Advanced Filter Tester for Size Resolved Penetration Measurements

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ADVANCED FILTER TESTER FOR SIZE RESOLVED PENETRATION MEASUREMENTS

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Abstract

Aerosol filtration is the most widely used process to capture aerosol particles. It is used in various applications throughout the different areas of interest (emissions cleaning, occupation safety and health, air-conditioning, etc.). In most of these applications, it is useful to have information about penetration, or filtration efficiency, of the chosen filtration material. Information available from filter manufactures, a background of a decision on which filter to use for the specific purposes, is usually not detailed enough. There are well-known standards describing how to perform the testing of filter efficiency, such as EN 1822 for HEPA and ULPA filters; EN 143 and 149 for respirators. Nevertheless, all these tests give only limited and sometimes even misleading information about penetration of tested filter material (giving information only about total penetration; using polydisperse aerosol with mode at about 300 nm). Therefore, new, fully controlled filter testing instrument was developed and thoroughly tested, providing a size-dependent penetration; proving a very good precision and reproducibility of the results. Using this instrument we have measured several commercial filter materials including standard filters (Whatmann, Milipore, Pall) and personal respirators (e.g. 3M). For personal respirators the maximum penetration was ranging between units and tens of percent, while the pressure drops were usually in hundreds of Pa. In the case of standard filters the maximum penetrations were in orders of tenths to hundredths of percent having pressure drops in orders of kPa units. The most penetrating particle sizes were in vast majority of cases bellow 100 nm.

Key words:

Filter tester, size resolved penetration, filters, respirators.

1. INTRODUCTION

Filtration process is known and well described for several decades [1; 2]. The first filtration methods for water treatment are even mentioned in ancient Sanskrit text (3rd or 4th century CE) [3]. Generally, filtration is a process dealing with capture of liquid or solid materials from liquid or gas media using different types of filtration media. It is utilized in variety of applications as emissions cleaning [4], occupation safety and health [5], air-conditioning [6], or vacuum cleaning. Or in other words, the filtration touches many different branches of everyday life (such as industry, medicine and many others). In aerosol science, filters are used either for aerosol sampling or for production of particle-free air (HEPA filters) [7], e.g. in clean rooms or laminar boxes. In most of these applications, it is commendable to determine penetration, or filtration efficiency, of the chosen filtration unit.

The standards describing how to perform the testing of filter efficiency can be easily found, such as EN 1822 for HEPA and ULPA filters; EN 143 and 149 for respirators. Nevertheless, all these tests are performed using polydisperse aerosol with given Count Median Diameter (CMD) positioned close to the Most Penetrating Particle Size (MPPS), assumed to be at 300 nm in diameter. Moreover, these tests measure only overall penetration giving no information about the real MPPS that is often shifted towards smaller diameters. It also means that the standard omits the fact that penetration is a function of particle size. Thus, the results of such analysis give only limited information about penetration of tested filter material.

Another issue regarding the official filter testing methods is related to the choice of testing particle material [8]. Shape of these particles (cubical shape for NaCl) does not fully comply with the commonly used theoretical assumption in aerosol science – spherical particles (e.g. when we select monodisperse particles in the DMA). Therefore, precise and detailed filter testing requires size-resolved measurement using well-defined aerosol particles having proper shape (e.g. $(NH_4)_2SO_4$ – ammonium sulphate).

All of the previously mentioned issues may result in inaccurate or even misleading characterization of filters being tested. Therefore, we decided to develop a filter tester unit for size resolved penetration measurements of filter media giving us a complex control over the measurement process following all recommended suggestions for proper filter testing. The filter testing unit was thoroughly tested and a large quantity of filters and filtration media was characterized using this unit.

2. EXPERIMENTAL SET-UP

Even though commercial filter testers exist on the market (e.g. Automated Filter Tester 3160, TSI), we have developed our own filter testing instrument. The basic idea is to challenge the filter with a well-defined aerosol material having ideally one size of the particles (monodisperse aerosol) and to quantify the concentration in front and behind the tested filter media. The measurement is then repeated for several different particle sizes and consequently the resulting size resolved penetration (or filtration efficiency) is calculated).

The filter tester (see Fig. 1) is based on several important parts: aerosol generation, monodisperse particle size selection, filter holder and the detection of penetrated fraction. All individual parts are described in more details in following paragraphs.

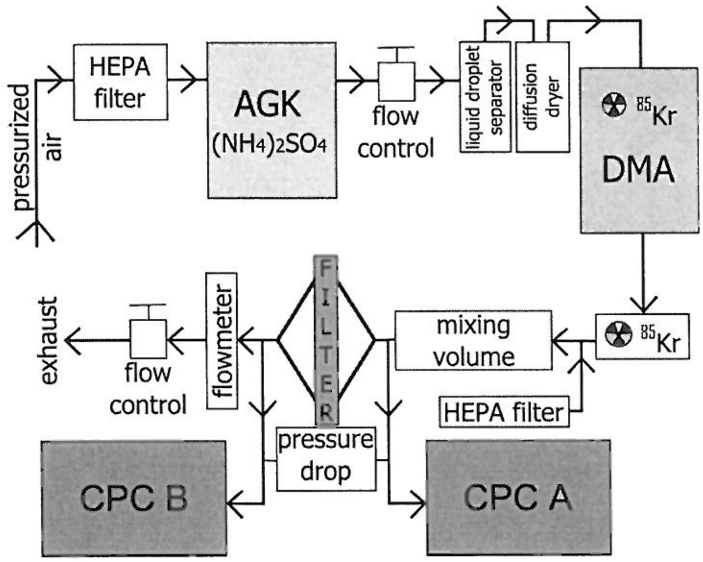

Fig. 1 Schematics of the filter tester.

The aerosol generation system consists of a pressurized air central supply, commercial (AGK 2000, Palas) or home-made (Squirrel, made at IAC, AS CR, Brno) aerosol generator (both nebulizer type), flow control, liquid droplet separator and diffusion dryer. The system generates dry aerosol particles of known composition – ammonium sulphate (AS) particles were used in most of the measurements. Drying of aerosol particles before entering the DMA is vital for proper particle size selection. For example, in the case of ammonium sulphate, the over-sizing could make up to 20% in diameter at 40% RH.

Particle size selection system consists of a DMA (Differential Mobility Analyzer, Vienna type, home-made at ICPF) built into home-made electrostatic classifier and two ^{85}Kr neutralizers. The selection of chosen size fraction is based on the separation of narrow size fraction of originally polydisperse aerosol in electrostatic field (electrical mobility of aerosol particles). Two radioactive neutralizers are used in the system. First one was used to reach Boltzmann charge equilibrium on entering polydisperse aerosol and second one to prevent monodisperse aerosol particles from deposition on tubing walls due to electrostatic charge on particles selected by the DMA.

The filter holder can accommodate filter media having 47 or 25 mm in diameter or gas mask filters. The holder was designed to be air tight to prevent possible errors in the measurement.

The detection part of the system is based on two CPCs (Condensation Particle Counter, 3025, TSI). It includes also a system of solenoid valves, which allows switching between the two CPCs to account for possible different readings of both CPCs as well as for changes in concentration of challenging material in front of the filter. The correction for differences in counting of the two CPCs as well as for the different location of each CPC (upstream or downstream of the filter) was taken into account in our calculations.

The size range of size resolved measurement was set-up from 20 nm to 450 nm. The flow-rate was set according to current requirements - usually several tens of lpm (typical flow rates through filters). The whole system is controlled by the means of home-made LabVIEW code. The minimum penetration of such a filter testing system is limited by the accuracy of CPCs used – in our case it corresponds to penetration of 0.001% (or filtration efficiency of 99.999%).

Such a filter testing unit offers complex control over the measurement procedure, utilization of any challenging material in a properly defined way and clear interpretation of results.

3. EXAMPLE OF RESULTS

Variety of materials was used during the testing of the filter testing unit. In order to check the consistency of tested filter material and the variability between individual filtration sheets or pieces, we have usually repeated the measurement several times. The monitoring of filter material loading was also included within this study. Basically, two different types of materials were studied - PPE (Personal Protective Equipment) masks and filter media used in aerosol science for sampling of different types of aerosol particles.

Several PPE materials were measured including various manufacturers (3M, Segre, Refil) as well as different labeling (FFP1 – FPF3). Usually, more pieces of the same mask were cut and tested to verify the material variability. Moreover, different pieces of the same mask type were taken to check the variation between individual pieces.

The aerosol sampling filters included four basic types of materials (cellulose, Teflon membrane, glass and quartz fibers and polycarbonate). All of them were made by various manufacturers (Millipore, Whatmann and Pall). Again, the study of these materials included the reproducibility of the measurements, the variability of filter materials (within the same batch). Furthermore, it included the study on loading of different filtration materials.We have performed also testing of filtration materials for commercial companies to perform a detailed characterization of the filter media they had manufactured.

Even though an extensive study was performed on all the materials, this contribution is not aimed to present detailed results of the measurement. Moreover, the capacity of the abstract is limited and does not allow for a thorough presentation of all the obtained results together with comprehensive discussion of the outcomes. It means that only very general figure displaying the average values of different materials measured is presented here (see Fig. 2). This study is focused mainly on the filter tester unit itself, its design, its performance and advantages of such a system.

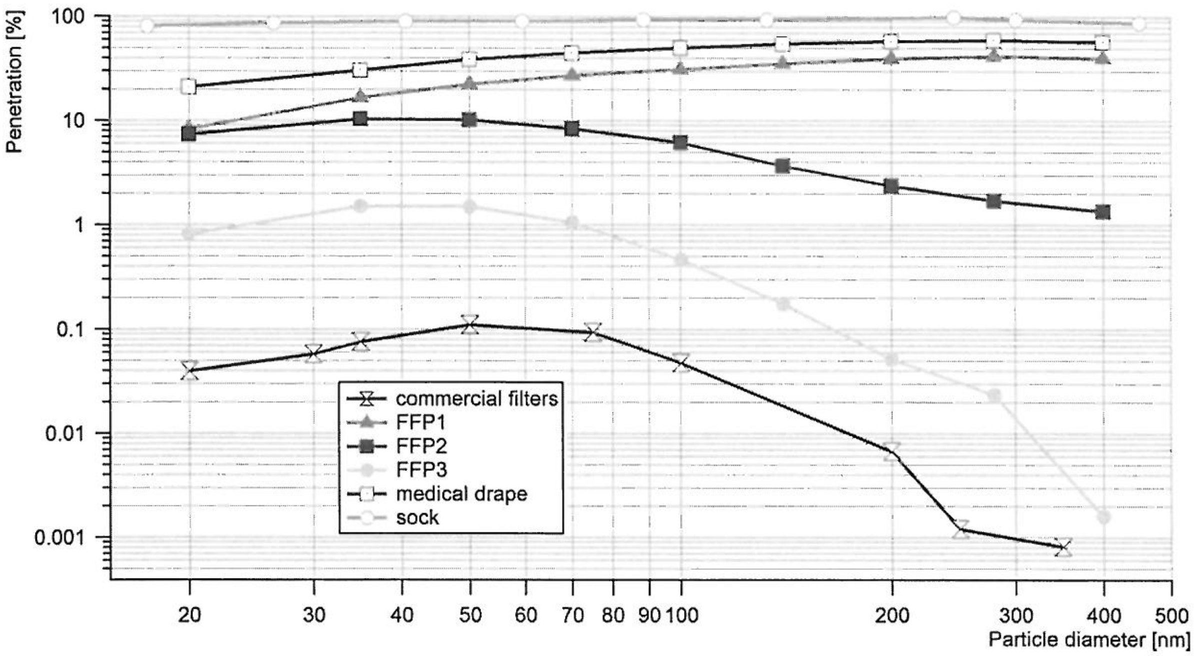

Fig. 2 Size resolved penetration of different filtration media

As can be seen from Fig. 2, it is obvious that different filtration media cover a wide range of penetration (filtration efficiency). The commercial filters (materials used for aerosol sampling) were mostly having penetrations about 0.1 % and lower depending on the material, porosity and other characteristics. The pressure drops measured for these materials were ranging in units of kPa. The penetration of PPE can be easily differentiated by their grade – starting at 1 % for FFP3 and going up to 10% for FFP2 and FFP1. Nonetheless, since these materials should not inhibit breathing of the person, who is using it, the pressure drops of these materials are usually in tenths of kPa. The medical drape used in hospitals to prevent the doctors from being infected by their patients and vice versa was displaying very poor performance (penetration in units of tens of percent). In other words such a material protects people just from very large particles in form of big droplets (sneezing, coughing) – several microns in diameter. The measurement of penetration through common sock was added to compare the results to other materials measured in order to have measure of performance of common material.

4. CONCLUSIONS

Testing of various filter materials proved the functionality, good precision and reproducibility of a home-made filter tester. During the testing of filtration materials we have measured several commercial filter materials including standard filters (Whatmann, Milipore) and personal respirators (e.g. 3M). In the case of personal respirators the maximum penetration were ranging from units to the tens of percent, while the pressure drops were usually in hundreds of Pa. In the case of standard filters the maximum penetrations were in orders of tenths to hundredths of percent having pressure drops in orders of kPa units. The MPPS were in majority of cases bellow 100 nm as was shown by extended study (not visible from example shown here).

This study also confirmed our initial doubts about the standard filter efficiency testing method, regarding the used testing material, setting of MPPS and measuring only the total penetration of polydisperse aerosol. Therefore, the results obtained with our filter testing unit could serve also as a basis for improvements in the filter efficiency standard method, which seems to give insufficient and in some perspectives limited or even misleading information.

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REFERENCES

[1] SPURNÝ, K. R., LODGE, J. P. *Collection Efficiency Tables for Membrane Filters Used in the Sampling and Analysis of Aerosols and Hydrosols.* NCAR-TN/STR-77, Vol. I, 1972.

[2] HINDS, W.C. *Aerosol technology: properties, behavior and measurement of airborne particles*, J.Willey & Sons, 2nd ed, 1998. p. 182-205.

[3] BAKER, M. N. *The Quest for Pure Water: the History of Water Purification from the Earliest Records to the Twentieth Century.* 2nd Edition. Vol. 1. Denver, Co.: American Water Works Association, 1981.

[4] de JONG, W., ÜNAL, Ö., ANDRIES, J., HIEN, K.R.G., SPLIETHOF, H. *Biomass and fossil fuel conversion by pressurised fluidised bed gasification using hot gas ceramic filters as gas cleaning.* Biomass and Bioenergy, 25, 2003. p. 59-83.

[5] NIOSH *Guide to the Selection and Use of Particulate Respirators Certified Under 42 CFR 84.* WashingtonDC: National Institute of Occupational Safety and Health Publication No. 96-101, 1996.

[6] WANG, F., YOSHIDA, H., KITAGAWA, H., MATSUMOTO, K., GOTO, K. *Model-based commissioning for filters in room air-conditioners.* Energy and Buildings, 37, 2005. p. 1225-1233.

[7] HERING, S.V. *Air sampling for evaluation of atmospheric contaminants.* American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 7th edition, 1989.

[8] BOSKOVIC, L., ALTMAN, I.S., AGRANOVSKI, I.E., BRADDOCK, R.D., MYOJO, T., MANSOO CHOI, M. *Influence of Particle Shape on Filtration Processes.* Aerosol Science and Technology, 39, 2005. p. 1184-1190.