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IMPACT OF THE COMBUSTION AIR DISTRIBUTION ON PM PRODUCTION IN WOOD STOVE

Michal Holubčík – Nikola Kantová – Radovan Nosek – Jozef Jandačka

ABSTRACT

The combustion leads to pollution of the atmosphere. One of the most watched emissions from combustion processes is particulate matter. These emissions are considered to cause the greatest harm to human health. They are dangerous for human when they are inhaled. The article deals with particulate matter and options for reducing these emissions. It examines the impact of the combustion air distribution on production of particulate matter in wood stove. The air supply to particulate matter is also followed by CFD simulations. Such measurements as well as modelling showed a positive contribution of inlets for distributing combustion air in combustion chamber of wood stove.

Keywords: particulate matter, emissions, biomass combustion.

INTRODUCTION

Approximately 14% of global energy is obtained from biomass (OLSON 2006; DEMIRBAS 2005). There is still a world support for the use of biomass as a source of heat and energy. Renewable energy sources are one alternative to fossil fuels. One reason is the reduction of SO_2 and NO_X in the atmosphere. Despite of this, biomass produces also emissions, as mentioned in the work (ESKILLSSON *et al*. 2004; OLSON 2006; YAO *et al.* 2009; WEBER *et al.* 2012; MARTINÍK *et al.* 2014; PAPUČÍK *et al.* 2014; DZURENDA 2015; HRONCOVA *et al*. 2016; JANDAČKA *et al*. 2016; DZURENDA *et al*. 2017). Air quality impacts the state of the environment, human health, as well as the various ecosystems. A considerable part is used for heating in the local heat sources, such as fireplaces or stoves. Creating thermal comfort in these devices is accompanied by a considerable environmental burden. The main emissions after combustion are CO, NO_X, SO_2 and particulate matter (PM). The emission values of CO are from 100 to 5000 $mg \cdot m^{-3}$. It depends on the method of combustion. Automatic heat sources have the greatest efficiency and open fireplaces have the lowest efficiency. The emission values of NO_X are from 100 to 400 $mg \cdot m^{-3}$. It depends mainly on the type of boiler and the temperature in the combustion chamber. Biomass has the minimum emission values of SO_2, because content of sulphur in the biomass is insignificant. Coal can contain maximum emission values of SO_2 about 1000 $mg \cdot m^{-3}$. The emission values of PM are maximum to 150 $mg \cdot m^{-3}$ (EN 303-5, 2012; JANDAČKA *et al.* 2016*a*). It depends on the method of combustion, type and moisture of fuel, quantity, temperature and velocity of the combustion air, etc.

Particulate matter or PM is a mixture of substances consisting of carbon, dust and aerosols. We meet with the concepts of: particulate matter (PM), solid aerosols, hard aerosols, airborne dust. They are a mixture of substances consisting of carbon, ammonium, metals, organic materials, nitrates and sulphates (YAO *et al.* 2009). Based on size, we distinguish two main groups of particulate matter. PM10 is the coarse fraction, which contains the larger particles with a size ranging from 2.5 to 10 μm. PM2.5 is the fine fraction, which contains the smaller ones with a size up to 2.5 μm. The particles in the fine fraction which are smaller than 0.1 μm are called ultrafine particles. We also know particles with coarser fraction than PM10 (WHO 2013).

With the aim of minimizing the production of particulate matters and improving air quality, there are used different methods to reduce emissions (ĎURČANSKÝ – JANDAČKA 2015). To the equipment producing particulate matters is to be added different filters and separators. These implementation and operation can be considerably difficult on finances, and moreover, often have complex maintenance. There are looking for solutions of reduction the producing of particulate matter with easier maintenance and also less financial difficulty (CHABADOVÁ *et al.* 2014).

The aim of this work is to present analyses of the impact of the combustion air distribution on PM production in wood stove.

MATERIAL AND METHODS

Small heat sources have a different design. Heat sources of simpler design combust fuel supplied to primary air. They are simple devices with lower efficiency and larger production of particulate matter. Heat sources of sophisticated design have secondary air supply and even some of them have tertiary air supply, see in Figure 1. Primary air supply is solved through the heating grate towards fuels. The primary air is important for the evaporation of water from the fuel and also for the release combustible gases. The secondary air ensures complete combustion of residual combustible gases. Without secondary air supply, these gases would be left unused in the combustion gases to the chimney, which it would result in a lower efficiency of the heat source and larger fuel consumption.

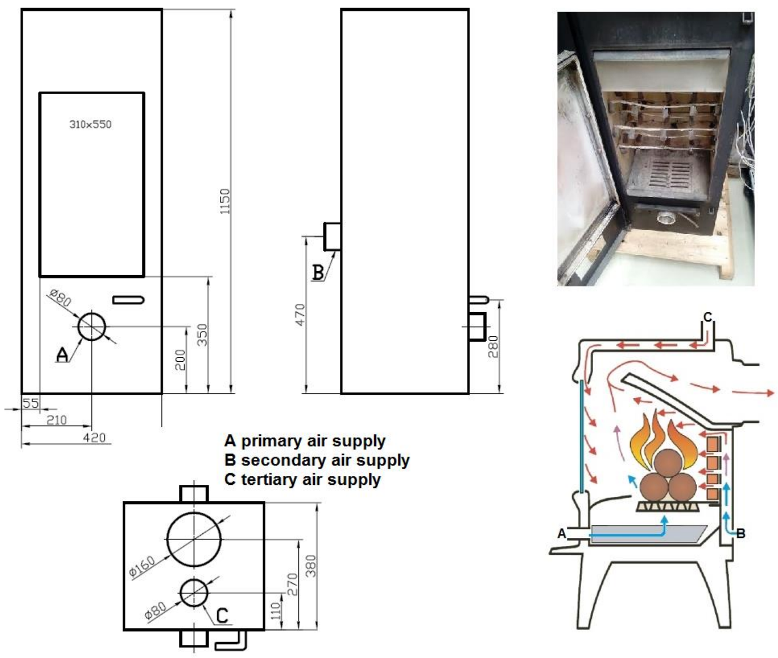

Fig. 1 Wood stove with three types of air supply.

The tertiary air is used for blowing glass front. It also contributes to complete combustion. The supply of tertiary air is pre-heated supply air to the combustion chamber, because of the rest of unburned residual gases and carbon monoxide (CO) (JANDAČKA *et al.* 2016*b;* SOOS *et al.* 2012).

Experimental measurement examines the impact of the air supply to particulate matter which is taken with supply air from the furnace. The samples were obtained from the combustion of wood chips from spruce wood in boiler with moving grate. The samples of PM were collected from the electrostatic precipitator for combustion of biomass. These samples correspond with the particulate matter, which take away from the heating grate and flow to outlet from small biomass heat source into flue gas tract. Size distribution of these samples made by vibratory sieve shaker machine showed that the largest amounts of PM were in the size range 50–100 µm and then 20–50 µm, see in Figure 2.

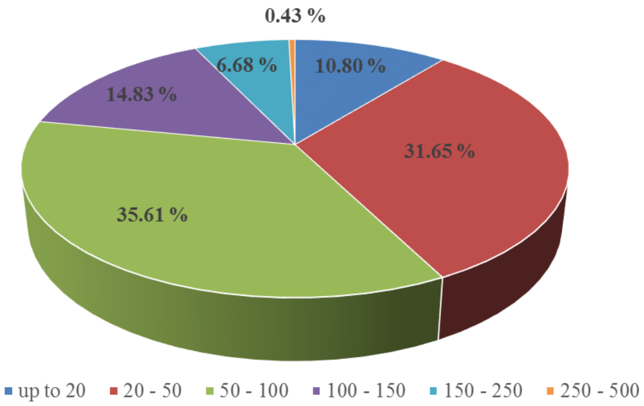

Fig. 2 Particle matter size distribution.

For the measurement was designed and constructed the experimental model of wood stove to scale 1:3, see in Figure 3. The measurement was realized coldly without the need for combustion. It was used the surrounding air with temperature of 20 °C, relative humidity of 40% and atmospheric pressure 1021 hPa. The model of wood stove consists of two plexiglas plates with dimensions of 100 × 100 × 2 mm, which form the upper and lower part of the prism, and four plates with dimensions of 100 × 170 × 2 mm, which form the remaining parts. These parts were glued together. In the parts of prism were successively drilled holes for air supply. On the front part, there are drilled two holes with diameters of 7 mm. On the back part, there are drilled 24 holes with diameters of 3 mm. On the top wall, there are drilled three holes with diameters of 4 mm. The model also includes plexiglas tubes with a diameter of 50/46 mm, siphon tubes and elbows, filter, reduction of 50/32 mm and an anemometer to measure the speed of particulate matters. Geometric similarity was observed with a scale of 1: 3 compared to the real wood stove with a measuring track during the implementing the model.

There were realized the three types of measurements. The first measurement contained a primary air supply with two holes on the front part of prism. The second measurement contained primary and secondary air supply with two holes on the front part and 24 holes on the back part of prism. The third measurement contained primary, secondary and also tertiary air supply with two holes on the front part, 24 holes on the back part and 3 holes on the top part of prism. On the anemometer, it was reached a speed of 15 m s^{-1}. Measurement also serves to determine the decrease in the quantity of PM in the furnace and increase their weight in the filter. In the furnace, there was set a sample of PM with weight of 1 gram with an accuracy of ± 0.002 g. Turning on the vacuum source to the required speed was for 30 minutes. Then the samples were weighed.

All measurements were realized 3 times and the results are average values. During the measuring, there were not reported unusual events which could influence the results.

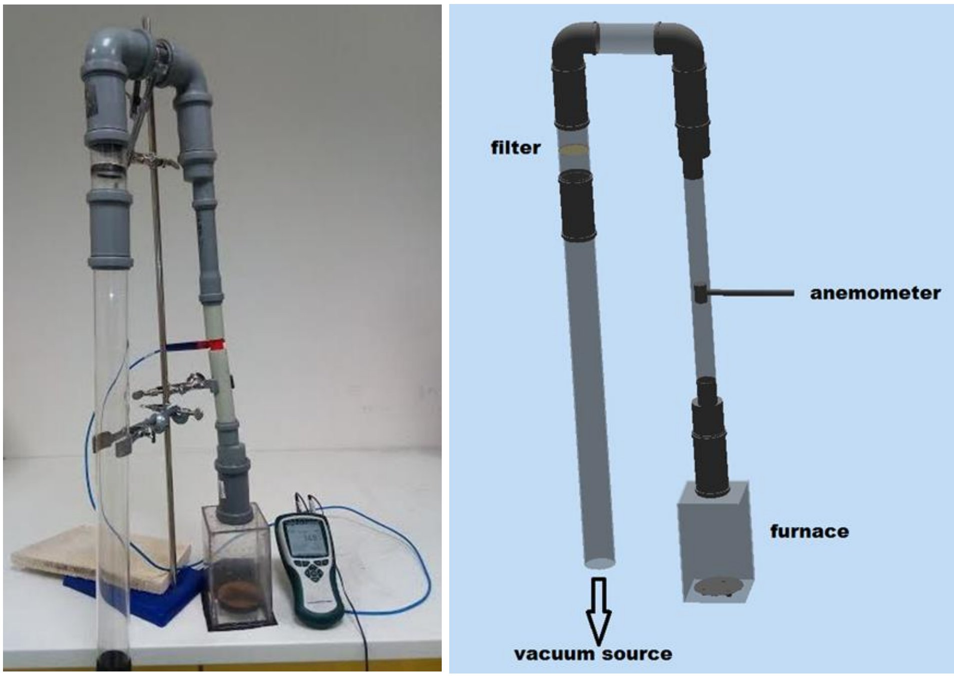

Fig. 3 Model for experimental measurement.

The air supply to particulate matter was followed by CFD simulations. CFD stands for computational fluid dynamics, which is a branch of fluid mechanics that uses numerical analysis and algorithms to solve and analyse problems that involve fluid flows (ČERNECKÝ – PLANDOROVÁ 2016). It was assumed turbulent flow and therefore we chose k-ε model. K-ε model is a two equation model, that means, it includes two extra transport equations to represent the turbulent properties of the flow (VASCELLARI – CAU 2012; ČARNOGURSKÁ *et al.* 2012). Simulations were made without temperature effect. They consider only the velocity distribution of the particles based on the mass flow in chimney. It was set up the same mass flow for all three types at the chimney of 0.00461 $kg \cdot s^{-1}$.

RESULTS

The results of measuring are graphically represented in figure, see Figure 4. During first measurement with only primary air supply, there rose up 50.4 % of sample from heating grate and flowed up the chimney. It was captured about 18.4 % from the risen sample in the chimney filter. During second measurement with primary and secondary air supply, there rose up 18.2 % of sample from heating grate and flowed up the chimney. It was captured about 3.7 % from the risen sample in the chimney filter. During third measurement with primary, secondary and also tertiary air supply, there rose up 14.6 % of sample from heating grate and flowed up the chimney. It was captured about 1.7 % from the risen sample in the chimney filter. Many of PM have been settled on the walls of the model. It can be evaluated that due to secondary air supply, it rose up 32.2% fewer particulates and addition of also tertiary air supply, it rose up 35.8 % fewer particulates. By measuring, it was found that the amount of take-off PM decreases with increasing number of holes.

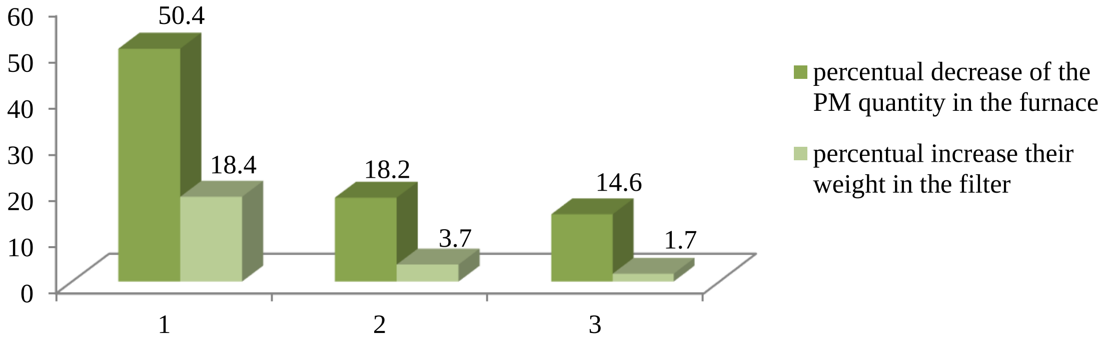

Fig. 4 Results of measurement.

The air supply to solid polluting substances followed by CFD simulations can be seen in the following pictures.

In the Figure 5, there is displayed primary air supply. The air is introduced into the furnace with speed of 51.10 m·s^{-1}.

In the Figure 6, there is displayed secondary air supply. The air is introduced into the furnace with speed of 16.75 m·s^{-1} from primary holes and 16.86 m·s^{-1} from secondary holes.

In the Figure 7, there is displayed tertiary air supply. The air is introduced into the furnace with speed of 13.27 m·s^{-1} from primary holes, 13.85 m·s^{-1} from secondary holes and 13.29 m·s^{-1} from tertiary holes.

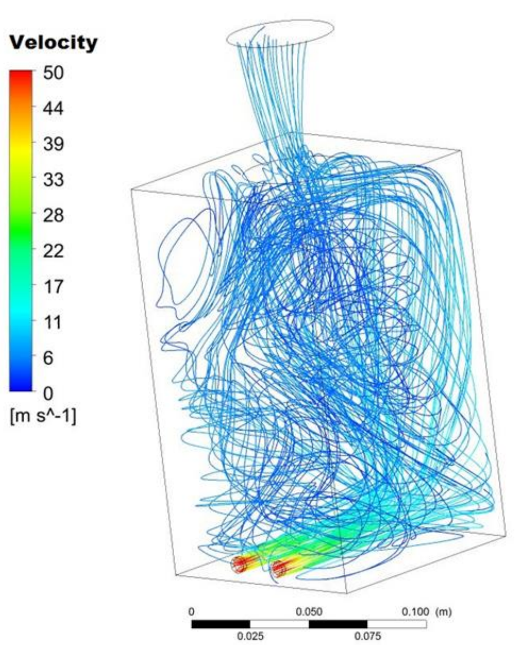

Fig. 5 Primary air supply.

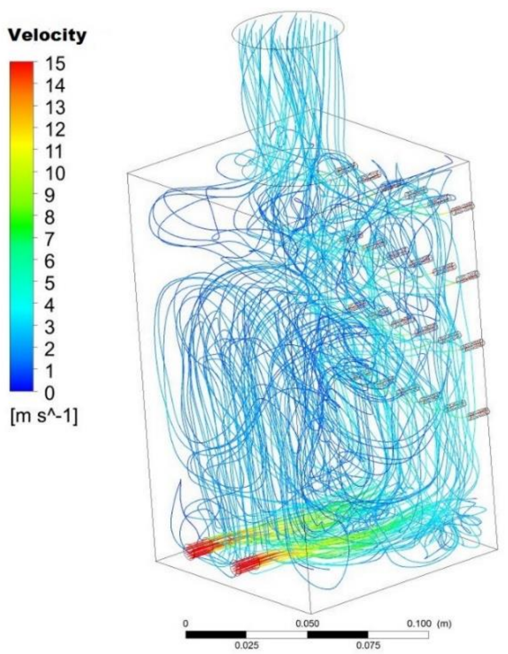

Fig. 6 Secondary air supply.

The largest speed of air supply was found out during first CFD simulation. There was lower speed with increasing number of holes. More amounts of holes reduce the speed of air supply to the furnace.

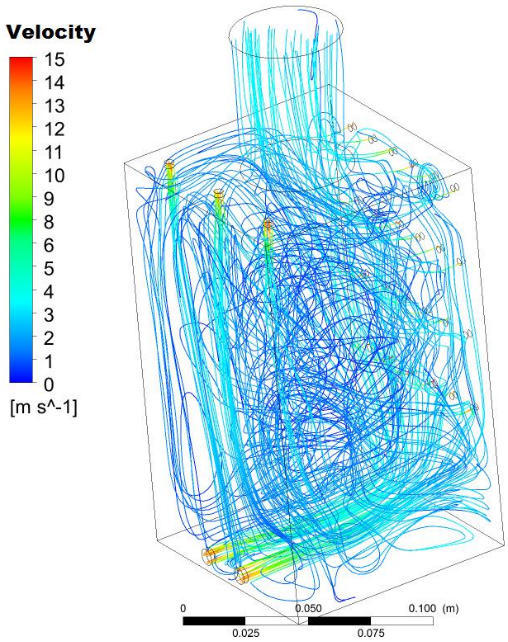

Fig. 7 Tertiary air supply.

CONCLUSIONS

By measuring, it was evaluated the impact of the combustion air distribution in wood stove on PM production. It was investigated primary, secondary and tertiary air supply into the model. By primary air supply with two holes on the front part of model, it took away half of the sample from heating grate. Due to secondary air supply, by addicting 24 holes on the back part of model, it took away 32.2% fewer particulates from heating grate. Addition of also tertiary air supply, by even addicting three holes on the top part of model, it took away 35.8 % fewer particulates from heating grate. Such measurements as well as modelling (numerical simulation CFD) showed a positive contribution of holes for distributing combustion air in combustion chamber of wood stove. The amount of taken away PM from heating grate decreases with increasing number of holes. One of the possibilities of elimination of PM can be more holes for air supply to the heat source with the lowest possible speed. The air supply to particulate matter was also followed by CFD simulations. The largest speed of air supply was found out during first CFD simulation, where it was measured the largest amount of taken away PM from heating grate in the model. By the CFD simulations, there was lower speed with increasing number of holes.

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AUTHORS ADDRESS

Ing. Michal Holubčík, PhD.
Ing. Nikola Kantová
doc. Ing. Radovan Nosek, PhD.
prof. Ing. Jozef Jandačka, PhD.
University of Žilina
Faculty of Mechanical Engineering
Department of Power Engineering
Univerzitná 8215/1
010 26 Žilina
Slovakia
nikola.kantova@fstroj.uniza.sk
radovan.nosek@fstroj.uniza.sk
michal.holubcik@fstroj.uniza.sk
jozef.jandacka@fstroj.uniza.sk