LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
FACULTY OF TECHNOLOGY
BIOENERGY TECHNOLOGY

MASTER'S THESIS

THE CURRENT SITUATION OF SEWAGE SLUDGE AND MANURE TREATMENT IN LIVESTOCK ENTERPRISES IN THE LENINGRAD REGION

Examiners: Professor, Dr.Sc. (Tech.) Mika Horttanainen
M.Sc. (Tech.) Hanna Värri

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ABSTRACT

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Master's Thesis
2009
62 pages, 6 figures, 25 tables and 2 appendices
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Keywords: Livestock enterprises, manure, sewage sludge, treatment.

The problem concerning livestock waste handling in the Leningrad region has been subjected to a number of research works. However, the requirements for use of manure and sewage sludge as well as for treatment processes are not certain. So, this problem remains relevant and, therefore, further investigation ought to be made.

Currently a large amount of sewage sludge and manure is generated in the Leningrad region. These livestock wastes have to be obligatory treated. The most common methods for treatment in the region, such as anaerobic digestion, composting and aging as well as the most potential methods are described in the thesis. The most potential methods for the Leningrad region are anaerobic digestion, composting and combustion. Each method has strengths and weaknesses, which are also considered in the paper. Aging was not considered as potential treatment method because it does not meet the sanitary and epidemiological requirements. Furthermore, the work gives an overview and comparison of Finnish and Russian legislative and normative acts concerning livestock wastes handling. On the whole the requirements of the Russian Federation concerning sewage sludge and manure are not much different from the Finnish ones.

TIIVISTELMÄ

Lappeenrannan teknillinen yliopisto
Teknillinen tiedekunta
Bioenergiatekniikka

Yuliya Gaisina

Jätevesilietteen ja lannankäsittelyn nykytila Leningradin alueen karjatiloilla

Diplomityö
2009
62 sivua, 6 kuvaa, 25 taulukkoa ja 2 liitettä
Tarkastajat: Professori Mika Horttanainen
Diplomi-insinööri Hanna Värri

Hakusanat: Karjatila, lanta, jätevesiliete, käsittely.

Karjatilojen jätteiden käsittely Leningradin alueella on ollut usean tutkimuksen aiheena. Tästä huolimatta lannan ja jätevesilietteen käsittelyn edellytykset eivät ole täysin selvillä. Tämä ongelma on pysynyt merkityksellisenä ja siksi lisätutkimukset ovat aiheellisia.

Leningradin alueen karjatiloilla syntyy nykyään merkittävät määrät jätevesilietteitä ja lantaa. Näiden jätteiden käsitteleminen on pakollista. Tässä työssä on kuvatta alueella käytetyt tyypillisimmät menetelmät, kuten mädätys, kompostointi ja poltto. Jokaisella menetelmällä on omat vahvuutensa ja heikkoutensa, joita on käsitelty tässä työssä. Vanhentamista ei pidetä potentiaalisena käsittelymenetelmänä, koska se ei täytä hygieenisiä ja epidemiologisia vaatimuksia. Työssä on myös vertailtu yleisellä tasolla Suomen ja Venäjän Federaation maataloudessa syntyvien jätteiden käsittelyyn liittyviä lakeja ja normeja. Kokonaisuudessaan Venäjän Federaation lainsäädäntö ei eroa merkittävästi Suomen lainsäädännöstä.

ACKNOWLEDGEMENTS

This Master Thesis was carried out at Lappeenranta University of Technology.

I would like to thank the supervisors of my diploma Professor Mika Horttanainen and M.Sc. Hanna Värri for the possibility to work under your leadership, valuable suggestions and your scientific guidance.

I want to thank Professor Lev Isyanov from St. Petersburg State Technological University of Plant Polymers for his contribution to the work.

Furthermore, finally, I am feeling very gratitude for all moral supports from my family and my friends.

Lappeenranta, 2009
Yuliya Gaisina

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NOMENCLATURE

Abbreviations

AIC	Agricultural Industrial Complex
APC	Air Pollution Control
BFB	Bubbling Fluidized Bed
C/N Ratio	Carbon/Nitrogen Ratio
CFB	Circulating Fluidized Bed
CJSC	Closed Joint-Stock Company
DSTD	Departmental Standards for Technological Design
EC	European Community
FCCW	Federal Classification Catalog of Wastes
FZ	Federal Law
GOST	State Standard
HELCOM	Helsinki Commission
MPC	Maximum Permissible Concentration
OM	Organic Matter
OZ	Regional Law
ppm	Parts per million
PCDDs	Polychlorinated Dibenzo-p-Dioxin Compounds
PCDFs	Polychlorinated Dibenzo-Furan Compounds
RI	Research Institute
Rosselhoznadzor	Federal Service for Veterinary and Phytosanitary Supervision
SanPiN	Sanitary Regulations and Norms
SPb STUPP	Saint-Petersburg State Technological University of Plant Polymers
STD	Standards for Technological Design
TS	Total Solids
TU	Technical Requirements
VS	Volatile Solids

Symbols

B_o	Ultimate methane yield per day from 1 kg of organic matter	[m^3 CH_4/kg $_{org.\ matter}$]
C	Content of dry matter	[%]
$C_2H_4O_2$	Acetic acid	
$C_{57}H_{104}O_6$	Lipid	
$C_5H_7O_2N$	Protein	
$C_6H_{10}O_5$	Lignin	
CH_4	Methane	
CO	Carbon monoxide	
CO_2	Carbon dioxide	
C_Σ	Total output of dry matter	[kg/d]
F_{VS}	Fraction of volatile solids in the manure	[%]
G_{VS}	Standard value for the methane yield per mass of volatile solids in the manure	[m^3 CH_4/t $_{volatile\ solids}$]
H_2	Hydrogen	
H_2S	Hydrogen sulphide	
K	Kinetic coefficient	
NH_3	Ammonia	
NO_x	Nitrogen oxides	
Q_{manure}	Actual annual amount of manure	[$t_{dry\ matter}$ /a]
S	Content of organic matter	[%]
S_o	Input concentration of organic matter	[kg/m^3]
SO_x	Sulfur oxides	
T	Work temperature	[°C]
V_{biogas}	Yield of biogas	[m^3]
Vs	Yield of methane	[m^3 CH_4/m^3 $_{reactor}$]
W_{manure}	Volume of manure	[m^3/d]
Θ	Mean cell-residence time	[d]
ρ_{manure}	Density of manure	[kg/m^3]
μ_m	Maximum rate of microorganisms growth	[d^{-1}]

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1 INTRODUCTION

Currently in the Russian Federation much is done to preserve the environment. That is the introduction of innovative technologies in enterprises, reducing their adverse impact on the environment, programmes to reduce energy intensity of production, the emergence of new legislation to protect natural resources. There are international projects to protect the environment. But the current ecological situation is still complicated, especially in big cities and their suburbs. Because big cities, as a rule, are industrialized cities and the rapid development of industry, intensification of agriculture, improving the cultural and living conditions and other factors cause great harm to the environment (The Concept № 1663, 2008).

Most big Russian cities have problems associated with treatment of industrial emissions and wastewater, sludge treatment processes, waste recycling and reusing, etc. Treatment technologies of emissions and wastewater are imperfect and not competitive with up-to-date technologies; the majority of treatment facilities are out of date. Unfortunately, this is a typical phenomenon in many industries of big cities and their suburbs. Saint-Petersburg and the Leningrad region are not exceptions. Saint-Petersburg and the Leningrad region have combined sewerage system, which receives wastewater from households, industry, social and cultural establishments as well as rain, drainage water, and water from melted snow. The existence of the combined sewerage system also gives some difficulties for wastewater treatment. Sludge from the treatment plants contains a significant amount of heavy metals, so it cannot be reused or recycled (Alikbaeva, 2007).

One of the industries causing harm to the environment is agriculture, i.e. livestock enterprises (pig, cattle and poultry enterprises). In general, the situation we have is that the wastewater from the areas of livestock enterprises runs through the drainage channels into waterways without treatment, and concentrations of pollutants are reduced to acceptable values by mixing with natural waters. So, sometimes concentrations exceed maximum permissible concentration (MPC). There are also contaminant losses from facilities and pipelines (especially nitrogen and phosphorus) and accidental sewage discharges (Zhuravleva, telephone interview, 7 February, 2009).

All of this leads to the nutrient pollution or eutrophication of water bodies. Nitrogen and phosphorus are important natural nutrients; they do not have any direct hazards. Where eutrophication occurs aquatic ecosystems become burdened by excessively high nutrient inputs, which stimulates algal growth, and leads to imbalances in the ecosystems functioning.

In the Leningrad region the influence of the agriculture to the nutrient pollution of water bodies is redoubled because most enterprises are situated too close to the water bodies, especially to the Baltic Sea. Not only Russia but other countries cause nutrient pollution of the Baltic Sea. That is why eutrophication remains an issue of major concern almost everywhere around the Baltic Sea (HELCOM, 2006). There are also a number of other problems concerning manure treatment and storing in the agriculture. Therefore, it is very important to Russia and in this case to the Leningrad region to solve environmental problems, to learn the experience of other developed countries, such as Finland, Sweden and Estonia. Bearing in mind the crucial issues, mentioned above, the main task of the Master's thesis is to give an overview of livestock waste handling in the Leningrad region, find out problems and possible solutions for them. One issue is focusing to cattle and pig waste and leaving the poultry waste outside the frame.

2 SEWAGE SLUDGE AND MANURE PROPERTIES AND PRODUCTION

2.1 Sewage and Sewage Sludge of Livestock Enterprises

Participation of agriculture in biogenic pollution of water is continuously increasing, especially with the increasing of ploughing-up of the earth, the using of mineral and organic fertilizers, and construction of livestock farms. Surface and ground water is polluted through the drainage and surface runoff from agricultural areas. The greatest threat for water sources is caused by the livestock enterprises. Livestock enterprises during their work consume a certain amount of clean water and discharge treated or untreated sewage, which leads to surface water pollution. The main sources of pollution are:

- untreated or inadequately treated industrial and domestic wastewaters;
- surface effluents from livestock enterprises territory;
- leakage of hazardous substances from tanks, pipelines and other facilities;
- sewage discharges during the accidents;
- dry and liquid manure.

Together with rain and melting water nitrogen and phosphorus are washed into the natural water bodies, leading to eutrophication. Eutrophication of water bodies occurs when the concentration of phosphorus in the water exceeds 0.15 mg/l, and nitrogen – 2.2 mg/l (RIVM, 2005). Clean water contains hundredths-thousandths ppm of phosphorus. Decreasing of species diversity of aquatic organisms occurs in the eutrophication process. Research has shown that phosphorus and nitrogen cause the greatest contribution to the eutrophication process. Other factors are organic carbon, microelements, vitamins, etc.

Manufacturing wastewaters of livestock enterprises include effluents from milking departments, boiler rooms, etc. Domestic wastewaters are effluents of administrative buildings. Surface effluents are divided into rain and melting waters. Wastewaters, mentioned above, contain contaminants which can be divided into mineral, organic and biological types. Mineral contaminants include sand, cement, solutions of mineral salts, acids, alkalis, etc. Organic contaminants include forage remains, litter, excrements, animal hair, etc. As a result of manure infection of various bacteria, viruses, eggs of helminths, etc., wastewaters are exposed to biological contamination. The sludge is formed in the settling tanks during the wastewater treatment process. Characteristics of sludge are shown in Table 1.

Table 1. Characteristics of livestock enterprises sewage sludge. (Sidorenko, 2001)

Content of organic matter, %	Water content, %	Content of ash-free substances, %	Ash content, %	Content of total nitrogen, %
50-70	95-97.5	67-77	20-30	2.5-3.6

2.2 Manure of Livestock Enterprises

2.2.1 Cattle Enterprises

Cattle enterprises in Russia can be divided to dairy and fattening ones. Depending on the cattle stock, they divide to farms (less than 50000 animal units) and complexes (above 50000 animal units). The area to accommodate the farms and complexes is chosen according to the Construction Regulations and Rules "The general plans of agricultural enterprises ". Farms and complexes are closed enterprises. They must be protected and separated from the nearest residential area by sanitary protection zone. Complexes and farms are mostly located in rural less populated areas. When choosing a site for construction of livestock enterprises the possibility of recycling manure and other industrial effluents must be taken into account (STD 1-99, 1999).

Cattle manure is a complex multi-colloid semi-dispersed medium, consisting of the components of organic and mineral origin, water, salts, gases, microorganisms and animal hair. Formation, composition and properties of cattle housing have some features. Depending on the animal housing technology, diets and manure removal technology there can be litter, semi-liquid, liquid manure and manure wastewater.

Litter manure consists of a mixture of excrement, urine and litter material. Moisture of the manure, depending on the quantity and type of litter is 85% or less. Litter has a direct influence on the manure properties as fertilizer. The cutting straw is mostly used for bedding, as it absorbs liquid manure well and ensures uniform moistening of the manure. Housing of animals with litter is mainly used in the cattle enterprises. Chemical composition of fresh litter cattle manure is presented in Table 2.

Table 2. Chemical composition of fresh litter cattle manure. (Brockhaus & Efron, 1998; Järvinen et al., 2006)

With natural moisture content						Moisture, %	pH	C/N ratio
Organic matter,%	**Ash, %**	**Total content of nitrogen,%**	**Ammonia nitrogen,%**	**P_2O_5, %**	**K_2O, %**			
15.1-21.0	4.0-6.9	2.5-3.5	0.05-0.09	0.28-0.33	0.50-1.80	65-75	7.8-8.4	16-19

In terms of the fertilizer elements content and the degree of danger to the environment there should be distinguished fresh and decomposed manure. Averaged content of fertilizer substances in fresh manure is given in Table 3. Changes of the manure, depending on the degree of decomposition, are also represented in Table 3.

Table 3. Averaged content of fertilizer substances in fresh manure. (Bezuglova, 2003)

The degree of decomposition	Indicators of the manure quality, %		
	Nitrogen	**Phosphorus**	**Mass loss**
Fresh	0.52	0.31	–
Semi-decomposed	0.60	0.38	29
Decomposed	0.66	0.43	47.2
Humus	0.73	0.48	62.4

Operating properties of manure depend on the timing and manner of storage. Depending on the degree of decomposition should be distinguished fresh, semi-decomposed (dark-brown straw), decomposed manure (straw is completely decomposed, the manure has the form of black greased mass) and humus (mellow earthy mass). The higher the degree of decomposition of manure is, the greater the percentage of nitrogen, phosphorus, potassium and other nutrients is. Fresh manure is becoming semi-decomposed in 3-5 months. As can be seen from Table 3, the highest fertilizer properties have decomposed manure and humus.

However, it is more efficient to use semi-decomposed manure, which retains nitrogen better, particularly ammonia nitrogen, and contains more organic matter than the well-decomposed manure. Fresh manure is desirable to use neither on the fertilizer properties, nor on sanitary-biological indicators. This is reflected in the classification of different types of manure from the cattle according to the degree of the danger to the environment. There is the Federal Classification Catalog of Wastes (FCCW) in Russia and five degrees of danger for wastes in it. I degree means especially dangerous waste; II degree is really dangerous waste; III – moderately dangerous; IV – low dangerous; V – non-dangerous waste. According to the FCCW fresh cattle manure has IV degree of danger, decomposed manure – V (FCCW, 2002).

Manure may be without litter material (non-litter manure). In this case manure is divided to liquid, semi-liquid and manure wastewater. Semi-liquid manure is a mixture of excrement, urine, forage remains and production water and has moisture less than 92%. Liquid manure is a mixture of excrement, a certain amount of water, forage remains and other inclusions and has moisture 92-97 %. When water washout is used at enterprises, manure has the form of a mixture of excrement, forage remains, production water and large quantities of dilution water, moisture – 97 % and above (manure waste water).

Litter manure is used as organic fertilizer. It has positive effects on physical, physico-chemical and biological properties of soil. Liquid manure can be applied in following ways: on the field surface, subsoil application, and watering. The most efficient and environmentally safe way is subsoil application. It reduces nutrients loss, e.g. nitrogen. Semi-liquid manure can be used for composting or for surface application. Manure wastewater is directed to crop irrigation. With the right selection of doses and timing, they lead to increasing of humus content and total nitrogen in the soil, reducing of the exchange and hydrolytic acidity, decreases content of aluminum and manganese mobile forms in the soil and increases the degree of base saturation. Above all, during the fertilizing of the soil with manure, the plants get potassium nutrition. The most rational application of manure is using it with other mineral fertilizers. But it is prohibited to apply liquid fertilizers in water protection zones, such as fish breeding ponds, etc. (Brockhaus & Efron, 1998; Järvinen et al., 2006).

2.2.2 Pig Enterprises

Depending on the type of products there are following pig enterprises in Russia: enterprises with a complete production cycle (reproducing, growing and fattening of pigs), reproductive (enterprises are intended for reproduction and rearing of pigs with subsequent selling) and fattening enterprises (pigs fattening on meat). Pig enterprises like cattle enterprises are divided to farms (less than 50000 animal units) and complexes (above 50000 animal units). The area to accommodate the farms and complexes should be chosen according to the Construction Regulations and Rules "The general plans of agricultural enterprises". They are closed enterprises and must be protected and separated from the nearest residential area by sanitary protection zone and must have the possibility of recycling manure and other industrial effluents (DSTD 2-98, 1998).

Pig manure is a mixture of different substances: excrement, urine, forage remains, animal hair, various disinfectants and other components. Litter manure also includes litter material. Chemical composition of fresh litter pig manure is shown in Table 4 and characteristics of pig manure – in Table 5.

Table 4. Chemical composition of fresh litter pig manure. (Brockhaus & Efron, 1998; Isyanov, 2007)

With natural moisture content					C/N ratio
Content of organic matter,%	Total content of nitrogen,%	Ammonia nitrogen,%	P_2O_5, %	K_2O, %	
17.8-20.9	0.70-0.90	0.15-0.17	0.38-0.40	0.62-0.90	11-14

Table 5. Characteristics of pig manure. (Brockhaus & Efron, 1998; Järvinen et al., 2006)

Manure humidity, %	Ash content, %	pH
70-80	2.0-3.0	5.2-8.3

Indicators of the liquid manure, which characterize its structural and mechanical properties, are determined by viscosity and fluidity. Pig manure with the same quantity of dry matter is more liquid than cattle manure. At the pig enterprises animals are mainly housed without litter. The chemical composition of manure depends on the diets, gender and age of pigs, feeding technology, breed features and other conditions. In general, the pig manure is no less valuable than the cattle manure. The main mass of organic substances contained in the excrement is presented by carbohydrates, cellulose, proteins and fats. In pig excrement protein represents as an undigested portion of the albumen contained in the forage in the mixture with the endogenous secretions of digestive glands. It also contains a large amount of cellulose components, pentose and starch, various micro-elements.

Excrements also contain biogenic elements. The quantity of these substances depends on the type of forage, content of nutrients, species and productivity of animals. For example, the concentration of potassium in the pig manure with the potato forage is 1.5-2 times higher; content of nitrogen and phosphorus is lower by 15-20% compared to the grain forage. Nitrogen in manure is represented by 50-70% by ammonia and ammonium carbonate, and nitrate form. The nitrogen compounds, such as nitrates and nitrites, may have the negative impact on the environment (Brockhaus & Efron, 1998; Järvinen et al., 2006). It was ascertained that liquid pig manure is the most dangerous animal waste, because it is resulting in infectious and invasive illnesses, especially with the increasing of moisture. Among the impurities of the pig manure it is necessary to note eggs of helminths and pathogenic microflora in spore form. They determine the environmental danger and their content is higher than in cattle manure. The degree of danger to the environment is different for fresh and decomposed manure. According to the FCCW fresh pig manure has the III degree of danger, decomposed manure – IV (FCCW, 2002).

Poultry enterprises are not considered in this Master's thesis because of significant differences in enterprise's structure, housing of animals, waste composition, and treatment technologies of wastes with cattle and pig enterprises. Therefore, problem of wastes of poultry enterprises should be subjected to other research work.

3 SEWAGE SLUDGE AND MANURE TREATMENT TECHNOLOGIES

Manure and sewage sludge from livestock enterprises are a threat to the environment, therefore, they must be obligatory treated and disinfected. For treatment of manure and sewage sludge, the following methods can be used: biological, physical and chemical. Methods also should be divided into pretreatment and treatment methods. The most common used methods are anaerobic digestion, composting and combustion. Figure 1 illustrates the methods structure.

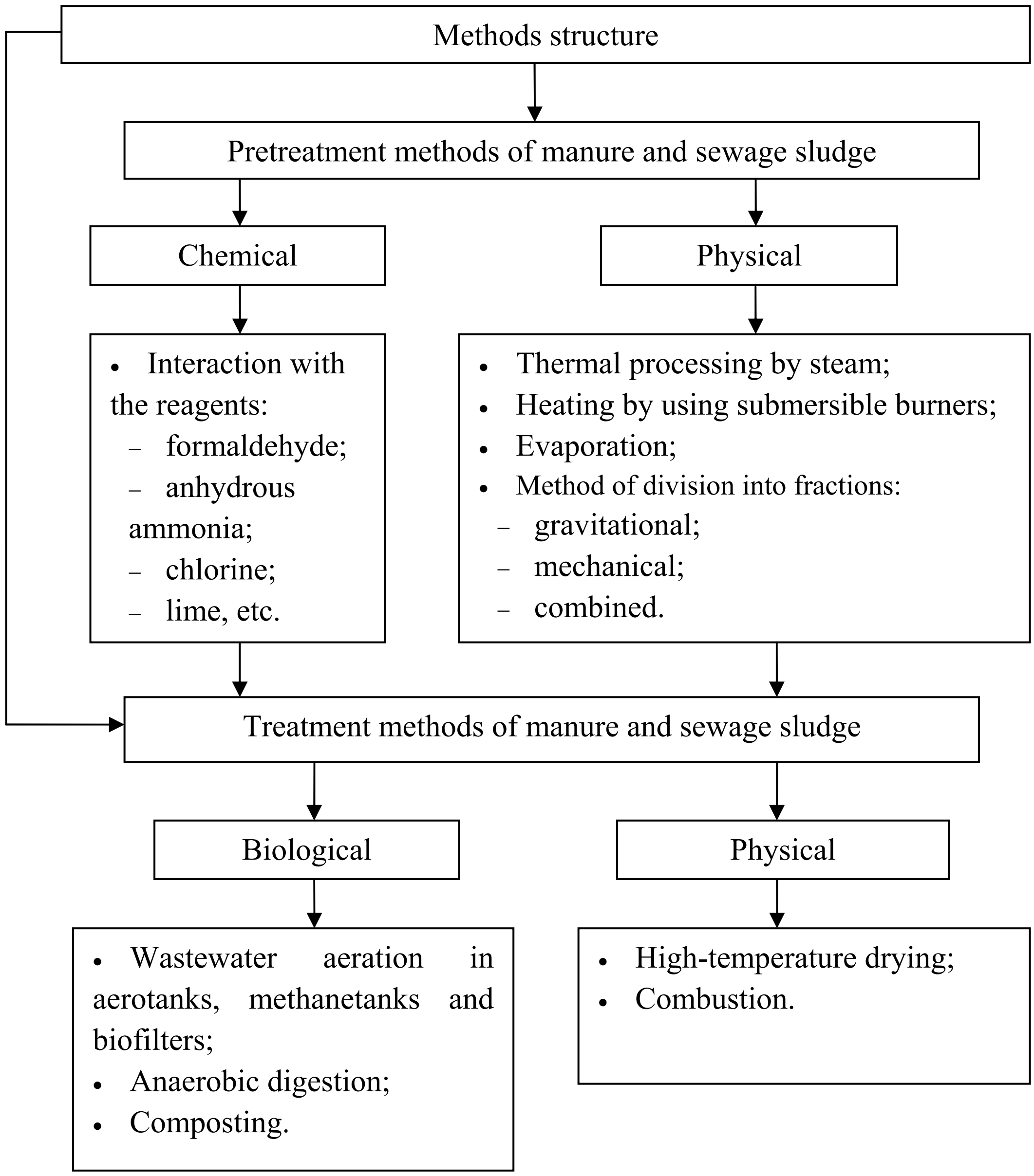
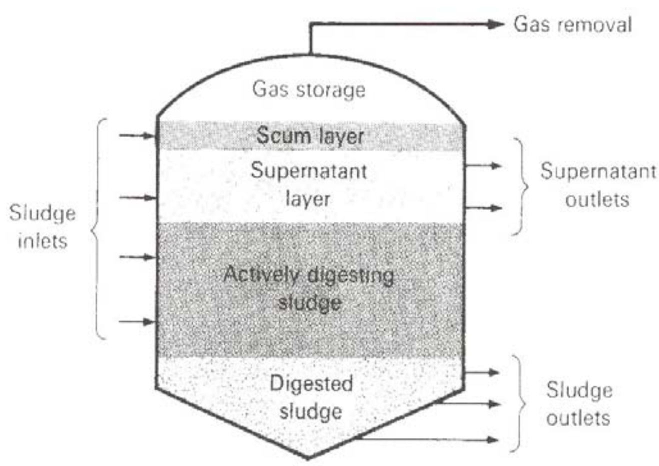


Figure 1. Treatment methods structure of manure and sewage sludge. (Ovtsov, 2002)

3.1 Anaerobic Digestion

One of the methods of biological treatment of livestock enterprises manure and sewage sludge is anaerobic digestion in biogas plants for the purpose of biogas obtaining. Anaerobic digestion is the process used for the stabilization of sludge. It can be applied for sludge from settling tanks and non-litter manure. The process includes the decomposition of organic matter in the absence of molecular oxygen. During the anaerobic digestion process, the sludge from settling tanks and non-litter manure in the mixture of manure wastewater is decomposed biologically, under anaerobic conditions, mainly to methane (CH_4) and carbon dioxide (CO_2). The mixture of CH_4 and CO_2 is called biogas. The process must be carried out in an airtight reactor. The stabilized sludge after anaerobic digestion has reduced content of pathogens and organics and also it becomes nonputrescible.

There are two types of most common anaerobic digesters: standard-rate and high-rate. Figure 2 depicts schemes of anaerobic digesters. The required detention time for standard-rate process varies from 30 to 60 days, for the high-rate digestion – from 5 to 20 days (Tchobanoglous, 1991). The detention time for anaerobic digestion process depends also on the kind of material, charge doze, operation mode, operation rate, and maximum level of organic matter decomposition.



(a)

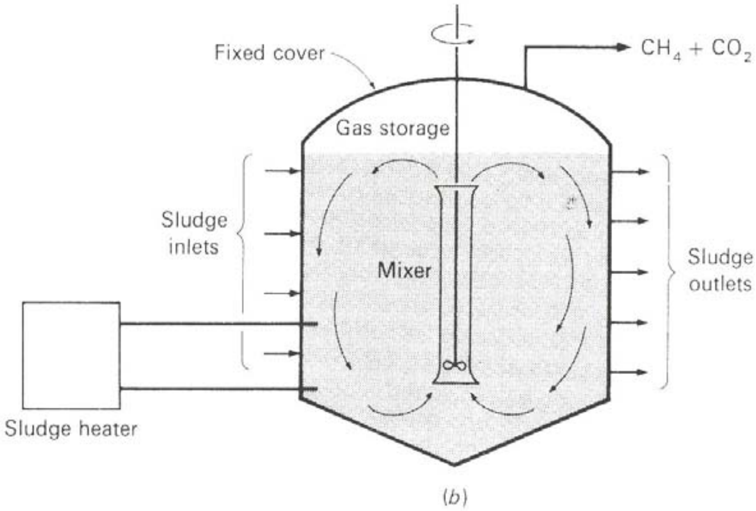


Figure 2. Typical anaerobic digesters: (a) conventional standard-rate single-stage process, (b) high-rate, complete-mix, single-stage process. (Tchobanoglous, 1991)

The biological conversion of organic matter is carried out in three steps. The first step of the process is hydrolysis of higher-molecular-mass compounds into more simple compounds (such as ammonia, hydrogen sulphide, etc.). The second step (acidogenesis) involves the bacterial conversion of compounds resulting from the first step into lower-molecular-mass compounds (hydrogen, hydrocarbon, acetate, etc.). The third step (methanogenesis) involves the bacterial conversion of intermediate compounds from the second step into simpler end products, principally methane and carbon dioxide. The conversion of organic matter occurs thanks to anaerobic micro-organisms. These micro-organisms are divided into two groups: acid formers and methane formers. Acid formers are anaerobic bacteria, which hydrolyze organic matter to acids and alcohols. Acid formers are Lactobacillus, Actinomyces, Staphylococcus, Escherichia, etc. The methane formers convert acids and alcohols to methane and carbon dioxide. The methane formers are Methanococcus, Methanosarcina, Methanobacillus, etc. (Tchobanoglous, Theisen & Vigil, 1993).

Micro-organisms carry out methane formation by the following scheme:

$$C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3COOH + 4H_2 + 2CO_2$$

$$4H_2 + 2CO_2 \rightarrow CH_4 + CO_2 + 2H_2O$$

$$2CH_3COOH \rightarrow 2CH_4 + 2CO_2$$

$$C_6H_{12}O_6 \rightarrow 3CH_4 + 3CO_2$$

Anaerobic digestion of organic matter may take place in the following modes:

- mesophilic mode with a temperature range of 33 to 38 °C;
- thermophilic mode with a temperature range of 53 to 55 °C.

The requirements of anaerobic digestion process are as follows:

The initial mass should be:

- freshly mixed;
- homogeneous in composition;
- uniform in terms of solid and suspended particles concentration.

The initial mass should have:

- optimum parameters:
  - ✓ moisture content – 90 to 92 %;
  - ✓ pH – 6.9 to 8;
  - ✓ fat acids content – 600 to 1500 mg/l;
  - ✓ alkalinity – 1500 to 3000 mg/l of $CaCO_3$;
  - ✓ C/N ratio – 10 to 16;
- maximal content of organic matter;
- optimal temperature.

The initial mass should not contain:

- inclusions above 30 mm;
- solid particles, the density of which essentially exceeds that of a liquid (concrete, clay, sand, and other extraneous inclusions);
- substances which inhibit methane-producing microorganisms above permissible concentrations (ammonia nitrogen, heavy metals, alkaline, alkaline-earth metals, sulfides, oxygen, etc.) (Järvinen et al., 2006).

Anaerobic digestion can be also applied for dry manure with total solids (TS) content of about 22 percent or higher. This technology is relatively new and has not been developed fully. This process like process for sludge from settling tanks and non-litter manure has three steps. The different is at the end of process – digested sludge requires less effort for dewatering and disposing. The process microbiology is the same as for anaerobic digestion for sludge from settling tanks and non-litter manure (Tchobanoglous, Theisen & Vigil, 1993).

The final product of the process (biogas) has the following parameters: calorific efficiency is about 20 to 28 MJ/m^3, CH_4 content – 65 to 70 %, CO_2 – 25 to 30 %, biogas also contain traces of other gases, such as hydrogen sulphide (H_2S), ammonia (NH_3), hydrogen (H_2) and carbon monoxide (CO). This gas can be used to heat the digester itself or to produce electricity for internal use. Also it can be used to heat other processes, buildings or to produce electricity for other users if the process is effective (Järvinen et al., 2006). Table 6 lists the typical amounts of biogas generated from different types of manure (Scherbo, 2008; Koottatep, S. et al., 2008).

Table 6. The typical amounts of biogas generated from different types of manure. (Scherbo, 2008; Koottatep, S. et al., 2008).

Type of manure	Amount of biogas, l/kg $_{manure}$
Cattle manure	90-340
Pig manure	340-580

Manure digested in the methane tank is settled, and clarified effluent is used for field irrigation, and sediment is used for feed additives production. The anaerobic digestion process remains the composition of the product, while raising its fertilizer properties. Table 7 represents the main properties of the digested sludges.

Table 7. The main properties of the digested sludges. (Russell, 2009; Muchovej, Obreza, 2004)

Moisture content, %	Organic matter from TS, %	Inorganic matter, %	Nitrogen content, %	Phosphorus content, %	Potassium content, %
81-98	35-40	60-65	2.5-5.6	1-2.2	about 0.2

3.2 Composting

Process in which organic material, under aerobic conditions, is decomposed biologically to a stable end product is called composting. Composting can be used for both manure and sewage sludge. After composting manure and sewage sludge are become sanitary, nuisance-free, humus-like material known as compost. As organic matter in the manure and sewage sludge decomposes, the compost heats to temperatures in the pasteurization range of 50 to 70 °C, and enteric pathogenic organisms are destroyed.

The composting process involves distraction of organic matter and production of humic acid to produce a stabilized end product. During the process three major categories of microorganisms are active: bacteria, actinomycetes, and fungi. In the beginning of the process, mesophilic bacteria are prevailing. After the temperatures in the compost increase, the thermophilic bacteria become predominate, leading to thermophilic fungi. They appear after 5 to 10 days. In the final stages of the composting process, actinomycetes appear.

Thus, there are three stages of activity during the composting process: mesophilic, thermophilic, and cooling. Each stage has associated temperature. In the mesophilic stage, the temperature in the compost increases from ambient to approximately 40 °C, in the thermophilic stage temperatures range from 40 to 70 °C. The maximum degradation and stabilization of organic matter occurs in the thermophilic stage. Reduction in microbial activity is taken place in the cooling stage. During this stage thermophilic microorganisms replace with mesophilic ones. This stage is also characterized by water evaporation from the composed material, stabilization of pH and completion of humic acid formation. Most of the composting processes consist of the following major steps: (1) mixing dewatered sludge with special amendment agent and bulking agent (in some cases); (2) aerating the compost pile by using addition of air or mechanical turning (or both); (3) recovery of the bulking agent (if it is possible); (4) further curing and storage; (5) final disposal or using (Tchobanoglous, Theisen & Vigil, 1993; Tchobanoglous, 1991).

To the feed substrate, such as sawdust, recycled compost, straw, and rice hulls, an organic material is added; this material is called an amendment. It is used to reduce the bulk weight and increase the air voids for proper aeration and the quantity of degradable organic matter in the mixture. A bulking agent is used to increase the porosity of the mixture for effective aeration, and also to provide structural support. It can be both organic and inorganic material. The most common used bulking agents are wood chips, because they can be recovered and reused. Aeration is necessary both to supply oxygen and to remove excess moisture and control the composting temperature. There are three systems used for the composting: windrow, aerated static pile, and in-vessel. These systems are shown in Figure 3.

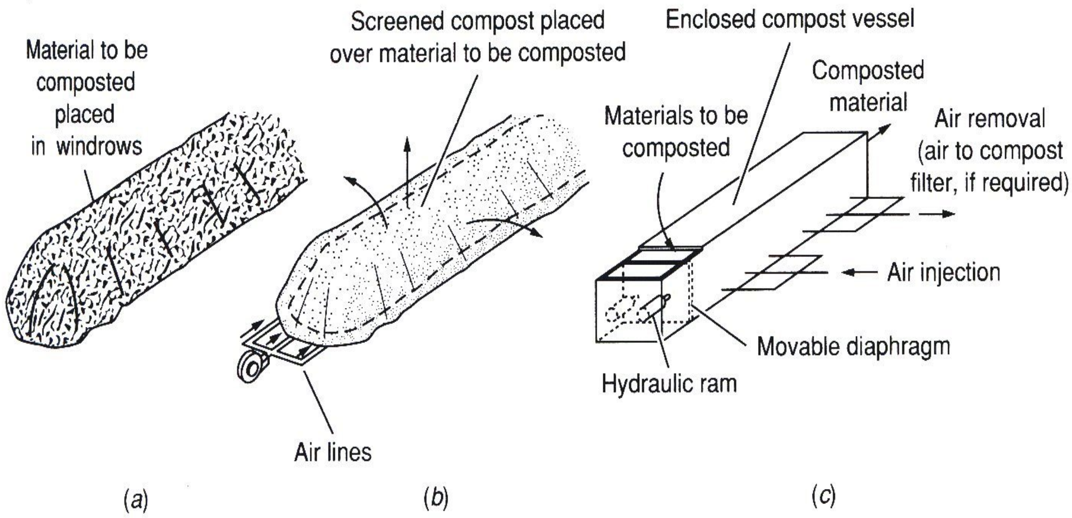


Figure 3. Schemes of composting systems: (a) windrow, (b) aerated static pile and (c) in-vessel composting system. (Tchobanoglous, Theisen & Vigil, 1993).

Aerated Static Pile. The aerated static pile system consists of a grid of aeration or exhaust piping. A mixture of dewatered sludge and bulking agent is located there. The typical bulking agent for the aerated static pile system consists of wood chips which are mixed with the dewatered sludge. Mixing occurs by using a pug mill type or rotating drum mixer or by movable equipment such as a front-end loader. The detention time for this system is 21 to 28 days, after that compost should be cured for another 30 days or longer. Typical pile height is approximately 2-2.5 m. Disposable corrugated plastic drainage pipe is usually used in the aerated static pile systems for air supply. It is recommended to have an individual blower in each individual pile for more effective aeration control. Screening of the compost is used to reduce the quantity of the end product and to recover the bulking agent.

Windrow. The mixing and screening operations in a windrow system are similar to operations of the aerated static pile system. Windrows are usually constructed from 1 to 2 m high and 2 to 4.3 m at the base. During the composting period the rows should be turned and mixed periodically. In some cases additional mechanical aeration is applied. The windrows must be turned a minimum of five times while the temperature is at or above 55 °C. The detention time of material in this system is about 21 to 28 days.

In-vessel Composting System. In-vessel composting is carried out inside an enclosed container or vessel. Such systems allow to reduce odors and process time by controlling conditions such as temperature, air flow, and oxygen concentration. In-vessel composting systems can be divided into two types: plug flow and dynamic (agitated bed). Plug flow system operates on a first-in, first-out principle; the composting material stays the same throughout the process. In dynamic system the material is mechanically mixed during the composting (Tchobanoglous, Theisen & Vigil, 1993; Tchobanoglous, 1991).

One of the varieties of composting is vermicomposting. Vermicomposting is a biotechnological method which consists of the processing of organic waste by using rainwater, California and other ringed worms. This method can be applied for livestock wastes such as manure, sewage and sewage sludge. In the case of sewage straw or wood chips should be added. Vermicomposting process is used to produce high-quality fertilizer with high content of humus matter. The basic operation in vermicomposting is preparation of substrate. This operation includes conditioning of manure to 75-78 % moisture content with subsequent fermentation to transform ammonia nitrogen into nitrate forms(Järvinen et al., 2006). Parameters of substrate for vermicomposting are listed in Table 8.

Table 8. Parameters of a substrate for vermicomposting. (Järvinen et al., 2006)

Moisture content, %	**pH**	**C/N ratio**	**Mineral matter content, %**	**Crude protein content, %**
70-75	6.5-7.5	20 : 1	up to 10	no more than 25

Vermicomposting of such substrate may be carried out during the whole year in closed heated rooms on racks and on floor beds. The height of the substrate layer should be up to 0.3 m. The width of the racks and floor beds should be up to 1.2 m, the length is not strictly specified. Vermicomposting may be organized on open grounds in beds, but only in the warm season, when the ambient air temperature is above 10 °C. The vermicomposting facilities output for the indoor and outdoor production is different. It is correspondingly: in terms of initial substrate of 1.5 and 0.7 t/m^2, ready biohumus – 0.7 and 0.33 t/m^2, biomass of vermiculture – 22 and 10.5 kg/m^2 per year. The end product of the vermicomposting process is biohumus. Average biohumus parameters (from the weight of absolutely dry matter) are presented in Table 9.

Table 9. Average biohumus parameters. (Järvinen et al., 2006)

Moisture content, %	pH	Total nitrogen, %	P_2O_5, %	Humus content, %
70	7.5	1.0-1.5	1.0-1.3	up to 12

3.3 Combustion

Combustion is one of the methods of thermal processing of wastes. Combustion of wastes is the chemical reaction of oxygen with organic materials. During combustion oxidized compounds are produced, and the process is accompanied by the emission of light and rapid generation of heat. Final products are hot combustion gases and noncombustible residue (ash). Combustion gases consist mainly of nitrogen, carbon dioxide, oxygen, and water vapor (flue gases). Small amounts of sulfur dioxide, nitrogen oxides, ammonia, and other trace gases are also present. In the presence of excess air, the combustion of organic waste can be represented by the following equation:

organic matter + air → $N_2 + CO_2 + H_2O + O_2$ + ash + heat

Excess air is needed to provide the complete combustion. Energy can be recovered from the hot combustion gases by using heat exchanger. There are following types of combustion systems:

- grate firing systems;
- fluidized bed systems:
  - bubbling fluidized bed (BFB);
  - circulating fluidized bed (CFB) (Horttanainen, Värri, 2008).

Grate incinerators. There are different designs for the grates used in waste incineration. Grate systems are used to transport the waste through the furnace and to promote combustion by agitation and mixing with combustion air. The grate with wastes passes through the drying stage where the most volatile compounds are burnt. The wastes move further, down the grate and continue to burn slowly until getting the burnout stage before the discharging of ash. Ash temperatures can limit the operation of grate systems. If the temperature is high enough for the ash melting and slag forming, the slug reduces the air supply because it blocks up the grates. Air injection above the grates is applied to provide enough air for combusting of flue gas and the particulate material it contains. At the same time air injection provides the cooling of the metal portions of the grate to protect them from oxidation and heat damage. Average heat release rate range from 13,500 to 16,000 kcal/h/m^2. Some of the most common grates systems used in waste incineration are:

1. *Roller systems.* These systems consist of drums placed to form an inclined surface. The drums rotate slowly in the direction of the waste movement.
2. *Reciprocating systems.* The grates are placed above each other and alternated grate section slide back and forward while the adjacent sections remain in place.
3. *Reverse reciprocating.* The grates move forward and then reverse direction.
4. *Continuous.* Two sections are placed in cascade. This process is chip and reliable, but there is no agitation of the waste in it, and it needs large amounts of air, which in turn produces large amounts of flue gas.
5. *Rocking grates.* The grates are disposed across the width of the furnace. Alternate rows of grates are rocked to produce an upward-forward motion. This motion agitates and moves the waste forward through the incinerator (McDougall, White, Franke., 2001; Tchobanoglous, Theisen & Vigil, 1993). Reciprocating grate system is shown in Figure 4.

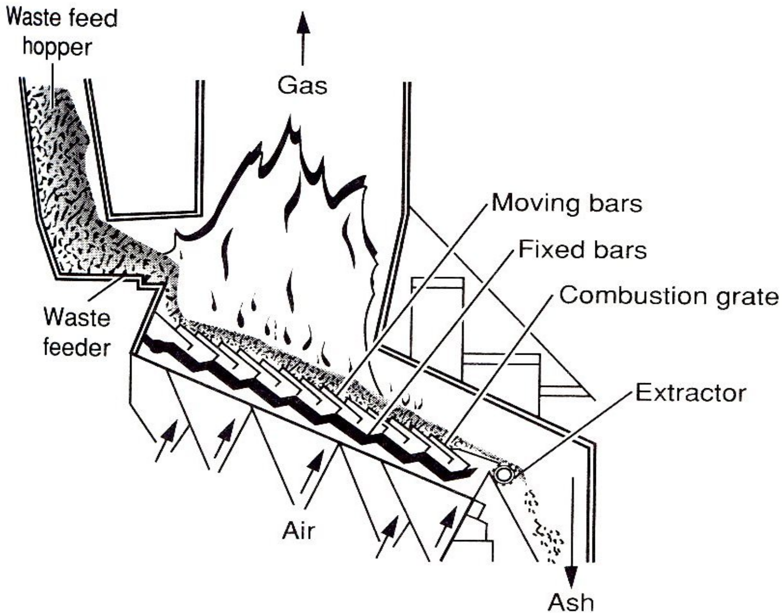


Figure 4. Reciprocating grate system. (Tchobanoglous, Theisen & Vigil, 1993)

Bubbling fluidized bed. The fluidized bed furnace is a simple combustor. It is usually applied in sludge incineration. The conventional BFB sludge incinerator represents a vertical, cylindrically shaped vessel. Vessel is made from refractory-lined steel with a perforated grid in the lower section supporting a bed of sand. The depth of the static bed is usually 0.9-1.2 m and rest is a brick dome or refractory-lined grid. The sand bed support area contains tuyeres. Tuyeres are the orifices through which air is injected to the incinerator at pressure of 20 to 35 kN/m^2 to fluidize the bed. The bed material can be sand or limestone. The incinerator ranges in size from 2.7 to 7.6 m in diameter. Heat release rates in the bed range from 900,000 to 1,800,000 kcal/hr/m^2. The BFB incinerator can be applied to the drying and combustion of variety of wastes. Figure 5 illustrates the typical BFB incinerator (Tchobanoglous, Theisen & Vigil, 1993).

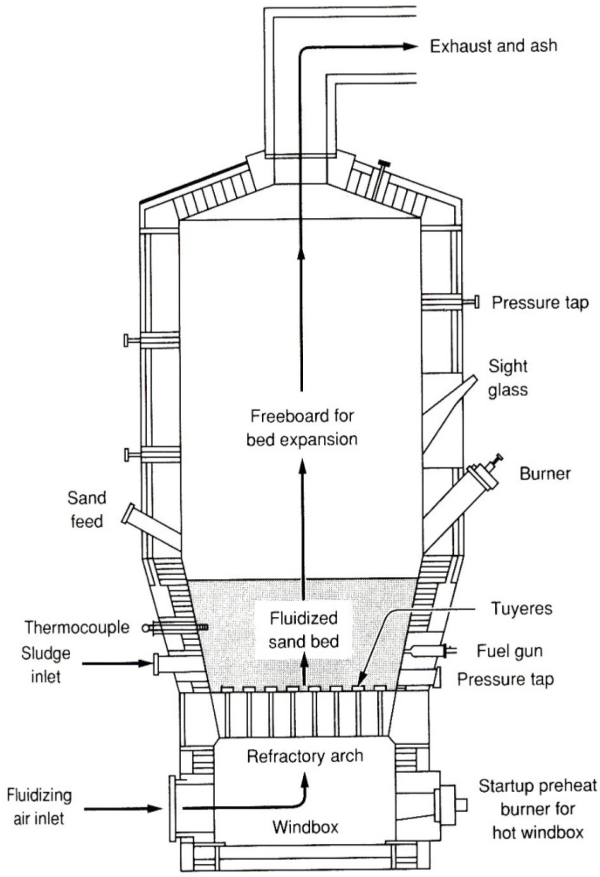


Figure 5. Typical Bubbling fluidized bed incinerator. (Tchobanoglous, 1991)

The principle of work of this system is following: air at high pressure is forced through a bed of sand; the sand particles become suspended in the rising gas and take on the behavior of a turbulent liquid: bubbling and flowing. The gas rising through the bed represents clearly defined gas bubbles. The fluidized bed behaves like ordinary liquid. The average gas velocity is 0.7-1.0 m/s. At active and operating temperatures the mass of suspended particles and gas expands approximately in two times the at-rest volume. Sludge is mixed quickly within the fluidized bed by the turbulent action of the bed. Evaporation of the water and combustion of the sludge also occurs rapidly. The minimum temperature needed in the sand bed before the injection of sludge is approximately 700 °C. Temperatures throughout the bed volume maintain uniform. Gas temperatures vary less than 5 to 8 °C. The temperature of the sand bed is controlled between 760 to 820 °C.

There is a large, cylindrical disengaging space (freeboard) above the fluid bed. The freeboard is provided about 3-4 seconds of residence time for final burnout of particles (combustible material). Operation temperatures of freeboard are the same with the bed temperatures or slightly above. The divided ash is swept out of the bed and collected in air pollution control (APC) system (e.g. scrubber). Coarse or heavy particles remain in the bed. The sand grains have the scrubbing action. They abrade sludge cake introduced into the hot bed. The sludge particles rapidly dry and then burn, and release most of their fuel value in the bed.

The sand in the bed is in a state of turbulent recirculating motion that maintains uniformity of temperature and gas composition in the bed. The protection against rapid fluctuations in temperature if the feed rate or net heating value changes is provided by the large mass of the sand, heated to bed temperature which is called thermal flywheel effect. When grains of hot sand strike the incoming sludge surface, a quantity of water is flashed out. The surface is rapidly dried and abraded that prevents layer of ash developing (Tchobanoglous, 1991).

Circulating fluidized bed. The CFB incinerator is a next-generation incinerator. It can effectively satisfy the diverse demands made of sludge incineration. For example, it can accommodate variety of sludge properties, and load changes, and incinerate sludge mixed with other waste materials. The CFB incinerator consists of the combustion chamber (riser), APC system (e.g. cyclone) that separates the sand discharged to outside the incinerator from the combustion gas, and a downcomer that returns the separated sand to the riser. The temperature inside the incinerator is uniform and, hence, stable combustion can be achieved for a wide range of sludge properties. The CFB incinerator operates with slightly higher temperatures ranged from 760 to 870 °C. Velocity range allows to maximize the relative speed of gas and particles, thus maximizing their contact efficiency and, hence, high-intensity combustion is possible. It also allows reducing incinerator size, saving of space.

In the circulating bed incinerator, the reactor gas passes through the combustion chamber at velocities, ranging from 5 to 10 m/sec. Thus, the velocities of circulating fluidized bed are high enough to move solid particles to the off-gases. At these velocities, the bubbles in the fluidized bed disappear and streamers of solid particles and gas prevail. The whole mass of entrained particles flow up the reactor shaft to a particle separator in a several seconds, and are returned back to the primary combustion zone which is in the bottom of the reactor. There is a dense region near the base and gradient in solid particles concentration falling smoothly from the bottom of the top of the vessel in the CFB incinerator. In-bed tubes are not feasible in CFB systems because of the high velocities (Tchobanoglous, Theisen & Vigil, 1993; Tchobanoglous, 1991).

Heat release in these systems is often from 60,000 to 70,000 kcal/hr/m^2. Membrane "water walls" are used for heat removal. CFBs are usually tall and thin. Heat transfer rates to the wall are approximately 170-215 kcal/hr/m^2°C. Additional heat removal surface is often achieved by inserting vertical membrane wall panels into the riser chamber. These panels are called "wing walls". Ash is removed continuously from the bottom of the bed. On turndown, the circulating bed becomes a bubbling bed. This system is shown in Figure 6.

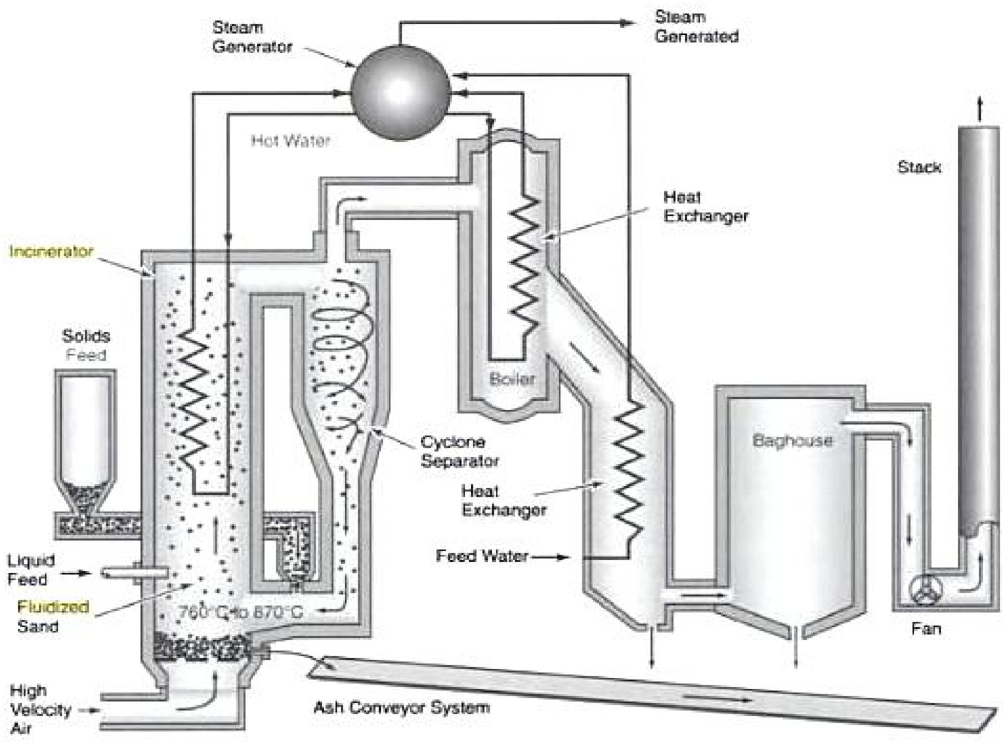


Figure 6. Circulating fluidized bed system. (Guyer, 1998)

4 LEGISLATION CONCERNING MANURE AND SEWAGE SLUDGE OF LIVESTOCK ENTERPRISES

4.1 Finnish Legislative and Normative Acts

1) Government Decision on the Use of Sewage Sludge in Agriculture № 282

The Decision contains regulations on the use of sewage sludge in agriculture to prevent harmful impacts on the environment and health.

a) *Treatment of sludge*. Treatment of sludge before agricultural use is obligatory. It can be carried out either by digestion or lime stabilization or by some other method in order to reduce pathogen content and odors and hazard to health or the environment arising from the use of sludge.

b) *Metal concentrations in sludge.* The heavy metal content should not exceed the maximum concentrations of heavy metals specified in Table 1 of Annex 1 of the Decision. Only in this case sludge can be used in agriculture. The same requirements refer to a sludge mixture (Table 2 of Annex 1).

c) *Quantity of sludge used*. The quantity of sludge used has to be determined depending on the soil quality and the nutrient needs of the cultivated crops (Government Decision № 282, 1994).

2) The Sewage Sludge Directive 86/278/EEC

This Directive is aimed to encourage the use of sewage sludge in agriculture. It regulates its use in such a way that any potential adverse effect on soil, vegetation, animals and human beings is prevented. According to this Directive the use of untreated sludge in agriculture is prohibited (Fytili, Zabaniotou, 2008).

3) HELCOM Recommendation 21/1. Regulation 2. "Plant nutrients"

a) *Animal density*: there must be a balance between the amount of animals on the farm and the amount of land available for spreading manure. Amount of manure produced should not excess the amount needed for arable land.

b) *Manure storage*: it must be organized in a proper manner in order to prevent losses of manure.

c) *Agricultural waste water and silage effluents*: waste water from animal housings and effluents from the preparation and storage of silage should be collected and stored in special stores to prevent pollution.

d) *Application of organic manures*: spreading of organic manures (slurry, solid manure, sewage sludge, composts, etc.) must be organized in a proper manner to prevent losses of plant nutrients. Organic manures should not be spread in winter time when soils are frozen, covered with snow, etc.

e) *Application rates for nutrients*: rates of nutrients should not exceed the crops nutrient requirements. They must be considered depending on soil conditions, soil nutrient content, soil type and slope; climatic conditions and irrigation; land use and agricultural practices, including crop rotation systems; all external potential nutrient sources.

f) *Winter crop cover*: the cultivated area should be sufficiently covered by crops in winter and autumn time to prevent the losses of plant nutrients.

g) Water protection measures and nutrient reduction areas: surface water, ground water, nutrient reduction areas should be established (HELCOM, 2000).

4) FE588 Air Pollution Control Programme 2010

The purpose of the programme is to reduce air and water pollution caused by agriculture by using agri-environmental support systems (Air Pollution Control Programme 2010, 2002).

5) Action Plan for the Protection of the Baltic Sea and Inland Watercourses

The Action Plan is aimed on reducing the leaching of nutrients into watercourses through using of fertilizes, and also storing and using of the manure (Action Plan for the protection of the Baltic Sea and inland watercourses, 2005).

6) National Water Protection Policy. Water Protection Targets for 2015

The aim of Policy is to reduce the nutrient loads entering water bodies from agriculture by a third by 2015 compared to their levels over the period 2001-2005, and halved over a longer timescale by promoting the recovery of manure, and by using of biogas from manure (National Water Protection Policy, 2009).

7) Finland's Natural Resources and the Environment Decree 2006

The Decree contains regulations concerning the storage, application and quantity of manure and the location and maintenance of livestock shelters, also regulations on the size of manure storage facilities, periods for manure spreading on the land, and the maximum nitrogen content of manure (Finland's Natural Resources and the Environment Decree 2006, 2006).

8) Objectives of the Finnish Ministry of the Environment for Cooperation with Russia 2008-2011

Cooperation is aimed on the protection of the Baltic Sea marine environment from harmful impact caused by manure. Reduction of impact is carried out by promoting the introduction of new manure handling technologies, particularly at large livestock farms (Objectives of the Finnish Ministry of the Environment, 2008).

9) Commission Regulation (EC) № 809/2003

This Regulation includes the processing standards for manure used in composting plants, and also requirements for equipment and laboratories of composting plants (Commission Regulation (EC) № 809, 2003).

10) Commission Regulation (EC) № 208/2006

This Regulation includes the processing standards for biogas; requirements for material used as raw material in biogas plants, and also requirements for equipment of composting plants (Commission Regulation (EC) № 208/2006).

11) Commission Regulation (EC) № 1678/2006

This Regulation contains rules concerning ways of using manure and requirements for means of manure disposal (Commission Regulation (EC) № 1678, 2006).

12) Commission Decision 2006/129/EC

This Decision lays down rules for the heat treatment process for manure (Commission Decision 129/EC, 2006).

13) Commission Decision 2003/329/EC

This Decision lays down rules to operators of premises and facilities for the heat treatment process for manure (Commission Decision 329/EC, 2003).

4.2 Russian Legislative and Normative Acts

1) Sanitary Regulations and Norms (SanPiN) 2.1.7.573-96. "Hygienic requirements to wastewater and sewage sludge use for land irrigation and fertilization"

These Sanitary Regulations and Norms define the quality requirements for wastewater and sewage sludge for irrigation and fertilization of land, selection of agricultural fields for irrigation and monitoring of their operation.

a) *Treatment of sludge*. Sewage sludge before agricultural use should be obligatory treated. It can be carried out by anaerobic digestion, composting, drying, lime stabilization, etc. in order to reduce pathogen content and odors and hazard to health or the environment arising from the use of sludge.

b) *Metal concentrations in sludge*. The heavy metal content should not exceed the maximum concentrations of heavy metals specified in the Appendixes 9 of SanPiN. Only in this case sludge can be used in agriculture.

c) *Quantity of sludge used*. The quantity of sludge used has to be determined for each case depending on the agrochemical parameters of soil (SanPiN 2.1.7.573-96, 1996).

2) Federal Environmental Protection Law № 7

This Federal Law establishes the legal framework of public policies on environmental protection. It is aimed on maintaining a supportive environment, biological diversity and natural resources, environmental security (Federal Environmental Protection Law № 7, 2002).

3) Federal Law № 89 "On Production and Consumption Refuse"

This Federal Law establishes the legal framework for management of production and consumption wastes in order to prevent the harmful effects of waste on human health and the environment, as well as the involvement of such waste in the economy as an additional source of raw materials (Federal Law № 89, 1998).

4) Federal Law № 101-FZ "On state regulation of ensuring of the agricultural land fertility"

One of the purposes of this Law is monitoring of the quality of fertilizers and agro-chemical pesticides used to ensure the fertility of agricultural lands and monitoring of its safe handling (Federal Law № 101-FZ, 1998).

5) Law of the Leningrad region № 41-OZ "On the soil fertility of agricultural lands of the Leningrad region"

One of the purposes of this Law is monitoring of the use of fertilizers and agro-chemical pesticides to ensure the fertility of agricultural lands (Law of the Leningrad region № 41-OZ, 1999).

6) State Standard (GOST) 26074-84. "Liquid manure. Veterinary and sanitary requirements for treatment, storage, transportation and utilization"

General requirements:

a) The treatment, storage, transportation and utilization of liquid manure should be carried out taking into account the environmental protection from pollution and safety for human health.

b) The treatment facilities for liquid manure should be located outside the fence of livestock complexes.

c) All facilities for treatment, storage, and transportation must be met to waterproofing.

Requirements for treatment and disinfection of liquid manure:

a) The liquid manure in the case of epizootics must be disinfected before the division into fractions by one of the following methods: chemical or thermal.

b) After disinfection and division the solid fraction of liquid manure should be treated by using one of the treatment methods (e.g. composting, etc.).

Requirements for storage of liquid manure:

Liquid manure should be stored in special manure reservoirs (GOST 26074-84, 2008).

7) Instructions for Receiving, Installation and Operation of Manure Treatment Facilities

This instruction is related to built and operated manure processing facilities of the livestock complexes and farms (Instructions for receiving, installation and operation of manure treatment facilities, 1985).

8) Sanitary Regulations and Norms (SanPiN) 3907-85. "Design, Construction and Operation of Reservoirs"

According to this SanPiN territories of cattle enterprises, as well as territories of storage and processing of raw materials of animal origin entering the zones of flooding and underflooding should be subjected to the sanitary treatment. Manure and manure wastewater should be disinfected in order to prevent eutrophication of reservoirs (SanPiN 3907-85, 1986).

9) Sanitary Regulations and Norms (SanPiN) 2.2.1/2.1.1.1200-03. Sanitary and Epidemiological Rules and Norms "Sanitary Protection Zones and Sanitary Classification of Enterprises, Buildings and Other Objects"

This SanPiN lays down that enterprises and their individual buildings which have the technological processes are sources of negative impacts on the environment and human health; they must be separated from the residential buildings by sanitary-protective zone. Sanitary-protective zones for livestock enterprises and facilities are determined by this SanPiN (SanPiN 2.2.1/2.1.1.1200-03, 2003).

10) Sanitary Regulations and Norms (SanPiN) 3.2.569-96. "Prevention of Parasitic Diseases in the Russian Federation"

This SanPiN determines disinfection methods for liquid manure and manure wastewater. The following methods can be used:

- storage of liquid manure and manure wastewater with moisture content of 95-98% in the storage tanks during 12 months;
- aerobic digestion of liquid manure with moisture content of 92-94% at a temperature of 51-57 °C with detention time of 3 hours;
- anaerobic digestion of liquid manure with moisture content of 92-95% in methanetanks at a temperature of 50-60 °C with detention time of 3 hours;

– thermal processing of liquid manure and sewage sludge at the temperature of 48-50 °C with detention time of 3 minutes;

– composting of the solid fraction of liquid manure with moisture content of 65-70% at the temperature of 63-65 °C with detention time of 1-2 months;

– composting of the solid fraction of liquid manure with moisture content of more than 72 % with detention time of 6 months;

– disinfection of excess sewage sludge by processing with liquid ammonia (with concentration of 3 %) at the temperature of 60-70 °C during 3 days (SanPiN 3.2.569-96, 1996).

11) Technical Requirements. TU 2191-019-00483493. "Vermicompost from Sewage Sludge"

This TU contains technical requirements for vermicompost from sewage sludge as a commercial product (TU 2191-019-00483493, 2000).

12) Technical Requirements. TU 9819-238-00008064-98. "Litter Cattle Manure"

This TU contains technical requirements for litter cattle manure (TU 9819-238-00008064-98, 1998).

13) Technical Requirements. TU 9821-242-00008064-98. "Litter Pig Manure"

This TU contains technical requirements for litter pig manure (TU 9821-242-00008064-98, 1998).

14) Technical Requirements. TU 0392-005-02983544-2000. "Compost"

This TU contains technical requirements for compost as a commercial product (TU 0392-005-02983544-2000). Requirements are listed in Table 10.

Table 10. Technical requirements for compost. (TU 9819-036-00483170-97)

Indicator	**Value**
Structure	friable
Particle size, mm	less than 120
Moisture content, %	less than 75
Mass fraction (%) of nitrogen phosphorus potassium	 more than 0.5 more than 0.2 more than 0.3
pH	6.0-8.5
Organic matter content, %	more than 75
C/N ratio	20-30
Nutrients content, %	more than 50
The content of foreign inclusions, %	0.5
Specific activity of natural radionuclides, Bq/kg of dry matter	less than 740
The heavy metals content, mg/kg of dry matter: Lead Copper Zink Mercury Arsenic Cadmium	 130.0 132.0 220.0 2.1 10.0 2.0
The content of pesticides, mg/kg of dry matter	Below or at the level of MPC (maximum permissible concentration)
Pathogenic microorganisms	none
Viable eggs and larvae of helminths	none

4.3 Comparison of Russian and Finnish Acts

Russian and Finnish requirements for sewage sludge before the use in agriculture are really similar. Comparative characteristic of requirements for sewage sludge is represented in Table 11. Requirements on the content of some heavy metals are more stringent in Russia. E.g. chromium content is in 50 times lower, zink – in 7 times, copper – in 4.5 times. Treatment technologies and requirements to quantity of sewage sludge needed for spreading on land in both countries are the same.

On the whole the legislation of the Russian Federation concerning manure is not much different from the Finnish one. According to both legislations manure is a waste, which represents the potential negative impact on soil, vegetation, animals and humans beings and on the environment in general. Therefore, the main purpose of both legislations is to prevent this negative impact. The list of methods recommended for manure treatment in both countries is the same. It includes the following methods: anaerobic digestion, combustion, drying, composting, etc. The main purpose of these methods is to stabilize and disinfect the manure. Recommended fields for use of the treated manure are also the same. It can be used in agriculture as fertilizer, compost, and in heating as energy (biogas).

Table 11. Comparative characteristic of requirements for sewage sludge. (SanPiN 2.1.7.573-96, 1996; Government Decision № 282, 1994).

Legislative act	Requirements			
	Treatment of sludge	Metal concentrations in sludge		Quantity of sludge used
Government Decision on the Use of Sewage Sludge in Agriculture № 282 (Finnish Legislation)	– anaerobic digestion – lime stabilization – some other method which can reduce pathogen content and odors.	Metal	MPC, mg/kg	The quantity of sludge used has to be determined depending on the soil quality and the nutrient needs of the crops cultivated.
		Cadmium	3.0	
		Chromium	300.0	
		Copper	600.0	
		Mercury	2.0	
		Nickel	100.0	
		Lead	150.0	
		Zink	1500.0	
Sanitary Regulations and Norms (SanPiN) 2.1.7.573-96 (Russian Legislation)	– anaerobic digestion – composting – drying – lime stabilization – some other method which can reduce pathogen content and odors.	Cadmium	2.0	The quantity of sludge used has to be determined for each case depending on the agrochemical parameters of soil (pH, nutrients content, heavy metals content, etc.).
		Chromium	6.0	
		Copper	132.0	
		Mercury	2.0	
		Nickel	80.0	
		Lead	130.0	
		Zink	220.0	

5 MANURE AND SEWAGE SLUDGE IN THE LENINGRAD REGION

5.1 Amount and Properties of Manure and Sewage Sludge

The environmental situation with manure in the territories of municipalities of the Leningrad region is not enough reliably reflected in the documentation. This situation, in particular, is because of the position taken by the management of most enterprises, according to which the manure is not a waste. But this position is contrary to the environmental legislation of the Russian Federation (Isyanov, 2007). In accordance with the Federal Classification Catalog of Wastes (FCCW) manure is a waste, and it represents a danger to the environment. Table 12 represents the degree of danger of manure to the environment.

Table 12. The degree of danger of manure to the environment. (FCCW, 2002)

Code	Name	Degree of danger
1310040103004	fresh cattle manure	IV
1310040101005	decomposed cattle manure	V
1310040203013	fresh pig manure	III
1310040201004	decomposed pig manure	IV

All municipalities of the Leningrad region have cattle enterprises, but only few of them have pig enterprises. Table 13 lists the livestock enterprises of municipalities of the Leningrad region.

Table 13. The livestock enterprises of municipalities of the Leningrad region. (Isyanov, 2007)

Municipality	Profile of enterprises	
	Cattle enterprises	Pig enterprises
The Boksitogorsky District	3	2
The Gatchinsky District	15	2
The Kingiseppsky District	8	–
The Kirishsky District	4	–
The Kirovsky District	2	–
The Lodeynopolsky District	6	–
The Lomonosovsky District	9	1
The Luzhsky District	12	–
The Podporozhsky District	3	–
The Prizersky District	10	3
The Tikhvinsky District	8	–
The Tosnensky District	6	–
The Volkhovsky District	10	1
The Volosovsky District	16	2
The Vsevolozhsky District	8	–
The Vyborgsky District	12	3

Average daily output and humidity excrements for different age groups of cattle and pig per one animal are listed respectively in Tables 14 and 15. The estimations have been done by the specialists of St. Petersburg State Technological University of Plant Polymers (SPb STUPP) together with the specialists of Federal service for veterinary and phytosanitary supervision (Rosselhoznadzor) by fieldwork.

Table 14. Average daily output and humidity excrements for different age groups of cattle per one animal. (Isyanov, 2007)

Age groups of cattle	**Indicator**	**Excrements composition**		
		Total	**including**	
			faeces	**urine**
Bulls	Mass, kg	40.0	30.0	10.0
	Humidity, %	86.0	83.0	95.0
Cows	Mass, kg	55.0	35.0	20.0
	Humidity, %	88.4	85.2	94.1
Calves:				
under 3 months of age	Mass, kg	4.5	1.0	3.5
	Humidity, %	91.8	80.0	95.1
under 6 months of age	Mass, kg	7.5	5.0	2.5
	Humidity, %	87.4	83.0	96.2
4 to 6 months of age	Mass, kg	14.0	10.0	4.0
	Humidity, %	87.2	83.5	96.5
Young animals:				
6 to 12 months of age	Mass, kg	14.0	10.0	4.0
	Humidity, %	87.2	83.5	96.5
12 to 18 months of age	Mass, kg	27.0	20.0	7.0
	Humidity, %	86.7	83.5	96.0

Table 15. Average daily output and humidity excrements for different age groups of pig per one animal. (Isyanov, 2007)

Age groups of pigs	Indicator	Excrements composition		
		Total	including	
			faeces	urine
Boars	Mass, kg	11.1	3.86	7.24
	Humidity, %	89.4	75.0	97.0
Sows:				
single sows	Mass, kg	8.8	2.46	6.34
	Humidity, %	90.0	73.1	97.5
gestating sows	Mass, kg	10.0	2.6	7.4
	Humidity, %	91.0	73.1	98.3
Piglets:				
from 26 to 42 days of age	Mass, kg	0.4	0.1	0.3
	Humidity, %	90.0	70.0	96.7
from 43 to 60 days of age	Mass, kg	0.7	0.3	0.4
	Humidity, %	86.0	71.0	96.0
from 61 to 106 days of age	Mass, kg	1.8	0.7	1.1
	Humidity, %	86.1	71.4	96.3

The quantities of manure produced were estimated also by the specialists of SPb STUPP together with the specialists of Rosselhoznadzor based on the average daily output and humidity excrements for different age groups of pig per one animal, data provided by enterprises, and taking into account the inventory carried out by Rosselhoznadzor in 2006, and refinements, carried out in 2007. Indicative data on manure formation in the Leningrad region by municipalities are presented in Table 16.

Table 16. Indicative data on manure formation in the Leningrad region. (Isyanov, 2007)

Municipality	**Manure production, t/a**
The Boksitogorsky District	less than 10,000
The Gatchinsky District	150,000–200,000
The Kingiseppsky District	about 100,000
The Kirishsky District	about 50,000
The Kirovsky District	about 50,000
The Lodeynopolsky District	about 50,000
The Lomonosovsky District	about 100,000
The Luzhsky District	150,000–200,000
The Podporozhsky District	less than 10,000
The Prizersky District	150,000–200,000
The Tikhvinsky District	about 50,000
The Tosnensky District	50,000–100,000
The Volkhovsky District	about 100,000
The Volosovsky District	150,000–200,000
The Vsevolozhsky District	100,000–150,000
The Vyborgsky District	about 100,000

Manure is formed in all municipalities of the Leningrad region. The average total amount of manure annually in the Leningrad region is 1,520,000 t/a. The condition in which manure was estimated is not mentioned in the source. Average chemical compositions of fresh litter cattle and pig manure are represented respectively in Tables 17 and 18.

Table 17. Average chemical composition of fresh litter cattle manure. (Isyanov, 2007)

With natural moisture content						Moisture, %	pH	C/N ratio
Organic matter,%	Ash, %	Total content of nitrogen,%	Ammonia nitrogen,%	P_2O_5, %	K_2O, %			
18.0	5.2	3.2	0.07	0.31	1.2	70	8.1	17

Table 18. Average chemical composition of fresh litter pig manure. (Isyanov, 2007)

With natural moisture content						Moisture, %	pH	C/N ratio
Organic matter,%	Ash, %	Total content of nitrogen,%	Ammonia nitrogen,%	P_2O_5, %	K_2O, %			
20.0	1.82	0.8	0.18	0.51	0.8	75	7.4	12

Sewage sludge is formed during the wastewater treatment. This sludge dries very slowly. It has a sharp unpleasant smell, attracts flies and hence it is dangerous in epidemiological terms. Average characteristics of sludge are represented in Table 19.

Table 19. Average characteristics of sewage sludge. (Isyanov, 2007)

Content of organic matter, %	Water content, %	Content of ash-free substances, %	Ash content, %	Content of total nitrogen, %
60	97	70	25	2.9

5.2 Sewage Sludge and Manure Treatment

The most common used methods for sewage sludge and manure treatment in the Leningrad region are anaerobic digestion, composting, and aging. Anaerobic digestion method is applied for many years in wastewater treatment plants for the treatment of fecal sewage. Concerning to livestock it can be considered as promising in biogas obtaining and burning it. Anaerobic digestion allows to destroy pathogenic microorganisms and decrease specific unpleasant odors of manure. Phosphorus and potassium after manure digestion are almost entirely preserved. Digested sludge and biogas are the end products of technology. This technology allows to produce thermal energy and reduce emissions of methane, as a result of its combustion. (Isyanov, 2007). Average biogas output from manure is given in Table 20.

Table 20. Average biogas output from manure. (Isyanov, 2007)

Indicator	Cattle manure	Pig manure
Manure output, kg/animal*day	55.0	3.5
Biogas output, kg/animal*day	1.62	0.32
Biogas volume, m^3/ton of dry matter	300	500

The most common used biogas plants operating in Russia and in the Leningrad region are the following: BIOEN-1, BF-500 (for complexes), BSU-25, BSU-500 (for farms), etc. Obtained thermal energy allows to heat the premises of 150–200 m^2, own energy needs to maintain the thermophilic process is 30% of the energy content of the biogas.

Composting is not the dominant method of livestock wastes stabilization. A large number of enterprises use composting as a supplementary method for treatment of excess manure. Number of enterprises composting the whole amount of manure is negligible. Failure to comply with the requirements when using composting as method for treatment of livestock wastes causes the following problems:

- mismatch of storage capacity with the annual accumulation of manure;
- air pollution by hydrogen sulfide, ammonia and methane;
- losses of nutrients during the manure storage;
- as a result of value of manure as fertilizer is decreased.

As a result of inventory of livestock enterprises of the Leningrad region was found the number of enterprises using the method of composting for waste stabilization. Prevalence characteristics of the composting method use in the Leningrad region are listed in Table 21.

Table 21. Prevalence characteristics of the composting method use in the Leningrad region. (Isyanov, 2007)

Municipality	Number of inventoried enterprises	The number of enterprises using composting method			
		Total	% of the total number of enterprises in the region	including	
				Composting	Vermicomposting
The Boksitogorsky District	3	1	33	1	0
The Gatchinsky District	19	8	42	7	1
The Kingiseppsky District	8	3	38	3	0
The Kirishsky District	4	2	50	2	0
The Kirovsky District	4	2	50	2	0
The Lodeynopolsky District	6	0	0	0	0
The Lomonosovsky District	14	3	21	3	0
The Luzhsky District	14	5	36	5	0
The Podporozhsky District	3	0	0	0	0
The Prizersky District	12	6	50	6	0
The Tikhvinsky District	8	5	63	5	0
The Tosnensky District	6	2	33	2	0
The Volkhovsky District	11	9	82	9	0
The Volosovsky District	16	9	56	9	0
The Vsevolozhsky District	10	0	0	0	0
The Vyborgsky District	16	6	38	6	0
Total number of inventoried enterprises	154	61	40	60	1

The most common method for stabilizing of livestock manure and sewage sludge in the Leningrad region is aging. The stabilization occurs naturally by storage of manure and sewage sludge. Aging can be carried out in special tanks or in ponds. According with SanPiN 3.2.569-96 "Prevention of parasitic diseases in the Russian Federation" timing of storage must be 12 months, depending on the epizootic situation, but in fact wastes are stored during just a few months.

Since sewage sludge is dangerous in epidemiological terms it should be disinfected before treatment. Sludge is fed to sludge platforms. Sludge platforms represent shallow basins filled with a filtering material. Purpose of sludge platforms is to concentrate in one place the whole sludge, neutralize it and make suitable for use in agriculture. For sewage sludge disinfection before the feeding to the platforms the following methods can be used: thermal, chemical, physical and biological. While thermal treatment sludge is heated to a certain temperature, as a result the pathogens die. The duration of disinfection depends on heating temperature and duration of exposure. Survival of pathogens in fresh sewage sludge is very high: the viruses remain viable in soil 10-100 days, 9-11 weeks of salmonella, eggs helminthes up to two years. When drying of sewage sludge at sludge platforms it must be firstly disinfected. Drying usually lasts 1-3 years.

For disinfection of sludge by chemical method lime can be used. The lime adding leads to an increase in alkalinity and temperature of sludge. Maximal destruction of pathogens is provided by increasing of sludge pH up to 12 and temperature up to 60°C, which is achieved with a dose of lime 30% of dry matter and detention time – 30 minutes. Physical methods of sewage sludge disinfection are currently less used. Physical methods include: radiation exposure, ultrasonic vibrations, and high-frequency current. Biological treatment of sewage sludge is mainly carried out for their stabilization. In most cases, dehydration of bio-stabilized sludge is carried out on sludge platforms. Therefore, it is advisable to carry out a biological stabilization at a temperature exceeding a threshold for the pathogens. When the temperature is 38-40°C full disinfection occurs for 7-10 days, at the temperature of 42°C – for 5-7 days (Isyanov, 2007).

6 ESTIMATION OF THE MOST SUITABLE TREATMENT TECHNOLOGIES FOR THE LENINGRAD REGION

For the manure and sewage sludge of the Leningrad region the following treatment technologies can be applied: anaerobic digestion, composting, and combustion. Aging is not a treatment method. Manure and sewage sludge processed by aging do not meet the sanitary and epidemiological requirements of Federal service for veterinary and phytosanitary supervision of the Russian Federation. Also during the aging the sewage sludge and manure represent sanitary hazard for operating personnel and surrounding area. This method should not be used henceforward. Let's consider the strengths and weaknesses of each method for the case of the Leningrad region.

Composting. The end product of composting process is valuable organic fertilizer which can be used in agriculture. This is the main strength of composting as a treatment technology. Also the advantages of this method are stabilization and disinfection of wastes of livestock enterprises. The disadvantages of this method are that land available for spreading fertilizer is not sufficient, and, moreover, disinterest of agricultural enterprises in cultivation of crops, for which could be used organic fertilizers.

Combustion. Combustion allows to disinfect livestock waste, and, which is very important, allows to reduce the volume of wastes. But ash generated during the combustion requires further disposal or use. Ash can be used in agriculture and in forestry as fertilizer or in road construction instead of cement. However, these technologies are relatively new and have not been developed fully in Russia, and in this case in the Leningrad region. Nevertheless, ash using can be considered as strength of combustion as a treatment technology. If ash is not in use it must be disposed in specially designated areas – landfills, and this territory cannot be used for other purposes. This is, of course, the weakness of the method. Another disadvantage of combustion is the flue gases, especially when combustion is incomplete. In this case the flue gases may contain besides oxygen, nitrogen, water vapor, carbon dioxides (CO_2), sulfur oxides (SO_x), nitrogen oxides (NO_x), and mineral acids, significant amounts of carbon monoxide (CO), unburned or partly burned organic particles, polychlorinated dibenzo-p-dioxin (PCDDs) and dibenzo-furan (PCDFs) compounds, etc. APC system must be obligatory.

Anaerobic digestion. The main products of anaerobic digestion process are biogas and digested sludge. Digested sludge can be used in agriculture as a valuable organic fertilizer and soil conditioner. The challenge with digested sludge usage in agriculture is that land available for spreading fertilizer is not sufficient, and moreover agricultural enterprises are not interested in it. Another challenge is that possibility of its recovery is restricted. And biogas can be used to heat the digester itself and to produce electricity for internal use. Also it can be used to heat other processes, buildings or to produce electricity for other users if the process is effective. However, there is no need in biogas production in the Leningrad region. In accordance with the «General scheme of gas supply of the Leningrad region for the period from 2005 to 2015», developed by JSC «Promgaz» and approved by the Government of the Leningrad region by 2015 the whole region will be equipped by natural gas network. There will not be fuel oil and coal boilers in the region. Priority use is gas boilers, and where it is impossible (not cost effective) will be use of biofuels, including biogas (Sokolova, 2008). But the share of biofuel use will be small. Another weakness of biogas usage is little generation potential compared to natural gas. But locally it could still be significant source of energy if natural gas is not easily available. These are the main weaknesses of anaerobic digestion method.

Nevertheless, to estimate the opportunity of biogas usage, the biogas production potential was calculated for two livestock enterprises of the Leningrad region. Calculations were made by two methods – the first one is based on Chen and Hashimoto's equation and the second – on specific biogas production per mass of manure. Description of the methods is shown respectively in Appendices I and II. As examples, the following livestock enterprises were taken: the agricultural industrial complex (AIC) "Kobralovsky" which is situated in the Gatchinsky District and closed joint-stock company (CJSC) "Agrotekhnika" which is situated in the Tosnensky District. Initial data was provided by the leadership of the enterprises, and is listed in Table 22. Value of indexes used for calculations are represented in Table 23 and the results of calculations – in Table 24.

Table 22. Initial data for enterprises. (Isyanov, 2007)

Name of the enterprise	Type of waste	Livestock, units	The actual average annual amount of manure, t/a
AIC "Kobralovsky"	Cattle manure	900	8200
CJSC "Agrotekhnika"	Cattle manure	2000	10800

Table 23. Value of indexes used for calculations.

Calculation method	Index	Value
Method based on Chen and Hashimoto's Equation	B_o, m^3 CH_4/kg $_{org.matter}$ C, % S, % Θ, d T, °C	0,41 10 6,8 12 35
Method based on specific biogas production per mass of manure	F_{VS}, % G_{VS}, %	10 450

Table 24. Biogas potential of manure.

Name of the enterprise	Annual biogas yield from actual amount of manure, m^3	
	Method based on Chen and Hashimoto's Equation	Method based on specific biogas production per mass of manure
AIC "Kobralovsky"	$2{,}7 \cdot 10^5$	$2{,}6 \cdot 10^5$
CJSC "Agrotekhnika"	$3{,}5 \cdot 10^5$	$3{,}4 \cdot 10^5$

The results of calculations show that biogas potential for these enterprises using of anaerobic digestion for manure treatment is expedient from economic and environmental point of view. Enterprises can use produced biogas locally or distribute it for other enterprises. Calorific efficiency of biogas is approximately 28 MJ/m^3 or 8 kWh. Energy potential of biogas produced is represented in Table 25.

Table 25. Energy potential of biogas produced.

Name of the enterprise	Energy potential of biogas produced, kWh	
	Method based on Chen and Hashimoto's Equation	Method based on specific biogas production per mass of manure
AIC "Kobralovsky"	$21{,}6 \cdot 10^5$	$20{,}8 \cdot 10^5$
CJSC "Agrotekhnika"	$28{,}0 \cdot 10^5$	$27{,}2 \cdot 10^5$

7 CONCLUSION

Livestock enterprises are one of the main sources of environmental pollution and represent a danger to human health. Sewage, sewage sludge and manure are sources of pathogens and nutrient pollution of natural water bodies. Hence, they must be obligatory treated and disinfected. Legislative acts concerning sewage, sewage sludge and manure handling must be adopted. And also special organizations for monitoring and control must be created.

The environmental situation with livestock wastes in the Leningrad region is not good. Data about manure are not enough reliably reflected in the documentation. This situation, in particular, is because of the position taken by the management of most enterprises, according to which the manure is not a waste. And this position is contrary to the environmental legislation of the Russian Federation. The wastewater is diverted from the areas of livestock enterprises through the drainage channels into waterways without treatment, and concentrations of pollutants are reduced to acceptable values by mixing with natural waters. So, sometimes concentrations exceed MPC. There are also contaminant losses from facilities and pipelines (especially nitrogen and phosphorus) and accidental sewage discharges. In order to change this situation the Government of the Russian Federation should take serious legal measures concerning livestock sewage and wastes handling. The penalties for offences concerning environmental pollution must be more stringent.

There are a number of problems concerning waste treatment technologies in the livestock enterprises. Use of aging as a treatment technology must not occur henceforward. Manure and sewage sludge processed by aging do not meet the sanitary and epidemiological requirements of Federal service for veterinary and phytosanitary supervision of the Russian Federation. Also during the aging the sewage sludge and manure represent sanitary hazard for operating personnel and surrounding area. Technologies such as composting, combustion and especially anaerobic digestion should be more in use. Further investigation and observation on new treatment technologies ought to be made. Investigation on use possibilities of ash from combustion processes, biogas from anaerobic digestion also ought to be made.

Therefore, to solve environmental problems it is very important to learn the experience of other developed countries, especially Nordic countries, such as Finland, Sweden and Estonia. There should be more international projects and workshops. International cooperation should be developed.

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APPENDICES

Appendix I. Calculation Method of Biogas Potential of Manure Based on Chen and Hashimoto's Equation.

The theoretical biogas production can be calculated from Chen and Hashimoto formula based on the analysis of large amounts of empirical data. Formula predicts methane yield depending on the type of substrate and the operating characteristics of the reactor (RI, 1998).

$$V_s = (B_o \cdot S_o/\Theta) \cdot [1 - K/(\Theta \cdot \mu_m - 1 + K)] \quad (1)$$

where Vs – yield of methane , m^3 CH_4/m^3 of reactor;

B_o – ultimate methane yield per day from 1 kg of organic matter (OM), m^3 CH_4/kg OM;

For cattle manure: $B_o = 0,36 \pm 0,05$;

S_o – input concentration of OM, kg/m^3;

$S_o = C_\Sigma / W_{manure} \cdot S$ (2)

C_Σ – total output of dry matter, kg/day;

$C_\Sigma = W_{manure} \cdot C$ (3)

C – content of dry matter, %;

W_{manure} – volume of manure, m^3/day;

$W_{manure} = Q_{manure}/\rho_{manure}$ (4)

Q_{manure} – actual annual amount of manure, $t_{dry\ matter}$ /a;

ρ_{manure} – density of manure, kg/m^3;

S – content of OM,%;

K – kinetic coefficient;

Θ – mean cell-residence time, d;

For cattle manure: $K = 0,8 + 0,0016e^{0,06 \cdot S}$ (5)

μ_m – the maximum rate of microorganisms growth, d^{-1};

$\mu_m = 0,013 \cdot T - 0,129$ (6)

T – work temperature, °C;

$V_{biogas} = V_s \cdot 0,7 \cdot W_{reactor}$, m^3;

Methane content in biogas is 70 %;

V_{biogas} – yield of biogas, m^3 (RI, 1998).

Appendix II. Calculation Method of Biogas Potential of Manure Based on Specific Biogas Production per Mass of Manure.

The theoretical biogas production can be calculated from Bushwell's equation (Møller, 2004):

$C_nH_aO_b + (n – a/4 –b/2)\ H_2O \rightarrow (n – n/2 – a/8 + b/4)\ CO_2 + (n/2 + a/8 – b/4)\ CH_4$ (1)

The average chemical composition of the volatile solids (VS) in the manure was calculated with the assumption of an average composition of VS lipid ($C_{57}H_{104}O_6$), VS protein ($C_5H_7O_2N$), VS carbohydrate ($C_6H_{10}O_5$), VS lignin ($C_6H_{10}O_5$) and VS acetic acid ($C_2H_4O_2$) and taking into account data on feed intake and digestibility of the feed. The carbohydrates were divided into an easily degradable part and a slowly degradable part.

The theoretical biogas yield from known animal production can be calculated by multiplying of standard value for the methane yield per mass of VS in the manure, the quantity of manure, methane content in biogas and the fraction of VS in the manure:

$V_{biogas} = Q_{manure} \cdot F_{VS} \cdot G_{VS} \cdot 0{,}7$ (2)

Where V_{biogas} – yield of biogas, m^3;

Q_{manure} – actual annual amount of manure, $t_{dry\ matter}$ /a;

F_{VS} – the fraction of VS in the manure, %;

G_{VS} – standard value for the methane yield per mass of VS in the manure, $m^3\ CH_4$/t VS.

Methane content in biogas is 70 % (Møller, 2004).