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Materials Science & Technology

Determination of the Effectiveness of Respilon and other Filter Media against Airborne Particles

The filtration efficiency of the filter medium was determined by measuring the particle number concentrations, as the most sensitive parameter for nanoparticles, upstream and downstream of the filter with Condensation Particle Counters (CPCs). The test aerosols were generated by a Collison type atomizer with diluted suspension of 2-ethylhexyl sebacate (DEHS) in 2-propyl alcohol. The test filter medium was subjected to the test air flow corresponding to the flow rate of 7.2 LPM (Liter/minute), which is corresponding to 10 cm/s face velocity on the filter medium.

Three particle size measurements were performed for each of the conditions, to get an overview of the size distribution of the generated nanoparticles, by a Scanning Mobility Particle Sizer (SMPS). Differential Mobility Analyzer (DMA) and CPC are combined together to function as SMPS. Partial flow of the test aerosol was sampled upstream of the filter medium and sent to the SMPS for measurement. The particle number-size distributions were obtained.

The filtration tests were performed with monodisperse test aerosols which were classified by a DMA. Partial flows of the test aerosol were sampled upstream and downstream of the filter, and the fractional penetration was determined from the upstream and downstream number concentrations. The size of the monodispsere particles exiting the DMA was further on adjusted by changing the DMA voltage and the values were chosen according to the scan performed in the particle size measurement. Particles were counted upstream and downstream from the filter medium using two condensation particle counters in parallel.

1. Test Setup

The schematic of the setup for the test using monodisperse nanoparticles is shown in Figure 1. The Collison type atomizer was used to generate nanoparticles from a DEHS solution. A diffusion dryer was used to dry out water vapor from the sample flow. Make-up air next to the DMA and a vacuum positioned downstream draws the test aerosol through the test filter mounting assembly. The flow rate was controlled and measured to match the desired test volume flow rate.

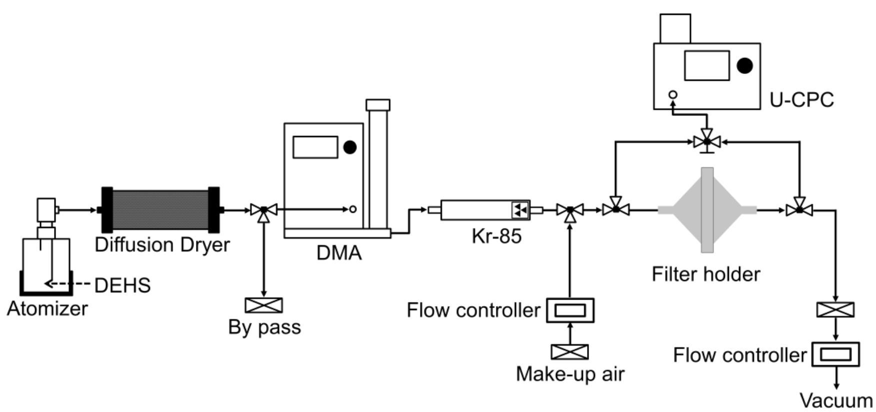

Figure 1. Setup for test using atomized nanoparticles.

2. Testing procedure

2.1 Preparatory checks

All the equipment was turned on following the manufacturers' instructions. The atomizer was turned on and enough time was provided for the particle generation to stabilize. The status of the CPCs and DMA was normal. The controllers for the sheath air and high voltage were checked. The filter medium was placed in the filter holder with proper tight connection. Firstly, the zero count was checked for the particle counter when measuring downstream particle concentration with the aerosol generator switched off and the filter medium in position. Leakage of the system was tested by measuring the upstream and downstream particle concentration with the aerosol generator switched off.

2.2 Measurement of size distributions of generated nanoparticles

For the measurement, the particle number-size distribution upstream of the filter medium was measured by the SMPS (Figures 2 and 3). The measurements were performed three times for each condition in order to obtain the average value and the respective standard deviation. In order to generate enough number concentrations of monodisperse nanoparticles for the filtration tests, two different sample suspensions with DEHS 0.05 and 0.1 % for 20-100 nm size range and 100-500 nm size range, respectively, were used in the tests. Figures 2 and 3 show size distributions of each condition.

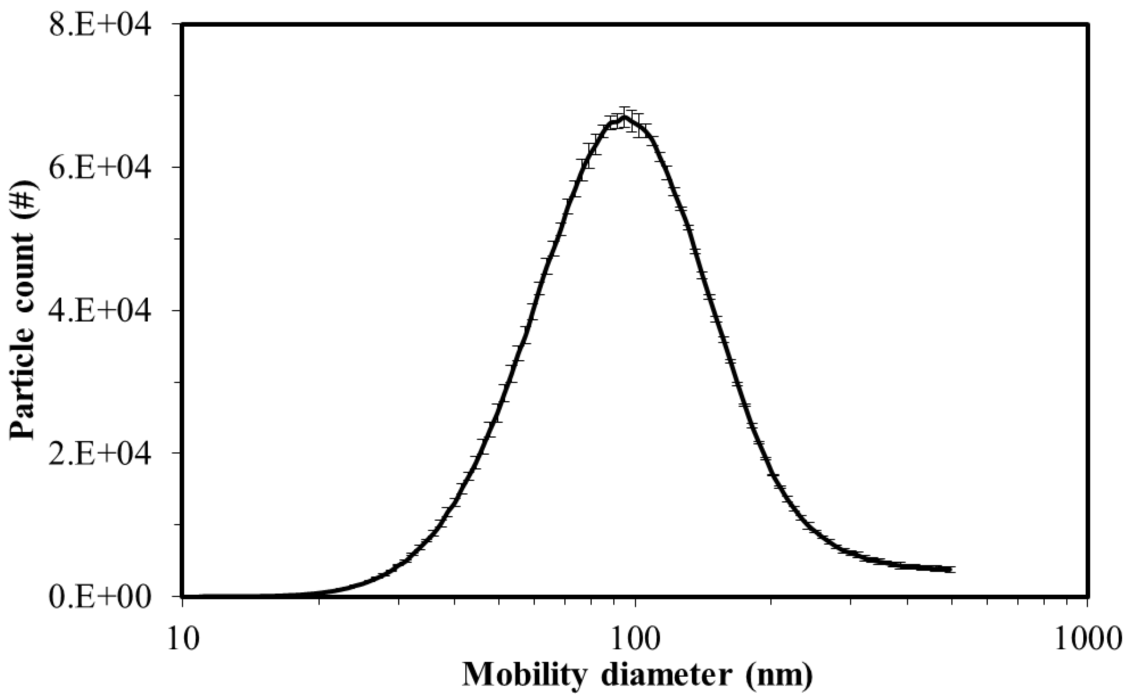

Figure 2. Size distribution upstream (DEHS 0.05 %, for 20-100 nm size range)

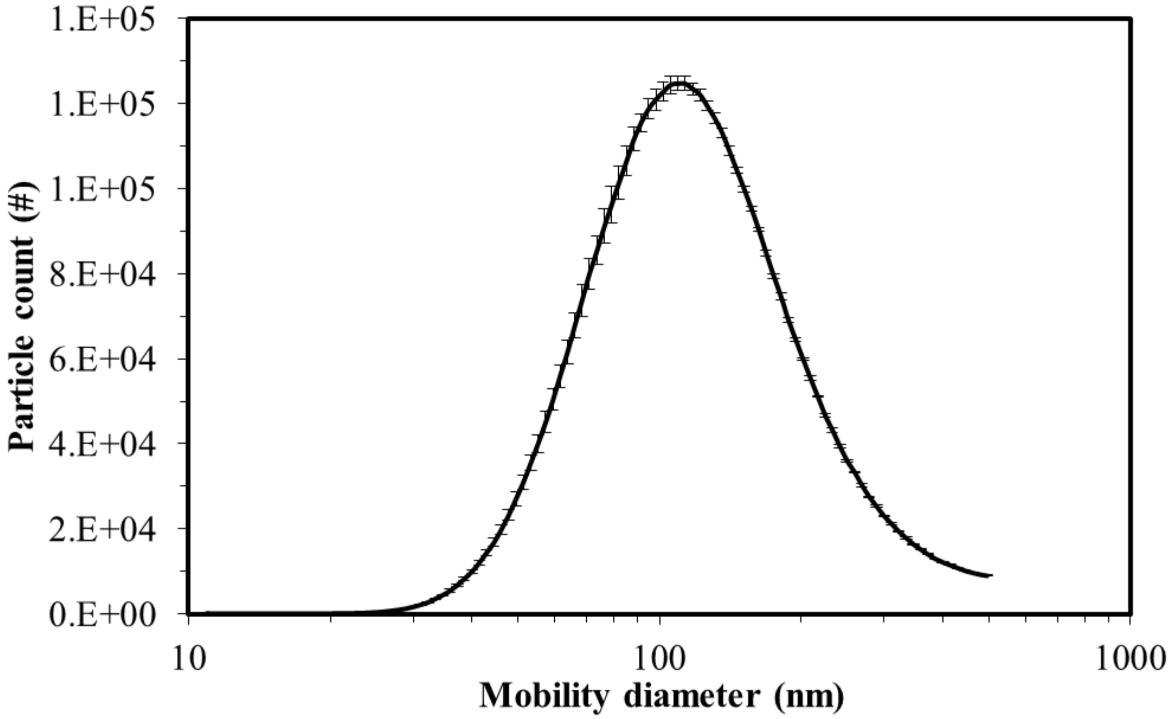

Figure 3. Size distribution upstream (DEHS 0.1 %, for 100-500 nm size range)

2.3 Measurement of the filtration efficiency using monodisperse nanoparticles

For the monodisperse tests, 9 interpolation particle sizes, 20, 30, 45, 70, 100, 150, 220, 335 and 500 nm, were selected from the range of the generated particles for the efficiency/penetration tests. The particle number concentrations upstream and downstream of the filter, were measured consecutively using the particle counter. When switching from one test particle size to another, a long enough waiting period was observed before starting the CPC measurement, to ensure that the particles of the previous size are flushed out of the system. In Table 1, the count values for each of the sizes, all of the experimental setup conditions and pressure drops on the clean filters are shown. Additionally, penetration and efficiency for each sample are calculated (Table 1) and presented in Figures 4-9. The comparison of the obtained efficiencies is shown in Figure 10. The figure of merit for each filter was also calculated and results were shown in Table 1 and Figure 11. For Pegatex S, the figure of merit wasn't able to calculate due to the lower pressure drop than measurement limit of the pressure gauge. The figure of merit Q is defined as

$$Q = -\ln(P)/\Delta p,$$

where P is the penetration and Δp is the pressure drop. Since $-\ln(P)$ provides a measure of the filter efficiency, the figure of merit represents the ratio between the efficiency and the pressure drop Δp. Good filters give high efficiency and low pressure drop, thus larger values of Q indicate better quality of the filters. It should be noted that Q is not the only criterion to evaluate filtration performance. Detail information for calculation of the figure of merit can be found in the published paper by Wang et al. (Journal of Aerosol Science 39, 323-334, 2008). Using 100 seconds of sampling time and taking the average value improve the accuracy of the measurement.

Table 1. Overview of the penetration/efficiency calculations

Respilon H11							
Particle size (nm)	Efficiency	Standard deviation	Average number count in 100 seconds		penetration	Pressure drop (Pa)	Figure of Merit, Q (1/Pa)
			Upstream	Downstream			
20	0.9367	0.0111	59,293	3,740	0.0633		0.0238
30	0.8768	0.0141	566,254	69668	0.1232		0.0181
45	0.8379	0.0109	3,009,807	487464	0.1621		0.0157
70	0.8098	0.0105	7,514,280	1430129	0.1902		0.0143
100	0.8174	0.0088	9,106,210	1660900	0.1826	116	0.0147
150	0.8253	0.0164	7,420,157	1297063	0.1747		0.0150
220	0.8561	0.0157	2,555,263	366915	0.1439		0.0167
335	0.9014	0.0115	441,629	43261	0.0986		0.0200
500	0.9356	0.0075	77,891	4981	0.0644		0.0236
Respilon 57							
Particle size (nm)	Efficiency	Standard deviation	Average number count in 100 seconds		penetration	Pressure drop (Pa)	Figure of Merit, Q (1/Pa)
			Upstream	Downstream			
20	0.9326	0.0111	60,325	4,108	0.0674		0.0186
30	0.8693	0.0012	562,312	73,495	0.1307		0.0140
45	0.7960	0.0085	2,509,233	511,161	0.2040		0.0110
70	0.7448	0.0018	7,332,730	1,871,151	0.2552		0.0094
100	0.7039	0.0022	8,766,899	2,595,818	0.2961	145	0.0084
150	0.7126	0.0044	8,411,110	2,418,249	0.2874		0.0086
220	0.7503	0.0057	3,025,093	755,409	0.2497		0.0096
335	0.8263	0.0030	567,849	98,633	0.1737		0.0121
500	0.8937	0.0011	95,354	10,132	0.1063		0.0155
Respilon PM2.5							
Particle size (nm)	Efficiency	Standard deviation	Average number count in 100 seconds		penetration	Pressure drop (Pa)	Figure of Merit, Q (1/Pa)
			Upstream	Downstream			
20	0.7030	0.0182	55,611	16,549	0.2970		0.0179
30	0.5850	0.0172	540,815	224,176	0.4150		0.0129
45	0.4545	0.0097	2,328,430	1,270,402	0.5455		0.0089
70	0.3997	0.0196	6,607,199	3,963,310	0.6003		0.0075
100	0.3967	0.0187	7,724,270	4,658,857	0.6033	68	0.0074
150	0.4467	0.0205	7,905,593	4,366,997	0.5533		0.0087
220	0.5179	0.0121	2,840,394	1,367,310	0.4821		0.0107
335	0.6209	0.0223	530,724	200,163	0.3791		0.0143
500	0.7000	0.0158	88,400	26,393	0.3000		0.0177

Particle size (nm)	Efficiency	Standard deviation	Average number count in 100 seconds		penetration	Pressure drop (Pa)	Figure of Merit, Q (1/Pa)
Pegatex 60gsm							
			Upstream	Downstream			
20	0.6098	0.0141	52,524	20543	0.3902	63	0.0149
30	0.5187	0.0095	453,746	218440	0.4813		0.0116
45	0.4394	0.0139	2,434,708	1363746	0.5606		0.0092
70	0.3000	0.0050	7,013,720	4909703	0.7000		0.0057
100	0.2383	0.0112	9,001,295	6859311	0.7617		0.0043
150	0.1799	0.0162	8,781,310	7204928	0.8201		0.0031
220	0.1602	0.0128	3,282,327	2757538	0.8398		0.0028
335	0.1279	0.0204	646,515	564429	0.8721		0.0022
500	0.1478	0.0214	113,603	96862	0.8522		0.0025
Pegatex 35gsm							
Particle size (nm)	Efficiency	Standard deviation	Average number count in 100 seconds		penetration	Pressure drop (Pa)	Figure of Merit, Q (1/Pa)
			Upstream	Downstream			
20	0.4972	0.0333	53,179	26,710	0.5028	30	0.0229
30	0.3858	0.0057	494,381	303,708	0.6142		0.0162
45	0.3097	0.0165	2,557,773	1,764,591	0.6903		0.0124
70	0.1481	0.0165	7,358,028	6,262,890	0.8519		0.0053
100	0.1038	0.0163	8,977,430	8,044,441	0.8962		0.0037
150	0.0894	0.0029	9,993,339	9,100,998	0.9106		0.0031
220	0.0456	0.0174	4,010,845	3,821,556	0.9544		0.0016
335	0.0167	0.0095	884,100	868,773	0.9833		0.0006
500	0.0143	0.0085	151,975	149,989	0.9857		0.0005
Pegatex S							
Particle size (nm)	Efficiency	Standard deviation	Average number count in 100 seconds		penetration	Pressure drop (Pa)	Figure of Merit, Q (1/Pa)
			Upstream	Downstream			
20	0.2405	0.0497	57,007	36,807	0.7595	-	-
30	0.1683	0.0287	531,987	415,482	0.8317		
45	0.0974	0.0374	2,490,326	2,156,472	0.9026		
70	0.0640	0.0170	7,125,935	6,456,240	0.9360		
100	0.0273	0.0244	8,647,059	8,178,594	0.9727		
150	0.0107	0.0078	10,027,299	9,780,556	0.9893		
220	0.0162	0.0074	3,933,680	3,797,030	0.9838		
335	0.0380	0.0201	845,480	765,790	0.9620		
500	0.0362	0.0057	165,955	144,539	0.9638		

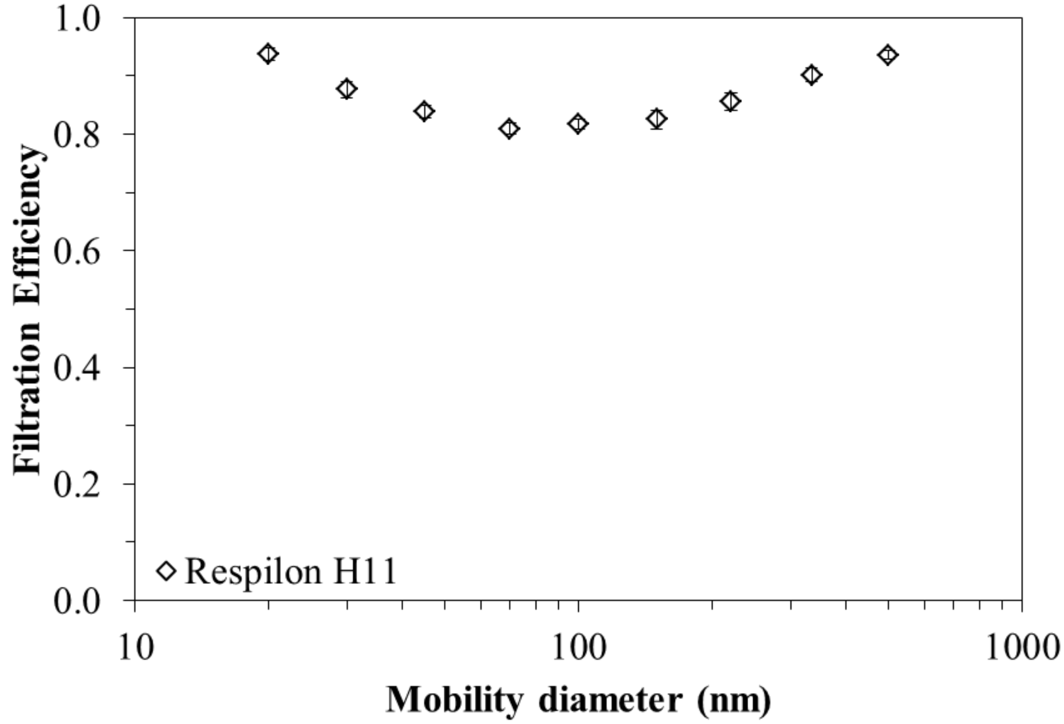

Figure 3. Filtration efficiency for Respilon H11

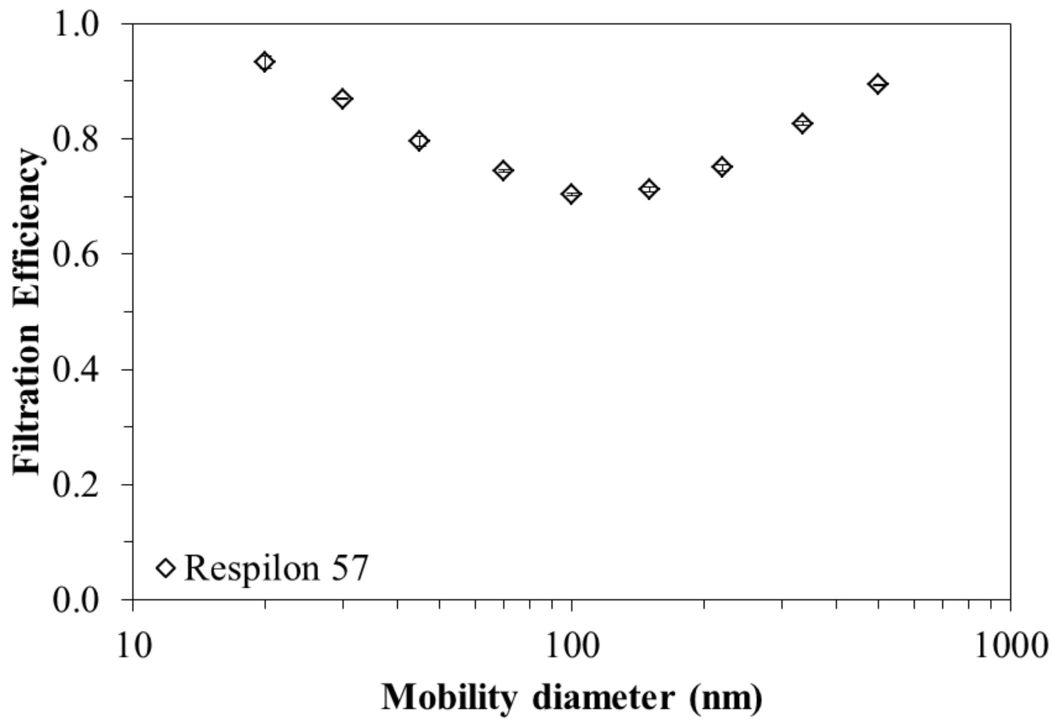

Figure 4. Filtration efficiency for Respilon 57

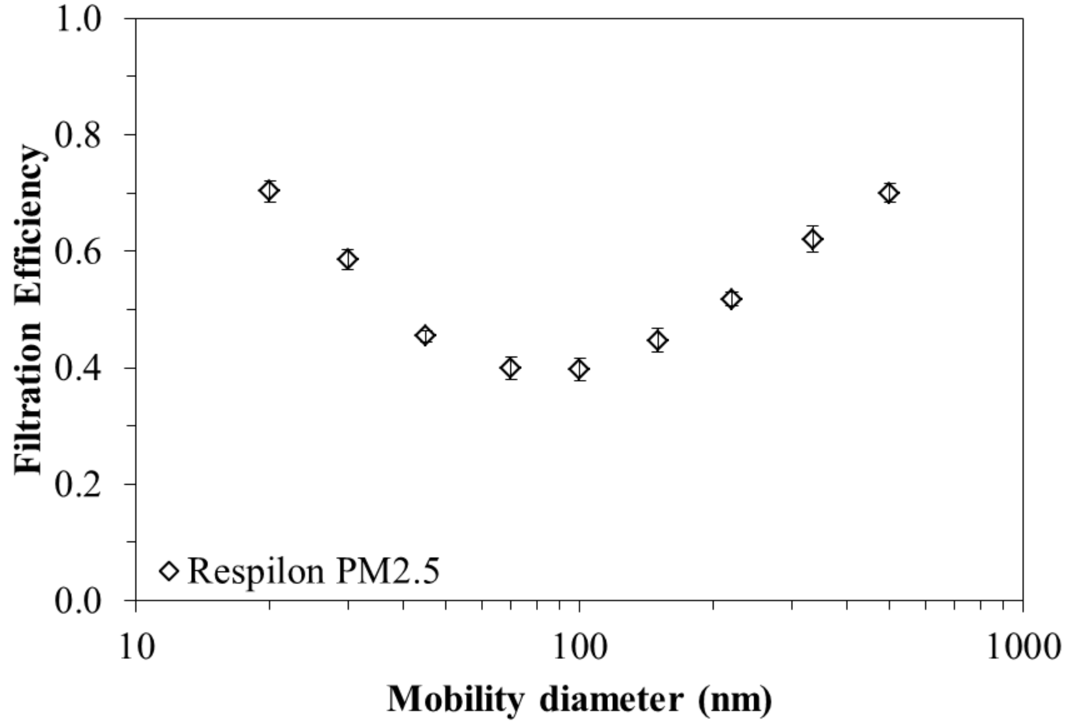

Figure 5. Filtration efficiency for Respilon PM2.5

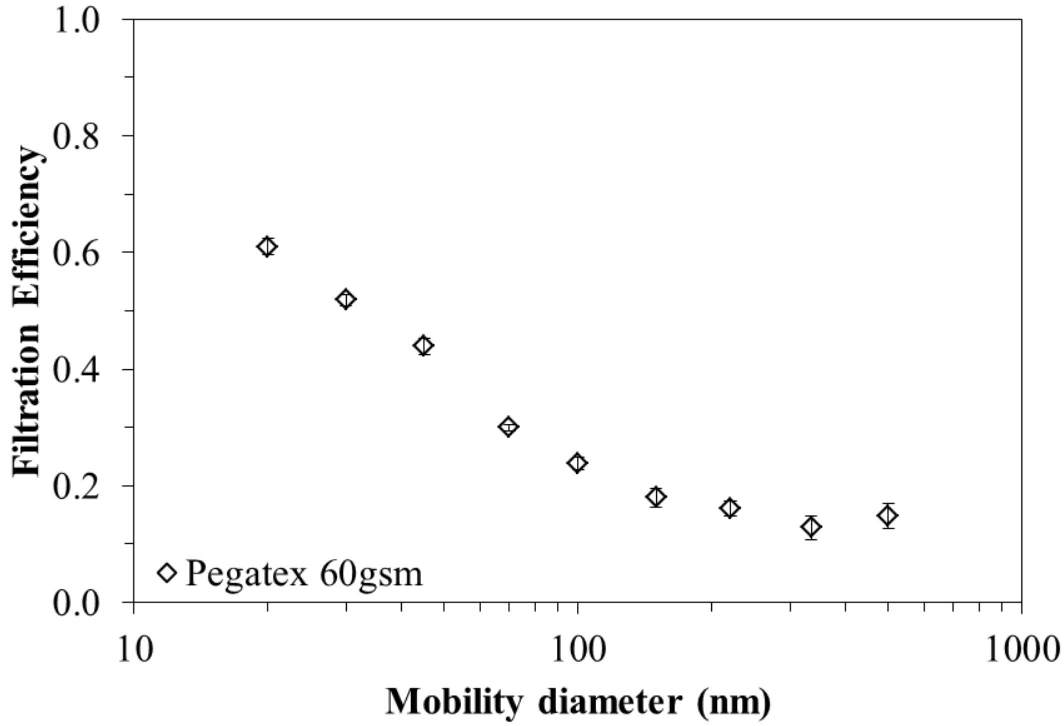

Figure 6. Filtration efficiency for Pegatex 60gsm

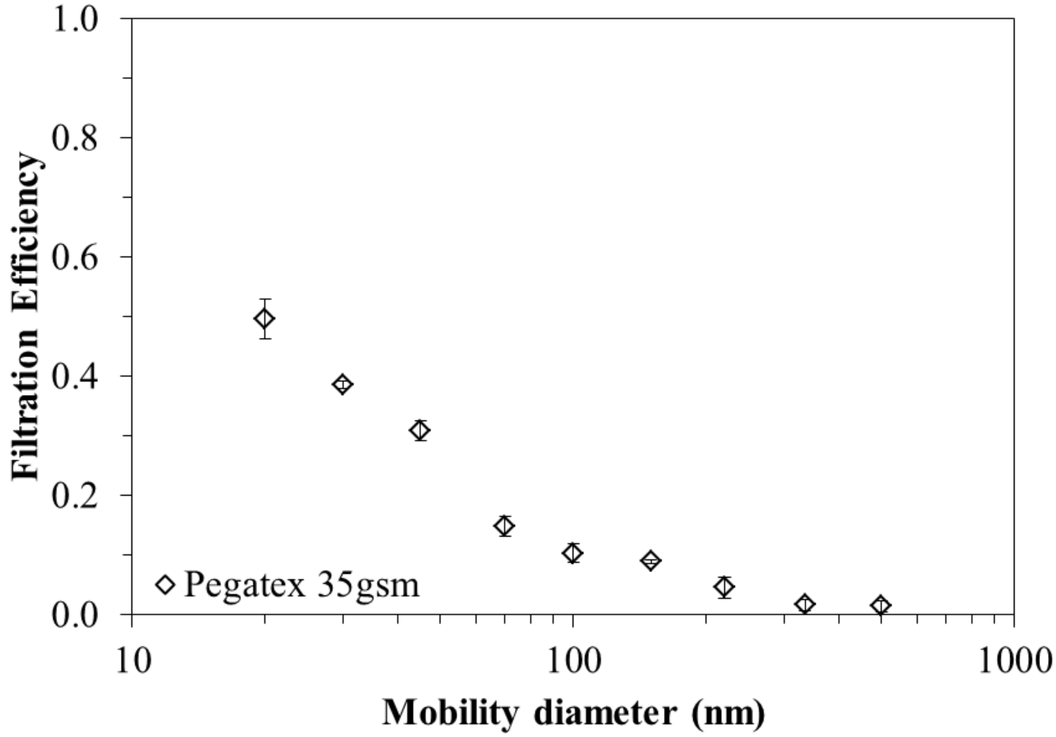

Figure 7. Filtration efficiency for Pegatex 35gsm

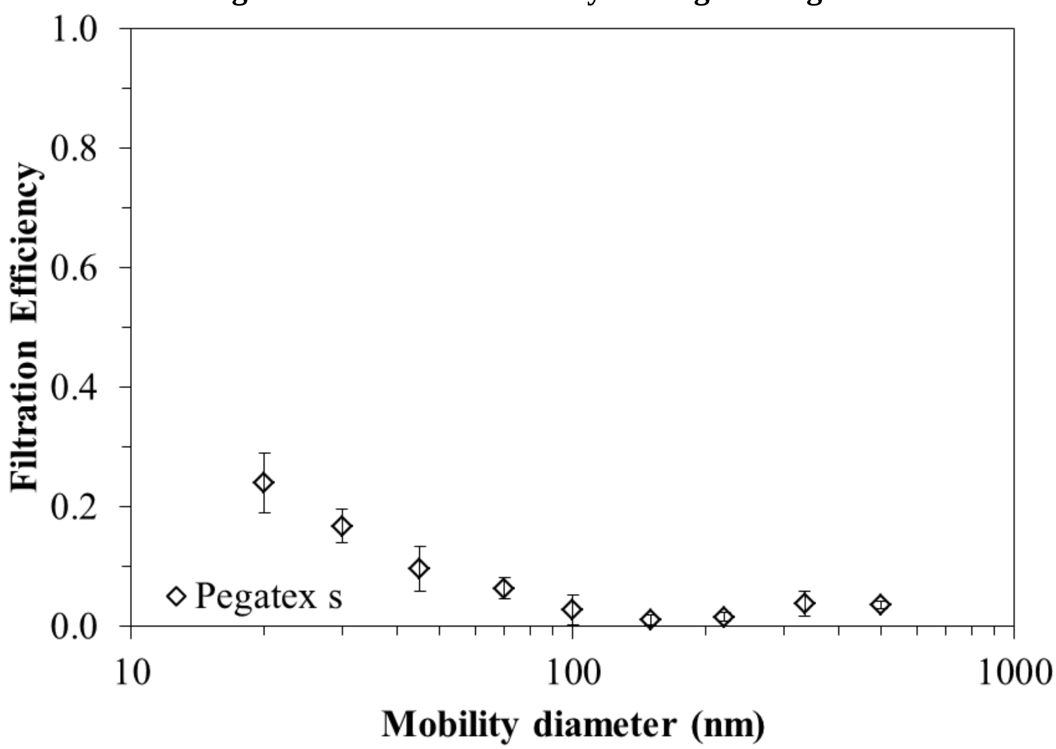

Figure 8. Filtration efficiency for Pegatex S

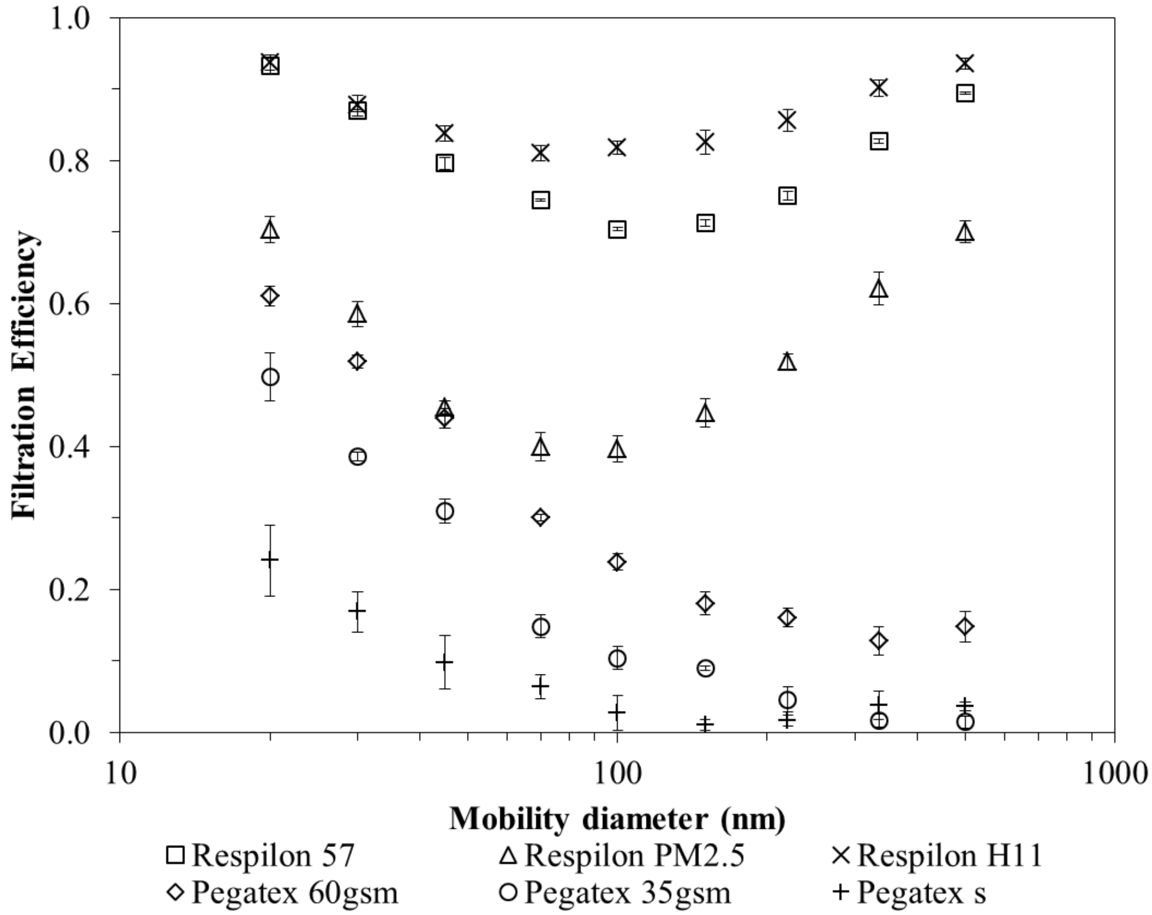

Figure 10. Comparison of filtration efficiencies for 6 different samples

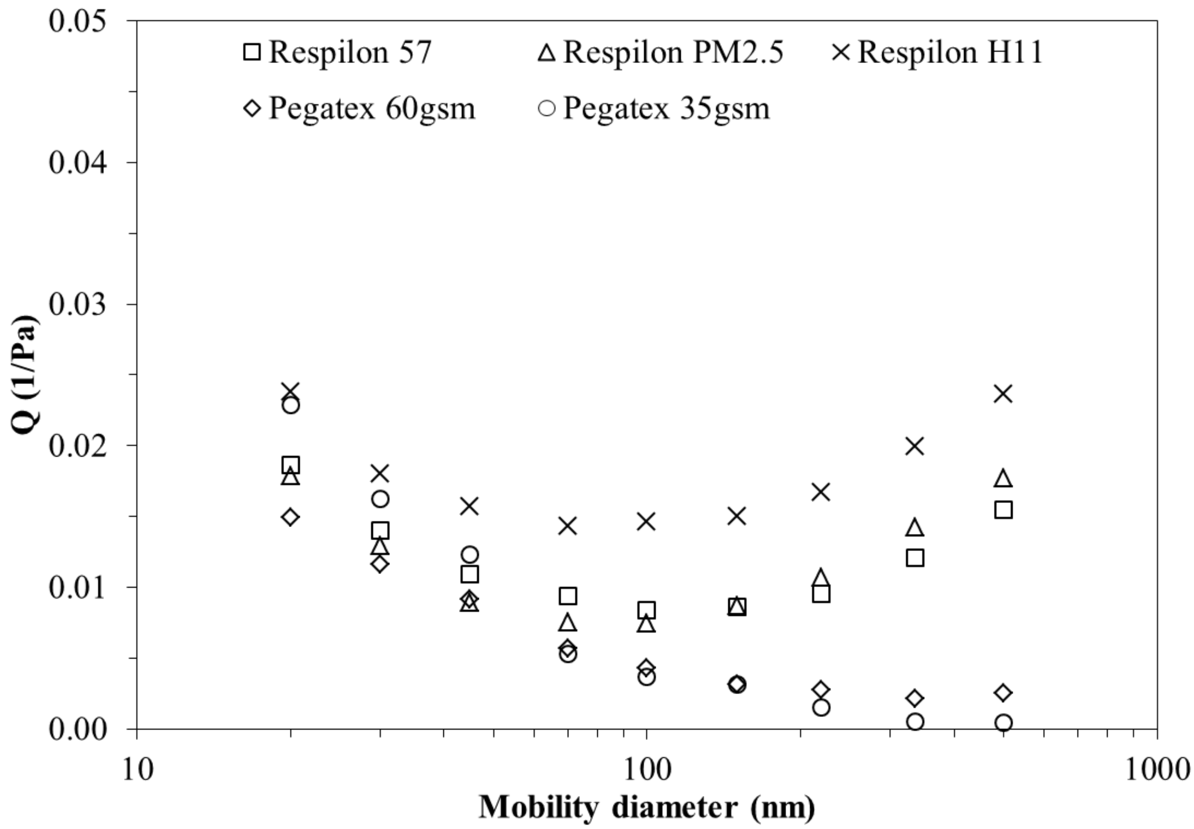

Figure 11. Comparison of figure of merit, Q for 6 different samples

3. Test evaluation

The procedures reported here were carried out consecutively three times for all of the test conditions. The statistics of the results, including the average value and standard deviation of the filtration efficiency were calculated and presented. Additionally, for each set of test conditions, the corresponding filter efficiency was determined.

4. Interpretation and Conclusion

For each test, all measurements and calculations are presented (upstream and downstream concentrations for 9 different sizes and corresponding efficiency). The system was checked before the filters were tested and data was taken with enough sampling time for each condition and sample in order to obtain accurate results. The results and comparisons are provided with a table and figures. The three Respilon media all show higher efficiencies than the three Pegatex media. Among them, Respilon H11 has the highest efficiency, followed by Respilon 57, then Respilon PM2.5. We use 100 nm particles as an example. If there exit 10,000 particles with 100 nm size upstream of the filter medium, and the filtration is carried out at 10 cm/s. Then the downstream particle count is about 1,826 for Respilon H11, 2,961 for Respilon 57, 6,033 for

Respilon PM2.5, 7,617 for Pegatex 60gsm, 8,962 for Pegatex 35gsm, and 9,727 for Pegatex S. It is known that the nanofiber media shift the most penetrating particle size (MPPS) to smaller sizes. The data show that the MPPS is about 70 – 90 nm for Respilon H11 and PM2.5 and is about 100 nm for Respilon 57. Please see Table 2 for the MPPS and corresponding efficiencies. In contract, the MPPS is in the range of 150 – 500 nm for the Pegatex media. The filtration performance of filters is evaluated in terms of the figure of merit. Respilon H11 shows the highest figure of merit among the available test data presented here. The three Respilon media all show higher figure of merit than Pegatex 60gsm and 35gsm in the particle size range larger than the MPPS of the Respilon media.

Table 2. The approximate MPPS size and corresponding efficiencies of the samples.

Sample	**MPPS size (nm)**	**Efficiency at the MPPS**
Respilon H11	~ 70 – 90	~ 80.5%
Respilon 57	~ 100	~ 70.4%
Respilon PM2.5	~ 70 – 90	~ 39.1%
Pegatex 60gsm	~ 335	~ 12.8%
Pegatex 35gsm	~ 500	~ 14.3%
Pegatex S	~ 150	~ 10.7%

5. Approver

Name	Title	Signature	Date
Jing WANG	Assistant Professor, ETHZ/EMPA	Jing Wang	25.03.2014