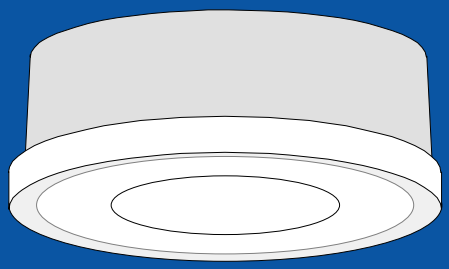
REPORT

Development and test of a passive sampler for fine particles

Martin Ferm
B1893
January 2010



This report approved
2010-01-20

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Report Summary

Project title

Utveckling av en passiv provtagare för fina partiklar

Project sponsor

Foundation for the Swedish Environmental Research Institute

Author

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Title and subtitle of the report

Development and test of a passive sampler for fine particles

Summary

A horizontally mounted Teflon filter facing downwards was tested as a surrogate surface for sampling of fine particles in ambient air. The sampler was tested in Sweden and Nepal and compared to a vertically mounted filter. The particles collected on the horizontally mounted filter contained more nitrate, sulphate and ammonium. These ions can either be due to reactions between deposited particles with their gaseous precursors or deposition of fine particles. Calcium is mainly found in coarse particles. The calcium content of deposited particles were very similar in parallely exposed horizontally and vertically mounted filters indicating that large particles are also deposited on the sampler developed here. Another design of passive sampler is therefore suggested.

Keyword

Water soluble particles, ambient air,

Bibliographic data

IVL Report B1893

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1 Introduction

There is sometimes a need for quantifying the deposition of particles instead of their concentration in ambient air. Deposited particles can lead to acidification, eutrophication, soiling and corrosion. Vertically mounted Teflon strings have earlier been used to estimate the particle deposition to coniferous forests (Ferm and Hultberg 1999). The deposition depends on the relaxation time of the individual particles, the size and roughness of the surface to which they are deposited, wind speed, turbulence etc. To calculate the deposition rate from particle concentration of a certain particle fraction is very difficult because the size (relaxation time) distribution and wind parameters in real time are needed. It is therefore better to measure the deposition directly. Since the deposition depends on the shape of the surface and chemical reactions often occur on the surface of interest, a standardised surrogate surface of an inert material is used instead. Such a surrogate surface is a passive sampler that can be used at places without electricity and also have other advantages such as small size and weight, the sampling is silent and produces averages over long time etc.

Another vertically mounted surrogate surface was later used to quantify the dry deposition of particles, in connection with a corrosion study. A surrogate surface consisting of a cylindrical Teflon filter was chosen within this project (Ferm *et al.*, 2006). Teflon is also very inert and suitable for chemically analysis. Corrosion rates were correlated with the deposition to this particular surface at several sites in Europe (Kucera *et al.*, 2007) as well as in Asia and Africa (Tidblad *et al.*, 2007). The main reasons for choosing Teflon was that the deposited mass can easily be measured as well as the soiling level.

Usually the concentration in ambient air of a fraction of particles is measured and not the deposition. The most common fraction is PM_{10}. PM_{10} represents a fraction of particles having a decreasing fraction with increasing relaxation time. At a relaxation time corresponding to a spherical particle of density 1000 kg m^{-3} and 10.5 μm diameter, the fraction (sampling efficiency) should be 50 %. Particles with the same relaxation time as a 5 μm spherical particle should be sampled with an efficiency of 85 % and one with 15 μm diameter with only 4 % sampling efficiency.

A theoretical calculation of the deposition rate to the vertically mounted Teflon cylinder has been made (Ferm 2004). The particle deposition is a complicated function of the aerodynamic diameter and depends approximately of the diameter to the power of six and the wind speed to the power of three. This implies that the maximum wind speed and the largest particles have a major impact on the deposition. The particle deposition to this sampler was compared to the PM_{10} concentration at all fourteen sites where PM_{10} was available in Europe. The correlation between the two was surprisingly good at all sites, except three. The three outliers were all situated close to particle sources.

The very constant ratio between the deposition and concentration (deposition velocity) was therefore not expected, but may be due to similar particle size distribution at different places in Europe.

The high correlation with the PM_{10} concentration offers new possibilities for the passive particle collector (Ferm *et al.*, 2009).

The passive particle collector based on impaction mainly collects larger particles. There is also a need for measurements of smaller particles that penetrates deeper into lungs and therefore may have more negative health impacts. Another principle has to be used if smaller particles should be

collected passively. Smaller particles have a higher diffusion coefficient than larger and are therefore faster transported to a surface by diffusion. Since it is difficult to increase the diffusion rate to a surface, one has to decrease the deposition rate by impaction in order to increase the fraction of small particles on the filter. This can be done by mounting the filter horizontally so that the trajectory of the particles will be parallel with the filter instead of perpendicular to it.

Brown et al (1994a, 1994b and 1995) have developed a passive sampler to which the particles are transported by the air movement. Inside the sampler there is an electric field that deposited the particles on an electrode. The sampler tested here is based on diffusion of small particles, but impaction due to vertical component of the wind can not be avoided.

2 Construction of the sampler

The sampler consists of a cylindrical (diameter 64mm, height 22 mm) natural coloured polypropylene container with a low density polypropylene lid. A centred 37 mm hole is made in the lid. A 47 mm Teflon filter (Zefluor) is placed over the hole. The filter is hold in place by putting a 22 mm high 60 mm in diameter polyurethane foam in the container between the bottom and the filter, see Figure 1.

During sampling the sampler is attached to the bottom of a larger container which acts as a rain shield, using a reclosable fastening system (3M SJ 352 D), see Figure 2. This larger container (diameter 100 mm, height 30 mm) as well as the sampler shown in Figure 2 is shown together with the previously described surrogate surface for larger particles in Figure 3. It is attached to the aluminium bar using another reclosable fastening system (3M SJ 355 D).

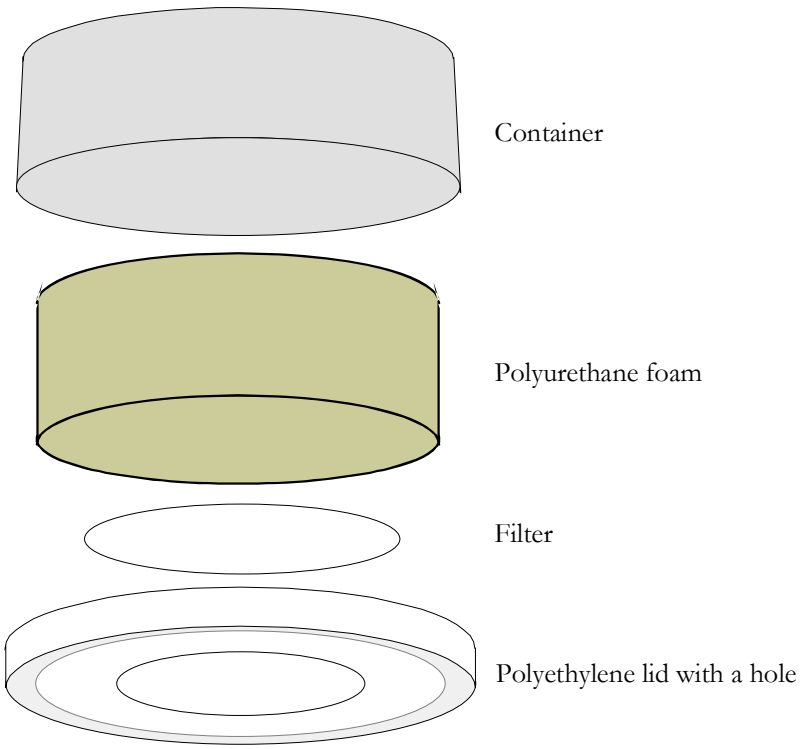

Figure 1. Construction of the passive particle collector for fine particles.

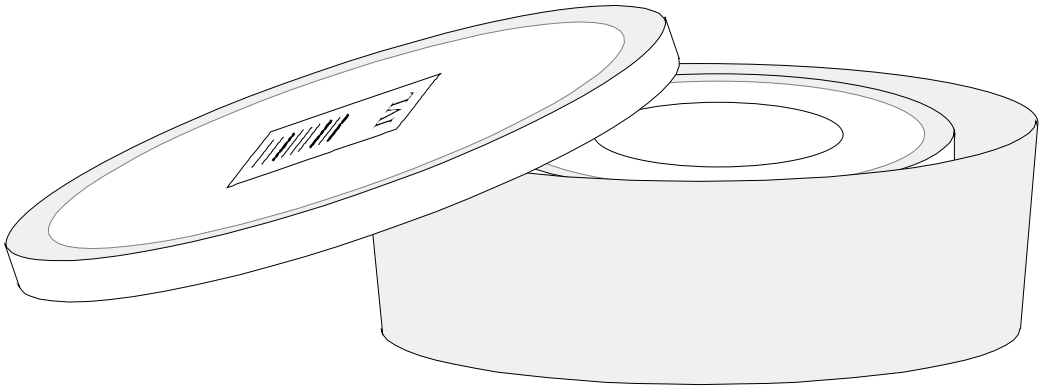

Figure 2. The passive sampler is attached to another container, which acts as a rain shield using a reclosable tape.

Figure 3. Photo of the passive sampler for fine particles (front) and the sampler for larger particles (farther).

3 Test of the sampler

3.1 Comparison between horizontally and vertically exposed filters

The passive collector for fine particles were exposed in parallel with the sampler for larger particles used in corrosion studies, see Figure 3. Three samplers were exposed in Sweden and four in Kathmandu, Nepal. The results are shown in Table 1 and 2 respectively and Figure 4. On average only 4 % of the total mass that was deposited to the vertically mounted filters were deposited to the horizontally mounted filters.

Hornsgatan, Nygatan and Putalisadak are street sites. Torkel Knutssonsg., New Baneswor, Thamel are urban background sites. Patan Hospital is an intermediate.

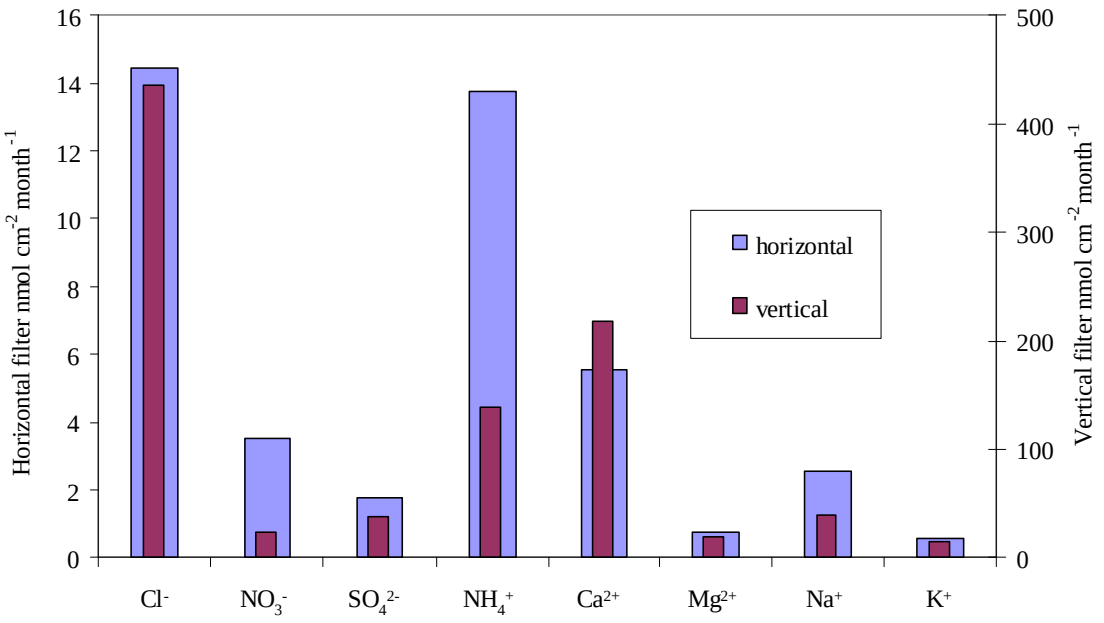

Figure 4. Average deposition of different ions to the horizontally and vertically mounted filters that were exposed in parallel. The scale for the horizontally mounted filters is only 3.2 % of the scale for the vertically mounted filter.

Four of the ions (NO_3^-, SO_4^{2-}, NH_4^+ and Na^+) in Figure 4 are overrepresented in the horizontally exposed samplers compared to the vertically exposed samplers (the scale for the blue bars are much higher than for the red bars). Fine particles are often acidic while large particles are often alkaline (basic). Three of the ions in Figure 4 (NO_3^-, SO_4^{2-} and NH_4^+) can also be present due to reactions of the deposited particles with gases in the atmosphere after the deposition.

Sulphur dioxide, SO_2 reacts with alkaline particles such as calcium carbonate forming sulphate (SO_4^{2-}). Nitric acid, HNO_3 can also react with alkaline particles or sodium chloride forming nitrate (NO_3^-). Ammonia, NH_3 can react with acidic particles forming ammonium ions (NH_4^+). This has, however, most likely already occurred in the atmosphere. It is more likely that ammonium ions

react with alkaline particles forming ammonia and is lost from the filter. There should be relatively more alkaline (large) particles on the vertically exposed sampler, and very low ammonium depositions have earlier been observed with this sampler. These three ions are also major constituents of fine particles since they are to large extent formed from gases. The horizontal orientation of the surrogate surface causes much less particle deposition and the deposited particles contain more of the gaseous precursors. It seems unlikely that the particles on the horizontal surface should have reacted more with gases.

The Na^+ and K^+ depositions to the horizontal surfaces are close to the detection limits. It is therefore difficult to interpret the results of these.

Gamble and Davidson (1986) have written a review on dry deposition of particles to surrogate surfaces. There are many different designs, but most of them are mounted horizontally, facing upwards. Only one paper was found in which the surface was facing downwards. In this paper (Elias and Davidsson, 1980) the deposition velocity for different element to upward as well as downward facing Teflon plates were measured. The deposition rate for fine particles (Pb) to a downward facing surface was about 0.5 mm s^{-1} and for coarse particles (K, Rb, Cs Ca, Sr and Ba) 5 mm s^{-1}. For the upward facing surface the deposition velocities were 4 – 10 times higher.

Figure 5. Hornsgatan, Stockholm

Figure 6. Torkel Knutssonsgatan, Stockholm

Figure 7. Nygatan, Mariestad

Figure 8. New Baneswor, Kathmandu

Figure 9. Putalisadak, Kathmandu

Figure 10. Patan Hospital, Kathmandu


Figure 11. Thamel, Kathmandu

Table 1. Deposition to a cylindrical vertical surface.

				µg cm^{-2} month^{-1}								
station	start	stop	days	mass	Cl^-	NO_3^-	SO_4^{2-}	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+
Hornsgatan	2006-03-13	2006-04-19	37	169	2.19	0.72	1.24	0.03	1.64	0.20	1.43	0.15
Torkel Knutssonsg.	2006-03-13	2006-04-19	37	37	0.49	0.84	0.58	0.02	0.67	0.06	0.45	<0.06
Mariestad	2006-02-28	2006-05-02	63	299	2.5	3.8	1.6	1.2	0.1	1.7	0.2	1.9
New Baneswor	2008-01-27	2008-05-01	95	41.7	0.08	0.45	1.31	0.09	1.62	0.05	0.09	0.15
Putalisadak	2008-01-28	2008-04-29	92	1681	104	2.48	15.8	17.1	46.3	2.44	1.86	2.57
Patan Hospital	2008-01-30	2008-04-30	91	217	2.85	1.14	4.00	0.10	6.97	0.30	0.38	0.63
Thamel	2008-02-05	2008-05-01	86	77.0	0.22	0.87	1.05	0.06	2.01	0.08	0.19	0.20

Table 2. Deposition to a flat horizontal circular surface.

				µg cm^{-2} month^{-1}								
station	start	stop	days	mass	Cl^-	NO_3^-	SO_4^{2-}	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+
Hornsgatan	2006-03-13	2006-04-19	37	5.6	0.05	0.52	0.07	0.09	0.17	0.03	0.06	<0.02
Torkel Knutssonsg.	2006-03-13	2006-04-19	37	2.5	0.02	0.63	0.05	0.11	0.16	0.03	<0.05	<0.002
Mariestad	2006-02-28	2006-05-02	63	15.6	0.11	0.17	0.05	0.04	0.30	0.03	0.24	0.02
New Baneswor	2008-01-27	2008-05-01	95	4.0	0.01	0.02	0.09	0.02	0.07	0.00	<0.02	0.01
Putalisadak	2008-01-28	2008-04-29	92	52.7	3.32	0.12	0.57	1.45	0.50	0.02	0.02	0.06
Patan Hospital	2008-01-30	2008-04-30	91	23.0	0.07	0.11	0.31	0.01	0.33	0.01	0.01	0.02
Thamel	2008-02-05	2008-05-01	86	1.9	0.01	0.01	0.03	0.01	0.02	0.00	<0.01	<0.01

4 Conclusions

The particles deposited to the sampler with the horizontally mounted filter which was developed in this project contains relatively more ammonium, nitrate and sulphate than the sampler with a vertically mounted filter. These ions can either come from fine particles or gaseous precursors that react with particles already deposited on the filter. The fact that the horizontally mounted filter contains similar calcium/total mass ratio as the vertically mounted filters (a little more calcium in Stockholm and a little less in Kathmandu) shows that it also contains a lot of coarse particles. This is not a property that is wanted. Another principle that favours the deposition of fine particles over coarse particles should therefore be used. A sampler consisting of a bunch of vertical strings (Ferm and Hultberg 1999) with diameters smaller than 1 mm could be a possibility worth testing.

5 Acknowledgement

The author wish to thank Bidya Pradhan, Pradeep Man Dangol and Rejina Byanju for exposing the samplers in Kathmandu.

Funding has been received from Foundation for the Swedish Environmental Research Institute.

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