Solid State Fermentation Systems for Bioremediation and Biodegradation
Cietfāzes fermentācijas sistēmas bioloģiskai attīrīšanai un biodegradācijai

Uldis Viesturs
Latvian State Institute of Wood Chemistry, e–mail: koks@edi.lv
LV Koksnes ķīmijas institūts, e–pasts: koks@edi.lv
Dzidra Zariņa, Laila Dubova, Andrejs Bērziņš
Institute of Microbiology and Biotechnology, University of Latvia, e–mail: lumbi@lanet.lv
LU Mikrobioloģijas un biotehnoloģijas institūts, e–pasts: lumbi@lanet.lv
Silvija Strikauska
Latvia University of Agriculture, e–mail: aazl@cs.llu.lv
Latvijas Lauksaimniecības universitāte, e–pasts: aazl@cs.llu.lv

Abstract. The waste gas from composting facilities contains different components, which create odour nuisance and acid rain. Biofiltration, which is a technology for reduction of odour emissions and involves the biochemical capabilities of native or modified biological systems, offers some advantages over the physical-chemical, burning or mechanical methods. These are as follows: low cost of installation, maintenance and operation, simplicity of the technological process and high efficiency of the biodegradation and utilization of different inorganic and organic compounds (Schmidt, 2000; Viesturs et al., 2003). We have developed a complex biofiltration system for removal of hydrogen sulphide and ammonia from the composting facility waste gas in a 3 l solid state reactor. Sulphate reducing bacteria *Thiobacillus thiopharus* were immobilized on glass bricks as the carrier material. The biodegradation efficiency of hydrogen sulphide amounted to 62.5% at the gas flow rate 11.2 l h^{-1}. The nitrificator association for regulating the circulation of nitrogen–ammonification and nitrification processes was isolated from activated sludge. The two-stage biofiltration system was more effective for treatment of the waste gas containing a high amount of ammonia. This biofiltration system makes it possible to clean waste gas from ammonia for at least a 3-month period, with the degradation efficiency 98%. Monitoring of the compost quality was realized by methods such as chemical and microbiological analyses, microbiotests (toxicity), and IR spectroscopy.
Key words: solid state fermentation (SSF), biofilters, composting, waste, biodegradation.

Introduction

The rapid increase of the world's population causes more and more different types of waste. Large quantities of organic waste are generated, and serious environmental problems become extremely urgent (Telysheva et al., 2000; Telysheva et al., 2002).

The major alternatives of bioconversion, waste included, are shown in Table 1.

The main hindrance of solid state fermentation (SSF) systems is homogenization of the substrate, heat removal included. As a rule, in commercial-scale bioreactors, the mixing intensity required for temperature control and oxygen supply leads to shear damages of the majority of cultures used (Viesturs and Leite, 1997; Berzins et al., 2001a, Berzins et al., 2001b; Priede et al., 2001). SSF systems could be also used as biofilters (Viesturs and Leite, 1997).

One of the cheapest and simplest ways to treat organic waste is composting (Table 1 –types 2, 3). Composting implies microbial processes that proceed inside bioreactors or windrows (Zarina and Utināns, 2003).

The aim of this work was to overlook SSF and composting systems in order to develop a complex system for biofiltration of gases, in particular, for elimination of hydrogen sulphide and removal of ammonia from the composting facility waste gas.

Materials

Bioreactors, their tooling and packing material

The developed and used equipment, its tooling and flow sheets are shown in Figs. 1-5.

Mixed systems (Fig. 1) were performed in a 3 l horizontal bioreactor, having a shaft with special blades (position 5) and rotation speed control.

The flow sheet of the waste gas biodegradation system is shown in Fig. 2.

The biofiltration system for hydrogen sulphide removal from the composting facility waste gas was realized in a 3 l solid state reactor (Fig. 3).

The oxidation of ammonia was also realized in the solid state reactor. The bioreactor was constructed from glass and stainless steel in a cylindrical shape (Fig. 3). Its internal diameter was 140 mm and the loading capacity was 2 l. At the bottom of the reactor, a 1.5 l vessel was placed. Dolomite broken bricks, 20–30 mm in size, were used as the packing material.

Table 1

SSF alternatives of the bioconversion process

Type of processing	Main features / peculiarities	Results
1. **Aerobic**	Constant, moderate temperature. Still alive helminthes, weed seeds, etc. High O_2 consumption that means a high heat release. The main performance – degradation of lignocellulose (LC). Shear sensitivity that demands the utilization of the stationary layer, hence, only low specific capacity could be achieved. Mixing is required, which leads to mycelia damages, high specific power consumption. Comparatively fast process. The organic part mainly converted into heat, CO_2 and biomass. The composition of the final product does not meet the main characteristics of the compost. Greenhouse effect – CO_2 release / O_2 consumption.	Yield of product 30–50%. Low humus content. High costs for maintenance of processing.
2**. Aerobic** with locally isolated microorganisms' association as inoculum for biodegradation of lignocellulose and other organic substances	Low-rate processes, rather long time to reach biological stabilization and humification of the compost. Practically necessary to use biphasic processes, thermophilic and mesophilic phases being separated: – the thermophilic regime 5–10 days, – then the mesophilic regime with special inoculum and aeration of moderate intensity with periodical mixing of substrate. Conversion of the organic matter in the presence of suitable amounts of air, moisture and inoculum into a humus-like product.	Yield of product ~ 30–40%. Qualitative humus with optimal C: N ratio, pH and without pathogen bacteria, helminthes eggs and weed seeds.
3. **Facultative anaerobic** according to classical composting technologies	Well-known technology, equipment and product. Long exposure time.	Yield of classical compost ~ 50–60%.
4**. Aerobic SS/submerged fermentation**	Specially developed, having multifunctional features.	Production of inoculum for biomass degradation; humification; biofiltration.
5. Mainly anaerobic according to the "bins" technology	Short exposure time. Low humification of the initial/raw material. Problems: – whether a considerable conversion of LC occurs at all, – selection of the culture's composition is required, as for the classical anaerobic version. Obviously, the product could be recommended for mulching, and not as a classical compost. However, a known market for mulch also exists (Viesturs et al., 2002).	Yield of specific compost for mulching ~ 80%.

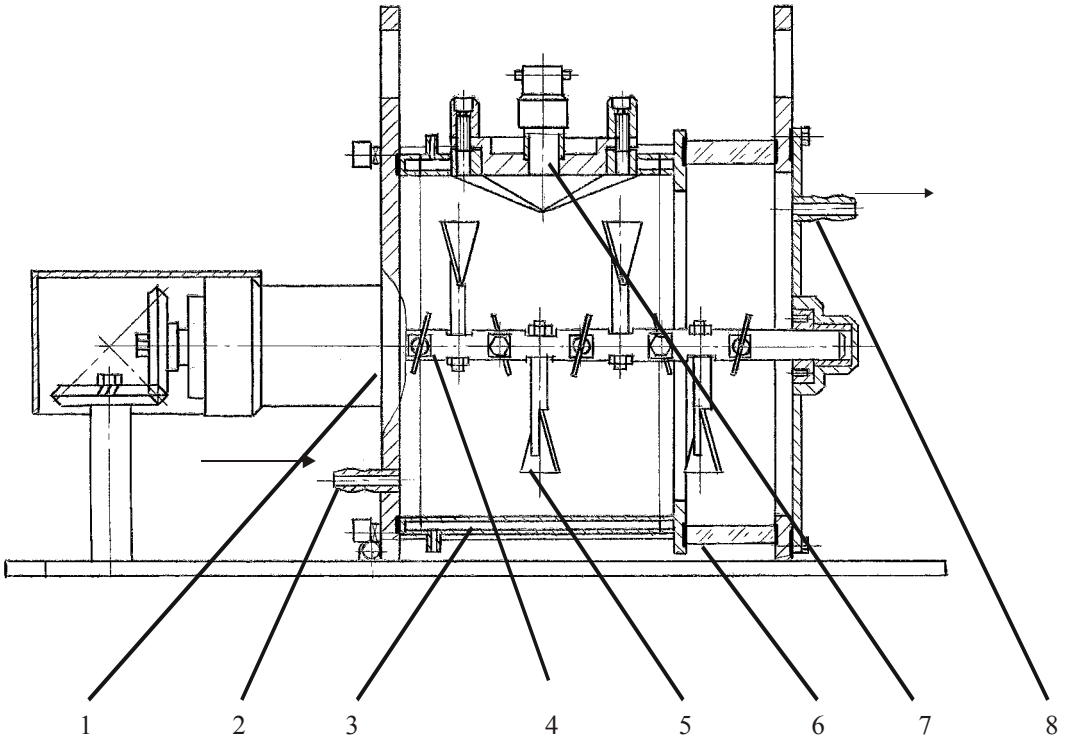

Fig. 1. Laboratory reactor with horizontal stirrer for aerobic and anaerobic bioprocessing (total volume 3 l):
1 – bioreactor; 2 – air inlet for aerobic process; 3 – cooling/heating jacket; 4 – rotating shaft;
5 – mixing blade; 6 – glass part of the cylinder; 7 – hatch; 8 – outlet gases.

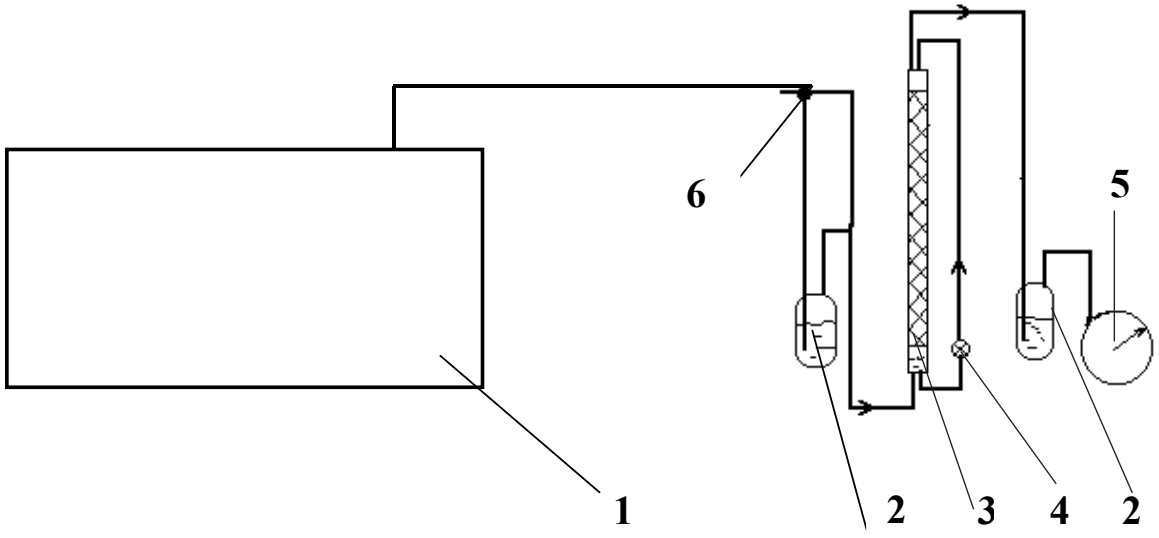

Fig. 2. Waste gas biodegradation system:
1 – waste/contaminated gas source; 2 – receptacle of hydrogen sulphide; 3 – glass bricks with the immobilized sulphide oxidation bacteria; 4 – peristaltic pump; 5 – gas measuring instrument; 6 – three-way cock.

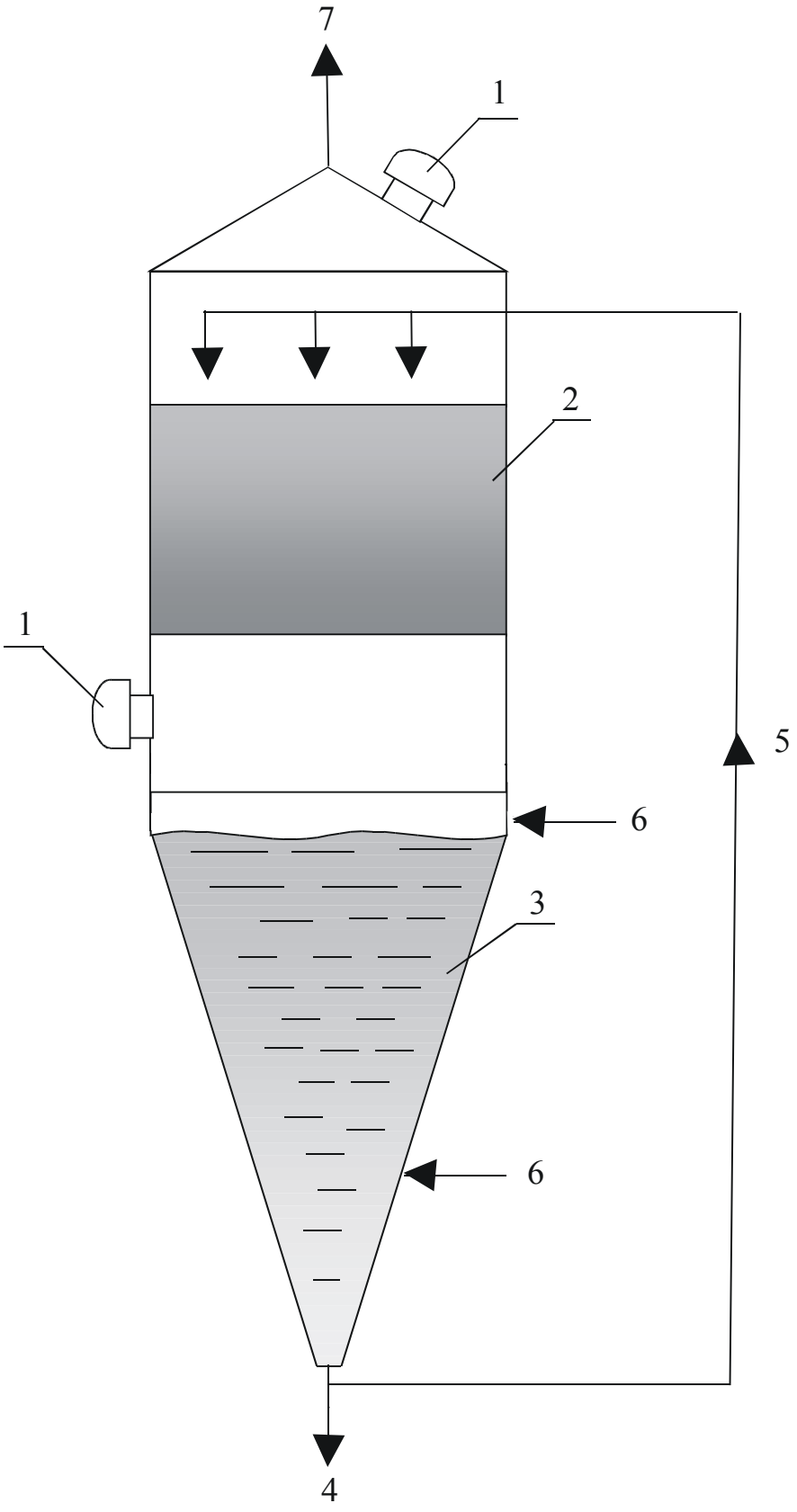

Fig. 3. Combined solid state/submerged bioreactor:
1 – hatch for inspection and solid product outlet; 2 – packed bed; 3 – liquid/submerged sector;
4 – liquid product outlet; 5 – culture liquid for t° control by circulation; 6 – inlet gas; 7 – outlet gas.

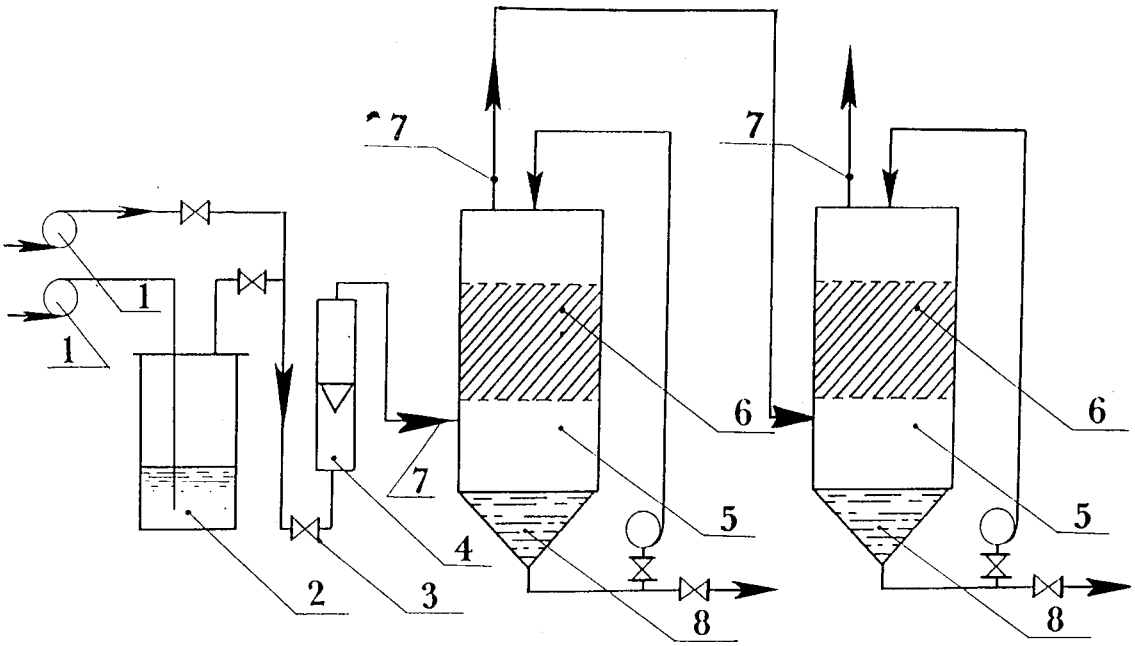

Fig. 4. Two-stage biofiltration system:
1 – compressor; 2 – vessel for contaminant under degradation; 3 – valve; 4 – measurement of volumetric flow rate; 5 – gas part of the bioreactor; 6 – biofilter; 7 – sampling points; 8 – submerged part.

The sulphide oxidation bacteria *Thiobacillus thiopharus* sp.–5 were isolated from the biological activated sludge and immobilized on glass bricks as the carrier material (Dubova et al., 2002).

Fig. 4 shows a two-stage biofiltration system consisting of two combined solid/submerged bioreactors (position 8) displayed in Fig. 3.

Fig. 5 demonstrates the flow diagram of all possible variants of biodegradation according to Table 1.

Position 3 relates to Fig. 1, position 2 – to Fig. 3.

Biodegradation conditions for waste gas

Isolated microorganisms were capable of functioning in the pH range 6.0–8.5 and under relatively dry conditions. Hence, these microorganisms allowed the operation of the bioreactor under conditions where moisture and pH could be less stringently controlled. During the microorganims' immobilization and the adaptation period, mineral nutrients were continuously pumped through the filter bed.

The ammonia removal efficiency (RE) and biological elimination capacity (EC) were used for the evaluation of the biodegradation process. EC was expressed as the mass converted per solid meter packing material per hour (g NH_3 $m^{-3}h^{-1}$) and obtained from the inlet and outlet waste gas concentrations corrected with the ammonia removal by drain. RE was obtained by calculating the differences between the inlet and outlet ammonia concentrations expressed in percentage.

Raw materials

The following substrates were utilized for experiments: sewage sludge from the WWTP "Daugavgriva" in Riga, brewers' yeast biomass from a brewery factory and/or deciduous solid waste – sawdust (separately or in a mixture).

Cultures used

Microorganisms: five bacterial strains, designated DN–1 (*Pseudomonas* sp.), DN–2 (*Nitrosomonas* sp.), DN–3 (*Nitrobacter* sp.), N–13 *(Sarcina* sp.) and *Thiobacillus thioparus*–5, were isolated from the biological active sludge and used in the ammonia and hydrogen sulphide biodegradation.

The aqueous medium used for the cultivation of the association for ammonia degradation was: $(NH_4)_2SO_4$, 1.0 g; K_2HPO_4, 2.0 g; $MgSO_4 \times 7H_2O$, 0.5 g; $FeSO_4 \times 7H_2O$, 0.001 g; $CaCO_3$, 10 g; H_2O, 1000 ml (pH 7.0–7.8). The same medium without ammonium sulphate was used for the filter bed humification in the one stage system, while 1% glucose was used for the two-stage biofiltration system.

The aqueous medium used for cultivation of *Thiobacillus thiopharus*–5 and for humification of the filter and glass bricks, was: $Na_2S_2O_3 \times 5H_2O$, 5.0 g; NH_4Cl, 0.1 g; $NaHCO_3$, 1.0 g; Na_2HPO_4, 0.2 g; $MgCl_2 \times 6H_2O$, 0.1 g; H_2O, 1000 ml (pH 8.0–8.5).

To promote the composting process, local microorganisms' associations (two *Trichoderma* strains: *Tr.*

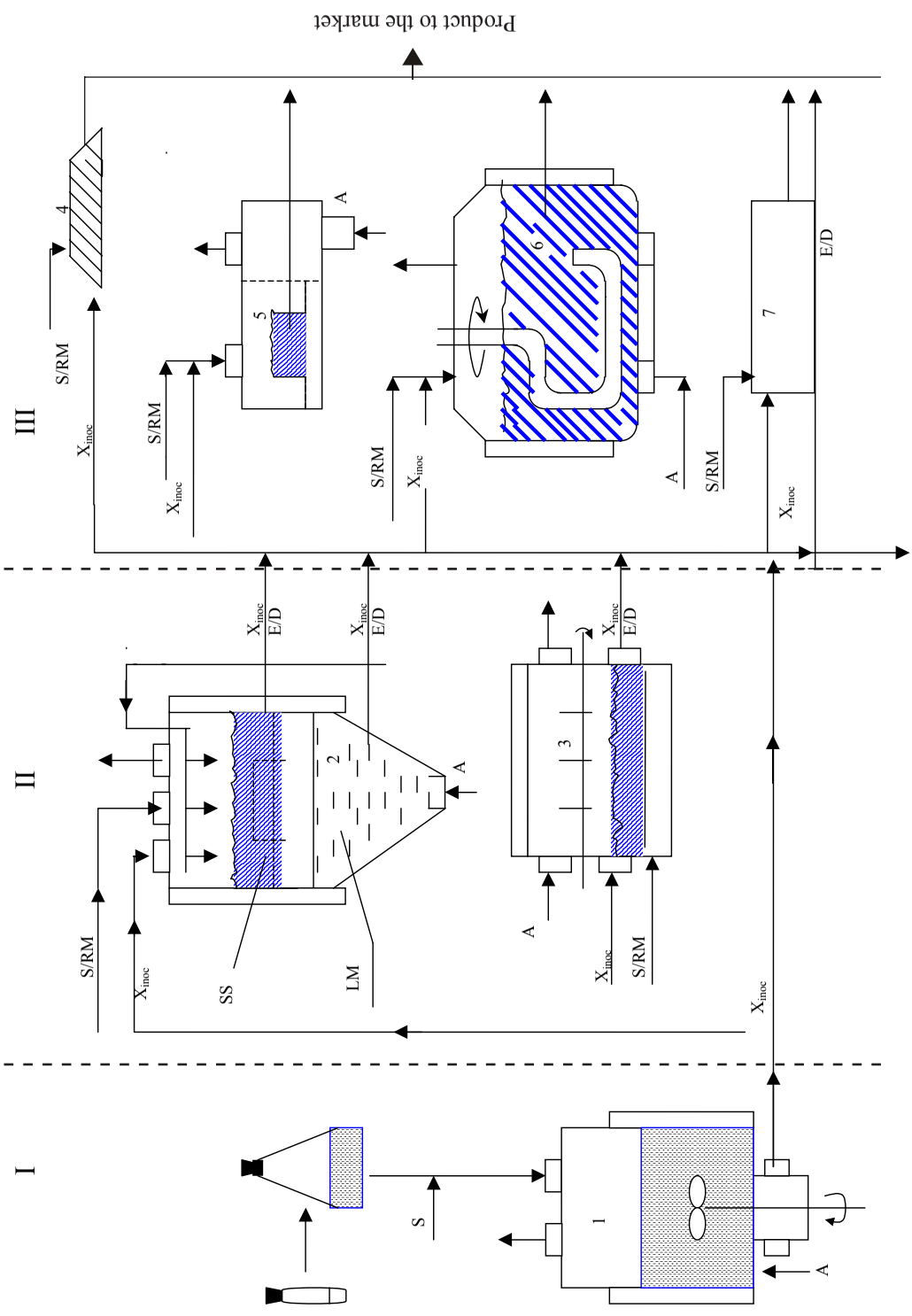

Fig. 5. Flow diagram of solid state (compsting included) conversion of lignocellulose-containing (non-solubles) raw materials and waste:
I – preparation of inoculum, II – pilot/demonstration stage, III – production;
1 – submerged bioreactor for production of inoculum; 2 – combined liquid/solid state bioreactor; 3 – mixed SS bioreactor; 4 – windrows;
5 – motionless or mixed sieves in climate chamber; 6 – production-scale mixed SS bioreactor; 7 – bin's technology: special bins for closed composting; S – substrate;
RM – raw material; X_{inoc} – seed material; E/D – experimental/demonstration products; A – air; SS – solid state; LM – liquid medium.

viride and *Tr. lignorum* (Viesturs et al., 1998), and a nitrificator association, regulating the circulation of nitrogen – the ammonification and nitrification processes were applied as the inoculum for biodegradation of lignocellulose and other types of organic waste in the composting process.

Methods

Chemical analyses

The concentrations of ammonia, nitrite, nitrate and hydrogen sulphide were determined by a FIAstar 5020 Analyzer. The total nitrogen was measured by the "Buchi" Kjeldahl Line. Total carbon was determined by the modified Tjurin's method (Rinkis et al., 1987). Then NO_3-N/NH_4-N and C: N ratios were calculated.

Microbiological analyses

The quantification of the total number of microorganisms, fungi, *Escherichia coli* and *Salmonella* sp. in the compost was performed. The plate count method was used for estimating the total number of microorganisms and fungi per 1 g of dry compost. The medium for quantification of the total number of bacteria was: Bacto nutrient agar (DIFCO LABORATORIES, USA); for fungi – Chapec medium, for *E. coli* – Endo agar; for *Salmonella* – agar Mak-Konky (Strikauska et al., 1999).

Microbiotests

- Rotoxkit F™, which measures the lethal effect of toxicants of rotifers freshly, hatched from cysts (with rotifers *Brachionus calyciflorus*), after 24-h exposure (Rotoxkit F™, 1992).
- Thamnotoxkit F™ with *Thamnocephalus platyurus*, which measures the lethal effect of toxicants of crustacean freshly, hatched from cysts, after 24-h exposure (Thamnotoxkit F™, 1995).
- Ostracodtoxkit F with the benthos organism *Heterocypris incongruens* is a "direct contact" chronically toxicity microbiotest. After 6 days, the crustacean morbidity and growth intensity are compared with the control (Ostracodtoxikit F, 2000).

The results of microbiotesting were evaluated according to the regulations of the method's authors, and the effect in percentage was observed in the no diluted sample (Persoone et al., 2003). The following hazard classification system was used for determination of the degree of toxic contamination in compost:

- Class I: no acute hazard = none of the tests showed a toxic effect;
- Class II: slight acute hazard = a statistically significant EP was reached in at least one test, while the effect's level was below 50%;
- Class III: acute hazard = the EP_{50} was reached or exceeded in at least one test, while the effect's level was below 100%;
- Class IV: high acute hazard = the EP_{100} was reached in at least one test;
- Class V: very high acute hazard = the EP_{100} was reached in all tests.

IR spectroscopy

Samples of the fermentation media or compost for IR-spectroscopy were dried at 60 °C. 50 mg of the sample was mixed with 1g of KBr and milled to obtain a homogenous mixture of the sample. 210 mg of the mixture was mixed with 890 mg of KBr, milled and pelleted. For spectral analysis of Na-humate, 25 mg of substance and 1g of KBr was used.

The prepared KBr pellets were registered on a FT-IR spectrometer Perkin Elmer (Spectrum RXIFT-IR), the absorption mode between 400 and 4000 cm^{-1}, resolution 4 cm^{-1}, 16 scans.

As a characteristic absorption band for identification of Na-humate, 1390 cm^{-1} (COOH group vibrations) was chosen (Haberhauer and Grzabek, 1999).

Results and discussion

To perform the composting process, two *Trichoderma* strains and the nitrificator association for regulating the circulation of nitrogen–ammonification and nitrification processes were applied. *Trichoderma lignorum* was a more active splitter of cellulose and lignin substrates, while *Trichoderma viride* was mainly the producer of Trichodermin (Apsite et al., 1998; Viesturs and Leite, 1996) and also the splitter of lignocellulose. Both of *Trichoderma* micromycetes were the basis of the plant protection preparation Trichodermin, which could limit plant infections (Apsite et al., 1998).

After a 2-month biodegradation of organic waste under anaerobic conditions at the thermophilic regime, the amount of *Escherichia coli* and *Salmonella typhimurum* was 0. However, after 6 months at the aerobic regime, applying the above-mentioned associations, the ammonium content in composting media averaged 410 mg per kg of the fresh weight of the compost, and the C: N ratio was 35–40. The determination of the percentage effect (EP) obtained with each of the applied microbiotests (Rotoxkit F™ with the rotifers *Brachionus calyciflorus*, Tamnotoxkit F™ with *Tamnocephalus platyurus* and Ostracodtoxkit F with the benthic ostracod crustacean *Heterocypris incongruens*) showed that the quality of the compost from the bioreactor was slight acute hazard. A statistically significant EP was reached in Ostracodtoxkit (EP – 26.6%) and Rotoxkit (EP – 21.3%) tests.

The composting process proceeded still two weeks until the content of ammonia decreased to 280 mg per kg of the fresh weight of the compost, and the C: N ratio was 25–30. The applied microbiotests showed that the toxicity of the compost was no acute hazard. EP values ranged from 3.3% to 13.3%.

Table 2

Concentration of hydrogen sulphide before and after biofiltration

No.	Gas flow rate ($l \cdot h^{-1}$)	Concentration of H_2S (%) (before biofiltration)	Concentration of H_2S (%) (after biofiltration)	Efficiency of biodegradation (%)
1	20.0	0.023	0.019	17.4
2	14.6	0.033	0.021	36.4
3	11.2	0.016	0.006	62.5

The total amount of bacteria during the composting process increased, and their amount at the end of the process was 6×10^7 cells per 1 g of dry compost. At the same time, the amount of fungi decreased from 3×10^3 to 3×10^2 cells per 1 g of dry compost.

IR spectra of different compost samples with the micromycetes strains *Trichoderma viride* and/or *Trichoderma lignorum* as destructors of lignin and cellulose and Na-humate were studied. The characteristic absorption band for identification of Na-humate was chosen, namely, 1390 cm^{-1}. In all spectra of the compost, this characteristic Na-humate peak is present, and its increasing intensity follows the composting process (Dubova et al., 2002).

The biodegradation efficiency of hydrogen sulphide could amount to 62.5% at the gas flow rate 11.2 $l \times h^{-1}$ (Table 2).

The oxidation of ammonia was realized in a solid state reactor with the association of microorganisms that was isolated from biologically activated sludge. The ammonia concentration in the inlet gas during the adaptation period (25 days) was maintained at values of 0.2–0.3 $g \times m^{-3}$.

After this period, the inlet gas concentration was increased to 0.5 $g \times m^{-3}$ with the ammonia load of 0.16 NH_3 m^{-3} h^{-1}. This stage was typical, with regular medium recirculation after 5 days for humification of the bed (Table 3).

Owing to the high ammonia solubility, the pH was adjusted in the liquefied phase to 7.0. As a result of the biomass growing in the liquid phase of the reactor, NH_3 was metabolized in nitrites and nitrates, and the pH control was not necessary any more. On the 25th day of the experiment, the concentration of N-NO_3 increased to 3.5 g m^{-3}, which created an inhibitory effect to the nitrification process (Table 3).

The removal efficiency under these conditions was stable during 6 months and reached 95–98%. EC amounted to 0.33 g m^{-3} h^{-1} at the ammonia load 0.41 g m^{-3} h^{-1} (Table 4).

RE started decreasing above the ammonia concentration 1.2 g m^{-3}, and the biofilter reached the EC 0.87 g m^{-3} h^{-1}. A considerable decrease in RE and EC was observed at the inlet ammonia concentration 4.1 g m^{-3}. Under these conditions, the microorganisms utilized about 25% of the inlet nitrogen amount. The ammonia load 5.6 g NH_3 m^{-3} h^{-1} decreased the EC and RE to 0.34 g m^{-3} h^{-1} and 20%, respectively.

Table 3

Formation of nitrification products and N-NH_4 during the ammonia biodegradation process

Inlet ammonia concentration ($g \cdot m^{-3}$)	Time (days)	N-NO_2 ($g \cdot m^{-3}$)	N-NO_3 ($g \cdot m^{-3}$)	N-NH_4 ($g \cdot m^{-3}$)
0.2	10	0.4	0	1.2
0.2	15	0.3	1.0	1.2
0.2	20	0.2	1.3	1.3
0.2	25	0.2	3.5	4.2
0.5	30	0.2	4.7	4.2
0.5	35	0.1	5.1	4.4
0.5	40	0.1	5.3	4.5

Table 4

Ammonia removal efficiency in one-stage biofiltration system

Experiment	Ammonia concentration in inlet gas ($g \cdot m^{-3}$)	Ammonia concentration in outlet gas ($g \cdot m^{-3}$)	Ammonia load ($g \cdot m^{-3}\ h^{-1}$)	Biological elimination capacity ($g \cdot m^{-3}\ h^{-1}$)	Removal efficiency (%)
1	0.5	0.01	0.41	0.33	98
2	1.2	0.10	0.97	0.87	92
3	2.0	0.30	1.62	1.13	85
4	2.5	0.50	2.03	1.20	80
5	3.0	0.71	2.43	1.20	74
6	4.1	2.20	3.30	0.75	46
7	5.0	3.12	4.05	0.50	37
8	7.0	5.63	5.67	0.34	20
9	5.0	3.2	4.05	0.01	35

In the two-stage biofiltration system, the partly treated gas from the first bioreactor was passed through the second one. The pumped liquid with the nitrification products was moved from the first column to the second one (Table 5). This two-stage configuration proved to be more effective for treatment of the waste gas containing a high amount of ammonia. The ammonia RE in the two-stage biofiltration system is shown in Table 5.

The two-stage biodegradation system was more efficient not only for the total RE, but also increased the biological degradation level. The considerable loss of the nitrogen in this system was assumed to result from the denitrification process that occurred in the second biofilter.

Conclusions

Organic waste: sewage sludge, ethanol factory waste and sawdust were processed using a 3 l horizontal laboratory reactor. The reactor was specially designed, since both fermentation stages, i.e. anaerobic and aerobic, were carried out in the same equipment.

The first step of the biodegradation process can be realized at the anaerobic thermophilic regime, providing the necessary mixing of the compost.

The second step of the biodegradation process should proceed at the mesophilic aerobic regime, providing an intensive aeration of the compost. The application of specific adapted microorganisms' associations for regulating the circulation of nitrogen-ammonification and nitrification processes in aerobic composting processes provides an effective and rapid composting of waste.

The biofiltration system for removal of hydrogen sulphide from the composting facility waste gas was realized in a 3 l solid state reactor. The sulphide oxidation bacteria *Thiobacillus thiopharus* sp.–5 were isolated from biological activated sludge and immobilized

Table 5

Ammonia removal efficiency in two-stage biofiltration system

Biofilter 1 ammonia concentration ($g \cdot m^{-3}$)		Biofilter 2 ammonia concentration ($g \cdot m^{-3}$)		Removal efficiency (%)
inlet gas	outlet gas	inlet gas	outlet gas	
2.0	0.1	0.1	0	100
2.5	0.3	0.3	0	100
3.0	0.7	0.7	0	100
4.1	1.1	1.1	0.3	92.3
5.2	3.2	3.2	1.4	73.1
7.0	5.6	5.6	2.5	64.3

on glass bricks as the carrier material. The biodegradation efficiency of hydrogen sulphide amounted to 62.5% at the gas flow rate 11.2 l h^{-1}.

The oxidation of ammonia was realized in a solid state reactor with the 4 bacterial strains: *Pseudomonas* sp., *Nitrosomonas* sp., *Nitrobacter* sp., *Sarcina* sp. isolated from activated sludge.

The biofiltration system makes it possible to clean continuously the waste gas from the composting facility from ammonia for at least a 3-month period, with the degradation efficiency 98%.

Monitoring of the composting quality was realized by methods such as chemical analyses, microbiotests for compost quality assessment (toxicity), microbiological methods for detection of human and animal pathogenic agents (*Escherichia coli*), and IR spectroscopy for spectral analyses of Na-humate.

Acknowledgements

We would like to thank Dr. Mara Grube for IR spectroscopy analyses. The study was supported by Projects No. 01.0398, 01.0370, 01.0369 of the Latvian Council of Sciences, and the International Project "Biofertilizer Production from Renewable Organic Waste".

References

1. Apsite, A., Viesturs, U. Šteinberga, V., Toma, M. (1998) Morphology and antifungal action of the genus *Trichoderma* cultivated in geometrically dissimilar bioreactors. *World J. Microbiol. Biotechnol*., 14, pp. 23–29.

2. Berzins, A., Rikmanis, M., Toma, M., Viesturs, U., Gonta, S. (2001a) Cultivation of *Zymomonas mobilis* 113S at different mixing regimes and their influence on the levan formation. *Acta Biotechnol.,* 21 (1), pp. 19–26.

3. Berzins, A., Toma, M., Rikmanis, M., Viesturs, U. (2001b) Influence of micromixing on microorganisms and products. *Acta Biotechnol.,* 21 (2), pp. 155–170.

4. Dubova, L., Zarina, Dz., Grube, M. (2002) Use of Toxikit microbiotests in the determination of pesticides toxicity in soil and groundwater. *Proc. Latv. Acad. Sci.,* 56 (3), pp. 127–133.

5. Dubova, L., Zarina, D., Strikauska, S., Bērzins, A., Viesturs, U. (2002) Complex bioconversion processes of organic waste and extracted waste gases; characteristics of the obtained compost. In: *Proceedings, International Scientific Practical Conference on New Trends in Quality Food Production.* Latvia University of Agriculture, Faculty of Food Technology, Jelgava, pp. 177–185 (in Latvian).

6. Haberhauer, G., Grzabek, M. H. (1999) Drift and transmission FT-IR spectroscopy of forest soils: an approach to determine decomposition processes of forest litter. *Vibrational Spectroscopy*, 19, pp. 413–417.

7. *Odour management practices for composting facilities. Division of Solid and Infectious Waste Management*. Fact Sheet No. 0497, September 1999.

8. *OSTRACODTOXIKIT F.: Chronic "direct contact" toxicity test for freshwater sediments. Standard Operation Procedure.* Creasel, Deinze, Belgium, 2000.

9. Persoone, G., Marsalek, B., Blinova, I., Zarina, Dz., Manusadzianas, L., Nalecz-Jawecki, G., Tofan, L., Stepanova, N., Tothora, L., Kolar, B. (2003) A practical and user-friendly toxicity classification system with microbiotests for natural waters and water wastes. *Environmental Toxicology*, 18 (6), pp. 395–402.

10. Priede, M. A., Vanags, J. J., Viesturs, U. E. (2001) Performance of *Aspergillus niger* cultivation in geometrically dissimilar bioreactors evaluated on the basis of morphological analyses. *Food Technol. Biotechnol.* 40 (1), pp. 57–66.

11. Rinkis, G. J., Ramane, H. K., Kunickaja, T. A. (1987) *Methods for Analysis of Soils and Plants*. Zinatne, Riga, 174 pp. (in Russian).

12. *ROTOXKIT F™: Freshwater toxicity test with Rotifer. Standard Operation Procedure*. Creasel, Deinze, Belgium, 1992.

13. Schmidt, D. (2000) Odour, hydrogen sulphide, and ammonia emissions from the composting of caged layer manure. Final Report. In: *Conference of the American Society of Agricultural Engineering,* 10 October 2000, pp. 1–9.

14. Strikauska, S., Zarina, D., Berzins, A., Viesturs, U. (1999) Biodegradation of ammonia by two stage biofiltration system. *Environmental Engineering and Policy.* 1 (3), pp. 175–179.

15. Telysheva, G., Dizhbite, T., Lebedeva, G., Rossinskaja, G., Jurkjane, V., Treikale, O., Viesturs, U., Daugavietis, M. (2002) Lignin-based products stimulating soil phytoremediation. *Acta Biotechnol.* 22 (1-2), pp. 167–173.

16. Telysheva, G., Lebedeva, G., Dizhbite, T., Zaimenko, N., Ammosova, J., Viesturs, U. (2000) Use of silicon-containing lignin products for *in situ* soil bioremediation. In: *Bioremediation of Contaminated Soils.* Wise, D. L., Trantolo, D. J., Cichon, E. J., Inyang, H. I., Stottmeister, U. (eds.) Marcel Dekker, Inc., New York – Basel, pp. 699–727.

17. *THAMNOTOXKIT F™: Freshwater toxicity test with Crustaceans. Standard Operation Procedure*. Creasel, Deinze, Belgium, 1995.

18. Viesturs, U. E., Leite, M. P. (1996) Physiological and technico-engineering aspects of lignocellulose solid-state fermentation with filamentous fungi. In: *Advances in Bioprocess Engineering*. Kluwer Academic Publishers, Dordrecht – Boston – London, pp. 81–87.

19. Viesturs, U., Leite, M. (1997) Certain new biotechnological processes and the equipment for their implementation (Review). *Appl. Biochem. Microbiol.,* 33 (3), pp. 213–235.

20. Viesturs, U., Steinberga, V., Apsite, A., Tula, A. (1998) Effect of Azotobacterin and Trichodermin upon sugar beet. In: *Biological Nitrogen Fixation for the 21st Century. Proceedings, 11th International Congress on Nitrogen Fixation.* Institut Pasteur, Paris, France, 20-25 July 1997, p. 417.

21. Viesturs, U., Zarina, Dz., Strikauska, S., Berzins, A., Zilevica, A. (2002) Solid state systems for bioremediation and biodegradation. In: *Proceedings, VI International Symposium on Environmental Biotechnology and IV International Symposium on Cleaner Bioprocesses and Sustainable Development.* Mexico, Veracruz, 1.2 pdf (CD).

22. Viesturs, U., Zariņa, Dz., Strikauska, S., Dubova, L., Bērziņš, A. (2003) Emission of odour gases during the composting processes of different organic wastes. In: *Proceedings, European Congress on Biotechnology.* Basel, Switzerland, 24-29 August 2003, p. 129.

23. Zariņa, Dz., Utināns, F. *Method for Biocomposting of Organic Waste in Field Conditions (Paņēmiens organisko atkritumu biokompostēšanai atklātā laukā).* Latvian Patent No. 13022, 20.09.2003 (filed 19.12.2001).

Anotācija

Straujais iedzīvotāju skaita pieaugums uz Zemes rada arvien vairāk atkritumu. Pēdējos gados Eiropā ir ievērojami pieaugusi organisko atkritumu pārstrāde. Plānots, ka no kopējās Eiropas atkritumu produkcijas tuvākajos 10 gados vismaz 30% no pilsētas un 40% no rūpnieciskajiem atkritumiem tiks pārstrādāti, tos kompostējot. Latvijā, tāpat kā pārējās Eiropas valstīs, ir aktuāla bioloģiski noārdāmo organisko atkritumu kompostēšana; šos procesus parasti pavada dažādu gāzu izdalīšanās apkārtējā vidē. Tās raksturojas ar nepatīkamu smaku un ir par cēloni tam, kāpēc rodas skābie lieti. Cietfāzes biofiltrācijas sistēmās (CFS) izmanto tādas tehnoloģijas, kuras spēj degradēt nepatīkamās smakas un izveidot dabīgas vai modificēti ietilpīgas bioloģiskās sistēmas, kuru pielietošanai ir daudz lielākas priekšrocības, salīdzinot ar fizikāli-ķīmiskām un mehāniskām metodēm. Tām ir zema pašizmaksa, vienkārša vadība, nesarežģīts tehnoloģiskais process un augsta dažādu organisko un neorganisko savienojumu biodegradēšanas un pielietošanas efektivitāte. Darba mērķis bija noskaidrot, kā sasaistīt cietfāzes fermentācijas un kompostēšanas sistēmas tā, lai varētu biodegradēt gāzes (sērūdeņradi un amonjaku), kuras izdalās apkārtējā vidē dažādu organisko atkritumu kompostēšanas procesā. Organisko atkritumu kompostēšanu veicām 3 l cietfāzes fermentātorā. Sulfātreducētājas baktērijas *Thiobacillus thioparus* bija imobilizētas stikla cilindrā uz stikla caurulīšu lauskām kā nesējmateriāla. Sērūdeņraža biodegradēšanas efektivitāte bija 62.5% pie plūsmas ātruma 11.2 l h^{-1}. Nitrifikātoru baktēriju asociācijas – slāpekļa aprites procesu regulētājas tika izolētas no aktīvajām dūņām. Pie augstas amonjaka koncentrācijas divpakāpju filtrācijas sistēma spēja daudz efektīgāk attīrīt piesārņoto gaisu no amonjaka. Biofiltrācijas sistēma 3 mēnešu darbības laikā attīrīja piesārņoto gaisu no amonjaka, un tās biodegradēšanas efektivitāte sasniedza 98%. Veicām arī komposta kvalitātes monitoringu, pielietojot ķīmiskās, mikrobioloģiskās, mikrobiotestēšanas (toksicitātes noteikšanas) un IS–spektroskopijas metodes.