Atmospheric Environment 57 (2012) 49–54

Contents lists available at SciVerse ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Artificial neural networks for modeling ammonia emissions released from sewage sludge composting

P. Boniecki, J. Dach*, K. Pilarski, H. Piekarska-Boniecka

Poznan University of Life Sciences, Wojska Polskiego 28, PL-60-637 Poznan, Poland

HIGHLIGHTS

► The research on ammonia emission from the composted sewage sludge have been made.
► The prediction neural models' file has been built.
► The optimal models for prediction of ammonia emission were tested and verified.
► It has been stated that pH was a key factor for ammonia emission from composting.

ARTICLE INFO

Article history:
Received 29 November 2011
Received in revised form
12 April 2012
Accepted 17 April 2012

Keywords:
Neural network modeling
Ammonia emission
Composting
Sewage sludge

ABSTRACT

The project was designed to develop, test and validate an original Neural Model describing ammonia emissions generated in composting sewage sludge. The composting mix was to include the addition of such selected structural ingredients as cereal straw, sawdust and tree bark. All created neural models contain 7 input variables (chemical and physical parameters of composting) and 1 output (ammonia emission). The α data file was subdivided into three subfiles: the learning file (ZU) containing 330 cases, the validation file (ZW) containing 110 cases and the test file (ZT) containing 110 cases. The standard deviation ratios (for all 4 created networks) ranged from 0.193 to 0.218. For all of the selected models, the correlation coefficient reached the high values of 0.972–0.981. The results show that he predictive neural model describing ammonia emissions from composted sewage sludge is well suited for assessing such emissions. The sensitivity analysis of the model for the input of variables of the process in question has shown that the key parameters describing ammonia emissions released in composting sewage sludge are pH and the carbon to nitrogen ratio (C:N).

1. Introduction

Ammonia released into the air has multiple adverse impacts on the ecosystems like soil acidification, eutrophication of natural aquatic and terrestrial ecosystems as well as may have adverse effects on human health (Nyord et al., 2008; Velthof et al., 2012). In economic terms, it has a negative and harmful impact on agriculture, mainly by undermining the effectiveness of fertilization (Plochl, 2001; Maia et al., 2012). Although a great number of research papers discuss various aspects of nitrogen losses during manure spreading (Søgaard et al., 2002; Misselbrook et al., 2005; Youngil et al., 2007), very little is said on modeling ammonia emissions generated in composting sewage sludge produced for agricultural usage (as fertilizer). Hutchings et al. (2001) mentioned that there were no statistical data describing sewage sludge treatment practice and so the emission is estimated to be 65% of the NH_3 used. However the EMEP/CORINAIR Emission Inventory Guidebook published by European Environment Agency (2007) estimated the contribution of sewage sludge spreading to the total ammonia emission from 28 European countries to be around 0.1%. But in the chapter "Compost Production from Waste" no ammonia emission was reported (EMEP/CORINAIR, 2007). However some recent experiments have showed potentially high ammonia losses during composting of sewage sludge (Piotrowska-Cyplik et al., 2009). It thus appears advisable to fill the knowledge gap by developing an advanced model of the process based on empirical evidence.

Composting is a biological process of organic matter decomposition run by microorganisms under oxygenic conditions. Therefore, by its very nature, the process eludes formal descriptions, especially the classical modeling. An effective instrument suited for solving complex problems is Artificial Neural Networks, used increasingly in various fields of research and various sciences (Boniecki et al., 2009;

* Corresponding author.
E-mail address: jdach@up.poznan.pl (J. Dach).

1352-2310/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.atmosenv.2012.04.036

Ozkaya et al., 2007). Such networks usually take the form of specialized computer simulations reflecting the way information is processed in the brain. An advantage of neural models is their ability to generalize on the knowledge acquired through learning. The feature makes the resulting models applicable in real life, in particular in identifying new previously unknown signals. Note that such identification remains beyond the "grasp" of classical models (be it structural or empirical) which rely on algorithms to process data (Boniecki et al., 2011; Slosarz et al., 2011).

The author applied Artificial Neural Networks to model the biochemical processes seen in composting to gather representative empirical data on the relationships which arise in the course of analysis (Kim et al., 2011; Abu Qdaisa et al., 2010).

The aim of the study was to investigate the options of applying Artificial Neural Networks as a predictive instrument for modeling ammonia emissions released in composting sewage sludge. It has to be underlined that ammonia concentration in the air (daily, monthly and yearly) is strictly defined in Polish law and it is one of the most important factor influencing the localization of the installations for producing or treatment both, animal and human faeces i.e. farms, composting plants or urban wastewater treatment plants.

The research challenge tackled in the study was to verify that a predictive neural model describing ammonia emissions generated in composting sewage sludge is well-suited for accurately assessing emissions levels. The sub-challenges encountered in the project suggested the following questions:

1. What neural topology is appropriate for modeling ammonia emissions released in the course of sewage sludge composting?
2. To what extent do the postulated physical and chemical parameters affect ammonia emissions estimates?
3. Can the resulting neural model of ammonia emissions be used effectively to utilize sewage sludge in agriculture (e.g. in designing and utilizing composting technologies)?

2. Materials and methods

The study objective required that a laboratory test as well as adequate learning file be developed as needed to generate a family of neural models. Specifically, it was necessary to:

- build a test facility to simulate natural composting processes under controlled laboratory conditions,
- carry out a series of tests covering a wide range of factors,
- gather a file of empirical data to describe the process,
- convert the test data with learning file which would then be used to train neural models,
- generate a file of neural topologies and select optimal models,
- assess the quality of and validate the resulting Artificial Neural Networks.

2.1. Experimental set-up

The concept of a bioreactor for studying organic waste decomposition was developed in 2002 by the Institute of Agricultural Engineering (Wolna-Maruwka and Dach, 2009). After its completion, the bioreactor allows testing processes involved in the biological decomposition of organic matter on laboratory scale (Fig. 1).

2.2. Raw material

The authors investigated sewage sludge originated from three wastewater treatment plants located in the towns of Szamotuły and Czarnków (small plants serving communities of under 40,000) and the Wastewater Treatment Plant of Poznan [LOS] (a large facility serving a population of over 300,000 as well as a great number of industrial plants). The sewage sludge were sampled at the production line on test days to avoid these anaerobically stored sludge to be altered through internal processes. The parameters range obtained for the different proportions (Table 1) of raw materials are mentioned below:

- percent share of sewage sludge in mix (30–75% of dry mass),
- the C:N ratio (12–35),
- moisture content (50–82%),
- compost mixture density (250–520 kg m^{-3}).

The proportions of the composted ingredients for the individual tests were as given in Table 1. The key parameter of each

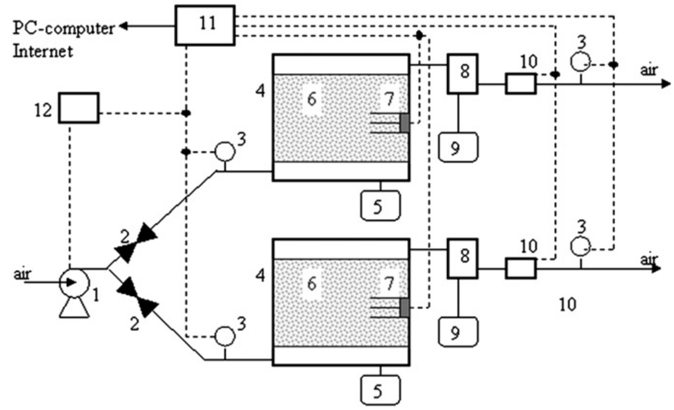

Fig. 1. Schematic diagram of the 2-chamber bioreactor: 1. Pump, 2. Flow regulator, 3. Flow meter, 4. Isolated chamber, 5. Drained liquids container, 6. Composted mass, 7. Sensors set, 8. Air cooling system, 9. Condensates container, 10. Column of gases content analysis (NH_3. O_2. CO_2. CH_4. H_2S), 11. 16-channel recorder, 12. Air pomp steering system (Wolna-Maruwka and Dach, 2009).

Table 1
Proportions (%) of composted substrates within set of 6 experiments in 4 bioreactor chambers.

Experiment	Ingredient	Bioreactor chambers (1–4)			
		1	2	3	4
		Substrate share [%]			
1	Sewage sludge	60	60	75	75
	Straw	10	10	5	5
	Sawdust	30	30	20	20
2	Sewage sludge	65	65	65	45
	Straw	5	5	5	5
	Sawdust	30	30	30	50
3	Sewage sludge	75	75	39	39
	Straw	5	5	5	5
	Sawdust	20	20	56	56
4	Sewage sludge	40	40	40	40
	Straw	–	–	5	–
	Sawdust	35	10	15	–
	Coarse bark	25	50	–	–
	Cuttings	–	–	40	10
	Hemp waste	–	–	–	50
5	Sewage sludge	45	45	45	45
	Straw	5	5	5	5
	Sawdust	–	15	35	50
	Fine bark	50	35	15	–
6	Sewage sludge	75	60	45	30
	Straw	5	5	5	5
	Sawdust	20	35	50	65