Biofilters - The Influence of Different Filter Materials on the Reduction Efficiency

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The influence of five different filter materials on the reduction efficiency of biofilters has been investigated in parallel long-term measurements in a stall for fattening pigs. The greatest odour reduction (approximately 81%) was achieved with biochips and a mixture of coconut fibre and fibre peat as filter materials. All filter materials additionally reduce ammonia emissions by an average of about 9 - 30%. Biofilters with biochips caused considerably lower flow resistance and electricity consumption than filters with other materials.
Biofilters allow odour emissions from farm animal husbandry to be reduced by approximately 25 - 95%. Ammonia emissions also diminish to a certain extent (about 0 - 35%). However, very high operating expenses are attached to the use of biofilters if they are used properly (HARTUNG et al., 1997; HOPP, 1998; MANNEBECK, 1994). For this reason, they are used only when the minimum distance required by the VDI 3471 (1986) and VDI 3472 (1986) guidelines as well as the TA Luft (1986) (German Air Pollution Regulations) cannot be kept. The selection of the filter material provides a significant possibility to further optimize biofilters.The present study was conducted to establish the odour reduction achieved by selected filter materials. Additionally, it was the goal of this research to examine the influence of the filter material on the reduction of the emission of NH_3, CO_2, CH_4, and N_2O, as well as flow resistance and electricity consumption.

Keywords
Biological air purification, biofilters, filter material, flow resistance

Material and Method

Five biofilters with a closed design (scale of half full size) were connected to a forced ventilated test stall for fattening pigs and operated in parallel from the 7th to the 22nd calendar week 1999 (HARTUNG et al., 1999). The individual biofilters (base surface: 2.19 m^2) were filled with a 0.5 m high layer of the following filter materials:

- biochips (test material from the company Roth GmbH, Oberteuringen),
- a mixture of coconut fibre and fibre peat (mixture ratio 1:1),
- a mixture of bark and chopped wood (from spruce, mixture ratio of bark and chopped wood: 1:1)
- BioContact fibre pellets + bark (34 cm + 16 cm)
- biocompost (oversized compost particles > 25 mm).

Figure 1 shows diagrams of individual biofilters and the arrangement of the measuring points. The outgoing air (waste air) is diverted from the exhaust air flue of the stall and flows into an air distributor. With the help of five radial fans, the air in the individual biofilters is forced through the filter material from the bottom to the top and is then discharged from the biofilters through exhaust air chimneys on the filters.
A data logging system controls the measuring point change-over to gas analysis, the radial fans, and the registration of the data (gas concentrations, air flow rate, air temperatures, air humidity, electricity- and water consumption). **Table 1** provides a complete overview of the measuring instruments used and their measuring principles.
During a 20 minute measuring cycle, NH_3- and CO_2 concentrations are measured both before and after the air passes through the individual biofilters (waste air/purified air). Before each of these measuring cycles, a new set value for the proportional volume flow of the individual biofilters is calculated based on the current volume flow of the outgoing air from the stall. With the help of PID-controllers units, the radial fans are controlled in such a way that the air flow rates which are measured in the exhaust flues of the biofilters with calibrated measuring fans meet the set value. This control system makes it possible for all biofilters to have a nearly identical filter volume load within one measuring cycle while the typical daily course of the exhaust air flow rate from the stall can be retained. A set of nozzles moistens the filter material from the top until the desired humidity of the material is reached. For humidity control, an automatic humidifier is used, whose humidity sensors were calibrated for the individual filter materials in a pre-trial (MARTINEC et al., 1999). According to the draft of the European standard „Air Quality Determination of Odour Concentration by Dynamic Olfactometry“ (1997), odour samples are taken twice a week before and after the air passes through each biofilter and analyzed with a TO7 olfactometer. In addition, samples of waste and purified air are taken once a week to establish the CH_4 and N_2O concentrations with a gas chromatograph (FID- or ECD detector).

Results

With regard to odour reduction, significant differences were established between the individual filter materials (**table 2**). Biochips and coconut fibre-fibre peat achieved the highest mean odour reduction of about 81%. Minimum reduction was approximately 45 and 32% respectively. The other filter materials reduce the odour by an average of about 60 to 66%. In some cases, odour reduction was even in the negative range.
With regard to all filter materials, a positive linear correlation between specific odour cleaning efficiency [$OU \cdot m^{-3} \cdot h^{-1}$] and specific odour loading rate [$OU \cdot m^{-3} \cdot h^{-1}$] has been established (**figure 2**). Biochips and coconut fibre-fibre peat exhibit significantly steeper regressions and less straggling of single data than the other filter materials. If specific odour

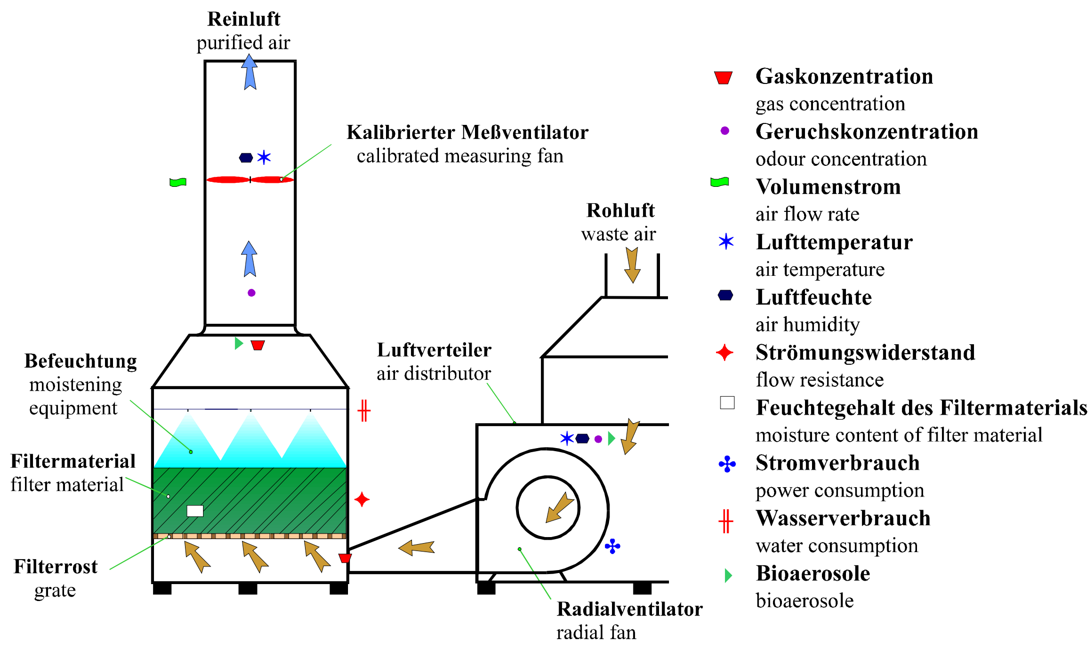

Figure 1: Construction of biofilters and arrangement of measuring points

Table 1: Summary of used measuring devices

measured quantity	measuring device	measuring principle	range / dimension
NH_3 – concentration	Binos® gas analyser	NDIR	0 bis 100 ppm
CO_2 – concentration	Ultramat gas analyser	NDIR	0 bis 5.000 ppm
CH_4 – concentration	gas chromatograph	FID-detector	-
N_2O – concentration	gas chromatograph	ECD-detector	-
odour concentration	olfactometer TO7	-	1 to 64.000 OU/m³
air flow rate	measuring fan	measurement of fre-quencies	150 to 5.000 m³/h
air temperature	thermocouple	Ni-Cr/Ni	- 40 to 105 °C
air humidity	humidity sensor	capacitive	0 to 100 %
flow resistance	pressure difference sensor	membrane	0 to 500 Pa
moisture content of filter material	soil moisture content sensor	electric conductivity	-
power consumption	power counter	measurement of fre-quencies	from 8.3^{-4} kWh
water consumption	flowmeter	measurement of fre-quencies	from 0,01 l

loading rate are the same, biochips and coconut fibre-fibre peat thus allow higher odour cleaning efficiency to be achieved.

Odour concentration in the waste air (before treatment in the filter) constituted the main factor that influenced odour cleaning efficiency (HARTUNG et al, 1997; MANNEBECK, 1995), as shown in **Figure 3** using three filter materials as examples. The increasing filter volume load under the present trial conditions does not exert a decisive influence on odour cleaning efficiency.

Over the entire trial period, the mean ammonia reduction achieved by the individual filter materials varied from between ca. 9% (biochips) and 33% (compost) (**table 3**) with an average ammonia concentration in the waste air of ca. 12 ppm. The emission rate was 3.9 - 4.3 g/h. During the entire trial time, ammonia reduction by all filter materials was subject to tremendous fluctuations. As evidenced by the range of the mean daily values, only compost enabled positive average reduction to be achieved on all measuring days. The generally very small reduction can be traced to factors such as the very high air flow rates and the insufficient dwell time of the air in the filter material. The dwell time fell well below the necessary 40 seconds required for the elimination of ammonia (BUWAL, 1993). This connection (i.e. the dependence of ammonia reduction upon the filter volume load) can be shown using the mean daily values achieved by biochips as an example (**figure 4**). As already described by HARTUNG et al. (1997), ammonia reduction diminishes as the filter volume load grows.

During the entire trial period, the CO_2 reduction measured for all filter materials ranged from between approximately -5 and 5% with a mean carbon dioxide concentration in the waste air of 802 - 807 ppm. The emission rate was 669 - 753 g/h. The varying CO_2 reduction is mainly caused by the great variation in the CO_2 concentration in the outgoing air from the stall (positive correlation with animal activity). The measuring system did not allow concentrations in the waste and purified air to be measured simultaneously. The concentrations had to be measured one after another at a distance of 2 minutes. Continuous measurement of the CO_2 concentration in the waste air showed that two measurements taken consecutively differed by -27 to 41%. The mean value calculated for the individual filter materials yielded a CO_2 production of ca. 0.1 - 0.7% for the entire trial time, which is caused by biochemical oxidation (FISCHER et al., 1990).

Mean CH_4 reduction varied between ca. 8% (biochips) and 14% (compost) (**table 4**) with an average methane concentration in the waste air of 12.9 - 14.1 ppm and an emission rate of 3.7 - 4.6 g/h. During the entire trial period, methane reduction by all filter materials ranged from between ca. -24% and 49%. No significant difference between the individual filter materials could be seen.

Mean N_2O reduction varied from ca. -115% (compost) to 4% (biochips) (**table 5**) with an average concentration of nitrous oxide in the waste air amounting to 349 - 353 ppb. The emission rate was 0.12 - 0.135 g/h. In contrast to methane,

Table 2: Odour reduction of each filter materials

	biochips	coconut-peat	wood-bark	pellets+bark	compost
average [%]	**81.3**	**81.6**	**62.4**	**60.4**	**65.9**
median [%]	85.2	86.1	69.3	63.4	69
maximum [%]	95.4	96.7	88.9	90.7	93
minimum [%]	44.8	31.6	-4.2	-9.1	28.2
average of fvl [m^3 m^{-3} h^{-1}]	613	529	558	618	473
variation fvl [m^3 m^{-3} h^{-1}]	139 - 1247	163 - 783	162 - 813	227 - 896	205 - 775
number of measured data	36	37	37	36	35

fvl = filter volume load

Table 3: Ammonia reduction of each filter materials (calculated from daily averages)

	biochips	coconut-peat	wood-bark	pellets+bark	compost
average [%]	**9.2**	**25.1**	**16.0**	**11.4**	**33.1**
median [%]	8.1	27.3	19.6	11.2	32.5
maximum [%]	31.0	50.3	41.2	47.8	60.1
minimum [%]	-7.8	-12.3	-17.3	-22.2	11.7
average of fvl [m^3 m^{-3} h^{-1}]	506	450	463	509	436
variation fvl [m^3 m^{-3} h^{-1}]	181 - 831	214 - 728	182 - 745	230 - 822	257 - 807
number of measured days	76	76	70	76	76

fvl = filter volume load

Table 4: CH_4 reduction of each filter materials

	biochips	coconut-peat	wood-bark	pellets+bark	compost
average [%]	**8.0**	**9.3**	**9.2**	**8.9**	**13.8**
median [%]	2.3	6	9.9	12.4	12.2
maximum [%]	32.9	48.6	26.8	37.9	43.4
minimum [%]	-10.6	-11.7	-17.5	-23.9	-19.3
average of fvl [m^3 m^{-3} h^{-1}]	532	487	503	525	467
variation fvl [m^3 m^{-3} h^{-1}]	171 - 985	211 - 640	223 - 686	203 - 970	254 - 680
number of measured data	10	12	11	10	10

fvl = filter volume load

Table 5: N_2O reduction of each filter materials

	biochips	coconut-peat	wood-bark	pellets+bark	compost
average [%]	**4.1**	**-13.5**	**-11.6**	**-18.2**	**-115.2**
median [%]	2.9	0	-8.1	-10.7	-127.9
maximum [%]	35.5	74.1	23.5	18.5	3.0
minimum [%]	-17.1	-123.5	-84.8	-75.8	-251.5
average of fvl [m^3 m^{-3} h^{-1}]	532	487	503	526	467
variation fvl [m^3 m^{-3} h^{-1}]	171 - 985	211 - 640	223 - 686	203 - 970	254 - 680
number of measured data	10	12	11	11	10

fvl = filter volume load

significant differences between the individual filter materials were established as of the 13th calendar week. Compost caused N_2O concentration in the clean air to increase continuously until it reached its peak in the 20th calendar week, which led to very high negative separating performances. Filter with biochips produced additional N_2O only in the 20th and 21st calendar week. The remaining filter materials caused N_2O concentration in the clean air to grow as of the 17th calendar week. The measured nitrous oxide production is likely caused by the growing compression of the filter material and the resulting anaerobic processes. Since the mean values are based on only 10 - 12 single measurements, it is currently

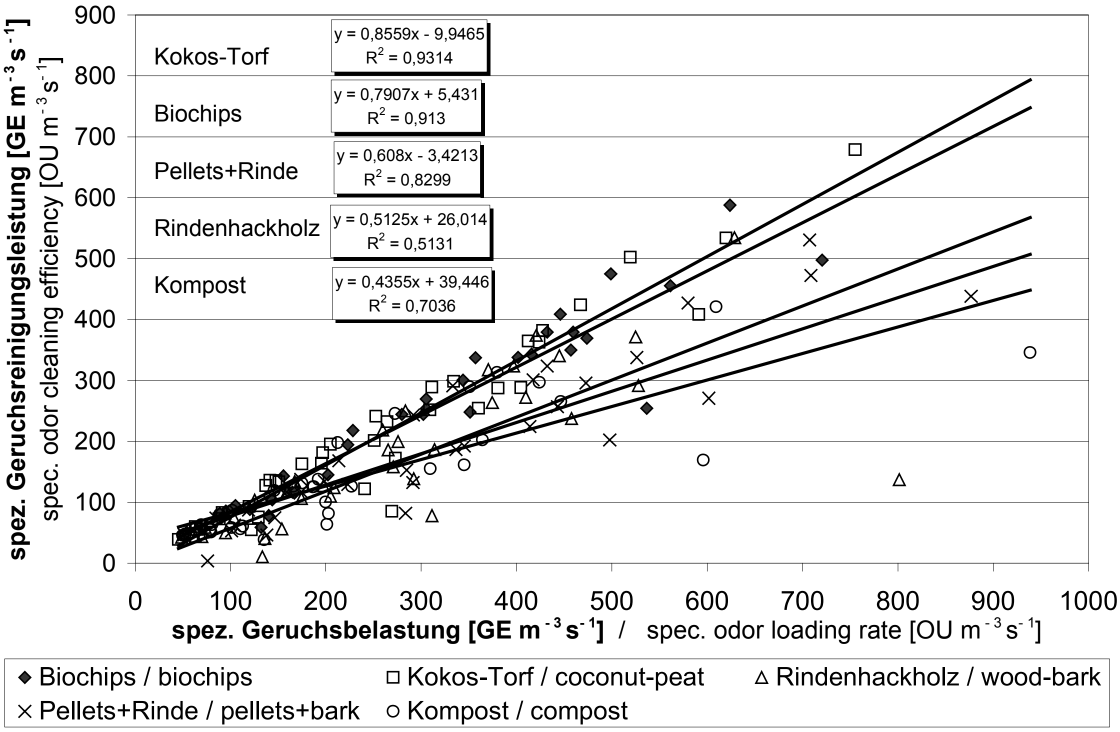

Figure 2: Relation between the spec. odour cleaning efficiency and the spec. odour loading rate

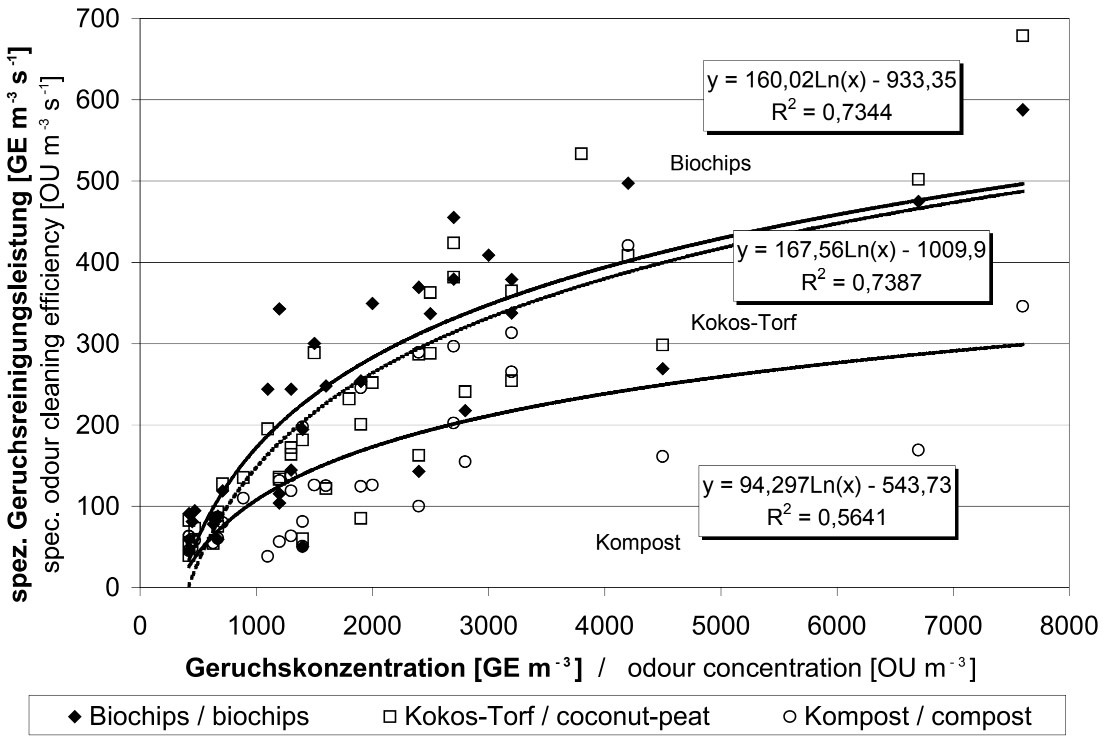

Figure 3: Relation between the spec. odour cleaning efficiency and the odour concentration in the waste air

impossible to give more precise values regarding the reduction/production of methane and nitrous oxide. Only trends can be shown. Other, possibly continuous, studies are necessary in order to be able to explain the influence of the filter material on the emissions level.

Figure 5 shows the measured level of flow resistance (average value, minimum, and maximum) and the compression of the filter materials in relation to the time when the trial was conducted at a filter volume load of 600 $m^3 \cdot m^{-3} \cdot h^{-1}$. This is the maximum filter volume load recommended by ZEISIG (1993) for coconut fibre-fibre peat.

The lowest flow resistances were established for the coarsely structured filter materials biochips and pellets/bark (ca. 18 Pa and 55 Pa respectively). These values remained constant over the entire trial time. However, the flow resistance of the remaining, finely structured filter materials as much as quadrupled. This is mainly caused by the high compression of the filter materials due to their own weight and the deposition of dust in the filter material. With finely structured filter materials, material humidity also has an influence on the varying level of flow resistance. After the filter material has been moistened, the small pores between the individual particles of the material fill with water, which leads to a considerable increase in flow resistance. During the last three weeks of the trial, the specific power requirements [W/1,000 m^3 of conveyed air] of filter with biochips were ca. 30% lower than those of filters with co-

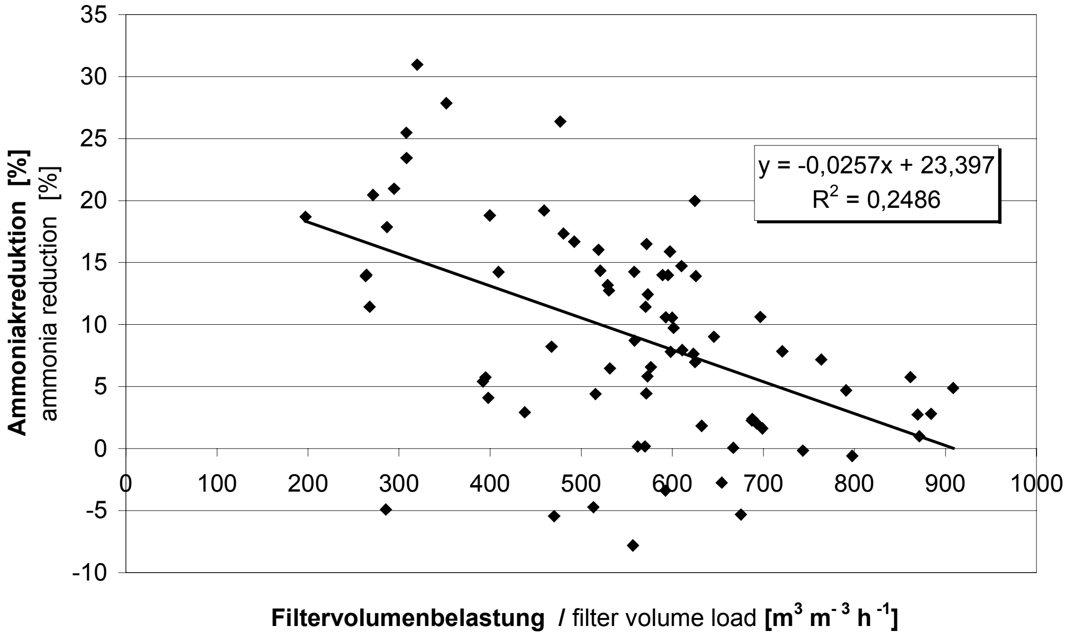

Figure 4: Relation between the ammonia reduction and the filter volume load for biochips

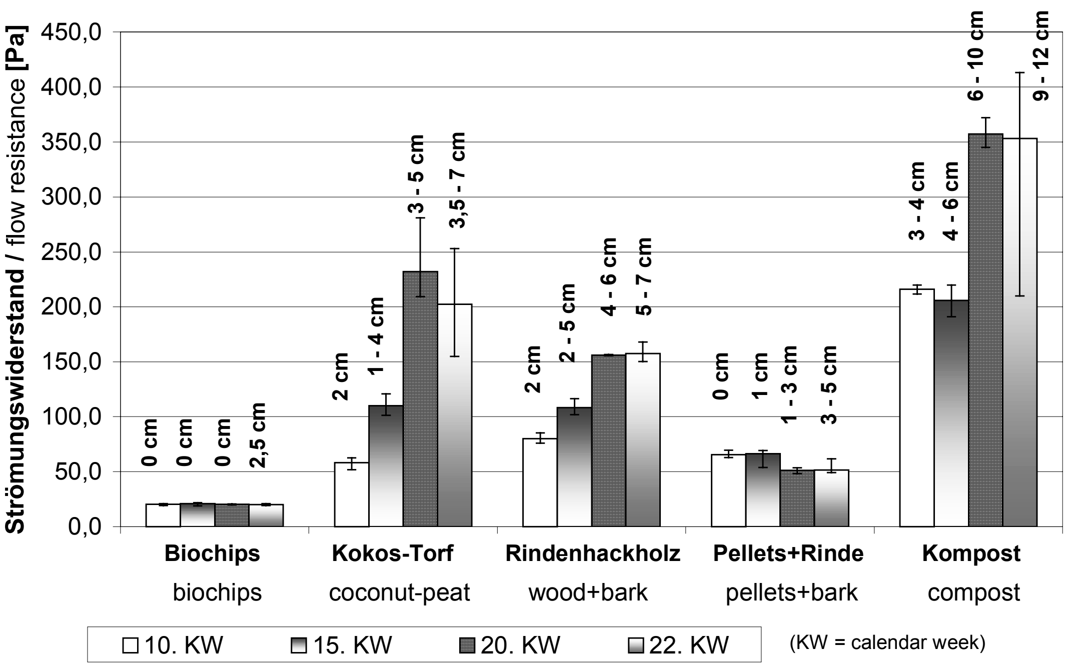

Figure 5: Flow resistance and subsidence of each filter material during the experiments at 600 m³ ·m⁻³ ·h⁻¹ filter volume load

conut fibre-fibre peat. This only applies to the radial fans used for this trial. For every other biofilter system, the specific power requirements must be calculated anew based on the air throughput, the resulting flow resistance of the system, and the fan parameters.

Conclusions

With the use of a new filter material (biochips), the same odour reduction (ca. 81%) can be achieved as with the mixture of coconut fibre-fibre peat often used in practice. Biochips distinguish themselves through their significantly lower flow resistance, which leads to a reduction in operating expenses (electricity costs). Further continuous studies on the influence of filter materials on the emission levels of CO_2, CH_4, and N_2O are to be carried out. In another trial, filters with a 1 m layer of biochips will be tested, which could make possible a reduction of the building expenses (smaller area requirements). After completion of the trials and evaluation, an assessment of the economic viability will be performed and published in a later article.

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