Performances of HVAC fibrous prototype filters during combined filtration of mineral, organic and microbial aerosols

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Keywords: HVAC, IAQ, Fibrous Filter, Microbial Aerosols.

HVAC systems are implemented in buildings to manage Indoor Air Quality (IAQ) and air conditioning to satisfy health requirements and people welfare. Ventilation stops are realized for energy saving reasons. This study aims to evaluate in lab conditions the influence of stop/go cycles on the filtration performances regarding inert and microbial aerosols.

A lab-scale HVAC unit, with 2 filtration stages, was developed. The following configuration of prototype filters, described in Table 1, was studied: G4 pleated filter and F7 bag filter, according to European standard EN779, in first and second stage respectively. In order to be representative of the wide chemical composition of urban aerosols with mineral, organic and biological fractions, a mixed aerosol was used for the clogging test. Filters were clogged sequentially (powder generator RBG 1000, Palas) at their nominal filtration velocity, first with alumina particles (50×10^3 part.cm^–3, medium diameter considering number distribution d50n=0.3µm) and then with micronized rice particles (15×10^3 part.cm^3, d50n=1.0 µm) until reaching half maximal pressure drop of the first filtration stage. Finally, microbial aerosol consortium was generated (AGK 2000, Palas) upstream the first filtration stage composed with Bacillus subtilis and Aspergillus niger (10^7 CFU.m^3 and 10^5 CFU.m^3 respectively). According to the literature, the rod-shaped B. subtilis is between 0.5 and 1.8 µm (Agranovski et al., 2003) and the spherical spores of A. niger have a diameter between 3 and 5 µm (Reponen, 1995). After clogging, stops during weekends and restarts of ventilation were simulated for 6 weeks. Optical particles counting were performed (Welas, Palas) during the clogging and at the restarts of ventilation so as microbial sampling with BioSampler and CFU counting.

Table 1. Main characteristics of the prototype filters.

<table>
<thead>
<tr>
<th>Filter</th>
<th>G4</th>
<th>F7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nature of the filters</td>
<td>Cotton and polyester</td>
<td>Glass</td>
</tr>
<tr>
<td>Filtration surface (cm^2)</td>
<td>615 ± 109</td>
<td>3567 ± 500</td>
</tr>
<tr>
<td>Nominal filtration velocity (m/s)</td>
<td>0.18</td>
<td>0.1</td>
</tr>
<tr>
<td>Maximal pressure drop (Pa)</td>
<td>250</td>
<td>450</td>
</tr>
</tbody>
</table>

The evolution of the performances, ratio between the filter pressure drop dP and the initial pressure drop dP0 and particle collection efficiency, during the clogging are represented Figure 1. The cultivable microbial efficiency of B. subtilis, 97±3%, was quite comparable with the number-based efficiency of the F7 filter clogged with alumina and micronized rice particles considering 1-µm-particle-diameter (Figure 2). As expected because of their size, A. niger spores were not detected downstream the G4 and F7 filters suggesting their collection by the filters.

At the restarts of ventilation, particles were detected downstream the second filtration stage with a particle size distribution close to the most penetrating size of the filters (around 0.2 µm). Regarding the microbial concentration downstream the filters, the value was below the detection limit (110 CFU.m^3).

Figure 1. Pressure drop (■), number (◇○) and mass (▲●) efficiency for G4 (left) and F7 (right) filters.

Figure 2. Fractional efficiency of the F7 filter at the different clogging stages.

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Lifetime and performance of filter media challenged by ultrafine metallic aerosols: An experimental study in a 160 t steel/heat EAF meltshop

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Keywords: membrane filter, clogging, blinding, residual pressure drop, ultrafine aerosol.

Electric Arc Furnace (EAF) steel production results on large flue gas flows and, thus large filtration units. In this work, the nominal gas flow is 2.10⁶ Nm³/h for a multicompartment filter equipped with 10⁴ bags (7m length). For meltshops are frequently located near urban areas, stringent policies regulate Pb and Zn (Choel et al., 2006) and an efficient filtration is a critical issue. The process consists of heats of 50 min. Thus, the filter is challenged with high concentration metallic content aerosol under rapidly variable process conditions. Lifetime of media is conditioned by early blinding. The implications of a cautionary replacement every year motivate an experimental study looking for a rationale for filter media selection adapted to the specific characteristics and dynamics of the raw aerosol.

The experimental strategy encompasses a dual approach: A pilot plant (4 10³ Nm³/h nominal) as a media rig, and tests on the full-scale filter. Off-line analysis of loaded media includes: SEM/EDX, fractional efficiency and mechanical tests. Aerosol sampling and analysis is done upstream and downstream of the full-scale filter and pilot plant. The size distribution of incoming aerosol (Figure 1) is a critical input, as lead and zinc concentrate in the ultrafine and submicronic mode.

Results include the time series analysis of residual pressure drop at the full-scale filter (Kavouras, 2005), the assessment of cleanability and the onset of unstable behaviour of media (Binnig et al., 2011), (Stoecklmayer et al., 1998). Figure 2 shows the differences in early clogging.

This work was supported by the Basque Government under grant Etorgai/NUPROSS/FILDEP.

Stoecklmayer, Ch. et al. (1998). Filtration & Separation, 373-380
Evaluation of Bio-Efficiencies of Different Respiratory Protection Masks Using UV-APS

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Keywords: Respirator, UV-APS, Bioaerosol

Respiratory tract infections by viruses cost a tremendous toll both on human life and economy every year worldwide. The development of efficient inhalation protection method is central to controlling respiratory infections and disease outbreaks. Here, we applied a manikin-based system to evaluate the biological aerosol filtration efficiencies of various commercially available inhalation masks using an Ultraviolet Aerodynamic Particle Sizer (UV-APS). In addition, the pressure drop for each different type of respiratory mask was also measured. Last, a new nano-material based mask was developed, and its protection efficiency and the pressure drop were evaluated using UV-APS and pressure-meter. Our data showed that for most inhalation masks we have tested the absolute filtration efficiencies were observed very high, in most cases more than 95%, however their practical protection efficiencies were observed at least 20% lower due to the mask leakage. In addition, we also investigated the use of nano-material for developing new respiratory mask in this work. Our results showed that 10-µm-pore-size filter support with 0.2 mg/cm² loading of nano-material exhibited a comparable bio-filtration efficiency (up to 80%) with an activated carbon based fabric, while having similar pressure drop of 83Pa at 3 L/min. Increasing flow rate increases the pressure drop for all respirators tested, with the highest observed with N95 respirator brands. Overall, it is applicable to use nano-material based fabric to develop next generation respiratory mask for various purposes.

Acknowledgement
This work is supported by National Science Foundation of China grants (21277007 and 41121004). Relevant technology has been filed for a patent.
Do aerosol filters certified based on testing with NaCl challenge provide the targeted protection against combustion aerosols?

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Keywords: filter, respirator, HVAC, combustion aerosols, penetration

Exposure to combustion aerosols, which are comprised primarily of ultrafine particles, has been associated with adverse health effects. Stationary filters of heating, ventilation and air conditioning (HVAC) systems aim at reducing the indoor exposure, including combustion-generated aerosol hazards. Filtering facepiece respirators (FFRs) are deployed to directly control the inhalation aerosol exposure; the relevant workers’ populations include firefighters, first responders, first receivers and other groups. The performance of commonly used high-efficiency HVAC filters and FFRs is usually determined through a laboratory testing with charge-equilibrated NaCl (or KCl) particles. For example, the US National Institute for Occupational Safety and Health (NIOSH) certifies FFRs based on such a testing. However, it has not been examined how well the data obtained with the NaCl aerosol challenge represent the actual protection offered by the filters against combustion airborne particles. The present study addressed this question.

A MERV 14 HVAC filter (filter efficiency $\geq 85\%$–$90\%$, or particle penetration $\leq 10\%$–$15\%$) and a NIOSH-certified N95 FFR (filter efficiency $\geq 95\%$, or particle penetration $\leq 5\%$) were evaluated in this investigation while challenged with NaCl as well as combustion aerosols generated inside an exposure chamber by burning paper, wood and plastic. The penetration through filter samples mounted on a specially designed holder was determined as a ratio of particle concentrations downstream ($C_{\text{down}}$) and upstream ($C_{\text{up}}$) of the tested filter measured using a Nanocheck (Grimm Technologies, Inc., Airing, Germany). The experiments were performed under various conditions representing two typical indoor air flow rates (75 and 150 CFM) for the HVAC filter and four inhalation regimes (15, 30, 55, and 85 L/min) for the respirator filter. Based on the recent data collected by our team on the particle size distributions of the three combustion aerosols as well as the NaCl challenge (He et al., 2013) and considering the limit of detection of the aerosol instrument used in this effort, the particle size range of interest was 15–150 nm. Nine particle size channels were chosen within this range. Each aerosol concentration value was determined by integrating at least ten scans. Each experiment was performed in three replicates, and the calculated mean and standard deviation of the filter penetration were presented for each particle size.

For all three burning materials, both filters and all tested flow conditions, we found that the penetration of particles produced by combustion was significantly greater than that of NaCl particles ($p<0.05$, paired t-test for all particle sizes combined). The biggest difference was observed between plastic and NaCl. The size-selective analysis suggests that differences occurred mainly at 20–80 nm (depending on the filter, burning material and flow rate). Figure 1 is an example featuring the data collected with a N95 FFR filter exposed to the three combustion aerosols and to the NaCl challenge particles under experimental conditions representing an inhalation flow rate of 85 L/min – the rate at which the NIOSH respirator filter certification test is conducted. The differences in penetration are attributed to an interaction between the particles and filter fibers, which is affected by various factors, including particle morphology, charges and surface properties.

![Figure 1](image)

We concluded that the protection offered by the tested filters against “real” combustion aerosols is generally not as good as the one obtained when testing with NaCl surrogates, at least for smaller particles.

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*Currently with the National Personal Protection Technology Laboratory of NIOSH, Pittsburgh, PA, USA
Exposure assessment of nanosized engineered agglomerates and aggregates using Nuclepore filter

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Keywords: engineered agglomerates, exposure assessment, Nuclepore filter, fractal dimension.

Engineered nanoparticles often exhibit unique physicochemical properties which impart specific characteristics in engineered nanomaterials. However, only limited knowledge is known about what effect these properties may have on human health. Workplace personal exposure assessment is attracting increasing attention because data from real work conditions can be obtained. In our previous study (Chen et al., 2013), Nuclepore filter collection with subsequently electron microscopy analysis has been validated to be a method that can provide the particle size distribution of personal exposure. However, the method was only valid for spherical particles and many of the released particles have elongated shapes such as nanotubes, chain-like or branch-like agglomerates. For example, such particles may be released from carbon nanotube manufacturing, welding process (Friedlander & Pui 2004), nanopowder manufacturing, etc.

In this study, penetrations of Ag open agglomerates, aggregates and spheres and soot agglomerates through Nuclepore filters were studied experimentally and the data were compared with modified capillary tube models by Chen et al. (2013). Figure 1 shows an example that the model agrees with the data very well for Ag spheres through 1 μm pore diameter Nuclepore filter with 2 cm/s face velocity (I=0.53). It also compares the penetrations of Ag spheres, open agglomerates and aggregates between data and models. It is seen there was a significant penetration difference between spheres and open agglomerates of the same mobility size, which might lead to a severe error in converting the surface deposition to the size distribution in the air if incorrect model was used.

Table 1 summarizes the number of Ag particles collected on filter surface determined by the Spurny-Kim and Spurny-sphere models and SEM analysis for the 80, and 200 nm RT agglomerates, 150 nm aggregates and 100 nm spheres. The average upstream concentration of the filter, C_up, determined from CPC, for the 80, 100, 150 and 200 nm particles was 4913±383, 4640±280, 1790±32 and 1705±49 #/cm³ respectively. The relative difference of the surface collections determined by the two methods was less than 15%.

Figure 1. Comparison of particle penetration between data and models for different fractal Ag particles.

Table 1. Comparison between theoretical predictions and experimental measurements.

<table>
<thead>
<tr>
<th>Particle size, face velocity and Dß</th>
<th>surface deposition (#), by model</th>
<th>impactation + surface diffusion (##), by SEM</th>
<th>interception (##), by SEM</th>
<th>difference between SEM and SMPS, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 nm (Dß=2.07) 5 cm/s</td>
<td>(368±29)×0.46 =169±13</td>
<td>66±10</td>
<td>88±13</td>
<td>9.7</td>
</tr>
<tr>
<td>100 nm (Dß=3.0) 2 cm/s</td>
<td>(77±4)×0.41 =31±2</td>
<td>15±4</td>
<td>18±3</td>
<td>9.7</td>
</tr>
<tr>
<td>150 nm (Dß=2.25) 2 cm/s</td>
<td>(49±2)×0.59 =29±1</td>
<td>10±2</td>
<td>24±5</td>
<td>14.7</td>
</tr>
<tr>
<td>200 nm (Dß=2.07) 5 cm/s</td>
<td>(128±4)×0.80 =102±3</td>
<td>16±4</td>
<td>93±12</td>
<td>6.8</td>
</tr>
</tbody>
</table>

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Emissions during active regeneration of a particle filter

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Keywords: combustion aerosol, DPF, active regeneration, emission

To improve air quality in Europe the EU has tightened the emission limits leading to EURO VI in 2014. In these ambitious emission limits a particle number emission limit was introduced for the first time in the HD emission legislation. The rigorous PN limits enforce the use of closed diesel particle filters (DPF).

The particle filters with filtration efficiencies of more than 99 % need to be regenerated to get rid of the accumulated soot.

The regeneration of the particle filter can be accomplished continuously in a passive system with the aid of NO2 or periodically in an active system.

For an active regeneration the exhaust temperature needs to be raised up to 600°C to enable the oxygen driven soot oxidation.

A hydro carbon injection system (HCI) is used for this purpose. Fuel is injected in the exhaust line upstream of a special diesel oxidation catalyst (DOC). There the fuel is exothermically oxidised and this increases the exhaust temperature.

Due to the high temperatures the filtration efficiency of the DPF can be reduced and secondary emissions can occur. These emissions are object of possible additional regulations.

To study these emissions the following setup was chosen. A HD-diesel engine (10.5 l, Euro IV) on an engine test bench was equipped with HCI system, DOC (12”x8”, 60g Pt:Pd 4:1) and a DPF (12”x12”, SiC, uncoated). The gaseous emissions were measured with exhaust gas analyser (MEXA 7100 DEGR) and FTIR spectrometer (Ansyco). The particulate matter emissions were measured with EEPS (engine exhaust particle sizer, TSI 3090) APC (Advanced Particle Counter, AVL 489) and MSS (Micro Soot Sensor, AVL 483).

The filter was loaded with approximately 3 g/l soot overnight. Then an active regeneration was accomplished at stationary load points for 20 min and the emissions were measured. After a complete regeneration an additional regeneration was accomplished to study the effect of an empty filter.

During active regeneration an increase of the soot and PN emissions can be found (see figure 1). The filtration efficiency is reduced from 99 % to 95 % during active regeneration. After the end of the active regeneration it takes nearly 15 min to reach again the high filtration efficiency of 99 %.


Filtration of ultrafine dust emitted by biomass combustions with a baghouse filter using precoat materials

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Keywords: precoat filtration, ultrafine dust, baghouse filter, reuse of precoat, wood combustion

To comply with the legal requirements a compact baghouse filter has been developed. It combines excellent separation efficiency with convenience in operation for wood-fired heaters (e.g. pellet heaters) (Schiller, 2013). In order to prevent clogging of the filter cloth by sticky and ultrafine particles, it is necessary to use a precoat. For this purpose different precoat materials have been analysed (e.g. limestone powder).

With this very efficient technology, extremely high separation efficiencies > 99 % and ultrafine dust concentrations < 1 mg/m³ could be reached in a long-term stable process.

The costs of the material are negligible when it comes to the calculation of the needed mass of a private household. However, due to the large-scale quantities in the industrial sector the reuse of the precoat material can generate significant savings.

Therefor, different tests were performed to reuse and mix the precoat materials several times. During these tests the filtration behaviour was detected by measuring the total collection efficiency, the grade efficiency, and the pressure drop curve of the filter. In addition to that different characteristics (porosity, bulk flow properties, particle size distribution) of the precoat materials have been analysed after every step of reusing or mixing to detect the influence of the reuse.

After that the experiences made with the laboratory build-up (pellet heater, nominal output: 15kW) were used to do a scale-up for a real application (pellet heater, nominal output: 320kW).

Because of the operating method of the two plants (single-line-dedusting-mode) the resulting pressure drop curves show an inhomogeneous filtration behaviour (fig. 1).

The behaviour shown in fig. 1 can be described with a known model from the literature (Krammer, 2002). For the validation of the model, the quantity of data carried in the laboratory tests were used.

To get a better understanding of the agglomeration and the adhesion of the ultrafine dust particles and the precoat particles as an input for the simulations and the modelling optical test were made with a scanning electron microscope (SEM) after separating single particles (fig. 2).

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A model for deep-bed metal fiber venting filters

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Keywords: Fibrous filter, deep-bed, pressure drop, modelling, COCOSYS

In case of a severe accident in a nuclear power plant a containment over-pressure failure is prevented by using a filtered venting system. The so-called “dry filter system” used in some German NPPs consists of two metal fiber filters (MFF) and an iodine sorption filter. To simulate the aerosol retention in this multi-stage deep-bed venting filter and to calculate the fission products released into the environment, a MFF model was developed for the Containment Code System COCOSYS and verified on two tests of the ACE-A filter series (Dickinson, 1990).

The MMF model calculates the retention of aerosols and condensate droplets in the six pre-filter layers with decreasing fiber diameters and in six fine-filter layers with identical fiber sizes. The diameter of the stainless steel fibers of the filters varies between 2 and 60 µm. Additionally, the pressure loss of the gas flow through unloaded and loaded filters and the filter plugging as consequence of dry and wet deposits is considered (G. Weber, 2013).

The size-dependent retention of the aerosol particles is calculated semi-empirically using fluid-dynamic numbers. The processes diffusion, interception and impaction (Lee and Liu, 1982) are treated. The theoretical retention characteristic can be refined (calibrated) by use of suitable measurement data, e.g. with a mono-disperse aerosol. The behavior of up to 7 chemically different aerosol components and water can be considered in each layer of the pre-filter and the fine-filter. The aerosol size distribution can be discretized into a maximum of 20 classes.

The pressure drop on the unloaded filter is modelled according to Ergun (1952) and the impact of loading by a polynomial equation with empirical coefficients. Plugging of the venting filter, which was observed in ACE test AA20, is described by an empirical correlation developed according to Frising et al. (2005), taking into account the movement of liquid within the filter.

The dry test AA19 and the wet test AA20 were performed with insoluble Mn aerosol with a MMD mass median diameter of 1.2 µm and the hygroscopic Cs aerosol with 2.1 µm. Both tests were analyzed with COCOSYS including the new MFF model. The measured high decontamination factors (DF) for the insoluble Mn aerosol and the hygroscopic Cs aerosol were well reproduced (Table 1). The Cs concentration in the outlet was below the detection limit. The penetration is highest for particles smaller than 1 µm.

Table 1: Calculated and measured DF in ACE-AA19

<table>
<thead>
<tr>
<th>Aerosol</th>
<th>DF calculated</th>
<th>DF measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cs</td>
<td>1.5E8</td>
<td>&gt; 3.7E6 (det. lim.)</td>
</tr>
<tr>
<td>Mn</td>
<td>3.3E6</td>
<td>8.2E5</td>
</tr>
</tbody>
</table>

In the dry test AA19 98 % of the aerosol mass is deposited in the pre-filter, one third of which is deposited in layer no. 5. In the wet test AA20 the droplets with dissolved Cs material are also predominantly retained in layer no. 5 (Figure 1). Only a small amount of aerosol reaches the fine filter.

When the liquid loading exceeds the critical value, which is estimated to be 1.8 kg/m² of water including the soluble Cs, spontaneous plugging occurs in layer no. 5 and the pressure loss increases by a factor of 80.

Figure 1: Calculated MFF loading in AA20

For reduction of still existing model uncertainties, which concern mainly the pre-filter, data from new experiments would be needed.

This work was funded by the German Federal Ministry of Economics and Technology (BMWi) in project RS1508.

Ergun, S., Chem.Eng. Progress, 48(2) 89-94 (1952)
Frising, T., et al., Chemical Engineering Science, 60 (10) 2751–2762 (2005)
Filtration performances of a lab bag-filter unit under specifications of incineration flue-gas treatment

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Keywords: nanowaste incineration, flue-gas treatment, filtration, bag filter, porous media.

Up to now, there is no peculiar approved procedure for the waste management of nanoobjects at their end of life, mainly because the current regulation does not consider the typical nano-specificity of such emerging products. The French project “NANOFlueGas” aims to provide data and to examine nanosafety aspects at the destruction stage of nanomanufactured products by incineration. One part of the project deals with the evaluation of the performances of a bag filter unit regarding its clogging with a characteristic nanosize aerosol emitted from nanowaste incineration in boiler output.

A laboratory-scale filtration unit was developed where a single bag filter was implemented (reduced height to 0.44 m). The porous media was constituted from Teflon fibers. The main structural parameters of the media are presented in Table 1. The aerosol used for clogging tests was formed by a mix of suspended particles of activated carbon and sodium bicarbonate (SAG 420, TOPAS), mainly introduced in the flue gas treatment line for dioxin/furan and acid gas removal, and a condensation aerosol from graphite monoliths (DNP 2000, Palas) whose particle-size distribution and shape were chosen in order to be representative of the aerosol emissions determined from preliminary tests with a laboratory-scale incineration unit and a nanowaste (Tran et al., 2012).

In order to be consistent with the real operating conditions in flue gas treatment lines, the airflow and the bag filter were heated to 150°C, the filtration unit was insulated and 10-12% of water content was maintained in the airflow by water injection. Filtration velocity through the bag filter was 1.9 cm/s. Figure 1 represents the particle size distribution of the aerosol upstream the bag filter. The performances were evaluated throughout the clogging in terms of filter pressure drop and particle collection efficiency from hot sampling and dilution before particle counting (ELPI, Dekati). Three experimental tests were carried out. The evolutions of the filter performances are displayed in Figure 2. Results showed a high particle collection efficiency of the filtration unit whatever the level of clogging. The study of fractional efficiency led to the same conclusions whatever the particle size. As expected, the filter pressure drop increased with the clogging. Initial pressure drop values increased with the tests which can be explained by the off-line cleaning procedure implemented.

This work was financially supported by ADEME (grant 1181C0088).

Tran, D. T. et al. (2012) in Proc. SENN2012, Helsinki (Finland), 87.

Table 1. Main structural parameters of the media.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (µm)</td>
<td>1256 ± 31</td>
</tr>
<tr>
<td>Median fiber diameter (µm)</td>
<td>19.5</td>
</tr>
<tr>
<td>Porosity (-)</td>
<td>0.64</td>
</tr>
<tr>
<td>Media weight (g/m²)</td>
<td>750</td>
</tr>
<tr>
<td>Air permeability (l/dm²/min)</td>
<td>100</td>
</tr>
</tbody>
</table>

Figure 1. Number particle size distribution upstream the bag filter (ELPI, Dekati).

Figure 2. Bag filter performances during the 3 tests.
Integration of an electrostatic precipitator into the wood combustion boiler

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Keywords: wood combustion boiler, electrostatic precipitator, reduction of particulate emissions

Wood combustion in small and medium scale boilers is widely used for domestic heating. In Germany the Ordinance for Small Scale Combustion (1.BImSchV) regulates the level of particle emissions from biomass combustion facilities of 4 up to 1000 kW. In 2015 the particulate emissions from biomass combustion boilers should be reduced to 20 mg/m³.

The electrostatic precipitators (ESP) are the most attractive devices for reduction of fine particle emissions. In recent years, various ESPs are developed for exhaust gas cleaning from wood combustion stoves, ovens and boilers. These developments include both dry and wet precipitators and conventional and space-charge ESPs. The units differ by the place of their maintenance, e.g. downstream the combustion facility, inside of the gas duct or on the ruff of the house. The review of such developments is presented in the reports Obernberger (2011), Ulbricht (2011) and Bologa (2010).

In spite of the fact of existing developments and proposals, still various questions need their answers and solutions.

The purpose of the current work is the development of the technical solutions for integration of an electrostatic precipitator into a wood combustion boiler to reduce particulate emissions according to the demands of the 1.BImSchV Ordinance.

In the report the authors review the existing approaches for the development of the ESPs from the point of view of the perspectives of their integration into the wood combustion boilers. First, the attention is given to the analysis of existing ESPs taking into consideration the combustion conditions (high gas temperatures, exhaust gas composition, particle mass and number concentrations). Second, the authors analyze the advantages and disadvantages of dry conventional and space-charge ESPs used for exhaust gas cleaning from wood combustion. Third, the attention is given to the analysis of ESP parameters which ensure long-term operation stability.

On the basis of the review, the authors propose the compact ESPs which ensure effective gas cleaning from fine particles coming from biomass combustion boilers. The investigations are carried out in the framework of the BMU project 03KB083.

The electrostatic precipitators are operated on the principle of particle charging in the DC negative corona discharge and precipitation of charged particles in the grounded collector stage. The ESP is equipped with an ionizer and two grounded brush-electrodes which are installed inside of a thermo-isolated casing.

The ESP CCA-50 (Fig.1) designed for operation with a wood combustion boiler with heat capacity of 50 kW, is operated at voltage up to 20 kV and corona current up to 1.0-1.2 mA. The power consumption of the ESP is ca. 40 W/h. The ESPs were investigated both at the test CCA facility and at the test set-up of the boiler manufacturer.

The authors analyse the results of the tests of “stand-alone” ESPs. Among the ESP parameters attention is given to the precipitator long-term operation stability. In the report the authors also discuss the possibility of integration of the ESPs into a boiler: from “rucksack” solution (Fig.2), when ESP is installed direct downstream the boiler, up to “integrated ESP”, when ESP is integrated into the boiler casing.

Marine exhaust gas cleaning by charged spray.

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Keywords: Diesel exhausts, PM removal, electrostatic scrubbing, gas cleaning

Marine engine emissions became one of the most important sources of air pollution, especially in the vicinity of harbor areas. Due to their toxic composition, the emission of exhaust gases by these sources has drawn an attention recently. Until 2005, maritime transport remained unregulated referring to restrictions on air pollution. Since that date, however, the emission limits concerning SO₂, NOₓ, ozone-depleting substances (ODS) and volatile organic compounds (VOC) have become gradually more restrictive. Due to harmful effect of particulate matter (PM) on human health and environment, these regulations will apply also to PM emission in the near future. The submicron particles are dangerous not only due to their size and structure, but also due to the presence of heavy metals in their chemical composition. Present after-treatment solutions, which are used commercially, successfully reduce SO₂, but are still ineffective in removing PM2.5, particles smaller than 2.5μm. The low efficiency of conventional devices results from decreasing magnitudes of inertial forces, which are utilized for the removal of micron and larger particles.

This paper considers an application of charged sprays for the removal of submicron and nanoparticles from exhaust gases. In such device, known as electrostatic scrubber, electrically charged droplets in the form of spray collect oppositely charged particles due to attractive Coulomb forces. A schematic of electrostatic scrubbing process is shown in Fig. 1. In a device utilizing the method the particles are charged electrically in a corona-discharge PM charger, and droplets are sprayed by a mechanical atomizer and charged by induction using an electrode connected to a high voltage unit.

By this method, it is possible to modify the trajectories of moving particles in such a way that their deposition onto droplets become more efficient. It was also shown that electrostatically dispersed water aerosol allows also increased SO₂ absorption. Such technique can therefore be used for simultaneous gas cleaning to acceptable SO₂ and PM emission levels. Moreover, the electrically charged aerosol, which disperses the droplets more uniformly within the space of scrubber can reduce water consumption, which implies economic profits from this.

In order to optimize the electroscrubbing efficiency, some tests with various versions of pressure-swirl atomizers with induction charging with respect to droplets charge maximization have been carried out. One of the atomizers tested has been selected and applied in electrostatic scrubber column for the removal of particulate matter and SO₂ absorption from a two-stroke marine Diesel engine. The particle size distribution in the exhaust has a distinctive bimodal size distribution with two peaks at 20–40 nm and 100-300 nm. The experimental results show that over 90 number% efficiency of PM removal, which is higher comparing to conventional scrubbing methods, can be obtained.

Fig. 1. Schematic of electrostatic scrubbing process

The results has been obtained within the EU DEECON project No. 284745.
### Carbon nanotube penetration through fiberglass and electret respirator filter media and Nuclepore filter: experiments and models

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⁴Institute of Energy and Environmental Technology e.V., Bliersheimer Str. 60, 47229 Duisburg, Germany
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Keywords: multiwalled carbon nanotube, personal protection, exposure control, electrostatic filtration.

Functionalized MWCNTs were produced by the nitric acid refluxing method and aerosolized using a homemade nebulizer. The generated MWCNTs were then used to challenge two electret and one fibrous respirator filter with face velocities of 5.3 and 10.6 cm s⁻¹. Nuclepore filters were also used to study the mechanical deposition mechanisms of the MWCNTs. SEM analysis was conducted to obtain the effective length of the MWCNTs and to observe their shape changes at different mobility diameters. It is seen 50 and 100 nm MWCNTs compared to larger diameter ones possess straighter and higher aspect-ratio structures. MWCNTs with 200 to 500 nm were generally with a higher level of curling, bending and agglomeration. Based on the measured effective length, single fiber theory and the superposition of theoretical electrostatic deposition developed by Lathrache & Fissan (1986) were adopted to predict the MWCNT penetration through the electret and fibrous filters. NaCl penetration data of these filters from Li et al. (2012) were used to compare the penetration difference with MWCNTs. Table 1 shows the information of the tested filters. The electret filters had a much lower air resistance than the fiberglass.

<table>
<thead>
<tr>
<th>Table 1. Specifications of the tested filter media</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
</tr>
<tr>
<td>ΔP (in-H₂O)@ 5 cm s⁻¹</td>
</tr>
<tr>
<td>Fiber diameter (μm)</td>
</tr>
<tr>
<td>Thickness (mm)</td>
</tr>
<tr>
<td>Solidity</td>
</tr>
<tr>
<td>Fiber density (g cm⁻³)</td>
</tr>
<tr>
<td>Charging (C m⁻²)</td>
</tr>
</tbody>
</table>

Figure 1 shows the comparison of MWCNT penetration with that of NaCl at 5.3 and 10.6 cm s⁻¹ face velocities in HD-2583 fiberglass (left), 3M electret #1 (middle) and 3M electret #2 (right) filters. The MWCNTs generally had lower initial penetrations (clean filter condition) than that of NaCl at the same mobility size, which was due to the longer interception length of the MWCNTs and stronger electrostatic effect in the electret filters. Alignment effect caused by high face velocity (≥10 cm s⁻¹) was observed for the MWCNTs in this study. The effect is more significant for 30-50 nm in the respirator filter media and 50-100 nm in the Nuclepore filter and more caution should be exercised when the respirators are used to mitigate ultrafine MWCNTs especially with the face velocity higher than 10 cm s⁻¹.

The single fiber theory predicted the penetration of both sphere-like NaCl and elongated MWCNT through the fiberglass and electret filters well at small sizes but consistently overestimated the penetration at larger sizes due to the underestimation of interception and electrostatic depositions. The electrostatic effect was significant on the MWCNTs in the electret filters. The current data could be used to improve the single fiber theory on both interception deposition and electrostatic deposition mechanisms in fibrous and electret filters in the future.

This work was supported by NSF Grant (Award ID: 1236107), by the European Committee for Standardisation in the frame of mandate M/461 the Center for Filtration Research, CFR.


Testing the appropriateness of N95 halfmask respiratory protection for aerosolized nanoparticles: development of test methods and results

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Keywords: Airborne nanoparticles, respiratory protection, test method.

The industrial use of nanoparticles is nowadays becoming more and more common and its technologies are growing fast. However, this rising production and use of engineered nanomaterials can create new risks and generates several concerns related to their potential environmental, safety and health impacts. One of the main production methods creates nano powder, which can suffer a process of aerosolisation.

All airborne particles are a hazard to our health, which increases when someone gets near the place where those particles are produced. The use of personal protective equipment (PPE) is a way of controlling hazards by placing protective equipment directly on workers’ bodies, such as Respiratory Protection Equipment (RPE). According to the regulation for RPEs, like EN149:2001 to the RPEs test for dust protection, the smaller particles to use is 300nm of size, but nowadays the industry uses smaller size particles, like 7nm Al₂O₃. Thus, the RPE which works for these regulations cannot guaranty their efficiency for nanoparticles airborne protection.

In order to develop a test method and know if the actual regulation is enough to guaranty safety, ITENE developed the Test and Research Equipment for Nanoparticles (TREN), based on the ETNA test bench, from the IRSN (Hinds and Kraske, 1987a,b; Balazy et al., 2006; Eninger et al., 2008; Brochot et al., 2012; etc.).

This chamber was designed to test PPE and reduce any particle leaks. The air recirculates inside the TREN chamber; an electric fan makes the air go to the nanoparticle inlet and transports them to the sample chamber. Then, the air crosses an HEPA (High Efficiency Particle Arresting) filter, which cleans the air and returns to the fan, and the cleaned air recirculates until it returns to the nanoparticles inlet. The TREN designed allows to control the airflow velocity, and measures the temperature and the differential pressure. The TREN has connections to 4 different test equipment, testers, forced airflows, particle counters, and these connections allow several configurations.

A Sheffield head placed inside the TREN can reproduce the conditions simulating its use in the workplace. This Sheffield head is actually a manikin head with internal pipes which allow us to collect the air from the inside of the mask. A 4 litters per minute air flow, forced with a constant pump inside the mask, simulates the human respiration at low energy tasks. Once the aerosolizer conditions are fitted, for the different nanoparticle types, the test is repeated measuring the number of nanoparticles at both sides of the mask, using TSI CPC 3007, OPS3330 and/or Aerosens-Philips Nanotracer.

Tree different halfmask are tested in this study, with five nanoparticles, namely ZnO, Fe₂O₃, TiO₂, Al₂O₃ and CoAl₂O₃. Before testing them, the machine turns on at a maximum speed at least 5 minutes, to eliminate all possible nanoparticles inside the TREN. After that, the background inside the TREN is measured. After every test the machine works at a maximum speed during at least 10 minutes, in order to eliminate the nanoparticles inside the TREN, and monitoring that nanoparticle levels go back to their initial levels at least 5 minutes. Once the machine test condition is stable the aerosol is generated and measures simultaneously both sides of the mask, analysing outside and inside nanoparticles concentration, and compares both values to calculate the penetration factor.

<table>
<thead>
<tr>
<th>Nanoparticle</th>
<th>RPE</th>
<th>Penetration Factor %</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZnO</td>
<td>A</td>
<td>59.9</td>
</tr>
<tr>
<td>ZnO</td>
<td>B</td>
<td>79.3</td>
</tr>
<tr>
<td>ZnO</td>
<td>C</td>
<td>54.7</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>A</td>
<td>77.7</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>B</td>
<td>85.2</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>C</td>
<td>20.3</td>
</tr>
<tr>
<td>TiO₂</td>
<td>A</td>
<td>82.5</td>
</tr>
<tr>
<td>TiO₂</td>
<td>B</td>
<td>89.3</td>
</tr>
<tr>
<td>TiO₂</td>
<td>C</td>
<td>53.3</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>A</td>
<td>36.6</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>B</td>
<td>32.8</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>C</td>
<td>21.1</td>
</tr>
<tr>
<td>CoAl₂O₃</td>
<td>A</td>
<td>73</td>
</tr>
<tr>
<td>CoAl₂O₃</td>
<td>B</td>
<td>46</td>
</tr>
<tr>
<td>CoAl₂O₃</td>
<td>C</td>
<td>57.6</td>
</tr>
</tbody>
</table>

Table 1. Penetration factor values.

For a N95 mask, regulation indicates that it must have a protection factor higher than 95%, which is equivalent to a penetration factor lower than 5%. Results of the study, as indicated in table 1, show that all the half masks tested are not adequate under the penetration factor criterium.
References


Filtration Performance of Particulate Air Filters for General Ventilation Lab Testing vs. Real Life Tests

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Keywords: DIN EN 779, filter efficiency, synthetic filter media, general ventilation

The first test standards for measuring the performance of air filters for general ventilation were introduced more than 40 years ago. The basic design of the test rig and the test procedures of DIN EN 779:2012 have been developed from EN 779:2009. The ‘minimum efficiency’ at particle size 0.4 µm was new and has become the most important criteria.

However the practical relevance of data derived from lab testing is still an open question. People argue that these tests fail to predict the performance of filters in real life and may overestimate the efficiency of electrostatically enhanced filters.

Table 1: Classification of fine dust filter according to DIN EN 779:2012

<table>
<thead>
<tr>
<th>Filter class</th>
<th>Average efficiency [%]</th>
<th>Minimum efficiency [%] IPA treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>M5</td>
<td>40 ≤ Eₐ &lt; 60</td>
<td>-</td>
</tr>
<tr>
<td>M6</td>
<td>60 ≤ Eₐ &lt; 80</td>
<td>-</td>
</tr>
<tr>
<td>F7</td>
<td>80 ≤ Eₐ &lt; 90</td>
<td>35</td>
</tr>
<tr>
<td>F8</td>
<td>90 ≤ Eₐ &lt; 95</td>
<td>55</td>
</tr>
<tr>
<td>F9</td>
<td>95 ≤ Eₐ</td>
<td>70</td>
</tr>
</tbody>
</table>

In this study fine filters (filters classified in one of the classes F7 up to F9) have been installed in the regular ventilation systems of both involved institutes, removed after some month, tested in the lab and installed again. When filters have been transported to the laboratory for testing, care has been taken not to disturb the dust cake that had accumulated on the media.

Synthetic filters as well as glass fiber filters have been aged over three to twelve months. These filters have been used for testing and the results were compared to standard test results using ASHRAE dust for pressure increase or DEHS for measuring the efficiencies at 0.4 µm. In contrast to field testing in this study well defined particles were used and testing took place at defined air climate conditions (50 % rel. humidity, 293 K).

Figure 1 indicates that the increase of pressure drop for fine filters using ASHRAE dust is much higher than found in real life.

Figure 2 shows the retentions of the synthetic filters for 0.4 µm particles. The efficiencies of filters (manufacturer A and B) decreased very fast and are mainly close to the minimum efficiency. Using ASHRAE leads to unrealistic high values for all kind of media.

Experiments with isopropanol for discharging have been performed and results are compared to the ones using other surface treatments (surfactants and diesel exhaust particulates).

Furthermore, the efficiency of filters placed in a ventilation system was determined with ambient air in accordance with DIN EN ISO 29462. The particle size and number distribution in raw and clean gas was measured using Fast Mobility Particle Sizer.

The project (no. 17659 N) is supported by the Federal Ministry of Economic Affairs and Energy on the basis of a decision by the German Bundestag within the scope of the Industrial Collective Research (IGF) via AiF.
Aerosol transfer modelling through cracked concrete walls

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Keywords: cracks, aerosol, model, deposition

Introduction

This study takes place within the framework of nuclear facilities containment assessment. The objective is to determine aerosol deposition correlations into cracks network, further to accidental situation (e.g. seism). Experiments were performed on a concrete wall (128 cm in width, 75 cm in height and 10 cm in thickness), cracked by shear stresses. Currently, characterization of real crack parameters (width, extent, length) is difficult; so, for a first approximation, we determined the “aeraulic” crack parameters by a specific method. We considered that the crack length is the wall thickness \( L_g = 0.1 \) m and the crack network extent is measured with a curvimeter \( l_g = 11.8 \) m. Then, the Poiseuille law in laminar compressible flow was used to determine the aeraulic crack width \( e \). A value of 49.2 \( \mu \)m was thus obtained.

This study of aerosol deposition into crack network is divided into two parts. First, tests were performed in the diffusional domain with 60 nm aerosols; experimental results were compared with the Bowen diffusion model (Bowen, 1976) by using aeraulic crack parameters. Then, tests were performed with 1.1 \( \mu \)m aerosols (intermediate domain: sedimentation and inertial impaction at crack entrance); experimental results were compared with gravitational model and a model for the inertial impaction at crack entrance was determined.

Experiments with 60 nm aerosols

Experimental results show that aerosol deposition decreases with flowrate, but these results do not fit well with the Bowen diffusion model using aeraulic crack parameters. So it can be concluded that aeraulic parameters are unsuited for brownian aerosol deposition. Hence, experimental results were fitted with Poiseuille law and experimental aerosol deposition results with Bowen diffusion model to determine geometric crack parameters. It allowed determining the new geometric crack parameters: \( e_g = 67.2 \) \( \mu \)m – \( l_g = 6.8 \) m – \( L_g = 0.127 \) m.

Experiments with 1.1 \( \mu \)m aerosols

Experimental results were compared with a sedimentation model including geometric parameters, showing a good agreement for low flows; but, for higher flows, inertial impaction at crack entrance must be considered. To be the most representative of a crack, we used an inertial model adapted by Eleftheriadis et al. (1992) for inertial impaction by rectangular strips (1):

\[
Fr = 1 - \frac{1}{1 + a \ Stk^b} \quad \text{with} \quad Stk = \frac{\rho_p d_p^2 C_c}{18 \mu D e_G l_g} q
\]

where \( Stk \) is the Stokes number, \( D \) a characteristic dimension (here the crack width), \( \rho_p \) the particle density, \( d_p \) the particle diameter, \( C_c \) the Cunningham coefficient, \( \mu \) the air viscosity, \( q \) the flowrate and \( a \) and \( b \) unknown constants. To determine the latter, experimental results were fitted with inertial model (Figure 1). The following values were obtained:

\[ a = 85.9 \quad \text{and} \quad b = 1.2. \]

Figure 1. Comparison between experimental results and sedimentation/inertial model (1.1 \( \mu \)m)

CONCLUSION

This study allowed determining all the characteristics of a crack network by using a diffusion deposition model and an aeraulic model. It allowed also to validate a sedimentation model and to determine an experimental inertial model for the impaction at cracks network entrance. These models have been also validated with other experiments with submicron aerosol (0.5 \( \mu \)m) and integrated in a global method making it possible to characterize a concrete wall and to evaluate the aerosol deposition as a function of the pressure drop between the upstream and downstream of the wall. Finally, this method could be applied to a reactor containment.

REFERENCES


Comparison between Electrical Mobility Based Aerosolization Technique and Spectrophotometry in the Measurement of Filtration Efficiency of Liquid-borne CNTs

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²Analytical Chemistry, EMPA, CH- 8600, Dübendorf, Switzerland

Keywords: Aerosol measurement, Spectrophotometry, Filtration efficiency, CNTs

Carbon nanotubes (CNTs) vary largely in length. In the filtration study of both gas-borne and liquid-borne CNTs, it is important to measure the filtration efficiency as a function of a characteristic size of CNTs. The mobility diameter may be used as such a characteristic size. In this study, the electrical mobility based aerosolization technique (Ling et al., 2009) and widely used spectrophotometry are utilized and compared with each other to test the filtration efficiency.

In the experiments, CNTs were well dispersed in solutions with various concentration of ammonium acetate as well as deionized water. Then Nuclepore filters were used to filter the suspension. Finally the filtration efficiency was tested by the two methods. For the aerosolization technique, the liquid suspension was firstly aerosolized by an atomizer. Then CNTs with different electrical mobility diameters were separated and counted respectively, the number distribution of CNTs related to different mobility diameters was obtained. By comparing the number distribution of upstream and downstream suspension, we calculated the filtration efficiency of CNTs. For spectrophotometry, the upstream and downstream liquid suspensions were tested directly by a spectrophotometer, and the overall filtration efficiency of CNTs regardless of their sizes was calculated. Fig.1 and Fig.2 showed the tested filtration efficiency by the two methods.

The filtration efficiency was influenced by the concentration of ammonium acetate in the suspension. Comparison between Fig.1 and Fig.2 showed that the aerosolization technique could identify the differences due to ammonium acetate concentration clearly. However, spectrophotometry was not sensitive enough. The electrical mobility based aerosolization technique has advantages over spectrophotometry, because it could offer more precise results of filtration efficiency related to specific mobility diameter of CNTs. Meanwhile, it was more sensitive to distinguish the different filtration efficiencies caused by different conditions of the suspension.

Figure 1. Filtration efficiency of CNTs tested by aerosolization technique

Figure 2. Filtration efficiency of CNTs tested by spectrophotometry

The properties of electrospun nanofiber media could be widely used for different filtration applications. Due to unique characteristics, such as large surface-area-to-volume ratio, low basis weight, nanoporous structures, as well as the uniform fiber size, electrospun nanofiber media could be employed for separation of airborne particles. The nanofiber media is characterized by ability to capture submicron particles, thus, decrease of fiber diameter leads to a better filtration of such particles.

The aim of this study was to analyse filtration properties of electrospun polyamide nanofiber media for monodisperse (100 and 300 nm) airborne particles filtration. Fiber diameter and basis weight were essential parameters characterising nanofiber media.

The samples of nanofiber media were electrospun from Nylon 6/6 (8 w/v and 14 w/v) and Nylon 6 (28 w/v) solutions. The electrospinning setup consisted of syringe pump (LSP01-1A, Longerpumps, PRC), internal diameter of syringe - 0.6 mm, infusion rate - 0.2 ml/h; and high voltage power supply (1.25 kV/cm), tip-to-collector distance - 16 cm. Nanofibers were collected on a vertically positioned cylindrical collector rotating at a linear speed of 150 cm/min. The cylinder was coated by polyester fabric (17 g/m2; ΔP=0.8 Pa).

The morphology of nanofiber media and average diameters of nanofibers were defined by using scanning electron microscope (Hitachi S-4800, Japan). The basis weight of nanofiber media was controlled by the duration of electrospinning process and was defined using ultra-microbalances (UYA 3Y, Poland).

In order to define filtration efficiency and pressure drop, authors developed filtration-measurement system. The monodisperse polystyrene latex (PSL) particles (diameter = 100 and 300 nm) were suspended in deionized water and were supplied to the aerosol generation system (CN 24 J, BGI Inc., USA). Particle measurements were performed applying ELPI+ instrument (Dekati Ltd., Finland). Pressure sensor (P300-5-in-D, Inc., USA) was used to measure pressure drop. In each test, the face velocity was maintained 5.3 cm/s.

Table 1 summarizes characteristics nanofiber media and filtration parameters. The highest filtration efficiency was received for N6/6_30s and N6_40 nanofiber media, which indicates that combination of fiber diameter and basis weight of nanofiber media could ensure good filtration efficiency. As reference, HEPA E11 filter properties were compared (see Table 1). HEPA E11 showed the highest filtration efficiency (89.1%) for 100 nm particles, whereas N6/6_30s and N6_40 nanofiber media indicated higher filtration efficiency for 300 nm particles.

The measurements of pressure drop for nanofiber media revealed high values, resulting in rather low quality factors compared to HEPA E11 filter (see Fig.1).

Table 1. Characteristics of tested filter media.

<table>
<thead>
<tr>
<th>Filter media</th>
<th>Fiber diameter, nm</th>
<th>Basis weight, g/m2</th>
<th>Filtration efficiency at 100 nm, %</th>
<th>Filtration efficiency at 300 nm, %</th>
<th>Pressure drop, Pa</th>
</tr>
</thead>
<tbody>
<tr>
<td>N6/6_10</td>
<td>75</td>
<td>0.20 ± 0.05</td>
<td>39.7 ± 3.0</td>
<td>52.0 ± 1.4</td>
<td>9.8 ± 0.44</td>
</tr>
<tr>
<td>N6/6_20</td>
<td>75</td>
<td>0.32 ± 0.01</td>
<td>60.8 ± 2.2</td>
<td>71.9 ± 2.0</td>
<td>25.6 ± 1.7</td>
</tr>
<tr>
<td>N6/6_30</td>
<td>75</td>
<td>0.48 ± 0.01</td>
<td>84.9 ± 1.1</td>
<td>90.9 ± 3.2</td>
<td>69.7 ± 2.7</td>
</tr>
<tr>
<td>N6/6_40</td>
<td>365</td>
<td>0.25 ± 0.01</td>
<td>28.2 ± 3.2</td>
<td>21.9 ± 1.1</td>
<td>11.0 ± 0.2</td>
</tr>
<tr>
<td>N6_20</td>
<td>225</td>
<td>0.26 ± 0.00</td>
<td>39.9 ± 0.6</td>
<td>33.8 ± 2.2</td>
<td>14.1 ± 2.1</td>
</tr>
<tr>
<td>N6_30</td>
<td>225</td>
<td>0.36 ± 0.00</td>
<td>55.6 ± 1.0</td>
<td>57.1 ± 0.0</td>
<td>35.6 ± 1.9</td>
</tr>
<tr>
<td>N6_40</td>
<td>225</td>
<td>1.01 ± 0.02</td>
<td>87.7 ± 2.0</td>
<td>87.0 ± 2.0</td>
<td>105.2 ± 1.2</td>
</tr>
<tr>
<td>HEPA E11</td>
<td>&gt;1000</td>
<td>130</td>
<td>89.1 ± 1.0</td>
<td>79.2 ± 0.4</td>
<td>19.0 ± 0.5</td>
</tr>
</tbody>
</table>

Interestingly, that the N66_s nanofiber media with smallest fiber diameter (75 nm) had higher filtration efficiency for 300 nm particles compared to 100 nm particles. This supports hypothesis that nanofiber media with such small fiber diameter is more suitable for filtration of bigger particles (300 nm) than nanoparticles (<100 nm).
Natural polymeric self-assembled filters

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Keywords: Filtration, Natural polymers, Nanoparticles.

Porous matrices obtained through mineralization of self-assembling blends of natural polymers (e.g. collagen, chitosan, cellulose, gelatin, fibroin) exhibit high open and interconnected porosity (Tampieri et al. 2008). The porous-like structure of the macromolecular template contributes to the capture of nano-particles (particle diameter < 100 nm). Preliminary results for use as filtering devices will be shown.

The raw materials used to synthesize the porous samples were gelatin (from pig skin), chitosan and genipin as cross-linker of both the polymers. Gelatin and genipin solutions were prepared dissolving commercial powders in bidistilled water, while the chitosan solution was prepared adding the commercial chitosan powder in acetic acid 2% w/w (pH \approx 3) and stirring at room temperature till its complete dissolution. The solutions were blended by mixing in a different ratio gelatin and chitosan (70:30 and 50:50) and cross-linking by genipin was carried out after mixing. The obtained blend, with the aspect of a gel, was poured into cylindrical molds to obtain the final shapes after freeze-drying.

Filtration efficiency tests were carried out on 70:30 samples using a NaCl polydisperse aerosol particles and an SMPS system (Grimm, L-DMA mod. 5400). Atomization ordinarily generates some charged droplets with an extra or more electrons. Therefore an electrostatic precipitator (EP) is used to neutralize the aerosol before arriving at the filter test section (Figure 1). Particles coming from the dilution chamber are introduced between two horizontal parallel conducting plates. The electrical potential difference between the plates is 8000 V.

Individual filtration efficiency values were calculated from three sequential samples (upstream-downstream-upstream), and the upstream particle number concentration was the average of the two measurements. Thus, any variation of the upstream concentration had minor influence on the accuracy of the determined filtration efficiency.

Figure 2 shows filtration efficiencies against particle size for 70:30 gelatin/chitosan samples (four samples). Mean filtration efficiency value was 67% on the overall particle size distribution and more than 80% below 20 nm. The most penetrating particle size was around 120 nm. The average pressure drop at a face velocity of 5 cm s\textsuperscript{-1} was 12 mbar, while for 50:50 samples was higher (19 mbar).

Preliminary results show fairly good filtration properties. The freeze-drying process will be modified to arrange polymeric internal structures in order to increase the nanoparticle collection efficiency.

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Simulating oil-mist filters

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Keywords: mist filtration, coalescence filter, blow-off, simulation, model.

The removal of liquid mists from gas streams is vitally important in applications such as crankcase ventilation, lubricated machining and cutting processes, compressed air operations and oil and gas processing. Likewise, the removal of water from oil or vice versa is an essential process operation in many industries, especially automotive (bio)fuel filtration.

The filtration of mists is a distinctly different process to the filtration of solid particles. While it is easy to design a filter with a high removal efficiency for both liquid or solid particles, the coalescence of liquid within a filter rapidly changes the effective structure of the filter during collection.

Whilst the fundamental processes of coalescence filtration have been known for almost as long as dust filtration, research into optimizing coalescing filters has not progressed as rapidly. An added complexity is closed crankcase ventilation (CCV) filters, where the oil mist being collected contains a significant amount of nanoparticle soot. To correct the gaps in knowledge and overcome the range of current problems - research into coalescence filtration is expanding at an ever increasing rate.

This work will summarise all previous models, including recent work by Kampa et al. (2014). The work will also present a fully coupled computational fluid dynamics (CFD) model (Fig. 1) which incorporates the fundamental physical processes which occur in mist filters (capture, coalescence, drainage, entrainment). Such a model, although relatively computationally intensive, appears to allow relevant processes to be resolved accurately at both micro- and macro-scales.

The work will then consider the future outlook for both the further development of the CFD model, and also the numerous gaps which remain in the science of mist filtration.


Figure 1: Coupled simulation of capture, coalescence and drainage using an Open-FOAM (CFD) based model (Mead-Hunter et al. 2013).
Diffusiophoresis of soot particles in a laminar gas flow

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Keywords: diffusiophoresis, soot aerosol, particle deposition mechanism, particle separator

Fouling of automobile EGR (exhaust gas recirculation) heat exchangers is a considerable problem caused by several deposition mechanisms of soot particles. One of them is diffusiophoresis (Hörnig et al., 2011). Whereas in this case deposition of soot is undesirable, applications exist where high deposition is aimed at like in a separator for removing microorganisms from a gas stream (Lipatov, 1991).

Diffusiophoresis describes particle motion in the same direction as a substance diffusing due to evaporation, condensation or absorption. In presence of an opposite directed diffusion by a second substance (carrier gas), the particles move in the direction of the substance with the heavier molar weight. In a wider sense diffusiophoresis can include a hydrodynamic flow called Stefan flow usually opposed to the flow of the carrier gas and in same direction as the particles (Davis, 1966).

To understand the physical effects according to diffusiophoresis a separator was designed, where a test aerosol is exposed to a concentration gradient of a diffusing substance (see figure 1). Applicable substances are those with high diffusion coefficients (water) or high vapour pressures (cyclohexane). To maintain a quasi steady-state gradient two capacious chambers can be filled with a diffusing substance or an absorbent. These chambers directly have contact with the gas flow or are separated by a membrane for selective separation of diffusing substances like water (Leckrone & Hayes, 1997).

Further investigations should give some information about a comparison between theoretical calculations and measured results. Important to know is the dependence of the diffusiophoretic velocity on particle size and diffusing streams. It will be worked towards quantifying these impacts. Additionally the aim is to find out conditions with preferably high diffusiophoretic effects, especially using convenient absorbents to achieve high concentration gradients.