

## FINE AND ULTRA FINE PARTICLES FORMED DURING THE BIOMASS COMBUSTION IN SMALL COMBUSTION DEVICES

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### Abstract

Currently, more and more emphasis is placed on improving the air quality and promoting alternative methods of household heating, including the use of biomass. Although these combustion processes are considered to be environment-friendly, the fine and ultra-fine particles are also produced in these cases, which can have a negative impact on human health. The paper presents the results of experimental biomass combustion, where the concentrations and generated particle sizes were monitored during the process. In particular, selected combustion parameters were taken into account such as temperature, amount of oxygen, etc., which have a significant influence on particle formation. The particles were sampled during the measurements with the aim to determine their morphology and chemical compositions. The gathered results are intended to be used for the design of the technical measure based on the principle of temperature stabilization, leading to reducing the concentration of fine and ultra-fine particles produced by small combustion devices.

**Keywords:** Combustion devices, experiment, parameter, analyses, risk, fine and ultrafine particles

### 1. INTRODUCTION

Air pollution caused by emissions from combustion processes is currently a serious problem. Among the significant contributors to this problem are small combustion devices. The difficult situation is even worse under poor dispersion conditions with a large number of released pollutants. The fuel which is currently widely used for local fire chambers is biomass thanks to the accessible prices [1]. Biomass is also a renewable source of energy for local fire chambers. In the Czech Republic, biomass is defined by Act No. 165/2012 Coll., on the supported sources of energy as amended, as the biologically degradable part of products, waste, and residues of biological origin from farming and forestry and the related industries, agricultural products grown for energy purposes and the biologically degradable part of the industrial and municipal waste. [2].

Although biomass combustion processes are considered environmentally friendlier than fossil fuel combustion, fine particles are formed during these processes as well. Their formation depends on the properties of the fuel, chemical composition, humidity, type of the combustion device and the combustion conditions. They are organic compounds with different values of partial pressure. After the saturation point is reached, a new phase starts to be formed. The molecules crowd to form ultrafine particles of 0.1  $\mu\text{m}$ . These particles can further grow through the coagulation mechanism (crowding of colloid macromolecular organic particles into larger clusters), agglomeration (connecting based on surface adhesiveness), oxidation or condensation reactions on the surface of the particles. The particles are formed in different sizes in each mode depending on the source type, composition of aerosol particles and the atmosphere composition. The modes overlap in the size spectrum. The size of the particles constantly changes as a result of condensation, coagulation, accumulation, fragmentation, and evaporation. [3]. Fine particles are usually in the 10 nm to 1000 nm size fraction and ultrafine particles from 1 to 100 nm. Therefore, technical measures reducing the formation of these particles are searched for. While in large industrial applications the particles are separated by an electrostatic filter, in local fire chambers the separation of fine particles from the combustion products is problematic. There are

studies dealing with catalytic decomposition or the development of small electrostatic separators. The influence of combustion operational parameters in small applications has been observed so far primarily with regard to gas emissions. One of the most suitable solutions in terms of operation is limiting the production of particles through a suitable modification of the fire chamber, which directly influences the formation and growth of fine particles.

Legislative measures monitoring the emission of solid pollutants are currently in force for local fire chambers. However, the emission of fine particles from local fire chambers is not monitored in detail and that is why the project focuses on particles of up to 1  $\mu\text{m}$  ( $\text{PM}_{10}$ ) in size. Legislation has not addressed these particles yet. However, with regard to their significant impact on human health, more attention has started to be paid to their production. The situation is also difficult for health risk evaluation methods for  $\text{PM}_{10}$  particles and smaller. No internationally recognized procedure has been determined in this area, which also concerns ultrafine particles.  $\text{PM}_{10}$  and smaller particles can, under normal circumstances, get into the organism through the respiratory tract, digestive system or skin [4,5,6]. Inhalation is probably the most significant way of nanoparticles getting into the organism [7], where they can get as far as the alveoli [8]. As soon as they get into the blood circulation system, they spread into the whole organism [9] and they get through the cell surface membranes easily [10]. The results of some studies suggest that sufficiently small particles of the order of 10nm, which is the size of a water molecule, are able to get through the hematoencephalic barrier from the blood circulation system into the brain [11]. The World Health Organization (WHO), the European Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) or the United States Environmental Protection Agency (U. S. EPA) have not published any comprehensive methodology on the evaluation of nanoparticle health risks nor have they determined the highest permissible concentrations. Only general recommendations and case studies have been published [12,13,14,15]. Therefore, it is currently possible to use the U.S. EPA and WHO methodologies to evaluate health risks posed by particles of  $\text{PM}_{10}$  or  $\text{PM}_{2.5}$ . Thus nanoparticles follow the same rules as these larger particles, which are generally considered less hazardous [16,17]. It is also important to emphasize that for particles smaller than 1000 nm the current health risk evaluation approaches are primarily focused on nanomaterials and nanotechnologies in work environment.

The paper presents results obtained through measurements in small combustion plants (used for household heating) with selected biomass types (for example pellets, sawdust, etc.). The main focus was placed on the monitoring of the size, concentration and morphology of the formed particles in the individual phases of the combustion process when the combustion parameters, especially temperatures, are not constant. Obtained results aim to propose new measure focused on stabilizing the combustion temperature at an early stage, which will reduce the concentration of ultrafine particles and thus contribute to reducing air contamination, hence, reducing health risks.

## 2. MATERIALS AND METHODS

### 2.1. Experimental combustion device for fine particle sampling

The experiment was carried out with the VERNER A251.1 automatic pellet boiler. It is a warm-water boiler of emission class 3 designed for heating small spaces such as houses. Its capacity is 7.5 - 28 kW. Different types of biomass can be combusted in this boiler (grain, wood pellets, energy plant pellets) with the diameter of 6 to 14 mm.

The device is equipped with a burner, a mechanical grate, a fuel storage bin (240 l) with an automatic batching system and an emergency fire extinguisher. The spout is connected to the boiler with a spiral feeder, which supplies fuel in pre-set intervals. The boiler has its own ignition system. The supplied fuel is combusted in the burner, where flue gases are formed. They then transfer the heat to the water which is distributed through the heating system. Air, which ensures proper combustion, is supplied into the combustion chamber through an

overpressure ventilator. The automatic operation of the boiler is secured by the controller microprocessor unit, which secures the automatic start as well as putting the boiler out of operation. Based on the heating water temperature at the boiler outlet and the flue gas temperature during normal operation, the regulator controls the electric motor of the fuel conveyor and the combustion air ventilator and thus the output of the entire boiler [18].

## 2.2. Fine particle sampling

The fine particles were measured using the SMPS (Scanning Mobility Particle Sizer) device by TSI. Part of the flue gas was removed in the duct system approximately one meter above the mouth of the boiler. Using a rotating disk thermodiluter the flue gas was diluted with clean air in a ratio of 1:8. Then it entered the SMPS device, where it was sorted into monodisperse aerosol using a DMA (Differential Mobility Analyzer). The particle concentration was assessed by an optical method using a CPC (Condensation Particle Counter) device. The connection is shown in the figure:

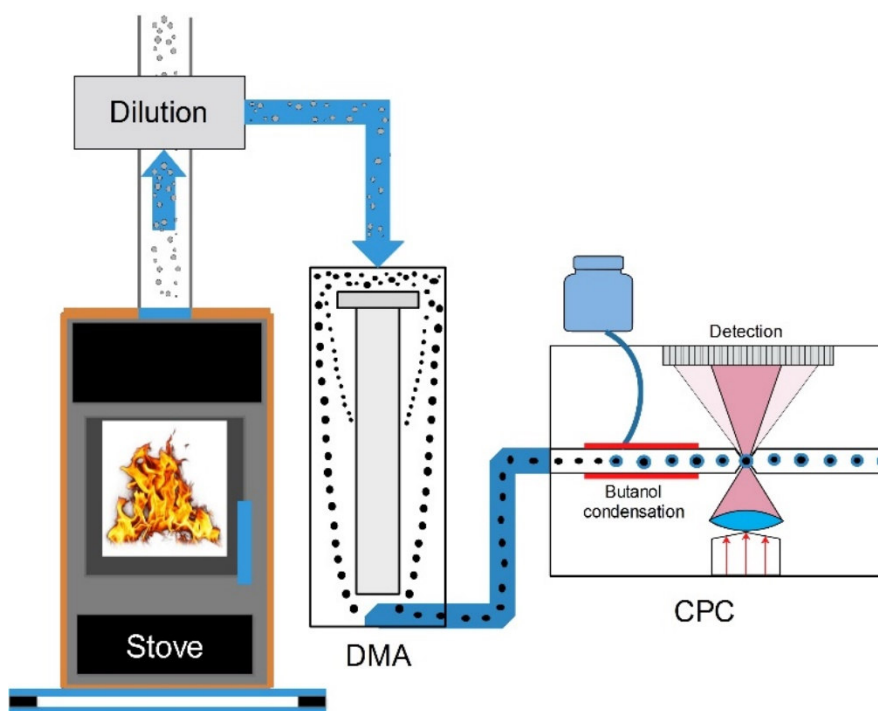


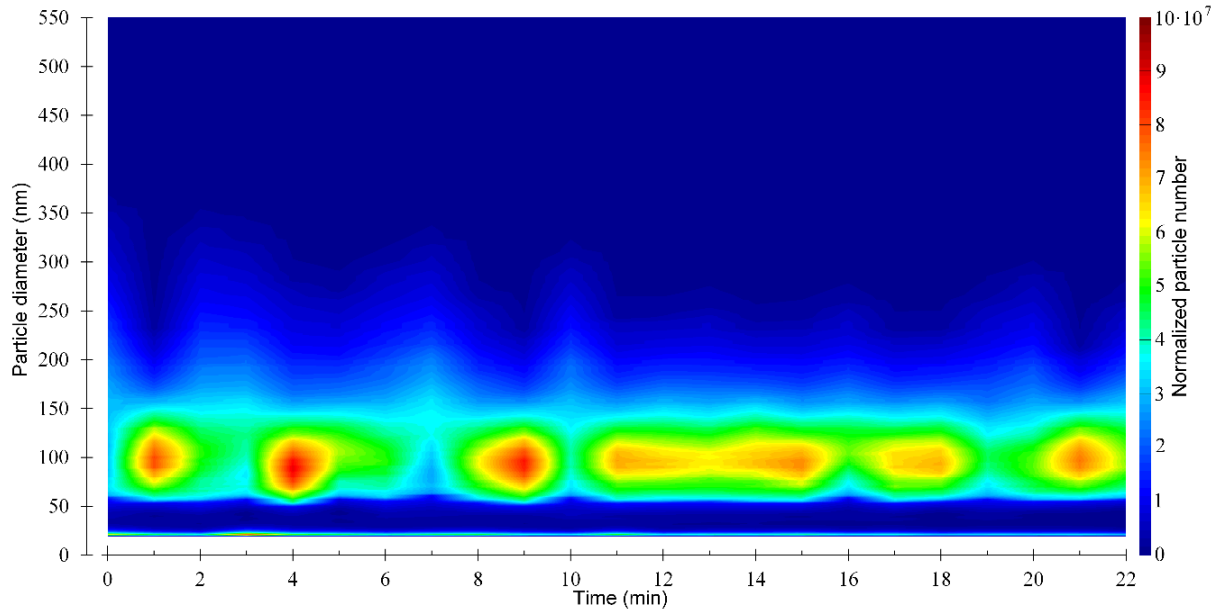
Figure 1 - Diagram of fine particle sampling from a Verner automatic boiler

## 3. RESULTS

The nanoparticles measured were from 18 to 550 nanometres in size. For this experiment beech wood pellets with the diameter of 6 mm and humidity of 7% were burned. The combustion took place at the boiler output of 26 kW. The content of oxygen in the flue gas was 8% throughout the measurement. The average temperature in the combustion chamber was 223 °C. The particle sampling lasted 22 minutes.

The graph shows the concentration and the size spectrum of fine particles at the time of sampling. As can be seen, the highest concentrations correspond to particles of 50 to 150 nm in size. We can also observe occasional concentration fluctuations, especially in the first half of the measurement. This is caused by imperfect optimization of the fuel supply speed and the amount of the combustion air. This is caused by insufficient temperature in the combustion chamber. The pellets cannot burn fast enough in the burner and

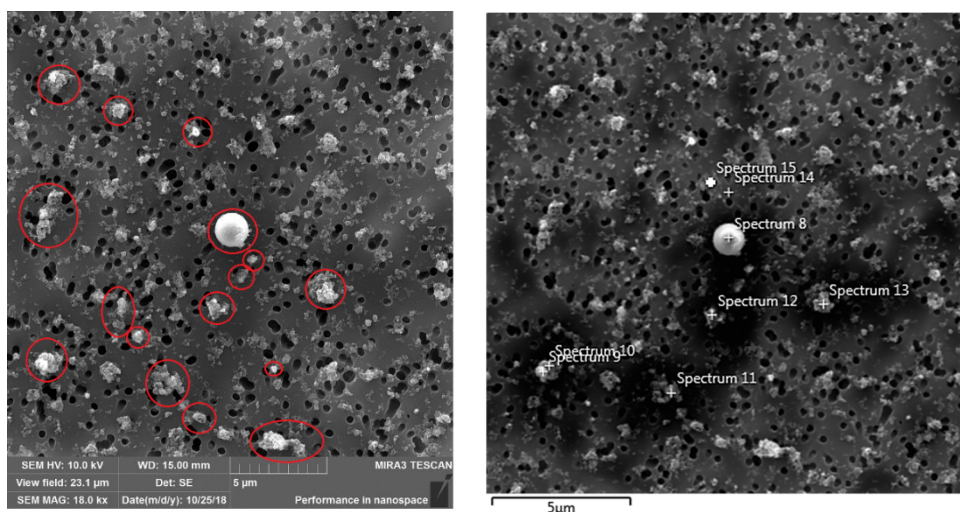
they decay in the ash removal device. This causes the fine particle concentration in the flue gas to increase. In the second part we can observe a more stabilized process in terms of fine particle concentration.



**Figure 2** A graph showing the concentration of fine particles in flue gas produced by combustion of wood pellets in the Verner A251.1 boiler.

### 3.1. Analysis of the samples

The significance of the analyses made lay in gaining information and data on the morphology and chemism of particles formed in flue gases. Polycarbonate filters with the pore diameter of 0.4 µm were used. An analysis of these filters was carried out using the MIRA3 scanning electron microscope by TESCAN, Ltd., which is used by the Czech Hydrometeorological Institute (Brno branch) for their experiments.



**Figure 3** Picture of the SEM particles analyzed with EDX (MIRA3, Ltd.)

**Figure 3** shows pictures of one of the samples taken using the polycarbonate filters (37 mm, 4 µm, SKC, Inc.). A manual analysis of the sample for selected particles was carried out. The picture shows X-ray spectra from the analysis at different points (on particles, often clusters). In the captured spectra 14 and 15 (**Figure 3**) the

particles were too small for analysis and therefore the signal was taken from the filter and thus the result cannot be considered for comparison. After analyses, the highest percentage of elemental representation is for carbon and oxygen but also silicon, sodium, potassium, magnesium, calcium, and zinc. Spectrum 8 (**Figure 3**) particle can be considered a spherical particle which does not have to be part of the flue gas.

With respect to morphology it was found that especially in the initial phase of the process the particles are smaller than PM<sub>1</sub>, namely 1 - 400 nm. As the temperature increases, these particles cluster and become larger in size. When making the sample analysis using the SEM method (MIRA3, Tescan Ltd.), it is important to realize that the observation of particle morphology is limited as the view is two-dimensional. However, there are currently no other methods enabling viewing samples in 3D. Particle morphology is one of the input data for fine particle risk assessment when using the currently known methods. The efficiency of deposition in the human respiratory tract depends, besides other things, on the size of the particles. For example, particles of 1 - 100 nm deposit the most in the tracheobronchial area (trachea, bronchial tube, bronchi, and alveoli); particles of 1 - 10 µm deposit especially in the extrathoracic area (outside the chest).

#### 4. CONCLUSION

The results confirmed observation of the development of particle size distribution, where especially in phases of different parameters (temperature, amount of oxygen, humidity, etc.), such as beginning and end of combustion process, small particles (<PM<sub>1</sub>) with high concentration are released. There was recorded the significant increase of the particles during the beginning of the process. There were the different temperature conditions. The high concentration was detected for the particle's diameter from 50 to 150 nm. These particles have a high level of deposition to the human respiratory system (into alveolar part). The obtained results are also used to assess the potential health risks associated with the formation of these particles. Therefore, the authors are currently focusing on measures to reduce the number and concentration of these particles. There is used the principles of thermal stabilization at an early stage of the ignition and combustion process. There are conduct tests to monitor the evolution of particles before and after the introduction of the measures.

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