ACTA ABP BIOCHIMICA POLONICA

Vol. 60, No 4/2013
747–751
on-line at: www.actabp.pl

Regular paper

The use of oak chips and coconut fiber as biofilter media to remove vocs in rendering process*

Leszek Tymczyna[1], Anna Chmielowiec-Korzeniowska[1]✉, Zbigniew Paluszak[2], Magadalena Dobrowolska[1], Marcin Banach[3] and Jolanta Pulit[3]

[1]University of Life Sciences, Lublin, Poland; [2]University of Technology and Life Sciences, Bydgoszcz, Poland; [3]Cracow University of Technology, Kraków, Poland

The study evaluated the effectiveness of air biofiltration in rendering plants. The biofilter material comprised compost soil (40%) and peat (40%) mixed up with coconut fiber (medium A) and oak bark (medium B). During biofiltration average VOCs reduction reached 88.4% for medium A and 89.7% for medium B. A positive relationship of aldehyde reduction from material humidity (r = 0.502; α<0.05) was also noted. Other biomaterial parameters did not affect the treatment efficiency.

Key words: rendering plants, biofiltration, oak bark, coconut fiber

Received: 11 October, 2013; revised: 29 November, 2013; accepted: 29 November, 2013; available on-line: 28 December, 2013

INTRODUCTION

Processing of animal origin waste in rendering plants serves a substantial sanitary-hygienic, proecologic and economic function. It eliminates epidemiological hazards, protects environment against pathogens and allows obtaining products (meat and bone meal, animal fat) used in various branches of economy. However, the animal waste processing operation in a rendering plant can pose a serious environmental threat. One of the major hazards associated with utilization of animal by-products (ABPs) is emission of gases, especially odors (Chmielowiec-Korzeniowska *et al*., 2012).

Air contamination in the vicinity of animal mortality processing plants and nuisance of offensive odors result from decomposition of processed raw material (proteins and fats). The compounds are released during fermentation, heating and thermal degradation of animal tissues (Luo & Lindsay, 2006; Sironi *et al*., 2007). A major source of emission are waste material storage sites and technological lines of the utilization process, especially destructor halls (Chmielowiec-Korzeniowska *et al*., 2012).

Thermal treatment of animal tissues in destructors induces breakdown mechanisms (Maillard reaction, Strecker degradation) when a wide range of odoriferous sulfur compounds (hydrogen sulfide, mercaptans and sulfides), nitrogen (ammonia and amines) acids, ketones and aldehydes are generated (Luo & Lindsay, 2006; Rappert & Müller, 2005). Besides, at high drying and sterilization temperature alcohols and amines are also produced. These compounds have not only an odorogenous character but frequently show irritating and toxic properties and hence, purposive activities limiting compound formation and reducing their emission should be undertaken.

In utilization plants, the mounted deodorization installations are based primarily on thermal combustion (Sironi *et al*., 2007), chemical scrubbing and strong oxidants, e.g. ClO_2 (Kastner & Das 2002). Sironi *et al*. (2007) evaluating the efficiency of odor emission reduction systems concluded that combustion chambers make the most effective system of odor removal in the disposal plants. However, it should be noted that this method is one of the most expensive technologies for reducing odor release. Therefore, a biofiltration technique which is cost-effective and environment-friendly (no by-products) proves to be promising in this field. Low cost of investment and maintenance caused that media have become increasingly popular means for controlling odors in the food industry and urban economy. Removal of volatile organics from waste gases through biodegradation is performed with application of bioscrubbers, membrane bioreactors or biofilters, which are discussed in the present work. Differentiation of these installations results from a type of mobile phases, gas carriers or the mode of active biomass location in reactors in which the direct contact with a bacteria population induces partial or complete degradation of gaseous pollutants (Ramírez-López *et al*., 2003). Descriptions of biofiltration technology employed to eliminate odorogenous compounds generated in the animal waste processing plants are presented in several publications (Ánet *et al*., 2013; Sironi *et al*., 2007). However, these publications are based on olfactometric studies and do not analyze degradation of single compounds. Hence, the objective of the present research was to assess the efficiency of organic and inorganic volatile compounds removal from air at biofiltration performed with two different biofilter media. In present experiment, the effect of physicochemical and microbiological media on the biofiltration performance was also evaluated.

MATERIALS AND METHODS

The studies were conducted in a rendering plant. The plant, just like 60% of plants registered in Poland, belongs to a group of small businesses and its monthly average production reaches 500–600 tons of animal wastes. The basic material processed in the Plant comprises wastes of fallen or slaughtered animals (02 01 82) (ca. 150 tons/month) or waste animal tissue (02 02 81)

✉e-mail: anna.korzeniowska@up.lublin.pl
*Presented at the 5th Central European Congress of Life Sciences „EUROBIOTECH 2013", Kraków, Poland.

(ca. 400–500 tons/month). Animal tissue waste is classified as the 1st category material (52.2%), 2nd category (21.8%) and 3rd category (26.0%) and according to the European Union regulation, this unsorted animal waste represent the waste material of 1st category, i.e. specified risk material.

The Plant obtains waste material primarily from the meat industry (92.4%), in that slaughter houses and butchers, then poultry industry (3.4%) and finally, dairy industry (2.2%).

A technological process of ABPs management in the Plant includes the following stages: waste collection, transportation, waste weighing, cleaning, washing and disinfection of transportation equipment after unloading, waste crushing into particle size under 5 cm in the dissection hall, waste sterilization in destructors, separation of fat from meat and bone meal, meal storage in warehouses and fat in tanks, disposal of products.

Waste, according to the requirements, is sterilized at 133^{o}C degrees, under a pressure of 3 bars for 20 minutes and the size of fragmentation does not exceed 5 cm. The produced meal and fat as energy biomass are delivered to the incinerator, in that cement factory, where to guarantee complete waste combustion the incineration gases have to be kept at a temperature no less than 850^{o}C for at least 2 seconds.

Meat and bone meal is obtained by heating, drying and crushing of solid parts or parts of warm-blooded land animals, without organic solvent residues. Meal is stored in 500–700 kg BIG-BAG type bags laid on pallets, in a dry and airy product storage hall. Rendering fat is obtained during the technological acquisition of meat and bone meal and stored in air-tight, specially prepared tanks.

An installation auxiliary for the installations to the disposal of waste animal tissue are coal-fired boilers of 10 m^3 capacity and thermal power 2.1 MW. The generated sewage is cleaned in the sewage biotreatment plant and disposed of to the nearby river through the pipeline system and ditch.

Experiment design. A closed biofilter device was connected to the duct discharging the leachate from the destructors in which waste material was sterilized and dried. The gases collected above the effluent stream (destructors — a major source of volatile contaminants) were directed to the biofiltration system through the air-tight ducts. The biofilter comprised two filter chambers (A and B) filled with various organic mixtures.

Medium A was composed of compost soil (40%), acid peat (40%) and coconut fiber (20%), whereas in medium B, fiber was substituted by oak chips (20%).

The studies began 30 days after the biofilter start-up (after the medium stabilization period) and were conducted at 5 successive series, at monthly intervals. The air samples for analysis were collected at 3 measurement points. At the pre-biofiltration stage, the samples were taken from gas streams directed to the biofilter (1), whereas at post-biofiltration — from above the medium A (2) and medium B (3). At each series and measurement point, two air samples were collected using the aspiration method.

The volatile organic compounds were determined by gas chromatography (GC). The air samples were drawn to Tedlar bags (2–3 l) with an electric pump. Organic compounds contained in the air samples were concentrated through adsorption on the probes type MX-06-2131 and then desorbed using a thermal desorption unit TDV Model 890 Dynatherm Analytical Instruments Inc. for the chromatography system Hewlett Packard HP 5890 Series II equipped with selective flame-photometric detector (FPD) combined with S-filter of 393nm wavelength. In the analysis, data collection from the chromatographic analysis course was carried out at two parallel paths, i.e. the digital path equipped with 3396 series II integrator and the analog path with A/D, interface, SRI Peak Simple program, III Dynacal permeation models VICI Metronics. Gas permeation models (chromatograms) were prepared in the permeation chamber heated up to a temperature specific for a given permeation tube.

Table 1. Concentration of volatile organic and inorganic compounds in air during biofiltration

Group	Average concentration (maximum)			Efficiency rate [%]	
	Biofilter inlet	Biofilter outlet			
		Medium A	Medium B	A	B
Organic compounds [µg/m³]					
Total (in that unidentified)	17237.90 (59847.00) **ab**	2001.90 (7183.00) **a**	1781.30 (3345.00) **b**	88.4	89.7
Alcohols	255.1 (1198.9)	145.5 (686.1)	353.0 (1649.0)	42.9	b.r.
Aldehydes	1719.4 (17046.6)	14.3 (73.4)	8.6 (26.2)	99.2	99.5
Amines	1497.0 (14306.8)	157.7 (943.3)	32.3 (123.7)	89.5	97.8
Aromatic hydrocarbons	172.7 (808.7)	77.0 (338.4)	53.3 (206.0)	55.4	69.1
Aliphatic hydrocarbons	1025.6 (5992.4)	47.1 (167.0)	28.1 (72.2)	95.4	97.3
Others	91.1 (596.3)	51.1 (192.2)	40.6 (173.7)	43.9	55.45
Inorganic compounds [mg/m³]					
Total	33.1 (66.8) AB	9.14 (43.1) A	0.79 (1.6) B	72.4	97.6
Ammonia	28.9 (58.0) AB	7.81 (39.0) A	0.3 (0.9) B	73.0	99.0
Nitrates	1.12 (1.8) AB	0.26 (0.9) A	0.11 (0.2) B	76.8	90.2
Nitrites	0.82 (1.7) Aa	0.26 (0.8) a	0.1 (0.1) A	68.3	87.8
Chlorides	1.09 (3.1)	0.4 (1.2)	0.15 (0.3)	63.3	86.2
Sulfides	1.17 (3.2) Aa	0.41 (1.2) a	0.13 (0.2) A	65.0	88.9

a, b, values denoted in column by the same letters are different at $p<0.05$; A, B, values denoted in columns by the same letters are different at $p<0.01$

Table 2. Level of VOCs identified during biofiltration [μg/m³]

Compound	Average concentration (maximum)			Efficiency rate [%]	
	Biofilter inlet	Biofilter outlet			
		Medium A	Medium B	A	B
methane	5.5 (37.6)	0.25 (0.7)	0.6 (2.2)	95.4	88.6
ethanol	34.0 (320.5)	0.0 (0.0)	0.0 (0.0)	100.0	100.0
2-butanamine	0.04 (3.0)	5.8 (30.0)	1.0 (10.4)	b.r.	b.r.
propanol	65.7 (630.8)	16.8 (168.4)	6.4 (57.8)	74.4	90.2
cyclobutanol	0.4 (3.6)	0.1 (1.1)	2.7 (18.9)	61.3	b.r.
1-propanol	2.3 (23.4)	35.7 (334.4)	9.9 (34.3)	b.r.	b.r.
1-butanol	101.5 (896.1)	50.0 (491.2)	18.4 (169.6)	50.7	81.9
2-pentaamina	1496.0 (14306.8)	151.9 (943.3)	31.3 (123.7)	89.9	97.9
2-methylpentan	941.6 (5989.0)	42.2 (159.2)	13.3 (66.9)	95.5	98.6
2-methyl 1-propanol	2.6 (11.9)	13.7 (67.5)	18.0 (81.9)	b.r.	b.r.
benzene	126.7 (779.0)	35.8 (252.0)	25.3 (156.6)	71.7	80.0
trichlorethylen	57.4 (320.7)	5.7 (12.2)	5.3 (18.5)	90.1	90.8
1-pentanol	48.6 (29.0)	29.2 (250.5)	297.6 (1522.3)	40.0	b.r.
indole	32.0 (274.2)	41.0 (178.5)	31.9 (164.5)	b.r.	0.5
ethylbenzene	3. (10.6)	14.1 (63.6)	6.1 (25.8)	b.r.	b.r.
xylenes	24.3 (61.2)	12.2 (37.7)	12.2 (27.6)	49.5	49.6
phenol	1.7 (4.6)	4.4 (29.8)	3.5 (14.1)	b.r.	b.r.
methylcyclopentan	78.4 (561.2)	4.66 (18.0)	14.2 (44.7)	94.1	81.9
toluene	18.3 (54.7)	14.8 (105.4)	9.6 (41.5)	19.2	47.5
hexanal	7.3 (23.7)	2.7 (11.0)	3.1 (10.8)	62.6	57.4
pentanal	1712.1 (17022.9)	11.6 (62.4)	5.5 (21.0)	99.3	99.7

On the basis of the zero line analysis, there were established threshold values of file detection. Chromatogrpahic analyses of air models and samples were conducted under the same operating conditions of the chromatographic system.

Determination of inorganic compound content in the samples aspirated into bubbling washers was performed in accordance with the Polish Norm (PN-Z-04008-00:1984P) for ion chromatography using Waters liquid chromatograph coupled with the analytical column IC-PAK Anion HR filled with Waters anion solvent combined with a conductometric detector and UV.

The air chromatographic analysis was carried out together with the analysis of physicochemical and microbiological properties of the filter material. Air temperature and moisture were measured with a thermohygrometer (model RT811E, Technik, Warsaw, Poland), filter material reaction by a pH meter CP-104, while measurement of a moisture content by a gravimetric method.

Evaluation of microbial population was made by dilution plating technique with surface inoculation onto appropriate culture media. Mesophilic and psychrophilic bacteria were inoculated into the agar and incubated at 37°C and 22°C degrees for 24 and 72 h, respectively. Fungi were isolated on Sabouraud medium at 26°C degrees for 5 days.

The indication results and calculated biofiltration performance were tabulated presenting the arithmetic mean with maximal value. The concentration values established before the biofiltration process and after it, were compared by means of Wilcoxon non-parametric test. A relationship between the treated compounds reduction and physicochemical and microbiological parameters of the filter material was identified with Spearman's test and statistical software Statistica version 9.1.

RESULTS AND DISCUSSION

The chromatographic analysis of the air collected above the destructor leachate stream has shown that average concentration of organic and inorganic compounds exceeded 17.0 mg/m³ and 33.0 mg/m³, respectively (Table 1). Among the VOCs identified, the highest level was recorded for aldehydes, then amines and aliphatic hydrocarbons. Anet *et al.* (2013) studied the air in utilization plants and reported that the air directed to the biofilter is composed of more than 300 various volatile compounds but only 20% could be isolated. Notably, beside sulfur compounds, aldehydes were considered most responsible for noxious odor formation.

Air contaminants that pass through the biofilter are biodegraded by active bacteria and consequently, the air samples collected at the post-biofiltration stage showed reduced concentration of volatile organic and inorganic compounds. The observed differences were significant statistically for organic and inorganic compounds ($p<0.05$ and $p<0.01$). Average biofiltration efficiency rate calculated for the bed with oak bark (medium B) reached 89.7% and was slightly lower compared to the bed with coconut fiber (medium A). The best elimination efficiency was achieved for aldehydes characterized by the highest load rate of the biofilter. Irrespective of

Table 3. Physicochemical and microbiological properties of tested media

Medium		Physicochemical properties			Microbiological propertiesrobiologiczne		
		Temperature [°C]	Moisture [%]	pH	Total mesophilic bacteria count [cfu/g]	Total psychrophilic bacteria count [cfu/g]	Total fungi count [cfu/g]
A	Average	21.9	66.8	6.2	4630	5740	27
	Range	19.2–25.1	62.1–73.9	5.9–6.8	1600–7450	2200–1110	17–43
B	Average	23.6	68.6	6.3	3110	3710	30
	Range	22.4–26.4	62.4–77.2	5.9–6.8	1250–5000	2750–4700	18–51

the packing material applied, cleaning efficiency rate of aldehydes, amines and aliphatic hydrocarbons was very high and surpassed 95%. Inorganic compound degradation in medium B reached a level of 98%, whereas in medium A only 72%.

Comparing the removal efficiency of the tested media for given compounds, it was found that the material with oak bark additive (medium B) provided better biodegradation conditions (Table 2). In both media, complete reduction/adsorption of ethanol occurred,while high biodegradability was recorded for 2-methylpentane, methane, trichloroethane and methylcyclopentane. High 2-pentamine loads, actually the highest for all the compounds identified at the pre-biotreatment stage, did not affect the level of efficiency. Whereas at the post-biofiltration stage, there was noted a substantial concentration decline with average reduction 89.1% and 97.9% for medium A and B, respectively.

Not all the volatile organic compounds identified underwent bioreduction. Concentration of seven organics was noted to increase after the biofiltration application and, irrespective of packing material employed, 2-butanamine, 1-propanol, ethylbenzene and phenol were generated in the media. The air leaving the filter material comprising coconut fiber (medium A) showed elevated indole concentration, while in the filter material applied in medium B, alcohols were generated, in that cyclobutanol and 1-pentanol. These phenomena were previously reported by other authors. During ethyl acetate degradation process, Deshusses *et al.* (1997) found higher concentration of ethanol and other degradation byproducts beyond the biofilter, which they attributed to a high load rate of the media. This fact, according to Sercu *et al.* (2005) can subsequently lead to nutrient depletion, change in C:N:P ratio and reduced biodegradation efficiency. Kośmider *et al.* (2002) noted that for heterotrophic bacteria, the optimal concentration of biogenic elements and appropriate ratio is 100:5:1 and only improved C:N:P ratio, as well as the medium enrichment with microelements can restore the biofiltration efficiency. Finally, reduced elimination capacity even at low loading rates may indicate development of preferential flow paths in the medium, and that can be prevented using appropriately selected filter material (Anet *et al.*, 2013).

Properly chosen packing material, i.e. its physicochemical and microbiological characteristics, is a determinant of not only the biofiltration performance but biofilter installation operating costs as well. The analyses of the biofilter material have shown stabilization of the determined parameters (Table 3). Moisture content of the biofilter medium throughout the studies was close to the values recommended for peat (70–80%). Measurement of the filter material reaction demonstrated its slight acidification with biodegradation metabolites, however, as other authors report (Anet *et al.*, 2012; Kastner *et al.*, 2003), only the extreme pH values are likely to affect biofilter operation.

The analysis revealed a significant relationship ($\alpha < 0.05$) between a volatile inorganic compounds reduction rate and mesophilic bacteria counts that colonized the biofilter material (Table 4). Total number of psychrophilic bacteria decided only about alcohol degradation efficiency, whereas thermal-moisture properties proved to have significant influence on aldehydes and nitrates decomposition. It was noted that increasing me-

Table 4. Effect of physicochemical and microbiological properties of media on reduction efficiency of volatile contaminants

Compound group	Temperature	Moisture	pH	Total mesophilic bacteria count	Total psychrophilic bacteria count	Total fungi count
Organic compounds (total)	–0.038	–0.131	–0.202	–0.101	0.079	0.087
Alcohols	0.331	–0.033	0.175	0.358	0.563*	0.414
Aldehydes	0.155	0.502*	–0.162	0.432	0.184	0.032
Amines	0.137	0.267	0.151	–0.004	0.145	0.392
Aromatic hydrocarbons	–0.052	0.161	0.281	0.078	0.117	0.087
Aliphatic hydrocarbons	–0.380	–0.029	0.103	0.119	0.011	–0.191
Inorganic comp.(total)	–0.267	–0.253	0.012	–0.534*	–0.347	–0.008
Ammonia	–0.322	–0.147	–0.242	–0.510*	–0.427	–0.169
Nitrates	–0.447 *	–0.411	0.165	–0.485*	–0.177	0.070
Nitrites	–0.125	–0.306	0.710*	–0.245	0.084	0.419
Chlorides	0.093	–0.171	0.463*	–0.507*	–0.257	0.269
Sulfides	0.057	–0.074	0.443	–0.192	–0.031	0.310

Correletion coefficient *r* calculated acc. to Spearman's rank order; *Denoted correlations significant at $\alpha < 0.05$

dium pH values elevated nitrate and chloride reduction rate. Other filling parameters had no significant effect on the efficiency of purification.

The studies have shown high removal efficiency of the biofilter with bioactive natural support treating volatile compounds emitted from rendering plants. Importantly, only slightly higher performance was obtained for a mixture of compost, peat and oak bark. The research results were consistent with the findings of Anet *et al.* (2012) who tested 11 various organic and inorganic materials and found that organic biomedia provided the optimal biodegradation conditions. Irrespective of an odorogenous compounds load rate, the highest purifying efficiency was reported for composted forest litter — average 75–93%. Organic material, such as compost or peat naturally colonized by microorganisms, is characterized by the short adaptation period. However, organic substance-rich compost tends to cake and thus, may contribute to porosity loss, as well as the increased resistance of gas flow. Morgan-Sagastume & Noyola (2006) highlighted the occurrence of preferential flow paths for gases in compost structure. Structural changes of the material, caking and thus, a pressure drop in the compost medium limits its applicability. Tree bark is characterized by more stable physical properties and its large specific surface area makes it a good adsorption material for both, volatile and microbiological particles, at the same time showing relative resistance to caking and settlement (Luo & Lindsay, 2006). A biomedium filled with compost and crust can maintain a very low drop of pressure and good efficiency of odor control, without medium exchange. The tested coconut fiber is used as a horticulture substrate or greenhouse substrate component, because of its perfect capillary network that distributes water evenly and maintains optimal medium humidity. Very high porosity increases the medium aeration, which is a key factor limiting the biodegradation process course.

In Poland 2013, a list of approved utilization sector rendering plants included 104 processing plants, 33 incinerators and co-incinerators, which like other disposal plants, are obliged to maintain relevant registration of animal waste and are subjected to the Regulation of the Minister of the Environment of 11.12. 2001 (Dz.U.2001. No152, item 1740] and also have a duty to register collected and processed animal waste, as well as the control of contaminant release in the environment. Implementation of novel technologies in waste management sector brings not only safe and economically justified products but, notably, are likely to minimize the effect of a plant on public safety and the quality of the environment.

The obtained research results indicate that a biofilter installation with organic filter material rich in microorganisms can be successively mounted on the devices for sewage or foul air discharge (outlet air). High efficiency of the tested media guarantees deodorizing effects and minimize the spread of gaseous compounds generated and released during disposal of dead animals.

Acknowledgements

The work within the framework of KBN research project N N209 755940 "Application of nanotechnology in air biofiltration at animal waste utilization".

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