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# BIOFILTER COMBINED WITH A BIOTRICKLING FILTER AND A CHEMICAL AIR SCRUBBER

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**ABSTRACT** The aim of this study was to investigate if a biofilter with crushed tree roots as a filter material combined with a commercial biotrickling filter and a chemical air scrubber could increase the odour reduction of these air scrubbers. Two experimental setups were made with a biotrickling filter from SKOV A/S. In the first setup, a biotrickling filter with two filters of cellulose was followed by a biofilter. In the second setup, a cellulose filter with an increased surface area of 40 % compared to traditionally used cellulose filters was installed followed by a biofilter. An experimental setup was also made with a chemical air scrubber from ScanAirclean A/S / INNO+. This setup consisted of a plastic filter, which was moistened with sulphuric acid liquid at a pH of 2.2, followed by a biofilter. On each experimental setup, a measuring campaign of 6-10 days was performed during the summer months. Results from the biotrickling filters showed that the biofilter did not contribute any further to the odour reduction. However, the cellulose filters did reduce the odour concentration by 45-48 %. Results from the setup with the chemical air scrubber showed an odour reduction of 57 % during the first four days of the measurement period. However, no significant odour reduction was seen during the last six days of measuring. The reason for this could be an unintended load of at least 15 kg sulphuric acid into the recirculation liquid of the plastic filter. This increased load of acid presumably affected the microbial conditions on the biofilter. Investigations of the biofilter showed colonization of fungi. A theory could be that a sudden growth of fungi may have settled as a layer on top of the active biofilm and thereby eliminated aerobic odour transferable processes.

**Keywords:** Odour, ammonia, hydrogen sulphide, biofilter

**INTRODUCTION** Trials from the Pig Research Centre have demonstrated that air scrubbers with wood chips as filter material can reduce odour concentration in the air from pig houses. In a trial with the BIO-REX Hartmann Bio-filter, odour concentration from a finisher house was reduced by 77 % (Riis & Jensen, 2007). In this trial, a large consumption of water and a high pressure drop across the filter material were recorded, and therefore further development of the filter was required. A vertical biofilter according to American principle demonstrated a 58 % reduction in odour concentration in the summer and 60 % reduction in odour concentration in the winter from a finisher house (Riis et al., 2008).

SKOV A/S developed the biotrickling filter Farm AirClean BIO system that consists of two cellulose filters. In several trials, Pig Research Centre has documented a 30 % reduction in odour concentration in the summer and a reduction in ammonia from 4-9 ppm to 1-2 ppm by leading the air through the Farm AirClean BIO system (Jensen & Hansen, 2006; Lyngbye & Hansen, 2008; Lyngbye, 2008). In order to investigate the possibilities for further reductions in odour with the Farm AirClean BIO system, two experimental setups were established. In these two setups, the Farm AirClean BIO modules were combined with a biofilter in which the filter material consisted of crushed tree roots.

Until the company went bankrupt in 2008, ScanAirclean A/S had the rights to sell air scrubbing systems from the Dutch company INNO+ in Denmark. These systems were based on chemical purification for reduction of ammonia in air from pig houses. One trial demonstrated that by leading the air from a combined weaner and gilt facility through a central air scrubber from ScanAirclean A/S, ammonia concentration in the air was reduced by 92 %. However, the odour concentration was not reduced (Riis, 2009). INNO+ produces the so-called combi-scrubber that ScanAirclean A/S wanted to introduce to the Danish market in a modified version. In the Netherlands, the combi-scrubber includes three steps: a filter element for elimination of dust after which the air passes a filter element for reduction of ammonia, and finally the air passes a filter element with crushed tree roots for reduction of odour.

The aim of this study was to investigate if a biofilter with crushed tree roots as a filter material combined with a commercial biotrickling filter and a chemical air scrubber could increase the odour reduction of these air scrubbers.

## MATERIALS AND METHODS

**Two experimental setups with a biotrickling filter from SKOV A/S** The trial was conducted in a finisher facility with 500 pig places. The facility had fully slatted floor and the pigs were fed dry feed ad lib. A Farm AirClean BIO module from SKOV A/S was set up on each of the four exhausts, of which two were rebuilt and included in the trial. The Farm AirClean BIO module is traditionally built with two filter elements of cellulose that are sprinkled with water. Each filter element was 1.8 m wide, 2.0 m high and 0.15 m deep. The sprinkling water for the two filter elements was recirculated from a vessel under each filter. An automatic washer that regularly cleaned the filter elements was set up between the first and second filter elements.

<u>Experimental setup 1 (E1)</u> One of the four Farm AirClean BIO modules was extended with a third filter element consisting of 60 cm crushed tree roots (Figure 1). The roots were not sprinkled with water, but moistened from the humidity in the air after passing the Farm AirClean BIO module.

<u>Experimental setup 2 (E2)</u> On the other of the four Farm AirClean BIO modules both filter elements were removed. In the first step, a 15 cm thick filter element of cellulose was established with a 40% larger volume specific surface area. In step two, a 30 cm thick filter element of crushed tree roots was established (Figure 2). The first filter element was sprinkled with water and the crushed roots were regularly moistened by the automatic washer.

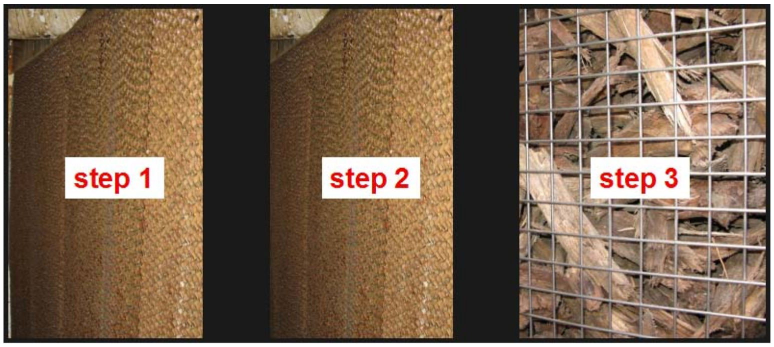


Figure 1. Experimental setup 1 consisting of three filter elements. A Farm AirClean BIO module extended with a biofilter consisting of 60 cm thick layer of crushed roots.


Figure 2. Experimental setup 2 consisting of two filter elements. A cellulose filter element with 40 % larger volume specific surface area than traditional cellulose filters and a biofilter consisting of 30 cm crushed tree roots.

**One experimental setup with a chemical air scrubber from ScanAirclean A/S / INNO+ (E3)** The trial was conducted in a finisher house with 120 pig places, fully slatted floor and ad lib dry feeding. The air scrubber was connected to the ventilation exhaust on the roof. The air scrubber consisted of two filter steps from the Dutch company INNO+, while the control was from ScanAirclean A/S. The first step was a vertical filter element of plastic sprinkled with a sulphuric acid solution. Under the filter element, a vessel was established from which the liquid was recirculated. The other filter element consisted of crushed tree roots moistened with water from nozzles on the top of the filter element and on the inside of the filter element. Moistening of the crushed roots was timed so that moistening took place 45-60 seconds every 45 minutes. However, the nozzles on the top of the filter element were only activated when the temperature after the biofilter was above 25 ºC. The first filter element was 1.9 m wide, 1.35 m high and 0.55 m deep. The other filter element was 1.9 m wide, 2.71 m high and 0.60 m deep. In the vessel under the first filter element, 96 % concentrated sulphuric acid was added to the sprinkling water. The addition of sulphuric acid was pH regulated with a desired pH of 2.2. In the vessel, water was added via regulation by level sensors. When sulphuric acid was added to the vessel, a certain amount of liquid was emptied from the vessel to a pallet tank.


Figure 3. ScanAirclean A/S chemical air scrubber in combination with a biofilter consisting of 60 cm crushed tree roots.

## Analytical methods

The test period ran from July 2008 to October 2008. The measurements of odour and ammonia reduction were performed over 6-10 days spread over the trial period. The odour samples were collected in 30 L nalophan odour bags. The bags were placed in an airtight container and filled by creating a vacuum in the airtight container with a pump. On each day of measurement, two odour samples were taken from the air stream before the first filter, between the filters and after the air scrubber, respectively. The first round of odour samples were taken between 11.00 a.m. and 11.30 a.m., and the second round between 12.30 p.m. and 1.00 p.m. The collection of the odour samples and the analyses of odour concentration ($OU_E/m^3$) were performed in accordance with European olfactometric standard EN:13725 (CEN, 2003). The analyses of the odour concentration were performed at the odour laboratory at Danish Meat Research Institute (Roskilde, Denmark) and the odour laboratory at Eurofins (Galten, Denmark). After collection of odour samples, ammonia and hydrogen sulphide were measured in the same spots. Ammonia concentration was measured using Kitagawa gas detector tubes 105SD (Komyo Rikagaku Kogyo K.K., Japan). Hydrogen sulphide was measured using a Jerome 631-XE instrument (Arizona Instrument LLC, USA). The airflow in each unit was determined by a Fancom measuring fan. Temperature and the relative humidity of the air stream and outdoor were measured using a TSI VelociCalc Plus 8386 instrument (TSI Incorporated, USA). The number of animals and their weight were recorded on each measurement day. On two days, pH was measured on the surface of the crushed roots in the experimental setup from ScanAirclean A/S / INNO+ (E3) with pH sticks (Baker pHIX, pH 4,5-10). Samples were also taken from the crushed roots and analysed at the Biological Institute at Aarhus University for content of nitrite ($NO_2^-$), nitrate ($NO_3^-$) and colonisation of bacteria and fungi. The concentration of $NO_2^-$ and $NO_3^-$ was determined by using sticks (Merckoquant 1.10007 Nitrite test and 1.10020 Nitrate test). At the laboratory, scrapes were made of the surface of the crushed roots and, in microscopes, examined for bacteria. Furthermore, entire pieces of the crushed roots were examined with a stereo magnifier for fungi. Ammonia and hydrogen sulphide concentrations and the logarithmically transformed odour concentration were processed using an analysis of variance in the MIXED Procedure in SAS (SAS Inst. Inc., Cary, NC).

**RESULTS AND DISCUSSION** When the measurement period started on August 28, 2008 on E1 and E2, there were 495 pigs in the facility with an average weight of 72 kg. On the last day of measurement, October 1, 2008, there were 277 pigs with an average weight of 93 kg. Measurements on E1 and E2 were made at an average outdoor temperature of 15.6 ºC (range: 11.1 – 18.3 ºC) and a relative air humidity of 81 % (range: 75 – 95 %).

At the start of the measurement period on E3 on July 30, 2008, there were 98 pigs in the facility with an average weight of 65 kg. The day after the last measurement, August 27, 2008, all pigs were delivered for slaughter. Measurements on E3 were made at an average outdoor temperature of 19.8 ºC (range: 14.6 – 27.5 ºC) and a relative air humidity of 68 % (range: 28 – 95 %).

**Concentration of ammonia, odour and hydrogen sulphide** Table 1 shows the concentrations of ammonia, odour and hydrogen sulphide before the first filter element, between the filter elements and after the biofilter, and the reduction in per cent across the filter elements in E1. By leading the air through E1, ammonia concentration was reduced from 10 ppm to 0.7 ppm, corresponding to a 93 % reduction (table 1). The majority of the reduction took place on the first two filter elements of cellulose where ammonia was reduced to 1.2 ppm. However, the biofilter further reduced the ammonia concentration to 0.7 ppm. Leading the air though E1 also significantly reduced the concentration of odour and hydrogen sulphide. The odour concentration was reduced by 45 %, but the entire reduction took place on the first two steps, and the biofilter did not contribute to the reduction, which was its primary function. The concentration of hydrogen sulphide was reduced by 45 % of which the biofilter accounted for 16 %.

Table 1. Concentration of ammonia, odour and hydrogen sulphide before the first filter element, between the filter elements and after the biofilter, and the reduction in per cent across the filter elements in E1. 95 % confidence limits are shown in brackets.

| Place of measurement | Ammonia concentration (ppm) | Odour concentration ($OU_E/m^3$) | Hydrogen sulphide concentration (ppb) |
|---|---|---|---|
| Before 1st filter element | 10.0<br>(9.3 – 10.6) | 1.500<br>(1.200 – 1.900) | 472<br>(397 – 547) |
| After 1st filter element | 6.3<br>(5.7 – 6.9) | 890<br>(700 – 1.100) | 378<br>(303 – 453) |
| After 2nd filter element | 1.2<br>(0.6 – 1.8) | 730<br>(580 – 930) | 313<br>(239 – 388) |
| After 3rd filter element (biofilter) | 0.7<br>(0.1 – 1.3) | 720<br>(570 – 910) | 236<br>(162 – 311) |
| Reduction after 1st filter element in % | 35***<br>(25 – 44) | 37**<br>(21 – 54) | 16**<br>(8 – 25) |
| Reduction after 1st and 2nd filter elements in % | 87***<br>(83 – 91) | 45*<br>(16 – 74) | 29**<br>(17 – 42) |
| Reduction after biofilter in % | 93***<br>(87 – 98) | 49***<br>(37 – 61) | 45***<br>(38 – 51) |

*, **, *** Significant difference, *: P<0.05; **: P<0.01; ***: P<0.001.

By leading the air through E2, ammonia concentration was significantly reduced from 11.4 ppm to 5.6 ppm, corresponding to a 50 % reduction (table 2). Odour concentration was reduced by averagely 48 %, and, as in E1, the biofilter did not contribute to the reduction of odour. For the cellulose filters, the results revealed an increase in odour reduction in E2 by using one cellulose filter with a larger volume specific surface area compared with using two cellulose filters in E1 as is traditionally used in the Farm AirClean BIO modules. As opposed to E1, the concentration of hydrogen sulphide was not reduced by leading the air through E2. Measurements in E1 and E2 showed that the setup with crushed tree roots and airflow rate did not result in any odour reduction (Figures A1 and A2 in Appendix A). Compared with other investigations that demonstrated a reduction in odour concentration with wood chips, the filter material in this investigation was exposed to an airflow rate that was approx. 4 times as high, and at the same time the crushed roots had a coarser texture than the wood chips used in previous trials (Riis & Jensen, 2007; Riis et al., 2008).

Table 2. Concentration of ammonia, odour and hydrogen sulphide before the first filter element, between the filter elements and after the biofilter, and reduction in per cent across the filter elements in E2. 95 % confidence limits are shown in brackets.

| Place of measurement | Ammonia concentration (ppm) | Odour concentration ($OU_E/m^3$) | Hydrogen sulphide concentration (ppb) |
|---|---|---|---|
| Before 1st filter element | 11.4<br>(10.8 – 12.0) | 1.400<br>(1.100 – 1.800) | 429<br>(363 – 494) |
| After 1st filter element | 7.1<br>(6.5 – 7.7) | 700<br>(540 – 900) | 406<br>(340 – 471) |
| After 2nd filter element (biofilter) | 5.6<br>(5.0 – 6.2) | 710<br>(550 – 920) | 387<br>(321 – 453) |
| Reduction after 1st filter element in % | 37***<br>(31 – 43) | 48***<br>(31 – 66) | $4^{NS}$<br>(-5 – 13) |
| Reduction after biofilter in % | 50***<br>(43 – 57) | 48***<br>(36 – 60) | $7^{NS}$<br>(-13 – 26) |

*, **, *** Significant difference, *: P<0.05; **: P<0.01; ***: P<0.001.
NS: Not significant difference.

Table 3 shows the concentration of ammonia, odour and hydrogen sulphide before the first filter element, between the two filter elements and after the biofilter, and the reduction in per cent across the two filter elements in E3 from ScanAirclean A/S / INNO+. After the air passed the first filter element, ammonia concentration dropped from averagely 7.9 ppm to 3.0 ppm corresponding to an average reduction efficiency of 62 %. The concentration of ammonia after the first filter element was higher than what was recorded in a trial of ScanAirclean's air scrubber in a combined weaner and gilt facility. In that trial, ammonia concentration was reduced from averagely 11.7 ppm to 1.0 ppm (Riis, 2009). The increased ammonia concentration after the first filter element in this trial can be explained by the fact that between measurement days six and seven a small leak was observed above the first filter element in which a small part of the air was able to pass unhindered. Despite the fact that this leak was closed immediately and the ammonia concentration after the first filter element was lower the following days, the average ammonia concentration was still higher than the level recorded in the previous trial. However, the ammonia concentration in the air was reduced to averagely 0.9 ppm when it passed the second filter element with crushed roots. Overall, ammonia concentration was significantly reduced by averagely 91 % over the ten days of measurement by leading the air from the finisher house through the air scrubber.

A small numeric increase was observed in odour concentration after the first filter element, which was not significant. However, there was a tendency to an odour reduction of averagely 23 % over the ten days of measurement when the air had passed both filter elements in the air scrubber (P=0.08). On the first four days of measurement, the reduction in odour concentration averaged 57 % by leading the air through the air scrubber. This result was in accordance with what had previously been recorded in investigations of biofilters (Riis & Jensen, 2007; Riis et al., 2008). However, there was no significant reduction in odour concentration on the last six days of measurement in the trial period. There was a tendency to a reduction in hydrogen sulphide concentration of averagely 7 % by leading the air through the first filter element in the air scrubber (P=0.06). However, the concentration of hydrogen sulphide was reduced by averagely 46 % when the air passed both filter elements. Figure A3 shows the airflow rate through E3 and pressure drop across the air scrubber on the measuring days.

Table 3. Concentration of ammonia, odour and hydrogen sulphide before the first filter element, between the filter elements and after the biofilter, and the reduction in per cent across the filter elements in E3. 95 % confidence limits are shown in brackets.

| Place of measurement | Ammonia concentration (ppm) | Odour concentration ($OU_E/m^3$) | Hydrogen sulphide concentration (ppb) |
|---|---|---|---|
| Before 1st filter element | 7.9 | 2.500 | 570 |
| | (6.3 – 9.6) | (1.800 – 3.400) | (349 – 792) |
| After 1st filter element | 3.0 | 2.700 | 530 |
| | (2.0 – 4.0) | (2.100 – 3.400) | (308 – 752) |
| After 2nd filter element | 0.9 | 1.600 | 343 |
| (biofilter) | (0.0 – 1.8) | (900 – 2.700) | (122 – 564) |
| Reduction after 1st filter | 62*** | -18[NS] | 7[(*)] |
| element in % | (53 – 72) | (-49 – 12) | (0 - 15) |
| Reduction after biofilter | 91*** | 23[(*)] | 46*** |
| in % | (84 – 98) | (-4 – 50) | (26 – 66) |

*, **, *** Significant difference, *: P<0.05; **: P<0.01; ***: P<0.001.
(*): Tendency, P<0.10.
NS: Not significant difference.

<u>Problems with dosing of acid in E3</u> The reason for the lack of reduction in odour concentration from measurement day 5 onwards could be that from August 7 to 11, min. 15 kg concentrated sulphuric acid was added to the vessel under the first filter element. Throughout the measurement period, the dosage of acid added to the vessel under the first filter element was adjusted manually as dosing did not take place automatically as planned. The relatively large load of sulphuric acid that was added was therefore not intended, but the result of failing automatic adjustment of pH in the vessel. In the vessel, pH therefore varied during the day in the entire measurement period due to the manual dosing. However, on the individual measurement days it was ensured that pH was close to the desired 2.2 before measuring the reductions in odour and ammonia concentration of the air scrubber.

<u>Examination of the biofilter in E3</u> Due to the sudden stop in odour reduction, the surface of the crushed roots in the biofilter was examined in detail on August 21. pH was measured to 5.5-6.5 on the surface of the crushed roots. In comparison, pH measured 7 on the surface of the crushed roots that were moistened and that had not been in contact with the air scrubber. Thereby pH on the surface of the crushed roots in the air scrubber was 0.5-1.5 pH units lower than pH on the crushed roots that had not been in contact with the air scrubber. Production of nitrite ($NO_2^-$) was recorded in the top, middle and bottom of the crushed roots. On the inside of the filter element, 20-30 mg/L $NO_2^-$ were measured in sporadic measurements. On the outside of the filter element 5-80 mg/L $NO_2^-$ were measured. However, no production of nitrate ($NO_3^-$) was recorded. It can be concluded that ammonia oxidation did take place sporadically in the biofilter and that the produced

$NO_2^-$ was apparently not oxidised further to $NO_3^-$. Nitrification in itself triggers a drop in pH in the surrounding environment, but if the produced $NO_2^-$ is not eliminated, nitrification will in most cases stop around pH 6 due to the inhibition with nitrous acid ($HNO_2$) of the ammonia oxidation (Anthonisen, 1976). It is therefore assumed that the ammonia oxidation was inhibited or possibly that the group of $NO_2^-$ oxidising bacteria was not present in the filter element. With microscopy, it was confirmed that bacteria were present on the crushed roots. On August 11, purple coating was observed in large areas of the crushed roots. With a stereo magnifier, white mould fungi were detected as were large areas with fungi with purple "grain" in the mycelium. It could therefore be concluded that the purple coatings were caused by fungi colonisation. If a sudden heavy growth of fungi had taken place, these may have settled as a layer on the outside of the active biofilm and thereby have eliminated aerobic odour transferable processes. The biological activity in the filter element ahead of the sudden stop in odour reduction was not known, and it was therefore not possible to compare the biological activity before and after the reduction in odour stopped. For instance, colourless fungi may have been widely represented before the purple fungi were observed. It is therefore not certain that the odour-reducing biological processes were affected by the low pH. In comparison, pH in other biological systems with documented reduction in odour often ranges between 6.5 and 7.5 (Jensen & Hansen, 2006; Sørensen & Riis, 2008).

**CONCLUSION** It was not possible to increase the reduction in odour concentration with the Farm AirClean BIO modules by combining them with a biofilter where the filter material consisted of crushed tree roots. In comparison with other investigations in which a positive reduction in odour was documented with woodchips, this investigation showed that the filter material was exposed to an airflow rate 4 times as high, and at the same time the crushed roots had a coarser texture than the woodchips used in previous investigations.

On the first four days of measurement, the reduction in odour concentration averaged 57 % when the air passed both filter elements in the air scrubber from ScanAirclean A/S / INNO+. However, no significant reduction in odour concentration was measured on the last six days of the period. Over the ten days of measurement, there was a tendency to a 23 % reduction in odour concentration. The reason why odour reduction stopped from day 5 onwards was apparently that 15 kg concentrated sulphuric acid was unintentionally added to the vessel under the first filter element over a few days. This resulted in an extremely acid environment that probably affected the microbiological conditions on the second filter element. Subsequent examinations of the crushed roots revealed colonisation with fungi. A sudden heavy growth of fungi may thereby have settled on the outside of the active biofilm and eliminated aerobic odour transferable processes. However, the biological activity in the filter element ahead of the ceased reduction in odour was not known, and it was therefore not possible to compare the biological activity before and after the reduction in odour stopped. The biofilters with crushed roots did contribute with further reduction of ammonia in all experimental setups.

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## APPENDIX A

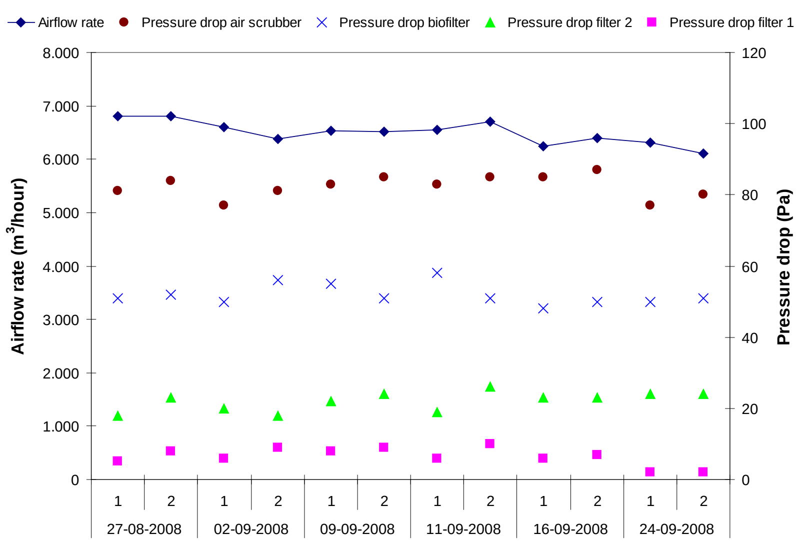


Figure A1. Airflow rate through E1 and pressure drop across the air scrubber and the individual filter elements on the measuring days.

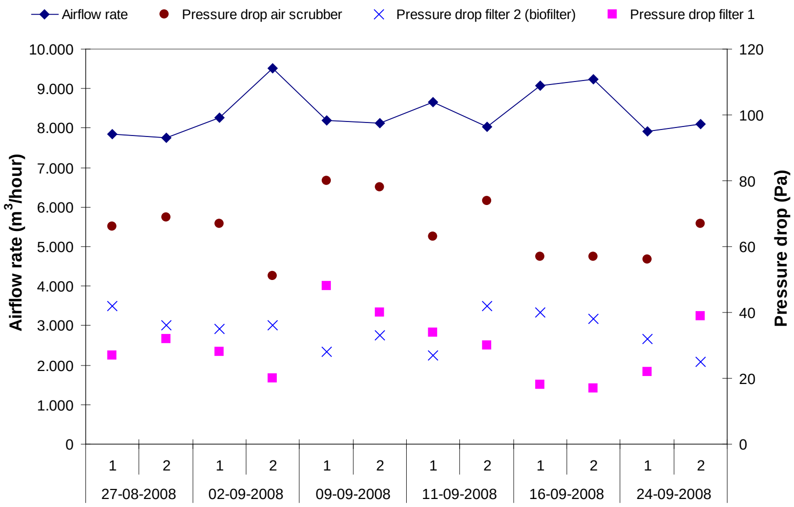


Figure A2. Airflow rate through E2 and pressure drop across the air scrubber and the individual filter elements on the measuring days.

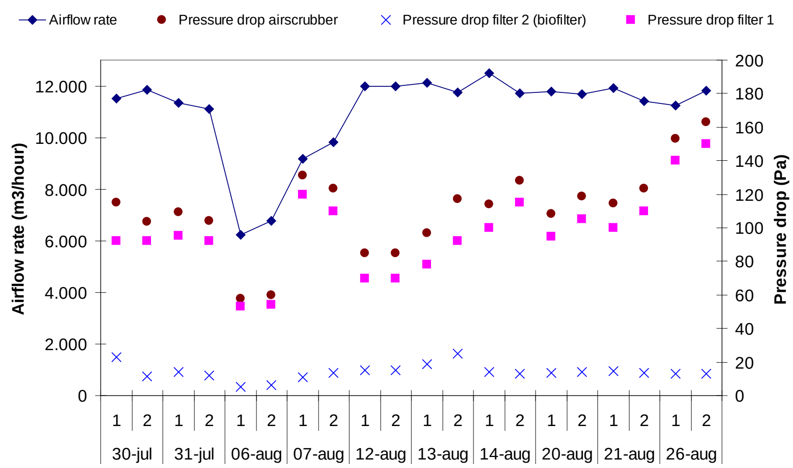


Figure A3. Airflow rate through E3 and pressure drop across the air scrubber and the individual filter elements on the measuring days.