ERROR RESEARCH ON A HEPA FILTER MEDIA TESTING SYSTEM OF MPPS(MOST PENETRATION PARTICLE SIZE) EFFICIENCY

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ABSTRACT
Referring to the Europe Standard En1822, we design a MPPS (most penetration particle size) efficiency testing system for HEPA filter media. This Standard is based on particle counting methods with optical particle counter. It also allows ULPA (ultra low penetration air) filters media to be tested, which is not possible with the previous test methods because of their inadequate sensitivity. In our error analysis, we analyses the data from the testing result and study the possible reason to produce error in the procedure. First, we determine that the mainly error sources lie in the three part of testing procedure, viz. particle counting, flow rate determining and dilution system. Then, the stochastic errors’ effect is considered to the testing system. Last, we draw the conclusion that our testing equipment has good stability and the testing data can repeat well.

INDEX TERMS
MPPS (Most Penetration Particle Size), error, filter media, filtration efficiency

INTRODUCTION
With the development of modern science and technology, people have higher control in quantity and size of particles in air than before. Because the filter media efficiency is the most important index of aerosol controlling, a useful testing method is more and more important. The present China’s standards have not been amended for many years and aren’t adapting to the development of filter media. According to it, Tianjin University design a MPPS (most penetration particle size) efficiency testing system for HEPA filter media, referring to the Europe standard En1822(BSI 1998).

This European Standard applies to high efficiency particulate and ultra low penetration air filters (HEPA and ULPA) used in the field of ventilation and air conditioning and for technical processes, e.g. for clean room technology or applications in the nuclear and pharmaceutical industry. It establishes a procedure for the determination of the efficiency on the basis of a particle counting method using a liquid test aerosol, and allows a standardized classification of these filters in terms of their efficiency (R. Wepfer 1995).

Specimens of the sheet filter medium are fixed in a test filter assembly and subjected to the test air flow corresponding to the prescribed filter medium velocity. Furthermore, the measurement of the pressure drop is made at the prescribed filter medium velocity. In order to determine the efficiency, partial flows of the test aerosol are sampled upstream and downstream of the filter medium. Using a particle counting instrument, the number concentration of the particles contained is determined from various particle sizes. The results of these measurements are used to draw a graph of efficiency against particle size for the filter medium, and to determine the particle size for which the efficiency is a minimum. This particle size is known as the "most penetrating particle size" (MPPS). When measuring the particles on the upstream side of the filter medium it may be necessary to use a dilution system in order to reduce the concentration of particles down to the measuring range of the particle counter used.

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PARTICLE COUNTING ERROR ANALYSIS
In an optical particle counter, the particles are led individually through an intensively illuminated measuring volume. When passing through the measuring volume, the particle scatters light, which is detected at a defined spatial angle by a photo detector and transformed into an electrical pulse and transformed into an electrical pulse. The level of this pulse allows conclusions to be drawn about the size of the particle, and the number of pulses per unit time is an indicator of the particle concentration in the air volume, which is analyzed.

Our testing system chooses Japanese RION KC-22A optical particle counter. Which have five channel: 0.1µm~0.15µm, 0.15µm~0.2µm, 0.2µm~0.3µm, 0.3µm~0.5µm, >0.5µm, sampling volume is 0.1 CFM. According above, the calculate method of overlap loss is

\[
\frac{C}{C_0} = e^{-CV}
\]

Where C is particle concentration measured by OPC; C₀ is actual particle concentration in the sampling air; V is air volume through OPC

Through the actually testing the overlap loss of OPC is showed in the figure 2:

From the figure 2, we can see that when the particle concentration exceeds 10000 Entries/ L, the overlap loss will reach 5%. So it is an important factor. To the optical particle counter KC-22A, the measured concentration should
less than 10000 Entries/litre in order to ensure the veracity (Yongxiang Li 2004). If the particle concentration is too high so-called coincidence errors (overlap loss) occur. In order to testing the HEPA and ULPA medium, the upstream concentration is so high that we should adopt suitable dilution number to dilute upstream particle concentration, as a result keep the particle number in sampling air less than 10000 Entries/ L.

DILUTION SYSTEMS ANALYSIS

Dilution systems reduce the concentration of an aerosol to a defined extent by the addition of a particle-free gas (usually air). The dilution number for the relevant particle size ranges independent of the particle size and shall be constant over time.

As is narrated above, when measuring the particles on the upstream side of the filter medium it may be necessary to use a dilution system in order to reduce the concentration of particles to the measuring range of the particle counter used. Consequently, the dilution proportion becomes an important factor to the veracity of testing. The filter efficiency is calculated by:

\[
E = \frac{P_{\text{upriver}} \times D - P_{\text{downriver}}}{P_{\text{upriver}} \times D} \quad (2)
\]

Where \( E \) is filter efficiency; \( P_{\text{downriver}} \) is downriver particle number (measured by OPC); and \( P_{\text{upriver}} \) is upriver particle number (measured by OPC); \( D \): Dilution proportion

In case the dilution proportion change, the filter efficiency will change a lot. To validate the relationship between the proportion difference and the testing error, we do the experiment. The detail information is showed in the table 1.

\[
\text{Table 1} \quad \text{Dilution proportion difference result in filter efficiency error}
\]

<table>
<thead>
<tr>
<th>Particle size</th>
<th>Normal Testing efficiency</th>
<th>Diff 20%</th>
<th>Diff 30%</th>
<th>Diff 40%</th>
<th>Diff 50%</th>
<th>Most error</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mu m )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.12</td>
<td>99.6049%</td>
<td>99.5572%</td>
<td>99.5526%</td>
<td>99.4297%</td>
<td>99.3057%</td>
<td>0.2992%</td>
</tr>
<tr>
<td>0.17</td>
<td>99.6497%</td>
<td>99.6067%</td>
<td>99.5445%</td>
<td>99.4730%</td>
<td>99.3443%</td>
<td>0.3054%</td>
</tr>
<tr>
<td>0.25</td>
<td>99.8879%</td>
<td>99.8798%</td>
<td>99.8593%</td>
<td>99.8351%</td>
<td>99.7879%</td>
<td>0.1000%</td>
</tr>
<tr>
<td>0.4</td>
<td>99.9937%</td>
<td>99.9949%</td>
<td>99.9923%</td>
<td>99.9932%</td>
<td>99.9877%</td>
<td>0.0060%</td>
</tr>
</tbody>
</table>

Note: the mean of Diff20% is the true proportion less the nominal proportion 20%, and so on.

As the usage of the testing system, dilution proportion will be changed. The particle number measured by OPC multiplying the dilution proportion will less than the actual number. The condition is same as the table 1. We can see from the table 1 that Diff50% will not influence the filter efficiency. To draw the all-pervading conclusion, we do the theoretic analysis.

\[
\text{Table 2} \quad \text{Basic conditions}
\]

<table>
<thead>
<tr>
<th>Normal Dilution Proportion</th>
<th>( P_{\text{upriver}} )</th>
<th>( P_{\text{downriver}} )</th>
<th>Filter Efficiency</th>
<th>Wrong Dilution Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n_i )</td>
<td>( A_i )</td>
<td>( B_i )</td>
<td>( E_i )</td>
<td>( m_i )</td>
</tr>
</tbody>
</table>

When the dilution proportion changes, it results in the exchange of the proportion from \( n_i \) to \( m_i \). Then the filter efficiency \( E_i \) will change to \( E'_i \):

\[
E'_i = \frac{m_i \cdot A_i - B_i}{m_i \cdot A_i} = \frac{m_i \cdot A_i - n_i \cdot A_i \cdot (1 - E_i)}{m_i \cdot A_i}
\]

(3)

Defining the dilution proportion exchange rate is \( Y_i \), namely \( Y_i = \frac{m_i}{n_i} \), the formula change to:
When the dilution proportion change, the new filter efficiency $E'_i$ relate with the $Y_i$ and original efficiency $E_i$. According to the EN1822’s filter class, we can draw the conclusion listed in the table 3.

<table>
<thead>
<tr>
<th>EN1822 filter class</th>
<th>Over value</th>
<th>$Y_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MPPS</td>
<td>100%</td>
</tr>
<tr>
<td>H10</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>H11</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>H12</td>
<td>99.5</td>
<td>99.5</td>
</tr>
<tr>
<td>H13</td>
<td>99.95</td>
<td>99.95</td>
</tr>
</tbody>
</table>

From the table 3, we can know that the less of the filter medium efficiency, the more influence of the proportion difference. To the grade H13 or the higher filter, 40% dilution proportion difference will not affect the filter proportion.

**TEST AIRFLOW RATE DETERMINING**

To the MPPS testing system, the filter element is tested at nominal air volume flow rate. In the testing procedure, the airflow rate should be maintained regularly in accordance with the manufacturer’s instructions. If airflow changes happen, the filter efficiency will alter. To see the change, we do the experiment in our system. In this experiment, we assume the original flow rate is 2.67 cm/s. Then the flow determining error happens: the actual flow reach to 6.99 cm/s, 5.33 cm/s, 3.99 cm/s, namely change 261%, 200%, 150%, but the device shows the flow rate is 2.67 cm/s. The efficiency curve is showed in figure 3.

![Figure 3](image-url)
We can see the relationship between the airflow rates and filter medium efficiency. Namely, as the increase of the airflow rate, the efficiency will enhance. The conclusion is accordance with the Air Filter ABC (Caijie 2002). We can see form the figure 3, the flow rate change 261%, the filter penetration variety to 0.12μm will reach 355%. From the many experiment we find that in order to ensure the testing accuracy the flow rate change should be remained ±5%.

STOCHASTIC ERRORS ANALYSIS

To validate the stochastic errors’ effect (Qianwei 2001) to the testing result, we test A~F series filter at different time and test one series filter more than 5 times. Although the testing result is not same completely, the filter efficiency is consistent and the difference is less than 5%. It showed our testing system have good stability. Stochastic errors are not the mainly factor to the machine.

CONCLUSION

Form the analysis above, we can find the mainly error source may occurred in the three-part procedure in the testing: namely particle counting, dilution system and flow rate determining. To ensure the accurate of counting, the particle concentration should less than 10000 Entries/ L; to ensure the accurate of upstream particle concentration, the dilution proportion change should be remained in 40%, otherwise exchange it; to ensure the testing accuracy, the flow rate change should be remained ±5%. From many testing results, we draw the conclusion that our testing equipment has good stability and the testing data can repeat well.

REFERENCES