Disposal methods and treatment of wastes from piggeries

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Introduction

Expansion of agricultural and livestock production has contributed to considerable aggravation of environmental problems. Environmental protection in Poland is regulated by the "Environmental Protection Law" [1] of 2001, "Act on wastes" [2] of 2001 and amendment to the latter of 2010 [3]. Particular attention is given to protection of soil and water against pollution and to protection of water against eutrophication, caused by excess amounts of nitrogen and phosphorus compounds discharged into the environment. Pig manure, which is used as a natural fertilizer, is regarded as one of the sources of these compounds. Expansion of hog raising resulted in excessive production of liquid manure, the amount of which has surpassed the receiving capabilities of farmland. Therefore, it became important to develop efficient methods of processing this material. This paper describes the major ways of managing pig manure.

Composition of pig manure

Liquid manure is a mixture of faeces and water. It is generated in litter-free (dry) hog raising farms as a by-product and waste [4]. Among the compounds making up liquid manure, there are compounds that mainly form the solid fraction, e.g. organic compounds or phosphorus compounds, as well as constituents of the liquid fraction, such as nitrogen compounds and minerals in the form of oxides of sodium, potassium and magnesium [5]. The content of these substances depends on the hog raising and feeding procedures [6]. An example composition of pig manure from the Netherlands is shown in Table 1.

Table 1

Composition of pig manure [5]

Constituent	Percentage content, %
Water	73.11
Dry solids	8.12
Suspended solids	6.50
COD	9.75
Amine N (including ammonia N)	0.65 (of that 0.49)
P (as P_2O_5)	0.41
K (as K_2O)	0.65
Ca (as CaO)	0.33
Mg (as MgO)	0.16
Cl^-	0.16
S (as SO_4^{2-})	0.16

A totally different content of the above compounds has been found in the case of liquid manure from a Canadian pig farm [7]. The percentage content of organic matter was 40.69%, suspended solids 50.08%, whereas total content of potassium P_{tot} and that of nitrogen *TKN* were 2.03% and 7.20%, respectively. Despite the differences in composition, the values of pH of these mixtures were similar. The pH value for the Dutch manure was 7, whereas that for the Canadian manure was 7.5.

Nuisance caused by waste from hog raising farms

The nuisance caused by pig manure results mainly from its composition. It is characterised by high content of nitrogen and phosphorus compounds, which pollute soil and water and lead to eutrophication of surface water bodies. Liquid manure can also cause odorous pollution of air as an effect of releasing ca. 400 volatile foul smelling organic and inorganic substances, such as ammonia, amines, methyl sulphides, hydrogen sulphide, mercaptans and skatoles. Compounds of this type should be, as far as possible, neutralised, as excessive concentration thereof may diminish the population of reared pigs, and may also cause respiratory system and skin infections in farm workers [4]. In order to reduce foul smells, bismuth compounds are used, e.g. bismuth subgallate (BiG, Dermatol), as well as chlorophyllin copper complex (CCC) and powdered activated charcoal (PAC). These substances are also added to animal feed as the so-called internal disinfectant. Moreover, they can also be mixed with excreta [8].

A serious environmental hazard is also the presence of antibiotics and other pharmaceuticals in animal faeces. In effect this is followed by growth of pathogenic micro flora and antibiotic-resistant strains of microorganisms in soil, surface and groundwater [4].

Adverse effect of liquid manure on the environment compels to treat and process it into materials less harmful or totally neutral, applicable as agents for enriching soil with mineral matter, promoting vegetation growth, and also as potential sources of energy. These, in addition to pressure from environmentalists and official authorities, have contributed to the development of liquid manure treatment and processing technology.

Processing pig manure into fertilizers

Large portion of liquid manure is used as liquid organic fertilizer. Today, in virtually all countries of the European Union, in regions of extensive industrial hog raising, the volume of manure produced exceeds substantially the amount that could be utilised for application to farmland. Due to the fact that farmland should be manured only during plant vegetation, with maximum annual nitrogen dose being 170 kg per hectare, large-sized storage facilities have to be used [4]. On the other hand storage of such waste is associated with excessive NH_3 emissions to air. Environmental problems concomitant with liquid manure production induce the pursuit of new methods of processing thereof. The aim is to process waste into material less harmful or virtually non-threatening to the environment.

The products of liquid manure processing are fertilizers. In Poland, work on the above was undertaken in the 1970s. Initially, liquid manure was just stored for utilising as a fertilizer at a later date. Later on the usefulness of liquid manure was increased by composting it with an addition of organic materials able to absorb the liquid fraction of the waste. The most widely used material of this type was peat, as it was relatively cheap. Additionally the compost was enriched with phosphorus fertilizers to turn it into an assimilable organic fertilizer. The processing of liquid manure into a fertilizer also included separation thereof into solid and liquid fractions. This is effected by mechanical separation or sedimentation. Liquid manure separation and further processing methods are continually modified and improved.

The most widely used mechanical separation methods include pressing, centrifugation and filtration. A special polymer may also be added to induce flocculation of the organic waste contained in the liquid fraction. Chemical and biochemical transformations brought about by the separation operations make the separated fractions less harmful to the environment. There are a number of commercially available animal waste separation methods, e.g. decanter centrifugation (*Pieralisi, GEA Westfalia separator A/S Alfa Laval*), chemical treatment and belt press separation (*Kemira Water A/S*), rotating filter drum and screw press (*Samson Bimatech*), centrifugation and vibration filtration (*PCK consulting A/S*), separation by centrifuging (*SWEA A/S*) [9].

Fertilizers obtained from liquid manure take on different forms. There can be liquid fertilizers, suspension fertilizers, pelletised or granular fertilizers. An example of a liquid fertilizer is the organic and mineral fertilizer, obtained by improving liquid manure with mineral fertilizers, mainly phosphate fertilizers, aerating and separation into solid and liquid fraction using peat or compressed straw slabs. The slabs obtained are rich in solid constituents of the manure and are used as a substrate for plant growing. The excess liquid fraction, not absorbed by peat, is again blended with mineral fertilizers, aerated, conditioned and diluted with water to appropriate concentration to be used as fertilizer [10].

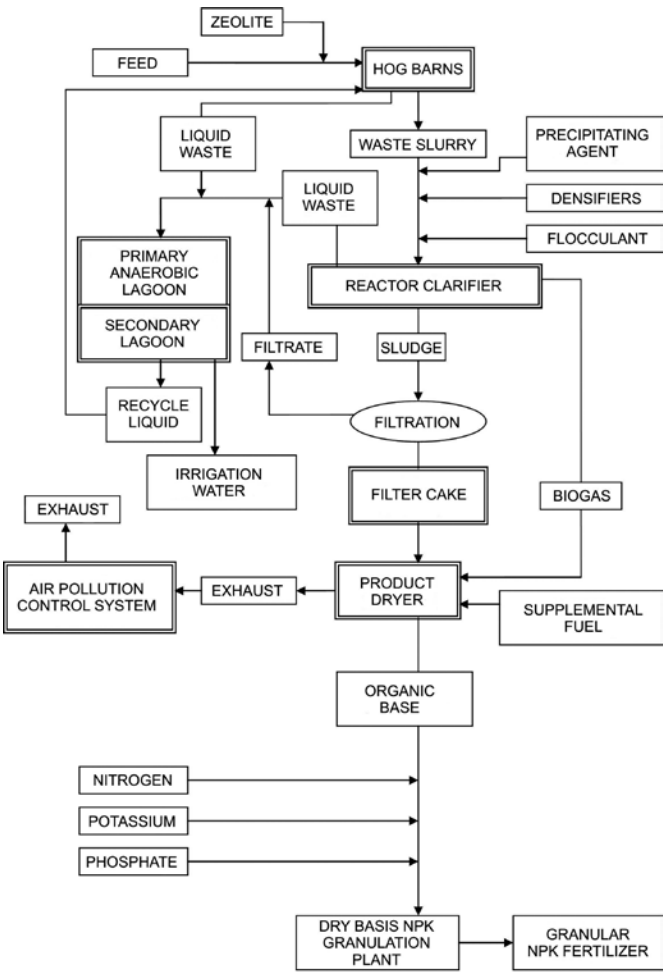

Fig. 1. Block diagram of pig manure processing methods [11]

Examples of treatment and use of liquid waste from hog raising farms, aimed principally at manufacture of organic fertilizer, are given in Figure 1.

A method of obtaining organic fertilizer in the form of a concentrate enriched with nitrogen and phosphorus is also known. The process consists in mixing the waste with liquid paraffin – organic carrier liquid. The mixture is then concentrated, treated anaerobically, the vapour generated is condensed, and the effluent from the anaerobic process is treated aerobically [12].

As mentioned, fertilizers can also be manufactured in the form of suspension. To organic animal waste, such as liquid manure, appropriate amount of water is added to form a dispersed solution. Then a predetermined amount of acid, e.g. sulphuric acid, is added to the mixture, transforming it into colloidal form. The product obtained is admixed with anhydrous or aqueous ammonia and inorganic plant nutrients. The suspension fertilizer can be made not only with pig manure, but also with organic waste derived from other animals [13].

There is also a method of producing an organic and mineral fertilizer in a solid form. The liquid manure is admixed, in appropriate amounts, with organic fillers (15% in relation to animal waste), followed by coagulating chemicals (50% cyanoacrylate in acetone) and mineral substances. Solids, used directly as a fertilizer, are then relatively easily separated from the liquid manure by passing the mixture through a screen. The method described also allows complete recovery of water [14].

There are more methods of converting liquid manure into a solid organic and mineral fertilizer. Waste containing 7-11% dry solids is mixed with an organic component of moisture content up to 30% (peat, compost or lignite) enr iched with nitrogen, potassium or phosphate fertilizer, and with dolomite calcined at 150-200°C ground to 0.25 mm grain size. Proper weight ratios of the components should be maintained. A moist and loose mixture is obtained, which is conditioned for at least 10 hours [15].

An organic solid fertilizer can also be obtained by mixing liquid manure with harvest leftovers, and grinding the mixture to appropriate particle size enabling complete adsorption and absorption of liquid fraction components. The apparatus for producing this fertilizer comprises a grinding and blending device; supply of material is independent of the type of liquid substrates used. The method can be applied to livestock excreta as well as to wastewater of other origin. The apparatus used enables grinding the harvest leftovers to micron size particles, which are absorbed more readily into soil [16].

An organic and mineral fertilizer can also be produced in the form of pellets. This is a multistage process: starts with decantation and flocculation, followed by biological separation of phosphorus and nitrogen, microfiltration of organic matter, completed by introducing ammonium sulphate and phosphate and disinfecting with ultraviolet radiation [17].

A slow release nitrogen fertilizer can also be obtained in pelletised form. The raw material used is animal excreta, derived, for instance, from pig farms, rich in nitrogen compounds. The fertilizer production process consists in admixing the dry excreta with liquid urea-formaldehyde oligomer. Introduction of this compound increases nitrogen content in the fertilizer by 15 to 85% [18].

Fertilizer obtained from animal waste, having the form of pellets, may be free of pathogens and foul smell. The production process is based on complete separation of suspended matter and dissolved matter, preventing thereby emissions of gases. The fertilizer is obtained by mixing the waste with a flocculant, phosphate precipitants, thickener and enriched with microelements and soil conditioners. The process is conducted at temperature close to incineration point to render the fertilizer pathogen- and odour-free.

Microbe-free fertilizers can also be produced from animal excreta in an exothermic reaction with concentrated sulphuric acid followed by thermal pasteurization. The product is enriched with mineral substances. This method of waste processing enables removal of 90% of pathogens contained therein [19, 20].

Composting of pig manure

An environment friendly and economically alternative method of processing solid organic waste is composting. Products of this process may be used as a fertilizer for soil improving, soil conditioning, enhancing plant growth and inhibiting plant pathogen growth. This, however, applies only to the so-called stabilized products, as treating soil with an "immature compost" can lead to phytotoxicity and adverse environmental effects. Therefore it is important to properly assess the stability of compost by analysing its physical parameters: temperature, smell, colour, etc., as well as chemical parameters, such as C/N ratio in liquid and solid fractions, cation exchange capacity, organic material content, etc. Additionally biochemical and microbiological parameters are determined, and the composted material is subjected to spectroscopic analysis [21].

Liquid manure is a material that provides good composting results. For experimental purposes the manure was mixed with sawdust. It was demonstrated that the maturation time of the compost based on the said substrates was 63 days. During this time the readily degradable organic constituents, such as aliphatic chains, polysaccharides, alcohols, as well as proteins, were converted into aromatic structures of higher stability [21].

Biogas production from pig manure

The stress laid on biogas production is increasing. There is a growing interest in agricultural biogas, which to a large degree is associated with animal farming. The raw material used in its production is biomass in the form of liquid manure, cow dung, animal and vegetable waste. The so-called non-agricultural biogas is produced from sewage and municipal waste [22].

In chemical terms, biogas is a mixture composed mainly of methane and carbon dioxide, with possible low content of hydrogen sulphide and carbon monoxide. It is obtained in the process of anaerobic digestion, mainly methane fermentation, of the materials mentioned. During this process microorganisms oxidize partly many organic compounds, resulting in the generation of acetate and hydrogen, as well as, in smaller quantities, propionate and butyrate, and some alcohols. Acetic acid bacteria transform propionate and butyrate into acetate and hydrogen, which are subsequently transformed into methane by *Archaeabacteria* methane-generating bacteria. Some microorganisms oxidize the acetate to hydrogen and carbon dioxide, rather than to methane [23].

A relatively important issue in the production of biogas is the selection of ingredients, which differ in composition and show different fermentation efficiency. Pig manure is a low methane yield substrate (from 290 to 550 litres CH_4/kg organic matter), as much of it comprises water. To increase biogas output from liquid manure, the latter is subjected to high temperatures and changed pH. Thermal modifications were carried out in the temperature range of 70 to 190°C, in appropriate apparatus and during predetermined time. In case of temperatures below 100°C, the manure was held for 3 hours in a 2-litre glass reactor, equipped with magnetic stirrer. For higher temperatures a Zipperclave reactor (autoclave) was used equipped with a ceramic oven, and the process duration was 20 minutes. Chemical and thermal modifications consisted in adding to the manure sodium hydroxide in such quantities as to adjust pH value to between 10 and 12. The pH was changed prior to the thermal modification. In the first case, the highest Biochemical Methane Potential (BMP), up to 48%, was obtained at 190°C, whereas the optimum temperature range seemed to span from more than 135°C to less than 190°C [24]. At such high temperature the liquid manure is thermally hydrolyzed [25]. Chemical/thermal modification of liquid manure at pH=10 and 190°C did not increase BMP as regards the liquid fraction, whereas BMP related to the whole increased in comparison to results obtained with untreated manure by 78%. At pH value of 12, BMP decreased, both related to the liquid fraction as well as to the whole, irrespective of the temperature it was heated to [24]. The tests carried out indicate that in order to increase biogas output from liquid manure, it helps heating it or modifying its pH to 10 and heating, prior to the fermentation process.

Methane output from biomass can also be increased by selecting appropriate raw materials. Fermentation was carried out of material based on pig manure with added corn silage, pomace and cow dung. The highest economical efficiency was obtained for a mixture of manure and pomace, whereas the biogas output from the individual substrates was 18.0 and 112.7 m^3/h, respectively. Equally high efficiency is achieved in fermentation of corn silage, which is relatively expensive, and makes the process unprofitable [22].

The course and efficiency of anaerobic degradation depends principally on the temperature of the process, which in turn relies on the presence of specific micro flora in animal waste. In most cases fermentation proceeds in the temperature range of 30 to 35°C, in the presence of mesophiles, and in temperatures of 50 to 55°C, in the presence of thermophiles. Anaerobic degradation at temperatures below 20°C or above 60°C results in lower methane output [26]. The results of anaerobic fermentation at these temperatures are shown in Tables 2 and 3.

Table 2

Methane accumulation from liquid pig manure under mesophilic conditions [26]

Fermentation time, months	Methane accumulation at various temperatures, mmol/l			
	6°C	10°C	20°C	28°C
1	Traces	Traces	0.5	3.0
3	Traces	6.0	11.0	52.0
9	2.9	11.8	46.3	Not detected
15	34.2	42.3	73.1	Not detected

Table 3

Methane and hydrogen production from liquid pig manure under thermophilic conditions [26]

Fermentation time, days	Temperature °C	Initial pH	Final pH	H_2, %	CH_4, %
2	40	6.6	5.6	0	20.6
2	55	6.6	6.0	0	4.0
2	73	6.6	6.1	3.27	6.1

Biogas obtained in the process of anaerobic fermentation is used as a source of thermal energy. An example of a plant for generating and processing thermal energy is shown in Figure 2 [27].

Biomass is supplied to the plant at a rate of 8 t/day, to provide 300 kW electrical power. Fermentation proceeds in a fermentation vessel, and the biogas obtained is transferred to a compensation tank, and therefrom to the combustion chamber of steam generator 7[I], from which the superheated steam flows to a steam turbine and exits in the form of steam and condensate transferred to the heat releasing section of the heat exchanger. Three-phase alternating current generator is driven by the shaft of the steam turbine, and the generated current is transmitted to the grid. Thermal energy is generated by means of intermediate carrier in the form of water, which is heated in the heat absorbing section of the heat exchanger, and then transferred to heat consuming devices 22. Water is circulated by a water pump and the circulation is based on forced convection. Any excess heat is absorbed by the device for compensating heat consumption variability. The heat consumers may include, for instance, a meat processing plant or a pig farm [27].

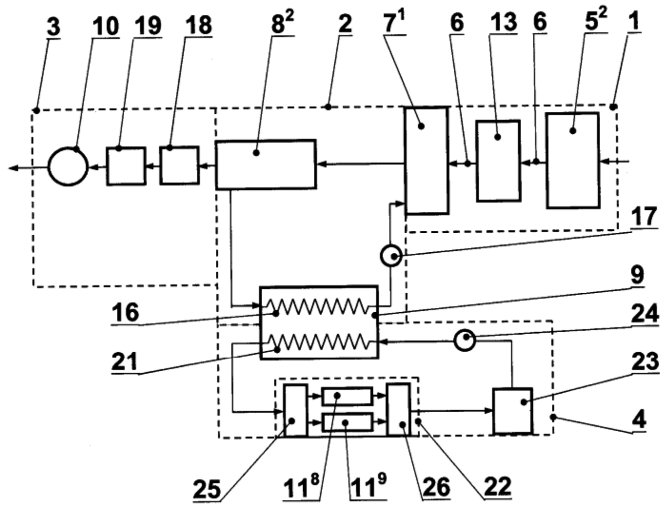

Fig. 2. Flow diagram of a plant for generating and processing thermal energy from liquid manure, agricultural waste and food processing waste [27]

1- system for producing intermediate energy carrier, 2 - intermediate energy carrier circulation system, 3 - electric power generating system, 4 - heat loop, 5^2 – fermentation vessel, 6 - gas pipe, 7^1 - high pressure steam boiler, 8^2 - steam turbine (apparatus for converting heat into mechanical energy),9 - heat exchanger, 10 - electric current generator, 11^8 - 11^9 - heat consuming units 8 - 9, 13 - compensation tank, 16 - heat releasing section of heat exchanger, 17 - water pump, 18 - coupling system, 19 – transmission, 21 - heat absorbing section of heat exchanger, 22 - heat consuming devices , 23 - device for compensating heat consumption variability, 24 - water pump, 25 - distribution device, 26 - collecting device.

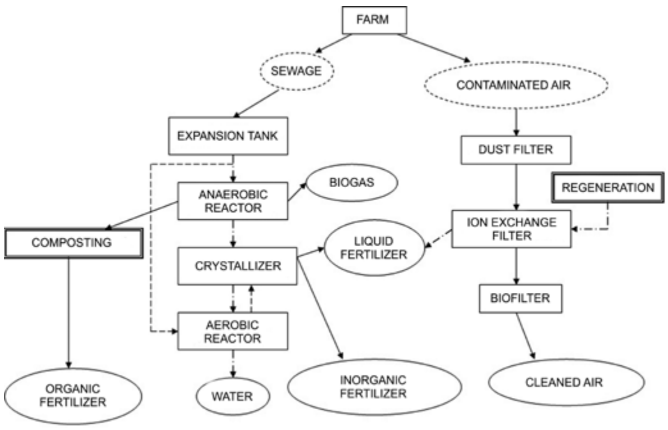

Fig. 3. Flow diagram of the integrated process of treating wastewater from animal farming [4]

Integrated treatment process for liquid manure from hog raising farms

Increased liquid manure production and its adverse effect on the environment compelled the development of the so-called integrated treatment of liquid waste from hog raising. It is based on the concurrence and confluence of specific processes: mechanical wastewater treatment, anaerobic fermentation, composting, chemical wastewater treatment, etc. A flow diagram of the process of treating wastewater from animal farming, inclusive of air and gas cleaning in dust filters, ion exchangers and bio-filters is shown in Figure 3.

Important stage of the process discussed is biological treatment of liquid manure, consisting in mesophilic or thermophilic digestion of wastewater under anaerobic conditions, carried out in appropriate bioreactors. At this stage the manure is also sequentially aerated in order to oxidize ammonia to nitrates, followed by reduction of the latter under anaerobic conditions to molecular nitrogen (denitrification). The sequential mode of nitrification eliminates emissions of methane and odours, and also excludes pathogenic substances and reduces biochemical oxygen demand (BOD). At this stage phosphorus is also reclaimed in the form of magnesium ammonium phosphate. It is obtained in the reaction of phosphate and ammonium ions with magnesium ions, fed to the crystallizer in the form of an oxide or inorganic salt. The thus obtained struvite can be used as a slow release fertilizer [4].

The process of treating manure also involves treatment and reduction of gas emissions, mainly by means of biofilterts, scrubbers, where absorption proceeds, and by ozonization or using chemical additives [4].

Integrated treatment process is also based on the manufacture of organic fertilizers and includes the step of ammonia nitrogen recovery by ion-exchange filtration. Ammonium ions are adsorbed on a zeolite bed, which is afterwards regenerated with sodium chloride solution or seawater yielding a solution of ammonium ions, which is concentrated by ammonia absorption. This way it is also possible to remove ammonia and amines from process solutions and gases [4].

Integrated manure treatment contributes to reduced soil and water contamination, and also to energy saving. It also enables isolation of valuable ingredients and in-situ application thereof or transportation over longer distances.

Summary

Pig manure is a raw material which, if treated inadequately, may pose a serious hazard to the environment, but it also constitutes a substrate for obtaining various products. In order to reduce the adverse effect of manure on soil and water, and also to increase its fertilizer effectiveness, it is processed into mineral/organic and organic fertilizers of various forms (liquid fertilizers, solid fertilizers, suspended or pelletized fertilizers). Liquid manure is also subjected to composting, in the course of which readily degradable compounds are converted into more stable and more useful aromatic substances.

Liquid manure, being a biomass, constitutes a raw material for generating biogas, which is a source of thermal energy convertible into mechanical energy. Although liquid manure is not highly efficient in anaerobic fermentation processes, its cost-effectiveness can be increased by blending it with a co-substrate, e.g. fruit waste.
Methane fermentation is generally carried out under mesophilic or thermophilic conditions. The process has low effectiveness at temperatures below 20°C and above 60°C, which to a large degree is due to the activity of specific micro flora, responsible for the course of fermentation. Anaerobic digestion processes depend on the type of substrates used and on the temperature of the process.

The developed integrated treatment of liquid waste from hog raising farms enables reducing the adverse effect of manure on the environment, increasing the efficiency of manure processing and saving energy by generating biogas.

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