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THE METHODS OF POSSIBLE JOINT TREATMENT OF MANURE AND SEWAGE SLUDGE IN THE LENINGRAD REGION

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ABSTRACT

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The nutrient load to the Gulf of Finland has started to increase as a result of the strong economic recovery in agriculture and livestock farming in the Leningrad region. Also sludge produced from municipal wastewater treatment plant of the Leningrad region causes the great impact on the environment, but still the main options for its treatment is disposal on the sludge beds or Landfills.

The aim of this study was to evaluate the implementation of possible joint treatment methods of manure form livestock and poultry enterprises and sewage sludge produced from municipal wastewater treatment plants in the Leningrad region. The study is based on published data. The most attention was put on the anaerobic digestion and incineration methods. The manure and sewage sludge generation for the whole Leningrad region and energy potential produced from their treatment were estimated. The calculations showed that total amount of sewage sludge generation is 1 348 000 t/a calculated on wet matter and manure generation is 3 445 000 t/a calculated on wet matter. The potential heat release from anaerobic digestion process and incineration process is 4 880 000 GJ/a and 5 950 000 GJ/a, respectively. Furthermore, the work gives the overview of the general Russian and Finnish legislation concerning manure and sewage sludge treatment.

In the Gatchina district it was chosen the WWTP and livestock and poultry enterprises for evaluation of the centralized treatment plant implementation based on anaerobic digestion and incineration methods. The electricity and heat power of plant based on biogas combustion process is 4.3 MW and 7.8 MW, respectively. The electricity and heat power of plant based on manure and sewage sludge incineration process is 3.0 MW and 6.1 MW, respectively.

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Viktoriya Kapustina

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LIST OF SYMBOLS

AD	anaerobic digestion	
AHR	anaerobic hybrid reactor	
B	yield of biogas	[CH_4 m^3/a] [CH_4 m^3/hour]
BAT	best available techniques	
C	methane content in the biogas	[%]
C/N	carbon to nitrogen ratio	[dimensionless]
CH_4	methane	
CHP	combined heat and power	
CO_2	carbon dioxide	
CSTR	continuously stirred tank reactor	
Cu	copper	
E	energy production	[GJ/a] [TWh]
EU	European Union	
Fe	iron	
G	index of the biogas yield	[m^3/t]
H_2S	hydrogen sulfide	
l	latent heat of water evaporation	[MJ/kg]
LHV	lower heating value	[MJ/kg] [MJ/m^3] [MJ/l]
Mn	manganese	
n	yield of feedstock production	[t/unit/a]
N	number of unit	[unit]
q	fuel economy	[l/100km]
Q	mass flow	[t/a] [m^3/day]
S	distance	[km]
T	number of trucks	[unit]

TS	total solids	
TVS	total volatile solids	
UASB	up-flow anaerobic sludge blanket	
UWWTD	Urban Waste Water Treatment Directive 91/271/EEC	
V	volume	[m^3]
VFA	volatile fatty acids	[g acetic acid]
VS	fraction of VS	[%]
w	moisture content of feedstock	[%]
Y	retention time	[day]
Zn	zinc	
ρ	density	[kg/m^3]
η	conversion efficiency	[-]

Subscripts

ar	as recieved
biogas	biogas
CH4	methane
c,w	consumption for dewatering of feedstock
d.m	dry matter
diesel	parametrs of diesel
inc	incineration
ihitial	initial parametrs
total	total amount

trans	transportation
truck	truck
w	water
w.m	wet matter

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1 INTRODUCTION

The concept of sustainable agriculture has become one of the main topics nowadays. Animal welfare, technological development, energy and nutrient recycling combined with minimizing the environmental impact are the main objects of sustainable agriculture.

There are large amount of manure in the Leningrad region. Although the declining of production in the agricultural sector during last decade can be observed (Antishina I.V.et al. 2007), the course of realizing of the State Program «The Development of Agriculture and Regulation of the Markets of Agricultural Products, Raw Materials and Food for 2008-2012», in 2012 year livestock production is expected to increase by 32.9% as compared to 2006 year.

This fact leads to increase the amount of manure generated from the farming and problems associated with the disposal of manure will rapidly increase. It was reported that nowadays the animal husbandry already produces too much manure as compared to the arable land available (Project PRIMER 2009). Vast amount of manure accumulated near the livestock enterprises is a source of environmental pollution and also they require alienation of fertile arable land. Risk is increased due to the availability and long storage in an active state in the products of farms agents of infectious diseases spreading through the air or water for hundreds of kilometers. The odor from them is spread over large distances, causing a hazard of human physiological reactions (Ministry of Natural Resources and Ecology of the Russian Federation 2004). The high concentration of nitrogen and phosphorus in ground water and water bodies are observed. This causes to the nutrient pollution or eutrophication of water bodies (Järvinen 2006, 7).

In recent years, there is also another organic waste that course environmental problem in the Leningrad region such as sewage sludge from municipal wastewater treatment plants. The quantity of generated sludge are increasing due to increasing requirements to quality of the wastewater that is discharged to the water bodies, intensifying of the efficiency of the wastewater treatment plants.

Currently the centralized sewage systems are available in 30 cities, 33 urban villages and 222 rural settlements in the Leningrad region. Amount of generated sludge from treatment plants of the Leningrad region is about 54000 tons annual (calculated on the dry matter) (Antishina I.V.et al. 2007, 135). These wastes contain large quantities of harmful components, so their disposal and storage requires a special approach (Alikbaeva L.A. 2007, 3).

Nowadays sludge is mostly disposed in sludge beds or Landfills. The option to dispose sludge has different kind of problems and the significant of them are the following: lack of area to dispose it, the alienation of the new territory, uncontrolled emission of gases such as methane and carbon dioxide (which are green house gases and they should be taken into account due to Kyoto Protocol).

For these reasons, the handling waste from livestock enterprises and sewage sludge from municipal wastewater treatment plants are a matter of great concern from an environmental point of view. There are several options for treatment technologies of manure and sewage sludge which increase level of environmental protection. The more common options are anaerobic digestion, composting and incineration. In this study more attention will be put on anaerobic digestion and incineration methods. Furthermore, an overview of Finnish and Russian legislation and normative acts which concern requirements for manure and sewage sludge handling will be represented.

To evaluate the parameters from implementation of treatment processes the data of sewage sludge and manure generation in the Leningrad region, as well as their properties will be represented. The possible energy production from these methods for the whole Leningrad region will be calculated.

The district with large manure and sewage sludge generation will be chosen to study the influence of energy consumption from transportation of feedstock while implement the centralized treatment plant for joint treatment of manure and sewage sludge. As methods for joint treatment will be the anaerobic digestion process with following combustion of biogas produced and the direct incineration of sewage sludge and manure.

2 SEWAGE SLUDGE AND MANURE CHARACTERISTICS

It is well known that the type of treatment technology depends on properties of matter that will be treated. The properties of manure and sewage sludge depend on different factors. For instance, for manure they are the following: the species and the age of animal, type of bedding and others (Järvinen 2006, 39). For sludge their quality is strongly dependent on the original pollution load of the treated effluent and also, on the technical and design features of the waste water treatment process (Fytili 2008, 118; Pugacheva 2003, 6).

2.1 Sewage Sludge characteristics

In Russia the sewage sludge annually produced by the wastewater treatment has been estimated and exceeded 3.4 million tones of dry matter. The estimation of sewage sludge amount in Russia's regions in 2009 is reported in table 1 (Khomjakov 2009, 2).

In EU after the implementation of the Urban Waste Water Treatment Directive (UWWTD (91/271/EEC)) the production of sewage sludge increased up to 50% since 1991 by year 2005, i.e. 10 million tons annually (Fytili 2008, 118).

Table 1. The estimation of urban sewage sludge amount in 2009. (Khomjakov 2009, 2)

Regions of Russian Federation	Sewage sludge, tonnes dry matter
The Russian Federation	3 378 000
The Central Federal District	856 000
The Northwestern Federal District	338 000
Southern Federal District	570 000
Volga (Privolzhsky) Federal District	677 000
Urals Federal District	289 000
Siberian Federal District	482 000
Far Eastern Federal District	166 000

Wastewater treatment process includes different stages and during these stages liquids and solids are being separated. After all stage various components removed from wastewater: large particles (rags, sticks, etc.), intercepted on grates that have size of slits 16 mm; mineral particles precipitated in grit chambers; organic particles floating in the primary sedimentation tanks; excess activated sludge collected in the secondary sedimentation tanks; compacted activated sludge after concentration tank; anaerobically digested sludge after the digester; cake (sludge dewatered or dried on the sludge drying bed) (Fytili 2008, 119; Pugacheva 2003, 6).

Sewage sludge produced by waste water treatment process is biodegradable material. The total and volatile solids concentrations, contain of heavy metals, C/N ratio, alkalinity and organic acid content, pH levels, biogas production rate, energy (thermal) content of sludge are significant operational parameters that should be monitored in treatment processes of sewage sludge (D. Fytili 2008, 119).

Physical properties of sewage sludge are determined by the type of treatment technology and retention time in the treatment facilities (Khomjakov 2009, 3). Sewage sludge after the stage of mechanical dewatering is mass with lumpy structure. The dry solid content of the sludge is in the range 2 - 12% by weight (Fytili 2008, 119; Yakovlev 2006, 247). The bulk density is over the range 650 to 800 kg/m^3(Khomjakov 2009, 3).

The moisture content of sewage sludge is one of the important indicators. In the thermal treatment method (incineration) with increase of moisture content the calorific value of waste decreases. There are also difficulties associated with unburning particles and increase of treatment cost due to use of backup fuel, which fed into the furnace to ensure necessary requirements and standards of waste incineration. However, in anaerobic digestion (AD) process the opposite effect is observed: the decreasing of the moisture content changes for the worse the process parameters. Fujishima et al. (2000) reported that decreasing of the moisture content since 97.0 % to 89.0% the volatile solids (VS) removal efficiency changes from 45.6% to 33.8%, and the carbohydrate removal efficiency decreases from 71.1% to 27.8%. If moisture content is less than 91.1% this results in declining of methane formation. Also the moisture contain is one of the main important parameters used to choose the technology and equipment for process treatment, especially in what concerns mixing and pumping needs. The anaerobic process, with moisture contain under 85% (dry process), has less sensitivity to the input of untreatable material to the reactor, because particles segregation does not happen inside of the reactor as in wet systems. On the other hand dry processes are not capable to attain removals as high as the ones for wet processes (Capela I. 2008, 246). The moisture contain is often determined in literature using another characteristic such as total solids concentration (TS). Also it should be mentioned that the increase in moisture content even within the 2-5% will noticeably increase the transportation cost (Khomjakov 2009, 3).

Sewage sludge contains nitrogen and phosphorous and this gives sludge unique fertilizing benefits, since those elements contained in sludge are essential to plants for growing. In the untreated sludge nitrogen contain typically ranged from 3 to 6% calculated as dry matter (Khomjakov 2009, 4). The content of phosphorous is over the range 0.8 to 3.1% (Fytili 2008, 119; Khomjakov 2009, 4; Lopes 2003, 861).

Sewage sludge is a type of biomass and it could be used as fuel. Sludge composition and higher heating value of dry matter are the most important input data for evaluation of heat balances of sludge incineration. The lower heating value of sludge is over the range 13.1 – 17.0 MJ/kg on dry matter (Lopes 2003, 861; Fytili 2008, 126). A typical chemical composition and properties of untreated sludge is reported in table 2.

Table 2. Typical chemical composition and properties of untreated sewage sludge. (Fytili 2008, 119; Khomjakov 2009, 4; Wong 1995, 3; Kizilkaya 2005, 194; Seghezzo 1998, 176; Lopes 2003, 861)

Proximate analysis (wt.%, dry matter)			Nutrients content (wt.%, dry matter)			Moisture, %	pH	C/N ratio	Alkalinity (mg/l as $CaCO_3$)	$LHW_{d.m.}$ (MJ/kg)
Volatile matter	Ash	Fixed carbon	N_{total}	P_2O_5	K_2O					
60 - 80	12 - 32	7.0-7.4	3 – 6	0.8 – 3.1	0 – 1	92 - 98	5.0 – 8.0	9:1	500-1500	13.1 – 17.0

Contents of heavy metals in sewage sludge are within a wide range. Typical metal concentrations are reported in table 3.

Table 3. Typical metal content in sewage sludge. (Fytili 2008, 120)

Metal	**Dry sludge, mg/kg**
Arsenic	1.1 – 230
Cadmium	1 – 3.410
Chromium	10 – 990000
Cobalt	11.3 – 2490
Copper	84 – 17000
Iron	1000 – 154000
Lead	13 – 26 000
Manganese	32 – 9870
Mercury	0.6 – 56
Molybdenum	0.1 – 214
Nickel	2 – 53 000
Selenium	1.7 – 17.2
Tin	2.6 - 329
Zinc	101 – 49 000

Sewage sludge should be treated, before disposal or recycling, for reducing its water content, its fermentation proclivity or the existence of pathogens. The following treatment processes can be used at the processing stage: thickening, dewatering, stabilization, disinfection and thermal drying. After treatment, several different options can be employed for recycling or disposal of sewage sludge and they are the following: the agriculture utilization (land spreading), the waste disposal sites, silviculture, land reclamation and restoration, incineration, wet oxidation, pyrolysis and gasification (P. Przewrocki 2003, 237; D. Fytili 2008, 124).

2.2 Characteristics of poultry and livestock manures

The yearly production of poultry and livestock manure on centralized farms in Russia exceeded 635 million tons on wet matter (Belilovsky V.A. et al, 2009). Steinfeld et al. (2006) reported that in the EU-27, the yearly production of animal manure is more than 1500 million ton.

Poultry and livestock manures consist of excreta, water, salts, gases, microorganisms, animal hair or feathers and bedding material (straw, wood sawdust, shavings, sand etc). There are different types of manure depending on the animal housing technology, diets and manure removal technology. Depending on the moisture content it can be solid manure, semi-liquid, liquid manure and manure-contaminated wastewater (Järvinen 2006, 38). Depending on the stage of decomposition manure is distinguished as fresh manure, semi-decomposed, decomposed and humus.

In general manure contains a wide range of minerals and nutrients, including abundant amounts of the three main chemicals: nitrogen, phosphorus and potassium. It also contains many trace elements. However, their contents depend on animal type. For example, pig manure is relatively high in nitrogen and low in potassium; however cattle manure is high in potassium and low in nitrogen (Järvinen 2006, 39). Bellow, it will be consider the properties in more details for pig, cattle and chicken manures.

2.2.1 Characteristics of cattle manure

The characteristic of the cattle manure, as mentioned above, depends on various factors. Such factor as using bedding materials affects on moisture content of the manure. In Livestock enterprises straw, sawdust, mats or sand can be used as bedding material. Using of straw as a bedding material leads to an increase the percentage of difficult degradable organic matter and it needs higher retention time. Using of sand as a bedding material causes the operational problems in digestion system due to an increase the percentage of inorganic part (ash content) in manure (Steffen R et al. 1998, 10).

The most common removal method for cattle manure is mechanical method. Cattle manure is typically collected from feedlots by a scraper system or by dozer. Commonly little water is added for more complete removal of manure and to ensure sanitary conditions of animals, therefore dilution with water is minimal (Steffen R et al. 1998, 15). Typical moisture contain of cattle manure is over the range 88 to 95% (Järvinen 2006, 39; Sharon 2007, 1157).

Cattle manure is a waste with high amount of nutrients such as nitrogen (fundamentally ammonium), potassium, and calcium. It also contains many trace elements, such as iron, manganese, zinc, copper etc. Chemical composition of fresh cattle manure is presented in Table 4.

Table 4. Chemical composition of fresh cattle manure. (Järvinen 2006, 46; Thobanoglous et al. 1993, 689; Alvarez R. 2003, 728; Capela I. 2008, 246; Sharon 2007, 1157; Li X. 2009, 4636)

Proximate analysis (wt.%, dry matter)			Nutrients content (wt.%, dry matter)			Moisture, %	pH	C/N ratio	Alkalinity (g/l as $CaCO_3$)	$LHV_{d.m.}$ (MJ/kg)
Volatile matter	Ash	Fixed carbon	N_{total}	P_2O_5	K_2O					
75 - 85	15 - 17	7.0-7.4	1.1 – 3.2	0.4-1.8	0.7-5	88 - 95	7.4 – 8.2	6 - 20	1.8-4.2	12.0 – 17.0

Moreover cattle manure is may contain pathogenic bacteria of different species such as Salmonella, Listeria, Escherichia coll, Campylobacter, Mycobacteria, Clostridia, and Yersinia. Several of these microorganisms are persistent to the changing of temperature, and some of them may cause infections in both animals and people (Maranon 2006, 137).

2.2.2 Characteristics of pig manure

Pig manure (especially in large farms, those with more than 1000 animals) is typically collected as liquid slurry. Pigs are usually kept in feedlots with open floors, where manure typically falls through a slotted floor. The removed manure has high amount of liquid (95–98% moisture content). In the event that manure is removed by mechanical method (using scraper systems) the moisture content will be lower and over the range 85 to 95 % (Steffen R et al. 1998, 9; Merzlaya G.E. 2006, 211). The average chemical composition of pig manure is presented in Table 5.

Table 5. Chemical composition of pig manure. (Järvinen 2006, 46; Sharon 2007,1157; Kaparaju 2005, 117; Burton C.H. 2007, 212;Thobanoglous et al. 1993, 689; Merzlaya G.E. 2006, 211; Klein E. Ileleji et al. 2008, 3)

Proximate analysis (wt.%, dry matter)			Nutrients content (wt.%, dry matter)			Moisture, %	pH	C/N ratio	Alkalinity (mg/l as $CaCO_3$)	$LHV_{d.m.}$ (MJ/kg)
Volatile matter	Ash	Fixed carbon	N_{total}	P_2O_5	K_2O					
70- 85	15-22.6	7.0-7.4	2.8 - 6	2 - 3.2	1 - 4	85 - 98	5.2 – 8.3	3-20	1742-7882	12.0 – 17.0

Liquid pig manure is the most dangerous animal waste. Due to the high moisture content of manure the temperature does not increase and pathogenic agents retain in the waste long period of time. The toxicity level to the environment is different for fresh and decomposed manure.

2.2.3 Characteristics of poultry manure

Chickens are usually held on in large scale units keeping up to several hundred thousand animals (Steffen R et al. 1998, 9). The quantitative output and qualitative composition of manure are defined by poultry specific features such as age, and by feeding and housing conditions. As for cattle and pig manure, poultry manure can be combined with littering material (litter manure), or contain no litter (manure) depending on the technology used in the poultry housing. A litter made of various materials is widely used at poultry-farming enterprises. The basic litter types are: straw, wood sawdust, shavings, sunflower seed shells, crushed sunflower stems, etc.

Depending on the water content, manure can be solid, semi-liquid and liquid. Typically chicken manure is lower in moisture content than pig and cattle manures and their moisture content is in the range 70-90%. The chemical composition of manure includes considerable amounts of basic nutrients, such as phosphorous, potassium and high amount of nitrogen. Chicken manure is typically higher in NH_4^+ -N concentrations than pig and cattle manure (Steffen R et al. 1998, 9). The chemical composition of fresh chicken manure is presented in Table 6.

Table 6. Chemical composition of chicken manure. (Järvinen 2007, 28; Ward 2008, Sharon 2007, 1157; Salminen E. 2002, 14; Thobanoglous et al. 1993, 689; Klein E. Ileleji et al. 2008, 3)

Proximate analysis (wt.%, dry matter)			Nutrients content (wt.%, dry matter)			Moisture, %	pH	C/N ratio	Alkalinity (mg/l as $CaCO_3$)	$LHV_{d.m.}$ (MJ/kg)
Volatile matter	Ash	Fixed carbon	N_{total}	P_2O_5	K_2O					
60 - 85	8-33	7.0-7.4	8.5-6.7	1.8-3.5	1.78-2.1	70 - 90	5.2 – 8.3	3-15	2500-4000	12.6 – 18.4

Fresh chicken manure is potential contaminators of the environment due to the high concentration of nitrogen. The emissions of nitrates, nitrites and ammonia most of the time occur during manure storage and from fields fertilized with fresh manure. Those emissions can be reason of eutrophication of water bodies (Järvinen 2006, 7).

3 SEWAGE SLUDGE AND MANURE TREATMENT TECHNOLOGIES

There are different technologies of sewage sludge and manure treatment. The classification in Figure 1 shows the possible ways of handling manure and sewage sludge.

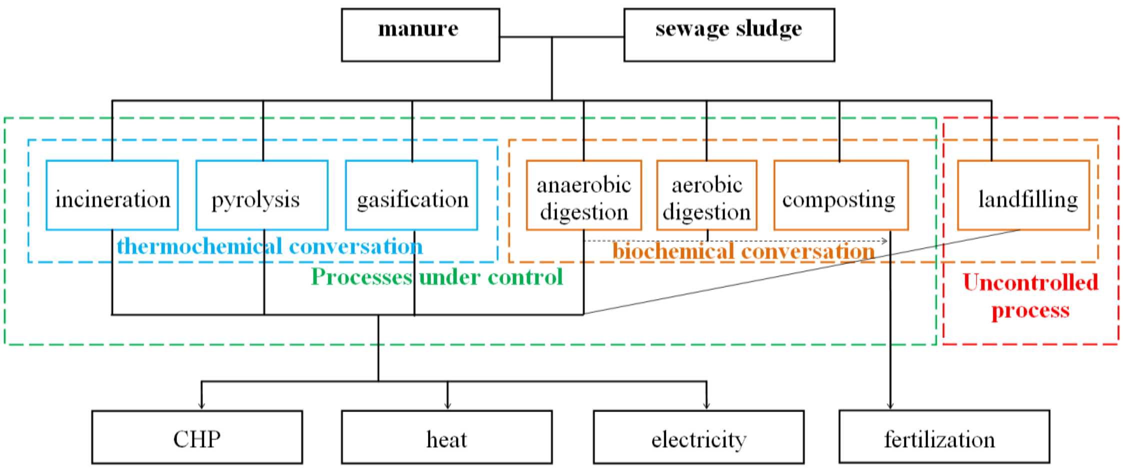


Figure 1. The possible ways of handling manure and sewage sludge and end-products of their handling. (Roinn Cumarsaids 2004).

The converting organic biomass is based on two basic platforms: the biochemical and thermochemical platforms. The incineration, pyrolysis and gasification are based on thermochemical platform. Biochemical platform contains landfilling, aerobic and AD processes.

The main factor that is needed to provide thermochemical treatment methods is a high temperature. Incineration of waste is carried out in high temperature (more than 850^0C) at optimum excess air levels. Gasification is the partial combustion of waste under substoichiometric conditions to generate a combustible gas containing carbon monoxide, hydrogen, and gaseous hydrocarbons. Pyrolysis is the thermal processing of waste in complete absence of oxygen (Tchobanoglous G. et al. 1993, 627). The processes included in biochemical platform based on the natural processes of vital activity of heterotrophic microorganisms. The difference between anaerobic and aerobic digestion processes consist in oxygen demand.

The landfilling is uncontrolled process and it is more similar to anaerobic process. For long period of time landfilling was the most common waste management practice because it was easy and economical favorably. However, the high costs associated with waste disposal, the impact on the environment, the short lifetime of landfills and restricting landfilling of organic wastes are stimulated engineers to consider new approaches to their treatment before disposal (Keri B. Cantrell 2008, 7941). Nowadays the most common option for manure and sewage sludge handling are anaerobic digestion, composting and incineration.

The final products of these technologies can be the following: fertilizers, due to manure and sewage sludge contain important elements such as phosphorus and nitrogen needed for plant growth; biogas, used as fuel: heat from the incineration and ash, which can be used in the construction as a binder, as fertilizer or be disposed at Landfill. The operational characteristics of anaerobic, aerobic and incineration systems of sewage sludge and manure handling will be described in this chapter.

3.1 Anaerobic digestion

Currently, most of studies were carried out for better understanding of AD method. This method of waste treatment can solve problems such as: waste utilization and sustainable delivery of local energy sources (biogas). In addition to waste utilization, other environmental benefits arise from this method including odor reduction, pathogen control, reducing sludge production, conservation of nutrients and reduction in green house gas emissions.

It was reported that 44% of the world's biogas plants are located in Europe. In central and north Europe, in particular, AD is widely applied in the agricultural sector. Centralized biogas plants predominantly co-digest manure together with other organic wastes (Capela I. 2008, 246).

AD treatment of animal manure with other organic substrates increases the yield of biogas (Cavinato C. et al. 2010, 545). Murto M. et al. (2003) reported that treatment of municipal sludge with suitable organic waste can be technically more successful due to using the extra capacity of the anaerobic digesters.

In this chapter will be considered the processes of AD method, how chemical composition of manure and sewage sludge influences on process behavior, quality and quantity of end-products. And also the equipment for anaerobic treatment of manure and sewage sludge will be reviewed.

3.1.1 Anaerobic digestion process

The AD treatment process is a complex of biological degradation of organic waste in anaerobic conditions (oxygen-free condition). The organic waste is degraded by special microorganisms convert it into biogas and fertilizer, leaving salts and refractory organic matter (Wilkie Ann C. 2005, 64).

This method includes four successive stages of degradation such as hydrolysis, acidogenesis, acetogenesis and methanogenesis (Claassen P.A.M. et al. 1999, 745) Separate groups of organic contaminants (carbohydrates, proteins, lipids, fats) in the process of hydrolysis are converted first to the corresponding monomers (sugars, amino acids, fatty acids). Further, these monomers in the course of enzymatic decomposition (acidogenesis) converted into organic acids, alcohols and aldehydes, which are then oxidized in the process of acetogenesis into acetic acid. Methanogenesis, carried out by slow-growing bacteria which are strict anaerobes, very sensitive to environmental changes especially to the pH (when it is less than 7.0 – 7.5) and temperature. As a by-product, along with methane is also formed a CO_2. Figure 2 depicts the different phases of the AD process.

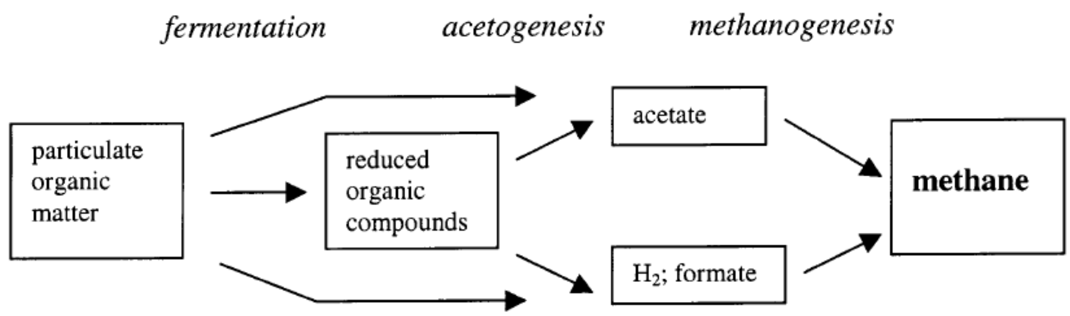


Figure 2. The different phases of the AD process. (Claassen P.A.M. et al. 1999, 745)

The biogas yield and the proportion of methane depend on the volatile content of dry matter and what kind of class of organic matter predominates in the waste. The class of organic matter is divided into carbohydrate, protein and fat. Carbohydrates in most cases it is easy to decompose, but they give a relatively smaller proportion of methane. The decomposition of fats provide a large amount of biogas with high methane content in it, however, they are decomposed very slowly (Engelhart Markus 2007).

The volatile content represents the fraction that may be converted into biogas. The most manures and sewage sludge have the volatile solids (VS) content over the range 60 to 90% of the total solids (TS) content (Capela I. 2008, 247). Capela (2008) reported that the sludge and cattle manure alone have total volatile solids (TVS) removal lower than 15%. But when the same amount of sludge and manure were treated together TVS removal of the binary mixture was higher, about 30%.

In result of degradation process of proteins the ammonia is released and formed ammonia bicarbonate. This improves AD process due to additional buffering of the digester liquid (Murto M. et al. 2004, 102). Poultry and livestock manures contain a large amount of ammonia and the degradation of proteins forms the additional quantity of ammonia. The methane-forming bacteria are very sensitive to the ammonia and may be inhibited by its amount leading to AD failure.

Excessive ammonia as well as fatty acids and hydrogen sulfide are inhibitors of methanogenesis only in their non-ionized forms. The forming of the non-ionized form is related to pH changing: the toxicity of ammonia increases above pH=7, however the toxicity of VFA and hydrogen sulfide increases below pH=7 (Murto M. et al. 2004, 105).

To avoid the inhibition of the process through formation of large quantities of ammonium, it is necessary that waste with low C/N ratio are treated in mixture with organic waste that have a low content of ammonia. Sakar et al. (2009) reported that the C/N ratio should be over the range from 20 to 30 for optimal operation.

The content of heavy metals in sewage sludge can have inhibitory effect on AD process. Therefore treatment sewage sludge with other waste is recommended, because it will reduce concentration of heavy metals and their toxicity (Steffen R et al. 1998, 19).

AD is a natural process. Wilkie Ann C. (2005) reported that biological methanogenesis occurs at temperatures over the range from 2 to 100 degree. In technical applications the most useful temperatures ranges are: psychrophilic temperature (15 - 25 degrees), mesophilic temperature (33 - 38 degrees) or thermophilic temperature (53 – 55 degrees). The thermophilic process usually has less retention time due to higher activity of bacteria at high temperatures. As a result is also a slight increase in the yield of biogas. However, this increases energy consumption of facilities to maintain temperature at high level and with higher temperature digesters are less stable.

One more important factors affecting on the rate of digestion and biogas output is the moisture content of feedstock. The optimal value of moisture content is considered as 90-94%. Fujishima et al. (2000) reported that decreasing of moisture content less than 91.1% results in declining of methane formation. Also the moisture contain is one of the main important parameters used to choose the technology and equipment for process treatment, especially in what concerns mixing and pumping needs. The anaerobic process, with moisture contain under 85% (dry process), has less sensitivity to the input of untreatable material to the reactor, because particles segregation does not happen inside of the reactor as in wet systems. On the other hand, as it was mentioned above, dry processes are not capable to attain removals as high as the ones for wet processes (Capela I. 2008, 246).

3.1.2 Treatment facilities

The main part of a biogas plant is the anaerobic reactor (digestor). Sakar et al. (2009) reported that the anaerobic treatments of sewage sludge, poultry, cattle and pig manures are carried out in the various types of reactors and some of these types are the following: fixed-film reactor, attached-film bioreactor, anaerobic rotating biological reactor, up-flow anaerobic sludge blanket (UASB), continuously stirred tank reactor (CSTR), anaerobic hybrid reactor (AHR), two-stage anaerobic systems etc.

In the report of Roos K.F. and Moser M.A. (2003) it was showed the relation of liquid and slurry manure characteristics and handling systems to specific types of biogas production systems. As it was decried earlier liquid, slurry, and semisolid systems have high biogas production potentials. It was reported that facilities that handle solid manure will find it difficult to adopt biogas technology. They will need to incorporate a new manure handling system but such changes can be expensive. In these situations, other effective manure management options (e.g., composting) should be considered. The dependence of manure characteristics and handling systems to specific types of biogas digester systems are presented in the Figure 3.

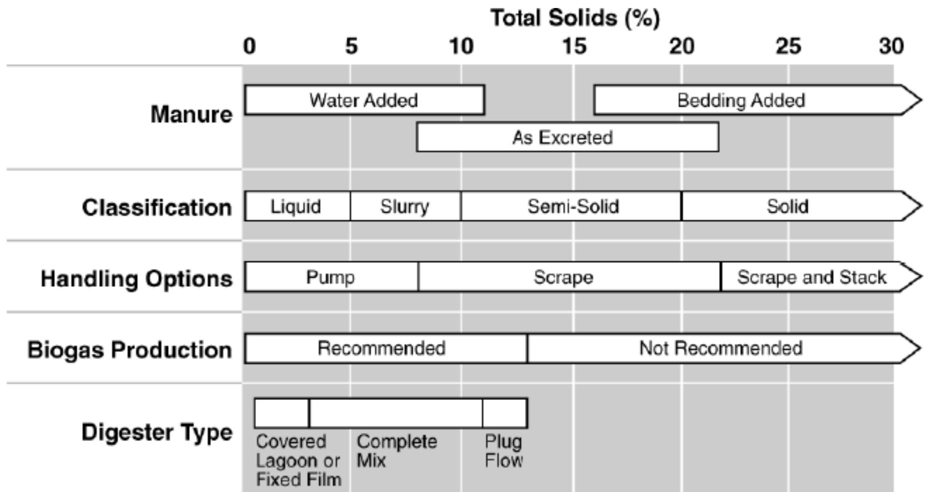


Figure 3. Appropriate manure characteristics and handling systems for specific types of biogas digester systems. (Roos K.F. and M.A. Moser 2003, 2-3)

According to the mode of feeding all types of digester are divided into three types of reactor systems, namely, batch process, plug flow and continuous process. It is typical for batch process that the feedstock is put into the reactor at the beginning of the digestion process, and then the reactor is closed for the whole period without more feedstock being added. The batch reactor is still the most widely used reactor type both in the laboratory and industry. However, industrial practice generally favors processing continuously rather than in single batches, because overall investment and operating costs usually are less (Bhattacharya A. N. et al. 2003). In plug flow and continuous process, the reactor is continuously fed with feedstock and continually emptied. The AD with continuous reactor systems is mostly used for treatment of waste with high water content while batch and plug flow reactor systems are normally used for treatment of waste with lower water content. All three types of systems are used in the digestion of animal by-products. Figure 4 depicts schematic sketch of anaerobic digesters according to the classification given above.

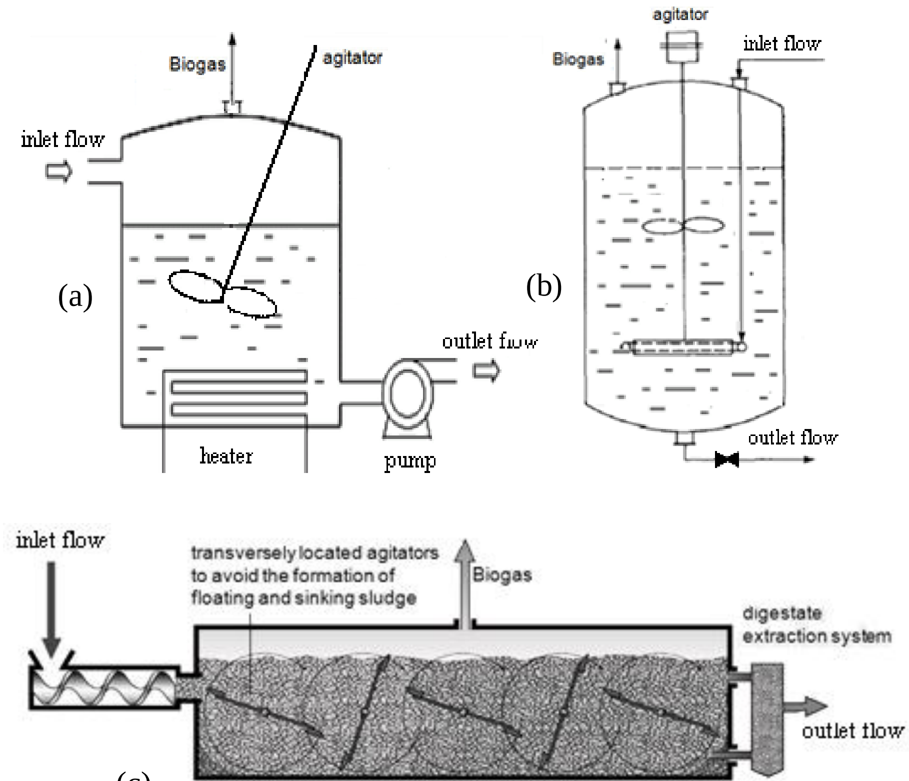


Figure 4. Schematic drawing of the anaerobic digesters according to the mode of feeding: (a) batch process reactor, (b) continuous process reactor and (c) plug flow reactor. (Bhattacharya A. N. et al. 2003; Scott MacKay, 2000)

As has been described previously, anaerobic process of waste treatment is carried out in the anaerobic reactor (digester). However, for the uninterruptible operation of the reactor and its profitability it is necessary that the biogas plant involves at the least the following elements: (1) the production unit, which includes the manure removal system or waste water treatment plant, where sewage sludge is produced, possibly an influent holding tank and/or a sanitation unit and the anaerobic digester, (2) the safety and gas upgrading equipment, (3) the gas storage facilities and (4) the equipment for gas and manure utilization (Wellinger A. 1999, 15). Figure 5 depicts the four basic elements of a biogas installation.

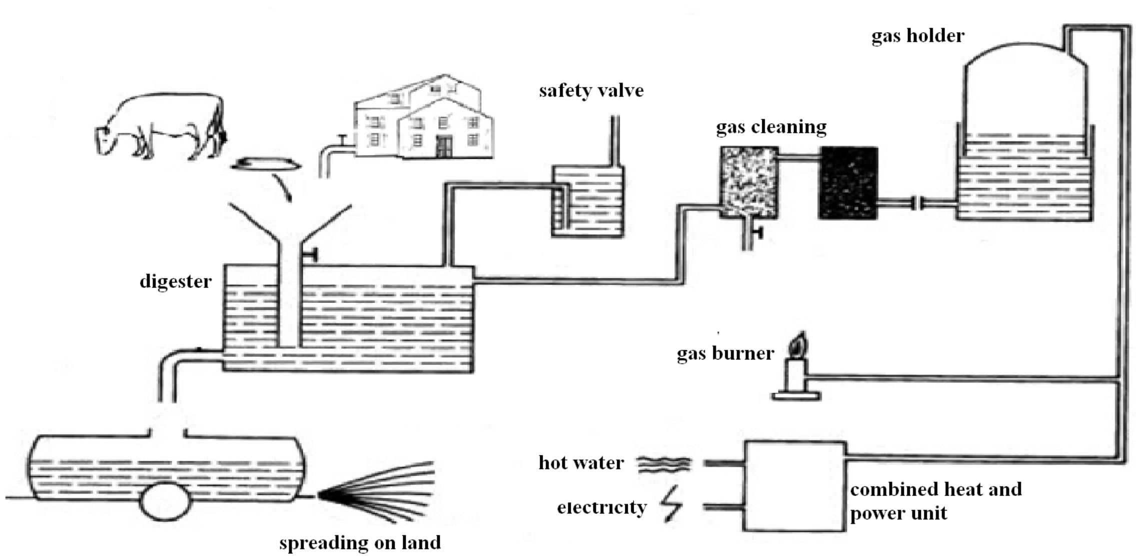


Figure 5. The four basic elements of a biogas installation (Wellinger A. 1999, 15).

If consider co-digestion process of sewage sludge and manure it is need to evaluate what is the most preferable site for their treatment. It could be treated in farms or in wastewater treatment plant. The choice depends on the different factors such as: economical profile of the area, the intensity and density of farming, general impact of manure or sewage sludge transportation, potential uses of waste heat in the area (district heating, in-plant uses) or uses of waste heat in the farm, existence of professional technology suppliers and consultants **(**Flotats X. et al. 2008, 5520**).**

3.1.3 End-products

The most attractive end-products from AD are biogas and digestate. Biogas basically consists of CH_4 and CO_2. The contents of CH_4 and CO_2 in biogas from manure and sewage sludge anaerobic digestion are over the range 40-70% (Järvinen 2006, 46; Scherbo 2008). Depending on methane content in gas mixture, after manure and sewage sludge digestion, the biogas lower heating value (LHV) is variable from 9,25 MJ/m^3 to 16,21 MJ/m^3 for dry biogas (Ludington D. 2006). The biogas also contains traces of other gases, such as hydrogen sulfide (0-3%), nitrogen (0-10%), hydrogen (0-1%) and oxygen (0-2%) (Bio-east 2007).

Carrère Hélène (2009) emphasized that biogas production from pig manure is relatively low: from 290 to 550 l CH_4/kg of organic matter. Methane potential of chicken manure is usually higher than from other manure and in the range from 0.04 to 0.06 m^3/kg wet weight (Salminen E. 2002, 20). The typical characteristics and operational parameters of manure and sewage sludge are presented in Table 7. Besides, the table 7 depicts the main substances which can be contained in feedstock and cause fails of digestion process.

Table 7. The typical characteristics and operational parameters of manure and sewage sludge and problems linked with these types of waste. (Scherbo 2008; Koottatep S. et al. 2008, 39; Klein E. Ileleji et al. 2008, 3; Horttanainen M. et al. 2009)

Type of feedstock	**Biogas yield**		**Retention time**	**CH_4 content**	**Unwanted substances**	**Inhibiting substances**	**Frequent problem**
	m^3,kg^{-1}_{VS}	**l/$kg_{d.m.}$**	**days**	**%**			
Cattle manure	0.20-0.30	90 – 310	20-30	55-75	Bristles, soil, H_2O, NH^{4+}, .straw, wood	Antibiotics, disinfectants	Scum layers, poor biogas yield
Pig manure	0.25 – 0.50	340 – 580	20-40	70-80	Bristles, H_2O, sand, cords, straw	Antibiotics, disinfectants	Scum layers, sediments
Chicken manure	0.35 – 0.60	310 – 620	> 30	60-80	NH^{4+}, grit, sand, feathers	Antibiotics, disinfectants	NH^{4+}-inhibition, scum layers
Sewage sludge	0.3	310 - 740		70-80	Grit, sand	Heavy metals	Scum layers, sediments

Biogas can be used to produced heat and generate electricity, serve as transportation fuels (Keri B. Cantrell et. al. 2008, 7941). For heat production from biogas combustion the boilers can be used. Boilers do not have a high gas quality requirement. For production both electricity and heat biogas is also used in Combined Heat and Power (CHP) units. For the application biogas in CHP the content of H_2S should be lower. The utilization of biogas as fuel for vehicles requires high quality of gas and it should be upgrade by removing H_2S, CO_2, NH_3, H_2O and particles matter. Some of technologies used to remove CO_2 and hydrogen sulfide for upgrading biogas are the following: water scrubbing, polyethylene glycol scrubbing, carbon molecular sieves, membranes separation, air/oxygen dosing to digester biogas, activated carbon, NaOH scrubbing etc (Monnet F. 2003, 18-21).

As a result of the biogas process residue called digestate is produced. It can be used as a soil conditioner to fertilize a land. Digestate is technically not compost although it is similar to it in physical and chemical characteristics. The structure of digested sludge is fine and homogeneous; color is nearly black or dark gray (Yakovlev 2006, 247).

Table 8. Characteristics of the digested sewage sludge and manures. (Karakashev 2008, 4085; Yakovlev 2006, 251; Voća N. 2005, 264; Merrington G. et al. 2002, 23; Kricka T. et al. 2003; Adelekan B.A. and Bamgboy A.I. 2009, 1337)

Parameters	**Type of treated waste**			
	Sewage sludge	**Poultry manure**	**Cattle manure**	**Pig manure**
pH	6.5-7.5	6.7-8.1	7.5	5.4-8.1
TS, %	6-12	7.6 - 28.75	8-10	3.8
$N-NH_4^+$, %		0.52-1.6		0.1
N-total on dry matter, %	1.6 – 6.0	2.16-5.4	2.06	2.14 – 6.5
P-total, %	1.4 – 4.0	1.14	0.69	1.02
$P-PO_4^{3+}$, %		1.7 - 1.96		1.7
K_2O, %	0-3.0	3.6	0.58	3.6

In addition, a complete destruction of pathogenic microflora, helminthes eggs and weed seeds is achieved. Anaerobically digested materials can be used as animal feed, but legislation becoming tighter and restricting this practice (Salminen E. 2002, 22).

3.2 Composting

Tchobanoglous G. et al. (1993) reported that composting of sewage sludge has received increased attention as a cost-effective and environmentally sound alternate for stabilization and ultimate disposal of sewage sludge since the mid-1970s. Currently in Europe, due to the increasing demand for biomass fuels and new renewable energy policies the composting process of waste treatment becomes less popular. However it is still wide used for manure and sewage sludge handling. Below this method and its characteristics will be described.

3.2.1 Composting process

Composting is a process of decomposition of organic matter carried out under the action of aerobic microorganisms for the purpose of stabilization, decontamination and preparation of sewage sludge and manures for disposal as a fertilizer. Decomposition of organic matter is characterized by the following equations:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \quad (1)$$

$$C_{10}H_{19}O_3N + 12.5O_2 \rightarrow 10CO_2 + 8H_2O + NH_3 \quad (2)$$

These reactions are accompanied by heat release (Yakovlev 2006, 275).

The effective composting process occurs when moisture content of sludge does not exceed 60-80%, and the optimum ratio of carbon and nitrogen is C/N = 20:1-30:1 (Yakovlev 2006, 275). Insufficient high nitrogen levels (low C/N ratio) will result in odor, so it is important to ensure that the mixture meets the criteria for good composting (Saskatchewan Ministry of Agricalture 2008).

To create a porous structure of the sludge, the required moisture content and ratio of carbon and nitrogen the sludge is mixed with filler. Leaves, straw, sawdust, peat, dry sludge and other similar components are used as loosening and dehumidifying additives.

The composting process consists of two phases. The first phase lasts from 1 to 3 weeks and is accompanied by intensive development of microorganisms, and the temperature is raised to 50-80 °C. Disinfection and reduction of mass of treated material are reached during this phase.

The second phase is much longer. It lasts from 2 weeks to 3-6 months and accompanied by the evolution of simple organisms and arthropods. The temperature is lowered to

40°C and below. Increasing the ambient temperature intensifies the process of decomposition of organic substances.

The supplying of compostable material by oxygen is an important factor for the composting process. Stoichiometric oxygen demand for the process in accordance with the above equations is in average 1-1,5 kg of O_2 per 1 kg of organic matter. This amount of the air is necessary to start the process in the first 3-6 days and reach a temperature sufficient for decontamination. In subsequent periods, the need for air is also determined by the need to remove water from the sludge. The recommended conditions for rapid composting process are represented in the table 9.

Table 9. The recommended conditions for rapid composting process. (Saskatchewan Ministry of Agricalture 2008)

Condition	Reasonable range	Preferred range
Carbon-to-nitrogen ratio, C/N	20:1 – 40:1	25:1 – 30:1
Moisture content, %	45 – 65	50 – 60
Oxygen concentration, %	5	5
Particle size, cm	0.5 – 5.0	0.5 – 2.5
pH	5.5 – 8.0	5.5 – 8.0
Temperature, ^{0}C	43 – 66	54 – 60

3.2.2 Treatment methods

In recent years, various methods of composting of sewage sludge and manure are developed and applied, among which three are basic: windrow, aerated static pile and in-vessel. Basic operations of the process in all systems of composting are completely analogous.

The aerated static pile method is most prevalent. Its distinction from the windrow method is the forming of unmovable piles on the places with waterproof coating (asphalt or concrete).

Piles are spilled in trapezoid shape with the use of mechanization. Piles height is 3.5m, its width is of from 6 to 12 m and length is not restricted. Perforated pipes are laid under the foundation of pile. Its diameter is 100-200 mm with size of hole from 8 to 10 mm.

Air flow is adopted 10-25 m^3/h per ton of organic matter of the mixture. Technological regime provides covering of compostable mass by safe material, such as compost with a layer of 20 cm or more. Coverage is used to prevent breeding of flies and rodents and, furthermore, provides thermal protection of treated masses. The schema of this method is represented in Figure 6.

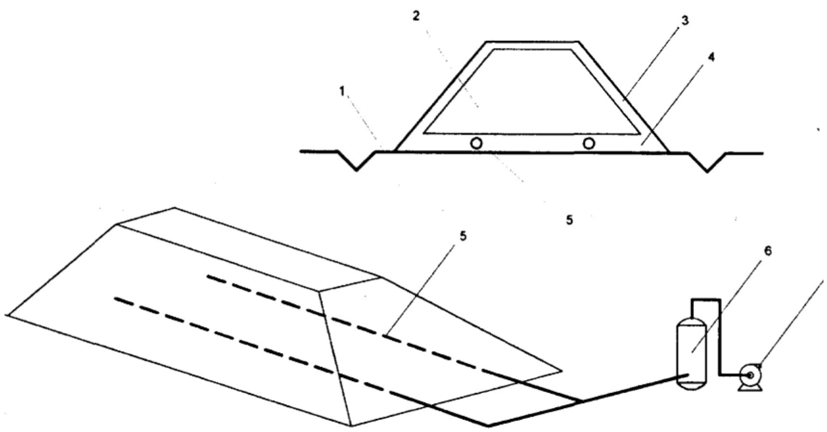
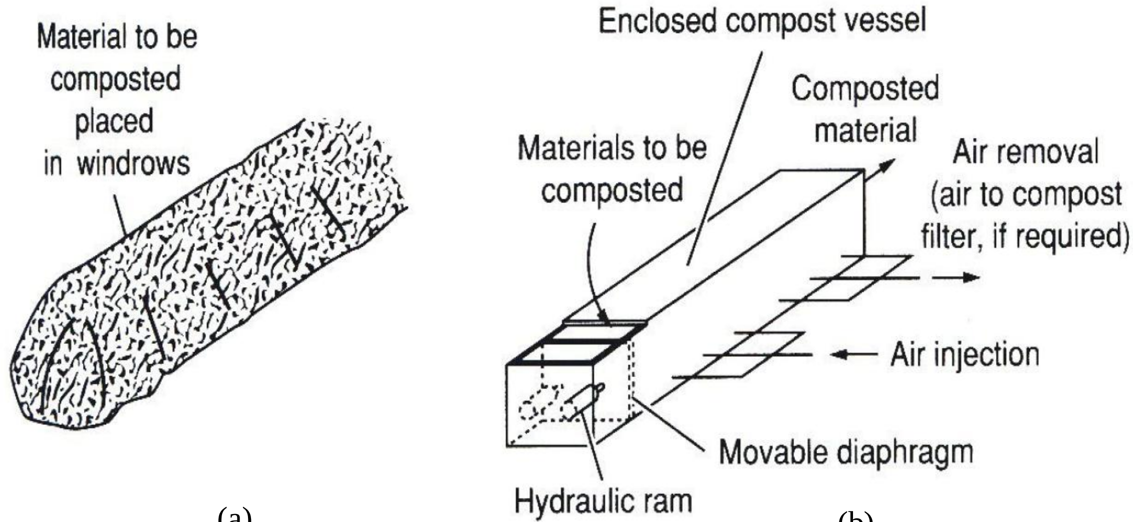


Figure 6. Schema of aerated static pile composting method with forced aeration.

1 – asphalt foundation; 2 – pile; 3 – covering material; 4 – base; 5 – perforated pipes; 6 – separator; 7 - vacuum fan (Yakovlev 2006, 277).

The composting process windrow carry out in open areas with natural ventilation and periodic turning of the mixture to ensure anaerobic conditions. The mixture of sludge with additives placed in the ridges of triangular cross section usually with a base from 1.8 to 4.6 m and a height from 0.9 to 1.5 m (Yakovlev 2006, 277).

In-vessel composting is realized inside an enclosed container or closed vessel. This method allows to reduce odors and to increase efficient of the composting system by controlling such as temperature, air flow, and oxygen concentration. In-vessel composting systems can be divided into two major categories: plug flow and dynamic. Plug flow system operates on the first-in, first-out principle, whereas in the dynamic system the material is mechanically mixed during the composting (Thobanoglous et al. 1993, 685). These windrow and in-vessel composting systems are shown in Figure 7.



(a) (b)

Figure 7. Schemes of composting systems: (a) windrow and (b) in-vessel composting system. (Thobanoglous et al. 1993, 685)

3.2.3 End-products

As a result of the composting process the compost is produced with less moisture content (about 40-50%), no smell and no rotting. It can be used as a good fertilizer (Yakovlev 2006, 276). Poultry manure has significantly more nitrogen, phosphorus and potassium than the manure of cattle and pigs. Number of nutrients of poultry manure is changed significantly depending on the conditions of feeding and housing of poultry. Poultry manure contains elements such as boron, copper, manganese, molybdenum, zinc, iron. The properties of organic fertilizer based on sewage sludge, chicken manure, cattle manure and pig manure are shown in Table 10.

Table 10. Properties of organic fertilizer based on sewage sludge, chicken manure, cattle manure and pig manure. (Guselnikov P.N. and Chugulaev F.K. 2010; Vergnoux 2009, 2393; Wong 1995, 3; Perez-Murcia 2006, 124; Terrance D. 2002; Järvinen 2007, 31)

Type of feedstocks		Moisture,%	C/N ratio	pH	N_{total}, g/l	P_{total}, g/l	K_{total}, g/l
Sewage sludge		13.3-34	9.1-13.5	6.83-8.0	0.69-0.86	0.59	
Chicken manure	with litter	45	18 - 20	6.0-8.5	1.8	0.7	0.6
	young poultry	65	18 - 20	6.0-8.5	1.4	0.4	0.5
	mature	75	18 - 20	6.0-8.5	1.2	0.3	0.3
Cattle manure		22.9	21.4-7.9	6.7	0.88	0.66	0.74
Pig manure		31.3 – 53.4	10.7	7.4-8.3	1.69	1.17	2.06
According to TU 9819-036-00483170-97		70	20-30	6.0-8.5	> 0.6	> 0.6	> 0.5

Organic fertilizers enrich the soil with nutrients and also make it looser, improve its moisture and air regime. Organic fertilizers not only contribute to higher crop yields, but they also improve the quality.

The use of organic fertilizers (preparation, transportation, application) is cost intensive. Gained yield premium owing to organic fertilizers application has to cover the expenses on their use. The advantage of organic fertilizers over mineral fertilizers is also their long-term after-effect in soil.

However, the use of the material treated either by anaerobic or composting methods has some difficulties especially if the feedstock is the sewage sludge. The first difficulty lies in the fact that its application on land takes place once or twice a year; however, sewage sludge and manures are produced all year round, so there is need an extra place to storage treated material (Fytili 2008, 124).

3.3. Incineration

One more method for waste disposal is incineration. Fytili D. (2008) has reported that this method is one of the most attractive disposal method, currently in Europe. For instance, the amount of sludge being incinerated in Denmark has already reached the percentage of 24% of the sludge produced, 20% in France, 15% in Belgium, 14% in

Germany while in USA and Japan the percentage has increased to 25% and 55%, respectively. It has become popular due to the limitations of agricultural reuse of waste and prohibition of Landfill disposal of organic waste.

3.3.1 Incineration process

Incineration refers to technologies of thermal destruction. Incineration - is an oxidation process of organic part of sewage sludge and manure to non-toxic gases (CO_2, water vapor and nitrogen) and ash. The principal aim of incineration of sewage sludge and manure is the utilization of the stored energy in waste, on the one hand the reducing of environmental impacts, in order to meet the environmental standards (Fytili 2008, 124).

The combustion process consists of the following stages: heating, drying, volatilization of volatile substances, incineration of the organic part and calcinations to burn residual carbon. Ignition of sludge occurs at a temperature of 200-500 °C. The temperature inside the furnace should be between 850-1000 °C (Yakovlev 2006, 304). Also for keeping up this temperature, auxiliary fuel (e.g. natural gas) usually needs to be added.

Due to sewage sludge and manure contain high moisture content the majority of energy released during thermal processes is consumed to vaporize the moisture. To avoid this before the burning of sewage sludge and manure they have to be dewatered either mechanically, thermally or by both processes.

Novagro Finland Oy develops the method of manure processing that is based on the use of two incorporated processes: drying and incineration. The heat from the combustion of dried manure is used for the drying of raw manure. The amount of heat which can be received depends on the initial moisture content in manure and the percent of ash in dry matter (Järvinen 2007, 36).

Installations for the incineration of sludge should provide complete combustion of organic part of sludge and manure. It could be reach with optimal temperature (higher than 850 ^{0}C) and optimal air supply. Combustion gases mainly contain nitrogen, carbon dioxide, oxygen and water vapor (flue gases). Small amounts of sulfur dioxide, nitrogen oxides, ammonia, and other trace gases are also present. Due to sludge contains some amount of heavy metals the concentration of toxic components can be high and this can cause serious difficulties in the purification of flue gases before releasing them into the atmosphere (Stasta P. et al. 2006, 1421).

3.3.2 Facilities used for incineration process

For incineration of sewage sludge multiple-hearth furnaces and fluidized bed are commonly used (Yakovlev 2006, 304).

Incineration in multiple hearth furnaces. Frame of multiple-hearth furnace is a vertical steel cylinder lined inside with refractory brick. Fire-chamber divided by height into 7-9 horizontal hearths. There is a vertical shaft in the center of the furnace, on which the horizontal truss are located. Each has a hole, one hearth has hole located on the periphery, and second hearth has hole located in the central part.

Sludge is feed by conveyor through the loading hatch, and then it is moved to the hole and dropped to a lower lying, etc. Vertical shaft and truss are made hollow and cooled by air supplied by a fan.

On the upper hearths sludge is dried, on medium hearths an organic part of sludge is combusted at a temperature of 600-900 ^{0}C, and on the bottom hearths the ash is cooled before being discharged into the bunker. From the furnace gases are discharged in the wet dust collector and by smoke exhauster emitted into the atmosphere. This system is shown in Figure 8.

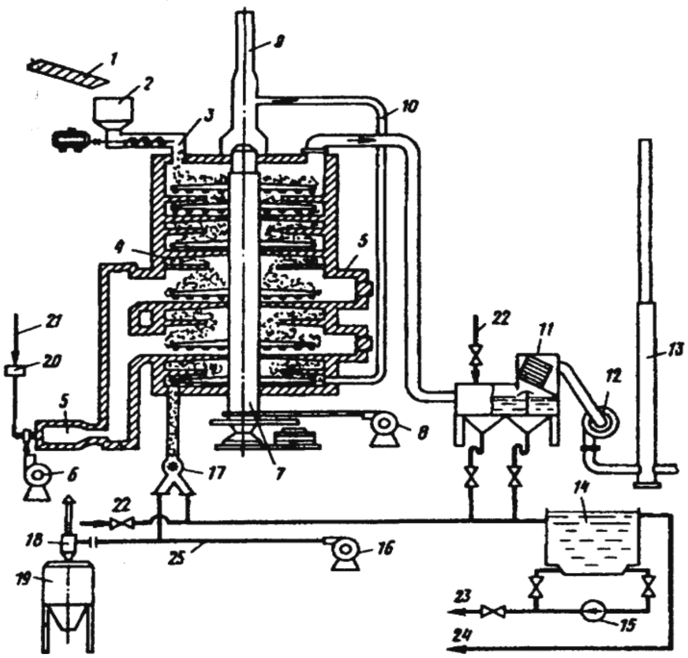


Figure 8. Schema of incineration of sewage sludge and manure in multiple hearth furnaces (Yakovlev 2006, 304):

1- belt conveyor; 2 – loading hatch; 3 - screw feeder; 4 - multiple hearth furnace; 5 – external chamber; 6 - blow fan; 7 - shaft; 8 - cooling fan; 9 - atmospheric pipe; 10 – recirculation pipe; 11 - wet dust collector; 12 - smoke exhauster; 13 - chimney; 14 – bunker of ash; 15 – pump for ash water; 16 – fan of pneumatic transport; 17 - lock feeder; 18 – outlet of cyclone; 19 – bunker of ash discharged; 20 - gas-regulating facility; 21 - pipe of fuel gas; 22 – water pipe; 23 – ash pipe; 24 - wastewater pipe; 25 - air pipe.

Multiple hearth furnaces are simple and reliable in operation. Its disadvantages include the high construction cost and large size of furnace (Yakovlev 2006, 304).

Fluidized bed furnace is a vertical steel cylinder, lined inside with refractory bricks. There is a perforated grid in the lower section supporting a bed of sand inside the furnace. The sand grain size is from 0.6 to 2.5 mm and the depth of the static bed is usually 0.8-1.2 m (Tchobanoglous G. et al. 1993, 622). The sand particles become suspended when air at high pressure is forced through the bed of sand. Sludge is fed into the furnace through the loading hatch.

The intensive mixing of sludge in the fluidized bed occurs in the furnace with instantaneous evaporation of moisture and the release of volatile organic compounds. This process lasts 1 - 2 min. 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.

The burnout particles are removed from the furnace by exhaust gases. Flue gases are cooled in the air heater and ash collected in air pollution control.

The advantages of fluidized bed furnace are compact size, intensity of the process, possibility of the incineration of sludge with different moisture content. The disadvantages are large concentration of ash in the exhaust gases and the need of air heater. This system is shown in Figure 9.

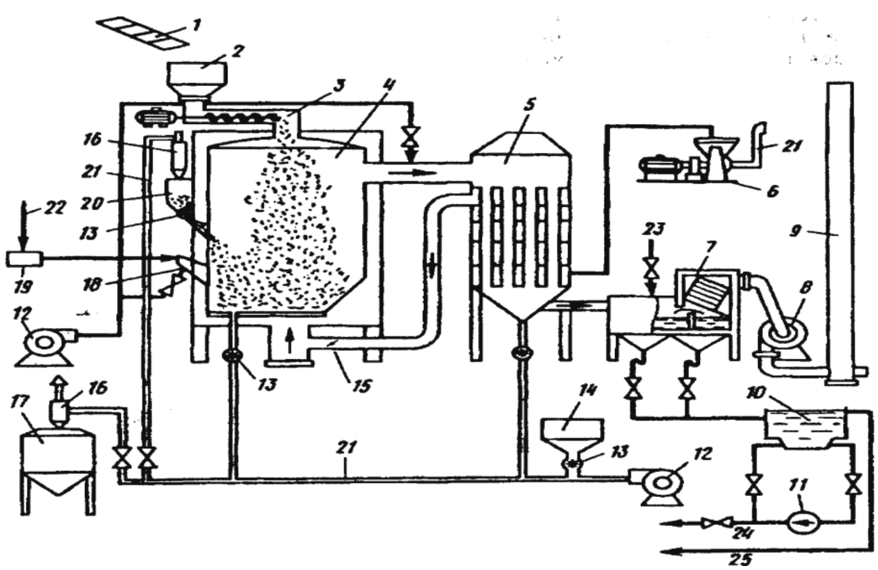


Figure 9. Schema of incineration for sewage sludge and manure in fluidized bed combustion system (Yakovlev 2006, 305): 1 - belt conveyor; 2 – loading hatch; 3 - screw feeder; 4 - fluidized bed furnace; 5 - recuperator; 6 - blow fan; 7 - scrubber; 8 - smoke exhauster; 9 - chimney; 10 - bunker of ash; 11 - pump for ash water; 12 - fan; 13 - lock feeder; 14 – bunker for sand; 15 - valve; 16 - outlet of cyclone; 17 - bunker of ash discharged; 18 – gas burner; 19 - gas-regulating facility; 20 - measuring hopper; 21 - air pipe; 22 – gas pip; 23 –water pipe; 24 – ash pipe; 25 – wastewater pipe.

3.3.3 End-products

In the case of incineration there is ash represents final residue. This can be used as a secondary building material or finally landfilled (Stasta P. et al. 2006, 1421). Järvinen et al. (2007) reported that ash can be used as raw material for fertilizer production. The ash analyses of manure and sewage sludge are represented in the table 11.

Table 11. Composition of manure and sewage sludge ashes. (Werther J. and Ogada T. 1999, 76; Miller S.F. and Miller B.G. 2007, 1157)

Component	**The value of components content according to the type of feedstock, wt% dry**			
	Poultry litter	**Sewage sludge**	**Dairy free-stall**	**Dairy tie-stall**
Al_2O_3	9.14	8-15	0.96	2.26
BaO	0.05		0.02	0.02
CaO	12.7	9-22	6.38	23.3
Fe_2O_3	4.04	5-23	1.29	1.37
K_2O	9.94		6.75	10.7
MgO	4.01	1-2	2.65	8.91
MnO	0.36		0.17	0.14
Na_2O	3.60		1.32	7.04
P_2O_5	14.0		2.90	14.7
SiO_2	39.4	30-49	74.98	26.0
SO_3	2.58		0.04	0.14
SrO	0.03		0.10	0.11
TiO_2	0.51		2.06	5.08

4 LEGISLATION CONCERNING TREATMENT METHODS OF MANURE AND SEWAGE SLUDGE

Legislation plays a key role in environmental protection. Although the legislation is quite comprehensive, it has been constantly evolving in response to changes in society and needs of society. The grow impact to the environment produced by the humanity leads to necessity to improve legislations and implement new acts and decree.

The knowledge of the laws and requirements for the quality of the environment allows providing technical and economic assessment to select cost-effective and environmentally friendly technology for waste management, and the knowledge of government programs for the protection of the environment helps to implement this technologies. In this section it will be shortly discussed the main draft legislations, programs and acts concerning of manure and sewage sludge treatment in Finland and Russian Federation.

4.1 Finnish Legislation and Normative Acts

In view of the fact that in 1995 Finland joined the European Union the main legislation is based on the directives and acts of the European Union. The Finland has adopted a number of Decrees and Acts aimed at guaranteeing environmental protection. The ones most relevant to sewage sludge and manure management are the following:

- **ENVIRONMENTAL PROTECTION ACT (86/2000)**

The European Union directive about Integrated Pollution Prevention and Control (IPPC) was integrated in Finland through the Environmental Protection Act (86/2000). This act aims to minimize pollution to air, water and soil caused by industry through the application of best available techniques (BAT) (Environmental Protection Act, 4 February 2000/86).

- **ENVIRONMENTAL PROTECTION DECREE (169/2000)**

This decree lists the activities that should have an environmental permit. For example livestock shelters, boiler plants, wastewater treatment plants and etc. An also activities not subject to environmental permit such as the recovery of treated, non-hazardous sludge from wastewater or septic tanks, manure, or non-hazardous ashes or cinders as soil improvement material or fertilizer (Environmental Protection Decree, 18 February 2000/169).

- **THE NITRATES DIRECTIVE (91/676/EEC)**

The aim of the Nitrates Directive is reduction the release of nitrates from agricultural sources into water bodies. In Finland, **the Nitrates Directive** is transposed to national legislation through **the Environmental Protection Act** (2000/86) and **Government Decree No 931/2000**.

- **GOVERNMENT DECREE (931/2000)**

The Decree specifies limits for the use of nitrate fertilizers and nitrate contained in animal manure. Some of the recommendations are the following (Government Decree, 9 November 2000/931):

- ✓ applying of manure is allowable from the first of April until the fifteenth of November;
- ✓ manure may not be applied on grassland after the fifteenth of September;
- ✓ applying manure on a field as fertilizer equivalent to a maximum of 170 kg/ha/year of nitrogen;
- ✓ applying of nitrogen fertilizers is prohibited on areas closer than five meters to a watercourse. Along the width of the next five meters, surface application of nitrogen fertilizers is prohibited if the field slope exceeds 2%;
- ✓ surface application of animal manure is always prohibited on fields with an average slope of over 10%;

- ✓ animal manure storage for waste products excreted by animals must be sufficiently large for manure accumulated over 12 months, excluding manure remaining on pasture during the same grazing season;
- ✓ manure storages and manure gutters must be watertight;
- ✓ using leak-proof equipments for manure storage and transportation.

- **THE WASTE ACT (1072/1993)**

One of the aims of this Act is prevention and restriction of the threat and harm to human health and the environment associated with waste (The Waste Act, 3 December 1993/1072).

- **FERTILIZER PRODUCTS ACT (539/2006)**

This Act is aimed to promote the appropriate use of sewage sludge in agriculture. In order to prevent harmful impacts on the environment and health it was established that only sludge containing less than the maximum concentrations of heavy metals may be used. Also the use of sewage sludge is governed by the complementary Decrees of the Ministry of Agriculture and Forestry, (12/07) on fertilizer products and (13/07) on carrying out activities concerning fertilizer products, in which the conditions for the utilization of sewage sludge as a fertilizer product are imposed. (Protocol on Water and Health to the 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes, 2008)

- **THE NATIONAL DECREE ON INCINERATION OF WASTE (362/2003)**

This Decree is based on the Directive 2000/76/EC. This Decree is aimed to prevent and reduce negative effect of the incineration of waste by setting limit values for emissions of pollutants to air due to waste incineration. It shall be carried out the continuously measurements of pollutants such as NO_x, CO, total dust, TOC, HCl, HF, SO_2 and at least two measurements per year of heavy metals, dioxins and furans (Decree on waste incineration, 15 May 2003/362).

- **GOVERNMENT DECISION ON LANDFILL SITES (861/1997)**

The Government Decision on landfills (861/1997, amendment 202/2006) sets general limitations on the landfilling of waste. (Government Decision on Landfill Sites, 4 September 1997/861)

- **NATIONAL WASTE PLAN UNTIL 2016**

The aims of this plan are to develop the Finnish waste management system and promoting waste prevention. Some of the goals of this plan are the reduction of hazard for health and the environment from waste management and developing and clarifying the organization of waste management. Among other things for reduction of hazard for health and environment the measures to promote the construction of biogas plants so that manure and certain other types of waste can be utilized will be included. And for implementation of developing and clarifying the organization of waste management goal it will be provided the additional guidelines concerning animal by-products, ash generated by waste incineration and waste management during exceptional situations. Municipalities will ensure that the collection of sludge in rural areas will be applied to an efficient basis and that the collection capacity is sufficient. This plan set the additional targets which are the following (The Finnish Environment 14/2009, 34):

- ✓ all manure from farming activity should be recovered;
- ✓ 90 % of sludge originating in sparsely populated areas should be treated in sewage treatment plants and;
- ✓ 10 % in biogas plants of farms;
- ✓ 70 % of construction and demolition waste should be recovered by material or energy recovery;
- ✓ 100% of the municipal sewage sludge should be recovered.

- **THE NATIONAL ACTION PLAN**

Finland has developed the National Action Plan to intensify the protection of the Baltic Sea and inland waters. The Plan is to be implemented by 2015. All activities are coordinated by HELCOM. One of the main goals is combating eutrophication.

The measures are targeted at reducing nutrient loads from agriculture, municipal wastewater, rural settlements, and industry and from neighboring countries. In the Action Plan target nutrient loads have been defined for various sectors, with a requirement to comply with targets by 2015–2021 (HELCOM 2009, 98).

- **NATIONAL BIOWASTE STRATEGY 2004**

This strategy aims to reduce the amount of biodegradable municipal waste which may be disposed in a landfill sites during the period 2006-2016. The measures used to reach this target is contain more recycling, the wider use of biological waste treatment methods such as composting, and the increased use of wastes in energy production (Ministry of the Environment, 2008).

4.2 Russian Legislation and Normative Acts

The fundamental legislation in the field of environmental protection in Russian Federation includes the following acts and standards:

- **The Federal Law №7-FZ «About Preservation of the Environment», dated 10.01.02**

One of the statements from this law is “that purposes of the agricultural management should include strict observance of environmental requirements and implementation of the measures to protect the land, soils, water bodies, plants, animals and other organisms against the adverse effect of economic and other activity on the environment”. This law obliges to the waste treatment and the safe waste disposal. (Waste, 2009)

- **Federal Law № 101-FZ "On state regulation of ensuring of the agricultural land fertility", dated 16.07.1998**

The main purpose of this law to establish the rights and obligations of legal entities and individuals engaged in agricultural production on the effective use of soil fertility. Among the other statement from this law is that land proprietors, owners, and users, tenants included, are obliged to organize agricultural production in such a way that fertility restoration of the lands of agricultural designation is guaranteed (Federal Law № 101-FZ, 1998). On the basis of this law the Law of Leningrad Oblast "On State Regulation of Agricultural Land" (№ 41, dated 12.07.1999) was adopted.

- **Federal Law № 89-FZ «Production and Consumption of waste», dated 24.06.1998**

This federal law defines the legal basis of waste production and consumption in order to prevent the harmful effects of waste production and consumption on health and the environment, as well as the contribution of such waste in the economic turnover as additional sources of raw materials (Federal Law № 89-FZ, 1998).

- **Federal Law № 96-FZ "Law of Air Protection", dated 04.05.1999**

This law regulates the requirements to prevent adverse effects on atmospheric air from wastes during their storage, treatment and disposal (Federal Law № 96-FZ, 1999)

- **The Land Code of RF dated 4 December 2006, № 200-FZ**

One of the purposes of this law is to obligate the users of land to protect the land from cluttering by waste from production and consumption (The Land Code of RF, 2006).

Environmental requirements in the field of waste handling are also regulated by the Water Code of the Russian Federation, the Forestry Code of the Russian Federation and the Criminal Code of the Russian Federation. (Waste - supplemental information system 2009.)

- **Environmental Doctrine of the Russian Federation**

This document determines the goals, direction, objectives and principles of the Russian Federation of a uniform state policy in the field of ecology in the long term. The main task is to reduce pollution produced by emissions, discharges and wastes. To solve this problem the following conditions should be met (Environmental Doctrine of the Russian Federation, 2002):

- ✓ to use resource-saving technology and waste less technologies in all spheres of economic activity;
- ✓ the gradual decommissioning of enterprises with out-of-date technologies;
- ✓ equipping of the enterprises with modern environmental equipment;
- ✓ support for eco-efficient production of energy, including renewable and recycled materials;
- ✓ development of systems using secondary resources, including waste;

To ensure the quality requirements of the environment during treatment of sewage sludge and manure, as well as their further use and deployment, it is necessary to observe the following standards, norms and regulations:

- **Sanitary Regulations and Norms (SanPiN) 1.2.1170-02 "Hygienic requirements to safety of agro chemicals"**

In this document the recommendation about organic fertilizers are given, and some of them are listed below (SanPiN 1.2.1170-02):

- ✓ organic fertilizers should be disinfected and be free from any pathogenic flora and;
- ✓ come from farms which are considered safe in terms of diseases common to humans and animals (poultry).

- **State Standard (GOST) 26074-84. “Liquid manure. Veterinary and sanitary requirements for treatment, storage, transportation and utilization”;**

In this document the rules to apply liquid manure is introduced. And it is recommended to apply the manure in autumn and spring-summer time. The most effected application is considered as autumn application with plowing. To apply liquid manure during the vegetation period it is essential to detect a waiting period from the last application to the harvest or yield use (GOST 26074-84).

- **State Standard (GOST) 17.4.3.07-2001 “Protection of Nature. Requirements to the wastewater sludge properties when used as fertilizers”;**

This document regulates the hygienic and sanitary parameters, the agro-chemical parameters and concentration of heavy metals of sludge formed during the treatment of household, urban (a mixture of household and industrial), as well as close to them on the composition of industrial sludge which is utilized for irrigation and fertilization of land. It is prohibited their land application if the heavy metal content in them exceeds the standards. The standards are shown in the table 12. In the case of exceeding these values it is allowed the preparation of composts on the basis of sewage sludge in a mixture with other components (peat, manure, vegetable waste) to bring the contents of heavy metals to the levels under of permissible concentrations (GOST 17.4.3.07-2001).

Table 12. The permissible content of components in sewage sludge used as fertilizer.

Components	The norms, mg/kg on dry matter	
	1st. group of sludge	**2nd. group of sludge**
Arsenic (As)	10	20
Cadmium (Cd)	15	30
Chromium (Cr^{3+})	7.5	15
Copper (Cu)	750	1500
Lead (Pb)	250	500
Mercury (Hg)	7.5	15
Nickel (Ni)	200	400
Zinc (Zn)	1750	3500

1st. group of sludge – all agriculture except mushrooms, strawberries, green vegetables.
2nd. group of sludge – technical, forestry, flower and other cultures; urban landscaping, storage and burying and special grounds and grounds for solid sanitary waste; use for rehabilitation of damaged lands and of the same above-mentioned grounds.

- **Standards for technological design removal systems and prepare for the use of manure from livestock and poultry enterprises (STD 1-99)**

This document contains technical dosing requirements for manure handling and utilization (STD, 1999).

The general legislation listed above is used for developing the federal, regional and then the municipal target programs aimed at the observance of human rights to a healthy environment by stabilizing the ecological situation and the gradual improvement in the territories with the highest levels of pollution. At present, relevant programs are the following:

- **Federal Program "Development of Agriculture and Regulation of the Markets of Agricultural Products, Raw Material and Foodstuffs in 2008 - 2012 years"**

The main objectives of the Program are the following: creating conditions for sustainable development of rural areas, improvement of general conditions for the accelerating of agriculture development; improving the financial sustainability of agriculture (Federal

Program "Development of Agriculture and Regulation of the Markets of Agricultural Products, Raw Material and Foodstuffs in 2008 - 2012 years ").

From the standpoint of processing sewage sludge and manure, the program promotes the development measures such as:

- ✓ The amendment drafting of federal law “On basics of bioenergy development in the Russian Federation”;
- ✓ The amendment drafting of the Program “Improving food production and processing of their waste through the advanced technologies and equipments”;
- ✓ This program include the task to analyze the development of bioenergy in Russia's regions and organize monitoring on an ongoing basis on:
- ✓ clarify the scope of investment;
- ✓ creation of production capacity;
- ✓ number of units of tractor and agricultures machineries working on alternative fuels.
- ✓ Prepare and carry out of council according to the results of the decision Agriculture Ministry of Russia “On the state and the main directions of development of bioenergy in Russia” (The Agriculture Ministry of RF, 2010).

- **“Social development of the village until 2012”**

This Program is aimed to realize activities of development of social and engineering infrastructure in the villages and settlements. This special program promotes the development of new sewerage networks and reconstruction of old, new construction and renovation of old treatment plants (Federal program “Social development of the village until 2012”).

- **The Leningrad Region Law № 107, dated 06.09.2006 "The regional special program "Support and Development of Protected Areas of the Leningrad region 2007-2010"**

The main purpose of this program is protection of the Leningrad region environment through elaborating a long-term development strategy and ensuring the effective functioning of the regional protection area network (Protected areas of the Leningrad region, 2009).

There are several institutions providing financing for the environmental investments in Russia. In respect of the environment protection against agriculture activities in the Leningrad region, in nowadays they are the following: the Ministry of the Environment of Finland (MoEF), Nordic Environment Finance Corporation (NEFCO), Northern Dimension Environmental Partnership (NDEP), Baltic Sea Action Group (BSAG) and European Neighbourhood and Partnership Instrument (ENPI) (Ramboll Finland Oy, 2008).

5 CHARACTERISTICS AND AMOUNT OF SEWAGE SLUDGE AND MANURE IN THE LENINGRAD REGION

The livestock and poultry enterprises of the Leningrad region in January-October 2009 have leading positions in the North-West region and the country as a whole for the production of livestock products (The Ministry of agriculture of RF, 2009). The cattle enterprises are represented in all municipalities of the Leningrad region. The largest cattle farms are situated in the Volosovsky, Gatchinsky and Luzhsky Districts. Large pig enterprises with high amounts of pig populations are located in the Gatchina, Priozersky and Vsevolozhsky Districts (Afanassiev V.N. 2005, 14; Antishina I.V.et al. 2007, 114). There are 18 poultry enterprises in the Leningrad region (Ramboll Finland Oy 2008, 3). Table 13 shows the amount of the livestock and poultry enterprises of municipalities of the Leningrad region.

Table 13. Number of livestock and poultry enterprises in municipalities of the Leningrad region. (Official website of Leningrad Goverments 2008; Isynov L.M. 2007; Sistema company website 2010; AgriConsulting 2008)

Municipalities	Profile of enterprises		
	Cattle enterprises	**Chicken enterprises**	**Pig enterprises**
The Boksitogorsky	3		3[a](1)[b]
The Gatchinsky District	15	4	3(2)
The Kingiseppsky	8		3(2)
The Kirishsky District	4		-
The Kirovsky District	5	2	-
The Lodeynopolsky	6		3(0)
The Lomonosovsky	10	6	1(0)
The Luzhsky District	14		4 (1)
The Podporozhsky	4		-
The Priozersky District	10		3(1)
The Tikhvinsky District	9		-
The Tosnensky District	5		3(3)
The Volkhovsky District	8		
The Volosovsky District	16		2(0)
The Vsevolozhsky	12	2	5(1)
The Vyborgsky District	11	4	6(1)
The Slantsy District	4		1(0)
The Leningrad region	144	18	37 (12)

[a]number of livestock enterprises that breeds cattle and pigs

[b]enterprises breeds only pigs

The difficulties with evaluation of sewage sludge amount in the Leningrad region are that centralized sewage systems have not existed in all settlement and it is difficult to find clear information about existing wastewater treatment plants. Antishina I.V.et al. (2007) reported that currently the centralized sewage systems present in 30 cities, 33 urban villages and only 222 (from 2907) rural settlements in the Leningrad region. The most developed systems are in the cities of Tikhvin, Gatchina, Vyborg, Kirishi and Volkhov. Below the amount of manure and sewage sludge produced in the Leningrad region and their characteristic will be represented.

5.1 The amount and characteristics of manure

In the literature, over the last three years, it was found that the amount of manure in the Leningrad region is ranging from 2.2 million to more than 3 million ton (Antishina IV et al. 2007, 146; Project PRIMER 2009, 8; Vinogradov S.V. 2009). The share of cattle manure accounts for 65%, the shares of poultry and pigs manure are near to 30% and 5% of the total amount, respectively (Project PRIMER 2009, 8). From regional point of view cattle enterprises produce most of the manure in the Luga Basin, while in the Northern and Southern basins the main part of the manure produced by poultry farms (Project PRIMER 2009, 8).

Because of a lack of clear information on manure production in the Leningrad region it was decided to calculate it. Estimation was carried out in according to population of cattle, pigs and poultry in the regions and using yields of manure in kg per one animal per day. The information about population of cattle, pigs and poultry was collected from different sources. Charles H. Lander et al. (1998) reported the yield of manure in kg per one animal unit per day (an animal unit represents 1,000 pounds of live animal weight), those values were taken and transformed to the yield of manure in kg per one animal per day with help of average weight for each type of animal, which was taken from “Methods of calculating emissions of pollutants into the atmosphere from livestock farms and fur farms” (1997). All values are shown in the table 14.

Table 14. The yields of manure and average weight of animal.

Type of animal	yield of manure [a], $kg_{w.m.}$/animal unit[b]/day	The average weight of one animal[c], kg	yield of manure, $kg_{w.\,m.}$/animal/day
Cattle	66	240	35
Chicken	62.8	1.45	0.2
Pig	33.5	64	4.7

[a] source: Charles H. Lander et al. (1998)

[b] animal unit aqua 1000 pounds of live weight of animal; 1000 pounds = 453.6 kg

[c]source: "Methods of calculating emissions of pollutants into the atmosphere from livestock farms and fur farms" (1997)

To calculate dry content of manure it was accepted some values for moisture content for each type of animal. The moisture content of cattle manure was taken 88%. It was reported that most of the pig manure in the Leningrad region use litter bedding material (Isyanov L.M. 2007) and average moisture content of litter manure is 68-78 % (STD 1999), so for calculation it was taken 70% of moisture content for pig manure. Antishina IV et al. (2007) were reported that for the Leningrad region the average moisture content of chicken manure is 85%. The amount of manure produced on wet matter within each municipality was estimated by the following equation:

$$Q_{w.m.} = n \cdot N \qquad (3)$$

$Q_{w.m.}$ – amount of manure produced on wet matter, t/a;

n – yield of manure, $t_{w.\,m.}$/animal/a;

N - number of unit in each municipality.

The manure quantity, in dry matter produced in each municipality was estimated by the following equation:

$$Q_{d.m.} = Q_{w.m.} \cdot (1 - w/100) \qquad (4)$$

$Q_{d.m}$ = quantity of manure on dry matter, t w – moisture content of manure, %

The collection information about number of livestock and poultry population in the Leningrad region and results of calculation equations 3 and 4 are shown in table 15 and 16, respectively.

Table 15. Number of livestock and poultry populating in the Leningrad region. (Isynov L. 2007; Project PRIMER 2009, 24)

Municipalities	**Number of livestock and poultry population**		
	Cattle	Chickens	Pigs
The Boksitogorsky District	643	-	115
The Gatchinsky District	17 592	2 600 500	44 765
The Kingiseppsky District	10 040	-	180
The Kirishsky District	5 510	-	-
The Kirovsky District	1 452	6 953 300	-
The Lodeynopolsky District	2 706	-	216
The Lomonosovsky District	9 160	4 964 300	442
The Luzhsky District	13 254	-	2 741
The Podporozhsky District	852	-	-
The Priozersky District	14 414	-	7 263
The Tikhvinsky District	5 712	-	-
The Tosnensky District	12 260	-	3 272
The Volkhovsky District	12 102	-	-
The Volosovsky District	21 136	-	1 057
The Vsevolozhsky District	7666	779 900	6 330
The Vyborgsky District	10 222	4 164 900	1 502
The Slantsy District	4 580	-	-
Total in the Leningrad region	149 301	19 462 900	67 883

Table 16. Amount of manure production in the Leningrad region.

Municipalities	Manure production, t/a						Total amount of manure, t/a	
	Cattle manure		Chicken manure		Pig manure			
	dry matter[a]	wet matter	dry matter[b]	wet matter	dry matter[c]	wet matter	dry matter	wet matter
The Boksitogorsky District	986	8 214	0	0	59	197	1 050	8 410
The Gatchinsky District	26 969	224 738	28 475	189 837	23 038	76 794	**78 500**	**491 000**
The Kingiseppsky District	15 391	128 261	0	0	93	309	15 500	129 000
The Kirishsky District	8 447	70 390	0	0	0	0	8 450	70 400
The Kirovsky District	2 226	18 549	76 139	507 591	0	0	**78 400**	**526 000**
The Lodeynopolsky District	4 148	34 569	0	0	111	371	4 260	35 900
The Lomonosovsky District	14 042	117 019	54 359	362 394	227	758	**68 600**	**480 000**
The Luzhsky District	20 318	169 320	0	0	1 411	4 702	21 700	174 000
The Podporozhsky District	1 306	10 884	0	0	0	0	1 310	10 900
The Priozersky District	22 097	184 139	0	0	3 738	12 460	25 800	197 000
The Tikhvinsky District	8 756	72 971	0	0	0	0	8 760	73 000
The Tosnensky District	18 795	156 622	0	0	1 684	5 613	20 500	162 000
The Volkhovsky District	18 552	154 603	0	0	0	0	18 600	155 000
The Volosovsky District	32 401	270 012	0	0	544	1 813	33 000	272 000
The Vsevolozhsky District	11 752	97 933	8 540	56 933	3 258	10 859	23 600	166 000
The Vyborgsky District	15 670	130 586	45 600	304 038	773	2 577	**62 100**	**437 000**
The Slantsy District	7 021	58 510	0	0	0	0	7 020	59 000
Total in the Leningrad region	**229 000**	**1 907 000**	**213 000**	**1 421 000**	**35 000**	**117 000**	**477 000**	**3 445 000**

[a] with moisture content 88 %

[b] with moisture content 85 %

[c] with moisture content 70 %

The calculation of quantity manure production in the Leningrad region has shown that the total amount of manure production in the Leningrad region is **3 445 000** t/a, of wet matter. The largest quantity of manure is produced from cattle enterprises (1 907 000 t/a, of wet matter) and the largest manure generation can be observed in the Gatchinsky, Lomonosovsky, Kirovsky and Vyborgsky Districts. The average characteristics for litter manure of cattle, chicken and pig are shown in the table 17.

Table 17. The average characteristics of cattle, chicken and pig litter manure. (Isynov 2007)

Manure characteristics	Cattle litter manure	Chicken litter manure	Pig litter manure
moisture content , %	70	75	75
Organic matter, %	18.0	17.3	20.0
Ash, %	5.2	6.9	1.8
N_{total}, %	3.2	1.2	0.8
P_2O_5, %	0.31	0.3	0.51
K_2O, %	1.2	0.3	0.8
pH	8.1	8.3	7.4
C/N ration	17	10	12

5.2 The amount and properties of sewage sludge

Antishina IV et al. (2007) reported that the amount of yearly sewage sludge production estimated by the norms of sludge formation, as recommended by State Unitary Enterprise “Vodocanal of St. Petersburg” (50 kg per person calculated on the dry matter). This rule was used with the proviso that this is value for the urban population of The Leningrad region. The amount of the sewage sludge production according to the Antishina IV et al. (2007) calculations is shown Table 18.

Table 18. The amount of sewage sludge produced in the Leningrad region. (Antishina IV 2007, 136)

Municipalities	Sewage sludge production, t/a dry matter
The Boksitogorsky District	1 485
The Gatchinsky District	**7 325**
The Kingiseppsky District	3 185
The Kirishsky District	2 800
The Kirovsky District	4 265
The Lodeynopolsky District	1 260
The Lomonosovsky District	435
The Luzhsky District	2 145
The Podporozhsky District	1 500
The Prizersky District	1 485
The Tikhvinsky District	3 330
The Tosnensky District	3 755
The Volkhovsky District	4 170
The Volosovsky District	645
The Vsevolozhsky District	4 160
The Vyborgsky District	**7 010**
The Slantsy District	1 930
Sosnovy Bor	3 155
The Leningrad region	**54 040**

From the table given above it can be observed that total amount of generated sewage sludge is **54 040 t/a.** The largest amount of sewage sludge was formed in the Gatchinsky and Vyborgsky Districts. The information given in table 15 refers to 2007 year. To have more fresh information it was decided to calculate the amount of sewage sludge production using number of urban residence in the Leningrad region in 2009 year. For comparison, the amount of sewage sludge production according to value of sewage sludge yield in Finland was estimated. Ronald J. LeBlanc (2008) reported that in Finland the amount of formed sludge per person is 94 g $d^{-1}person^{-1}$, dry matter. From this it follows that the annual yield of sewage sludge per person is 34 kg a^{-1} $person^{-1}$ of dry matter. The calculation was carried out by multiplying values of sewage sludge yield on number of urban residents within municipality. The result of calculation is shown in table 18. The amount of moist sewage sludge formed was also estimated. Antishina IV et al. (2007) reported that the formed sludge in average has 96-98% moisture content. If the wastewater plant has a centrifuge the sludge partially dehydrated and its moisture content is in range 80-85%. For the case of this study the average moisture content was taken as

96%. The amount of sewage sludge on wet matter was calculated by dividing the amount of dry matter on total solid content. The result from calculation is presented in the table 19.

Table 19. The amount of sewage sludge produced in the Leningrad region calculated using the number of urban inhabitants.

Municipalities	Number of habitants, thousands of person (2009)[a]	Number of urban residents, thousands of person (2009)[a]	Sewage sludge production[b], t/a		Sewage sludge production[c], t/a	
			d. m.	w.m.[d]	d. m.	w.m.[d]
The Boksitogorsky District	53 947	42 149	2 107	52 686	1 433	35 827
The Gatchinsky District	223 635	137 137	**6 857**	**171 421**	**4 663**	**116 566**
The Kingiseppsky District	80 704	60 864	3 043	76 080	2 069	51 734
The Kirishsky District	66 044	60 355	3 018	75 444	2 052	51 302
The Kirovsky District	94 753	67 798	3 390	84 748	2 305	57 628
The Lodeynopolsky	33 174	22 920	1 146	28 650	779	19 482
The Lomonosovsky	64 697	9 725	486	12 156	331	8 266
The Luzhsky District	75 057	41 419	2 071	51 774	1 408	35 206
The Podporozhsky District	32 016	26 952	1 348	33 690	916	22 909
The Priozersky District	59 407	21 939	1 097	27 424	746	18 648
The Tikhvinsky District	74 016	65 921	3 296	82 401	2 241	56 033
The Tosnensky District	111 286	92 440	4 622	115 550	3 143	78 574
The Volkhovsky District	93 631	68 035	3 402	85 044	2 313	57 830
The Volosovsky District	48 121	11 354	568	14 193	386	9 651
The Vsevolozhsky District	221 453	124 642	**6 232**	**155 803**	**4 238**	**105 946**
The Vyborgsky District	188 275	123 395	**6 170**	**154 244**	**4 195**	**104 886**
The Slantsy District	44 606	34 545	1 727	43 181	1 175	29 363
Sosnovy Bor	67 182	67 182	3 359	83 978	2 284	57 105
The Leningrad region	**1 632 004**	**1 078 772**	**53 900**	**1 348 000**	**36 700**	**918 000**

[a] source: Federal State Statistics Service 2009

[b] the norm annual sewage sludge formation per person is 50 kg/person/a

[c] the norm annual sewage sludge formation per person is 34 kg/person/a

[d] the moisture content is 96%

According to the calculation represented in tables 18 and 19 it can be concluded that the amount of sewage sludge calculated by multiplying amount of urban residence on the norm of annual sewage sludge formation per person as 50 kg $person^{-1}$ a^{-1} of dry matter that was produced in 2007 and 2009 years in the Leningrad region is almost the same: 54 040 t/a in 2007 year and 53 900 t/a in 2009 year. But some changes in municipalities can be observed, for example in 2007 the amount of sewage sludge in the Vsevolozhsky District was 4160 t/a and in 2009 year already 6232 t/a. Although, this is rough estimation of sewage sludge amount produced in the Leningrad region, but it should be taken into account as subsidiary calculation parameters for evaluation of needed capacity of WWTP and for further planning utilization sewage sludge when planning reconstruction or construction of new treatment plants. The other conclusion from this table is that according to the Finland's value of sewage sludge yield the amount produced in the Leningrad region should be near to 30 % less.

As it was described earlier, in chapter 2, the properties of sewage sludge vary depending on different factors. The parameters of sewage sludge produced in Kommunar wastewater treatment plant (Kommunar WWTP) is represented as an example of sewage sludge characteristics in the Leningrad region. These characteristics are shown in table 20.

Table 20. The sewage sludge characteristics formed in Kommunar wastewater treatment plant (Data of accredited laboratory of St. Petersburg CPC 2009; Lorentson A.V., 2010).

Physicochemical properties	Values
Total moisture content of sewage sludge after last stage of waste water treatment process, %	94
N_{total}, %	3 – 4.3
P_{total}, %	2.0 – 3.2
Ash,%	15 - 20
Ferrum (Fe), mg/kg $_{d.m.}$	40000± 5000
Cadmium(Cd), mg/kg $_{d.m}$.	2.1± 0.4
Manganese (Mn), mg/kg $_{d.m}$.	650± 100
Arsenic (As), mg/kg $_{d.m.}$	< 10
Nickel (Ni), mg/kg $_{d.m}$.	55± 11
Mercury (Hg), mg/kg $_{d.m.}$	0.73± 34
Lead (Pb), mg/kg $_{d.m}$	150± 40
Chromium (Cr), mg/kg $_{d.m.}$	80± 30
Copper (Cu), mg/kg $_{d.m}$.	332
pH	7.9

According to the GOST 17.4.3.07-2001 the sewage sludge contains chromium in excess level and it cannot be used as fertilizer. To have possibilities for land application it should be mixed with other organic waste to low the level of chromium content (GOST 17.4.3.07-2001).

6 THE CURRENT SITUATION IN TECHNOLOGIES FOR MANURE AND SEWAGE SLUDGE TREATMENT IN THE LENINGRAD REGION

The intensive activities of livestock and poultry enterprises in the Leningrad region raise a number of important issues related to environmental protection. One of the main issues is a problem of manure disposal. Antishina IV et al. (2007) reported that in the Leningrad region the farms have a practice to collect manure in dung-yard and further land application. Typically, dung-yards are open ground or buried facilities, which are exposed by atmospheric precipitation. Afanassiev V.N. 2005 has reported that most dung-yard have capacity in 1.5 - 3 times less than the average yield of manure, it follows that the manure is not kept in dung-yard a recommended period of time (in Russia it is at least 6 months for cattle manure and poultry manure, and 12 months for pig manure), and moved to the field during the year without meting the sanitary and epidemiological requirements. In addition, there may be overflow and polluted runoff into water bodies from dung-yard. Some of the livestock enterprises use composting method of manure treatment (Antishina IV et al. 2007, 145). Almost every enterprise has dung-yard or place for composting. In the Leningrad region composting is mostly carried out by the windrow composting process in open areas with natural ventilation and periodic turning of the mixture.

The treatment method of sludge varies in regions and it depends on sewage sludge composition. If the concentration of heavy metals is lower than permissible concentrations it may be applied as agricultural fertilizer. This method is usual for some settlements of Boksitogorsky, Volosovsky, Volkhovky, Lodejnoepolsky, Priozersky and Tosnensky districts.

The sludge which has higher concentration of heavy metals is disposed on sludge beds (Gatchina District) or stored in the wastewater treatment plan’s territory (Viborg, Pikalevo, Novaya Ladoga, Slantsy Districs and some other). In Svetogorsky city the sewage sludge is treated with sludge of pulp and paper industry and sludge is disposed together with ash and slag waste in Landfill, such as GRES-8, city Kirovsk.

The sludge formed in the urban area, where sewage systems does not exist, is collected in the pit, it is mostly used in land application (i.e. irrigation fields) or is directed to the drain station arranged on the city or settlement square. The poor technical condition and out of date equipment lead to the discharge of untreated and inadequately treated sewage into waters.

At the present time, there is no information about biogas plants for manure treatment in the Leningrad region. There is only news and plans for implementation of this technology. For example, Yriy Ivanov (director of pig farm “RusBelgo”) reported that the new AD plant for manure treatment will be constructed in its farm, but the year was not mentioned (Agrotechnic 2009). From the other source it was reported that in 2007 year in the poultry enterprises “Primorskay” (Vyborg District) the “investment for plant was found”, but again no any news when this technology will be introduced (Drankina E. 2007). At a meeting of public ecological Council of the Governor of the Leningrad region (July 29, 2009) it was reported that project for the construction of a biogas plant in one of the agro-industrial enterprises of Luzhsky District is under development (Community Environmental Council of the Governor of the Leningrad region 2009). Also it was found that in ZAO Ruchyi the Finnish Bioenergy Oy from Finland were going to implement the plant for biogas production and utilization but it has not been started yet (Ramboll Finland Oy 2008, 8).

Although there are no experiences of sewage sludge incineration in the Leningrad region, at present, there are three incineration plants for municipal sewage sludge in St. Petersburg. The raw sludge is incinerated without stabilization. The pretreatment of the sludge consists only of gravity thickeners and centrifuges for dewatering. The ash is disposed into special landfills (Vodokanal of Russian Federation 2008). The experience of incineration plants of Saint-Petersburg can be used in the Leningrad region.

7 CALCULATION OF ENERGY POTENTIAL FROM MANURE AND SEWAGE SLUDGE IN THE LENINGRAD REGION

With help of the information given above in this chapter will be calculated energy potential from livestock and poultry manure and sewage sludge in the Leningrad region. It will be carried out firstly by calculation the potential heat production from biogas combustion which is obtained from anaerobic digestion of manure and sewage sludge and secondly by calculation the potential of heat production from direct combustion of manure and sewage sludge.

7.1 The potential of energy production from combustion of biogas

To evaluate the energy potential from AD process firstly it is need to estimate biogas production from manure and sewage sludge. To estimate the potential of biogas production from manure and sewage sludge produced in the Leningrad region some simple calculations are carried out. If it is assumed that all manure and sewage sludge will be treated by AD the rough estimation of potential of biogas production can be calculated by the following equation:

$$B = Q_{d.m.} \cdot G_{d.m} \cdot C_{CH4}/1000 \quad . \tag{5}$$

B – yield of methane, thousands of m^3/a;

$Q_{d.m.}$ – amount of feedstock, $t_{d.m.}/a$;

$G_{d.m.}$ – index of the biogas yield per dry matter, $m^3/t_{d.m}$;

C_{CH_4} – methane content in the biogas, share;

1000 – coefficient for transformation m^3 to thousands of m^3.

The actual amount of feedstock is taken from tables 16 and 19. It is assumed the average values for indexes and for methane content according to the data given in the table 7 and these average values are shown in the table 21. The results from calculation equation 5 are presented in the table 22. The calculation of heat release from biogas combustion is realized though the following equation:

$$E_{biogas.} = B \cdot LHV_{CH4} \quad (6)$$

E_{biogas} - heat release from combustion of biogas, GJ/a;

LHV_{CH_4} – lower heating value of the methane, MJ/m^3.

The LHV_{CH_4} is 35.6 MJ/m^3. The biogas yield is calculated by the equation 5. The result of calculation equation 6 is presented in the table 22.

Table 21. Value of parameters used for calculations.

Type of feedstock	**Index of the biogas yield per dry matter in the feedstock, m^3/t$_{d.m.}$**	**Methane content in the biogas, %**
Cattle manure	200	65
Chicken manure	500	70
Pig manure	400	75
Sewage sludge	550	75

Table 22. The potential of biogas production from manure and sewage sludge in the Leningrad region.

Municipalities	**Amount of methane produced according to the type of feedstock, thousands m³/a**				**Total amount of methane produced, thousands m³/a**	**The heat release from biogas combustion, GJ/a**
	Cattle manure	**Chicken manure**	**Pig manure**	**Sewage sludge**		
The Boksitogorsky District	128	0	18	869	1 020	36 300
The Gatchinsky District	3 506	9 966	6 911	2 829	**23 200**	**826 000**
The Kingiseppsky District	2 001	0	28	1 255	3 280	117 000
The Kirishsky District	1 098	0	0	1 245	2 340	83 300
The Kirovsky District	289	26 649	0	1 398	**28 300**	**1 010 000**
The Lodeynopolsky District	539	0	33	473	1 050	37 400
The Lomonosovsky District	1 825	19 026	68	200	**21 100**	**751 000**
The Luzhsky District	2 641	0	423	854	3 920	140 000
The Podporozhsky District	170	0	0	556	726	25 900
The Prizersky District	2 873	0	1 121	453	4 450	158 000
The Tikhvinsky District	1 138	0	0	1 360	2 500	89 000
The Tosnensky District	2 443	0	505	1 907	4 860	173 000
The Volkhovsky District	2 412	0	0	1 403	3 820	136 000
The Volosovsky District	4 212	0	163	234	4 610	164 000
The Vsevolozhsky District	1 528	2 989	977	2 571	8 070	287 000
The Vyborgsky District	2 037	15 962	232	2 545	**20 800**	**740 480**
The Slantsy District	913	0	0	712	1 630	58 000
Sosnovy Bor	0	0	0	1 386	1 386	49 500
The Leningrad region	**29 800**	**74 600**	**10 500**	**22 300**	**137 000**	**4 880 000**

The calculation shows that the total potential amount of biogas production is **137** million m^3/a calculated on methane production. The biggest potentials of biogas production from manure and sewage sludge treatment can be achieved in the Gatchinsky, Kirovsky, Lomonosovsky and Vyborgsky Districts. The biggest source of biogas potential is a chicken manure (74.6 million m^3/a calculated on methane production). The heat release which can be received from biogas combustion in the Leningrad region is **4 880 000** GJ/a.

7.2 The potential of energy production from incineration

To evaluate the potential of energy production from incineration of manure and sewage sludge produced in the Leningrad region the following assumptions was carried out:

- to dewater the feedstock the mechanical methods is used;
- the energy consumption of dewatering is 0.02 MJ/kg for water mass (Horttanainen M. et al. 2009);
- the moisture content of each feedstock came into incineration is 65%

First of all it is need to calculate the average of lower heating value of the moist fuel (LHV_{ar}) for each feedstock. The calculation was carried out by using the following equation:

$$LHV_{ar} = LHV_{d.m.}(1-w_{inc}/100) - l \cdot w_{inc}/100 \quad (7)$$

LHV_{ar} – lower heating value of the moist feedstock, $MJ/kg_{w.m.}$;
$LHV_{d.m.}$ – lower heating value of the dry matter, $MJ/kg_{d.m.}$;
l – latent heat of water evaporation, equal 2.265 MJ/kg;
w_{inc} – moisture content of the feedstock came into incineration process, %

The $LHV_{d.m.}$ of each feedstock are taken from the tables 2, 4, 5 and 6. These values and results from calculations of equation 7 are presented in the table 23.

Table 23. The heating values of manure and sewage sludge.

The type of feedstock	Lower heating value of the dry matter, $LHV_{d.m.}$, $MJ/kg_{d.m.}$	Lower heating value of the moist feedstock[a], LHV_{ar}, $MJ/kg_{w.m.}$
Cattle manure	14	3.43
Chicken manure	17	4.48
Pig manure	14	3.43
Sewage sludge	16	4.13
[a] moisture content is 65%		

The evaporation of water takes a significant part of thermal energy in combustion process. Because moisture contents of manure and sewage sludge are in the range 70 – 96% it is need to carry out the dewatering of feedstock to low the moisture content up to 65%. It was assumed earlier that energy need for dewatering is 0.02 MJ/kg for water mass. The calculation of energy consumption for dewatering is carried out by the following equation:

$$E_{c,w} = E_w \cdot (m_{initial} - m_{d.m.}/(1-w_{inc}/100)) \quad (8)$$

$E_{c,w}$ – the energy consumption for dewatering, GJ/a;

E_w – the energy need to remove one kilogram of water from feedstock, equals 0.02 MJ/kg for water mass;

$m_{initial}$ – the mass of the feedstock with initial moisture content, t/a;

$m_{d.m.}$ – the mass of the feedstock of dry matter, t/a.

The mass of the feedstock with initial moisture content and mass of feedstock of dry matter is taken from tables 16 and 19. The results of calculation equation 8 are presented in the table 24.

Table 24. Energy consumption for mechanical dewatering of feedstock.

Municipalities	Energy consumption for dewatering, GJ/a				
	of cattle manure	of chicken manure	of pig manure	of sewage sludge	Total amount
The Boksitogorsky District	108	0	1	933	1 040
The Gatchinsky District	2 954	2 170	219	3 037	8 380
The Kingiseppsky District	1 686	0	1	1 348	3 030
The Kirishsky District	925	0	0	1 336	2 260
The Kirovsky District	244	5 801	0	1 501	7 550
The Lodeynopolsky	454	0	1	508	963
The Lomonosovsky	1 538	4 142	2	215	5 900
The Luzhsky District	2 225	0	13	917	3 160
The Podporozhsky	143	0	0	597	740
The Prizersky District	2 420	0	36	486	2 940
The Tikhvinsky District	959	0	0	1 460	2 420
The Tosnensky District	2 058	0	16	2 047	4 120
The Volkhovsky District	2 032	0	0	1 506	3 540
The Volosovsky District	3 549	0	5	251	3 810
The Vsevolozhsky District	1 287	651	31	2 760	4 730
The Vyborgsky District	1 716	3 475	7	2 732	7 930
The Slantsy District	769	0	0	765	1 530
Sosnovy Bor	0	0	0	1 490	1 490
The Lenigrad region	**25 068**	**16 238**	**333**	**23 887**	**65 500**

The total amount of energy needed for dewatering is 65 500 GJ/a. The main amount of energy is contributed by dewatering of cattle manure. The heat release from incineration of manure and sewage sludge is calculated by the following equation:

$$E_{inc} = LHV_{ar} \cdot m_{d.m.}/(1-w_{inc}/100) \qquad (9)$$

E_{inc} – heat release from incineration, GJ/a;

LHV_{ar} – lower heating value of the moist fuel, $MJ/kg_{w.m.}$;

$m_{d.m.}$ – the mass of the feedstock of dry matter, t/a;

The LHV_{ar} of each feedstock are taken from the table 23. The mass of the feedstock of dry matter is taken from table 16 and 19. The results of calculation equation 9 are presented in the table 25.

Table 25. The heat release from incineration of manure and sewage sludge

Municipalities	The heat release from incineration depending on type of feedstock, GJ/a				Total heat release, GJ/a
	Cattle manure	Chicken manure	Pig manure	Sewage sludge	
The Boksitogorsky District	9 660	0	581	24 863	35 100
The Gatchinsky District	264 292	364 486	226 256	80 913	**936 000**
The Kingiseppsky District	150 835	0	910	35 907	188 000
The Kirishsky District	82 779	0	0	35 612	118 000
The Kirovsky District	21 814	974 575	0	40 002	**1 036 000**
The Lodeynopolsky District	40 653	0	1 092	13 523	55 300
The Lomonosovsky District	137 614	695 796	2 234	5 735	**841 000**
The Luzhsky District	199 120	0	13 854	24 438	237 000
The Podporozhsky District	12 800	0	0	15 906	28 700
The Prizersky District	216 547	0	36 709	12 945	266 000
The Tikhvinsky District	85 814	0	0	38 893	125 000
The Tosnensky District	184 187	0	16 538	54 540	255 000
The Volkhovsky District	181 813	0	0	40 144	222 00
The Volosovsky District	317 535	0	5 342	6 702	330 000
The Vsevolozhsky District	115 169	109 311	31 994	73 538	330 000
The Vyborgsky District	153 569	583 752	7 592	72 806	**818 000**
The Slantsy District	68 807	0	0	20 379	89 200
Sosnovy Bor	0	0	0	34 682	39 600
The Leningrad region	**2 243 000**	**2 728 000**	**343 000**	**632 000**	**5 950 000**

The calculation shows that the total potential amount of heat release is **5 950 000 GJ/a**. The biggest potentials of heat release of incineration can be achieved in the Gatchinsky, Kirovsky, Lomonosovsky and Vyborgsky Districts.

The results of total heat release during both AD and incineration methods are presented in the table 26. The values are converted into the TWh energy unit.

Table 26. The potential heat release from both AD and incineration methods in the Leningrad region.

Municipalities	**Total amount of heat release from biogas combustion**		**Total amount of heat release from direct manure and sewage sludge incineration**	
	GJ/a	**TWh**	**GJ/a**	**TWh**
The Boksitogorsky	36 300	0.01	35 100	0.01
The Gatchinsky District	**826 000**	**0.23**	**936 000**	**0.26**
The Kingiseppsky District	117 000	0.03	188 000	0.05
The Kirishsky District	83 300	0.02	118 000	0.03
The Kirovsky District	**1 010 000**	**0.28**	**1 036 000**	**0.29**
The Lodeynopolsky	37 400	0.01	55 300	0.02
The Lomonosovsky	**751 000**	**0.21**	**841 000**	**0.23**
The Luzhsky District	140 000	0.04	237 000	0.07
The Podporozhsky	25 900	0.01	28 700	0.01
The Prizersky District	158 000	0.04	266 000	0.07
The Tikhvinsky District	89 000	0.02	125 000	0.03
The Tosnensky District	173 000	0.05	255 000	0.07
The Volkhovsky District	136 000	0.04	222 00	0.06
The Volosovsky District	164 000	0.05	330 000	0.09
The Vsevolozhsky	287 000	0.08	330 000	0.09
The Vyborgsky District	**740 480**	**0.21**	**818 000**	**0.23**
The Slantsy District	58 000	0.02	89 200	0.02
Sosnovy Bor	49 500	0.01	39 600	0.01
The Leningrad region	**4 880 000**	**1.36**	**5 950 000**	**1.65**

The calculation of heat release from both these methods has shown that heat release from direct incineration process of manure and sewage sludge is larger than from AD process.

However, for comparison these methods it is need to calculate net energy from both these methods. Thus it is assumed that combustion occurs in the CHP where electricity and heat is produced. In the case of this study net energy means energy flow (electricity and heat) that has included auxiliary power (losses and energy consumptions) of processes. This energy is used outside of the process (can be sold or utilized for other processes in the centralized plant such as needs for electricity of wastewater treatment). For both these method auxiliary power can be divided on two parts such as auxiliary power of feedstock treatment and auxiliary power of combustion process. For the AD method auxiliary power of feedstock treatment means energy needed for AD process which includes heat energy consumption for holding temperature in the digester in the required level, electricity consumption for pumping, mixing of the feedstock during AD process (Berglund M. and Borjesson 2006, 258), and auxiliary power of combustion process means energy needed during combustion of biogas which includes electricity energy consumption for pumping of feedwater, blowing of biogas and combustion air, conduction and radiation losses, flue gas losses and losses of electricity generation etc (Horttanainen M. et al. 2009). The auxiliary power of feedstock treatment for incineration of manure and sewage sludge mainly includes electricity consumption for dewatering process. Auxiliary power of combustion in incineration method includes almost the same types of losses and energy consumptions as for combustion of biogas but magnitudes of them are different. The main losses during combustion occur due to the high moisture content of feedstock (65%) and heat release mainly is spent for moisture evaporation. Also it should include energy consumption of electrostatic precipitator due to fly ash releases and flue gas treatment is needed.

The auxiliary power of combustion process (for both methods) is included in the total output energy flow (heat + electricity). The total output energy flow is calculated by multiplying total heat release on total efficiency. For combustion of biogas it is assumed that total efficiency of CHP equals 85%, where the electricity conversion efficiency is 30% and heat efficiency is 55%, thus the electricity energy equals 0.408 TWh and energy heat is 0.748 TWh. Berglund M. and Borjesson (2006) have reported that primary energy input in the AD process for electricity consumption is 11% of biogas produced and heat consumption is 13 % of biogas produced. The electricity consumption of AD process is calculated by multiplying heat release from biogas combustion on percentage of primary electricity energy input and it is equal 0.15 TWh. For calculation if heat consumption of AD process it is need to multiply heat release from biogas combustion on percentage of primary heat energy input and it is equal 0.177 TWh. Subtracting these values from the total energy the net energy of the AD method can be calculated. The electricity net production is 0.258 TWh and the heat net production is 0.571 TWh.

For incineration process it is assumed that combustion occurs in the CHP, which has a conversion efficiency of 20 % for electricity and 40 % for heat, thus the production of electricity equals 0.33 TWh and heat production will be 0.66 TWh. The net energy is calculated by subtraction energy consumption for dewatering from electricity production and it equals 0.31. All energy flows are presented in the table 27.

Table 27. Energy flows in both AD and incineration methods.

Type of method		Heat release from combustion process, TWh	Total energy production, TWh	Auxiliary power[a], TWh For treatment of feedstock[b]	Net energy, TWh	Total net energy, TWh
AD	electricity	1.36	0.408	0.15	0.258	0.83
	heat		0.748	0.177	0.571	
Incineartion	electricity	1.65	0.33	0.018	0.31	0.97
	heat		0.66	-	0.66	

[a]Auxiliary power for combustion method has included in the total energy

[b]In the case of AD method it is mean that energy consumption for AD process

Form the calculation presented in table 27, it is seen that net energy from incineration is large than from AD process. It was reported that electricity consumption in the 2011 will be near to 19 TWh (Interfax, 2009). If all manure and sewage sludge will be treated by the AD the share electricity production from this process will be near to 1.4% and if the incineration process will be implement the share will be near to 1.63 %.

7.3 Digestate and ash and their amount

Digeste is a product from AD process. Generally, amount of treated feedstock is not changed during AD process. Only content of dry matter will be changed due to some of organic part is converted to gases such as methane and carbon dioxide. Hence, the total amount of digeste produced in the Leningrad region can be assumed as sum of dry matter of manure and sewage sludge divided on dry content of digest material. The AD process it carried out with moisture content 92%, thus taking dry matter content of manure and sewage sludge from tables 16 and 19 and divided on dry content which equals 8% the possible amount of digeste material will be 6 636 000 t/a. To decreased the transportation energy consumption for delivering of digeste to the land where it will be used as fertilizer it is need to dewater it.

The amount of ash produced from incineration process will be less than amount of digeste. All organic part is combusted during incineration process. To calculate the ash produced during incineration the ash contents of feedstock are taken from tables 2, 4, 5 and 6. The average ash contents calculated on dry matter are the flowing: for chicken manure is 26%, for cattle manure 20%, for pig manure is 22% and for sewage sludge is 30%. Multiplying all amount of feedstock (calculated on dry matter) on their ash content (calculated on dry matter) the ash amount of each feedstock can be calculated, after that all received amount of ash are summarized to calculate total amount of ash, thus total amount of ash produced is 125 050 t/a. It can be seen that amount of ash produced during incineration more than 50 times less. But it should be mentioned that although ash can be utilized as fertilizer some part of nutrient is lost during incineration. And also content of heavy metal in fly ash can be high, due to content of heavy metal in sewage sludge and it cannot be utilized as fertilizer it is need to disposed it in a special landfill.

8 THE CALCULATION OF PLANT PARAMETERS FOR JOINT TREATMENT OF SLUDGE AND MANURE

In the case of this study it is need to calculate the parameters for joint treatment of manure and sewage sludge using AD and incineration methods. This calculation will be realized for Gatchina District of Leningrad region. For the reason that the high concentration of livestock and poultry enterprises are located in the Gatchina District (according to calculation the manure generation is on the second place in the Leningrad region and sewage sludge formation is the largest in the Leningrad region) it can be reasonable to carry out calculation for this district.

To evaluate what the appropriate place could be for manure collection (from distance point of view) it is need to find a place of farms (collection point of manure). In the case of this study, for the Gatchina district the map with all found enterprises was made. The view of this map is presented in Appendix I. After evaluation the area where the most sources of manure and sewage sludge are produced it was decided to choose the Gatchina WWTP as a collective place. In this system manure collected from different livestock enterprises should be delivered to WWTP for further treatment. The livestock and poultry enterprise from which manure is collected they were chosen by the criterion of distance. This criterion is that distance between WWTP and livestock enterprises should be less than 10 km to avoid the losses of benefits from energy production due to energy consumption for transportation (Strategic Policy Unit 2005, 6; Walden 3 Fundation 2005, 10). The initial parameters need for evaluation the centralized treatment plant are presented in the table 28. The amount of manure produced by each enterprise is calculated by the equation 3. The values of manure moisture content are taken the same as for calculation manure generation in the chapter 5.1 (for cattle manure is 88%, for pig manure is 70% and for poultry is 85%). Amount of sludge formation is calculated on the base of population in Gatchina city and norms of sludge formation equaled 50 kg per person calculated on the dry matter. Moisture content of generated sludge is 96% and density of sewage sludge is 1400 kg/m^3 (Yakovlev 2006, 277). For calculation of the volumetric flow of manure the densities of manure recommended by the STD (1999) and

STD (2001) were used and they are the following: for pig manure with 70% moisture content the density is 1094 kg/m^3, for cattle manure with moisture content 88% the density is 1025 kg/m^3 and for chicken manure with 70% moisture content is 700 kg/m^3.

Table 28. The initial parameters used for evaluation the centralized treatment plant.

The name of enterprises	**Type of enterprise**	**Number population**	**The amount of feedstock**				**Distance between WWTP and livestock enterprises, km**
			$t_{d.m./}a$	**$t_{w.m.}/a^{f}$**	**$t_{w.m.}/a^{g}$**	**m^3/a**	
LC "Rusbelgo"	Pig breeding	18666[a]	9606	32022	27447	29270	6.4
OJSC ”Novy Svet”	Pig breeding	17832[a]	9177	30591	26221	27962	10.0
LC ”Chernovo”	Cattle breeding	1135[b]	1740	14500	4971	14146	3.7
“Krasnogvardejskij” stock-breeding farm	Cattle breeding	2081[c]	3190	26585	9115	25936	7.1
OJSC "Verevo"	Cattle breeding	1151[c]	1764	14704	5041	14345	2.8
OJSC "stock-breeding farm Lesnoe"	Cattle breeding	2150[d]	3296	27466	9417	26796	2.2
"Thais" pedigree stock-breeding farm	Cattle breeding	540[d]	828	6899	2365	6730	5
”Skoritsy” poultry farm plant	Poultry breeding	676385[b]	7406	49376	21161	70537	2.3
Total transported feedstock and total distance			**37008**	**202142**	**105739**	**215724**	39.5
Gatchinsky WWTP		90147[e]	4507	112684	12878	80488	
Total amount of feedstock in the system			**41516**	**314825**	**118617**	**296212**	

[a] source: Agro-ingorm 2008

[b] source: Isynov L.M 2007

[c] source: Guzhina G.N. 2010, 35

[d] source: Antes 2009

[e] source: Federal State Statistics Service 2009

[f] initial moisture content of feedstock (it was assumed in chapter 7)

[g] moisture content is 65%

8.1 Calculation of transportation energy consumption

Transportation energy consumption may become an important constraint when planning the centralized treatment plant. As capacity increases, economies of scale in capital equipment are realized but transportation costs increase as manure must be carried longer distances to the plant site. Ghafoori E. and Flynn P. (2007) studied manure and digestion trucking, trucking of manure with return of digestate by pipelines, and pipelining of manure plus digestate when planning the centralized AD plant. They concluded that if digestate return for land spreading the most reasonable option for manure plus digestate transportation is by truck for the mixed-farming area and by pipelines for the concentrated feedlot area. But in the first stage of construction of centralized treatment plant it would probably be necessary to use the transport system and it is relevant to calculate the transportation energy consumption for manure transporting to the centralized treatment plant.

Flotats X. et al. (2008) reported that usually two different kinds of trucking can be used: owned by the farmer (10 – 20 m^3 capacity) or a centralized transport service (common tractor or truck of 20 m^3 capacity). Also it was mentioned that transportation manure by trucks owned by centralized treatment plant is allowed optimizing time of service and may be more economically rational. To calculate the energy consumption of manure transportation the following equation can be used:

$$E_{trans.} = S \cdot q_{fuel} /100 \cdot 2 \cdot LHV_{diesel} \cdot T_{truck}/1000 \quad (10)$$

E_{trans} - energy consumption of manure transportation, GJ/a

S – total distance between livestock enterprises and WWTP, km;

q_{diesel} - fuel economy, l/100km;

2 – means round trip pathway;

LHV_{diesel} – lower heating value of diesel, MJ/l;

T_{truck} – number of trucks needed annually;

1000 – coefficient for transformation MJ to GJ.

The average fuel economy for a truck with 20 m^3 capacity is 29 l/100km (Minibus 2010). Distance between livestock enterprise and WWTP is taken from table 26. The lower heating value of diesel (LHV_{diesel}) equals 35.5 MJ/l. Number of trucks annually needed is calculated by the following equation:

$$T_{truck} = Q/V_{truck} \tag{11}$$

Q – total amount of feedstock, m^3/a

V_{truck} – volume capacity of one truck, m^3

The number of tucks round off to the lager value due to it could come from farm not fulfill but fuel would be consumed. The result of calculation is referring to the whole system and with assumption that transportation energy consumption is evaluated only for deliver manure to the WWTP. The transportation energy consumption equals 8770 GJ/a or 2.4 GWh annually.

8.2 Joint treatment by anaerobic digestion

According to the table 28 total amount of feedstock is 41516 t/a on dry matter. The AD process has better performance with moisture content more than 92%. Feedstock comes to the centralized plant have average moisture content near to 70 – 88% (according to the values which were assumed at the beginning). The feedstock can be diluted by the wastewater from the wastewater treatment process or from dewatering of digeste material (Berglund M. and Borjesson 2006). The biogas production from the feedstock is calculated by equations 5 and 6, results of calculation are presented in the table 29.

Table 29. The biogas production from manure and sewage sludge

Source of feedstock	Amount of methane produced according to the type of feedstock, thousands m^3/a				Total amount of methane produced thousands m^3/a	The heat release from biogas combustion, GJ/a
	Cattle manure	Chicken manure	Pig manure	Sewage sludge		
LC "Rusbelgo"			2880		2 880	103 000
OJSC ”Novy Svet”			2750		2 750	98 000
LC ”Chernovo”	226				226	8 000
“Krasnogvardejskij” stock-breeding farm	415				415	14 800
OJSC "Verevo"	229				229	8 170
OJSC "stock-breeding farm Lesnoe"	428				428	15 000
"Thais" pedigree stock-breeding farm	108				108	3 830
”Skoritsy” poultry farm plant		2 590			2 590	92 300
Gatchinsky WWTP				1 859	1 860	66 200
Total	1 406	2 590	5 630	1 859	11 500	409 300

The calculation shows that total amount of biogas produced is **11.5** million m^3/a calculated on methane. The heat release which can be received from biogas combustion is **409 300** GJ/a or 113.7 GWh. The transportation energy consumption is subtracted from heat release. And heat release which includes transportation energy consumption equals 111.3 GWh. The percentage of energy consumption in this system is about 2% of total heat release.

Calculation of total energy from the biogas combustion is carried out as in previous chapter 7.2 with assumption that the electricity conversion efficiency is 30% and heat efficiency is 55%, thus multiplying heat release which includes transportation energy consumption on the conversion efficiencies. The electricity energy is 33.4 GWh annually and the heat energy is 61.2 GWh annually.

The net energy from AD method is calculated also as in previous chapter 7.2. It was assumed that primary energy input in the AD process for electricity consumption is 11% of biogas produced and heat consumption is 13 % of biogas produced. The electricity consumption of AD process is calculated by multiplying heat release (which includes transportation energy consumption) on percentage of primary electricity energy input, thus electricity consumption of AD process equals 12.2 GWh. The heat consumption of AD process equals 14.5 GWh. The net energy of the AD method can be calculated by subtracting these values from the total energy. The electricity net production is 21.2 GWh and the heat net production equals 46.7GWh.

The power of plant is calculated by dividing net heat and electricity production (without taking into account transportation energy consumption) on annual peak load operating time (often 8000 h/a for plants which are meant to be in operation as evenly as possible), thus the electricity power is 4.3 MW and heat power is 7.8 MW.

8.3 Joint treatment by incineration

The feedstock delivered to the centralized plant where option for treatment is incineration above all should be pretreated by dewatering. As it was mentioned in the chapter 7 the appropriate moisture content of the feedstock in the case of combustion is near to 65%, thus it is need to calculate the energy consumption for dewatering of feedstock to low moisture content up to 65%. The energy consumption for dewatering is calculated by the equation 8. The mass of the feedstock with initial moisture content and mass of feedstock of dry matter are taken from table 28. The moisture of feedstock comes into the incineration process is 65%. The heat release of incineration process is calculated by the equation 9. The mass of the feedstock of dry matter is taken from table 28. The results of calculation equations 8 and 9 are presented in the table 30.

Table 30. The heat release and energy consumption for mechanical dewatering in incineration process of manure and sewage sludge

Source of feedstock	The heat release from incineration, GJ/a	Energy consumption for mechanical dewatering, GJ/a
LC "Rusbelgo"	94 100	91.5
OJSC ”Novy Svet”	89 900	87.4
LC ”Chernovo”	17 100	191
“Krasnogvardejskij” stock-breeding farm	31 300	349
OJSC "Verevo"	17 300	193
OJSC "stock-breeding farm lesnoe"	32 300	361
"Thais" pedigree stock-breeding farm	8 110	90.7
”Skoritsy” poultry farm plant	94 800	564
Gatchinsky WWTP	53 200	1996
Total	438 000	3924

The calculation shows that total heat release is 438 000 GJ/a or 121.7 GWh. The transportation energy consumption is subtracted from heat release, and thus heat release which includes transportation energy consumption equals 119.3 GWh. The percentage of energy consumption in this system is about 2% of total heat release.

Calculation of total energy from the incineration of manure and sewage sludge is carried out as in previous chapter 7.2, with assumption that incineration occurs in the CHP, which has a conversion efficiency of 20 % for electricity production and 40 % for heat production, thus the electricity production equals 23.9 GWh and heat production equals 47.7 GWh. The net energy is calculated by subtracting energy consumption for dewatering from electricity production. Energy needed for dewatering is shown in table 29 and it equals 1.09 GWh, hence net electricity production equals 22.8 GWh. The electricity power for incineration plant equals 3.0 MW and heat power is 6.1 MW. All energy flows from both AD and incineration methods are presented in the table 31.

Table 31. Energy flows in both AD and incineration methods.

Type of method		Heat release from combustion process, GWh	Transportation energy consumption, GWh	Total energy production[a], GWh	Auxiliary power[b], GWh For treatment of feedstock[c]	Net energy, GWh	Power of the plant[c], MW
AD	electricity	113.7	2.4	33.4	12.2	21.2	4.3
	heat			61.2	14.5	46.7	7.8
Incineration	electricity	121.7		23.9	1.09	22.8	3.0
	heat			47.7		47.7	6.1

[a] includes transportation energy consumption;

[b]Auxiliary power for combustion process has included in the total energy;

[c]In the case of AD method it is mean that energy consumption for AD process;

[d] calculation on heat release.

The energy calculations of the both AD and incineration methods have shown that even total energy production from AD is higher than from incineration method (due to the higher conversion energy efficiency of the biogas combustion process) net energy of incineration process is slightly higher than for anaerobic digestion. It is happen because the energy consumption for running the AD process, according to calculation, contributes near to 23 % of total heat energy production and 37 % of total electricity production.

9 CONCLUSIONS

In the case of this study two options of joint treatment methods for manure and sewage sludge was evaluated. First of all it was collected the information about general characteristics of manure and sewage sludge, treatment methods for them, and most attention was put on the AD and incineration methods. After that some general legislation concerning manure and sewage sludge handling was observed. It can be saying that in the Russian Federation and in Finland in nowadays much legislation and programs are worked out to protect the environment and human health. However, as it can be seen from present situation with the environment the impact from agriculture enterprises and WWTPs in the Russian Federation are large and there is still much work have to be done. Among the other programs carried out in the Russian Federation to intensify agriculture production the Program "APK" can be seen as a signal that the impacts from livestock and poultry enterprises in the near future will increase significantly, hence the implementation this program it is need to place high emphasis on environmental management.

Next step was to collect information about present situation in the Leningrad region concerning manure and sewage sludge properties, generation amount and distribution within the Leningrad region, existing technology and methods for their handling. It was found that there is no industrial AD facility for production of biogas. There are three sewage sludge incineration plants in the St.Petersburg, but no for the sewage sludge incineration in the Leningrad region. The main options for manure treatment are aging and in some enterprises composting. The main options for sewage sludge treatment are sludge beds or landfills disposal.

The collection information about present livestock and poultry enterprises shows that: cattle enterprises are represented in all municipalities of the Leningrad region, the pig enterprises are located in some municipalities and poultry enterprises are located only within five municipalities (industrial scale). The largest cattle farms are situated in the Volosovsky, Gatchinsky and Luzhsky Districts. The large amount of pig populations present in the Tosnensky, Gatchina and Lomonosov Districts. Due to the lack of information about existing manure and sewage sludge generation in the Leningrad region their amount was counted. The estimated amount of manure generation in the Leningrad region is 3 445 000 t/a on wet matter and amount of sewage sludge generation is 1 348 000 t/a on wet matter. According to estimation the biggest sewage sludge amount is generated is in the Gatcina, Vsevologsky and Vyborgsky Districtcs; the biggest manure generation occurs in the Gatchinsky, Lomonosovsky, Kirovsky and Vyborgsky Districts. It was rough estimated the potential energy production from anaerobic treatment and incineration from all sewage sludge and manure produced in the Leningrad region. The possible net energy generation from biogas combustion is 0.83 TWh and from incineration process is 0.97 TWh, without taking into account energy consumption for manure transportation from the livestock and poultry enterprises and sewage sludge from WWTPs to the collective place. To evaluate the influence of transportation energy consumption on the treatment system it was decided to calculate centralized treatment plant for some district in the Leningrad region.

The Gatchina District was found the main source of both manure and sewage sludge. And the implementation of the centralized plant for joint manure and sewage sludge treatment looks feasible there. The map with location of all found farms in this district was created. The WWTP of Gatchina city was chosen as a collective place. All manure from the area not more than 10 km in radius should be delivered to the WWTP for further treatment.

In the WWTP two options of treatment process such as AD process and incineration process were evaluated from the energy point of view. It is difficult to compare these options because of differences in the environment, economic and social impacts from these methods. From the availability of energy it can be concluded that the incineration of manure and sewage sludge in centralized plant produced slightly more energy compare with anaerobic digestion. The net heat and electricity production from AD process are 21.2 GWh and 46.7 GWh, respectively; from direct incineration of manure and sewage sludge the net heat production is 22.8 GWh and electricity production is 47.7 GWh.

The main energy consumption processes which should be taken into account during implementation of AD method are transportation energy consumption (contribute near to 2% of total heat release) and for running the AD process (in total contribute more than 23% of total heat release). For direct incineration manure and sewage sludge the energy consumption processes are transportation energy consumption (contribute near to 2 % of total heat release) and pretreatment of feedstock such as dewatering to receive the moisture content on the level suitable for the combustion process (contribute near to 1% of heat release).

Further studies should be provided for more detail evaluation. It is better to collect information about mixture properties of different feedstock. It is need to create a map for evaluation a distances between existing and planning livestock enterprises and WWTP for better manure and sewage sludge handling. This map should have available data about livestock population, manure and sewage sludge generation. It is also need to evaluate the need of organic fertilizer produced in these treatment systems (either digeste or ash) within the each municipality and put on the map point where and how much it is need annually to evaluate transportation energy consumption for deliver it. Also legislation about electricity net work should be improved to be able to put in the national grid electricity generated in the centralized plant.

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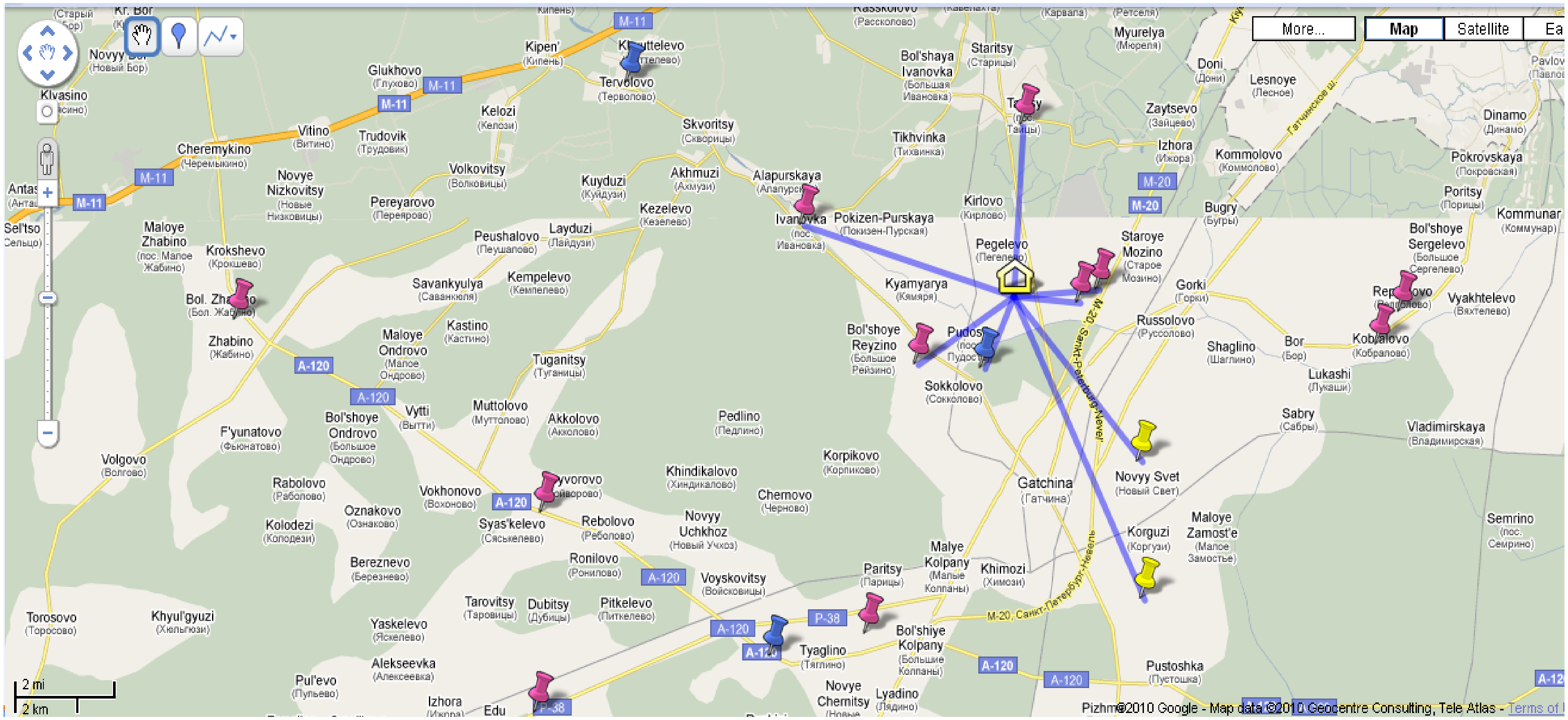
APPENDIX 1. Creation of map for distance evaluation



- WWTP; - livestock enterprise; - pig enterprises; - poultry enterprises.