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# Deodorisation of Industrial Gases Using a Biofiltration Plant

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## ABSTRACT

This paper proposes the use of natural fibres: cotton, hemp and jute, as an additive to the fillings in peat-bark biofilters used to deodorise industrial gases in order to increase the sorption properties of the biomass used. The subject of the studies involved waste gases from a grease trap, which were passed through biofilters to remove volatile fatty acids (VFAs) from them that are responsible for the odour nuisance of these gases. It was assumed that a set of microorganisms would be established on the biological material through a process of natural selection to convert the readily decomposable fatty acids into carbon dioxide and water. Gases were sampled upstream and downstream of the beds as well as analysed qualitatively and quantitatively on a gas chromatograph. On the basis of the changes in volatile fatty acid concentrations, the efficiency of the deodorisation process was evaluated. The deodorisation results were compared between the individual beds at the unstable stage of those beds filtration, i.e. during the period of biofilters activation and during their stable filtration. For each bed, the efficiency during each week of filtration was calculated. The efficiencies of removal of individual fatty acids from the waste gases were also compared. The studies show that a 3-month filtration period of the biofilter is sufficient for the biological bed to begin to effectively perform its function as a deodoriser of waste gases under industrial conditions. This period was characterised by considerable turbulence and activation of both the filter material and the microorganisms in the bed. During the first weeks of activation, the beds described in this paper showed relatively low deodorisation efficiencies (33–58%). In the next phase, there was an increase in flow resistance and a partial decrease in treatment effects to 32–47%. After that, there were fluctuations in deodorisation efficiency for several weeks until the microflora was established and adapted. During this period, the peat-bark bed had the best efficiency amounting to 70–80%. After 9 weeks, the beds were already partially activated, the microorganisms were moving towards equilibrium and the deodorisation efficiency with fibre beds was above 80%. After 15 weeks of filtration, the already activated biofilters reached efficiencies of over 90% and even 95% in the case of cotton.

**Keywords:** biofiltration, biological bed, deodorisation, volatile fatty acids.

## INTRODUCTION

Biofiltration is one of alternative methods of removing malodorous (odour nuisance) pollutants with a low detection threshold from waste gases, occurring in low concentrations in the post-process air. Its advantage, apart from its relatively low investment and operating costs [Miller 2018, Wysocka 2019], is that this process is virtually waste-free. It results in the actual elimination of pollutants, rather than simply changing the location or form of their occurrence, without generating additional waste. This is why biofiltration, using different types of filter materials, is currently preferred worldwide [Wierzbińska 2015, Wierzbińska 2017, Boehm et al. 2020, Christami et al. 2019, Caliskaner et al. 2020, Pineda et al. 2021, Osabutey et al. 2022].

The process of biofiltration involves the slow flow of polluted gas through a layer of sorption material populated by microorganisms specially selected for the type of pollutants. To maintain high efficiency of this process, optimum gas and bed conditions as well as operating parameters must be maintained. The pollutants diffuse into the liquid coating that covers the sorbent, the so-called biolayer or biofilm, where they are broken down by the microorganisms and their enzymes to carbon dioxide and water which are discharged into the atmosphere as harmless and non-toxic [Wierzbińska 2021a, 2021b; Schmidt at al. 2020].

## MATERIALS AND METHODS

The studies proposed the use of natural fibres: cotton, hemp and jute as additives to the fills in peat-bark biofilters used to deodorise nuisance industrial gases in order to increase the sorption properties of the biomass used. The use of waste fibres was assumed to eliminate an increase in investment costs of the plant.

The subject of the studies was waste gases from a grease trap, which were passed through biofilters (Fig. 1) to remove volatile fatty acids (VFAs) from them that are responsible for the odour nuisance of these gases. It was assumed that a set of microorganisms would be established on the biological material through the process of natural selection to convert the readily decomposable fatty acids into carbon dioxide and water.

The peat-bark biofilters with the addition of fibres were made of PMMA tubes with a diameter of 100 mm and a height of 1 m (Fig. 1-2). The tubes were filled with layers of biological material, being a mixture of peat and bark in 6 layers × 300 g each (approx. 6×12 cm), and with five layers made of natural fibres: one bed of cotton, another of hemp and the third one of jute, in 5 layers × 5 g in each bed (approx. 5×3 cm). The fibres were distributed evenly across the biofilter cross-section, creating layers with thickness of approx. 3 cm. Crude fibres, not subjected to any chemical treatment, were used to make the biological beds. In the case of jute and hemp, these were technical fibres.

**Figure 1.** Test rig for deodorisation of industrial gases using peat-bark filled biofilters and biofilters with plant fibre layers

Prior to inserting the fibre layers into the biofilters, tests were carried out to estimate the thickness, specific surface area and porosity of the fibre layers. The volume of each biofilter was 0.007 $m^3$, while the cross-sectional areas of the beds were 0.008 $m^2$. Gas was fed to the individual biological beds from the grease trap by means of a fan. Control valves were installed upstream of

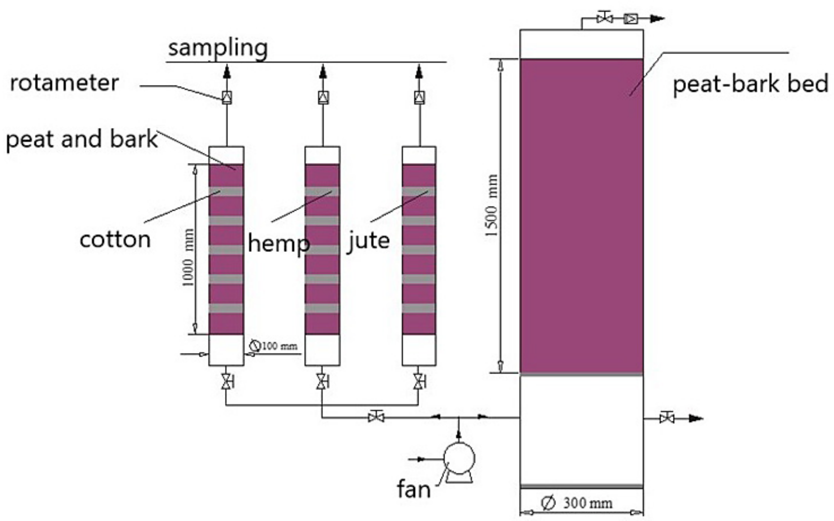


**Figure 2.** Schematic diagram of the test rig consisting of biological beds filled with a mixture of peat and bark, jute, hemp and cotton

the beds to equalise the flows through all the beds. Downstream of the filters, RDN 15 rotameters were placed, with which the flow rates were read, as well as pipes for sampling the gas after deodorisation. The load on the fibre beds was about 125 $m^3/m^2$ h and the gas retention time was about 25 sec. The conditions under which the tests were conducted were variable due to changes in ambient conditions and fluctuations resulting from factory production. The operating parameters of the plant varied:

- waste gas temperature: 40 ± 5°C,
- gas temperature in the bed: 27 ± 2°C,
- moisture content of deodorised gas: approx. 100 %.

The flow rate of polluted gas through the bed was set at 1$m^3$/h. To measure temperature and humidity, a dual-function portable meter by Lutron, type HT-3003, was used. Gases were sampled upstream and downstream of the beds as well as analysed qualitatively and quantitatively on a gas chromatograph. The efficiency of the deodorisation process was assessed on the basis of changes in volatile fatty acid concentrations. The gas samples were taken, after passing 50 l of gas through scrubbers containing 5 ml of 0.05 m KOH. Then, after adding a few ml of 1 m HCl to KOH (to obtain a weakly acidic reaction), 2 μl of the sample thus prepared were taken and fed into the dispenser in the chromatograph.

Chromatographic testing of waste gas samples was carried out on a Hewlett Packard gas chromatograph (GC System, HP 6890 Series), using a capillary column for polar compounds, 10 m long, 0.53 mm in diameter, coated with 1 μm layer of polyglycol modified with terephthalic acid (FF AP 10 m × 0.53 mm × 1 μm). Nitrogen was used as the carrier gas. Testing was carried out at the following parameters:

- initial oven temperature: 75 °C,
- final oven temperature: 150 °C,
- analysis time: 10 min,
- FID detector temperature: 250 °C,
- dispenser temperature: 250 °C.

The installed HP ChemStation software was used to control the chromatograph and calculate the obtained results. Calibration of the method was performed using an external standard. The VFA concentration values presented in this paper were the arithmetic mean of two consecutive analyses.

## RESULTS

The chromatograms obtained and the concentrations of the pollutants responsible for the odour nuisance of the tested waste gases, before and after the deodorisation process, were collated and compared. Calibration of the method on standards allowed the identification of five volatile fatty acids. The identified acids contained 2, 3, 4, 5, 6 carbon atoms per molecule, respectively. The three most odorous fatty acids, i.e. acetic acid, propionic acid and butyric acid, were analysed.

The results of deodorisation were compared between the individual beds during the unstable stage of bed filtration, i.e. during the period of biofilters activation and during their stable filtration. For each bed, efficiencies were calculated for each week of filtration. The efficiencies of removing individual fatty acids from the waste gases were also compared. It was assumed that the addition of natural fibres: cotton, hemp and jute, to the peat-bark mixture would increase the efficiency of the biofilter and thus improve the effectiveness of deodorisation of nuisance gases released into the environment as a result of technological processes. The crude fibres were examined in terms of parameters that are critical for biofiltration processes, such as the thickness of the fibres, their specific surface area and the porosity of the cotton, jute and hemp fibre layer.

On the basis of the chromatograms obtained, the concentrations of acetic, propionic and butyric acids in the gas samples tested were determined. Mean values from three measurements for the peat-bark filled biofilter are summarised in Table 1, for the bed with hemp fibres – in Table 2, for the bed with jute fibres – in Table 3 and for the bed with cotton fibres – in Table 4.

During the first week of biofilters operation, the total concentration of acetic, propionic and butyric acids decreased by 4.572 μg/$m^3$ for the peat-bark bed, by 2.970 μg/$m^3$ after passing through the bed with the addition of hemp, by 3.795 μg/$m^3$ for the bed with the addition of jute and by 4.405 μg/$m^3$ for the bed with the addition of cotton. After 3 weeks of filtration, an unexpected increase in the differences in biofiltration efficiency of the waste gases was observed. A decrease in their total concentrations was observed for the peat-bark bed by 4.494 μg/$m^3$, for the beds with hemp, jute and cotton the concentrations changed by 3,274 μg/$m^3$, 3.369 μg/$m^3$ and 2.305 μg/$m^3$, respectively. After 9 weeks, the effects of removal of nuisance

**Table 1.** Concentration of volatile fatty acids before and after the deodorisation process for the peat-bark filled biofilter

| Bed filtration time [weeks] | Concentration of volatile fatty acids [μg/m³ ] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Acetic acid | | Propionic acid | | Butyric acid | | Total | |
| | (1) | (2) | (1) | (2) | (1) | (2) | (1) | (2) |
| 1 | 2432 | 1020 | 5112 | 2633 | 1570 | 889 | 9114 | 4542 |
| 2 | 2102 | 881 | 5109 | 2107 | 1608 | 708 | 8819 | 3696 |
| 3 | 1220 | 433 | 5111 | 2109 | 817 | 112 | 7148 | 2654 |
| 4 | 2440 | 471 | 2788 | 1102 | 1560 | 601 | 6788 | 2174 |
| 5 | 1199 | 319 | 5207 | 1013 | 819 | 318 | 7225 | 1650 |
| 6 | 1213 | 302 | 5208 | 1003 | 1617 | 311 | 8038 | 1616 |
| 9 | 1217 | 298 | 5307 | 1001 | 5090 | 307 | 11614 | 1606 |
| 11 | 2440 | 213 | 5311 | 477 | 4709 | 267 | 12460 | 957 |
| 13 | 4766 | 361 | 8976 | 572 | 6569 | 303 | 20311 | 1236 |
| 14 | 8979 | 917 | 15760 | 1003 | 12663 | 806 | 37402 | 2726 |
| 15 | 8797 | 916 | 15890 | 893 | 11992 | 851 | 36679 | 2690 |

**Note:** (1) before deodorisation, (2) after deodorisation.

**Table 2.** Concentration of volatile fatty acids before and after the deodorisation process for the peat-bark filled biofilter with hemp fibres

| Bed filtration time [weeks] | Concentration of volatile fatty acids [μg/m³] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Acetic acid | | Propionic acid | | Butyric acid | | Total | |
| | (1) | (2) | (1) | (2) | (1) | (2) | (1) | (2) |
| 1 | 2432 | 2033 | 5112 | 3312 | 1570 | 799 | 9114 | 6144 |
| 2 | 2102 | 1217 | 5109 | 2219 | 1608 | 813 | 8819 | 4249 |
| 3 | 1220 | 578 | 5111 | 2987 | 817 | 309 | 7148 | 3874 |
| 4 | 2440 | 882 | 2788 | 1432 | 1560 | 891 | 6788 | 3205 |
| 5 | 1199 | 437 | 5207 | 1579 | 819 | 321 | 7225 | 2337 |
| 6 | 1213 | 571 | 5208 | 1201 | 1617 | 467 | 8038 | 2239 |
| 9 | 1217 | 402 | 5307 | 1101 | 5090 | 313 | 11614 | 1816 |
| 11 | 2440 | 227 | 5311 | 539 | 4709 | 388 | 12460 | 1154 |
| 13 | 4766 | 602 | 8976 | 779 | 6569 | 704 | 20311 | 2085 |
| 14 | 8979 | 987 | 15760 | 1037 | 12663 | 887 | 37402 | 2911 |
| 15 | 8797 | 856 | 15890 | 989 | 11992 | 971 | 36679 | 2816 |

**Note:** (1) before deodorisation, (2) after deodorisation.

compounds that were contained in the waste gases became similar. The concentration of acetic, propionic and butyric acids decreased in total by 10,008 μg/m³ after passing through the peat-bark bed, 9.798 μg/m³ after deodorisation on the bed with hemp layers, 9.781 μg/m³ after the bed with jute and 9.907 μg/m³ after the bed with cotton.

After 13 weeks of filtration, the efficiencies of the beds stabilised at similar levels with only slight fluctuations, resulting, among other things, from the variability of the production processes, i.e. the parameters of the incoming gas. The total concentration of the analysed volatile fatty acids after passing through the peat-bark bed decreased by 19.075 μg/m³, through the bed with hemp fibres by 18.226 μg/m³, after passing through the bed with jute by 17.685 μg/m³ and with cotton by 19.192 μg/m³. After 15 weeks, despite relatively high concentrations of the analysed pollutants (36.679 μg/m³ in total) (fluctuations in factory production), there was a decrease after the peat-bark bed by 33.989 μg/m³, after the bed with hemp layers by 33.863 μg/m³, after the bed with jute by 33.303 μg/m³ and 34.798 μg/m³ after the bed with cotton fibres.

In the following section of this paper, the percentage changes in the concentrations of the individual odours during the filtration are summarised.

**Table 3.** Concentration of volatile fatty acids before and after the deodorisation process for the peat-bark filled biofilter with jute fibres

| Bed filtration time [weeks] | Concentration of volatile fatty acids [μg/m³] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Acetic acid | | Propionic acid | | Butyric acid | | Total | |
| | (1) | (2) | (1) | (2) | (1) | (2) | (1) | (2) |
| 1 | 2432 | 1213 | 5112 | 3117 | 1570 | 989 | 9114 | 5319 |
| 2 | 2102 | 1011 | 5109 | 2301 | 1608 | 815 | 8819 | 4127 |
| 3 | 1220 | 567 | 5111 | 2899 | 817 | 313 | 7148 | 3779 |
| 4 | 2440 | 876 | 2788 | 1471 | 1560 | 902 | 6788 | 3249 |
| 5 | 1199 | 421 | 5207 | 1612 | 819 | 319 | 7225 | 2352 |
| 6 | 1213 | 566 | 5208 | 1106 | 1617 | 312 | 8038 | 1984 |
| 9 | 1217 | 410 | 5307 | 1106 | 5090 | 317 | 11614 | 1833 |
| 11 | 2440 | 203 | 5311 | 1219 | 4709 | 298 | 12460 | 1720 |
| 13 | 4766 | 897 | 8976 | 976 | 6569 | 753 | 20311 | 2626 |
| 14 | 8979 | 1004 | 15760 | 1403 | 12663 | 979 | 37402 | 3386 |
| 15 | 8797 | 997 | 15890 | 1401 | 11992 | 978 | 36679 | 3376 |

**Note:** (1) before deodorisation, (2) after deodorisation.

**Table 4.** Concentration of volatile fatty acids before and after the deodorisation process for the peat-bark-filled biofilter with cotton fibres

| Bed filtration time [weeks] | Concentration of volatile fatty acids [μg/m³] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Acetic acid | | Propionic acid | | Butyric acid | | Total | |
| | (1) | (2) | (1) | (2) | (1) | (2) | (1) | (2) |
| 1 | 2432 | 1081 | 5112 | 2830 | 1570 | 798 | 9114 | 4709 |
| 2 | 2102 | 909 | 5109 | 2211 | 1608 | 809 | 8819 | 3929 |
| 3 | 1220 | 748 | 5111 | 3678 | 817 | 417 | 7148 | 4843 |
| 4 | 2440 | 499 | 2788 | 1311 | 1560 | 597 | 6788 | 2407 |
| 5 | 1199 | 501 | 5207 | 2516 | 819 | 427 | 7225 | 3444 |
| 6 | 1213 | 304 | 5208 | 1104 | 1617 | 347 | 8038 | 1755 |
| 9 | 1217 | 301 | 5307 | 1097 | 5090 | 309 | 11614 | 1707 |
| 11 | 2440 | 212 | 5311 | 468 | 4709 | Below LOQ | 12460 | 489 |
| 13 | 4766 | 350 | 8976 | 488 | 6569 | 281 | 20311 | 1119 |
| 14 | 8979 | 613 | 15760 | 798 | 12663 | 503 | 37402 | 1914 |
| 15 | 8797 | 603 | 15890 | 780 | 11992 | 498 | 36679 | 1881 |

**Note:** (1) before deodorisation, (2) after deodorisation

The changes in the concentrations of acetic acid, propionic acid and butyric acid are shown in Figures 3–5, respectively. When analysing the changes in biofilters efficiency shown in Figure 3, it can be seen that during the first six weeks of biofilters operation, the peat-bark bed had the highest acetic acid removal efficiency. The efficiency in this case reached 60–80%. During the first two weeks, acetic acid was removed to the lowest extent when deodorised on the bed with hemp fibres (16%). Until the fourth week, this efficiency increased rapidly, reaching around 64%. Between the sixth and eleventh week of studies, the efficiency of acetic acid decomposition on the bed with cotton fibres equalled that of the peat-bark bed, still increasing between 75–93%. After the sixth week, this efficiency was the highest for the bed with cotton and the bed without added fibres (approx. 75%), while after thirteen weeks of studies, the bed with cotton fibres had the highest acetic acid removal efficiency – approximately 93%.

Figure 4 shows graphs of the changes in the removal efficiency of propionic acid from the analyzed gases in the deodorisation process on the four biological beds tested. The trends in changes in deodorisation efficiency for the individual biofilters

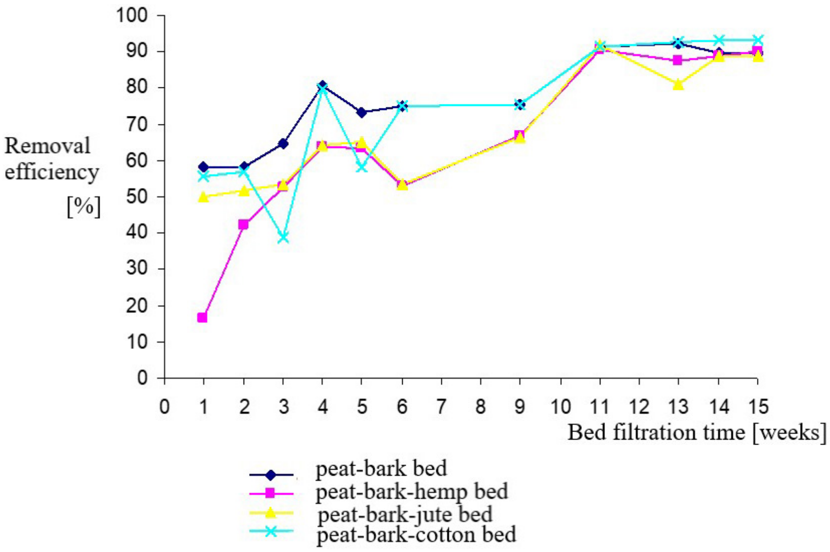


**Figure 3.** Acetic acid removal efficiency in the deodorisation process

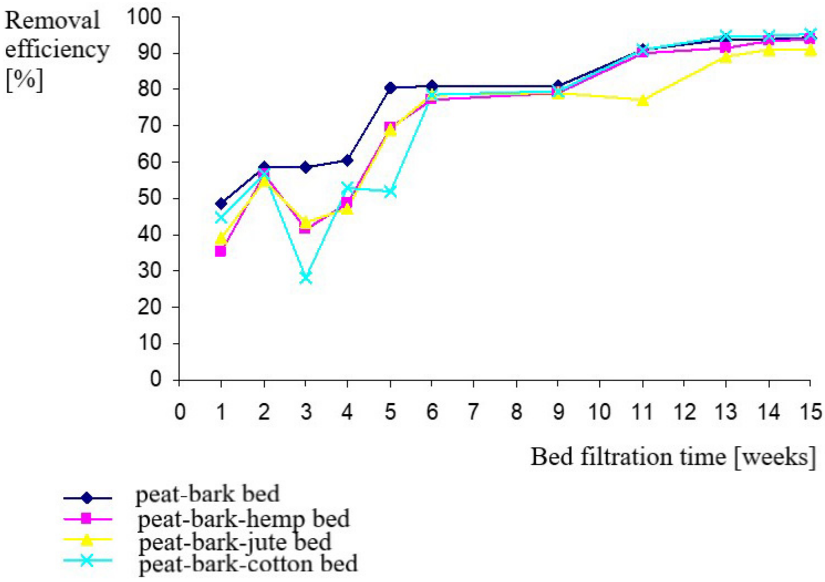


**Figure 4.** Propionic acid removal efficiency in the deodorisation process

are more similar to each other than for acetic acid removal. During the first week of the studies, the process efficiency increased for all beds, followed by a decrease in the second week for all biofilters as well. During this time, the peat-bark bed "performed" best and the bed with cotton fibres performed worst. From the sixth week onwards, the efficiencies of the beds increased to reach similar results, except for the bed with jute, the efficiency of which dropped to 77%. After thirteen weeks of filters operation, their efficiencies increased to reach similar values. The bed with cotton fibres had the highest efficiency (above 94%). When analysing the changes in biofilters efficiency shown in Figure 5, it can be seen that during the first five weeks of biofilters operation, the peat-bark bed removed butyric acid best. This efficiency unexpectedly increased in the third week to 86%, before dropping to around 60% in the following week. After five weeks of fluctuating filter efficiency, the efficiency of the deodorisation process began to increase in all cases. After nine weeks of studies, when all beds reached the same efficiency (approx. 94%), the effects stabilised at 93% for the peat-bark bed, 92% for the bed with jute and hemp and 96% for the biofilter with cotton fibres. Furthermore, it was found that acetic acid in the initial phase of the deodorisation process

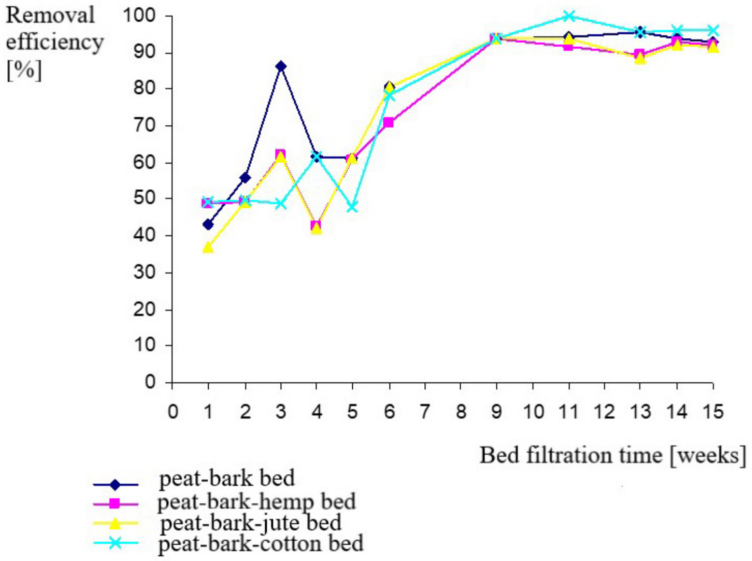


**Figure 5.** Butyric acid removal efficiency in the deodorisation process

was removed in 50–60% on average, while other odours were removed in 40v50%. The greatest fluctuation was in the removal efficiency of propionic acid, which decreased between the second and fourth weeks of biofilter operation. Table 5 summarises the changing over time efficiencies of individual beds during biofilter operation.

During the first week of studies, the peat-bark bed reached an efficiency of 50%, while the deodorisation efficiency with the biofilter filled with layers of peat, bark and hemp was 33%. Odour removal by acid absorption by the biological bed with jute reached 42%, while that with cotton reached 48%. After three weeks, it was found that the efficiency of the peat-bark bed increased to 63%, while the efficiency of the waste gas deodorisation process decreased to 46% for the bed with hemp, 47% for the bed with jute and to 32% for the bed with cotton. The increasing over time efficiency of the peat-bark bed here reached 86% after nine weeks of studies. The bed with cotton, after much fluctuation, reached 85% deodorising capacity for nuisance gases, as did the filters with hemp and jute fibres – 84%. Surprisingly, after 11 weeks of studies, the most effective biofilter turned out to be the peat-bark-cotton bed which achieved an efficiency of 96%, which, with such low concentrations of odour compounds, is a very optimistic result.

After 13 weeks of filtration, when the efficiencies of the beds stabilised at similar levels with only minor fluctuations, the efficiencies of the individual biofilters were 94%, 90%, 87% and

**Table 5.** Summary of the efficiencies of biological beds depending on their filtration time

| Week of filtration | Bed efficiency η [%] | | | |
|---|---|---|---|---|
| | Peat-bark | Peat-bark with hemp fibres | Peat-bark with jute fibres | Peat-bark with cotton fibres |
| 1 | 50 | 33 | 42 | 48 |
| 2 | 58 | 52 | 53 | 55 |
| 3 | 63 | 46 | 47 | 32 |
| 4 | 68 | 53 | 52 | 65 |
| 5 | 77 | 68 | 67 | 52 |
| 6 | 80 | 72 | 75 | 78 |
| 9 | 86 | 84 | 84 | 85 |
| 11 | 92 | 91 | 86 | 96 |
| 13 | 94 | 91 | 87 | 95 |
| 14 | 93 | 92 | 91 | 95 |
| 15 | 93 | 92 | 91 | 95 |

95%, respectively. After 15 weeks, the efficiencies of the beds still exceeded 91%, with the cotton bed achieving the highest efficiency – 95%. At this stage, no differences in gas deodorisation efficiencies over time were observed for the individual biofilters. They stabilised at the level of 93% for the bed without fibres, 92% for the bed with hemp fibres, 91% for the bed with jute fibres and 95% for the bed with cotton fibres, irrespective of ambient temperature fluctuations.

When analysing the results obtained, it can be seen that after one week of filtration of the beds with added fibres, when the beds were still not activated, only a 33–51% removal efficiency of odorous compounds was observed. During this period, only sorption of volatile fatty acids on the particles of the filter material took place. It should be assumed that the small population of microorganisms was not yet able to participate effectively in the conversion of odorous compounds into carbon dioxide and water. The factors having a favourable effect on the decomposition of pollutants were the high moisture content of the bed mass and the optimum temperature for the process, 25–30 °C in the case of the peat-bark bed and 30–40 °C in the beds with the addition of fibres. The moisture content of the gas fed into the biological beds was up to 100%. During the first two weeks of the studies, the peat-bark bed had the highest efficiency, but these differences were not high, given its larger size and lower pollutant load on that bed.

After 3 weeks of beds filtration, unexpectedly an increase in the differences in waste gases biofiltration efficiency was observed. Microorganisms were partly involved in the deodorisation process, which can be inferred from the increasing efficiency of the peat-bark filter. This would not have been possible without the participation of microorganisms due to the limited sorption capacity of the filter material. The efficiency of the biofilters was the resultant of the increasing participation of microorganisms and the lower proportion of sorption processes. There was a significant increase in flow resistance and load of beds with the addition of fibres. Using rotameters, a reduction in gas flow through the biofilters was observed and this was most evident in the case of the peat-bark bed with cotton. After 4 weeks of filtration, there was an increase in the efficiency of the biofilters and thus an increase in the efficiency of the deodorisation process of the nuisance gases. The bacterial flora was already largely established and the microorganisms were specialised in the breakdown of fatty acids into carbon dioxide and water.

Similarly, in the fifth week of filtration and attempts to adapt the microorganisms to the existing conditions, the humidity of the gas reached 100% and the temperature of the deodorised gas varied between 25 and 30 °C for peat and bark and 30 to 35 °C for peat, bark and natural fibres. While the efficiency of odour removal with peat, bark, hemp and jute increased over time, the efficiency of the biofilter with cotton decreased again. In fact, the excellent water absorption capacity of cotton caused such an increase in bed load that there was a drop in efficiency from 65% (at week 4) to 52% after week 5 of filter operation.

At the six-week filtration stage, a significant increase in the deodorisation efficiency of the gases passing through the peat-bark bed with cotton fibre layers was observed. This efficiency increased to 78%, placing this bed in first place among the studied biofilters filled with natural fibres in terms of device efficiency. These changes were also confirmed by organoleptic analyses of the gas at source and after deodorisation on the four biofilters, carried out by a group of three people. After 11 weeks of unstable operation of the biofilters and changes that occurred during filtration, the biological conditions began to stabilise. The equilibrium between the microorganisms and the amount of pollutants entering the beds, or more precisely their concentrations, was established. At this stage, the beds were already activated and, after the various turbulences occurring during the studies, the relationship and efficiency of the complex odour removal process were equalized. Sometimes, stabilisation of bed filtration is achieved already after 15 days of filtration. However, this is only possible in laboratory tests and not on a technical scale, where the conditions on the test rig change.

After 15 weeks of studies, with the onset of late autumn and a drop in ambient temperature, the gas deodorisation conditions changed. The ambient temperature fluctuated between 7 and 10 °C, while the temperature of the peat-bark bed did not fall below 20 °C and of the bed with fibres below 25 °C. This was due to the high, in the order of 40 °C, temperature of the waste gases in the grease trap. However, this did not affect the efficiency of the removal of odorous compounds from the polluted gas and did not disturb the microbiological equilibrium created in previous weeks. Neither "clogging" of the biofilter nor degeneration of the

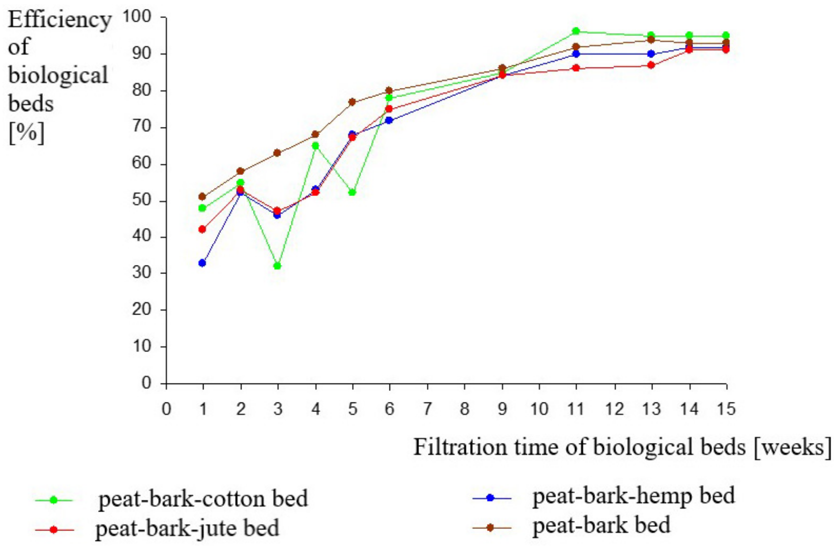


**Figure 6.** Graphs of changes in biofilters efficiency during their filtration time

filter material was observed at this stage of the studies. The studies show that a 3-month filtration period of the biofilter is sufficient for the biological bed to begin to effectively perform its function as a deodoriser of nuisance waste gases under industrial conditions. This period was characterised by considerable turbulence and activation of both the filter material and the microorganisms in the bed. The literature states that the incubation period, the adaptation of the microorganisms to the new environment, lasts about 10 days. Other sources state that this period lasts as long as 4 to 10 days. It is generally assumed that the adaptation period of the microbial flora ends when the pollutant removal efficiency is 80–98%. However, these data mostly refer to laboratory conditions. In the studies described in this paper, which were conducted on a semi-technical scale, under industrial conditions, the adaptation period of the microorganisms, and consequently the activation of the beds, took about 9 weeks. The test rig conditions made it very difficult for the microorganisms to adapt to the ambient conditions which, in contrast to the stable laboratory conditions established from the beginning, changed uncontrollably. This was particularly true for temperature, humidity and the quantitative composition of the gas flowing into the beds.

In the first weeks of activation of the beds described in this paper, they showed relatively low deodorisation efficiency. The degree of "reduction" varied between 33 and 58%. According to what was confirmed by the studies, this was a stage of absorption of odorous compounds in the biolayer covering the particles of the biological material. The microbial population, which was later to be the primary factor in an efficient odour removal process, was not yet developed. In the next phase of the studies, while the peat biofilter was increasing its efficiency, the beds with fibres began to "clog". There was an increase in flow resistance and a partial decrease in treatment effects to 32–47%. The implication is that the peat absorbed water more slowly, but effectively enough to allow microflora to develop on it earlier than in other cases. Fibres, on the other hand, and especially cotton, due to its superior hygroscopic properties, absorbed a considerable amount of water in a short time and then "clogging" of the beds occurred. This was followed by fluctuations in deodorisation efficiency for several weeks until the microflora was established and adapted. During this time, the peat-bark bed had the best efficiency amounting to 70–80% (Figure 6). After 9 weeks, the beds were already partially activated, the microorganisms were moving towards equilibrium and the deodorisation efficiency with fibre beds was above 80%. At this stage, the conversion of fatty acids by the microorganisms into carbon dioxide and water was the main factor that affected the processes taking place. After 15 weeks of filtration, the already activated biofilters reached efficiencies of more than 90% and even 95% in the case of cotton (Table 5).

## CONCLUSIONS

The studies conducted on the possibility of using natural fibres as an alternative additive to biological beds in the deodorisation process of industrial gases have led to the following conclusions. Biofiltration is an effective method for deodorisation of waste gases from the fat and oil industry. The effects of biofiltration depend on the type of filter material used. The addition of natural fibre layers to the peat-bark mixture increases the efficiency of the biofilter and thus improves the effects of deodorisation of waste gases from the fat and oil industry. The highest efficiency of fatty acid removal was achieved with a biological bed containing cotton fibre layers. Introduction of layers of cotton, jute and hemp fibres into the peat-bark bed improves the structure of the biomass, preventing the clumping of such a bed in the event of excessive moisture and the formation of anaerobic areas in the biological mass and consequently the release of gases which are products of anaerobic processes. The best filter material for making the biological bed proved to be cotton fibres which had the highest porosity and the largest specific surface area. Maintaining optimum conditions for the biofiltration process prevents acid hydrolysis of the fibres, which prolongs the life of the bed. The efficiency of biofilters peaked after nine weeks of beds filtration and did not decline over the next 6 months. The use of natural fibres, particularly cotton, to deodorise waste gases offers prospects for the development of biofiltration as an effective method of odour removal. The use of natural plant fibres as an additive to biological beds opens up new possibilities for the use of waste fibres from these raw materials.

## REFERENCES

1. Boehm A.B., Bell C.D., Fitzgerald N.J., Gallo E., Higgins C.P., Hogue T. S. & Wolfand J.M. 2020. Biochar-augmented biofilters to improve pollutant removal from stormwater–can they improve receiving water quality? Environmental Science: Water Research & Technology, 6(6), 1520-1537.
2. Caliskaner O., Tchobanoglous G., Imani L. N., Lund J., Davis B., Farias J.R. & Reid T. 2020. Performance Evaluation of Parallel Operation of Conventional Primary Treatment versus Primary Filtration and Biofiltration Systems. In: WEFTEC 2020. Water Environment Federation.
3. Christami M.N.A., Moersidik S.S., El Khobar M.N. & Silvia Y. 2019. Application of aerated submerged spongebed biofilter for raw water pre-treatment in drinking water installation. In: MATEC Web of Conferences, 270, 04008. EDP Sciences.
4. Lamprea Pineda P., Demeestere K., Toledo Padrón M., Boon N., Van Langenhove H. & Walgraeve C. 2021. Mesophilic and thermophilic biofiltration of N, N-Dimethylformamide: long-term performance evaluation and microbial communities' evolution. In: 9th IWA Odour and VOC/Air Emissions Conference.
5. Miller U., Sówka I., Grzelka A., Pawnuk M. 2018. Application of biological deodorization methods in the aspect of sustainable development. SHS Web of Conferences 57, 02006 https://doi.org/10.1051/shsconf/20185702006
6. Osabutey A., Cromer B., Davids A., Prouty L., Haleem N., Thaler R. & Yang X. 2022. Distribution of airflow and media moisture content across two vertical bed biofilters. AgriEngineering, 4(1), 179-189.
7. Schmidt D., Jacobson L. & Nicolai D. 2020. Biofilter design information. University of Minnesota Extension.
8. Wierzbińska M. 2017. Biofiltry jako budowle w inżynierii środowiska, Materiały Budowlane, Wyd. SIGMA-NOT, 12, 27-30.
9. Wierzbińska M. 2021a. The application of mineral sorbents to remove volatile organic compounds from the gases emitted from the composting processes. Journal of Ecological Engineering. 22(2), 98-110, DOI: 10.12911/22998993/130888
10. Wierzbińska M. 2021b. The removal of organic acids and aldehydes from gases emitted from composting municipal waste. Journal of Ecological Engineering. 22(3), 58-66, DOI: 10.12911/22998993/132434
11. Wierzbińska M., Modzelewski W.E. 2015. Zastosowanie biofiltrów do dezodoryzacji uciążliwych gazów. Ecol. Eng., 41, 125-132.
12. Wysocka I., Gębicki J., Namieśnik J. 2019. Technologies for deodorization of malodorous gases, Environmental Science and Pollution Research, 26, 9409–9434. https://doi.org/10.1007/s11356-019-04195-1