Violeta ČEPANKO

INVESTIGATION OF FERMENTED WASTE AND TECHNOLOGIES OF DISPOSAL

SUMMARY OF DOCTORAL DISSERTATION

TECHNOLOGICAL SCIENCES,
ENVIRONMENTAL ENGINEERING (04T)

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LEIDYKLA
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Introduction

Topicality of the problem

Unpleasant odours spreading from waste accumulation sites, inorganic compounds contained in waste and the increasing risk of infections and of surface and ground water pollution are very important preconditions for the application of advanced organic waste handling technologies. Consequently, organic waste treatment must, first of all, be oriented to dealing with ecological problems. Also, economic benefit can be derived seeking to obtain electric and thermal power or produce other valuable products. When evaluating the anaerobic waste treatment it is recommended to take into account the complex efficiency of the method. Attempts are made to find alternative techniques of treatment and recovery of such waste. Currently, research on biodegradable waste utilisation, especially after biogas recovery, has become increasingly relevant. One of priority research areas, therefore, is the design of new technologies intended for the use of renewable, local and waste energy resources; moreover that the development of renewable and local energy resource (biofuel from biomass) production and use technologies is one of the key aims of the Lithuanian energy. On the other hand, where sewage sludge or another biomass has a low level of pollution with, for instance, heavy metals, after having undergone anaerobic treatment it could be widely applied for agricultural needs. Currently, with the areas of farmlands decreasing concerns over the use of these areas for planting energy crops by using the filtrates of fermented or other types of waste are growing. In order to improve the quality of fermented waste and reduce soil pollution with heavy metals, composting of such waste with additives that are distinguished by absorptive properties is proposed. The best possibilities of developing the utilisation of the fermented organic waste are related with its use for energy recovery. Traditional wood burning in stoves may be simple and unproblematic where energy production volumes are low and labour force is cheap. Such method of energy production at large energy facilities requires high labour and energy costs. With the aim of automating the process of biofuel burning, some countries of the European Union (Austria, Germany, Sweden, and others) have adopted technical standards of wood briquette and granule quality. In the meantime insufficiently research has been done on the composition and thermal properties of solid biofuel recovered from fermented waste.

Object of the work – the fermented solid waste (substrate) and liquid (filtrate) fractions and their technologies of disposal.

Aim and tasks of the work

The key aim of this work is to analyse and evaluate the possibilities of using fermented wastes (sewage sludge, swine and poultry manure, fruit and vegetable waste, and grain) for fertilisation, composting and incineration taking into account their elementary composition and a level of pollution with heavy metals. Carry out an evaluation of gaseous pollutant (NO_x) emissions from the process of incineration through the employment of a digital model.

Key performance tasks are:

1. To identify the composition and thermal characteristics of the dewatered fermented waste and to carry out research on incineration with a view of evaluating the emissions of gaseous pollutants.
2. To carry out the investigations of willow (*Salix dasyclados*) growing in the filtrate of fermented waste under laboratory conditions and to evaluate the possibilities of cuttings to accumulate heavy metals.
3. To carry out research on composting fermented waste by inserting natural zeolite or biofuel ash and using a dynamic method in a designed equipment and to determine the quality of the obtained compost with regard to its suitability for fertilisation.
4. To carry out the modelling of gaseous pollutant emissions in the process of fermented waste incineration and to compare the obtained results with those received experimentally.

Scientific novelty

These are complex investigations of the use of fermented waste for fertilisation, compost production and incineration, and a digital modelling of pollutant emissions in the products of combustion.

Methodology of research

The methods of substrate incineration, willow growing in fermented waste filtrates and composting were used in this work. The investigations of fermented wastes and filtrates thereof were done according to the standardised methods. For the purpose of evaluating the concentrations of pollutants generating during fermented waste incineration empirical formulas were applied. The model of *Gaska&Wandrasz* was used for the modelling of nitrogen oxide emissions from fermented waste incineration.

Practical value. Results obtained from the investigations of fermented waste incineration will be useful to representatives from thermal power plants who will want to use solid recovered fuel as some compensation for the

growing need of wood fuel. Composting of the fermented waste, stabilised with natural zeolite and biofuel ash, will result in the reduction of its volume and preservation of nutrients during the process of composting that could be successfully used for agricultural needs. Farmers intending to cultivate energy plants and using fertilisers of the local origin will be able to make use of the performed analysis of fermented waste filtrate.

Defended propositions

1. Dry fermented waste is a calorific fuel the burning of which in low capacity installations causes nearly ten fold higher pollution with nitrogen oxides than the burning of wood granules.
2. The accumulation of heavy metals from fermented waste filtrate in different parts of the willow (*Salix dasyclados*) stem has a liner dependence on the assimilation of nutrients (nitrogen, phosphorus).
3. When inserted into the compost of fermented waste that is additionally stabilised with biofuel ash, natural zeolite allows the reduction of heavy metal concentrations in the compost's biomass up to two times.

The scope of the scientific work. The scientific work consists of the general characteristic of the dissertation, 6 chapters, and conclusions, list of literature and list of publications. The total scope of the dissertation is 180 pages, 86 pictures and 15 tables.

1. Generation and possibilities of using fermented waste

The chapter analyses the situation of fermented waste generation and handling in Lithuania and other countries, presents the comparison of technologies currently used for the handling of this type of waste, analyses the methods of determining fermented waste characteristics as well as levels of pollution, gas combustion, and digital modelling programmes of evaluation. The work has examined the characteristics of fermented waste (residues from biogas recovery) and the possibilities of its handling through the application of different recycling and utilisation methods. Currently, the use of fermented waste for fertilisation in agriculture has received encouragement. The filtrate that forms during fermented waste dehumidification is a source of nutrients for short rotation coppice and may be used as a fertiliser. However, there is a lack of data on the transport of heavy metals from the filtrate of fermented waste, particularly of industrial waste, into energy crops as well as on the peculiarities of accumulation in them. The technologies of incineration and composting are most widely applied for organic waste treatment; however, little research was

done on their application for fermented organic waste; apart from that, data on the introduction of such technologies at the industrial level is insufficient. Scarce attention currently is devoted to the implementation of low-capacity technologies of fermented waste handling. Due to this reason research on the efficiency and application possibilities of the mentioned technologies is highly relevant and necessary.

2. Experimental investigations of fermented waste incineration

The chapter presents the methods of the performed investigations of fermented waste characteristics, composition and incineration as well as the obtained results. The investigations were aimed at identifying the elementary composition of biomass and evaluating the level of environmental pollution from the incineration of different types of waste, such as fruit/vegetable and meat waste, poultry manure, swine manure, grain, and sewage sludge.

The chemical elementary composition of the dry biomass of fermented waste differs from that of fossil fuel. The average elementary composition of the biomass' combustible part varies in the following ranges: 42–51% for carbon, 5.7–6.3% for hydrogen, 39–43.7% for oxygen. In addition, around 01–0.2% of sulphur and around 0.25–0.3% of nitrogen was identified in the waste biomass. Subject to the conditions of treatment and preparation, the waste biomass also contains up to 0.2–0.75% of chlorine.

As research results showed, the highest contents of nitrogen were in the substrates of a mixture of swine manure and meat waste (at the ratio of 1:1) and grain reaching 9.80 and 4.38% of a dry mass, respectively. In other substrates the content of this element was 2 to 3 times lower. The content of nitrogen in wood granules was much lower than that determined for waste and accounted for 0.1% of a dry mass.

Fermented waste is characteristic of much higher ash content (3.84–18.95%) than wood granules (0.89%). This feature of the waste should be considered when designing incineration installations.

Investigations of fermented waste substrate incineration in the mono-cycle mode mean the investigations when fermented waste is incinerated from its one-off feeding until full combustion. During the process of combustion, the concentrations of combustion products (CO, CO_2, NO, NO_2, NO_x and SO_2) were determined when burning birch firewood (*1*), the substrates of fruit/vegetables (*2*), poultry manure (*3*), swine manure (*4*) and grain (*5*) together with firewood. Pollution generated from sewage sludge incineration was assessed by theoretical calculations and the obtained results are presented in Chapter 5.

The incineration of fermented waste substrates in an industrial installation included*:* wood granules (*1*), poultry manure with wood granules (*2c*) at a ratio of 1:2, swine manure (*3a*), swine manure with meat waste (*3b*) at a ratio of 1:1, swine manure with wood granules (*3c*) at a ratio of 1:2, and grain substrate (*4*).

It is determined experimentally that fuel humidity did not have a significant impact on a fuel combustion process as it varied within minor limits (1.31–2.54%).

In summary of the investigations of fermented waste incineration in a low-capacity stand it can be stated that the maximum temperatures of combustion products at a boiler outlet were achieved when burning wood granules and grain reaching 177.7 °C and 147.8 °C, respectively. In other cases temperatures were lower because of lower calorific value of the waste.

Comparison of $NO_{x,\ min}$ and $NO_{x,\ aver}$ concentrations with the permissible limit values, determined for the biomass pursuant to LAND 43-2001, show that exceedances reached 1.2–6.5 times and 2.0–7.8 times (Fig. 1), and according to the environmental requirements for waste incineration these exceedances varied from 1.5 to 8.0 and from 2.5 to 9.7 times.

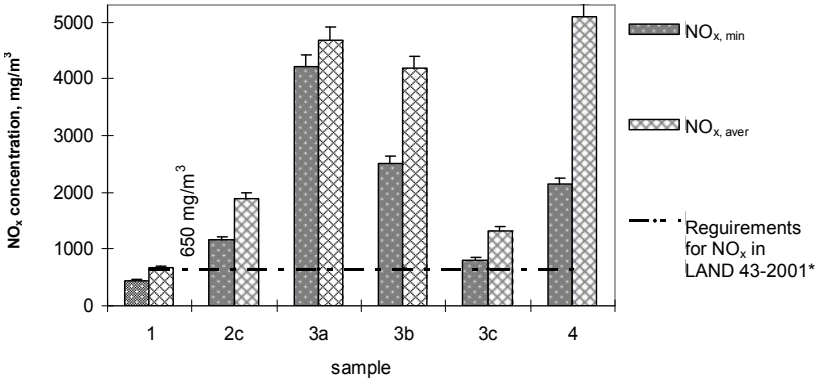


Fig. 1. The comparison of NO_x concentrations in the combustion gas when burning wood granules (1), poultry manure with wood granules (2c) at a ratio of 1:2, swine manure (3a), swine manure with meat waste (3b) at a ratio of 1:1, swine manure with wood granules (3c) at a ratio of 1:2, and grain substrate (4), when O_2 = 6%, with the normative limit values (LAND 43-2001*)

It is established that high concentrations of NO_x are predetermined by a high content of nitrogen compounds in the fermented waste. The comparative tests allow a conclusion that NO_x concentration in the products of combustion is

predetermined by fuel's NO_x. When designing industrial installations for fermented waste incineration, measures aimed at reducing NO_x generation or smoke treatment facilities have to be envisaged.

As determined during investigations, in all the cases substrate incineration the concentrations of CO exceeded the permissible limit values determined for the biomass and waste according to both LAND 43-2001 and the environmental requirements applicable to waste incineration. The comparison of CO_{min} concentrations with these values shows that the exceedances varied from 1.5 to 4.7 and from 2 to 20.8 times, respectively.

3. Experimental investigations on the possibilities of using filtrate for energetic plants growing

The chapter presents the methods of assessing of heavy metal accumulation in different stem parts of willow (*Salix* L.) in the context of their soilless growing in sludge and grain filtrate, and of estimating the influence of the filtrate nutrients and pH on HM accumulation ability and biomass increase.

Willow of the Swedish cultural species "Gudrun" (*Salix dasyclados*) was selected for this research. Willow seedlings were planted in Dargužiai, Varėna District, in May 2003. Filtrate specimens were taken for research from tanks of anaerobic fermentation, in which sewage sludge and grain waste were fermented. The filtrate was poured into a glass vessel and kept there until the beginning of willow research by the method of hydroponics. Willow stems were divided into three parts: I – top, II – middle, III – bottom. Before analysis, the cuttings had been weighed. 18–20 cuttings were grown in solutions of each type of filtrate (25%, 50% and 100% concentrations) and 20 units in the control solution (35 mg $Ca(NO_3)_2$ per one liter of distilled water). Heavy metal concentrations were measured in the filtrate of fermented waste as well as in willow cuttings after 21 days of growth in the filtrate solutions. Metal (Pb, Ni, Zn, Cr, Mn and Cu) concentrations in mineralized solutions were measured with a BUCK 210 VGP flame atomic absorption spectrophotometer (AAS). Quantitative measurements of pH in the filtrates of fermented sewage sludge and grain were taken employing a MultiCal 538 WTW pH meter with a glass electrode. The total phosphorus content in the filtrate was determined by the colorimetric method. The quantitative determination of total nitrogen in the filtrate was performed by the Kjeldahl method.

The concentration factor (CF) of HM was expressed as the ratio of HM concentration in willow samples grown in fermented waste filtrate and in the control filtrate. The CF values were below unity, i.e. no accumulation of heavy metals from the filtrate was noted.

HM accumulation according to the CF in willow cuttings kept in sewage sludge filtrate may be shown in the following order: the top part cuttings (I) – Ni > Cr > Cu > Pb > Zn > Mn; middle part (II) – Mn > Cr > Zn > Cu, bottom part (III) – Cu > Cr, while in the filtrate from fermented grain: the top part cuttings (I) – Mn > Zn > Cr > Cu; middle part (II) – Mn > Cr > Zn > Cu; the bottom part cuttings accumulated Pb and Zn only. According to the values of the highest concentration factor, the heavy metals studied could be ranked as follows: Pb > Cu > Cr > Zn > Ni. The highest CF values were determined for Cu (2.4), Ni (2.1), Zn (2.0), Cr (2.0) in willow grown in sewage sludge filtrate, and for Mn (1.7) in grain filtrate.

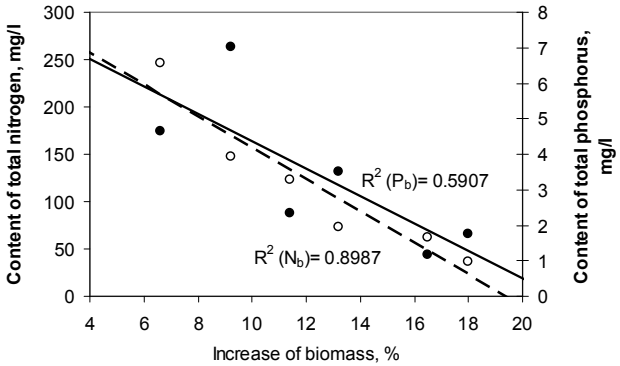


Fig. 2. Correlation between total nitrogen (N_b) and phosphorus (P_b) in fermented waste filtrate and biomass increase

The data showed (Fig. 2) a linear decrease in the accumulation of heavy metals with increasing filtrate concentration in the solution for 87% of plants, i. e. high concentrations of chemical pollutants caused an inhibitory effect.

4. Experimental research of composting

The chapter presents the methods of experimental investigations of composting the substrate, obtained after its anaerobic fermentation, with additives (zeolite and wood ash) as well as the analysis of investigation results.

Specimens of fermented waste (grain), fruit-tree (apple-tree) leaves, biofuel ash and natural zeolite were composed for composting.

Prior to starting a composting experiment, the following parameters of the fermented waste, leaves and biofuel ash were determined: humidity; the content of macro- (C, N, Na, Mg, P, S, K, Ca) and micro-nutrients (Mn, Zn, Cr, Pb, Cu,

Ni) and pH. Prior to the composting experiment, zeolite and ashes were dried at a temperature of 105 ^{o}C for 4 hours up to a dry mass.

The composting experiments were carried out from December 2008 until January 2010.

The investigations were performed in a laboratory composting equipment. The total volume of a composting cylinder to which the mixtures of fermented wastes with additives were manually supplied amounts to 46 l. The composted mixtures were aerated 4 times a day by continuously blowing air for 10 min and rotating the composting equipment's cylinder. The average air supply speed was from 0.2 to 0.5 m/s. The average cylinder rotation speed was 10 rev/min. The average duration of mixture composting was 4 to 5 weeks. The compost's composition (the content of macro- and micro-nutrients), humidity and pH were determined weekly.

Upon completion of the composting experiment of fermented grain with biofuel ash and with zeolite it was determined that heavy metal concentrations (Fig. 3) were decreasing according to the intensity of sorption as follows: Cd > Cr > Pb > Zn > Cu > Mn > Ni.

As determined according to the research results, the total cadmium (Cd) with its trace concentrations in the compost biomass was sorbed and stabilised by additives.

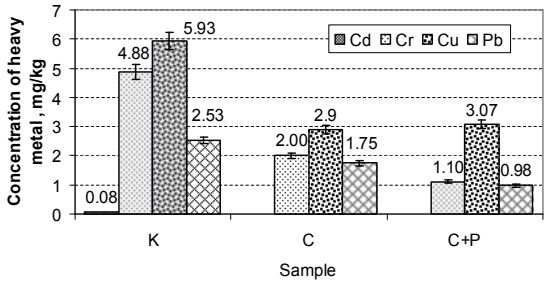
During the investigations differences between lead (Pb) concentrations in the control specimens and in the specimens of compost with zeolite and with ash were identified and, on average, reached 61%, and in the specimens containing only zeolite – 42%. As determined by investigations, upon mixing the composted mass with biofuel ash (10%) and natural zeolite (10%), Pb concentration in compost decreases up to 1.5 times.

As determined during investigations, the use of only natural zeolite is more suitable for nickel (Ni) stabilisation (the difference in concentrations reaches 25.8% compared with the control specimens).

Upon using an additive of natural zeolite, Mn and Cu sorbtion reached 20.5% and was by 2.9% higher than in the case of composting with zeolite and biofuel ash. As determined by investigations, a large amount of Cr can be stabilised upon mixing zeolite and biofuel ash into the composted mass as the decrease of its concentration in compost reached 77%. When only zeolite was used, the sorbtion capacity of chromium reached 59.0%.

As the investigations of grain composting show, 1 kg of grain compost mixed up with apple-tree leaves produced, on average, 94.25 mg/m^3 NH_4. When additives, zeolite and zeolite with ash, were used, this amount decreased up to 1.2 and 2.11 times, respectively. The same tendencies were also established for ammonia release from compost.

a)



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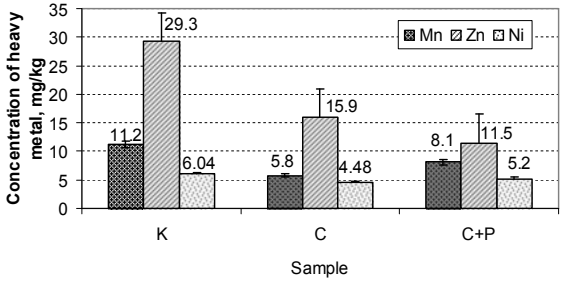

Fig. 3. Change of heavy metal (a – Cd, Cr, Cu and Pb; b – Mn, Ni and Zn) in composted mixtures after 4 weeks of composting (K – control specimen, C – compost with zeolite, C+P – compost with zeolite and ash)

When grain was composted together with leaves, 1 kg of compost released 58.5 mg/m^3 CH_4, H_2S – 25.68 mg/m^3 and 15.67 mg/m^3 of VOC during 4 weeks. It is determined that the use of natural zeolite reduced CH_4 emissions 1.16 times and H_2S emissions 1.28 times, and upon using zeolite with ash these differences reached 1.25 and 1.47 times, respectively.

5. Evaluation of fermented waste thermal properties and nitrogen oxides formation during combustion

As determined during investigations, in the case of fermented waste, the value of the coefficient of fuel nitrogen conversion into NO_x varies from 0.103 to 0.242 accounting for 10.3% and 24.2%. For comparison, a chart (Fig. 4) shows K_N values obtained from research done by K. Buinevičius (2009) and a composed chart that demonstrates a tendency.

According to the analysis of research results, at the presence of completely different sources of nitrogen and different types of combusted fuel, the fuel's nitrogen conversion into NO_x may approximately be generalised by the equation (R^2=0.8344, when p=0.05):

$$K_N = 14.941 \cdot N_k^{-0.854}, \quad (1)$$

there K_N – conversion factor of fuel nitrogen,%; N_k – nitrogen content in fuel, %.

By using formula (1), values of NO_x concentrations were obtained and compared with experimentally obtained values (Fig. 4).

The results obtained when using the *Gaska&Wandrasz* model for assessing NO_x concentration contents and by applying the adjusted coefficients of nitrogen conversion differ from the experimental results by: 14% for wood granules, 7% for fruit/vegetable waste, 39% for poultry manure, 21% for swine manure.

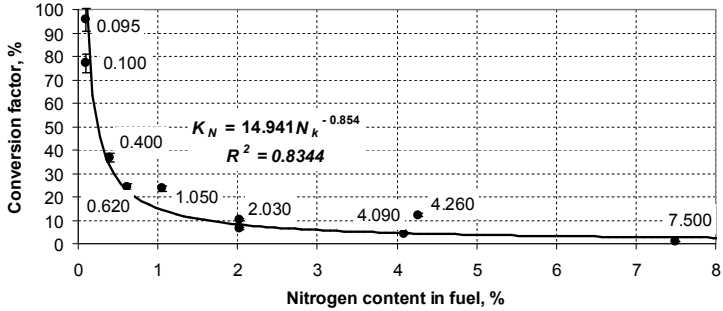

Fig. 4. Nitrogen conversion dependence on nitrogen content in fuels (0.095, 0.62, 1.05, 2.03, 4.26 – experimental values determined in the present work, 0.1, 0.4, 4.09, 7.5 – values determined by K. Buinevičius (2009)

NO_x concentration values determined during modelling differ, on average, by 12.7% from values identified during investigations, except for those established for fermented grain substrate. The main assumption for the formation of larger inadequacies can be related with instability of fuel combustion that is preconditioned by the bulkiness, porosity or ash content of fuel along with other factors. More detained research on the physical characteristics of fuel is necessary to have this assumption confirmed.

6. The developed methodology and designed equipment

The chapter presents the developed methodology intended for the optimisation of the composting process aimed at obtaining quality compost. It also presents a description of the designed equipment and the principle of its operation.

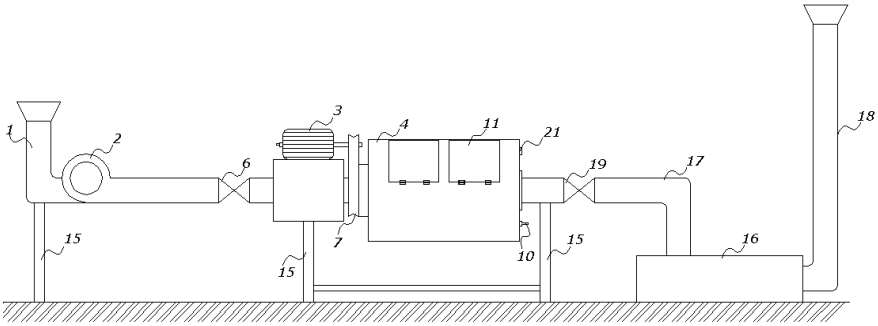

Fig. 5. Scheme of the composting equipment with air supply and release/treatment systems: 1 – air supply duct; 2 – ventilator; 3 – engine; 4 – composting cylinder; 6 – valve; 7 – belt drive; 10 – thermometer; 11 – openings for compost loading; 15 – legs, 16 – biofilter; 17 – air inlet duct; 18 – air outlet duct; 19 – valve; 21 – plug

The composting equipment (Fig. 5) has a central immovable part through which air is supplied at a different speed and a cylinder with a controllable speed of rotation. A biofilter is placed under the equipment for the collection and treatment of polluted air. Fig. 5 shows a side-view of the composting equipment with a biofilter. The advantage of the proposed composting equipment, which is intended for the treatment of low fermented waste flows (up to 400 kg per year), lies in the fact that it meets all the requirements of negative impact mitigation, particularly of dealing with the problem of unpleasant odours. The invention is aimed at improving the structure of the composting equipment with a view of improving the quality of compost and reducing the negative impact on the environment of biodegradable waste during composting, through the employment of complex measures (control of air supply and compost mixing speeds as well as polluted air collection and supply to the air treatment filter). For the optimisation of composting processes, methodological guidelines allowing the evaluation of the C/N ratio and humidity of the initial waste intended for composting have been developed. The work presents recommendatory formulas for the calculation of compost supply with air and compost mixing frequency.

General conclusions

1. The performed investigations of fermented waste incineration in mono-cycle mode show that high levels of NO_x concentration are predetermined by a large content of nitrogen compounds, compared to wood, in fermented waste. The investigations of combustion over time show that the concentrations of NO_x and CO under real conditions are up to 1 500 mg/m^3 and 5 000 mg/m^3, respectively, in the combustion zone of all substrates (poultry, swine manure and grain, except for fruit/vegetable waste) at an exhaust gas temperature of around 600 ^oC and concentration of O_2 of 6% and below.
2. During the experiments of fermented waste combustion in a low capacity stand it was established that the concentrations of CO_{min} and $NO_{x,\ min}$ recorded in the products of combustion had exceeded the limit values by 20.8 and 8.0 times, respectively. When incinerating fermented waste in industrial installations, technological means of emission reduction need to be introduced.
3. The performed experiments of willow (*Salix dasyclados)* growing under laboratory conditions (by the method of hydrophonics) show that, by the value of accumulation capacity reaching 2.1 and 1.8, respectively, the biomass of the top (*I*) and medium (*II*) parts of cuttings accumulated the largest amounts of Ni, whereas that of the lower pat (*III)* – Cu (2.4). The investigation data showed a linear decrease of heavy metal accumulation in 87 % of the cutting biomass with the concentrations of biogenic substances – nitrogen and phosphorus – in filtrate solutions increasing, which also predetermined nearly a threefold decrease in biomass increment.
4. On the basis of findings obtained during the investigations of waste composting in the designed equipment (Application No 2008 081 for a patient of the Republic of Lithuania) and composting natural zeolite mixed with grain and leaves, it was determined that this allowed an efficient reduction, over 50%, of the concentrations of Cd, Cr and Cu in the compost biomass compared with the control compost specimens. Upon zeolite insertion, the sorption of other heavy metals was: Zn – 45.7%, Mn – 48.2%, Pb – 30.8% and Ni – 25.8%.
5. The investigation results show that upon composting fermented waste with biofuel ash and additives of natural zeolite the content of heavy metals, Cd, Cr, Pb and Zn, in compost can be reduced by more than 50%. The concentrations of Cu, Mn and Ni in the compost biomass fall by 48.2%, 27.7% and 13.9%, respectively. This shows that a complex use of biofuel ash and natural zeolite additives for the

improvement of the process of composting allows a more efficient reduction (by over 2 times) of concentrations of some heavy metals in compost.

6. As determined during the investigations, 1 kg of compost, when using the additives of zeolite and zeolite mixed with biofiel ash for composting, produces by 1.2 and 2.11 times less of average methane and ammonia emissions per day, respectively.
7. It was determined during investigations that the lower calorific power of fermented waste varied in the range of 8 700 and 18 900 kJ/kg, and the amount of air necessary for combustion and the amounts of generating combustion products established for fermented waste substrates vary from 2.3 to 5.0 m^3/kg and from 2.6 to 5.5 m^3/kg, respectively.
8. The universal empirical formula developed during investigations may be used for the determination of the coefficient of NO_x conversion from fuel nitrogen compounds for various types of fuel at the stoichiometric consumption of oxygen (when $\lambda = 1.4$).
9. The results of investigations obtained when using the *Gaska&Wandrasz* model and by applying the coefficients of nitrogen conversion (22.47% for fruit/vegetable waste, 14.33% for poultry manure, 8.16% for swine manure) show that the values of NO_x concentrations differed, on average, by 12,7% from the concentrations obtained during experiments. The biggest difference, 64%, was determined for grain, and therefore, it can be stated the model *Gaska&Wandrasz* is not suitable for estimating NO_x emissions from the combustion of this substrate.

Recomendations

1. The designed composting equipment (Application of Lithuanian patent No 2008 081) is intended for biodegradable waste (fermented waste) digestion under anaerobic conditions at small agricultural farms and food processing enterprises. The laboratory model prototype of the equipment with a productivity of up to 400 kg compost of per year is recommended for the reduction of the emissions of gaseous pollutants, methane and ammonia, by directing gas emitted from the compost biomass to air treatment facilities.
2. It is recommended to dilute the filtrate of fermented waste obtained from waste dewatering (sewage sludge and grain) at a ratio of 1:3. Solutions prepared in this way create the optimum conditions for the assimilation of nutrients from filtrates into the willow biomass.

3. During the process of composting it is recommended to use a mixture of natural zeolite and biofuel ash (10% of each material of the total compost mass) with the aim of reducing gaseous pollutant emissions by up to 2 times. The same mixture which ensures the decrease of concentrations of heavy metals, Cr, Zn and Pb (by up to 1.31, 1.33 and 1.99 times, respectively) in the composted biomass may be used for compost stabilisation and quality improvement.
4. To improve fuel combustion efficiency and reduce the concentrations of NO_x in low capacity installations by automatically feeding fuel to the mouth it is recommended to set the proportion of fermented waste and wood amount at a ratio of 1:2.
5. The *Gaska&Wandrasz* model is suitable for the measurement of NO_x emissions during combustion of homogeneous waste and that with a low nitrogen content (up to 3 %).

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Patents

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FERMENTUOTŲ ATLIEKŲ TYRIMAI IR PANAUDOJIMO TECHNOLOGIJOS

Mokslo problemos aktualumas

Labai svarbi prielaida pažangioms organinių atliekų tvarkymo technologijoms taikyti yra jų kaupimo vietose sklindantys nemalonūs kvapai, taip pat atliekose esantys neorganiniai junginiai, didėjantis infekcijų, paviršinio ir gruntinio vandens užteršimo pavojai. Todėl apdorojant organines atliekas, visų pirma turi būti sprendžiamos ekologinės problemos ir kartu papildomai gali būti gaunama ekonominės naudos, siekiant išgauti elektros ir šiluminę energiją arba pagaminti kitus vertingus produktus. Vertinant anaerobinį atliekų perdirbimą, rekomenduojama atsižvelgti į kompleksinį šio metodo efektyvumą, ieškoma alternatyvių tokių atliekų pardirbimo ir panaudojimo būdų. Šiuo metu, ypač po biodujų išgavimo, biologiškai skaidžių atliekų, panaudojimo tyrimai tampa vis aktualesni. Todėl viena iš prioritetinių tyrimų sričių yra atsinaujinančių, vietinių ir atliekinių energijos išteklių naudojimo technologijų kūrimas, tuo labiau, kad atsinaujinančiųjų ir vietinių energijos išteklių (biokuro iš biomasės) gamybos ir naudojimo plėtra yra vienas pagrindinių Lietuvos energetikos tikslų. Kita vertus esant mažai užterštam, pavyzdžiui sunkiaisiais metalais, nuotekų dumblui ar kitai biomasei, jį po anaerobinio perdirbimo galima plačiai naudoti žemės ūkio reikmėms. Šiuo metu mažėjant dirbamųjų laukų plotams, didėja susirūpinimas šių plotų panaudojimu energetiniams želdiniams įveisti, panaudojant fermentuotų atliekų ar kitų rūšių atliekų filtratus. Siekiant pagerinti fermentuotų atliekų kokybę bei sumažinti dirvožemio užtaršą sunkiaisiais metalais, siūloma tokias atliekas kompostuoti su priedais, kurie pasižymi absorbcinėmis savybėmis. Geriausios galimybės plėtoti fermentuotų organinių atliekų naudojimą yra susijusios ir su jų naudojimu siekiant išgauti energiją. Tradicinis medienos deginimas krosnyse gali būti nesudėtingas ir neproblemiškas esant nedidelėms energijos gamybos apimtims ir esant pigiai darbo jėgai. Toks energijos gamybos būdas dideliuose energetiniuose objektuose reikalauja daug darbo ir energijos sąnaudų. Norint automatizuoti biokuro deginimą, kelios Europos Sąjungos šalys (Austrija, Vokietija, Švedija ir kt.) yra priėmusios techninius medienos briketų ir granulių kokybės standartus. Tuo tarpu kietojo biokuro, pagaminto iš fermentuotų atliekų, sudėtis ir šiluminės savybės yra mažai tyrinėti.

Tyrimų objektas – fermentuotų atliekų kietoji (substratas) ir skystoji (filtratas) frakcijos bei jų panaudojimo technologijos.

Darbo tikslas – išnagrinėti bei įvertinti fermentuotų atliekų (nuotekų dumblo, kiaulių ir vištų mėšlo, vaisių su daržovėmis bei žliaugto) panaudojimo tręšimui, kompostavimui bei deginimui galimybes atsižvelgiant į jų elementinę sudėtį ir užtaršos lygį sunkiaisiais metalais. Atlikti šių atliekų deginimo proceso metu išsiskiriančių dujinių teršalų (NO_x) įvertinimą naudojant skaitinį modelį.

Darbo uždaviniai

1. Nustatyti sausintų fermentuotų atliekų sudėtį, jų šilumines charakteristikas bei įvertinti šių atliekų deginimo proceso metu išsiskiriančių dujinių teršalų emisijas.
2. Atlikti gluosninių žilvičių auginimo fermentuotų atliekų filtrate tyrimus laboratorinėmis sąlygomis ir įvertinti auginių galimybes kaupti sunkiuosius metalus.
3. Atlikti fermentuotų atliekų kompostavimo, įterpus gamtinį ceolitą ir biokuro pelenus, dinaminiu būdu tyrimus sukurtame įrenginyje ir nustatyti gautojo komposto tinkamumui tręšti kokybę.
4. Atlikti fermentuotų atliekų deginimo proceso metu išsiskiriančių dujinių teršalų emisijų modeliavimą ir gautus rezultatus palyginti su eksperimento metu gautais tyrimų rezultatais.

Mokslinis naujumas – tai kompleksiniai fermentuotų atliekų panaudojimo tręšimui, kompostui gaminti ir deginimui tyrimai bei skaitinis taršalų emisijų degimo produktuose modeliavimas.

Tyrimų metodika

Darbe taikytos substratų deginimo, gluosnių žilvičių auginimo fermentuotų atliekų filtratuose bei kompostavimo metodikos. Fermentuotų atliekų bei jų filtratų tyrimai atlikti pagal standartizuotas metodikas. Siekiant įvertinti fermentuotų atliekų degimo metu susidarančių teršalų koncentracijas, naudotos empirinės formulės. Azoto oksidų emisijos fermentuotų atliekų degimo metu modeliuoti buvo naudotas *Gaska&Wandrasz* modelis.

Darbo praktinė vertė

Tyrimų metu gauti fermentuotų atliekų deginimo rezultatais galės pasinaudoti energiją gaminančių įmonių atstovai, kurie kietuoju atgautuoju kuru iš dalies norės kompensuoti augantį medienos kuro poreikį. Kompostuojant fermentuotas atliekas, stabilizuotas gamtiniu ceolitu ir biokuro pelenais, sumažės jų tūris, kompostavimo proceso metu bus išsaugotos maistingosios medžiagos, kurias bus galima sėkmingai naudoti žemės ūkio reikmėms. Ūkininkai, ruošiantys auginti energetinius želdinius ir naudojantis vietinės

kilmės trąšas, galės pasinaudoti fermentuotų atliekų filtrato sudėties tyrimų rezultatais, siekiant sumažinti dirbamų žemės ūkio plotų užtaršą biogeninėmis medžiagomis ir sunkiaisiais metalais.

Ginamieji teiginiai

1. Sausos fermentuotos atliekos – tai kaloringas kuras, kurio deginimas mažos galios įrenginiuose sukelia iki 10 kartų didesnę taršą azoto oksidais, lyginant su medienos granulių deginimu.
2. Skirtingose gluosninio žilvičio (*Salix dasyclados*) stiebo dalyse sunkiųjų metalų kaupimas iš fermentuotų atliekų filtrato tiesiškai priklauso nuo maistinių medžiagų (azoto, fosforo) pasisavinimo.
3. Gamtinis ceolitas, įterptas į fermentuotų atliekų kompostą, stabilizuotą papildomai biokuro pelenais, leidžia sumažinti sunkiųjų metalų koncentracijas komposto biomasėje iki 2 kartų.

Darbo apimtis. Disertaciją sudaro įvadas, šeši skyriai, bendrosios išvados ir rekomendacijos, literatūros sąrašas, autoriaus publikacijų sąrašas. Darbo apimtis yra 180 puslapių, tekste panaudotos 38 numeruotos formulės, pateikti 86 paveikslai ir 15 lentelių.

Bendrosios išvados

1. Atlikus fermentuotų atliekų deginimo vieno ciklo režimu tyrimus nustatyta, kad dideles NO_x koncentracijas lemia didelis, lyginant su mediena, azoto junginių kiekis fermentuotose atliekose. Degimo tyrimai laiko bėgyje parodė, kad visų substratų (vištų, kiaulių mėšlo ir žlaugto, išskyrus vaisių/daržovių atliekas) sudegimo zonoje, kai išmetimo dujų temperatūra siekė apie 600 ^oC ir O_2 koncentracija – 6 % ir mažiau, NO_x ir CO koncentracijos realiomis sąlygomis buvo atitinkamai iki 1500 mg/m^3 ir 5000 mg/m^3.
2. Eksperimentinių fermentuotų atliekų deginimo mažos galios stende tyrimų metu nustatyta, kad degimo produktuose išmatuotos $CO_{min.}$ ir $NO_{x,\,min.}$ koncentracijos viršijo ribines vertes atitinkamai iki 20,8 ir 8,0 kartų. Deginant fermentuotas atliekas pramoniniuose įrenginiuose būtina numatyti technologines priemones emisijoms mažinti.
3. Atlikus eksperimentinius gluosninių žilvičių (*Salix dasyclados*) auginimo laboratorinėmis (hidroponikos būdu) sąlygomis tyrimus, nustatyta, kad pagal kaupimo gebos vertes, kurios siekė atitinkamai 2,1 ir 1,8, viršutiniosios (*I*) bei viduriniosios (*II*) dalių auginių biomasė daugiausia sukaupė Ni, o žemutiniosios dalies (*III*) – Cu (2,4). Tyrimų duomenys rodo, kad 87 % auginių biomasėje buvo

nustatytas tiesinis sunkiųjų metalų kaupimosi sumažėjimas didėjant biogeninių medžiagų – azoto ir fosforo – koncentracijoms filtratų tirpaluose, kas lėmė ir biomasės prieaugio sumažėjimą beveik iki 3 kartų.

4. Remiantis fermentuotų atliekų kompostavimo sukurtame įrenginyje (Paraiškos Nr. 2008 081 LR patentui gauti) bei su gamtiniu ceolitu, sumaišyto su žlaugtu bei lapais, tyrimų metu gautais rezultatais nustatyta, kad tai efektyviai leidžia sumažinti daugiau negu 50 % Cd, Cr ir Cu koncentracijas komposto biomasėje lyginant su kontroliniais komposto bandiniais. Kitų sunkiųjų metalų sorbcija įterpiant ceolitą siekė: Zn – 45,7 %, Mn – 48,2 %, Pb – 30,8 % ir Ni – 25,8 %.
5. Tyrimais nustatyta, kad kompostuojant fermentuotas atliekas kartu su biokuro pelenais ir gamtinio ceolito priedais, sunkiųjų metalų – Cd, Cr, Pb ir Zn – kiekį komposte galima sumažinti daugiau negu 50%. Cu, Mn ir Ni koncentracijos komposto biomasėje atitinkamai sumažėja 48,2 %, 27,7 % ir 13,9 %. Tai rodo, kad kompleksinis biokuro pelenų ir gamtinio ceolito priedų, skirtų kompostavimo procesui pagerinti, naudojimas leidžia daug efektyviau (virš 2 kartų) sumažinti kai kurių sunkiųjų metalų koncentracijas komposte.
6. Tyrimais nustatyta, kad kompostavimui naudojant priedus – ceolitą ir ceolitą kartu su biokuro pelenais – vidutinis metano ir amoniako išsiskyrimas iš 1 kg komposto per dieną sumažėja atitinkamai iki 1,2 ir 2,11 karto.
7. Tyrimais įvertinta, kad fermentuotų atliekų žemutinis šilumingumas svyruoja nuo 8700 kJ/kg iki 18 900 kJ/kg, o degimui reikalingo oro ir susidarančių degimo produktų kiekiai, nustatyti fermentuotų atliekų substratams, svyruoja atitinkamai nuo 2,3 iki 5,0 m^3/kg bei nuo 2,6 iki 5,5 m^3/kg.
8. Tyrimų metu gauta nauja universali empirinė formulė gali būti naudojama įvairioms kuro rūšims NO_x konversijos iš kuro azoto junginių koeficientui nustatyti esant stechiometriniam deguonies suvartojimui (kai $\lambda = 1,4$).
9. Tyrimais nustatyta, kad NO_x koncentracijų vertės, gautos taikant *Gaska&Wandrasz* modelį bei naudojant azoto konversijos koeficientus (vaisių/daržovių atliekoms – 22,47 %, vištų mėšlui – 14,33 %, kiaulių mėšlui – 8,16 %), vidutiniškai skyrėsi nuo koncentracijų gautų eksperimento metu 12,7 %. Didžiausias nesutapimas buvo nustatytas žlaugtui ir siekė 64 %, todėl galima teigti, kad šio substrato degimo metu išsiskiriančioms NO_x emisijoms vertinti *Gaska&Wandrasz* modelis yra netinkamas.

Rekomendacijos

1. Sukurtas kompostavimo įrenginys (Paraiškos Nr. 2008 081 LR patentui gauti) skirtas bioskaidžių atliekų (fermentuotų atliekų) pūdymui aerobinėmis sąlygomis nedideliuose žemės ūkiuose bei maisto perdirbimo įmonėse. Laboratorinis įrenginio modelis, kurio našumas siekia iki 400 kg komposto per metus, rekomenduojamas naudoti dujiniams teršalams – metanui ir amoniakui – mažinti, nukreipiant iš komposto biomasės išsiskyrusias dujas į oro valymo įrenginius.
2. Fermentuotų atliekų filtratą, gautą nusausinus atliekas (nuotekų dumblą ir žlaugtą), rekomenduojama skiesti 1:3 santykiu. Taip paruošti tirpalai sudaro palankias sąlygas maistingųjų medžiagų pasisavinimui iš filtratų į gluosnių biomasę.
3. Kompostavimo proceso metu rekomenduojama naudoti gamtinio ceolito ir biokuro pelenų mišinį (po 10 % kiekvienos medžiagos nuo bendrosios komposto masės) siekiant sumažinti dujinių teršalų emisijas iki 2 kartų. Tas pats mišinys, kuris užtikrina sunkiųjų metalų – Cr, Zn ir Pb – koncentracijų sumažėjimą (atitinkamai iki 1,31, 1,33 ir 1,99 kartų) kompostuojamoje biomasėje, gali būti naudojamas kompostui stabilizuoti ir jo kokybei gerinti.
4. Kuro degimo efektyvumui gerinti bei NO_x koncentracijoms mažinti mažos galios įrenginiuose tiekiant kurą į pakurą automatiniu būdu rekomenduojama nustatyti fermentuotų atliekų ir medienos granulių kiekio proporciją santykiu 1:2.
5. *Gaska&Wandrasz* modelis tinka homogeniškų ir nedidelį azoto kiekį (iki 3 %) turinčių atliekų degimo metu išsiskiriančioms NO_x koncentracijoms vertinti.

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INVESTIGATION OF FERMENTED WASTE AND TECHNOLOGIES OF DISPOSAL

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