FILTRATION OF ULTRAFINE PARTICLES FROM TOBACCO SMOKE USING AN IONIZER IN COMBINATION WITH AN ELECTROSTATIC FIBROUS FILTER

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Keywords: Filtration, Electrostatic Fibrous Filter, Ionisation, Air Cleaning, Ultrafine Particles

SUMMARY

Second-hand smoke infiltration from neighbours in residential environments is an emerging public issue in Denmark. Due to their adverse health effects, ultrafine particles should be removed from the indoor air. The purpose of the present study was to compare the performance of an electrostatic fibrous filter with and without ionisation with ultrafine particles from tobacco smoke in a full-scale chamber. The experiments were carried out in the full-scale chamber with a volume of 32 m³. The ultrafine particles were generated by a lit cigarette in the chamber. The concentration of ultrafine particles and ozone were monitored during the measurements. The results showed that the effectiveness of the electrostatic fibrous filter without ionizer and the filter with ionizer were 0.64 and 0.73, respectively for the ultrafine particles from tobacco smoke in the full-scale chamber. The results of the measurements showed that by using ionisation, the effectiveness was improved by 14%.

INTRODUCTION

Numerous studies in Denmark have documented that tobacco smoke contributes to elevate the concentration of ultrafine and fine particles in residential buildings (Clemmensen et al., 2005; Afshari et al., 2010).

During recent years, investigations have indicated a possible association between exposure to ultrafine particles (UFPs) and human health (Dockery, et al. 1993; Bräuner, et. al., 2008). In order to remove UFPs, different air cleaning technologies have been invented. It was shown that an electrostatic fibrous filter can effectively remove UFPs compared with other air cleaning technologies (Ardkapan et al., 2013).

An electrostatic fibrous filter has electrostatically charged fibres. Different types of electrostatic fibrous filters are used to clean the air. The filtration efficiency of fibrous filters can be changed by changing some parameters, such as airflow velocity, the electrostatic charge of the filter fibres and particle concentration (Ardkapan, 2013; Lehtimäki et al., 2005).

Ardkapan (2013) performed experiments on this kind of filter in order to determine the efficiency and the effectiveness of the filter in removing candle particles. This technology was compared with other air cleaning technologies and it was shown that this kind of filters can remove UFPs effectively. However, very few studies have compared the performance of an
electrostatic fibrous filter with and without ionisation with UFPs from tobacco smoke in the indoor environment.

The effectiveness of air cleaners in a chamber is calculated using the following equation (Nazaroff, 2000).

\[
\varepsilon = \frac{\text{CADR} / [V(n_v + n_d)]}{1 + \text{CADR} / [V(n_v + n_d)]}
\]

Where \( n_v \) is the decay rate caused by ventilation and \( n_d \) is the decay rate caused by deposition. \( V \) is the volume of the chamber. In the equation, the assumption is that the air is well mixed in the chamber. Here \( \text{CADR} \) is the clean air delivery rate of the filter regarding UFPs and it is calculated by the following equation (Shaughnessy and Sextro, 2006).

\[
\text{CADR} = n_{AC} \times V
\]

Here \( n_{AC} \) is the increase in the UFP decay rate due to the use of an air cleaner.

The purpose of the present study was to evaluate the performance of an electrostatic fibrous filter with and without ionisation against UFPs from tobacco smoke in a chamber.

**METHODOLOGIES**

The experiments were performed in a full-scale chamber with a volume of 32 m\(^3\). Low concentrations of polluting gases and particles in the supply air were ensured by using a F7-class filter, a charcoal filter followed by a second F7-class filter and finally a HEPA filter. The desired UFP concentrations, generated by a lit cigarette, were provided in the full-scale chamber. Two small fans were in operation in the chamber during all experiments in order to ensure complete mixing.

During the experiments, the UFP concentration decay due to ventilation including sink effects and the electrostatic fibrous filter with and without ionisation device were monitored. The first step of the experiment was to determine the UFP removal rate by using ventilation system including sink effects.

The second step was to determine the UFP removal rate in the chamber when the fibrous filter unit was placed at a height of 1 m. The filter unit consisted of a fibrous filter, a fan and an ionizer. The airflow rate through the filter was 60 (l/s). The ionizer was turned off during this step.

The third step was to repeat the second step when the ionizer was turned on. The tracer gas decay method was used to determine the air change rate in the chamber. The UFP removal effectiveness of the filter with and without ionisation was calculated. The concentration of ozone, the temperature and the relative humidity in the chamber was monitored during the measurements.

Particle concentration in the chamber and in the supplied air was logged using two particle counters, NanoTracer PNT 1000. This kind of particle counter could count particles ranging between 10 and 300 Nano meters (nm) with a concentration range of 0-10\(^6\) UFPs/cm\(^3\). According to the manufacturer’s manual, the uncertainty of the readings of NanoTracer is ±1500.
The ozone level was logged by using the ozone monitor BMT 930 in the chamber and the ozone monitor 2B Technologies Model 205 for the supplied air. The ozone monitors could accurately detect the ozone level down to 1 ppb. The temperature and humidity of the chamber were also monitored using a humidity and temperature logger, Tinytag. The expended uncertainty of the efficiency is approx. 1%.

RESULTS AND DISCUSSION

The first step of the experiment was to determine the UFP removal rate obtained by using the ventilation system including sink effects in the chamber. Figure 1 shows the UFP concentration over the time. By using the trend line best fitted to the curve, it was possible to determine the UFP removal rate obtained by using the ventilation system 1.8 h\(^{-1}\).

![Figure 1 Removal of cigarette smoke particles by a ventilation system in a full-scale chamber.](image)

During the second step, the fibrous filter unit was placed in a full-scale chamber. The airflow rate through the filter was 60 l/s. Figure 2 shows the UFP concentration in the chamber over time. The UFP removal rate of the ventilation system together with the fibrous filter was determined to be 4.9 h\(^{-1}\).

![Figure 2 Removal of UFPs from cigarette smoke by a filter without ionisation in a full-scale chamber.](image)
Figure 3 shows the measurement results of the third step, when the fibrous filter unit was placed in the chamber and the ionizer was turned on. The UFP removal rate was determined to be 6.7 h\(^{-1}\).

By using Equation 1 and Equation 2, it was possible to determine the effectiveness of the fibrous filter for both cases, i.e. with ionizer and without ionizer.

Table 1 illustrates the calculations of CADR and effectiveness for both cases i.e. without ionization and with ionization. In the table, \(n_d\) shows the UFP removal by deposition, \(n_v\) removal of UFPs by means of ventilation system and \(n_{ac}\) the removal rate of air cleaner.

<table>
<thead>
<tr>
<th>Air cleaners</th>
<th>Particle decay rate with air cleaner ((n_v+n_d+n_{ac})) (h(^{-1}))</th>
<th>Particle decay rate of system without air cleaner ((n_v+n_d)) (h(^{-1}))</th>
<th>CADR (m(^3)/h)</th>
<th>Effectiveness ((\varepsilon))</th>
</tr>
</thead>
<tbody>
<tr>
<td>With ionization</td>
<td>6.7</td>
<td>1.8</td>
<td>147</td>
<td>0.73</td>
</tr>
<tr>
<td>Without ionization</td>
<td>5.0</td>
<td>1.8</td>
<td>97</td>
<td>0.64</td>
</tr>
</tbody>
</table>

Experimental data showed that an ionisation device improved the effectiveness of the filter. In addition, the concentration of ozone did not increase in the full-scale chamber during the measurements.

The results of the measurements showed that by using ionisation, the UFP removal rate was improved by 50%, which means that the effectiveness was improved by 14%. It should be noted that the concentration of ozone in the full-scale chamber was at the same level as the background concentration.
On the other hand, further examination of electrostatic fibrous filters with different properties is needed in order to study the long-term performance of an ionizer on the effectiveness of the filter in residential buildings.

CONCLUSIONS

The results showed that the effectiveness of the electrostatic fibrous filter without ionizer and the filter with ionizer for the ultrafine particles from tobacco smoke in the full-scale chamber was 0.64 and 0.73, respectively. Therefore, it is concluded that an ionizer can improve the effectiveness of a filter by 14%.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the financial support given by ELFORSK, Danish energy programme for research and development in energy efficiency.

REFERENCES