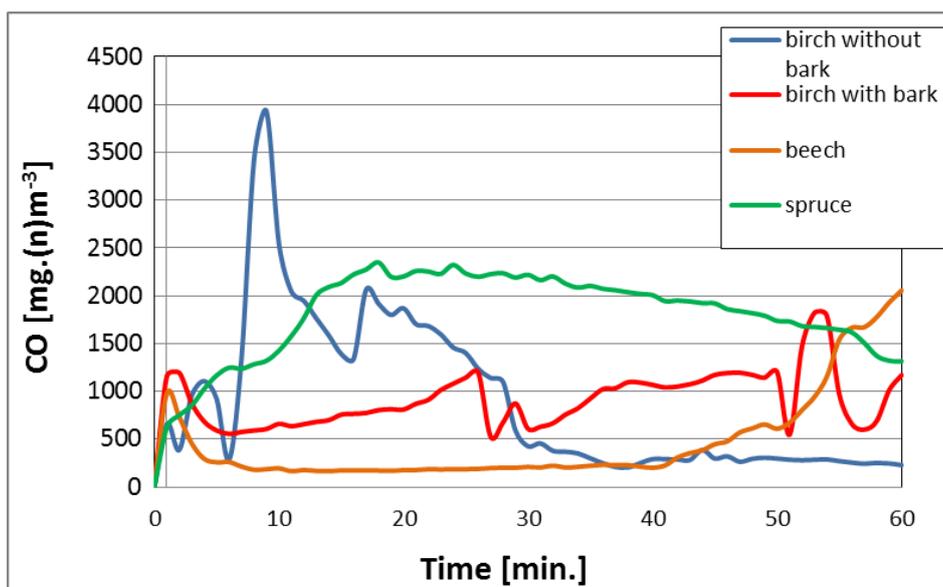


Fig. 3 Time course of production of CO

Time course of production of NO_x is on fig. 4. The lowest production of NO_x was measured during combustion of spruce where average production of NO_x was 6,53 mg.(n)m⁻³. The highest production of NO_x was measured during combustion of beech where average production of NO_x was 45,85 mg.(n)m⁻³. Average production of NO_x was 34,97 mg.(n)m⁻³, resp. 17,98 mg.(n)m⁻³ during combustion of birch without bark, resp. birch with bark. All these values are under emission limit (200 mg.(n)m⁻³) in accordance with standard EN 13240.

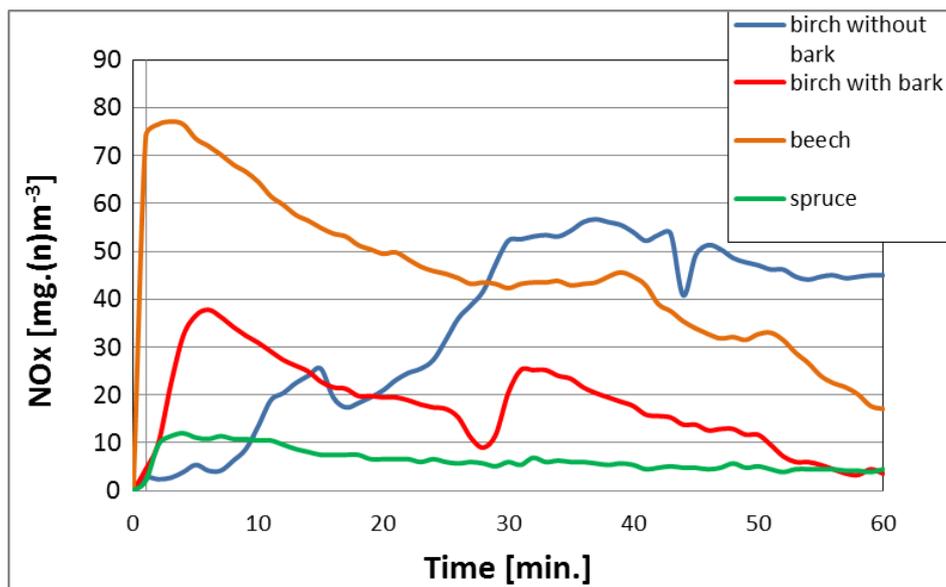


Fig. 4 Time course of production of NO_x

Particulate measurements were conducted on all types of wood for 30 minutes. During this time, the individual samples collected PM that were captured the filter. These were subsequently stripped of moisture and weighed. Concentrations of particulate matter were determined by difference weight of all three filters (PM<10 μ m, PM10 and PM2,5) before and after the measurement.

Production of PM is shown on fig 5. The highest amount of particulate matter was observed in measurements of birch with bark, where total production of PM was 113,44 mg.(n)m⁻³. The lowest amount of particulate matter was observed in measurements of birch without bark, where total production of PM was 45,77 mg.(n)m⁻³. Total production of PM during combustion beech, resp. spruce was 95,11 mg.(n)m⁻³, resp. 82,05 mg.(n)m⁻³. All these values except birch without bark exceed the emission limit 75 mg.(n)m⁻³ in accordance with standard EN 13240 and DIN Plus standard for stoves.

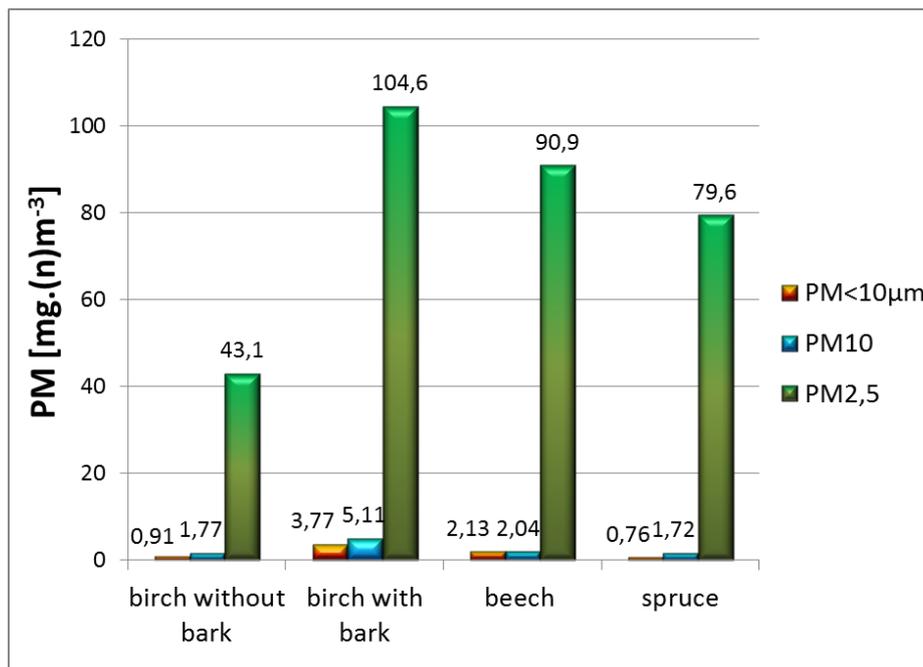


Fig. 5 Production of PM

Conclusion

Problematic of production of emission especially production of PM during combustion in small domestic fireplaces is very important today and these devices must be certified before using. Emission limits are increasingly stringent and common fireplaces do not meet them and it is necessary look for a solution to decrease production of emission especially production of PM.

The results of this work showed that it is very important what fuel, concrete what type of dendromass, is used. These results can be compared with results of other authors like Wieser & Gaegauf (2000) or Bäfver (2011) or Meyer (2012).

In this concrete work was birch without bark chosen like best dendromass fuel. For combustion of birch with bark, beech and spruce in tested fireplace is necessary use some filter or device for decreasing of PM production and compliance with the emission limit for PM production.

It is necessary look for some solutions of decreasing of PM production during combustion of dendromass and other fuels because particulate matter can be very dangerous for human life.

Acknowledgement

This work is supported by the financial assistance of the project ITMS 22410320106.

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